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NUCLEAR MATERIALS MANAGEMENT

Journal of the
INSTITUTE
OF
NUCLEAR
MATERIALS
MANAGEMENT

FEATURE ARTICLES

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EDITORIAL

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

The nuclear weapon freeze proposal has stimulated a new interest in international safeguards. One version of the "freeze" would call for a halt on the production of plutonium and high enriched uranium for use in weapons. In such a case, safeguarding non-military nuclear facilities in nuclear weapon states would become very important.

The International Atomic Energy Agency (IAEA) and many individuals who have contributed to the development of international safeguards have, to a considerable extent, solved many of the problems which would arise in this case. There is a lot of experience with the application of safeguards to power and research reactors, and some experience with safeguarding reprocessing and MOX fuel fabrication facilities. The TASTEX exercise was especially informative. Whether the inspections might be performed bilaterally or by an international agency, the experience with international safeguards is useful for planning.

However, there will be some new situations which have not been analyzed so far. One of these relates to enrichment plants designed to produce high enriched uranium, which is required for a few research reactors, for high-temperature, gas-cooled reactors, and for replacement cores for existing naval reactors. Another has to do with the facilities that fabricate naval reactor fuel, and a third concerns what measures might be credible and practical to permit the production of tritium for existing nuclear weapons.

A number of groups, official and unofficial, are now looking into these problems. Since a significant quantity for a major nuclear weapon power is the equivalent of many nuclear warheads, measurement uncertainties should not be a limitation. Credibility, on the other hand will be very important. The possibility that the nuclear weapon powers might agree on such a "freeze" depends on a number of factors, one of which is the technical capability to apply safeguards.

The following statement is relevant in this connection:

> "Safeguards have now successfully outgrown the experimental stage. If safeguards help to delay and prevent proliferation of nuclear weapons, or at least contribute to the confidence that a given state is not using its peaceful nuclear activities for military purposes, they will have justified their existence. They also constitute a unique exercise in international verification, which may eventually set a useful precedent for "real" disarmament measures, if not applicable in their entirety then in part: as an example, perhaps, of an international arrangement to gather data on the production of certain materials and devices, and of the manner in which use can be made of national systems of accounting and control."*

*B. Sanders, Safeguards Against Nuclear Proliferation, p. 55, Almqvist & Wiksell International, or the MIT Press, 1975.

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CHAIRMAN'S COLUMN

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

"You will observe that there has been a revision in the dues structure. This revision was supported unanimously by your Executive Committee at their Board meeting in July of this year.

For some time, it has been apparent that income from dues has been out-of-line relative to other sources of revenue needed to support the programs of your organization. When an organization is reluctant to seek out new members because it costs more to sustain a member (mailings to membership, journal subscriptions, annual meeting proceedings) than that member returns in dues, something is woefully out-of-balance. This has been our situation in recent years, a result of sharp increases in printing, mailing, and other operational costs.

Realizing that corrective action was needed, an Ad Hoc Committee was formed in February, 1983 to study the dues structure and recommend revisions. The Committee performed a detailed analysis, taking into account the costs of sustaining a member, the benefits to be derived from the ability to maintain and expand our Institute programs, and the dues structures of similar organizations. The recommendations of this Committee were acted upon in July, leading to the decision to revise the dues.

I ask for your understanding and acceptance of this Board action. At the same time, if you have member needs that are not currently being met by your Institute, I invite you to communicate them to me. I can be reached at (206)-453-4377, and am always open to discuss any aspect of your Institute's activities. If you prefer to write, my address is:

Exxon Nuclear Co., Inc.
600 108th Avenue N.E., C-00777
Bellevue, Washington 98009

I, and the other elected officers and Executive Committee members, along with the appointed committee and subcommittee chairpersons ask for, and need, your continued enthusiastic support as we face the challenges of the future as a vital organization supportive of the nuclear industry."

AWARDS COMMITTEE REPORT

KARL BAMBAS, CHAIRMAN

During an Awards Ceremony on Tuesday evening at the Vail Annual Meeting, Chairman John Jaech outlined the Institute's Awards Program. The Institute's MERITORIOUS SERVICE AWARD recognizes, primarily, contributions to Institute activities, and beyond this, the recipient's wider involvement in Safeguards. Sometimes this involvement is restricted to a single area and/or facility, but usually it has implications or applications of a broader nature. The DISTINGUISHED SERVICE AWARD is presented to an individual or organization (not necessarily to an INMM member) with either a long and broad history or a significant single contribution to our profession. It is a formal recognition by the Institute of these contributions and it is deemed to be not only an honor to the recipient, but also to the INMM, as it is in a position to publicly acknowledge their contributions. Awards are given upon recommendations of the Awards Committee, and such recommendations are given only if nominations are forwarded by the INMM membership. Mr. Jaech called upon the membership to respond with deserving nominations. It is not too early to decide who you will nominate for recognition in 1984.

Before naming this year's awards recipients, John said there was an unfinished matter left over from last year. At the 1982 Annual Meeting, Bob Keepin, the Distinguished Service Award recipient, was not present in Washington, and, for a variety of reasons, he was not able to receive the award in the time period since that meeting. In the delayed presentation at Vail, John said, "Bob, I want to state in front of your peers that this award is given to you because of your broad and varied contributions to the furtherance of safeguards over the years, notably in NDA development and application, but not restricted to that area. As those assembled here know, your experience and expertise has led to your involvement in U.S. and International Safeguards to the point where you are now Special Advisor to the IAEA Deputy Director General, Department of Safeguards, Vienna. I will also add that although this Distinguished Service Award was granted to you exclusive of your contributions to the Institute, I would be remiss were I not to acknowledge your impact on our organization. The INMM of today is not the same as the INMM before your influence was felt, in a variety of ways". In accepting the award at Vail, Bob dropped out of character and made a brief acceptance speech.

For 1983, the Institute named two long-term members as recipients of the MERITORIOUS SERVICE AWARD. These members distinguished themselves in their professional lives as creators and innovators and used these same attributes to enhance our Institute. The first MERITORIOUS SERVICE AWARD went to Duane Dunn, who professionally has been responsible for control and accountability of special nuclear materials at the Rocky Flats facility. In presenting the award, John Jaech pointed out that Duane's special expertise in plutonium safeguards is acknowledged by all in our discipline. Many techniques for accounting or measurement of plutonium now accepted as standard in the industry arose from innovations directly traceable to Duane. Further, he has served the Institute in many capacities, most recently as Chairman of the Annual Meeting Registration Committee. The smooth functioning of this committee shows that particular dedication to detail which is only typical of Duane's talent for organization.

The second MERITORIOUS SERVICE AWARD was made to Ed Owings, a member whose service to INMM spans twenty years. In his professional life, Ed's contributions to nuclear material control are evident by the innovative accounting and safeguards practices which are in place at one of the world's largest nuclear facilities. His efforts on behalf of the INMM will be documented forever, for not only has Ed been a successful manager of the INMM finances, he is the father of the INMM accounting system—the first structured system to be used by the Institute.

With a change of pace, Chairman Jaech then presented the 1983 Distinguished Service Award, not to an individual but to an organization—the Safeguards Department of the International Atomic Energy Agency (IAEA). In making the award, John took care to mention the inspectors of the IAEA who work under difficult conditions, frequently on extended field assignments. As Dr. Gruemm pointed out earlier, International Safeguards must be not only effective, but also perceived as such by the public. The IAEA inspectors working in a highly visible organization make a significant contribution to that objective. The 1983 INMM Distinguished Service Award was received by Dr. Gruemm on behalf of the IAEA.

Some years ago, the Institute established a competitive award that recognizes the best paper on a safeguards-related topic submitted by a university student. The award consists of a plaque, a check for $500, and a payment of expenses for attending the annual meeting. The award this year went to Mr. Terry L. Zimmerman, whose paper, "The Alarm Characteristics of an On-Line Air Monitor for Transuranics", written while he completed his Master's Degree work at Idaho State, was presented at Vail on Wednesday morning.

Chronology of Awards

Distinguished Service Awards
1979—None
1980—W.A. Higinbotham
1981—Roger M. Smith
1982—G. Robert Keepin
1983—International Atomic Energy Agency, Department of Safeguards

Meritorious Service Awards
1979—None
1980—Douglas E. George
1981—None
1982—Ronald D. Smith and John H. Ellis
1983—Edward Owings and Duane A. Dunn

Student Awards
1979—Mark H. Killinger
1980—Mohammad Sharafi, M.I.T.
1981—Houng Y. Soo, University of Washington
1982—Paul E. Benneche, University of Virginia
1983—Terry L. Zimmerman, Idaho State University

One-Time Awards
1978—Industry Award, presented to Tri-State Motor Transit, Inc.
1982—In Appreciation Award, presented to E.R. Johnson and Associates

1984 AWARD NOMINATION (S)

I nominate: ______________________

of: ______________________
Company Name/Address
____
____

for the: ☐ Distinguished Service Award
☐ Meritorious Service Award

Justification: (Qualifications/Contributions)
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____
____
____

Signature

Return to: INMM
8600 W. Bryn Mawr Ave.
Chicago, Illinois 60631
(312) 693-0990

I nominate: ______________________

of: ______________________
Company Name/Address
____
____

for the: ☐ Distinguished Service Award
☐ Meritorious Service Award

Justification: (Qualifications/Contributions)
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Signature

Return to: INMM
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(312) 693-0990

MEMBERSHIP COMMITTEE REPORT

THOMAS SHEA, CHAIRMAN
INET Corporation
Sunnyvale, California

Following the Executive Committee Meeting, the Membership Committee convened at the Marriott Hotel in Vail, Colorado, on Sunday, July 10th, 1983. Attending were:

T. Shea, Chairman
J. Barry, Past-Chairman
V. DeVito
R. Curl
J. Messervey
J. Lee
P. Ebel

Subsequent meetings were held with chairmen of other U.S. chapters, or their representatives: Wendell Belew, Dean Scott and Harvey Austin.

1. Current membership and time goals established in the Long Range Plan were reviewed. To meet the desired level of 1000 members by 1985, it will be necessary for the Institute to broaden its areas of emphasis to include waste management and transportation, and undertake an aggressive recruiting campaign.

2. In actions taken by the Executive Committee, Institute Membership Fees will be increased for the next fiscal year (starting October 1, 1983), as follows:

Regular Member—$45
Student Member—$15
Senior Member—$60

Sustaining Memberships:
0-19 employees—$250
20-49 employees—$500
more than 50 employees—$750

3. Actions to reach potential members in these areas of expansion should begin with earnest efforts to recruit participants at Institute Workshops concentrating on such areas, followed by efforts to broaden the Annual Meeting and the Journal to serve the needs of members with those interests.

4. Further actions to reach potential members in domestic and international safeguards are also required. The potential role for Chapters was recognized, and it was recommended that each chapter designate a Membership Chairman for coordinating actions at the grass roots level. Each Chapter should establish membership goals, then organize the effort required to reach potential members to encourage their participation. Personal contacts, and invitations to attend Chapter meetings should be emphasized.

5. Possibilities for reaching a broader spectrum of potential members through other journals was explored. Two possibilities merit action:

1) feature articles describing the Institute should be drafted, and submitted for publication; and

2) notices of free brochures describing the Institute should be submitted for publication in Nuclear News, for example.

Target journals include: *Nuclear News, Nuclear Engineering International,* the *IAEA Bulletin, ASIS* (the Journal of the American Society of Industrial Security), the *ESARDA Journal,* and the *Bulletin of the Atomic Scientists.*

6. Efforts to recruit sustaining, or corporate memberships were discussed. It was recognized that this area offers a very large potential for new revenue, and thus aggressive action is called for. J. Messervey indicated that he is able to sort through the membership lists for employers, which will identify the target list. The Membership Chairman will name an individual responsible for coordinating efforts in this regard.

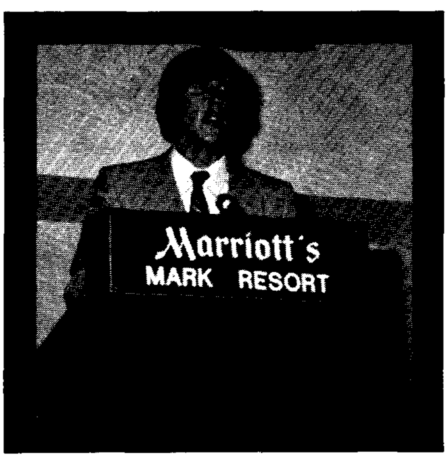
In a related discussion, thoughts on how to make this membership appealing were discussed. One possibility discussed was to print the names of sustaining members in the Journal, occasionally provide a short write-up of the sustaining member's activities in areas of interest to the Institute, acknowledgement during Annual meetings, and preferential treatment regarding exhibitions in conjunction with the Annual Meetings.

7. The idea of including blank membership forms in all issues of the Journal was discussed and approved. John Messervey indicated that this would be done starting with the next issue. In view of the changes required, the Membership Application Form was reviewed and changes made.

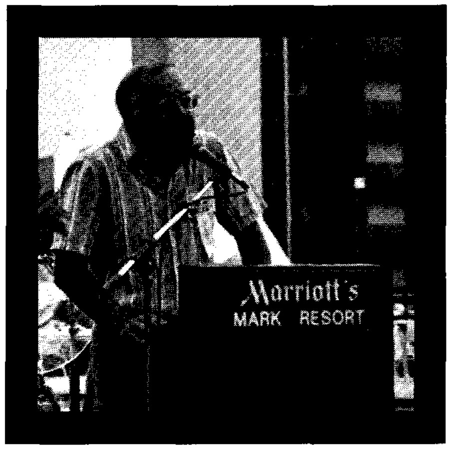
8. Final Business: T. Shea noted that having been elected to serve a two-year term as Member-at-Large on the INMM Executive Committee, it was necessary to step down as Membership Chairman. John Jaech was requested to name a successor.

1983 ANNUAL MEETING
VAIL, COLORADO

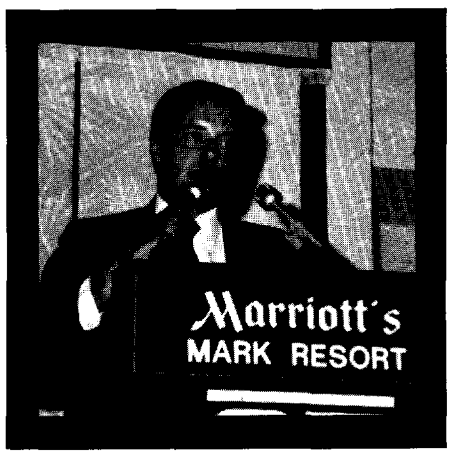
Hans Gruemm, Deputy Director General, ▲ IAEA, received the Distinguished Service Award on behalf of the Safeguards Department of the International Atomic Energy Agency (IAEA).



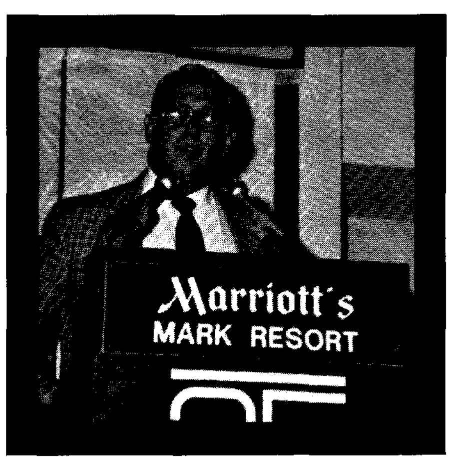
Student Award Winner, Terry Zimmerman, ▲ University of Idaho presented "The Alarm Characteristics of an On-Line Air Monitor for the Transuranics".



Chairman John Jaech addresses INMM ▲ members and guests at the Tuesday evening barbeque dinner.



Kermit Laughon, Director, Office of Spent ▲ Fuel Management and Reprocessing Systems, U.S. Department of Energy, presented *"Commercial Reprocessing in* the United States—To Be Or Not To Be?", at the Institute's 24th Annual Meeting.

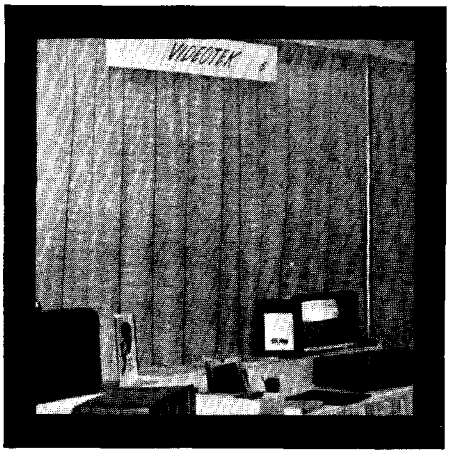


Duane Dunn, Rockwell International, ▲ receives the Institute's Meritorious Service Award for his years of dedicated service.

Ed Owings received the Institute's ▲ *Meritorious Service Award for his* numerous contributions to the Institute. Bill Mee (left) received the award on Ed's behalf.

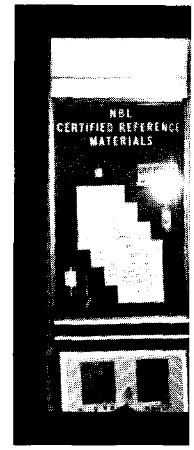
◀
Ashton O'Donnell, Vice President, Bechtel National, Inc., presented "Nuclear Fuel Reprocessing: A Time for Decision", at the plenary session.

24TH ANNUAL MEETING EXHIBITORS

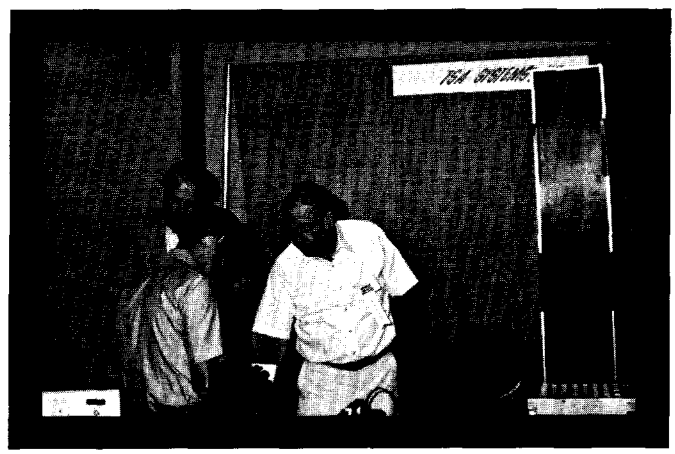


Videotek, Parsiprany, New Jersey

Globe Security Systems, East Lyme, Connecticut



Intex, Inc., Bethesda, Maryland

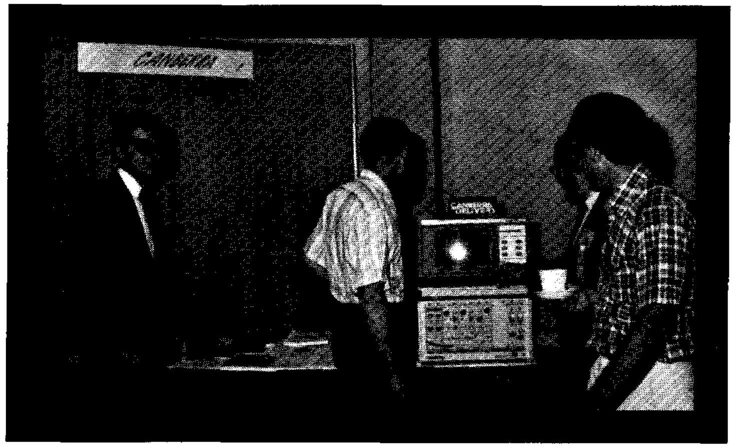


TSA Systems, Inc., Boulder, Colorado

IRT Corporation, San Diego, California

EyeDentify, Inc., Portland, Oregon

New Brunswick Laboratory, Argonne, Illinois



Canberra, Meriden, Connecticut

Ludlum Measurements, Sweetwater, Texas

Racon, Inc., Seattle, Washington

Brookhaven National Laboratory, Upton, New York

OWEN P. GORMLEY APPOINTED V.P. OF E.R. JOHNSON ASSOCIATES

E.R. JOHNSON ASSOCIATES, INC. (JAI) of Reston, Virginia announces the appointment of Owen P. Gormley as Vice President. From 1968 until joining JAI in June of 1983 Mr. Gormley held senior management positions in the U.S. Department of Energy and its predecessor organizations. In recent years he was Director of the DOE Divisions responsible for Spent Fuel Storage, Waste Treatment and Transportation. In these capacities he was responsible for design and operation of facilities for processing, packaging, storing and disposing of a variety of nuclear wastes from both commercial and defense nuclear operations as well as the transportation activities necessary to serve the facilities.

Prior to joining the AEC in 1968, Mr. Gormley was employed by the Westinghouse Electric Corporation on two submarine reactor programs and the nuclear rocket engine program.

Mr. Gormley is a registered professional engineer, holds a BSME from the University of Maine and has done graduate work in geology and management.

E.R. Johnson Associates, Inc. is a technical research and management service firm which specializes in nuclear fuel cycle engineering, spent fuel and waste processing and disposal, transportation of radioactive materials, economic analysis, quality assurance, safeguards and NRC licensing activities.

INMM EXECUTIVE COMMITTEE
CHAIRMAN John L. Jaech
VICE CHAIRMAN Yvonne M. Ferris
SECRETARY Vincent J. DeVito
TREASURER Robert U. Curl
MEMBERS AT LARGE
Richard F. Duda
E.R. Johnson
Tommy A. Sellers
Thomas E. Shea
Robert J. Sorenson

INMM COMMITTEE CHAIRMEN

Annual Meeting Arrangements	Tommy A. Sellers
Awards	Karl J. Bambas
Bylaws & Constitution	Roy G. Cardwell
Certification	Fred H. Tingey
Education	Harley L. Toy
Headquarters	John E. Messervey
Journal	John E. Messervey
Journal Technical Editor	William A. Higinbotham
Long Range Planning	Sam C.T. McDowell
Membership	Dennis Wilson
N-14 Standards	James R. Clark
N-15 Standards	Neil Harms
Physical Protection TWG	James D. Williams
Safeguards	Robert J. Sorenson
Statistics TWG	Carl A. Bennett
Waste Management TWG	E.R. Johnson

INMM CHAPTER CHAIRMEN

Japan	Yoshio Kawashima
Vienna	Tom Beetle
Central	Harvey Austin
Southeast	Wendell Belew
Northwest	Dean Scott

INMM CALENDAR OF EVENTS

NOVEMBER 14-17, 1983
Security Force Training TWG
Albuquerque Marriott Hotel, Albuquerque, New Mexico

NOVEMBER 28-DECEMBER 2, 1983
ANS/INMM Topical Course
Safeguards Technology: The Process-Safeguards Interface
Hilton Head Island, South Carolina

JANUARY 10-13, 1984
Spent Fuel Management Seminar II
Hyatt Regency Washington, Washington, D.C.

JULY 15-18, 1984
INMM 25th Anniversary Annual Meeting
Hyatt Regency Columbus, Columbus, Ohio

EXAMINING COMMITTEE ANNOUNCES SENIOR MEMBERS

Forty-six new Senior Members have been announced by the INMM Examining Committee as the first appointees under the Senior Member program adopted last year by the general membership. The new "Seniors" are:

Carl A. Bennett	Sheldon Kops
Carleton D. Bingham	John F. Lemming
Ernest W. Brach	Kenneth D. Long
Roy G. Cardwell	Garland A. Longhouser Jr.
R.N. Chanda	James E. Lovett
Thomas J. Collopy	Ralph F. Lumb
Robert U. Curl	Eugene V. McDonald
A.W. DeMershman	Roy Nilson
Everett A. DeVer	Ashton J. O'Donnell
Vincent J. DeVito	Thomas E. Shea
Byron F. Disselhorst	Julia M. Smith
E.J. Dowdy	Robert J. Sorenson
Kenneth C. Duffy	A.N. Spencer
John H. Ellis	Walter R. Thoma
O.E. Erickson	Fred H. Tingey
Homer M. Faust	Isabel P. Torres
Paul E. Fehlau	William R. Vroman
F. Gary Fetterolf	Don J. White
Bernard Gessiness	James D. Williams
Paul Goris	Robert A. Williams
Alexander M. Ironside	Dennis D. Wright
John L. Jaech	A. Keith Yancy
G. Robert Keepin	Edward R. Young

Senior Members certificates are being prepared and will be mailed in the near future.

Applications for Senior Membership are available from INMM Headquarters.

JAPAN CHAPTER REPORT

1. The meeting of the Executive Committee was held on 14th of Oct. 1982 to confirm the following results of election of officers and other members of the committee for FY1982-83 and FY1983-84:

Chairman, Yoshio Kawashima
Vice Chairman, Ryohei Kiyose
Secretary, Mitsuho Hirata
Treasurer, Reinosuke Hara

Members at large, Hideo Kuroi
Kouji Iwasaki
Toru Haginoya
Kazuhisa Mori

2. Members of the Japan Chapter for FY1982-83 are 82 in number, showing steady increase over the previous years. (61 in FY1980-81, 71 in FY1981-82). The members are from the following organizations;

(1) Nuclear energy organizations including Nuclear Material Control Center, Japan Atomic Energy Research Institute, Power Reactor and Nuclear Fuel Development Corp., Japan Atomic Industrial Forum	33
(2) Universities	6
(3) Industries—Electric Power	8
—Others	34

3. Annual Meeting was held on Apr. 22, 1983 in the Conference Room of JAERI. 93 persons participated in the meeting, including 39 Chapter members. In addition to the lectures given by the invited speakers the new arrangement was made so that the members of the Chapter could present the papers at the Annual Meeting. The Meeting was divided into the following sections;

Section 1. After introductory remarks made by Mr. R. Kiyose, Program Chairman, and Mr. Y. Kawashima, Chairman of the Japan Chapter, the following lectures were given by the invited speakers;

On Hexapartite project by Mr. T. Haginoya
On TRANSEAVER project in JAERI by Mr. H. Kuroi
On Progress of Theories of MUF Statistical Analysis by Mr. K. Ikawa
On 23rd INMM Annual Meeting by Mr. Y. Kawashima

Section 2. Presentation of the papers by the Chapter members. Ten papers were presented on the following subject;

(1) Review of nuclear material accountancy and study on the application of new safeguards measures in the reprocessing plant.

4 papers were presented by
Mr. M. Tsutsumi, Mr. Y. Asakura, Mr. K. Ikawa and Mr. H. Umezawa, respectively

(2) Study of chemical analysis and material sampling plan in safeguards implementation.

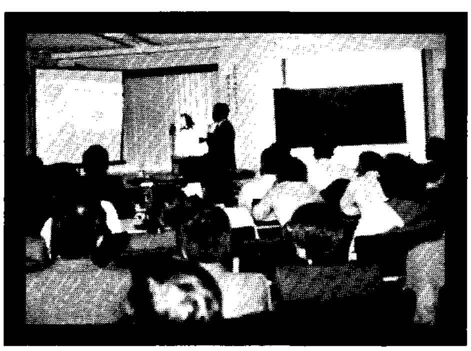
3 papers were presented by
Mr. H. Nishimura, Mr. C. Mizutani and Mr. M. Takahashi, respectively

(3) Development of new Containment and Surveillance system.

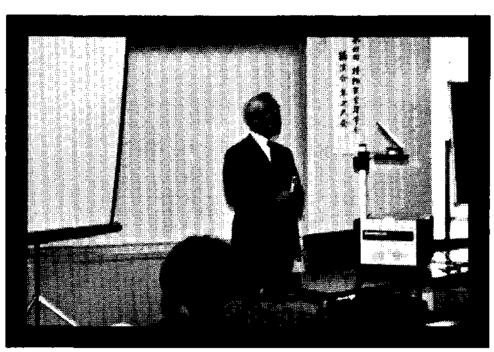
2 papers were presented by
Mr. T. Mukaiyama and Mr. M. Kikuchi, respectively

(4) Physical Inventory taking in the enrichment plant by Mr. M. Akiba

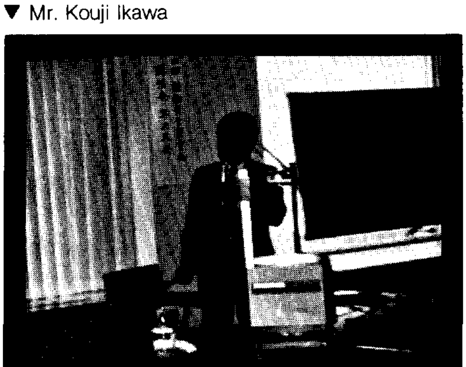
While the papers were originally presented abroad, presentation of these papers at the Japanese circle stimulated interests of participants in the Meeting.



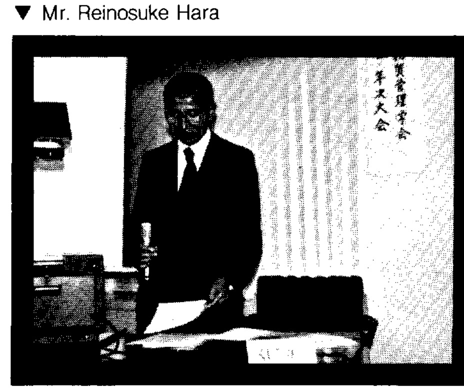
▼ Mr. Yoshio Kawashima



▼ Mr. Kouji Ikawa



▼ Mr. Reinosuke Hara



VIENNA CHAPTER REPORT

TOM BEETLE

Chapter Membership

The Chapter now has 86 members.

January

A luncheon meeting attracted 44 members and guests. Our speaker was Dr. Hans Blix, Director General of the International Atomic Energy Agency. He began his talk by saying that he feels that it is important to maintain open communications among all staff members at the Agency. On future United States participation in Agency affairs, in question at that time, he expressed an optimistic view which was upheld by subsequent developments. He noted that the Agency's two roles as 'promotional' and 'regulational' should not cause any conflict in the current status of the Agency, because the regulational activities can be regarded as promotional in the sense that they help provide confidence in the nuclear industry. He expects that the Agency's role will probably change towards increased activities in safety, waste disposal, and safeguards.

February

We had 26 members at a luncheon meeting to hear our speaker Mr. David Sinden, Manager of the Safeguards Division of the Atomic Energy Control Board of Canada. He described the unique Canadian nuclear fuel cycle where mining plays an important role and where there is no reprocessing at this time. In reviewing the Agency's safeguards activities in Canada, which started in 1972, he gave us an idea of the amounts of material and inspection effort involved in the activities. Inspection procedures for some 10 to 20 facilities have now been agreed upon with the Agency and are being implemented. He generally regards the objectives of the IAEA as being commendable.

◀ "Speakers Corner" L to R T. Dragnev, G.R. Keepin, B. Barnes, B. Pontes, A. Sandstroem, R. Abedin-Zadeh, N. Beyer, F. O'Hara.

◀ G.R. Keepin

▼ R. Abedin-Zadeh

March

Mr. Leon Green, Head of the International Safeguards Project Office (ISPO) in the United States, addressed us at a meeting with 30 members in attendance. He spoke about the past and future of ISPO which has been coordinating four different sources of U.S. support to IAEA safeguards. Some of the important contributions have been provision of cost-free experts to work in Vienna, the supply of NDA equipment, the improvement of TV surveillance systems, and assistance in training. Two areas of consideration for future activities are in-field expercises at HEU, MOX and LWR facilities for inspectors, and cost-free experts directly supporting the Operations Divisions. In reply to questions after the talk, Mr. Green expressed the general thought that the Agency's capabilities are becoming more known in his country, and that ISPO will continue to receive support for its work.

April

The Vienna Chapter Conference on "Safeguards Operations and Support Units Cooperation" was held in three morning sessions form 11 through 12 of April. There were 60 to 80 participants at each week session.

The papers were:

B. Agu, "Safeguards Operations and Support Units Cooperation."

G. R. Keepin, "IAEA Safeguards Equipment Survey and Assessment: An Example of Fruitful Operations/Support Cooperation."

J. Wilson, "Computerizing Safeguards Inspection Data."

G. Busca, S. Guardin, R. Abedin-Zadeh, T. Beetle, E. Kuhn, S. Deron, D. Terry, "Characterization of Plant Specific Reference Materials."

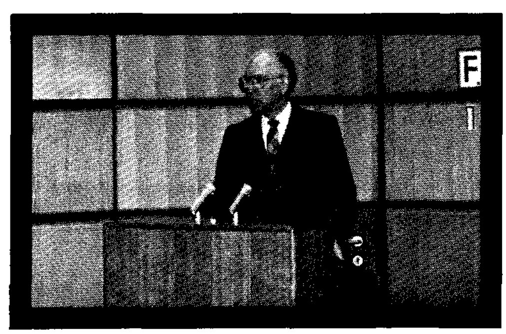
T. Dragney, B. Barnes, "Optimization of In-Field Measurements of Plutonium Isotopic Ratio by Gamma-Ray Spectroscopy."

A. Sandstroem, "NDA in the Agency Safeguards During the Next Five Years."

Dino Pontes organized the Conference with the help of the Safeguards Training Section Staff. The Department of Safeguards management gave encouraging support.

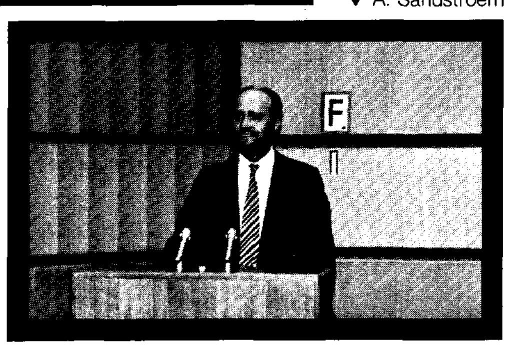
Forty participants attended a cold buffet luncheon on April 13 after the closing of the Conference.

◀ B. Barnes



◀ N. Beyer (Presenting J. Wilson's Paper)

▼ A. Sandstroem



L to R B. Pontes, ▶ Scientific Secretary; T. Beetle, Chairman.

HAZMAT '83 DRAWS 2,933 VISITORS

PHILADELPHIA—The first annual Hazardous Materials Management Conference and Exhibition (HazMat '83) drew 2,933 visitors from across the country. With 933 exhibitor personnel and 203 speakers and chairmen, more than 4,000 industry managers, consultants and government officials working in the field of hazardous materials management were in attendance.

Plans are already underway for HazMat '84 which will be held June 5-7, 1984, at the Philadelphia Civic Center. In addition, HazMat Southwest '84 will be held October 31, November 1 and 2, 1984, at the Astrohall, Houston, Texas. Show details will be announced in the near future.

For additional information on HazMat '84 and HazMat Southwest '84, please contact:
Robert L. Myhelic
Tower Conference Management Co.
143 N. Hale St.
Wheaton, IL 60187
312/668-8100

HOWARD MENLOVE NAMED LANL FELLOW

Menlove joined the Los Alamos staff 16 years ago and he has spent his entire Laboratory career in the field of nuclear safeguards. He is presently the project manager for International Safeguards. His major responsibility in recent years has been management of the Laboratory's part of the United States' Program of Technical Assistance to the IAEA Safeguards. Under Menlove's leadership, the Los Alamos program has achieved worldwide recognition and respect. In addition to management activities, Menlove has consistently produced techniques, instruments, and procedures for nondestructive assay of plutonium and uranium. Many of his instruments are now in routine use by IAEA inspectors at nuclear facilities throughout the world. In April 1982, Menlove was awarded a Laboratory Distinguished Service Award. In November, 1981, Menlove received that year's Radiation Industry Award by the American Nuclear Society for his outstanding contributions to the development of instrumentation for the nondestructive assay of nuclear materials.

NEWS RELEASES

NRC AMENDS REGULATIONS ON TRANSPORTATION OF NUCLEAR MATERIALS

The U.S. Nuclear Regulatory Commission is amending its regulations for the transportation of radioactive material to make them compatible with corresponding regulations of the International Atomic Energy Agency (IAEA) and thus with those of most other major nuclear countries of the world.

The amendments include several substantive changes aimed at minimizing complications and delays and encouraging a more uniform degree of safety for shipments of radioactive material. But the Commission's basic standards in this area will remain unchanged.

The Commission's current rules on transportation are generally compatible with the 1967 edition of IAEA's Safety Series No. 6, "Regulations for the Safe Transport of Radioactive Materials." Several years of experience with the use of these regulations in the United States and other countries have indicated that they are generally sound and practical and provide a reasonable degree of safety. Although several "Type B" packages (those containing intermediate and large quantities of radioactive materials) have been involved in severe accidents in the United States, no package failure has resulted.

However, since a more uniform degree of safety for various types of shipments was considered desirable, in 1971 and 1972 the IAEA convened panels (in which the United States participated) to review its transportation regulations and recommend appropriate amendments. The result was the 1973 edition of the IAEA's regulations in Safety Series No. 6.

The major changes to NRC's regulations that are being adopted to make them compatible with the 1973 IAEA regulations are:

(1) Elimination of the system currently used to specify the quantities of radioactive materials permitted to be shipped in certain types of packages. Under the present system, all radioactive materials are divided into seven transport groups to determine the amount of the materials that can be shipped in Type A packages and the amount that must be shipped in the more stringently designed, accident-resistant Type B packages. This system has proved to be unduly restrictive because less hazardous radioactive materials included in one transport group are required to be packed in the same way as other, more hazardous radioactive materials belonging to the same transport group. Under the rule change, the use of a Type A or Type B package would depend on the degree of radioactivity for each material being shipped.

(2) Establishment of two classifications of Type B packages. This change would facilitate foreign acceptance of U.S. export shipments by conforming package types to international standards.

The amendments, which are to Part 71 of the Commission's regulations, were published in the Federal Register in proposed form on August 17, 1979, for public comment. Some portions of the proposed rule have been deleted in the final rule to accommodate changes expected to be made in the 1984 revision of the IAEA regulations.

In addition to revising its regulations to make them compatible with IAEA's, the Commission is in the same rulemaking action formalizing a requirement—previously imposed by an NRC order dated August 15, 1975—stating that when plutonium is transported by air, it must be contained in a package specifically certified by the NRC as crash-resistant. The rule exempts plutonium contained in a medical device for individual human use or shipped in quantities small enough to present no significant hazard to the public health and safety even if released in an air crash.

The revised regulations will be effective September 6, 1983 (30 days after publication in the Federal Register on August 4, 1983).

NRC CONSIDERS LICENSE APPLICATION FOR NEW JERSEY NUCLEAR PLANT: PROVIDES OPPORTUNITY FOR HEARING

The Nuclear Regulatory Commission staff is giving notice that it is considering the application of Public Service Electric and Gas Company and Atlantic City Electric Company for a license to operate the Hope Creek Generating Station under construction in Lower Alloways Creek Township, Salem County, New Jersey.

The Hope Creek plant uses a boiling water reactor and at full power would have an electrical output of about 1067 megawatts. The site is about 18 miles southeast of Wilmington, Delaware and adjacent to the Salem Nuclear Generating Station, Units 1 and 2. A construction permit for Hope Creek was issued in November 1974.

The notice being published in the Federal Register on August 10, 1983 provides that any person whose interest may be affected may file a petition to intervene in the proceeding with respect to issuance of the operating license. Petitions should be filed with the Secretary of the Commission, U.S. Nuclear Nuclear Regulatory Commission, Washington, D.C. 20555, Attention: Docketing and Service Branch, by September 9, 1983.

Petitions for leave to intervene should set forth in detail the interest of the petitioner in the proceeding, how that interest may be affected by the results of the proceeding, and the specific aspects of the case on which the petitioner wishes to intervene.

If timely petitions are received, a notice of hearing or other appropriate order will be issued. In the event a hearing is held and a person is permitted to intervene, he or she becomes a full party to the proceeding and has a right to participate fully in the conduct of the hearing.

Whether or not there is a hearing, an operating license will not be issued until after completion of the safety and environmental reviews by the NRC staff and findings by the Commission that the license application complies with the requirements of both the Atomic Energy Act and the Commission's regulations. A license will not be issued until it is found that the plant has been satisfactorily completed and is ready for fuel loading. It is expected that construction will be completed by January 1986.

As they become available, all of the documents relating to the licensing of Hope Creek will be available for public inspection at the NRC Public Document Room, 1717 H Street, N.W., Washington, D.C. and at the Salem Free Public Library, 112 West Broadway, Salem, New Jersey. Documents already at those locations include the Final Safety Analysis Report and the Environmental Report submitted in support of the operating license application.

BOOK REVIEW

EUGENE V. WEINSTOCK
Brookhaven National Laboratory

THE WAR AGAINST THE ATOM, Samuel McCracken, Basic Books, Inc., New York, N.Y., 1982, 206 pp. $18.50.

Many factors have contributed to the present mess in which nuclear power finds itself, but surely a major one, as Samuel McCracken points out in this interesting and generally well-researched book, is the expectation that highly specialized technical issues are a suitable subject for public debate. The last two great technical innovations to be dealt with in this manner, he observes, were the railroads and vaccination (a relatively minor recent one was fluoridation), but at least in the former case the public opposition was limited "to the educated few who appeared at parliamentary hearings on the proposed new railway lines, and . . . was almost entirely quieted within a decade by the successful and peaceable operation of the allegedly dangerous railways." Maybe so, but in the U.S., at least, grade-crossing accidents were so common that, according to a sardonic comment by Mark Twain, the railroads would matter-of-factly send the victim's remains home to the widow in a basket with a note attached asking her to please return the basket.

By now, of course, railroads have killed thousands of people but no one seriously contests their usefulness or legitimacy. In contrast, nuclear power reactors have operated for thirty years without a fatal accident to the public, yet the opposition to them rages more strongly than ever, and in the course of time the struggle has taken on all the characteristics of a religious war, fully justifying the title of Mr. McCracken's book.

"The War Against the Atom" mounts a strong defense of nuclear power chiefly (and properly) by comparing it with the available alternatives: coal, oil, natural gas, and the so-called renewables, solar, biomass, etc. It does this very ably in the limited space available, but the chapter rebutting the criticisms of nuclear illustrates the difficulty of conducting this debate reasonably accurately and thoroughly even on the educated layman's level. In 48 pages the following topics are covered: (1) radiation levels in the vicinity of operating reactors, (2) reactor accidents, including Three Mile Island, (3) breeders and plutonium, (4) the Price- Anderson Act, (5) waste disposal, (6) decommissioning, (7) economics, (8) thermal pollution, (9) the "appropriateness" of fission to the end task of generating electricity, (10) occupational risks of nuclear workers, (11) nuclear terrorism, and (12) proliferation. That averages out to four pages per topic, hardly enough to permit more than summary conclusions. Under the circumstances, the best an author can do is to sketch in the skeleton of the facts and provide the reader with sufficient references to enable him to delve deeper into the subject if he wishes. This Mr. McCracken does very well, although with occasional lapses in documentation. For example, some calculations and comparisons of plutonium toxicity by Professor Bernard Cohen are presented without citing a specific reference, and a quotation concerning the causes of lung cancer in uranium miners is unattributed.

Of the twelve topics, normal radiation levels and reactor accidents, particularly the one at TMI, are covered in the greatest detail. The latter discussion could have benefited from better diagrams. Barring a future, worse accident, the TMI accident will always dominate any discussion of reactor safety. That one event scared the wits out of thousands of people, revitalized a nearly moribund (or, at least, stagnant) anti-nuclear movement, wiped out a multibillion dollar investment overnight, and brought down on the industry a flood of expensive new regulations and costly delays in the licensing of new plants. What the overall cost to the industry—and, ultimately, the general public—will be no one knows, but by now it undoubtedly far exceeds the cost of the reactor itself. McCracken rightly accuses the media of greatly exaggerating the danger, and echoes the familiar claim that the accident proved how inherently safe reactors are. However, that claim will be more reassuring to the technical experts than to the general public, which finds it difficult to understand how such a succession of failures on the part of the reactor designers, the equipment manufacturers, and the operators, culminating in what must have been one of the most expensive industrial accidents of all time, could have been allowed to happen. Whatever else it was, that fateful morning of March 28, 1979, was hardly the industry's most shining hour.

In the chapters comparing nuclear with the alternatives, McCracken goes on the offensive. For this reviewer the high points are not the comparisons with coal and oil, which are reasonably familiar, but those with the renewables. He reduces the sacred cow of solar energy to a shambles by analyzing the grandiose scheme of Barry Commoner for a gradual fifty-year shift to a solar economy and exposing its many flaws. Just one example: Commoner proposes that street lights be operated on electricity from photovoltaic cells energized by the sun. Unfortunately, he underestimates the required collector area by a factor of 10. When the correct area is used and the cost of storage is included, even with an assumed reduction of the present cost of photovoltaics by a factor of 10 the capital cost turns out to be a staggering $26,000 per installed kilowatt, or over $2 trillion just to convert all the streetlamps in America to solar operation.

Economic costs aside, a solar economy would impose severe constraints on the way we live. Architecture and landscaping would be heavily affected, since all roofs would have to face south, buildings would have to be low enough or far enough apart to shade each other, and shade trees would become an expensive luxury (and, where they affect a neighbor, illegal). The need for uninterrupted access to the sun would probably doom the high-rise building and, therefore, cities as we know them. Ironically, such buildings are probably the most energy-efficient form of construction. And, of course, the population dispersal required by solar energy would conflict with the need of an efficient mass-transit system for a concentrated population. These are aspects of conversion to a solar economy that the sun-worshippers seem to prefer not to discuss.

In the remaining chapters McCracken analyzes the origins, composition, and *modus operandi* of the anti-nuclear movement, profiles some of the best known organizations and leaders (the Union of Concerned Scientists, whose membership appears to include precious few scientists, Ralph Nader, Helen Caldicott, Barry Commoner, John Gofman, Ernest Sternglass, etc.), discusses the treatment of nuclear energy in the news and entertainment media, and takes a long-range look at the energy problem.

The chapter on the origins of the anti-nuclear movement, which were traced back through the environmental and anti-Vietnam war movements to, ultimately, the civil rights movement of the late 1950's, is the weakest in the book, consisting largely of undocumented assertions. These may be true but the reader must take them on faith. A particularly interesting question raised here is why liberals and leftists in the U.S. have embraced anti-nuclearism, although, as McCracken points out, there is no real philosophical connection. An objective, documented study of this question would be most useful.

Many readers will find the profiles of the anti-nuclear leaders and their ideas the most interesting part of the book. By and large they come across as social visionaries (Commoner and Lovins), fanatics (Nader), and the obsessed (Sternglass and Caldicott), with the common denominator of all appearing to be an overweening self-righteousness.

McCracken is particularly scathing on the subject of Sternglass, whose studies of the health effects of radiation from reactors are so full of statistical and other methodological errors as to render them worthless (recently, he has blamed low SAT scores on nuclear-bomb testing in the 1950's!) The author also relates a revealing incident witnessed by him personally when, after a public debate on nuclear power, Sternglass assured a pregnant woman who had come up to him afterwards for advice on some transcontinental flights she was planning to take that the increased exposure to radiation during the flights would be trivial, although, as McCracken points out, it would approximate what she would get from a full year of continuous exposure at the fence post of a power-reactor site. This double standard is indicative of the kind of intellectual dishonesty that seems to be a hallmark of the anti-nuclear movement and which seems, sooner or later, to infect every ideological crusade.

McCracken finds the record of the media in covering the nuclear issue to be generally abysmal, a conclusion which will hardly surprise members of the INMM. Before Three Mile Island, TV coverage was essentially nil. After that, it increased considerably, but, according to surveys by the Media Institute, became far less neutral, anti-nuclear spokesmen and groups accounting for 72% of the sources quoted by the networks. With few exceptions the print media have not done much better.

There are many reasons for the shallowness and bias of the reporting. One is inherent in the nature of journalism, which thrives on dramatic events like accidents and disasters. Another is the technical naivete of most reporters, which makes it difficult for them to distinguish between genuine experts and cranks. This is a particularly serious deficiency when the subject being reported is complex and requires some quantitative understanding. But perhaps the biggest factor of all, recently uncovered in public-opinion surveys by social scientists S. Robert Lichter and Stanley Rothman, is a political bias that predisposes many journalists, particularly those in major national media outlets such as the TV networks and the Washington Post and New York Times, against nuclear power. Unfortunately, these surveys were published too late for inclusion in McCracken's book.

"The War Against the Atom" is a combative, occasionally polemical, work that is unafraid to take on some of the sacred cows of the media elite and media manipulators. It presents most of the arguments for and against nuclear power and provides some useful data and comparisons, although inevitably in such a short book the treatment is sometimes sketchier than one might wish. In addition to the numerous references it includes a selected, annotated bibliography on the whole controversy which I found particularly interesting. The book's brevity and lively style makes it "an easy read," as they say in the trade, and a good introduction to the subject for anyone interested in the issues but, perhaps, hesitant to tackle them because of their technical complexity. It is a welcome addition to the small but growing collection of books that portray nuclear power not as Satan incarnate but as a safe, secure, and, when it is allowed to be, economical source of energy.

SAMPLE SIZE DETERMINATION FOR THE VARIABLES TESTER IN THE ATTRIBUTES MODE

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

1. Introduction

In a recently issued technical document [1], sample size formulas used in designing IAEA inspections are given, along with their bases. Specifically, Sections 4.3.1 and 4.3.2 provide the bases for sample size selection. Specific formulas are given for the attributes tester, (eq.4.4.1), and for the variables tester in the attributes mode, (eq.4.4.16).

In a recent paper, Sanborn [2] charges that this latter formula is not carefully justified. In responding to this charge, it is pointed out first of all that in the early development of the key formulas [3], the level 1 attributes tester was truly an attributes tester, i.e., it did not provide a quantitative value that could then be used to accept or reject an inspected item. From this perspective, the key formula given by (eq.4.4.16) of [1] is justified. However, as inspection capabilities have been developed over the years, with NDA measurements being used for attributes inspection, the attributes tester often does, in fact, produce a value, i.e., is variable in nature. In this event, it is true that the subject equation has not been properly justified.

In seeking to provide this justification, new sample size formulas are developed to replace (eq.4.4.16). The same basic approach is used as in [1], i.e., within a given stratum, inspection of a relatively large number of items by the attributes tester is followed by inspection of a smaller number of items by the variables tester. In determining the variables inspection sample size, this is chosen to be the larger of two sample sizes, one aimed at detecting so-called medium defects or data falsifications, (the focus of this paper) and the other at smaller ones. For a complete discussion, the reader is referred to Sections 4.3.1 and 4.3.2 of [1]. The overall approach differs somewhat from that developed by Sanborn [2] in some respects, e.g., items classified as defects by the attributes tester are re-inspected with the variables tester in Sanborn's approach. However, the key characteristics of the two approaches described in [1]-[3] are quite similar.

2. Notation

As in [1], the sample size for variables inspection in the attributes mode is considered for a given stratum of material. The notation is generally consistent with that used in [1], except for dropping the stratum subscript, k.

N = total number of items in stratum

$\bar{x}$ = average amount of element (isotope) per item in stratum

M = goal amount of element (isotope), expressed in same units as $\bar{x}$

β = probability of failing to detect the goal amount M through inspection

δ = error standard deviation for attributes tester, expressed on a relative basis

n_a = attributes tester inspection sample size

n_v = variable tester inspection sample size when used in the attributes mode

3. Sample Size Formulas from Reference [1]

From (eq.4.4.1) of [1], the formula for n_a is

$$n_a = N\,(1-\beta^{\bar{x}/M}) \qquad (3.1)$$

This formula remains unchanged in this development. From (eq.4.4.16) of [1], the formula for n_v is, with γ replaced by 4δ as is suggested in Section 4.3.1.1 of [1],

$$n_v = N\,(1-\beta^{4\delta\bar{x}/M}) \qquad (3.2)$$

In seeking to justify this formula for n_v, new formulas are derived in the succeeding section.

4. Basis for Modified Sample Size Formulas

As in [1], it is assumed in finding n_v that all M units are diverted through medium defects or data falsifications. In [1], the size of the medium defect for planning purposes was assumed to be $4\delta\bar{x}$. More generally, in the modified development, the size of the medium defect is assumed to be $\gamma\sigma\bar{x}$. Thus, the number of such defects is

$$n_o = M/\gamma\sigma\bar{x} \qquad (4.1)$$

The diversion is detected if at least one of these n_o defects is found in the inspection. The inspector has two chances of finding a defected item -- once with the attributes tester and again with the variables tester. Thus, non-detection occurs if:

Condition (a) there are no defects among the n_v items inspected by the variables tester (assuming that if a medium defect is inspected by the variables tester, it is certain to be labeled a defect); and further

Condition (b) all defects that exist among the n_a items inspected by the attributes tester are incorrectly classified as non-defects.

With respect to condition (b), an item is classified as a defect if

$$d > k\bar{x} \qquad (4.2)$$

where d is the size of the discrepancy between the operator's value and that determined by the attributes tester, with the appropriate sign, and k is a constant, thus far unspecified. In the existing problem formulation given in [1], Section 5.1.2.2, k is assigned the value 4δ so that the critical value of the attributes test, $4\delta\bar{x}$, was taken to be the same as the size of a medium defect. This formulation was not carefully justified in [1].

The problem is to assign values to the parameters k in (4.2) and $\gamma\sigma$ (and hence n_o) in (4.1). The sample size n_v is then found such that the nondetection probability is β. This sample size, n_v, will be a function of γo. The maximum value of n_v is selected as the sample size -- corresponding to the best strategy of the adversary for a given k. The problem is addressed for two limiting cases. In Section 5, it is assumed that the error in performing an attributes tester measurement is random while in Section 6, the error is assumed to be systematic.

5. Solution for Random Error Model

First, the critical value parameter for the attributes tester, k, is selected. This is chosen to control the value of α for the attributes test. From (4.2), the false alarm probability per item test is α given by

$$\alpha = \text{Prob } (d > \kappa \bar{x} \mid M=0) \qquad (5.1)$$

The probability that all n_a item tests are declared to be non-significant when M=0 is

$$\left\{\text{Prob } (d < k\bar{x} \mid M=0)\right\}^{n_a} = (1-\alpha)^{n_a} \qquad (5.2)$$

Choose k such that this probability is $(1-\alpha')$, where α' is the overall false alarm probability and will be an input parameter. The parameter α is therefore found by solving

$$(1-\alpha)^{n_a} = (1-\alpha') \qquad (5.3)$$

from which

$$\alpha = 1 - (1-\alpha')^{1/n_a} \qquad (5.4)$$

Given a knowledge of the density function for the random variable d, k then may be found by solving (5.1). Specifically, if d is normally distributed with mean zero (M=0) and standard deviation $\delta\bar{x}$, then k is the solution of the equation

$$\alpha = \frac{1}{\sqrt{2\pi}} \int_{k/\delta}^{\infty} e^{-t^2/2}\, dt \qquad (5.5)$$

For given α, k/δ may be found from a table of the normal distribution function.

Having found k, and for a given adversary strategy defined by the value assigned γo, the non-detection probability is found for given M. With regards to Condition (a) of Section 4, let

Q_v = Probability that no defects exist among the n_v items inspected by the variable tester.

Since there are n_o defects, calculated by (4.1) in the population of N items, and assuming N to be large relative to n_o, Q_v is simply

$$Q_v = (1-n_o/N)^{n_v} \tag{5.6}$$

Turning to Condition (b) of Section 4, let

Q_a = probability that all defects that exist among the n_a items subjected to the attributes tester are incorrectly classified as non-defects.

In calculating Q_a, note first of all that if a given item has a defect of size $\gamma o\bar{x}$, the probability of failing to identify this as a defect, given that it is inspected, is $(1-q)$, where

$$q = \text{Prob}\ (d>k\bar{x}\,|\,E(d) = \gamma o\bar{x}) \tag{5.7}$$

and q may be calculated if the density function of d is known. Again assuming d to be normally distributed, this time with mean $\gamma o\bar{x}$ not standard deviation $\delta\bar{x}$,

$$q = \frac{1}{\sqrt{2\pi}}\int_{(k-\gamma o)/\delta}^{\infty} e^{-t^2/2}\ dt \tag{5.8}$$

Next, for r items having defects of size $\gamma o\bar{x}$, the probability that all escape detection is $(1-q)^r$. Further, noting that the probability that there are exactly r defective items in the sample of size n_a is

$$\binom{n_a}{r}(n_o/N)^r\ (1-n_o/N)^{n_a-r} \tag{5.9}$$

it follows that

$$Q_a = \sum_{r=0}^{n_a}\binom{n_a}{r}(n_o/N)^r\ (1-n_o/N)^{n_a-r}\ (1-q)^r \tag{5.10}$$

In its alternate form:

$$Q_a = \sum_{r=0}^{n_a}\binom{n_a}{r}\ [(1-q)n_o\ /N)^r\ \ (1-n_o/N)^{n_a-r} \tag{5.11}$$

and it is noted that this is the binominal expansion of

$$[(1-q)\ n_o/N + (1-n_o/N)]^{n_a}$$

from which

$$Q_a = (1-qn_o/N)^{n_a} \tag{5.12}$$

Therefore, to achieve a probability (1-β) of detection of one or more of these medium defects,

$$Q_v\, Q_a = \beta \tag{5.13}$$

where Q_v is given by (5.6) and Q_a by (5.12). Equation (5.13) is solved for n_v, the required variables tester sample size for a given adversary strategy described by γo (and hence n_o). Solve

$$(1-n_o/N)^{n_v} = \beta\,(1-q\,n_o/N)^{-n_a} \tag{5.14}$$

The solution is

$$n_v = \frac{ln\,\beta - n_a\, ln\,(1-q\,n_o/N)}{ln\,(1-n_o/N)} \tag{5.15}$$

The variables tester sample size is a function of n_o. In application, the maximum value of n_v would be used. This maximum may be found by calculating n_v at various values of n_o and noting at which point it reaches a maximum. Alternately, an approximate explicit solution may be found by proceeding as follows.

It has already been assumed that n_o is small relative to N, and since $q<1$, use may be made of the following approximation to simplify (5.15).

$$ln\,(1-t) \approx -t \tag{5.16}$$

Then, n_v reduces to

$$n_v = -N\, ln\beta/n_o - n_a q \tag{5.17}$$

The maximum value of n_v is found by differentiating the RHS of (5.17) with respect to n_o, equating this to zero, and solving for n_o. In performing this differentiation, note that q is a function of n_o, defined by (5.8) if d is assumed to be normally distributed: Rewrite (5.8) using (4.1)

$$q = \frac{1}{\sqrt{2\pi}} \int_{\frac{kn_o\bar{x}-M}{n_o\bar{x}}}^{\infty} e^{-t^2/2}\, dt \tag{5.18}$$

In finding $\partial q/\partial n_o$, use is made of the following general result: [4]. If

$$\phi(\alpha) = \int_{u_o(\alpha)}^{\infty} f(x)dx \tag{5.19}$$

Then $$\frac{\partial\phi}{\partial\alpha} = -f\,(u_o)\ \partial u_o/\partial\alpha \qquad (5.20)$$

In applying this general result to (5.18),

$$\frac{\partial q}{\partial n_o} = \frac{M}{\sqrt{2\pi}\ \delta \bar{x} n_o^2}\ exp\left[\frac{(kn_o\bar{x}-M)^2}{2\delta^2 n_o^2 \bar{x}^2}\right]$$

$$\frac{\partial q}{\partial n_o} = \frac{M}{\sqrt{2\pi}\delta\bar{x}n_o^2}\ exp\left[-0.5\left(\frac{kn_o\bar{x}-M}{\delta n_o\bar{x}}\right)^2\right] \qquad (5.21)$$

Returning to (5.17),

$$\frac{\partial n_\nu}{\partial n_o} = \frac{N\,ln\beta}{n_o^2} - n_a\frac{\partial q}{\partial n_o} = 0 \qquad (5.22)$$

This reduces to solving the equation

$$\sqrt{2\pi}\,N\ \delta\bar{x} ln\ \beta + n_a M\ exp\left[-0.5\left(\frac{kn_o\bar{x}-M}{n_o\bar{x}}\right)^2\right] = 0 \qquad (5.23)$$

This further reduces to a quadratic equation in n_o of the form

$$a_o\ n_o^2 + a_1\ n_o + a_2 = 0 \qquad (5.24)$$

where

$$a_1 = \bar{x}^2\ (2R\delta^2 + k^2) \qquad (5.25)$$

$$a_1 = -2M\ k\bar{x} \qquad (5.26)$$

$$a_2 = M^2 \qquad (5.27)$$

$$R = ln\left(\frac{-\sqrt{2\pi}\ N\delta\ \bar{x}\ ln\beta}{n_a M}\right) \qquad (5.28)$$

Before giving an example to illustrate these results, the solution is given for the systematic error model.

6. Solution for Systematic Error Model

For the systematic error model in which the error in performing an attributes tester measurement is systematic in nature, the same thought process as was used for the random error model applies. The development of the results will therefore follow along the same lines as for the random error model, with the modifications required as a result of the model change noted.

First, in finding the critical value parameter k, it is noted that the probability that d for all n_a items exceeds $k\bar{x}$ is the same as the probability that the d's for any subset of the items exceed $k\bar{x}$, so that (5.4) becomes simply

$$\alpha = \alpha' \qquad (6.1)$$

Next, the quantity Q_ν in (5.6) is unchanged since it is unaffected by the error structure for the attributes tester.

In evaluating Q_a, equations (5.7)-(5.9) remain unchanged except, of course, that the value assigned to k will differ for the systematic error model. However, since the probability that all r defective items escape detection is the same as the probability that any single such item escapes detection, (5.10) becomes:

$$Q_a = (1-n_o/N)^{n_a} + (1-q) \sum_{r=1}^{n_a} \binom{n_a}{r} (n_o/N)^r (1-n_o/N)^{n_a-r}$$

$$= (1-n_o/N)^{n_a} + (1-q) \quad [1-n_o/N)^{n_a}]$$

$$= (1-q) + q\,(1-n_o/N)^{n_a} \qquad (6.2)$$

Thus, for this model, (5.15) becomes

$$n_v = \frac{ln\beta - ln[(1-q)+q(1-n_o/N)^{n_a}]}{ln(1-n_o/N)} \qquad (6.3)$$

As was true for the random model, the maximum value of n_v may be found by calculating n_v at various values of n_o and noting at which point it reaches a maximum. For the systematic model, it is not possible to determine this maximum explicitly. However, (6.3) can be simplified by noting that the quantity $(1-n_o/N)^{n_a}$ will be much smaller than β, and may be ignored. This is because $(1-n_o/N)^{n_a}$ is physically the probability that there are no medium sized defects among the n_a items selected for attributes inspection. There are many more medium sized defects than there are gross defects, and since the probability is β that there are no <u>gross</u> defects in this sample, the probability is much smaller than β that there are no <u>medium</u> defects. In equation form, since

$$(1-M/N\bar{x})^{n_a} = \beta \qquad (6.4)$$

then

$$(1-n_o/N)^{n_a} = (1-M/N\bar{x}\gamma o)^{n_a} << \beta \qquad (6.5)$$

since γo is $<<1$.

Thus, (6.3) simplifies to

$$n_v = \frac{ln\,\beta - ln\,(1-q)}{ln\,\beta(1-n_o/N)}$$

$$= \frac{ln[\beta/(1-q)]}{ln(1-n_o/N)} \qquad (6.6)$$

The determination of the sample size, n_v, under both the random and systematic error models is now illustrated with examples.

7. Examples

Example 1. See Example 4.2(a), page 197 of [1]. In this example,

$N = 12000$

$\bar{x} = 20$ kg U

$M = 1500$ kg U

$\beta = 0.05$

$\delta = 0.05$

From (3.1), $n_a = 12000\ (1-0.05^{1/75}) = 470$

The results for the random model are found first. Set $\alpha' = 0.01$. Then, from (5.4),

$$\alpha = 1 - 0.99^{1/470} = 0.00002138$$

Assuming d to be normally distributed and using (5.5),

$$k/\delta = 4.092, \text{ or } k = 4.092\delta = 0.2046$$

Then, n_o is calculated from (5.24). First, from (5.28),

$$R = ln\left[\frac{(\sqrt{2\pi})(12000)(0.05)(20)(ln\ .05)}{(470)(1500)}\right] = -2.057164$$

Then,

$$a_o = 400\ (-0.010286 + 0.041861) = 12.6301$$

$$a_1 = -(3000)(0.2046)(20) = -12276$$

$$a_2 = 2{,}250{,}000$$

The quadratic equation is

$$12.6301 n_o^2 - 12276\ n_o + 2{,}250{,}000 = 0$$

which yields the solutions

$$n_o = 245;727$$

It is quite apparent that $n_o = 727$ is the appropriate solution for if $n_o = 245$, then from (4.1) γo is 0.3061. For $\delta = 0.05$, this means that the adversary strategy is to create medium defects of a size that is 6.12 standard deviations of a given measurement. For $n_o = 727, \gamma o$

is 0.1032. Then from (5.8),

$$(k-\gamma_o)/\delta = (0.2046 - 0.1032)/0.05 = 2.028$$

$$q = 0.0213$$

From (5.15), n_v = 38.2 or 39 as the sample size. When in doubt as to which solution of the quadratic equation is the appropriate one, n_v may be calculated for each solution and the maximum value used.

Turning now to the results for the systematic error model, since $\alpha = \alpha' = 0.01$, $k = 2.3263 = 0.1163$. To find n_v, different values of n_o are inputted and n_v calculated from (6.6). Again, the maximum value of n_v becomes the sample size.

γ_o	n_o	q	n_v
1.0δ	1500	0.09242	21.7
1.5δ	1000	0.20440	31.8
2.0δ	750	0.37221	39.2
2.5δ	600	0.56907	42.0
3.0δ	500	0.74984	36.9

Finer devisions are made in the neighborhood of $\gamma o = 2.5\delta$

γo	n_o	q	n_v
2.3δ	652	0.48963	41.6
2.4δ	625	0.52949	41.9
2.5δ	600	0.56907	42.0
2.6δ	577	0.60796	41.8
2.7δ	556	0.64580	41.3

Thus, for the systematic error model, the required sample size is n_v = 42. Recall that for the random model, it was n_v = 39, in good agreement for these two extreme models. It is noted that in the cited reference, the sample size for $\gamma o = k = 4$ was 96.

Example 2. See the example in Section VII of reference [1]. Here,

$N = 100$

$\bar{x} = 2.2$ kg Pu

$M = 8$ kg Pu

$\beta = 0.10$

$\delta = 0.09$

From (3.1),

$$n_a = 100\ (1-0.10^{2.2/8}) = 47$$

Following the cited example, k is chosen to be 2δ so that, for the random model, with $\alpha = 0.02275$, the overall false alarm rate is

$$\alpha' = 1 - 0.97725^{47} = 0.661$$

Sanborn [2] handles this high false alarm rate by remeasuring attributes-tester rejects by the variables tester. In this example, we would expect to remeasure 1.1 such items. If α' is fixed at 0.01, then, from (5.4) for the random model,

$$\alpha = 1 - 0.99^{1/47} = 0.000214$$

From (5.5), again assuming normality,

$$k/\delta = 3.522 \text{ or } k = (3.522)(0.09) = 0.3170$$

In calculating n_o from (5.24), R is first calculated from (5.28),

$$R = -1.1909$$

Then,

$$a_o = 0.3930$$

$$a_1 = -11.1584$$

$$a_2 = 64$$

The quadratic equation (5.24) yields the solutions

$$n_o = 8;\ 21$$

If $n_o = 8$, then γo is 0.4545, and the number of standard deviations corresponding to a medium size defect is 0.4545/0.09 = 5.05. It is quite apparent that $n_o = 21$ is the appropriate solution. For $n_o = 21$,

γ_o is 0.1732 and, from (5.8),

$$(k - \gamma_o)/\delta = 1.598$$

$$q = 0.0550$$

From (5.15), n_ν = 7.5 or 8 is the required sample size.

For the systematic error model, again taking $\alpha = \alpha' = 0.01$, $k = 2.3263\delta = 0.2094$. The following table gives the iterative results:

γ_o	n_o	q	n_ν
1.0 δ	41	0.09242	4.2
1.5 δ	27	0.20440	6.6
2.0 δ	21	0.37221	7.8
2.5 δ	17	0.56907	7.8
3.0 δ	14	0.74984	6.1

It is noted that the q values are, of course, the same as those in the previous example since α' is 0.01 as in that example. As for the case of the random error model, n_ν = 8 is the sample size. In the cited example, the sample size was also 8 whereas in application of the formulas of [1], the required sample size is 21.

It is noted that in both the examples considered here, the sample size is about the same for models in which the attributes tester error is either completely random or completely systematic. How general a result this is has not yet been studied, nor has it been determined what will be the sample size for intermediate models.

As a final note, Sanborn's [2] model is the systematic error model, and further, remeasurement of items rejected by the attributes tester is called for in his approach. For this model, and in a given inspection, either all n_a items will be remeasured, or none of them will. Thus, the expected number of items that will require remeasurement in his development is meaningful only if interpreted over a number of inspections. For a given inspection, it is more discriptive to speak of the probability that all n_a items will require remeasurement. In his cited example, this probability is 0.023.

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PLAN OF ACTIVITIES LEADING TO THE ROUTINE USE OF IAEA CONTAINMENT AND SURVEILLANCE (C/S) EQUIPMENT

C.S. SONNIER
Sandia National Laboratories
Albuquerque, New Mexico

R.M. SMITH
Whiteshell Nuclear Research Establishment
Atomic Energy of Canada Limited
Pinawa, Manitoba, Canada

P. VODRAZKA
Division of Development and Technical Support
Department of Safeguards
International Atomic Energy Agency
Vienna, Austria

ABSTRACT

A Plan of Activities Leading to the Routine Use of IAEA Containment and Surveillance Equipment, proposed by the 1982 IAEA Containment and Surveillance Advisory Group, is described. Key elements of this plan are specifications, qualification and acceptance test criteria, and delineation of the responsibilities of the IAEA and the equipment development organization.

The various stages in the proposed plan are described, together with the rationale for the steps within each stage. The unique relationships between the IAEA and its Member States are also considered, with emphasis on the impact the introduction of newly developed equipment may have on safeguards strategies, facility operations, and facility attachments.

This concept offers significant potential to accelerate development programs, as well as to contribute to the overall cost effectiveness of such programs.

SUMMARY

The IAEA relies upon Member State support for development of the majority of equipment used by its inspectors. Efficient conduct of such development programs, and the attendant testing activities, requires significant interaction between the development organization and the Agency, with well-defined responsibilities assumed by both parties.

In general, equipment development activities commence with a specific need being stated by the Agency or being anticipated by a Member State. At the initial interaction between the development organizations and the Agency, key elements (e.g., purpose of the equipment, basic specifications, qualification/acceptance testing criteria, etc.) and responsibilities are defined and agreed upon. These key elements and responsibilities are reviewed throughout the program and revised as required.

In June 1982, an IAEA C/S Advisory Group met in Vienna. Among other subjects, the Group was asked by the Agency to recommend procedures and techniques that would expedite the equipment testing and acceptance process. The Advisory Group proposed a "Plan of Activities Leading to the Routine Use of IAEA Containment and Surveillance (C/S) Equipment," i.e., a plan for the development, testing, production, and implementation of this equipment. This plan proposes activities which are generally accepted in conventional projects, with modifications to accommodate the Member State/IAEA relationships.

Key elements of this concept include equipment specifications and qualification/acceptance testing criteria for all phases of a development project, as well as identification of decision points aimed at determining whether the development project should proceed to the next logical phase.

This "Plan of Activities" has been tested by applying it to two C/S devices currently under development. Detailed plans and specifications were prepared and submitted to the Agency and Advisory Group participants. The results of these reviews showed the "Plan of Activities" concept to be quite satisfactory.

This paper describes the various steps in the proposed "Plan of Activities," together with the rationale for the various elements within each step. This concept offers significant potential to accelerate development programs, as well as contribute to the overall cost effectiveness of such programs. A principal factor is agreement between the IAEA, the Member State supporting this development, and the equipment development organization, on the equipment specifications and the specific tests that will be conducted to verify that the specifications are met. Such agreements are made at the initial interface with the Agency and revised at appropriate steps throughout the project. While this concept has been developed for C/S equipment, it may be applicable to other types of safeguards equipment (e.g., NDA equipment).

INTRODUCTION

In June 1982, the "IAEA Advisory Group on Containment and Surveillance (C/S) Instrumentation for IAEA Safeguards" met at IAEA Headquarters. Experts from Australia, Bulgaria, Canada, Czechoslovakia, EURATOM, France, Federal Republic of Germany, India, Italy, Japan, United Kingdom, U.S.A. and U.S.S.R. participated in this meeting. Most of the Member States represented have, or will soon have, technical support programs for IAEA safeguards.

A wide spectrum of C/S topics were discussed, with emphasis on those identified in the Agency's working paper for this Advisory Group. One of the principal subjects on which the Agency sought advice was means to expedite the qualification and acceptance process required for the development and production of C/S equipment for routine safeguards use.

The Advisory Group formulated a "Plan of Activities Leading to the Routine Use of IAEA Containment and Surveillance (C/S) Equipment," i.e., a plan for development, testing, production, and implementation of this equipment. This plan contains the steps required from the first interaction between the Agency and Member State* and/or the equipment development organization. This interaction could commence at virtually any step and terminate at any subsequent step. With respect to any or all of the steps, the Member State may delegate its responsibility to the development organization. The Advisory Group recommended adoption of the "Plan of Activities" concept and suggested that, as a test of this concept, detailed draft plans be prepared on the following two C/S devices currently in the development phase:

1. The Passive Environmental Monitor, developed by Sandia National Laboratories under the sponsorship of the DOE/OSS, USA, and
2. The AECL Random Coil Seal/Sandia Seal Pattern Reader, developed by AECL and Sandia National Laboratories, under the sponsorship of AECL/AECB, Canada and DOE/OSS, USA.

As a result, these plans were prepared by AECL and Sandia, based on the Advisory Group's suggestions. These plans were reviewed at an informal meeting of the 1982 C/S Advisory Group in November 1982. Participants in this review were the IAEA, Canada, Czechoslovakia, EURATOM, Federal Republic of Germany, Japan, and the United Kingdom. Those present at this meeting considered that the plans prepared by AECL and Sandia for these two C/S devices were satisfactory for the development of this equipment. This substantiated the Advisory Group's recommendation that the "Plan of Activities" concept should be adopted by the Agency and Member States who develop equipment for the IAEA under technical support programs.

The "Plan of Activities" includes conventional steps used in domestic development programs and additional steps required due to the IAEA/Member State relationships. The principal elements are specifications, qualification and acceptance test requirements, decision points to determine if a development program should proceed to the next logical step, and delineation of the responsibilities of the Agency and the development organization.

This paper describes the various steps and the rationale for the elements within each step. This "Plan of Activities" concept should significantly assist in the conduct of the development programs and the acceptance process.

The plan outlines the requirements and procedures for complex safeguard equipment requiring extensive development and testing programs. Simpler plans could be prepared on a case-by-case basis to cover the requirement for simpler equipment, or equipment that has reached an advanced state of development prior to the initial interaction with the Agency. However, regardless of the complexity of the equipment, or its state of development, agreement must be reached on the specifications, acceptance test criteria, and the IAEA's/development organization's responsibilities.

* "Member State" as used in this paper refers to the representative of the State that is providing this development assistance to the IAEA under a technical support program.

Throughout this paper, reference is made to the equipment classification used by the U.S. International Safeguards Project Office (ISPO):

Class I (Laboratory Device) - used to demonstrate principle of operation.

Class II (Development Prototype) - used for joint IAEA/Developer evaluation, including laboratory and limited field testing.

Class III (Field Evaluation Unit) - used for final evaluation prior to developing production capability and for limited field use.

Class IV (Production Model) - used for routine field use; development of equipment has been completed and all production drawings, specifications and production test procedures are available.

PLAN OF ACTIVITIES

The steps in the Plan of Activities are:

Class I (Laboratory Device)

- Prepare Class I Laboratory Device Specifications.
- Define Class I Development Project.
- Conduct Necessary R&D.
- Define Qualification and Acceptance Test Criteria for Class I Laboratory Device and Schedule for These Tests.
- Conduct Laboratory Tests.
- Decide Whether to Proceed to Class II Development Prototype Stage.

Class II (Development Prototype)

- Prepare Class II Development Prototype Specifications.
- Define Class II Development Project.
- Conduct Necessary R&D.
- Define Qualification and Acceptance Test Criteria for Class II Development Prototype and Schedule for These Tests.
- Conduct Laboratory and Limited Field Tests.
- Decide Whether to Proceed to Class III Field Evaluation Unit Stage.

Class III (Field Evaluation Unit)

- Prepare Class III Field Evaluation Unit Specification.
- Define Class III Development Project.
- Conduct Necessary R&D.
- Define Qualification and Acceptance Test Criteria for Class III Field Evaluation Units and Schedule for These Tests.
- Conduct Laboratory and Field Tests.
- Define Training Program.
- Define Maintenance Program.
- Decide Whether to Proceed to Class IV Production Model Stage.

Class IV (Production Model)

- Prepare Class IV Production Model Specifications.
- Commence Production of Class IV Prototype.
- Establish Training Program.
- Establish Maintenance Program.
- Define Detailed Production Prototype Acceptance Test Program.
- Conduct Production Prototype Acceptance Test Program.
- Modify Specifications as Required.
- Commence Production of Equipment.
- Commence Operational Use of Equipment.
- Establish a Program for Continuing Analysis of Device Use, Performance and Reliability Throughout the Routine Use Period.

It will be noted that the Class I, II and III steps are essentially the same. Some instruments may have reached an advanced stage prior to interaction with the Agency and the "Plan of Activities" has been structured accordingly. However, regardless of whether the interaction with the Agency starts at the Class I, II or III stage, the first step should always be to reach agreement on specifications, qualification and acceptance test criteria, and responsibilities.

In this plan, certain IAEA responsibilities and actions are defined. The IAEA may delegate these responsibilities or actions to some other organization for the purpose of the equipment development.

A description of the action to be taken respecting some of these steps is given below.

SPECIFICATIONS

Equipment specifications are considered to be fundamental to all Agency and development organization activities. Early agreement between the Agency, Member State and the development organization on the equipment specifications is essential for cost-effective conduct of development projects.

Specifications are required even at the early Class I stage so as to ensure that the developer has a clear concept of what is required. In the preparation of these specifications, the need for this equipment and anticipated quantities required, together with the impact of the use of this equipment in the applicable safeguard strategies, facility attachments and facility operations should be taken into account. In some cases this impact may also be reviewed by the State safeguard authorities and the operators of facilities where this equipment may be used.

The Advisory Group's "Plan of Activities" included a check-list of the factors to be considered in the preparation of detailed specifications. This check-list, which is shown below, is meant to cover the factors that should be considered in the development of IAEA C/S equipment. However, it should be noted that not all of these factors are applicable to some C/S equipment.

Detailed Specification Check-List

- Design Function
- Technical Function
- Reliability
- Tamper Resistance
- Safety Requirements
- Concealment of Operating Status
- False Alarm Probability
- Detection Probability
- Potential Facility Interference
- Installation and Operating Parameters
- Verifiability
- Time Required to Evaluate the Data
- Robustness
- Frequency of Use
- Duration of Use
- Maintenance
- Anticipated Cost
- Anticipated Availability Schedule

The specifications should be updated during each development step, based principally upon the results of the laboratory and field tests. The final specifications will be prepared and accepted prior to full production of the device.

DEFINITION OF QUALIFICATION AND ACCEPTANCE TEST CRITERIA

Having reached agreement on the equipment specifications, the development organization will proceed to design and fabricate the device, and conduct the necessary laboratory tests to insure that it operates properly. Interaction with the Agency will be maintained throughout this development and testing activity. Prior to, or concurrent with, these activities, the Agency and the Member State and/or development organization will jointly prepare and agree on the qualification and acceptance test criteria and the schedule for these tests. The criteria and schedule will provide the following information:

1. Type and quantity of data to be obtained, including the parameters to be determined and the precision with which they are to be determined.
2. Specific laboratory and field evaluation tests to be conducted to verify the specifications.
3. Procedures for obtaining reliable records of tests results.
4. Methods for data interpretation.
5. Test schedule(s).
6. Test location(s).
7. Specific responsibilities of the Agency and the development organization respecting these tests.

The conduct of field tests in operating nuclear facilities requires the concurrence and cooperation of the facility operators and of the appropriate national authorities. This process often can be quite time consuming and must be considered in formulating the test schedule(s) and test location(s).

LABORATORY AND FIELD TESTS OF CLASS I, II OR III EQUIPMENT

Laboratory and field tests will be conducted by the Agency, the Member State and the development organization according to the agreed-upon test criteria and schedule. The test data will be collected and analyzed in accordance with agreed-upon guidelines; there will be a frequent exchange of results between the Agency, the Member State, and the development organization. Where practical, joint field tests of Class II and Class III equipment will be conducted with participants from the IAEA Division of Development and Technical Support, IAEA Divisions of Operations, the Member State and the development organization. The Agency may also request an independent evaluation of the tamper resistance of the device.

The results of the laboratory and field tests form the basis for a decision to proceed to the next development or production step.

DECISION AS TO WHETHER TO PROCEED TO NEXT DEVELOPMENT STAGE

The decision to proceed with, repeat some steps, or terminate the project may occur at any stage of the development. This will be resolved between the IAEA, the Member State, and the development organization. If the development is to proceed, the Agency, the Member State, and the development organization will, as required, formulate and agree upon:

1. Revised specifications.
2. Revised statements related to the impact of the device on safeguards strategies, facility operations, and facility attachments.
3. Qualification and acceptance test criteria and schedule for the next stage.

4. Revised training and maintenance requirements and programs.

The above items should be finalized for the advancement of the project from the Class III stage to the Class IV Production Model stage. In addition the IAEA should determine the subsequent actions, the quantity of the Production Models required, the supplier, the manner in which the production process will be monitored for quality control, and the final acceptance tests to be performed; the unit cost would also be estimated.

In some cases, particularly when only a few units of the equipment are required, the development may not proceed to the Class IV Production Model stage. The development program may conclude at the end of the Class III Field Evaluation Unit stage and these units may constitute the safeguard equipment that is used in an operational role.

TRAINING AND MAINTENANCE PROGRAMS

Training and maintenance programs should be considered at an early stage to ensure effective use and maintenance of the equipment by inspectors and maintenance personnel.

The training and maintenance programs may be initiated in the Class III stage, and fully resolved in the Class IV stage. These should be based on manuals to be provided by the development organization and related experience at the Agency. The manuals should be provided to the Agency during the Class III stage. The development of these programs should be closely coordinated with the Class III and Class IV test and evaluation activities. Functional training and maintenance programs should be available when the equipment is placed in routine safeguards use. These programs may be modified as the result of operational experience.

The introduction of more complex equipment will necessitate increased maintenance manpower, training and test equipment. Maintenance support may be provided by the IAEA, the development organization or by some other organization under IAEA contract. When the maintenance is not performed by the IAEA, the Agency should verify the proper operation of the repaired equipment, particularly when this maintenance is performed in the field.

PRODUCTION OF CLASS IV PROTOTYPE

The IAEA would place a contract for the construction of production prototypes with the selected producer. Sufficient prototypes should be provided to allow the performance and reliability goals contained in the specifications to be verified in the scheduled test period. The documentation supplied by the producer with the prototype should include:

1. Instrument description, operators manual, maintenance manual.
2. Program and schedule for acceptance tests of the production prototype.
3. Price for regular production.
4. Producer's production capabilities.
5. Guarantees with respect to this prototype and routine production models that will be supplied by the producer.

As required, the Agency, or other organizations acting on its behalf should conduct regular visits to the producer's facility to monitor the production of the devices.

PRODUCTION PROTOTYPE ACCEPTANCE TEST PROGRAM

The acceptance test procedures should be specified in as much detail as necessary. The acceptance tests may take place at the producer's facilities, at the developer's laboratory, and/or at the Agency's Headquarters. The number of production prototyes and the testing times should be carefully determined to achieve the required test results and to provide devices for use in conjunction with the training and maintenance programs. The collection and analysis of test data should be planned, together with the methods to be used for the evaluation of this data. The experience gained in the Class III test program will assist in preparing these plans. The acceptance test program should take into account information or comments from the IAEA inspectors, the IAEA maintenance staff and the plant operators during the Class II and Class III activities.

The Prototype Production process should be monitored by the Agency or an organization acting on its behalf. In addition, acceptance tests should be performed by the Agency, or an organization acting on its behalf, and the producer. Within the framework of a support program to IAEA safeguards, Member States and/or development organizations may undertake the production monitoring and acceptance testing, based on a well-defined program agreed upon by the Agency. However, the final acceptance is the responsibility of the Agency.

The Production Prototype acceptance tests will lead either to acceptance of the equipment for routine production or agreement on necessary modifications. When the prototype is accepted and the production specifications finalized, the IAEA will proceed with the procurement and operational use of the equipment.

FINAL SPECIFICATIONS

The Class IV Production Model specifications may be modified as the result of the Production Prototype acceptance tests. These specifications will be used in the production of the equipment to be used in routine safeguards applications.

PRODUCTION OF EQUIPMENT FOR OPERATIONAL USE

The key steps in the Class IV Production Model stage are placement of the order, and performance of independent acceptance tests. In addition, monitoring the production process to verify quality control may be performed. As in the case of the Prototype Production stage, the Member State and/or the development organization may assist the Agency in the monitoring and acceptance test activities at this stage.

OPERATIONAL USE OF EQUIPMENT

The equipment will normally be put into routine use as soon as production models become available.

Training in the use of this equipment will normally have been accomplished prior to routine use. In addition, a continuing training program will be required for new inspectors and for periodic retraining. A maintenance program for this equipment should also be established, together with a program for the evaluation of the use, performance and reliability of the device.

PROGRAM FOR CONTINUING ANALYSIS OF DEVICE USE, PERFORMANCE, AND RELIABILITY THROUGHOUT THE OPERATIONAL USE PERIOD

Once the equipment is placed in operational use, the Agency should continue analysis of its use, performance, and reliability. This analysis should contribute to optimum use of the equipment and identify necessary modifications to the equipment, training program, and maintenance program. This analysis should include documentation on use of the equipment, conditions of use, results, and environmental exposure data.

OTHER APPLICATIONS OF THE "PLAN OF ACTIVITIES" CONCEPT

This "Plan of Activities" has been established to meet the requirements for the supply of C/S safeguard equipment. A similar plan could be established and could produce the same benefits for other types of equipment required by the IAEA, e.g., NDA equipment.

CONCLUSION

This systemized plan for the development, testing, production, and implementation of C/S equipment will ensure that due consideration is given to the factors that should be considered for such equipment, e.g., operational requirements, operating conditions and reliability requirements. This approach should result in an efficient program for the supply of C/S equipment to meet IAEA requirements.

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THE PROPAGATION OF ERRORS IN THE MEASUREMENT OF PLUTONIUM ISOTOPIC COMPOSITION BY GAMMA-RAY SPECTROSCOPY*

T.E. SAMPSON
Los Alamos National Laboratory
Los Alamos, New Mexico

R. GUNNINK
Lawrence Livermore National Laboratory
Livermore, California

ABSTRACT

We discuss methods for the propagation of errors in the determination of plutonium isotopic composition and specific power by gamma-ray spectroscopy techniques. The 1975 ANSI calorimetry standard is shown to be in error in this regard. The developed formulas are compared with measurements for applicable cases. Some examples of the sensitivity of the specific power to measurement biases are presented.

I. INTRODUCTION

In recent years, several U.S. laboratories have developed computer codes to analyze the gamma-ray spectra from plutonium samples to determine the isotopic composition of the plutonium.[1-4] These techniques are, in general, versatile, accurate, and precise. For some cases, the precision of the measurement approaches or exceeds that obtained using conventional mass spectrometric techniques. The measurements have been applied to reprocessing plant solutions as well as to solids and many forms of scrap and waste.

These nondestructive techniques are particularly useful in conjunction with calorimetry when applied to bulk solids to obtain accountability information and to resolve shipper/receiver differences. For use with calorimetry, it is important that the measurement uncertainty in the specific power arising from the gamma-ray measurement be determined accurately so that the uncertainty in the total plutonium content can be estimated properly.

In this paper we will present expressions for the uncertainties in the plutonium isotopic fractions and specific power arising from the counting statistics of the gamma-ray measurement. The expressions will be derived for several different measurement methods and compared with experimental results where applicable. In addition, we will address the problem of how much bias is introduced into the specific power by a given bias in the basic gamma-ray measurement.

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II. PLUTONIUM MASS FROM CALORIMETRY

The plutonium mass of a sample measured by calorimetry is given by:

$$M = W \times P \quad , \tag{1}$$

where

M = plutonium mass in grams,

W = sample power in watts,

P = sample specific power in watts/g Pu.

The sample specific power, P, is given by

$$P = \sum_i K_i f_i \quad , \tag{2}$$

where

K_i = specific power of the ith isotope in the sample in watts/g isotope, i = ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{242}Pu, ^{241}Am ^{241}Am for most samples,

f_i = isotopic fraction of the i^{th} isotope in the sample in g isotope/g Pu.

In Eq. (1) the measurement of W is independent of the measurement of the specific power, P, and thus the combination of uncertainties in the two measurements is straightforward. In Eq. (2) the uncertainty in P is a function of the uncertainties of the isotopic fractions, f_i. For this analysis we will neglect the uncertainties in the isotopic specific powers, K_i, because they only contribute a bias to the final result. They do not contribute to the statistical precision of P.

It is tempting to compute the uncertainty in P by propagating assumed independent errors in the isotopic fractions in Eq. (2).[5] However, this is incorrect. The isotopic fractions, f_i, are correlated because of the constraint that

$$\sum_i f_i = 1.0 \quad . \qquad i = {}^{238}Pu,\ {}^{239}Pu,\ {}^{240}Pu,\ {}^{241}Pu,\ {}^{242}Pu \text{ for most samples.}$$

Thus the isotopic fractions, f_i, are not independent variables. Although it can be seen that Eq. (21) of ANSI N15.22[5] is in error in this regard, it is more difficult to write the correct expression in the general case. The correct expression depends upon the details of the gamma-ray measurement as will be described.

III. STATISTICAL ERRORS IN THE ISOTOPIC FRACTIONS AND SPECIFIC POWER

In this section we will derive error expressions for the isotopic fractions and the sample specific power by considering the uncertainties in the fundamentally measured independent variables of the problem.

We will consider three different measurement methods corresponding to analysis schemes that are in use or could possibly be used in the future.

Case I: Here we assume the measurement of five independent quantities and their standard deviations, $A \pm \sigma_A$, $B \pm \sigma_B$, $C \pm \sigma_C$, $D \pm \sigma_D$, and $E \pm \sigma_E$. These quantities are proportional to the isotopic fractions of ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, and ^{241}Am, respectively. The plutonium and ^{241}Am isotopic fractions are given by

$$f_{238} = A/(A+B+C+D) \quad ,$$

$$f_{239} = B/(A+B+C+D) \quad ,$$

$$f_{240} = C/(A+B+C+D) \quad ,$$

$$f_{241} = D/(A+B+C+D) \quad ,$$

$$f_{Am} = E/(A+B+C+D) \quad , \qquad (3)$$

where the plutonium fractions are defined as g isotope/g Pu and the americium fraction is defined as g Am/g Pu. Because ^{242}Pu cannot be measured directly, it is ignored. Although its contribution to the specific power is usually negligible, its incorrect estimation can bias all the other isotopic fractions and result in an error in the total plutonium when combined with calorimetry. Because the errors in the measured quantities are assumed to be independent, we have[6]

$$\sigma^2(f_i) = (\delta f_i/\delta A)^2\sigma_A^2 + (\delta f_i/\delta B)^2\sigma_B^2 + (\delta f_i/\delta C)^2\sigma_C^2 + (\delta f_i/\delta D)^2\sigma_D^2 + (\delta f_i/\delta E)^2\sigma_E^2 \quad . \qquad (4)$$

If we define the relative standard deviations (RSDs) as

$$\sigma_r(A) \equiv \sigma_A/A \quad , \ldots,$$

$$\sigma_r(f_i) \equiv \sigma(f_i)/f_i \quad ,$$

then the square of the RSDs in the isotopic fractions is given by

$$\sigma_r^2(f_{238}) = (1-f_{238})^2\sigma_r^2(A) + f_{239}^2\sigma_r^2(B) + f_{240}^2\sigma_r^2(C) + f_{241}^2\sigma_r^2(D) \quad ,$$

$$\sigma_r^2(f_{239}) = f_{238}^2\sigma_r^2(A) + (1-f_{239})^2\sigma_r^2(B) + f_{240}^2\sigma_r^2(C) + f_{241}^2\sigma_r^2(D) \quad ,$$

$$\sigma_r^2(f_{240}) = f_{238}^2\sigma_r^2(A) + f_{239}^2\sigma_r^2(B) + (1-f_{240})^2\sigma_r^2(C) + f_{241}^2\sigma_r^2(D) \quad ,$$

$$\sigma_r^2(f_{241}) = f_{238}^2\sigma_r^2(A) + f_{239}^2\sigma_r^2(B) + f_{240}^2\sigma_r^2(C) + (1-f_{241})^2\sigma_r^2(D) \quad ,$$

$$\sigma_r^2(f_{Am}) = f_{238}^2\sigma_r^2(A) + f_{239}^2\sigma_r^2(B) + f_{240}^2\sigma_r^2(C) + f_{241}^2\sigma_r^2(D) + \sigma_r^2(E) \quad . \qquad (5)$$

Note the symmetry of the equations for the plutonium isotopic fraction RSDs.

Now, expand this analysis to computing the standard deviation of the specific power computed from the isotopic fractions. The specific power, P, is given, in terms of the independent variables of the problem, by

$$P = K_{238}A/(A+B+C+D) + K_{239}B/(A+B+C+D) + K_{240}C/(A+B+C+D) + K_{241}D/(A+B+C+D) + K_{Am}E/(A+B+C+D) \quad , \qquad (6)$$

where the K's are constants (watts/g isotope) for each isotope. Because A, B, C, D, and E are independent, $\sigma(P)$ can be computed using the form of Eq. (4). The result for the variance of P is

$$\sigma^2(P) = (P-K_{238})^2 f_{238}^2 \sigma_r^2(A)$$
$$+ (P-K_{239})^2 f_{239}^2 \sigma_r^2(B)$$
$$+ (P-K_{240})^2 f_{240}^2 \sigma_r^2(C)$$
$$+ (P-K_{241})^2 f_{241}^2 \sigma_r^2(D)$$
$$+ K_{Am}^2 f_{Am}^2 \sigma_r^2(E) \quad . \qquad (7)$$

Note that the precision of the specific power is given in terms of the precisions of the fundamentally measured independent variables. It is not given in terms of the precisions of the isotopic fractions.

These equations enable one to predict the precisions of the isotopic fractions and the specific power. Also, by using Eqs. (3) and (6), one can study the sensitivity of the isotopic fractions and specific power to biases in any or all of the measured parameters.

Case II: In this case we assume the measurement of four independent isotopic ratios. "Independent" means that there are no common peaks among the eight different peaks forming the four ratios. All the plutonium ratios are measured with respect to ^{241}Pu, whereas americium is measured with respect to ^{239}Pu. Although it is difficult, in practice, to assure complete independence, this assumption can be a good one for ratios with respect to ^{241}Pu. The validity of the assumption can easily be checked by comparing the predicted precisions to those observed by repeated measurements. Let us denote the measured ratios and their standard deviations by

$$^{238}Pu/^{241}Pu \equiv R_8 \pm \sigma(R_8) \quad ,$$
$$^{239}Pu/^{241}Pu \equiv R_9 \pm \sigma(R_9) \quad ,$$
$$^{240}Pu/^{241}Pu \equiv R_0 \pm \sigma(R_0) \quad ,$$
$$^{241}Am/^{239}Pu \equiv R_{Am} \pm \sigma(R_{Am}) \quad .$$

The isotopic fractions are given by

$$f_{238} = R_8/(R_8 + R_9 + R_0 + 1) \quad ,$$
$$f_{239} = R_9/(R_8 + R_9 + R_0 + 1) \quad ,$$
$$f_{240} = R_0/(R_8 + R_9 + R_0 + 1) \quad ,$$
$$f_{241} = 1/(R_8 + R_9 + R_0 + 1) \quad ,$$
$$f_{Am} = R_{Am} \times f_{239} = R_{Am} R_9/(R_8 + R_9 + R_0 + 1) \quad . \qquad (8)$$

Defining the RSDs in the same fashion as before, the squares of the RSDs in the isotopic fractions are given by

$$\sigma_r^2(f_{238}) = (1-f_{238})^2 \sigma_r^2(R_8) + f_{239}^2 \sigma_r^2(R_9) + f_{240}^2 \sigma_r^2(R_0) \quad ,$$

$$\sigma_r^2(f_{239}) = f_{238}^2 \sigma_r^2(R_8) + (1-f_{239})^2 \sigma_r^2(R_9) + f_{240}^2 \sigma_r^2(R_0) \quad ,$$

$$\sigma_r^2(f_{240}) = f_{238}^2 \sigma_r^2(R_8) + f_{239}^2 \sigma_r^2(R_9) + (1-f_{240})^2 \sigma_r^2(R_0) \quad ,$$

$$\sigma_r^2(f_{241}) = f_{238}^2 \sigma_r^2(R_8) + f_{239}^2 \sigma_r^2(R_9) + f_{240}^2 \sigma_r^2(R_0) \quad ,$$

$$\sigma_r^2(f_{Am}) = f_{238}^2 \sigma_r^2(R_8) + (1-f_{239})^2 \sigma_r^2(R_9) + f_{240}^2 \sigma_r^2(R_0) + \sigma_r^2(R_{Am}) \quad , \qquad (9)$$

and the variance of the specific power is given by

$$\sigma^2(P) = (P-K_{238})^2 f_{238}^2 \sigma_r^2(R_8)$$
$$+ (P-K_{239} - K_{Am}R_{Am})^2 f_{239}^2 \sigma_r^2(R_9)$$
$$+ (P-K_{240})^2 f_{240}^2 \sigma_r^2(R_0)$$
$$+ K_{Am}^2 f_{Am}^2 \sigma_r^2(R_{Am}) \quad . \qquad (10)$$

Case III: In this last example we again assume independently measured isotopic ratios; this time all ratios, including that for americium, are taken with respect to ^{239}Pu. In practice, Case III would appear to be the most difficult in which to satisfy the independence assumption because of the natural pairing up (or lack thereof) of neighboring peaks. It is difficult in the 100- to 400-keV region to measure $^{240}Pu/^{239}Pu$ and $^{238}Pu/^{239}Pu$ independently of each other and of $^{241}Pu/^{239}Pu$. Nevertheless, we will proceed with the independence assumption. In this case, the RSDs of the isotopic fractions are given by

$$\sigma_r^2(f_{238}) = (1-f_{238})^2 \sigma_r^2(W) + f_{240}^2 \sigma_r^2(X) + f_{241}^2 \sigma_r^2(Y) \quad ,$$

$$\sigma_r^2(f_{239}) = f_{238}^2 \sigma_r^2(W) + f_{240}^2 \sigma_r^2(X) + f_{241}^2 \sigma_r^2(Y) \quad ,$$

$$\sigma_r^2(f_{240}) = f_{238}^2\sigma_r^2(W) + (1-f_{240})^2\sigma_r^2(X) + f_{241}^2\sigma_r^2(Y) ,$$

$$\sigma_r^2(f_{241}) = f_{238}^2\sigma_r^2(W) + f_{240}^2\sigma_r^2(X) + (1-f_{241})^2\sigma_r^2(Y) ,$$

$$\sigma_r^2(f_{Am}) = f_{238}^2\sigma_r^2(W) + f_{240}^2\sigma_r^2(X) + f_{241}^2\sigma_r^2(Y) + \sigma_r^2(Z) , \quad (11)$$

where we have defined

$$^{238}Pu/^{239}Pu \equiv W \pm \sigma(W) ,$$

$$^{240}Pu/^{239}Pu \equiv X \pm \sigma(X) ,$$

$$^{241}Pu/^{239}Pu \equiv Y \pm \sigma(Y) ,$$

$$^{241}Am/^{239}Pu \equiv Z \pm \sigma(Z) ,$$

and

$$f_{238} = W/(W+X+Y+1) ,$$

$$f_{239} = 1/(W+X+Y+1) ,$$

$$f_{240} = X/(W+X+Y+1) ,$$

$$f_{241} = Y/(W+X+Y+1) ,$$

$$f_{Am} = Z/(W+X+Y+1) . \quad (12)$$

Let us compare Eq. (11) (ratios with respect to ^{239}Pu) with Eq. (9) (ratios with respect to ^{241}Pu) and assume that we can measure a given ratio with respect to ^{241}Pu with the same relative precision as that with respect to ^{239}Pu: that is, $\sigma_r(R_8) = \sigma_r(W)$, $\sigma_r(R_9) = \sigma_r(Y)$, and $\sigma_r(R_0) = \sigma_r(X)$. Then we observe that measuring ratios with respect to ^{239}Pu gives better precision for all the isotopic fractions except f_{241} for cases where ^{239}Pu is the major isotope. This observation may be academic because of the difficulty of actually satisfying the independent ratio assumption for Case III.

For Case III the precision of the specific power is

$$\sigma^2(P) = (P-K_{238})^2f_{238}^2\sigma_r^2(W) + (P-K_{240})^2f_{240}^2\sigma_r^2(X) + (P-K_{241})^2f_{241}^2\sigma_r^2(Y) + K_{Am}^2f_{Am}^2\sigma_r^2(Z) . \quad (13)$$

IV. PRECISION CALCULATION EXAMPLES

For the three cases discussed in Sec. III, we will calculate some isotopic and specific power precisions based on the formulas displayed above. To show how these results may vary as a function of different burnup, we assume the five different burnup classes represented in Table I. An americium content equivalent to a two-year ingrowth after chemical separation has been assumed.

TABLE I

TYPICAL ISOTOPIC ABUNDANCES AS A FUNCTION OF BURNUP[a]
TWO-YEAR AMERICIUM INGROWTH ASSUMED

Class	Burnup (MWd/t)	^{238}Pu (wt%)	^{239}Pu (wt%)	^{240}Pu (wt%)	^{241}Pu (wt%)	^{242}Pu (wt%)	^{241}Am (μg/g Pu)	Specific Power (mW/g Pu)
I	∿2,000	0.01 (2.4)	93.45 (76.4)	6.00 (18.0)	0.50 (0.72)	0.04 (0.002)	506. (2.4)	2.3603
II	∿9,000	0.10 (17.0)	87.10 (50.4)	10.00 (21.3)	2.50 (2.5)	0.30 (0.01)	2,530. (8.7)	3.3315
III	∿17,000	0.25 (29.3)	76.25 (30.4)	18.00 (26.4)	4.50 (3.2)	1.00 (0.02)	4,554. (10.7)	4.8405
IV	∿26,000	1.00 (57.2)	58.00 (11.3)	25.00 (17.9)	9.00 (3.1)	7.00 (0.08)	9,107. (10.5)	9.9186
V	∿39,000	2.00 (69.9)	45.00 (5.3)	27.00 (11.8)	14.00 (2.9)	12.00 (0.09)	14,167. (10.0)	16.2346

[a]Percent of total power contributions are shown in parentheses.

In Table II we show the percent RSD for each isotopic fraction when each measured independent variable (peak area, Case I; peak ratio, Cases II and III) has an RSD of 1%. It can be argued that the comparisons in Table II are unfair to Case I because the same RSD assigned to a peak ratio containing two peak areas (Cases II and III) is assigned to a single peak area, Case I. Table III accounts for this by assigning to the ratios errors that are $\sqrt{2}$ times the single peak errors, that is, 1.414% RSD. By comparing Cases II and III from Table III with Case I in Table II, we see that Cases I and III give similar uncertainties in the isotopic fractions and specific power, although we do see some trends as burnup changes. For low burnup, Case III (Table III) is somewhat better than Case I (Table II) for specific power precision. This situation crosses over as burnup increases, so that Case I (Table II) has better specific power precision than does Case III (Table III) for high burnup. For practical situations these differences may not be important. In comparing Case II to Case III, we see that better isotopic and specific power precision is obtained by measuring ratios with respect to a major isotope (^{239}Pu in Case III) rather than a minor isotope (^{241}Pu in Case II). Also we note that the

TABLE II

PERCENT RELATIVE STANDARD DEVIATION IN ISOTOPIC ABUNDANCE AND SPECIFIC POWER, ASSUMING A 1% RELATIVE STANDARD DEVIATION IN ALL MEASURED INDEPENDENT VARIABLES SIMULTANEOUSLY

Burnup Class	Isotope	Isotopic Abundance (wt%)	Case I	Case II	Case III
I	238	0.01	1.37	1.37	1.00
	239	93.45	0.089	0.089	0.060
	240	6.00	1.33	1.33	0.94
	241	0.50	1.37	0.94	1.00
	Am	0.0506	1.37	1.00	1.00
Specific Power, 2.3603 mW/g Pu:			0.21	0.21	0.13
II	238	0.10	1.33	1.33	1.00
	239	87.10	0.165	0.163	0.103
	240	10.00	1.25	1.25	0.90
	241	2.50	1.31	0.88	0.98
	Am	0.253	1.33	1.01	1.01
Specific Power, 3.3311 mW/g Pu:			0.43	0.43	0.22
III	238	0.25	1.27	1.27	1.01
	239	76.25	0.30	0.30	0.19
	240	18.00	1.12	1.12	0.82
	241	4.50	1.24	0.78	0.97
	Am	0.4554	1.27	1.04	1.02
Specific Power, 4.8394 mW/g Pu:			0.56	0.56	0.32
IV	238	1.00	1.18	1.17	1.03
	239	58.00	0.50	0.49	0.27
	240	25.00	0.95	0.95	0.76
	241	9.00	1.11	0.63	0.94
	Am	0.9107	1.19	1.11	1.03
Specific Power, 9.9105 mW/g Pu:			0.74	0.74	0.58
V	238	2.00	1.12	1.11	1.03
	239	45.00	0.63	0.61	0.30
	240	27.00	0.87	0.86	0.74
	241	14.00	1.01	0.53	0.90
	Am	1.4167	1.14	1.17	1.05
Specific Power, 16.2207 mW/g Pu:			0.81	0.81	0.71

TABLE III

PERCENT RELATIVE STANDARD DEVIATION IN ISOTOPIC ABUNDANCE AND SPECIFIC POWER, ASSUMING A 1.4% RELATIVE STANDARD DEVIATION IN ALL MEASURED ISOTOPIC RATIOS (CASE II AND CASE III) SIMULTANEOUSLY

Burnup Class	Isotope	Isotopic Abundance (wt%)	Case II	Case III
I	238	0.01	1.94	1.42
	239	93.45	0.126	0.085
	240	6.00	1.87	1.33
	241	0.50	1.32	1.41
	Am	0.0506	1.42	1.42
Specific Power, 2.3603 mW/g Pu:			0.30	0.18
II	238	0.10	1.88	1.42
	239	87.10	0.24	0.146
	240	10.00	1.77	1.27
	241	2.50	1.24	1.39
	Am	0.253	1.43	1.42
Specific Power, 3.3311 mW/g Pu:			0.61	0.31
III	238	0.25	1.79	1.43
	239	76.25	0.42	0.26
	240	18.00	1.58	1.16
	241	4.50	1.11	1.37
	Am	0.4554	1.48	1.44
Specific Power, 4.8394 mW/g Pu:			0.79	0.45
IV	238	1.00	1.66	1.45
	239	58.00	0.69	0.38
	240	25.00	1.34	1.07
	241	9.00	0.89	1.33
	Am	0.9107	1.57	1.46
Specific Power, 9.9105 mW/g Pu:			1.05	0.82
V	238	2.00	1.57	1.45
	239	45.00	0.87	0.43
	240	27.00	1.21	1.05
	241	14.00	0.74	1.27
	Am	1.4167	1.66	1.48
Specific Power, 16.2207 mW/g Pu:			1.14	1.01

precision for the isotopic abundance of the major ^{239}Pu isotope is much better (by as much as a factor of 10 or more) than the precision of the independent measurement of its peak area or isotopic ratio. This "improvement" factor decreases as burnup increases because of the relative increase in the fraction of other isotopes present.

Direct comparisons of the methods are somewhat difficult. The independent variables of Cases II and III contain two peak areas while that of Case I has only one. In Cases II and III a total of eight peak areas are measured; in Case I only five are measured. If three more peak areas are measured for the major isotope in Case I and an average is used, then Case I becomes better than Case III in all instances. Also, in actual cases, seldom do all the independent variables have the same precision; the most important factor contributing to the precision of each independent variable is the specific peak or peaks used in the analysis.

For techniques where ratios are measured with respect to both ^{239}Pu and ^{241}Pu and common peaks are used for different ratios,[4] the analysis is much more complex and the Case II or Case III results are probably not directly applicable.

V. COMPARISON OF CALCULATED PRECISION WITH EXPERIMENTAL MEASUREMENTS

This section compares the results of the predicted precision with the precisions observed from repeated measurements.

For Case I, comparisons are made for four samples having different isotopic compositions. The comparisons for Case I are given in Table IV. The methods described in Refs. 1 and 2 for analysis of aged solutions are used as an example of Case I. For Case I, the predicted isotopic precisions and the specific power precision are given by Eqs. (5) and (7), respectively.

For Case II, comparisons presented in Table V are made for two different samples. The methods of Ref. 3 are used for analysis. The predicted isotopic precision is given by Eq. (9) and the specific power precision is given by Eq. (10). We know of no published analysis scheme that represents Case III.

The last entry for each sample in Tables IV and V show the peak area or peak ratio precision, that is, the precision of the fundamentally measured independent variable that is the basic input to Eqs. (5), (7), (9), and (10).

The assigned errors to the observed RSDs are a function of the number of measurements made and are derived from standard statistical formulas for the standard deviation of the sample variance.

The overall agreement between the predicted and observed precisions is satisfactory. Differences between the observed and predicted values can be ascribed to the difficulty of exactly predicting the precision of the peak area or peak ratio used as input. The methods for predicting the precisions of the basic area or ratio used in Refs. 1-3 are complex. Because of this complexity, it is difficult to be assured that the precisions are rigorously correct even though much experimental data indicate that they are generally very acceptable. A second reason for possible differences is that the general complexity of the analysis in Refs. 1-3 could lead to results for the fundamentally measured independent variables that are not truly independent. We note, for example, that in all cases the observed precision for the specific power is less than that predicted.

We have also calculated the precision of the specific power from propagating the errors in the isotopic fractions as suggested by Eq. (2). This incorrect method gives precisions that are ∿30% higher than the predictions of this paper and ∿70-80% higher than the observed values for Case II. For Case I the incorrectly calculated values are much closer to the predictions of this paper, although still 10-30% larger, in general.

TABLE IV

COMPARISON OF PREDICTED ISOTOPIC AND SPECIFIC POWER PRECISION WITH PRECISION OBSERVED FROM REPEATED MEASUREMENTS
CASE I: INDIVIDUAL, INDEPENDENT MEASUREMENT OF EACH ISOTOPE
N = 15 MEASUREMENTS

	^{238}Pu	^{239}Pu	^{240}Pu	^{241}Pu	^{242}Pu	^{241}Am	Specific Power
Avg meas values (wt%)	0.0166	93.350	6.217	0.3543	0.062	66.5 μg/g Pu	2.35638 mW/g Pu
Observed precision % RSD, 15 meas.	1.5 ± 0.3	0.031 ± 0.006	0.46 ± 0.09	0.42 ± 0.08	-	0.78 ± 0.15	0.090 ± 0.017
Predicted precision % RSD (Eq. 5,7)	2.2	0.042	0.63	0.31	-	0.53	0.12
"Peak area" precision % RSD	2.2	0.20	0.64	0.24	-	0.49	
Avg meas values (wt%)	0.0469	89.295	9.665	0.8165	0.176	627. μg/g Pu	2.77456 mW/g Pu
Observed precision % RSD, 15 meas.	1.3 ± 0.2	0.046 ± 0.009	0.42 ± 0.08	0.20 ± 0.04	-	0.19 ± 0.04	0.13 ± 0.02
Predicted precision % RSD (Eq. 5,7)	1.2	0.060	0.55	0.27	-	0.27	0.15
"Peak area" precision % RSD	1.2	0.24	0.56	0.16	-	0.15	

TABLE IV (continued)

COMPARISON OF PREDICTED ISOTOPIC AND SPECIFIC POWER PRECISION WITH THAT OBSERVED FROM REPEATED MEASUREMENTS
CASE I: INDIVIDUAL, INDEPENDENT MEASUREMENT OF EACH ISOTOPE
N = 15 MEASUREMENTS

	^{238}Pu	^{239}Pu	^{240}Pu	^{241}Pu	^{242}Pu	^{241}Am	Specific Power
Avg meas values (wt%)	0.0669	86.775	11.784	1.132	0.242	904. μg/g Pu	3.03171 mW/g Pu
Observed precision % RSD, 15 meas.	0.71 ± 0.13	0.071 ± 0.013	0.51 ± 0.10	0.36 ± 0.07	-	0.32 ± 0.06	0.14 ± 0.03
Predicted precision % RSD (Eq. 5,7)	1.0	0.071	0.51	0.28	-	0.27	0.17
"Peak area" precision % RSD	0.97	0.27	0.52	0.14	-	0.13	
Avg meas values (wt%)	0.0630	81.660	16.482	1.442	0.354	14071 μg/g Pu	3.31254 mW/g Pu
Observed precision % RSD, 15 meas.	0.86 ± 0.16	0.065 ± 0.012	0.31 ± 0.06	0.30 ± 0.06	-	0.28 ± 0.05	0.14 ± 0.03
Predicted precision % RSD (Eq. 5,7)	1.22	0.097	0.47	0.30	-	0.29	0.19
"Peak area" precision % RSD	1.19	0.31	0.48	0.13	-	0.12	

TABLE V

COMPARISON OF PREDICTED ISOTOPIC AND SPECIFIC POWER PRECISION WITH PRECISION OBSERVED FROM REPEATED MEASUREMENTS
CASE II: INDEPENDENT ISOTOPIC RATIOS MEASURED WITH RESPECT TO 241, Am MEASURED WITH RESPECT TO 239
N = 30 MEASUREMENTS

	^{238}Pu	^{239}Pu	^{240}Pu	^{241}Pu	^{242}Pu	^{241}Am	Specific Power
Avg meas values (wt%)	0.0120	93.893	5.826	0.2514	0.0179	490. μg/g Pu	2.35726 mW/g Pu
Observed precision % RSD, 30 meas.	8.1 ± 1.1	0.22 ± 0.03	3.5 ± 0.5	0.65 ± 0.08	-	8.2 ± 1.1	0.46 ± 0.06
Predicted precision % RSD (Eq. 9,10)	9.7	0.27	4.3	0.47	-	8.6	0.64
"Peak ratio" precision % RSD	238/241 = 9.7		239/241 = 0.41		240/241 = 4.6	Am/239 = 8.6	
Avg meas values (wt%)	0.0675	86.994	11.622	1.143	0.173	1095. μg/g Pu	3.05040 mW/g Pu
Observed precision % RSD, 30 meas.	3.0 ± 0.4	0.27 ± 0.04	2.0 ± 0.3	0.58 ± 0.08	-	4.8 ± 0.6	0.45 ± 0.06
Predicted precision % RSD (Eq. 9,10)	2.3	0.32	2.4	0.50	-	4.8	0.56
"Peak ratio" precision % RSD	238/241 = 2.3		239/241 = 0.45		240/241 = 2.7	Am/239 = 4.8	

Even though the calculations of this paper satisfactorily predict the observed measurement precision, the discrepancies that are observed point out that any error analysis in a code of this type must be thoroughly proven by repeated measurements. One cannot fully accept the analytical error predictions without verification.

VI. EFFECT ON THE SPECIFIC POWER OF A BIAS IN A SINGLE INDEPENDENT VARIABLE

In this section we attempt to answer the question, "How accurately do I have to measure this ratio or peak area so that the error in the specific power is less than some value?"

For this example, we first assume a correct isotopic composition; that is, the values for the five burnup cases in Table I. From these correct isotopic fractions we calculate the correct isotopic ratios R_8, R_9, R_0, R_{Am} for Case II and W, X, Y, Z for Case III. We also assume that the correct values of A, B, C, D, and E (Case I) are proportional to the correct isotopic fractions. Now one changes one of the correct independent variables by, say, 1%, to simulate a bias in that variable. The biased isotopic factions are recalculated from Eq. (3) (Case I), Eq. (8) (Case II), and Eq. (12) (Case III), and the biased specific power is recomputed according to Eq. (2).

In Table VI, the effect of a +1% bias in a single independent variable is expressed as a percent change in the specific power. A +1% bias is defined as

$$\frac{\text{biased variable}}{\text{correct variable}} = 1.01 \quad .$$

We find that the change in the specific power is the same for all cases when the peak variable is the same as the numerator of the ratio variable. The sensitivity values in Table VI can be combined to give results where more than one measurement is biased. Refer to the two following examples for illustrations.

Example 1:
Burnup Class II
Case II, ratios with respect to ^{241}Pu

Assumed Biases:

$^{238}Pu/^{241}Pu$	3% low	1 - 3(0.00169)	= 0.99493
$^{240}Pu/^{241}Pu$	5% low	1 - 5(0.0011)	= 0.9945
$^{242}Pu/^{241}Pu$	50% high	1 + 50(-0.00003)	= 0.9985
		Π	= 0.9880

Total effect on specific power is -1.2%.

Example 2:
Burnup Class I
Case I, Independent Peak Areas

Assumed Biases:

^{238}Pu	5% high	1 + 5(0.00024)	= 1.0012
^{239}Pu	0.5% low	1 - 0.5(-0.0015)	= 1.00075
^{242}Pu	40% low	1 - 40(-0.000004)	= 1.00016
^{241}Am	10% high	1 + 10(0.00025)	= 1.0025
		Π	= 1.0046

Total effect on specific power is +0.46%.

VII. SUMMARY

We have computed expressions for errors in the isotopic fractions and specific power for the measurement of plutonium isotopic composition by gamma-ray spectroscopy. These expressions are formulated in terms of the errors in the independent measured variables; that is, the peak areas or peak ratios. The analysis for the specific power errors does not use the errors in the isotopic fractions because they are correlated.

TABLE VI

PERCENT CHANGE IN THE SPECIFIC POWER FOR +1% BIAS IN A SINGLE INDEPENDENT VARIABLE (ALL OTHER VARIABLES CORRECT)[a]

Case I Case II Case III	238 238/241 238/239	239 239/241 	240 240/241 240/239	241 241/239	242 242/241 242/239	Am Am/239 Am/239
Burnup I	+0.024	-0.15	+0.12	+0.002	-0.0004	+0.025
Burnup II	+0.169	-0.28	+0.11	+0.002	-0.003	+0.087
Burnup III	+0.29	-0.36	+0.09	-0.012	-0.009	+0.107
Burnup IV	+0.56	-0.38	-0.06	-0.05	-0.07	+0.105
Burnup V	+0.68	-0.33	-0.14	-0.10	-0.11	+0.10

[a]See Table I for isotopic compositions of burnup classes.

In principle, for measuring isotopic ratios, the best precision is obtained using ratios measured with respect to the major component of the sample. In practice, independent ratio measurements of all isotopes with respect to ^{239}Pu have not been implemented.

Agreement of the precisions predicted in this paper with the precision of observed measurements has been found to be satisfactory for two published data analysis methods.

We have also illustrated the sensitivity of the specific power to biases in any of the independent measured variables.

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IAEA SAFEGUARDS AT A TURNING POINT

JAMES M. DE MONTMOLLIN
Sandia National Laboratories
Albuquerque, New Mexico

DIPAK GUPTA
Kernforschungszentrum Karlsruhe
Federal Republic of Germany

Abstract

IAEA safeguards are suffering from an erosion of confidence, at a time when the number of safeguarded facilities is growing rapidly, along with increasing dissension over nonproliferation policies. The reasons for the current problems are discussed, and suggestions for improving safeguards are explored.

IAEA SAFEGUARDS AT A TURNING POINT

These are difficult times for IAEA safeguards. A growing skepticism as to safeguards effectiveness has accompanied a shift in nonproliferation policy toward greater reliance on unilateral measures at the expense of international institutions. The events of the last two years especially -- the attack on the Iraqi reactor, increasing concern over Pakistan, the confrontation at last year's General Conference -- have widened and intensified criticisms of IAEA safeguards.

As a means of assurance that the spread of nuclear weapons can be prevented, safeguards are inevitably judged subjectively in terms of hopes and fears, expectations and perceived performance. Hopes rise with growing emphasis on international institutions, and skepticism grows when national policies turn inward. Earlier, idealistic expectations for the future generated widespread support through a period of rapid development. Now, at a time when the operational limitations have become more generally apparent, there is growing suspicion and hostility between advanced and developing countries and a continuing shift toward more restrictive export controls, largely because of erosion of confidence in IAEA safeguards.

Let us examine some of the reasons for the present situation. First, safeguards suffer the consequences of the general swing from internationalist policies with exaggerated and idealistic expectations to a period of reaction and isolation. The IAEA became established during a period of international cooperation, which continued through the negotiation of the NPT and the consequent rapid growth of safeguards. That began to change in 1974, although financial support for the Agency continued to increase until recently. It has now leveled off and the future is increasingly uncertain.[1]

A second reason for the present stage in the evolution of IAEA safeguards is that, within the present operational concept, technical development is approaching maturity. It is characteristic of R&D that when a new field opens up -- whether because a state-of-the-art breakthrough, or as in this case, a new set of specialized needs -- early progress is the most rapid. Fundamental needs that can be easily met are filled quickly, and later improvements are ever more marginal and difficult to accomplish. A somewhat similar limitation of diminishing returns applies to incremental additions of inspectors and other operating resources, especially since increased resources are required just to keep up with growth. One cannot avoid the question of how much improvement toward achieving the ultimate purpose of safeguards -- assurance to the general public -- some further addition of resources could be expected to provide. Such questions never arose in the early stages of safeguards activities, when any gain was significant.

Still another factor contributing to the erosion of confidence in safeguards arises from misconceptions of what safeguards can be expected to accomplish. It is the nature of a function such as safeguards that first, the final judges are political leaders and the general public, both far removed from the specialized and technical details of safe-

The views expressed in this paper are those of the authors and not necessarily those of their respective organizations or governments.

guards operations, and second, their assessments of effectiveness are based on varying expectations and perceptions of performance. In recent years there has been a widening gap between what the clients believe safeguards must do and a growing realization that performance falls short of that. Safeguards can perform a vital and necessary function, but in order to do so they must instill confidence in the minds of the clients. That can only be done if expectations and performance are brought into closer harmony. Progress must be made on two fronts: conveying a better understanding of the role of safeguards, and restructuring safeguards concepts and inspection goals to close the remaining gap.

Another contributing factor is that safeguards were caught in the crossfire of the battles over nuclear power. Before 1974, national policies almost without exception favored nuclear power, and with it, safeguards. While there was some controversy over how intrusive safeguards need be, there was general agreement that they could effectively provide adequate assurance. Beginning in 1974, new voices came to dominate. The extension of nuclear power was no longer a principal objective; rather, unless safeguards could meet a goal of what amounted to zero risk, exports must be restricted, whatever the consequences to nuclear-power use. Many of those who took such strong stands saw no great loss, and to some the curtailment of nuclear-power growth was an end in itself. The result in many cases has been to saddle safeguards with unreasonable standards of effectiveness that are neither politically nor technically feasible to attain.

Problems With The Present System

If developments in recent years have driven safeguards to a turning point, in what new direction should they be turned? First, we offer our own analysis of the shortcomings of the present concepts.

A fundamental difficulty with IAEA safeguards is confusion as to whether the system is adversarial or cooperative. The problem is that it has elements of both. How can it function, if the other party is the potential adversary and the system depends on his cooperation? The seeming dilemma can be resolved, but only if there is universal agreement on the purpose of safeguards and a clear understanding of how safeguards operations serve that purpose. The problem is more than a lack of understanding: whether one views the ultimate purpose as adversarial or cooperative determines one's judgment as to what constitutes effective performance.

Let us be more specific. The purpose as stated by the Agency is to provide assurance that States are complying with their peaceful-use undertakings.[2] Safeguards are accepted voluntarily, although sometimes in exchange for direct benefits. Nevertheless, there is a commonality of interest between the State and the rest of the international community in providing assurance by means of safeguards. On the other hand, some perceive the purpose to be the detection of a violation in order to trigger immediate responsive action, which is clearly an adversary position.

Safeguards provide the assurance by means of independent verification, reporting an inability to assure if the declared status cannot be verified. Only at the level of technical operations, where the means of verification are determined, is an adversary role assumed, and that is merely hypothetical. The IAEA safeguards function is no more adversarial than is an independent, outside audit of corporate accounts to assure stockholders; each is adversarial only hypothetically and only to the degree necessary to be independent.

Since safeguards arrangements must be negotiated in detail with the State, the whole activity could hardly be described as anything but cooperative, for a common purpose. In that fundamental respect it differs profoundly from State controls, in which regulations are imposed unilaterally and inspection is for the purpose of enforcement.

The perception of safeguards as adversarial has spread from both sides -- the political and the technical -- until it has come to dominate and distort understanding of the role of safeguards. On the other hand, in some States in particular the purpose is seen by policymakers since 1974 to be to provide an alarm that is adequate to permit immediate corrective action to be taken. The whole concept of "timely warning" grew from that adversarial view. At the technical end, attention has been properly focused on hypothetical diversion scenarios. But without a general understanding of the ultimate purpose of assurance, the technical designs based on hypothesized adversary actions served to reinforce and confirm a widely-held view that the ultimate purpose itself is adversarial. How an adversarial system could be built that must necessarily depend on the cooperation of the adversaries led to an insoluble dilemma that could only undermine confidence in the whole enterprise.

Inspection Goals

"Assurance" is a subjective, intangible quality that depends as much on judgment as fact. There must be some connection between what clients perceive to be adequate assurance and the results of Agency inspection activities. Quantified inspection goals, and the extent to which they are attained, are intended to form that connection. To do so, it is necessary that they be attained routinely, and second, that attainment provide the necessary assurance. Inspection goals are thus the critical element that determines effectiveness.

In the Statute (1956) it was envisioned that safeguards would cover "special fissionable and other materials, services, equipment, facilities, and information", and that inspectors would have access at "all times to all places and data and to any person...who deals with materials, equipment, or facilities... to be safeguarded".[3] With INFCIRC/66 (1965) and especially with the negotiation of the NPT, the scope of safeguards was narrowed substantially. The NPT provides that safeguards will be directed only at fissile materials, and only at selected "strategic points".[4] The goal was a system free of subjective judgments, and some believed that if the desired threshold values for timeliness and quantity were assigned that goal could be accomplished.[5] Since some thought it essential that safeguards be able to detect a one-bomb-quantity diversion in a time less than conversion time, that came to be accepted by many as the degree of assurance needed to accomplish the purposes of the treaty and of safeguards.[6] "Detection goals" are defined to support that objective. Since detection goals are not physically attainable in important cases, relaxed goals, termed "inspection goals", are defined for specific facilities. Where inspection goals are not met, which occurs in a substantial number of cases, the Agency attributes that to inadequacies in the State system and insufficient Agency resources. Thus, "inspection goals" are "detection goals" that are technically, but not necessarily actually, attainable. However the goals are ordered, the problem remains: the Agency accepts the pro-position that the system should detect a one-bomb diversion within conversion time, at the same time acknowledging that that is not feasible in situations of greatest concern. The elaborate hierarchy of goals serves only to separate what is technically and what is operationally infeasible. The clients and the general public inevitably measure performance against a detection threshold at the one-bomb level and find it inadequate, especially in the case of large bulk plants. The Agency's rationalization in terms of distinctions between "detection" and "inspection" goals only confirms the wide gap between expectations and performance, with a consequent loss of confidence in the entire institution.

Based on Individual Facilities

Safeguards became established when they were applied to individual Agency projects or exports, and the activities and findings were in relation to separate, individual facilities. Under the NPT the entire State's nuclear activities are safeguarded, and the significant finding is with respect to the State as a whole. Since the numbers of safeguarded facilities vary widely among States, and findings are with respect to individual facilities, present inspection goals based on absolute quantities do not provide a common basis for findings with regard to each State as a whole. Safeguards have never been applied on an integrated, Statewide basis, as was envisioned when NPT safeguards were first developed.[7] The result is, the larger a State's nuclear program, there is relatively less assurance as to the State's activities, in spite of the efforts expended to safeguard the larger numbers of facilities.

A New Direction

If safeguards are to escape the limitations of the present approach, the Agency must strike out boldly in a new direction. It must seek new technical approaches that employ the full potential of the INFCIRC/153 concept. A major effort must be undertaken to convey an understanding of the role and purposes of IAEA safeguards, in layman's language, to the worldwide general public. The Agency can no longer afford to suffer the consequences of erroneous perceptions, attacks based on those misconceptions, misplaced expectations, and nonoptimum use of resources.

Action Must Proceed on Several Fronts

Role. Non-proliferation measures fall into two general classes: restrictive and cooperative. Much of the problem with safeguards has been confusion as to which class safeguards belong. It must be made abundantly clear that safeguards are absolutely dependent on cooperation, and attempts to apply them to a restrictive or coercive effort will ultimately destroy their base of support. Not only are safeguards dependent on cooperation for day-to-day operations; they are accepted only on the basis of some bargain in an exchange of benefits. Safeguards should be associated with cooperative arrangements of a positive nature, such as assured supply, technical assistance, fuel-cycle services, and strengthened commercial ties. We must not forget that support for safeguards, except for a very few supplier States, was gained through expectations of increased cooperation. That support is eroding largely because, since 1974, safeguards are seen increasingly to be restrictive and coercive. Coercive measures must be left to unilateral or group actions by States, disassociated from safeguards.

Quantitative Goals are of paramount importance. They form the tie that links purpose, expectations, and performance, and they are the basis for safeguards technical design. They must support a safeguards strategy that can be applied without discrimination to all States. They must support findings based on a common level of assurance with regard to each State as a whole. They must be carefully defined to insure that they strike a proper balance among all these requirements and the constraints of feasibility and resource limitations.

Present goals are based on detecting a diversion related to a threshold of consequences: the fabrication of a single explosive. The credibility of such a diversion varies widely with the State and with the circumstances in each facility. Application of such fixed criteria across the board results in widely-disparate levels of performance and degrees of assurance provided. It relates more directly to a "burglar-alarm" function, which the Agency has taken some pains to disavow, than to the primary purpose of assurance that the State is complying with its peaceful-use undertakings.

Safeguards are based on accounting for fissile materials, explicitly in the case of NPT safeguards.[8] It follows that the purpose of safeguards is accomplished directly by a finding that all the State's materials are accounted for. Such a statement must be further qualified with estimates of precision and confidence limits. If the probability of the statement being in error exceeded some defined limit, the finding would be that the Agency was unable to verify that the State's materials were accounted for within an acceptable level of assurance. In order to generate such a finding for the State, the safeguards effort could be allocated among the separate facilities that comprised the State's particular nuclear program, so that the aggregate findings were in terms of the State as a whole. Discrimination among States could be avoided by tailoring the State-wide effort to that necessary to meet the same criterion: the confidence level associated with the statement. The effort would be applied to each State to the degree necessary to meet the common goal. The concept would be based on proportionate inspection goals, which relate to assurance, rather than fixed values defined by the potential consequences of a threshold level of diversion.

Public Understanding. The Agency must undertake a major effort, with the full support of the Board of Governors, to inform member governments and the general public of the proper role of safeguards, and to show how new approaches are being undertaken to fill that role. In the past few years the Agency has become more aware of that need, but fundamental contradictions need to be rectified. Above all, safeguards must be seen by developing countries as an integral part of a cooperative and constructive regime that supports their individual interests. The Agency must no longer allow safeguards to be perceived as part of an enforcement mechanism managed by the advanced States.

IAEA safeguards are truly at a turning point, and we must seek new directions. Technical innovations are needed that will lead safeguards into closer harmony with political factors, to restore and strengthen confidence in safeguards as an essential element in the control of proliferation. We hope that some of the thoughts presented in this paper will stimulate new concepts and approaches.

NOTES

1. From 1962 through 1970 the IAEA regular budget grew at an average annual rate of 8.2 percent. From 1971 through 1980 the growth rate averaged almost 21 percent. In 1982 the budget actually decreased --- 1957-1982, 25 years: International Atomic Energy Agency, IAEA, Sept. 1982, p. 6. The annual budget has since increased, by seven percent and nine percent in 1983 and 1984, over the respective preceding years. -- Nucleonics Week, June 16, 1983, p. 5.

2. Some of that assurance derives from the deterrent effect of safeguards, which is stated to be a complementary purpose.

   The terms "purpose" and "objective" are somewhat ambiguous in the documents, and they are often confused in common usage. INFCIRC/66-Rev. 1 (par. 46), the NPT (Art. III.1), and INFCIRC/153 (par. 1) all state the purpose in terms of assurance. When the NPT safeguards system was devised in 1970, material accountability had become the basis for safe-guards, and the need for a quantifiable technical objective as a basis for design of operations was recognized. Such an "objective" was specified in par. 28 of INFCIRC/153 as the timely detection of significant quantities of diverted material. When values were assigned, the "purpose" became the detection of such a de minimus diversion, rather than assurance of no diversion. Recently the Agency has tried to emphasize the distinction between purpose and design objective; the former is defined in terms of assurance as the "political objective", and the latter as the "technical objective" (IAEA/SG/INF/3, 1981, p. 12). The use of the term "objective" for both may be unfortunate.

3. Statute of The International Atomic Energy Agency, 1956, Art. III.A.5; Art. XII.A.6.

4. Treaty on the Nonproliferation of Nuclear Weapons, 1968, Preamble; Art. III.

5. The rationale was presented by Imai in 1972 and again in 1977:
   --- Ryukushi Imai, "Nuclear Safeguards", Adelphi Papers Number 86, The International Institute for Strategic Studies, 1972
   --- Ryukushi Imai, "Safeguards Against Diversion of Nuclear Material: An Overview," Annals of the American Academy of Political and Social Science, v. 430, Mar. 1977, p. 60,62

6. Mason Willrich was remarkably prescient in a prediction he made in 1971, when the NPT safeguards concept had just been formulated:

   "As nuclear power programs are established in more and more nations, and as these programs increase in size, definite accountability standards will be required. The development of parameters may be a technical task, but the choice of standards within those parameters will be political. The nations affected will probably not leave the important choices to the IAEA bureaucracy. The review and refinement of safeguards standards will thus become a continuing, controversial, and politicized process within the IAEA."---Mason Willrich, Global Politics of Nuclear Energy, Praeger Publishers, 1971, p. 88.

7. The Structure and Content of Agreements between the Agency and States Required in Connection with the Treaty on the Nonproliferation of Nuclear Weapons, INFCIRC/153 (corrected), IAEA, 1972, par. 81.

8. Containment and surveillance play a complementary role in accounting for materials. The relationship is discussed by de Montmollin and Hartman, "The Function of Containment and Surveillance in IAEA Safeguards", Proceedings of the 3rd ESARDA Symposium on Safeguards and Nuclear Materials Management, Karlsruhe, Federal Republic of Germany, 6-8 May,

UNDERWATER SEAL AND SEAL IDENTITY READING INSTRUMENT FOR NUCLEAR SAFEGUARDS

V.H. ALLEN
AECL
Chalk River Nuclear Laboratories
Chalk River, Ontario, Canada

J.M. McKENZIE
Sandia National Laboratories
Albuquerque, New Mexico

ABSTRACT

A newly developed underwater seal for CANDU reactor irradiated fuel containment units is described. The instrument developed to read the identity/integrity of the seals is also described. The seals are unique and highly tamper resistant. A qualititative discussion of the statistical interpretation of the IAEA development acceptance tests is included.

INTRODUCTION

Most irradiated reactor fuel is stored underwater. When the irradiated fuel inventory is placed under international safeguards the fuel elements or assemblies are counted at regular intervals by IAEA inspectors. This counting procedure is simplified and requires less manpower if larger numbers of assemblies are stored in sealed containment units. At each inspection the identity and integrity of the seals can then be checked.

The seal is intended for IAEA use on underwater containment units for Canadian Deuterium Uranium (CANDU) reactor irradiated fuel. After installation, a portable electronic instrument, acquires and stores the ultrasonic identity of the seal. At subsequent inspections the instrument acquires a new identity and compares it, using a cross-correlation technique, with the original identity. This provides an objective verification of the identity and of the integrity of a seal.

CONTAINMENT OF IRRADIATED CANDU FUEL

A CANDU fuel assembly or bundle is 50cm long, has an outer diameter of 10cm, and contains 37 fuel pencils. Irradiated bundles, in the storage bay, are placed in trays and stored in containment units each of which contain about 1000 bundles. One form of containment unit consists of a stack of 19 trays with a wire mesh cover (Figure 1). The trays interlock to prevent removal of fuel from the sides of the stack. Two AECL Random Coil (ARC) cap seals secure the cover to rods attached to the base plate of the stack. The depth of water at the seal is 4.5m. About four to five spent fuel stacks are created each year by a 600 MW CANDU reactor.

THE ARC/SPAR SYSTEM

The ARC/SPAR System, Figure 2, consists of the ARC cap seal; a reading fixture to position the interrogating transducer above the ARC; and a Seal Pattern Reader (SPAR) to provide the necessary electronics.

The ARC Cap Seal

All safeguards seals must meet some general requirements which include uniqueness of identity, integrity, and the ability to be verified.(1) In addition, seals for irradiated fuel containment units must be installed, and verified in situ at a water depth of 4.5m. Furthermore, greater than ten years seal life and the ability to withstand a total radiation dose of about 10^7Gy are required. The ARC cap seal was developed to meet these special requirements.(2,3,4) It is installed from a gantry above the pool using a 6m long hand held tool.

The seal consists of a threaded cap that screws on a stud. The latter is welded to the rod passing up through the stack of fuel. The seal attachment involves both the thread and a non-return mechanism in the form of a shouldered pin in the cap which engages a split collet in the stud. Since the split collet captures the shouldered pin, unscrewing the seal will break the pin at its weakest point--an intentionally machined fracture link near the shoulder. The unique identity element, the ARC, is located in a well in the seal. One end is welded near the upper surface of the seal. The other end is fed through a hole in the shouldered pin and is welded to its base. In effect, the ARC is welded across the fracture link. Unscrewing the seal and breaking the fracture link distorts and ultimately unravels the coil thus destroying its identity. This gives the seal integrity.

One method of making the ARC is to wind 10 turns of 0.010" stainless steel wire on a 1/8" triangular form. The stainless steel wire is first prekinked by twisting two wires together and then untwisting them.

The Reading Fixture

To read the identity/integrity of the seal, a transducer is positioned in water at about 40 mm above the ARC. The transducer is shock excited by a sharp electrical pulse from the SPAR and rings at its resonance frequency, 5 MHz, for about 5 cycles after which it is used to listen for echos. A well-collimated sound pulse propagates in the water at about 1.5 mm/μs from the transducer towards the coil. (See Figure 3). This sound pulse is reflected from any surface it encounters. The time of reflection, referenced to the transducer energizing pulse, depends on the distance of the surface from the transducer; the magnitude of the reflected echo depends on the area of the surface encountered; while the direction of the echo depends on the angle of incidence of the sound pulse with the surface. Only those surfaces approximately normal to the sound beam will return echoes to the transducer. The ARC is mounted to one side of the well in the seal. This places one side of it in the sound beam. The pre-kinking of the wire provides random surfaces normal to the beam. Also, as the coil is removed from the triangular winding form it rotates. This provides additional randomness to the coil. Even fixing the coil ends provided a randomness. It is the amplitude and temporal characteristics of the echoes from the ARC, as gathered by the listening transducer, which form the seal's unique identity.

The temporal characteristics of the identity depend on the velocity of sound in water. This is a function of the water temperature. Higher than normal water temperatures will cause the first refection to be early and the identity to be compressed. Conversely, lower temperatures give a late first reflection and an expanded identity. To compensate for this effect a small ledge, called the velocity ledge, is machined into the reading fixture. At 25°C in deionized water, the transducer to velocity ledge distance is adjusted so that the maximum of the reflection from this ledge occurs at a set time after the transducer energizing pulse. Temperatures above 25°C cause the maximum to come earlier, while temperatures below 25°C cause the maximum to come later. The SPAR uses this time shift to expand or to compress the measured identities and thus it provides a normalized or 25°C identity.

A 6m long extension tube with a handle attaches to the reading fixture and completes the tool.

The SPAR

The SPAR is a microprocessor controlled instrument for the acquisition, digitizing, processing, comparison, and storage of data. For the ARC/SPAR system the SPAR pulses the 5 MHz ultrasonic transducer and then uses the same transducer to listen for echoes. The functional block diagram for this system is shown in Figure 4. The magnetic bubble memory can hold up to 49 seal identities and 1 calibration seal identity.

On power-up the SPAR enters a self-test routine. When this is completed, the interactive feature of the SPAR directs the operator to one of several options. The choice enables the software operating system to control the SPAR as dictated by the operator. For example, the operator can select reading and storing, reading and comparing, reading and plotting, plotting stored identities, listing stored seals, etc.

The reflections from an ARC converted to an analog signal by the transducer are shown in Figure 5A. The temporal separation of the reflections is a function of the spacial separation of the reflecting regions of the coils of the ARC and also a function of the velocity of sound in water. Since the echo pattern of an ARC is sound velocity dependent, the SPAR first makes a sound velocity measurement. This is shown in the left hand panel of Figure 5. The SPAR only digitizes a sufficient time interval (6 μs) of the analog signal from the transducer, Figure $5B_L$, to enable it to determine the time of the maximum of the reflection from the velocity ledge. It records only the absolute values of the digitized analog signal, Figure $5C_L$. Thus it effectively software rectifies the signal. The SPAR then smooths the rectified signal, Figure $5D_L$, to remove the 5 MHz oscillating frequency of the transducer. Finally, it differentiates the smoothed signal, Figure $5E_L$, to enable it to find the maximum of the reflection from the velocity ledge.

Based on the time position of the maximum reflection from the velocity ledge the SPAR software determines the time delay after the transducer energizing pulse to start digitizing to obtain the ARC identity. The reflection from the velocity ledge, of course, is not included in the ARC identity. Once the identity digitizing is complete, Figure $5B_R$, the SPAR rectifies, Figure $5C_R$, and smooths, Figure $5D_R$, the signal. Also based on the time position of the maximum reflection from the velocity ledge the smoothed signal, Figure $5D_R$, is expanded or contracted to give a normalized, or 25°C, identity. Depending on the operator directive, this identity may be stored in the magnetic bubble memory, compared with an identity already stored in the bubble memory, etc.

The SPAR compares identities by calculating a correlation coefficient

$$r = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{\left[\sum_{i=1}^{n} (x_i - \bar{x})^2 \cdot \sum_{i=1}^{n} (y_i - \bar{y})^2 \right]^{\frac{1}{2}}}$$

where x_i and y_i are the present and previous digital amplitudes in the ith digitized interval; $\bar{x}$ and $\bar{y}$ are the average values; n equals the number of digitizings

and $-1 \leqslant r \leqslant 1$

If the present and previous identities are exactly the same $r = 1$; if one is an exact mirror image of the other $r = -1$. For no correlation between identities, r is about 0.

EXPERIMENTAL RESULTS

The identities are measurements of the reflections from sections of the coils of the ARC and have errors associated with them. These errors, however, can be minimized. For example, using the same transducer mounted in a fixture left on the ARC ensures that the relative positions of the ARC and transducer are unchanged. Making the measurements at the same temperature and using the same electronics eliminates other errors. However, in the "real world" transducers and fixtures may be different, a different SPAR may be used, and the temperature will probably be different. These parameters degrade the correlation coefficient. In the final analysis, the ARC/SPAR system has to read seals in the "real world" and has to provide matches or mismatches with some confidence. For the ARC/SPAR system to provide this information three questions must be answered satisfactorily.

1. How random is the ARC?

2. Can the SPAR adequately read the identity over the required temperature range, with different transducers or fixtures, and with different SPAR's?

3. How well does the correlation algorithm separate repeated readings of the same seal (auto correlations) from the readings of different seals (cross correlations)?

These questions are answered in References 5 and 6 and are summarized here.

Experimentally some parameters have almost no effect on the correlation coefficient. The particular SPAR used for the acquisition, and the fixture positioning the transducer above the coil all cause only minor degradations in correlation coefficient. The fixture, of course, is made within some tolerance. However, the tolerances on both the seal and the fixture, are not unreasonable.

The interchange of transducers has some effect on correlation, temperature also has an effect, and some coils just seem to be inherently poorer correlators than others. Coils made in a particular way and mounted in a particular way have a population distribution of correlation coefficients. This distribution is perturbed mainly by temperature and to some extent by transducer interchange.

The identities of a significant number of coils were recorded. Each of the identities was correlated with a subsequent reading of the identity of the same coil. A probability distribution of correlation coefficients as a function of the correlation coefficient was formed. This distribution, of course, does not include all the ARCs in the world but is a significantly representative sample of that population. There is a considerable advantage if this sample probability distribution, represented in an algebraic form, follows a specific probability distribution. This allows for more precise statistical inferences. For example, an algebraic form of the population based on the sample results gives more information on the probability of finding an auto correlation below some value rather than merely noting the number of auto correlations measured below this value. The same is true for the cross correlation population. The algebraic form of the cross correlation population gives the probability of finding cross correlation greater than some value.

Statistical inferences of correlation coefficients as a function of temperature requires a knowledge of the pool temperature as a function of time. Our recent experiments, however, indicate that most of the time the pool is within ±5°C of its normal temperature. It is perhaps only rarely that a measurement is required when the pool is very different from normal. Based on the ±5°C variation an autocorrelation coefficient less than 0.8 could be expected twice in 10^4 measurements. Thus using 0.8 as a discrimination level

$r < 0.8$	$r \geqslant 0.8$
different seals	same seal

the SPAR would, twice in 10^4 comparisons, indicate different seals when indeed the measurements were of the same seal. Or the probability of indicating a different seal given that it is the same seal is 2×10^{-4}. From the cross correlation population at a cross correlation discrimination level of 0.66

$r \leqslant 0.66$	$r > 0.66$
different seals	same seal

the SPAR, when reading different seals, would give correlations >0.66 three times in 10^5 readings. This is the frequency, at a 0.66 discrimination level, at which the SPAR would identify a different seal as the same seal.

The preceding is based on a random selection of ARCs made by the same process. Attempts to reproduce ARCs have failed. Although they may appear visually similar, their ultrasonic images are significantly different. When welded into the seal the ARCs are usually under compression and torsion or tension and torsion. Thus any attempt to defeat the seal by cutting the upper fixation point and leaving the inner core intact disturbs the ARC and irreversibly changes the ultrasonic identity. An ARC is unique to parts in 10^5 at a discrimination level of 0.75 and is highly tamper resistant.

Transducers can be matched into groups of 3 or 4, with auto correlations $\geqslant 0.92$ where different transducers are used to identify the same ARC at the same temperature. These transducers were made by Search Unit Systems, Inc., San Antonio, TX, to specifications provided by the NDT group, Rockwell International, Rocky Flats, Co.

CONCLUSIONS

The ARC/SPAR system provides an IAEA inspector with a means of making an objective determination of the identity/integrity of the seals on CANDU spent fuel stacks. The system will operate over the required shipment, installed and operational environmental conditions. Projections indicate that if the reading temperature of the ARC's is relatively constant the SPAR will differentiate between the same and different ARC's at levels of a few false acceptances or rejections in 10^5 comparisons. Commercial manufacture of interchangeable transducers has been demonstrated.

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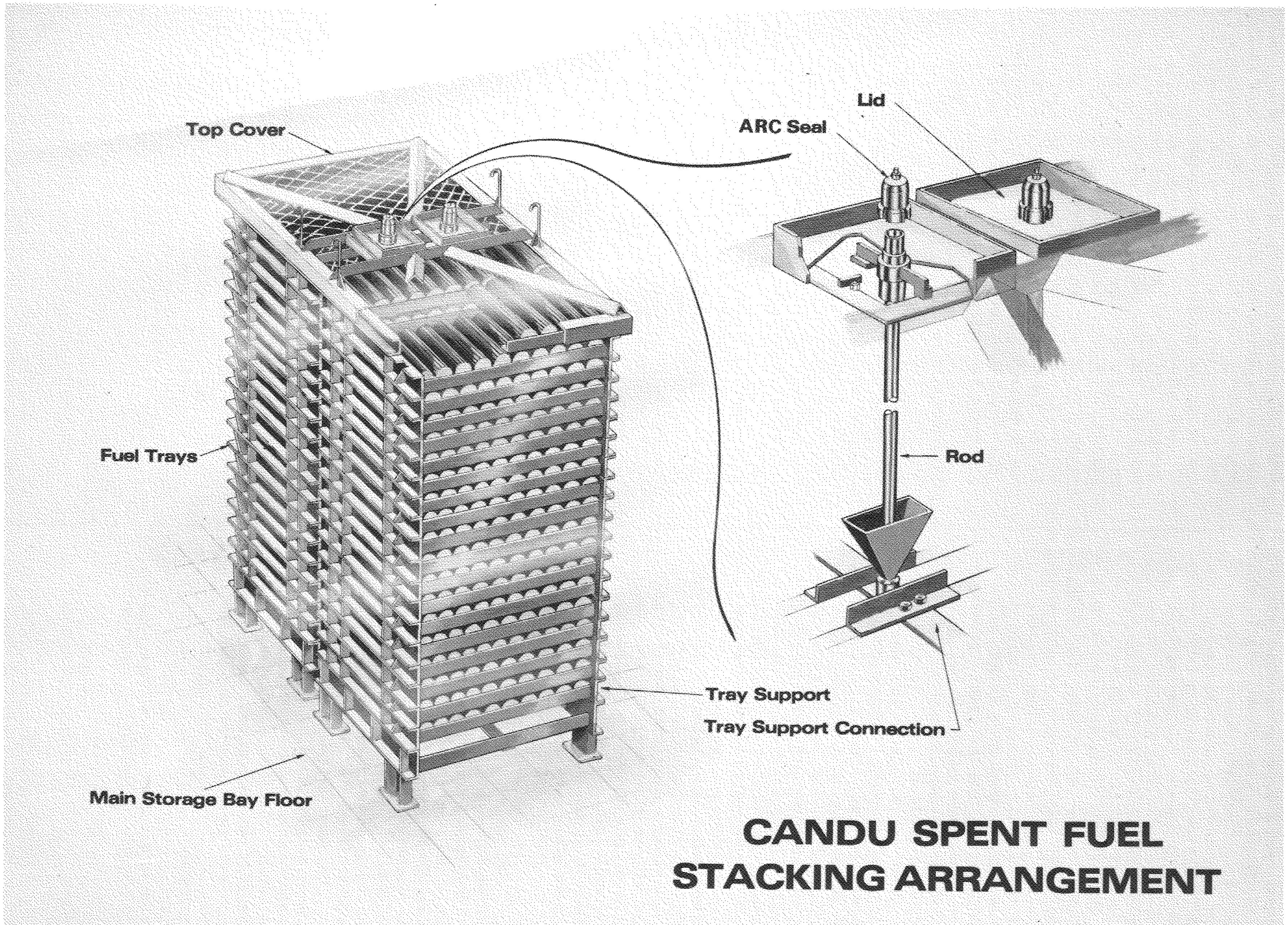

Top Cover
Lid
ARC Seal
Fuel Trays
Rod
Tray Support
Tray Support Connection
Main Storage Bay Floor
CANDU SPENT FUEL
STACKING ARRANGEMENT

Figure 1

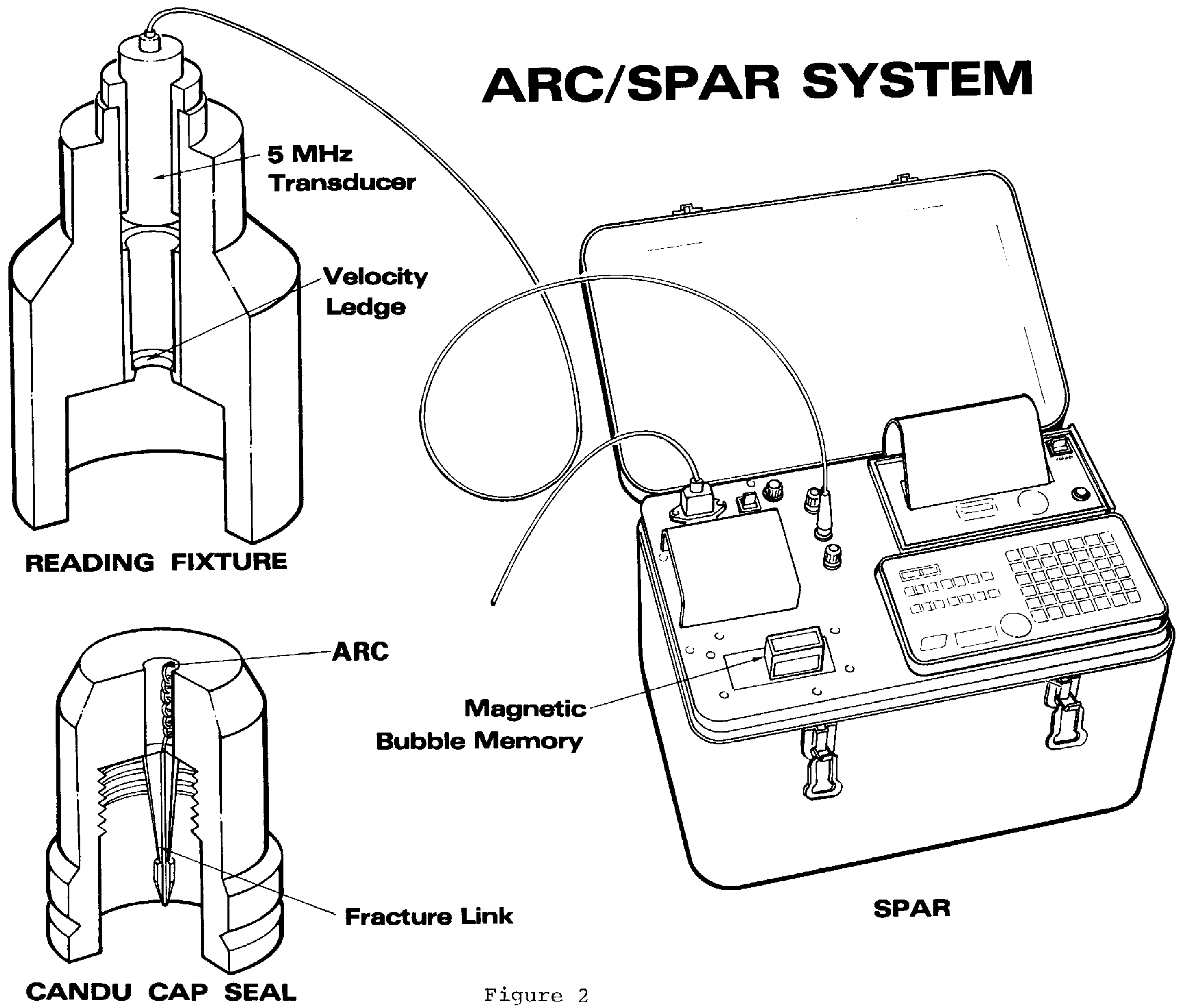

ARC/SPAR SYSTEM
5 MHz Transducer
Velocity Ledge
READING FIXTURE
ARC
Magnetic Bubble Memory
Fracture Link
CANDU CAP SEAL
SPAR

Figure 2

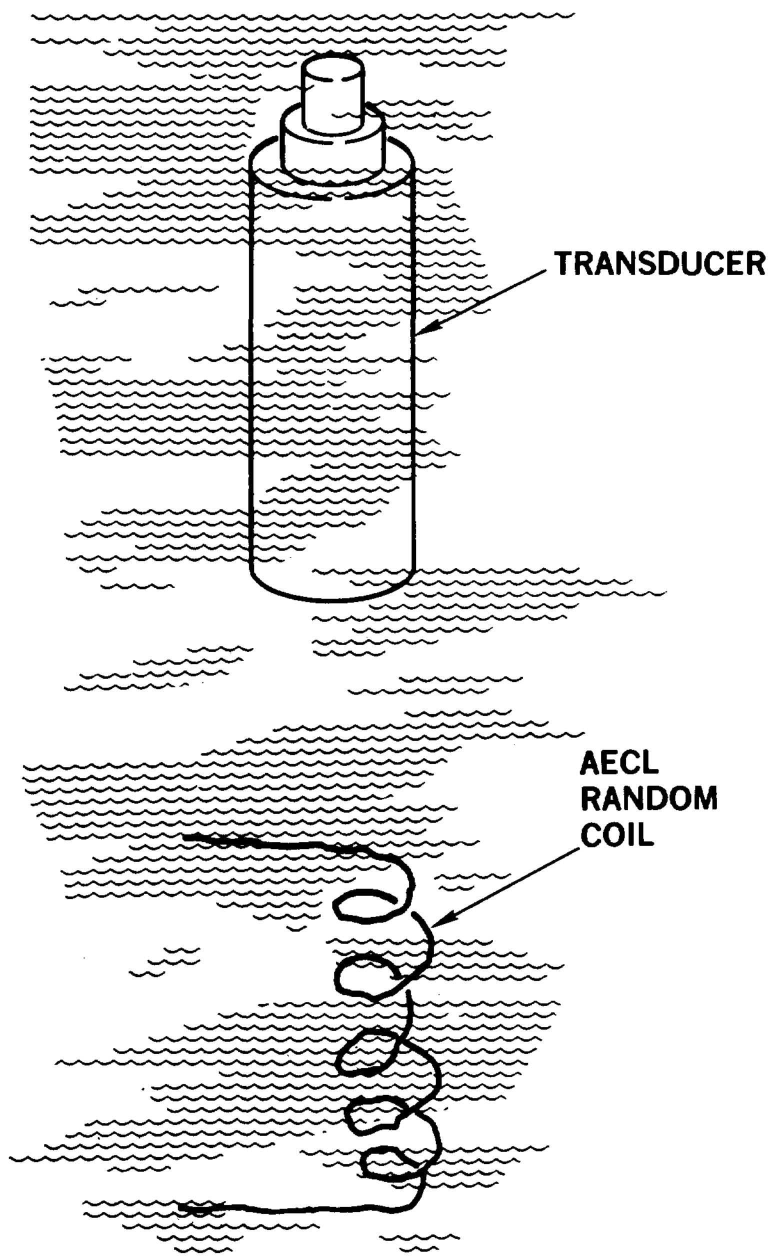


Figure 3
Relative Position of the Transducer to the ARC

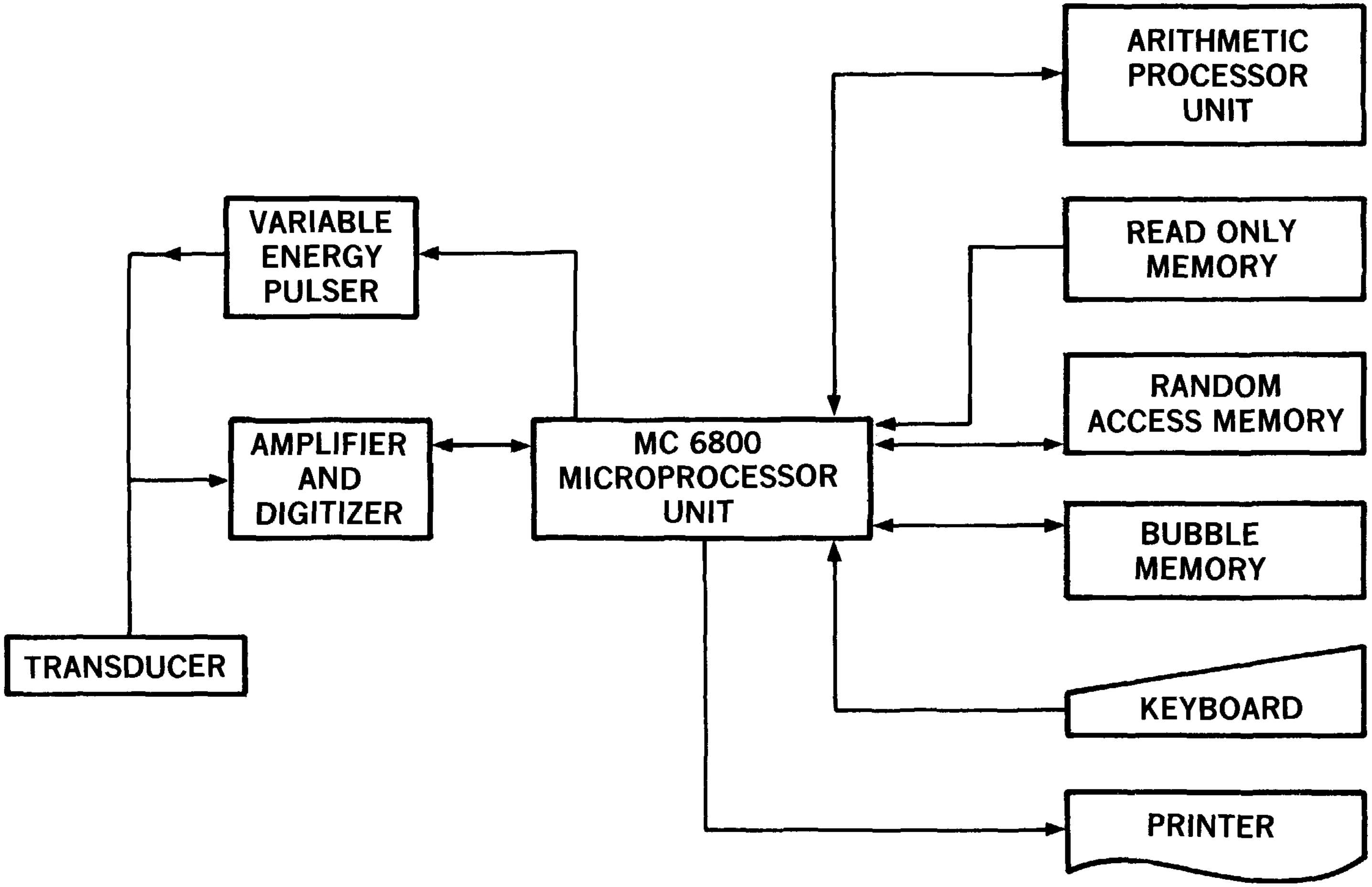
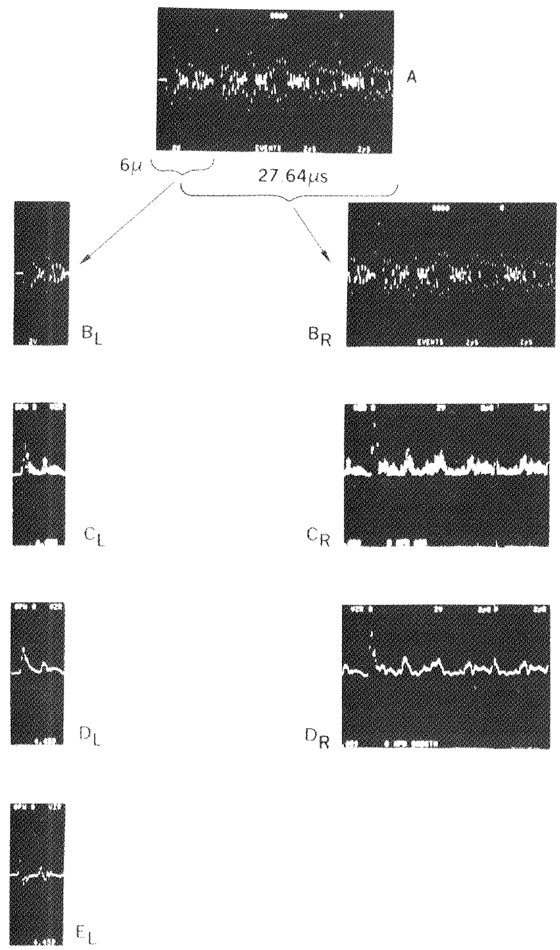


Figure 4

FUNCTIONAL BLOCK DIAGRAM OF
ARC/SPAR SYSTEMS



A ANALOG SIGNAL FROM AN ARC

LEFT HAND PANEL SHOWS THE METHOD OF LOCATING THE MAXIMUM OF THE VELOCITY LEDGE

B_L 6μs OF SIGNAL DIGITIZED

C_L MADE ABSOLUTE

D_L SMOOTHED

E_L DIFFERENTIATED TO LOCATE MAXIMUM

RIGHT HAND PANEL SHOWS THE METHOD OF ACQUIRING THE ARC SIGNATURE

B_R 27.64μs DIGITIZED

C_R MADE ABSOLUTE

D_R SMOOTHED

Figure 5
SPAR Data Acquisition Process