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NUCLEAR MATERIALS MANAGEMENT

Journal of the
INSTITUTE
OF
NUCLEAR
MATERIALS
MANAGEMENT

FEATURE ARTICLES

TABLE OF CONTENTS

REGULAR FEATURES

SPECIAL ARTICLES

ANNOUNCEMENTS AND NEWS

ADVERTISING INDEX

EDITORIAL

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

1982

No new nuclear weapon states this year.

Dr. Hans Blix became Director General of the IAEA on January 1.

On September 4, the IAEA General Conference voted not to accept the credentials of the Israeli representative and the United States initiated a boycott of Agency functions.

The IAEA Expert Group on an International Plutonium Storage Regime submitted its report to the Director General in September.

The IAEA's Standing Advisory Committee on Safeguards Implementation, or SAGSI, attempted to review and to refine IAEA safeguards goals, criteria, and strategies.

As technical editor, I feel it inappropriate to criticize political issues. However, it would seem acceptable to note that proliferation depends on political as well as on technical considerations. IAEA safeguards activities are an important mechanism to provide assurance that nations continue to respect their non-proliferation promises. But many other political issues are also important to contain proliferation.

The unfortunate General Conference incident and its aftermath are in the political sphere. With the permission of Ambassador Gerard C. Smith, the letter he wrote to the New York Times on this event on behalf of himself and three other former U.S. Ambassadors to the IAEA is reprinted in this issue.

The INMM Subcommittee on Government Liaison has studied the voluminous, four-year record of the IAEA's Expert Group on International Plutonium Storage. Its summary of these proceedings, the present status, and potential future actions is contained in this issue. This analysis is the result of a considerable amount of effort and discussion.

The Journal has published several articles on IAEA goals, criteria, and strategies.[1,2,3] These are subjects which anyone interested in the future of the Agency should take the time to think through carefully. Although political as well as technical issues are involved, the technically competent members of the Institute have a duty to consider what is technically achievable and how this might be achieved in our real world, and to communicate their conclusions to the appropriate governmental officials. One way to do these is to contribute to the Journal.

Tommy Sellers reminded me that I forgot to give credit to the representatives of the Federal Republic of Germany for their contribution to the containment/surveillance section of the International Working Group on Reprocessing Plant Safeguards, in my editorial in the spring 1982 issue of the Journal. I thank Tommy, and apologize for the omission.

References:
1. Gruemm, H., Designing IAEA Safeguards Approaches, Jour. INMM, Vol. IX, Proceedings Issue, 14-24, 1980.
2. de Montmollin, J.M. and Weinstock, E.V., Performance Goals for International Safeguards, Jour. INMM, IX, No. 1, 56-59, 1980.
3. de Montmollin, J.M., What Do We Mean by Safeguards? Jour. INMM, IX, No. 1, 67-69, 1980.

continued on page 4

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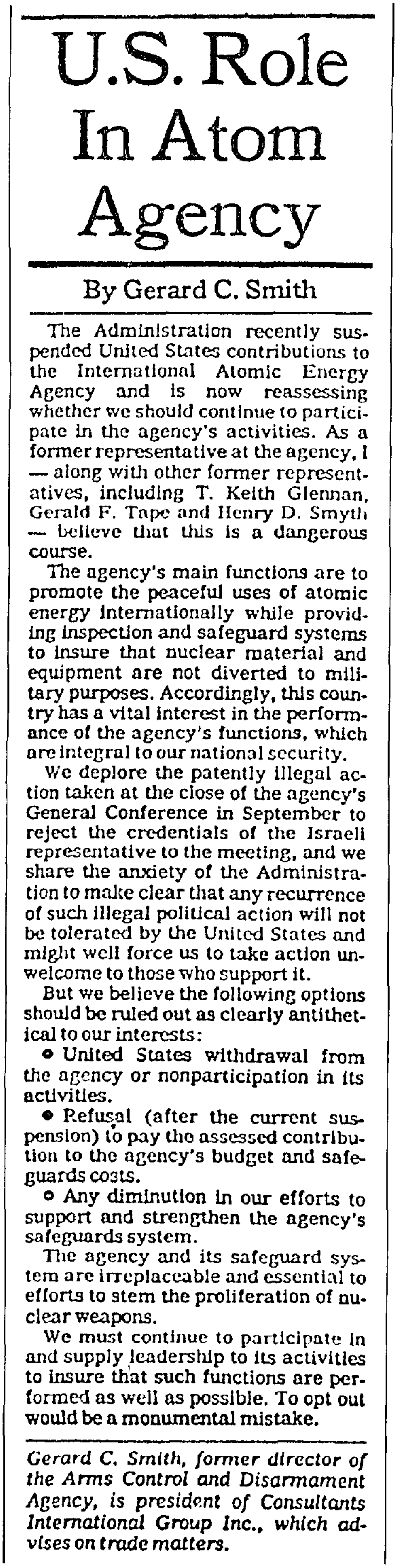
continued from page 3



U.S. Role In Atom Agency

By Gerard C. Smith

The Administration recently suspended United States contributions to the International Atomic Energy Agency and is now reassessing whether we should continue to participate in the agency's activities. As a former representative at the agency, I — along with other former representatives, including T. Keith Glennan, Gerald F. Tape and Henry D. Smyth — believe that this is a dangerous course.

The agency's main functions are to promote the peaceful uses of atomic energy internationally while providing inspection and safeguard systems to insure that nuclear material and equipment are not diverted to military purposes. Accordingly, this country has a vital interest in the performance of the agency's functions, which are integral to our national security.

We deplore the patently illegal action taken at the close of the agency's General Conference in September to reject the credentials of the Israeli representative to the meeting, and we share the anxiety of the Administration to make clear that any recurrence of such illegal political action will not be tolerated by the United States and might well force us to take action unwelcome to those who support it.

But we believe the following options should be ruled out as clearly antithetical to our interests:

- United States withdrawal from the agency or nonparticipation in its activities.
- Refusal (after the current suspension) to pay the assessed contribution to the agency's budget and safeguards costs.
- Any diminution in our efforts to support and strengthen the agency's safeguards system.

The agency and its safeguard system are irreplaceable and essential to efforts to stem the proliferation of nuclear weapons.

We must continue to participate in and supply leadership to its activities to insure that such functions are performed as well as possible. To opt out would be a monumental mistake.

Gerard C. Smith, former director of the Arms Control and Disarmament Agency, is president of Consultants International Group Inc., which advises on trade matters.

CHAIRMAN'S COLUMN

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

In reflecting on how to begin the first column that I will write as your newly elected chairman, I began by looking backward to the first Executive Committee meeting that I attended in 1974 in my capacity as N15 Standards Committee Chairman. In reviewing the minutes of that meeting, I was struck by two facts. First, I have heard over the years that the INMM is run by the same few individuals, possibly wearing different hats but always the same individuals. Experience is in conflict with that implied criticism; of the 15 Executive Committee members and Committee chairman in attendance at the aforementioned 1974 meeting, only *two* plus myself were at the most recent such meeting held in Chicago in October of last year. To continue with that thought, only *three* individuals plus myself were at both the November, 1978 and the October, 1982 meetings of the Executive Committee. I hope that these facts will silence the criticism. At the same time, we all owe votes of thanks to those many INMM members past and present who have given and/or give so willingly and conscientiously of their time to serve the membership in one way or another.

The other fact that impressed me in reading the old minutes was the dramatic change in the breadth and depth of INMM-sponsored activities. Ours is a dynamic organization, always changing to meet the challenges and opportunities of the present and anticipated future years. This ability to expand existing activities, introduce new ones, and delete those no longer needed requires vision on the part of those in leadership roles, but more importantly, it calls for full membership support. Our outgoing Chairman wrote in his final column that ours is an apathetic membership, and he cites evidence to support his contention. I firmly believe that such apathy can be overcome if the leadership can remain in tune with the needs and desires of its membership; but to be and remain in tune demands communication. Let us hear from you. Your telephone calls, letters, and personal contacts are always welcomed.

As enjoyable as it may be to look backwards, it is more important that we look ahead. Our organization is not escaping the problems experienced by other professional societies, notably the lack of funding to permit as full a participation in INMM activities as we might like. There are challenges to meet. With fewer available resources at their disposal, it is essential that we provide the membership with activities that are truly needed, and programs that respond to the stated purpose of our organization. (Reread Article II of the Constitution published in the Spring 1982 Issue of the INMM Journal to refresh your memory as to why we exist.)

In scoping these activities, it is essential that we remain financially responsible. On some fronts, this calls for an expansion of activities; on others, we must contract. Having just completed a full two-day meeting of the Executive Committee, a meeting that was preceded by a full day review of the budget by your Officers and our Executive Director, I can assure you that the decisions that are being made now and that will be made in the coming months, while you may be in disagreement with some, are decisions that are made only after careful and thoughtful deliberation.

It is pointless for me to review the activities of our many active committees, but I would urge you to read and study, and react to, the various committee reports contained in this issue of the Journal. Become better acquainted with the INMM; it is your society.

SPENT FUEL AND WASTE MANAGEMENT PROCEEDINGS AVAILABLE

Proceedings of the INMM Spent Fuel Management and Waste Disposal Seminar, held October 20-22, 1982, in Washington, D.C., are available from INMM headquarters. Contact Marlene Yadron at 312/693-0990. Price: Members—$100, Non-members—$150.

INMM HEADQUARTERS REPORT

JOHN E. MESSERVEY
Executive Director

After years of dedicated service, Ed Owings has resigned as Treasurer of the Institute. Chairman John Jaech has appointed Robert Curl of EG&G Idaho to replace Ed, effective February 11, 1983.

Immediate Past Chairman Gary Molen has resigned from the Executive Committee. Gary no longer works in safeguards at the Savannah River Laboratory of E. I. DuPont. Chairman John Jaech has nominated Past Chairman Ed Johnson to serve for Gary Molen's unexpired term.

We have also learned that Ev DeVer of Monsanto Mound Laboratory has taken early retirement as of November, 1982.

Ed, Gary and Ev will be missed.

Annual Meeting Local Arrangements Chairman Ed Young and his committee are planning a wide array of conference activities for the July 10-13, 1983, gathering in Vail. Marriott's Mark Hotel offers INMM an exceptional conference facility, as well as numerous western recreation opportunities.

Wade Ballard (l) and Stanley Goldsmith (r) led a discussion of Site Selection for High-Level Waste Disposal at the Spent Fuel Management and Waste Disposal Seminar. Chairman E.R. Johnson reported 83 participants at the October 20-22, 1982, gathering in Washington, D.C. Proceedings from the seminar are available from INMM headquarters.

INMM SENIOR MEMBERSHIP

The INMM Executive Committee has recently appointed the first Examining Committee for Senior Members and Fellows. The new levels of membership were established with recent changes in the bylaws.

Roy Cardwell of Union Carbide Nuclear Division in Oak Ridge was named Examining Committee Chairman. Bill DeMerschman of Westinghouse-Hanford also serves on the committee.

The Examining Committee will review and recommend nominations for the grade of Fellow in the Institute, as well as applications for Senior membership.

Individuals seeking an application for membership should contact Marlene Yadron at INMM headquarters (312) 693-0990.

VAIL SELECTED 1983 ANNUAL MEETING SITE

We are pleased to announce that the site of our 1983 annual meeting has changed to Marriott's Mark Hotel in Vail, Colorado. Our meeting dates will remain the same, July 10-13, 1983. As you may recall, we were originally scheduled to meet at the Denver Marriott City Center.

The reasons for this change are economic. Last month, the Denver Marriott City Center announced an $80 room rate, single or double. This rate is far beyond the means of our membership and the INMM budget. With the unanimous concurrence of the Executive Committee, the Annual Meeting Committee negotiated a $45 single or double rate at Marriott's Mark Hotel in Vail. Vail is located 100 miles west of Denver via Interstate 70.

Special transportation to our new annual meeting site is being arranged. INMM charter buses and rental car discounts will be announced shortly. Meeting attendees may also fly to the Vail Airport via Rocky Mountain Airways.

During our planning sessions, the committee has been most impressed with the professionalism and facilities available at Marriott's Mark Hotel. We believe that our 1983 annual meeting will set new standards of excellence for the Institute.

John L. Jaech
INMM Chairman

Yvonne M. Ferris
INMM Vice Chairman
Annual Meeting Chairman

INSTITUTE OF NUCLEAR MATERIALS MANAGEMENT

INVITATION TO EXHIBIT

24th INMM Annual Meeting
Vail, Colorado ▪ July 10-13, 1983

The 1983 annual meeting of the Institute of Nuclear Materials Management [INMM] is being held at Marriott's Mark Resort, Vail, Colorado, July 10-13, 1983. As part of this meeting, the Institute welcomes exhibits which are of interest to INMM members.

Traditionally, the exhibits are simple, informative, and often of the table top variety. The exhibit space will be located in a room immediately adjacent to the meeting room. Coffee breaks and a poster session are planned to give maximum exposure to the exhibits. Booth display hours are limited to normal session hours.

You are invited to participate as an exhibitor in the 1983 meeting. The fee for participation is $375. This fee entitles your organization to space equivalent to one table and one registration for the meeting. A covered table [6 by 3 foot] will be provided. 110V electrical service is available.

Space will be allocated on a first come basis, based on the date of receipt of your check, payable to INMM. Please call me [505/667-7777] if you have any questions. We look forward to your participation in this important meeting.

Sincerely, **ARNIE HAKKILA,** Exhibits Chairman

Los Alamos National Laboratory
P.O. Box 1663, Mail Stop E-541
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SAFEGUARDS COMMITTEE REPORT

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

Both the Subcommittee on Government Liaison and the full Safeguards Committee met in Washington, D.C. during the last week of September. Dick Duda's subcommittee met at the State Department with Allen Sessoms of State and Arch Turrintine of ACDA. The meeting centered on (1) the current U.S. issues with the IAEA and the precipitous Israeli credentials vote, (2) the status of the International Plutonium Storage concepts, (3) an upcoming plutonium shipment from France to Japan via the U.K., and (4) issues surrounding the safeguarding of large reprocessing plants.

Roy Nilson reported during the Safeguards Committee meeting that the proposed LEU rule change was under consideration by the Commissioners. We now understand that the rule is approved for publication and public comment phase of rule making.

Also under consideration is the development of a U.S. industry position on the safeguardability of a large reprocessing-MOX plant. The approach seems to be to first develop the criteria for determining if the current systems are adequate to safeguard a reprocessing plant. A position paper on this subject will take a considerable amount of time and effort by a number of people. Dick Duda's subcommittee is proceeding with this very worthwhile activity.

The Safeguards Committee reaffirmed the importance and value of holding periodic meetings with Mr. Robert F. Burnett and his staff in the NRC. Our recent experience with the proposed LEU rule is an excellent example of where the government and a professional society have effectively worked together. We believe that the INMM's views were heard by the NRC and that we have been able to help in this rule making process. Therefore, we plan to continue with these meetings.

Leon Chapman held another meeting of his Subcommittee on Category I facility activities. The meeting covered the advance notice of the NRC's rule making dealing with 10 CFR Part 70, MC&A reform amendments. The meeting served as a forum for the NRC to more fully explain the rationale, objectives, and intent of the proposed rule, and for them to receive informal comments from those affected.

Prior to this meeting Leon Chapman also held a meeting to consider the NRC's 10 CFR Part 11 rule and the concerns of implementing this rule dealing with clearances of personnel having access to special nuclear material. The meeting was held on September 8 with seven industry representatives and several NRC personnel attending. The concerns primarily dealt with compatibility of clearances, NRC-DOE-DOD, and specific requirements for personnel clearances for those persons who have access to SNM at facilities and in-transit. The current rule was explained by NRC, and industry representatives made several pertinent comments. The NRC seemed very pleased to obtain clarifying comments and feedback from industry regarding the implementation problems associated with the rule. Likewise, industry representatives were very happy to provide operational experience and input regarding the Part 11 implementation as it pertains to their operations.

The next meeting of the Safeguards Committee is planned for the week of January 17, 1983 in Washington, DC. We welcome anyone who wishes to attend the meeting.

BAMBAS ANNOUNCES 1983 AWARDS PROGRAM

One of the most important ways in which the Institute can influence the world to the achievement of its own objectives is in the granting of recognition to others through awards. Carefully considered awards which are perceived as being appropriate and well-deserved are a powerful means of inspiring others to achieve. They also serve as a means of bringing to the Institute the recognition it deserves as a forum for rational thought on matters nuclear.

The Institute makes awards to both students for papers presented at the annual meeting, and to noteworthy individuals and organizations. The student awards program, which is entering its sixth year, is vitalized by posters and letters to university faculty soliciting papers for the competition.

Awards to individuals or organizations are based upon technical accomplishment or service to the Institute or the industry. Award recipients need not be INMM members. Each member of the Institute can influence the award program by suggesting candidates to the Awards Committee.

Your help is needed to identify candidates for the 1983 Distinguished Service or Meritorius Service Awards. Write a nominating letter describing the accomplishments, and giving a biography of your candidate. Send it to:

Karl Bambas
INMM Awards Committee
Allied-General Nuclear Services
P.O. Box 847
Barnwell, South Carolina 29812

Do it now!!!

PROGRESS TOWARD AN INTERNATIONAL PLUTONIUM STORAGE REGIME

JAMES DE MONTMOLLIN
Sandia National Laboratories
Albuquerque, New Mexico

The safeguards system of the International Atomic Energy Agency has become a central element in the structure of international arrangements to control the spread of nuclear weapons. The function of the system is to monitor the status of nuclear materials and to provide assurance that they are not covertly diverted to non-peaceful uses. There is widespread interest in extending the safeguards system into a significantly new area: to provide greater assurance that national stockpiles of plutonium, in excess of immediate needs, will not be suddenly and openly redirected to military purposes. Safeguards monitor the current status of plutonium stocks, but beyond the general pledge to abstain from the acquisition of nuclear weapons, there are no agreements on stockpiling. The possibility of a sudden renunciation of non-proliferation agreements will be of increasing concern as plutonium stocks continue to grow.

Background

Under the proposed extension of IAEA activities the Agency would accept deposit of excess plutonium until it is needed by the owner state for specified uses. The general scheme is called International Plutonium Storage, or IPS. The concept has a long history, going back to the IAEA Statute of 1957. Article XII of the Statute, which covers safeguards, contains the following provisions:

"A. With respect to any Agency project, or other arrangement where the Agency is requested by the parties concerned to apply safeguards, the Agency shall have the following rights and responsibilities to the extent relevant to the project or arrangement:

5. ... to require that special fissionable materials recovered or produced as a by-product be used for peaceful purposes under continuing Agency safeguards for research or in reactors, existing or under construction, specified by the member or members concerned; and to require deposit with the Agency of any excess of any special fissionable materials recovered or produced as a by-product over what is needed for the above-stated uses in order to prevent stockpiling of these materials, provided that, thereafter, at the request of the member or members concerned, special fissionable materials so deposited with the Agency shall be returned promptly to the member or members concerned for use under the same provisions as stated above..." (1)

That provision was intended to insure that any by-product material, especially that arising from Agency projects, would not be stockpiled, would be used for peaceful purposes, and would remain under safeguards in any future use (2). During the negotiation of the Statute, the language at the beginning of the Article was broadened to cover by-product material arising from other safeguarded activities as well, subject to agreement by the parties concerned.

President Carter, in his April 1977 statement on nuclear power policy, called for an International Fuel Cycle Evaluation to examine measures for controlling proliferation (3). The IAEA commissioned a study of international plutonium storage in September 1978 (4), which led to the establishment of an Expert Group in December of that year, to study various alternative arrangements. In its final report, INFCE Working Group 4 endorsed the ongoing work of the Expert Group and the Agency position that the problem of stockpiles would exist, regardless of any deferral of reprocessing, because of the growing stocks already in existence (5).

The Work of the Expert Group

The first meeting of the Expert Group was attended by representatives of 22 countries and the Commission of European Communities. By the summer of 1982 the number had grown to 37. The US has been an active participant from the beginning, as have all the IAEA member states with large nuclear programs, as well as many developing countries. Serious interest in some form of IPS has been exhibited by the participants throughout the almost four years since the Expert Group was established.

For the first three years or so, the Expert Group attempted to define a single IPS concept that would represent a consensus. The emerging concept had the following features:

1. Participation by States would be voluntary.
2. All plutonium separated from fission products and under safeguards would be covered.
3. Initially, and thereafter when separated from fission products, each state would register its separated plutonium, by either:
   a. submitting a use declaration, or
   b. depositing it in an IPS store.
   The use declaration would generally follow the provisions of the Statute; uses would be limited to peaceful research or fuel for reactors existing or under construction.
4. Deposited material would be returned upon submission of a use declaration.
5. Plutonium would be deregistered and pass from IPS jurisdiction when loaded into a reactor, or under specified conditions at the conclusion of research.

The Expert Group, with various subgroups, worked for more than two years on that general concept. By the spring of 1981 a consensus had been reached on the following points:

1. IPS stores would be at existing storage facilities at reprocessing plants and fabrication plants, operated by the plant operators. The IPS custodian would have authority to control material movements in and out, in accordance with IPS regulations.
2. "Use" included all processing and fabrication in preparation for the end use, such as fuel fabrication.
3. IAEA safeguards would provide all the information needed for IPS, in the form of verified plant design and inventory information. Additional analysis by the Agency would be necessary to correlate that with use declarations.
4. Guidelines for buffer-stock limits in connection with use declarations were developed.
5. General guidelines for research-use declarations were formulated.

While developing a wealth of detail that would be relevant to any IPS scheme, the Group avoided fundamental issues that might prove divisive because of national policy differences. The three IPS objectives that are implicit in the work of the Expert Group,

1. control of stockpiling,
2. disclosure of plans for use, and
3. strengthened controls on use,

were never explicitly agreed upon. At the beginning, the US claimed that the third was the dominant objective; others claimed that is was not an objective at all. How far IPS should go beyond what is explicit in Article XII.A.5 was also a matter of wide disagreement, as reflected in differences over details, but that was never addressed directly. The fundamental question of what discretionary authority, if any, the Agency would have to refuse a request for return of deposited plutonium was also not addressed directly; different participants continued to assume that it was absolute, non-existent, or somewhere in between.

The apparent consensus was shattered early in 1982 when Yugoslavia, after repeated attempts to bring the unstated premises and assumptions into open discussion, formally boycotted a meeting of the Working Group on IPS and Safeguards. India, joined by Yugoslavia and Argentina, then drafted an alternative concept, which was labeled Alternative B. It was considerably less restrictive than the "consensus" scheme, now called Alternative A, although at that time certain essential features of A had not been made clear, and what Alternative A meant depended to an important extent on the eye of the beholder. Some of those differences surfaced as the emergence of Alternative B began to fracture the apparent consensus.

As a counter to Alternative B, a small group* favoring a more restrictive system proposed Alternative C, offering to withdraw it if Alternative B were withdrawn. The Working Group did not examine the three alternatives, or attempt any sort of comparative analysis. rather, each was documented by a sub-committee of the respective proponents, and the Working Group forwarded them without comment to the Expert Group in its final report. The description of Alternative A is generally quite explicit, since it was developed in detail over three years. The other two were drafted hastily, in order to emphasize differences from Alternative A, and are consequently unclear and ambiguous on some important points. The draft final report of the Expert Group to the Director General also conveys the three alternatives without comment or recommendation. The final meeting of the Expert Group is scheduled for November 1982.

In the final reports, some of the earlier ambiguities of Alternative A have been clarified, and the three merge with major differences clearly defined. The most significant differences are:

1. Alternative B would cover only separated, safeguarded plutonium declared by the state to be in excess of planned uses. That would be deposited, to be returned upon submission of a use declaration and continuing under safeguards. It is not clear whether A and B are different with regard to verification of use. Alternative A mentions use verification specifically, but it was concluded that present safeguards would provide all the necessary information. Neither deals explicitly with how, or if, the safeguards information would be correlated with the use declaration, or how the findings would be disseminated.
2. Under Alternative A and B acceptance of a use declaration would be subject only to procedural requirements. Alternative C would give the Agency full authority to call for more information and to disapprove any use declaration or return of deposit, with final authority given the Director General.
3. Alternative C would cover all plutonium, not just that under safeguards, and would extend IPS jurisdiction beyond irradiation to cover discharged spent fuel as well. The operational consequences of these two features seem not to have been explored.
4. Alternative C would specifically ban peaceful nuclear explosives as an acceptable use. Alternatives A and B do not mention PNE's.

While the above differences distinguish the three alternatives, some important points remain unclear. We have noted some of them. An important question that is not covered by any of them is the nature and distribution of periodic reports by the Agency. The assurance provided by IPS would be greatly enhanced if stockpile quantities and use declarations were routinely published. Present safeguards would also be more effective if quantitative information in specific States could be released. However, safeguards can at least report whether inspection goals are met. With IPS, a mere statement that no stockpiling was discovered anywhere would seem to require supporting information, if IPS is to provide significant assurance.

The fragmentation of the earlier consensus into the three alternative schemes is a constructive development. By seeking a consensus in support of a single concept, the Expert Group was forced into a political negotiation, inappropriate for a technical-consultant group. The important accomplishment of the Expert Group is the development of detail, contained in over 200 working papers and reports, which will be necessary in the establishment of any sort of IPS arrangement. At the same time, the unresolved differences that emerged in the three alternatives provide a starting point for negotiation and bargaining in a proper forum.

The Next Steps

The final report of the Expert Group will be presented to the IAEA Board of Governors at the February 1983 meeting. The Board is expected to establish a negotiating conference of representatives from interested states, to seek agreement on an IPS arrangement that would be both effective and widely accepted. The work of the Expert Group provides detailed information that can be used to synthesize and evaluate other concepts, as well as the three that were defined.

continued on page 10

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*Australia, The Netherlands, and Sweden.

continued from page 9

Participation by the INMM Subcommittee on Government Liaison

In the spring of 1981 an arrangement for continuing liaison between industry representatives and the Federal government on policy matters involving safeguards was established under INMM auspices. A Subcommittee of the INMM Safeguards Committee was formed, chaired by Richard Duda of Westinghouse. The Subcommittee includes members from national laboratories, who serve in an advisory capacity, based on their specialized backgrounds in safeguards. The official point of contact on international matters is Allen Sessoms, State Department. The Subcommittee meets regularly with State Department and ACDA individuals for briefings, comments, and discussions on current developments. Since its inception, the Subcommittee's principal attention has been centered on IPS. The industry representatives have followed IPS developments with keen interest, believing that the future of the export market depends on the strengthening and extension of cooperative international arrangements such as IAEA safeguards and IPS. The relationship between industry and government that is nourished by the Subcommittee has proved to be constructive and mutually beneficial, and as the case of IPS illustrates, it has provided both parties with a clearer understanding of developments as they unfold.

NOTES

1. Statute of the International Atomic Energy Agency, October 26, 1956, Article XII.A.5.
2. An account of circumstances involved in the adoption of the deposit provision is given by Paul C. Szasz, *The Law and Practices of the International Atomic Energy Agency,* Legal Series No. 7, IAEA, p. 600.
3. Statement by the President on His Decisions Following a Review of U.S. Policy, April 7, 1977.
4. INFCE/DEP/WG4/129, International Management and Storage of Plutonium and Spent Fuel, IAEA, September 1978.
5. INFCE, *Reprocessing, Plutonium Handling, Recycle;* Report of Working Group 4, IAEA, 1980, Chap. 10.

George Weisz died November 16. George was director of the Office of Safeguards and Security in the Department of Energy from January 14, 1979 until October 1, 1981. He was especially interested in International Safeguards, in helping the IAEA to improve the effectiveness of its safeguards activities, in clarifying what the Agency was intended to accomplish, and in encouraging the development of additional international undertakings to complement the IAEA, such as an International Plutonium Storage Regime.

George was a gentleman. He read and he listened. Those who had the opportunity to work for him or with him will miss him.

Willy Higinbotham

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INMM CALENDAR OF EVENTS

FEBRUARY 14-17, 1983
Safeguards Central Control and Information Display
Colony Square Hotel, Atlanta, Georgia

FEBRUARY 28-MARCH 4, 1983
Selected Topics in Statistical Methods for SNMM Control
Richland, Washington

MARCH 21-25, 1983
Selected Topics in Statistical Methods for SNM Control
Oak Ridge, Tennessee

MARCH 29-APRIL 1, 1983
Decontamination & Decommissioning Workshop
Hyatt Regency on Capitol Hill, Washington, D.C.

MAY, 1983
Multidisciplined Education/Certification Course
Site to be determined

JULY 10-13, 1983
INMM 24th Annual Meeting
Marriott's Mark Hotel, Vail, Colorado

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

MEMBERSHIP COMMITTEE REPORT

T.E. SHEA, CHAIRMAN
INET Corporation
Sunnyvale, California

Emphasizing International Participation

The INMM provides a vital focus, a common vehicle we members use to concentrate our creative energies to providing effective controls over the disposition and use of nuclear materials. We give and receive in return, sharing the benefits of a technology we control, focused on our precise needs and interests. We share the camaraderie of like-minded specialists, each of us working in our distant domains.

Membership in the INMM continues to grow—in witness to the success of the Institute, the dedication of its membership, the quality of its thought, and the importance of its purpose. We still have room for growth, however, room especially to broaden INMM activities to nations where the benefits we enjoy through the Institute are not available. Moreover, we need to attract additional members from those regions of the world where we are active. Our purpose must be to share the technology we have developed and put to work, and to open that body of knowledge and experience to scrutiny and fresh insights.

We each have our reasons for participating in INMM. Those same reasons are valid for other would-be members as well, who sometimes need (or want) a little nudge before climbing on board. You know someone like that, someone you work with or an associate in a related activity. Do us all a favor—mention the INMM the next time you're talking with that person, and give that nudge.

John Barry set an excellent example in heading this Committee over the last two years. John concentrated on the utility sector; this year our emphasis will be in further internationalizing the Institute. We would hope to see additional chapters formed in countries where a collective interest should exist. The Institute may change a bit in the process, but the need for effective nuclear material control and management is widespread, if not quite universal. The chapters in Japan and in Vienna represent fundamental accomplishments in that process and we should all be encouraged by the vitality and success of those pioneer groups.

The European Safeguards Research and Development Association (ESARDA) satisfies the needs of the European common market countries. But other nations, in all continents, have peaceful nuclear activities which could benefit from improved nuclear materials control and management. The INMM provides limited needs for a few specialists in many of those countries now; it could and should do more.

Over the coming months, the Membership Committee will work towards stimulating interest in countries which may be ready for Institute participation. The most likely candidates include (in alphabetical order): Argentina, Australia, Brazil, Czechoslovakia, East Germany, Finland, Greece, Hungary, India, Indonesia, Iraq, Israel, Mexico, Norway, Pakistan, Philippines, Romania, South Africa, South Korea, Spain, Sweden, Switzerland, Taiwan, Turkey and Yugoslavia.

Hopefully we'll have some progress to report in the next issue. Until then, give your best.

Carl G. Ahlberg, U.S. Department of Energy, 9800 South Cass Avenue, Argonne, IL 60439, 312/972-2068

Willard D. Altman, U.S. Nuclear Regulatory Commission, MS EW-359, Washington, DC 20555, 301/492-8490

Jere T. Bracey, U.S. Department of Energy-NBL, 9800 South Cass Avenue, Argonne, IL 60439, 312/972-2456

Hattie V. Carwell, International Atomic Energy Agency, P.O. Box 200, A-1400 Vienna, Austria, 2360-2068

Frederick T. Daniels, International Atomic Energy Agency, Room A1783, P.O. Box 200, A-1400 Vienna, Austria, 2360-2153

Kenneth C. Dyar, Georgia Power Company, P.O. Box 598, Waynesboro, GA 30830, 404/722-6889

Eileen M. Fournie, System Planning Corporation, 1500 Wilson Blvd:, Arlington, VA 22209, 703/841-8816

William I. Fox, UN-IAEA, Safeguards Training Section, P.O. Box 200, A-1400, Vienna, Austria, 2360-6363

Seiichi Fujito, Shikoku Electric Power Co., Inc., 2-5, Marunouchi, Japan, 0878-21-5061

Charles A. Gentile, Jr., Long Island Lighting Company, 175 Old Country Road, Hicksville, NY 11801, 516/733-5012

Noel M. Grenon, UNC Naval Products, 67 Sandy Desert Road, Uncasville, CT 06382, 203/848-1511

Masaaki Hirayama, Toshiba Corporation, 4-1, Ukishima-cho, Kawasaki-ku, Kawasako, Japan, 044-277-3111

Michio Hosoya, Nuclear Material Control Center, 2-53, Aza Shirane Shirakata, Tokai-mura, Naka-gun, Ibaraki-ken, Japan, 02928-2-8001

John A. McBride, E.R. Johnson Associates, Inc., 11702 Bowman Green Drive, Reston, VA 22090, 703/471-7880

Takahiko Nagahora, The Kansai Electric Power Co., Inc., 3-3-22 Nakanoshima Kita-ku, Osaka, Japan, 06-441-8821

Thomas J. Nicholson, Boston Edison Co., Pilgrim Nuclear Power Station, R.R. 1, Rocky Hill Road, Plymouth, MA 02360, 617/746-7900

Ashton J. O'Donnell, Bechtel National, Inc., P.O. Box 3965, San Francisco, CA 94119, 415/768-7356

Tamiya Shigefumi, Japan Nuclear Fuel Service Co., Ltd., Fukokouseimei Bldg., 2-2, 2-Chome, Uchisaiwaicho, Chiyoda-ku, Tokyo, Japan, 03-580-6911

David Stahl, Battelle Columbus Laboratories, 505 King Avenue, Columbus, OH 43201, 614/424-7276

EGGERS RECEIVES SAFEGUARDS SPECIALIST CERTIFICATION

Mr. Robert F. Eggers, shown on the left, was recently awarded his certificate as a Safeguards Specialist by Mr. L.D. (Don) Williams, Manager, Energy Systems Department at Battelle. Looking on are, from the left, Bob Sorenson, Manager of Safeguards and Regulatory Analysis, and Rod Fleischman, Manager of Nuclear Energy Systems.

Bob Eggers is only the second person to receive certification through the examination process given by the INMM. Bob took the intern exam during the annual meeting in Palm Beach in 1980, and then last July during the annual meeting in Washington, D.C. he successfully completed the rigorous examination for Safeguards Specialist. His area of concentration was statistics.

Bob Eggers shown receiving plaque for certification as Safeguards Specialist.

TECHNICAL WORKING GROUP ON PHYSICAL PROTECTION REPORT

JAMES D. WILLIAMS, CHAIRMAN
Sandia National Laboratories
Albuquerque, New Mexico

The presently scheduled and planned workshops of the Technical Group on Physical Protection are listed below:

- Central Control and Information Display, February 14-17, 1983
- Security Personnel Training, Summer 1983 (Tentative)
- Integrating the Elements of Delay, Intrusion Detection and Entry Control into Physical Protection Systems, Fall 1983 (Tentative)
- Protection Against the Insider Threat, Winter 1983 (Tentative)

Workshops on other subjects of interest to physical protection personnel will be considered if enough interest is expressed. Additional details about the group activities are given below.

General

The Twenty-Fourth Annual Meeting of INMM will be held July 10-13, 1983 at Marriott's Mark Resort, Vail, Colorado. If our plans to expand and strengthen the Physical Protection Session at the annual meetings are to be fulfilled, we will need your help in contributing papers and encouraging others with experience in this area to do likewise. A session which addresses the insider problem is planned.

The workshop, Physical Protection Review—Getting the Most for Your Money, was held at Albuquerque, New Mexico, October 5-8, 1982. This was a very successful workshop and is discussed in detail by M. Teresa Olascoaga, Workshop Chairman, in the second part of this report.

Central Control and Information Display Systems

This workshop will be held February 14-17, 1983 in Atlanta, Georgia. The topics planned relate to controlling and displaying security, fire, safety, and other information on how to integrate such systems into a facility operation plan. If you would like to receive additional information and an invitation to this workshop, please contact Larry Barnes, Allied General Nuclear Services, P.O. Box 847, Barnwell, SC 29812, 803-259-1711.

Security Personnel Training

Summer 1983 (Tentative)
Contact Dr. L. Paul Robertson
Division 9259
Sandia National Laboratories
P.O. Box 5800
Albuquerque, NM 87185
Telephone (505) 844-7706
FTS 844-7706

The third workshop concerning the training of security personnel is in its very early planning stages. If you have ideas of topics to be covered or suggestions to make about this workshop, please contact Paul.

Integrating the Elements of Delay, Intrusion Detection and Entry Control into Physical Protection Systems

Fall 1983 (Tentative)
Contact James C. Hamilton
Goodyear Atomic Corporation
P.O. Box 628, Mail Stop 1231
Piketon, Ohio 45661
Telephone (614) 289-2331, Ext. 2204
FTS 975-2204

This workshop will be the fourth workshop on intrusion detection and entry control. During this workshop, the delay element (fixed barriers and activated barriers) will also be discussed. If you have ideas of specific topics to be covered or suggestions to make about his workshop, please contact Jim.

Protection Against the Insider Threat

This workshop is tentatively planned to be held in Winter 1983. Interest in the insider problem is growing and if enough persons indicate interest in attending a workshop on this topic, the plans will be finalized. Please notify J.D. Williams, Division 9269, Sandia National Laboratories, P.O. Box 5800, Albuquerque, NM 87185 of your interest in this workshop.

Physical Protection Review Workshop

M. Teresa Olascoaga
Workshop Chairman
Sandia National Laboratories
Albuquerque, New Mexico

The Physical Protection Technical Working Group sponsored a workshop entitled "Physical Protection Review—Getting the Most for Your Money" during October 5-8, 1982 at the Sheraton Inn-Old Town, Albuquerque. This workshop was planned in cooperation with the Department of Energy, the Nuclear Regulatory Commission, the Edison Electric Institute, and the American Gas Association. The purpose of the workshop was to provide the participants the opportunity to present, discuss, and exchange information on physical protection as it pertains to high technology applications.

Seventy-three participants, both international (Japan, the Federal Republic of Germany, and Canada) and domestic attended the workshop. Domestic representation included the DOE, its contractors and national laboratories, the NRC and its licensees, three armed force departments (Navy, Air Force, and Army), and private utilities and consulting firms.

Registration on the evening of October 5 was followed by a get-acquainted cocktail party. The Watermelon Mountain Jug Band provided a bit of local color to the workshop as they entertained the participants.

Wednesday morning, October 6, the opening session began with a welcome on behalf of the Institute by Tommy A. Sellers, INMM Executive Committee member. Tommy gave the group a brief history of the INMM with emphasis on past workshops as the focus of the Physical Protection Technical Working Group's activities. Jim Williams then provided a summary of proposed workshops for 1983 including a Central Control and Information Display Systems Workshop (February 1983) and a Security Personnel Training Workshop (Summer 1983).

The keynote address was given by Ed Penico of the Clinch River Breeder Reactor Project Office in Oak Ridge, Tennessee. Ed began his address with a short history of physical security in the United States going back to the pre-Vietnam years when interest in security revolved around protecting valuable materials such as money, gems, and classified documents. During the Vietnam War, the need for more sophisticated security measures was indicated. Following the war, interest in security waned until terrorist activity once again illustrated the importance of physical security. Today security is a growing industry.

Since physical security continues to be a growing area of concern, Ed discussed the importance of cost-effective security. In particular, Ed emphasized the contribution of the following factors to cost-effectiveness:

1. a *simple approach,* whenever possible, since the capability of a system is only as good as the potential to operate it correctly;
2. *coordination* of physical security system design *with operations* to allow for the benefits of "dove-tailing" and to improve the salability of the design to nonsecurity organizations;
3. *modeling and testing* of security elements and total systems to enhance the likelihood of adequate protection following implementation of the design;
4. *quality* of security equipment and work force;
5. *design* of the security system *to achieve a reasonable level of protection,* that is, provide adequate protection without over design; and
6. *design for the future* since a current system design may be technologically, economically or politically obsolete at the time of implementation.

In summary, Ed noted that careful consideration of all these and other pertinent factors should significantly improve the cost-effectiveness of physical security.

Following the opening session, the participants adjourned to special topic discussion groups which form the basis for the workshop. Each participant was assigned to four sessions according to the individual's responses to a registration questionnaire indicating topics of interest. A total of 16 discussion sessions were held on Wednesday and Thursday with 15-20 participants in each session. The session topics, moderators, and a list of major discussion items follow.

1. **Target Attractiveness—**Joseph P. Indusi, Brookhaven National Laboratory
    - vulnerability and threat analyses
    - vital area analysis
2. **Personnel/Procedure vs Hardware—**Roger M. Smith, Atomic Energy of Canada, Ltd.
    - complexity of hardware
    - use of specific hardware, e.g., fences, sensors, etc.
    - use of nonsecurity staff during emergencies

Keynote address by Ed Penico of the Clinch River Breeder Reactor Project Office in Oak Ridge, Tennessee.
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A typical workshop session

continued on page 16

continued from page 15

3. **Human Resources in Physical Security—**Elgin J. Arave, DOE-Dayton Area Office
   - guard morale and training
   - personnel screening, background investigations and psychological testing
   - legal constraints
4. **Performance vs Prescriptive Requirements—**James A. Prell, NRC/RES
   - definition of performance and prescriptive requirements
   - advantages/disadvantages of each
   - "marriage" of both types of requirements
5. **Performance Criteria for Requirements—**Glenn A. Hammond, DOE/OSS
   - need for achievable, enforceable, and inspectable performance criteria
   - coordination at integrated system level
   - INMM as an appropriate mechanism for developing performance standards and guidelines
6. **Threat Perception—**Elizabeth Quinn, NRC/NMSS and Joseph P. Indusi, Brookhaven National Laboratory
   - overview of NRC and DOE threat programs
   - insider threat
   - difficulty of obtaining resources for security systems in the absence of an actual threat
7. **Compliance Problems/Solutions—**Clay E. Higgins, CPP Stone & Webster Engineering
   - effect of public perception and reaction to nuclear incidents
   - protection of safeguards information
   - use of high technology security systems to reduce costs
8. **Safety/Security/Operational Interface—**Donald Cook, DOE-Richland Operations Office
   - technical interface within alarm monitoring stations
   - salability of security issues to facility management
   - multidiscipline approach needed for credibility
9. **Personnel/Procedure Performance—**Samuel L. Thompson, Detroit Edison Co.
   - identification of necessary security procedures
   - measurement of personnel/procedure performance
10. **Survey of Evaluation Techniques—**John W. Hockert, NRC/NMSS and Leon D. Chapman, Sandia National Laboratories-Albuquerque
    - summary of evaluation techniques
    - capability of evaluation methods to provide objective assessment of system performance
    - utility of models for design, evaluation, and inspection
11. **Comparability of Requirements—**Anthony Fainberg, Brookhaven National Laboratory
    - relevance of comparability issue given agency differences
    - anomalies in comparability among agency requirements
    - performance vs prescriptive requirements
12. **Insider Protection Options—**Dennis L. Mangan, Sandia National Laboratories-Albuquerque
    - motivations of the insider
    - administrative and procedural measures, physical protection, plant design features and damage control as protection options
    - effectiveness of clearance and access authorization programs
13. **Upgrade/Initial Design Problems—**Jerry C. Stout, Nuclear Fuel Services
    - security plan development and associated approvals
    - budget constraints
    - problems of retrofitting systems
14. **Performance Evaluation—**Douglas R. Cavileer, NUSAC, Inc.
    - techniques for evaluating total security programs, e.g., NRC Regulatory Effectiveness review procedure, and DOE Performance Appraisals
    - measures of effectiveness as function of cost programs
15. **Tactic Analyses—**William D. Telfair, CRC, Inc.
    - tactical abilities required of security force
    - effective and economic evaluation of tactic abilities
    - use of MILES/Laser Engagement Simulation System (LESS) for training and evaluation
16. **Integration of New Protection Schemes—**Ed Penico, Clinch River Breeder Reactor Project Office
    - systems approach needed for integration of physical protection schemes
    - man/machine integration

Following the first day's sessions, a dinner for the participants was held at the Barn Dinner Theater located in the Sandia Mountains.

During the closing meeting on Thursday afternoon, each session moderator presented a five minute summary of the discussion items in his/her session. More complete summaries and a final list of attendees will be compiled into proceedings of the workshop. Copies of the proceedings will be mailed automatically to each participant. Additional copies may be obtained by contacting:

M. Teresa Olascoaga
Sandia National Laboratories—Org. 9259
P.O. Box 5800
Albuquerque, NM 87185
(505) 844-1379

The workshop sessions were supplemented by equipment demonstrations and a tour of Sandia's physical protection R&D areas on Friday morning. The tour and demonstrations included the following:

Intrusion Detection—J.D. Williams
Entry Control—M.J. Eaton
Security Communications and Control System—R.C. Beckmann
MILES/Laser Engagement Simulation System—R.L. Wilde

Special thanks go to Ed Penico, Keynote Speaker, and to each of the session moderators whose outstanding effort was the basis for the workshop's success. The contributions of the INMM staff, especially Marlene Yadron, and the Sandia personnel involved in the equipment tour and demonstrations and of the members of the workshop staff, Dennis Mangan, Doris Laymon, and Paul Robertson (Sandia National Laboratories-Albuquerque) also are greatly appreciated.

A REPORT ON THE JUNE 1982 NEUTRON ASSAY WORKSHOP AT LOS ALAMOS

N. ENSSLIN AND G. ECCLESTON
Los Alamos National Laboratory
Los Alamos, New Mexico

The DOE Safeguards Technology Training Program at Los Alamos National Laboratory added a new workshop in 1982 aimed specifically at neutron-based nondestructive assay techniques. The 3½-day workshop was structured for a limited number of attendees so that the subject matter could be covered informally in small groups of attendees and instructors. The workshop was designed to complement two existing training courses at Los Alamos. A course entitled "Fundamentals of Nondestructive Assay of Nuclear Materials" provides an introduction to neutron and gamma-ray assay techniques. The new Neutron Workshop and a course entitled "Gamma-Ray Assay of Nuclear Materials" provide in-depth instruction in the various measurement techniques.

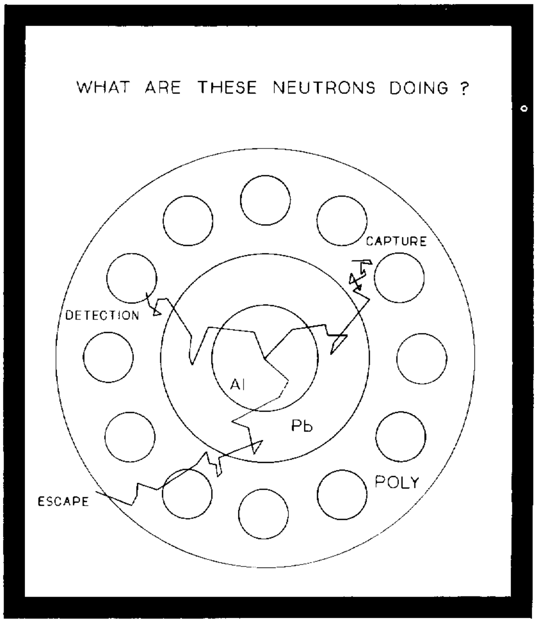
As shown in Fig. 1, participants in the workshop included representatives of the NRC, IAEA, private industry, Los Alamos, and other DOE laboratories. The 13 attendees worked with 8 Los Alamos instructors from the Safeguards Assay Group.

The Neutron Workshop covered a wide range of active and passive assay techniques and included in-plant instruments not covered in other courses. The first six half-day sessions were divided into morning sessions devoted to lectures and experiments on fundamentals and afternoon sessions devoted to assay of fuel cycle materials. The three morning sessions addressed neutron sources and detectors, neutron interactions with matter, and the principles of neutron coincidence counting. The three afternoon sessions demonstrated photoneutron assay, delayed neutron assay, and active and passive coincidence assay. The final half-day session was devoted to lectures on practical operating experience with neutron instruments and a wrap-up session that summarized and compared the performance characteristics of the neutron assay techniques featured during the week. In addition to the formal sessions, the course included a farewell banquet for attendees and instructors at a beautiful site overlooking the Rio Grande River canyon.

Several attendees recommended that a full week be allotted for future neutron courses to allow time for measuring additional material types and for discussing specific measurement problems of interest to the attendees. Accordingly, the next workshop will be expanded to a 4½-day Neutron Assay Course, to given June 6-10, 1983. The 1983 course will include a full day of introductory lectures and bench-top experiments, followed by three days of laboratory work with a wide variety of nuclear materials.

Figure 1. Attendees and instructors at the Los Alamos-DOE Workshop on Neutron Assay Techniques (from the left): Phil Rinard, LANL; Ron Augustson, LANL; Al Dumrose, LANL; Charles Barnett, LANL; Mark Hulet, University of Arizona; George Eccleston, LANL; Joy Clark, LANL; Steve Smith, Union Carbide; Mike Baker, LANL; Fay Hsue, LANL; Steve McLaughlin, Nuclear Fuel Services; Keith Fuller, Rockwell Hanford; Sandra Fratalli, NRC; Norbert Ensslin, LANL; Richard Murri, Bendix; Roddy Walton, LANL; Tom Crane, LANL; Sam Pillay, LANL; Tom Sampson, LANL; and Chris Hodge, LANL. Not pictured are Pantelis Ikonomou, IAEA; and Toshihide Sugiyama, PNC, Japan.

Figure 2. The motion of neutrons through matter is very complex, which makes the design and implementation of neutron-based nondestructive assay instrumentation an art as well as a science. In order to help attendees visualize the processes of neutron scattering and absorption in matter, a Monte Carlo code was used during the Neutron Workshop to trace neutrons through various materials. In the example above, neutrons originated at the center and moved out into concentric layers of aluminum, lead, and polyethylene. The irregular lines show their paths as they scattered, slowed down, and were absorbed.



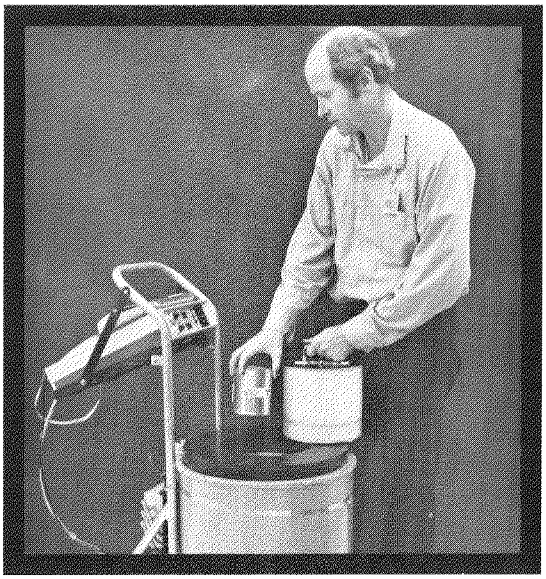


Figure 3. Howard Menlove prepares to insert a sample into the Active Well Coincidence Counter. Both passive and active neutron coincidence counters were used in the Neutron Workshop to assay a variety of plutonium and highly enriched uranium bulk samples. Dr. Menlove also gave a lecture on the applications of neutron-based nondestructive assay instruments in domestic and foreign facilities.

BOOK REVIEW

ANTHONY FAINBERG
Brookhaven National Laboratory
Upton, New York

The Atomic Complex: A World-wide Political History of Nuclear Energy by Bertrand Goldschmidt. Translated from the French by Bruce M. Adkins. American Nuclear Society, LaGrange Park, Illinois, 1982, 479 pages; $31.00 hardbound, $24.00 softbound.

Professor Goldschmidt, one of the most influential scientists in the world regarding things nuclear, has written an interesting and comprehensive book on both the military and civilian histories of nuclear energy. His point of view is, naturally, the French one, both because he is a Frenchman, and also because he himself played and plays a significant role in the formulation of French nuclear policies. As a scientist, he attempts to be as factual as possible when relating the political intrigues which developed around the vital questions having to do with both controlled and uncontrolled nuclear energy. He does, however, on occasion lapse into (always restrained) polemics when describing what he sees as bad behavior, chiefly on the part of the United States, but also on the part of what he delights, in calling "The Anglo-Saxon" powers. These include, of course, the U.K., Canada, and/or Australia, as well as the U.S., depending on the context. This Gallic way of extending the concept of "perfidious Albion" wears rather thin after a few hundred pages, and along with a concomitant defensiveness regarding virtually any French policy, constitutes the prime drawback of an otherwise most readable and informative book.

The book is divided into two sections: the first deals with the development of nuclear weapons, and the second with the later, parallel evolution of nuclear energy, with a bow to other peaceful uses of nuclear technology. The nuclear explosives story has, by now, been told by nearly everyone connected with the Manhattan Project, and a first reaction could be: "What, another version?" But the perspective here is somewhat different from what I, at least, have become used to. First of all, the emphasis is not on the personalities involved nor on the human dimension of working on such projects, but, as the book's subtitle indicates, on the political considerations surrounding the assembling of the scientists and information for the effort, as well as political factors controlling other, later weapons development programs elsewhere in the world. Additionally, the story is told from the French viewpoint, which includes the well-known (and partially justified) resentments at being treated as very much a junior partner in nuclear cooperation among the Western countries during and after the war. This must have been particularly galling to the French, since French nuclear research, particularly the work of Frédéric Joliot-Curie, had placed France in a pre-eminent position in this field by 1939.

What I found interesting was the double-dealing that went on between the U.S. and the British from, roughly 1942 to the mid-fifties, wherein whichever party thought itself ahead in nuclear research held off on much exchange of information, all the while paying lip service to the principles of mutual assistance. Given this state of non- and then minimal cooperation among us Anglo-Saxons, it is not hard to figure out where this left the French.

continued on page 20

continued from page 19

All this being said, it is difficult to take seriously French (Gaullist) policy that the Nuclear Test Ban Treaty was not a "genuine effort toward disarmament". Less easy still is it to accept as rational France's refusal to sign and ratify the Non-proliferation Treaty while, at the same time, promising to honor its spirit *and* letter. Goldschmidt's tolerance for these aberrant departures from France's tradition of logic and rationality is in sharp contrast with his merciless pillorying of the disarmament and non-proliferation policies of other countries. The most glaring omission in this book, from the point of view of non-proliferation policy, lies in the author's discussion of the Israeli attack on the Iraqi Tammuz reactor. Nowhere does the gentleman mention that France supplied highly-enriched fuel, which is a proliferation hazard, rather than insisting on the proliferation-resistant "caramel" fuel which is of low enrichment. Nowhere does he express any regret for supplying the Iraqi regime with a needlessly large reactor; a regime of unstable warmongers who, since the Israeli raid, have asked the world to supply them with nuclear weapons. Nowhere does he comment on the advisability of France offering to rebuild the reactor for such a regime. He is very happy to attack Israel's destabilizing action, and such criticism is certainly justified, but a refusal to address the causes of such action, (namely the desire of the Gaullists in France and in particular, of the then Prime Minister, Jacques Chirac, who is known to have close Iraqi ties, to ingratiate themselves with the Iraqi Baathists in return for promises of oil), is disingenuous, at best. The amusing irony in this connection (which should be appreciated by the French, who have a strong tradition in this rhetorical device) is that very little oil was gained by France, since Iraq's production has been greatly reduced due to its war with Iran.

There are, however, a number of good points made by the author regarding the recent history of non-proliferation, and the futility of the U.S. trying to embargo, unilaterally, nuclear technology as a means of preventing nuclear proliferation. An interesting note is a reference to the recent case of Howard Morland and his H-bomb articles in Progressive Magazine. Goldschmidt claims that access to such data would have saved French scientists years of work in developing their own H-bomb. I wonder if Morland still feels it was justified, in order to build a case against the nuclear weapons establishment, to make it that much easier for, say, Argentina or Pakistan to develop thermonuclear weapons. It is clear that publicizing such details was entirely irrelevant to his professed thesis, and was useful to him only in drawing attention to his work. A tragic irony could be that one day we may discover that a lot of people have died in order to give Morland a PR boost. To be fair, Morland should never have been able to obtain all the information which he did, in part due to a mistaken declassification of a report. The overall view to an outsider, however, is that one of the most serious proliferation breaches has occurred in the U.S., which, at the same time, professes extreme concern about proliferation.

In the discussion of nuclear power, Goldschmidt again presents history in a readable, comprehensive way. He decries the monopoly over much of the world's uranium resources after the war by the U.S. and the U.K., and I cannot find much fault with that. The rise in nuclear power in the major nuclear-generating countries in the world is given in an ordered analysis, which is easy to grasp. With reason, the author pats France on the back for now being the world leader in the field after having had a late start after the war. Anti-nuclear critics are mentioned, along with some of their objections to nuclear power. Although Goldschmidt's response to this movement consists of arguments which are essentially correct, he would have done better to give them somewhat longer shrift. His defense of nuclear power is so off-hand and cursory that it would not convince anyone who was not already convinced.

The book, as a whole, is worth reading as an engrossing description of the political history of nuclear energy. The outlook, being different from what we are generally used to in the U.S., makes the work doubly interesting, and should serve to humble us somewhat, perhaps making us realize that we really do not have the God-given right (or even capability) to dictate policies to the rest of the world, or even to our friends. Such attempts often backfire and leave long-lingering resentments, whether the subject is nuclear materials or, for example, gas pipelines.

Nevertheless, the book has its own set of prejudices which must be taken into account when reading. In particular, the whole question of the inherently discriminatory nature of non-proliferation (between weapons- and non-weapons states) is dealt with in an ambiguous way, because, I suppose, France was once a have-not and is now a have. There is, it seems to me, no way of resolving this problem. Any non-proliferation or other similar accord departs from an instant in time at which one would like to freeze the extension of whatever plague it is that one is dealing with. Such a process naturally will divide the world into two categories: those who have it, and those who do not. This is inherently discriminatory, but it is also inherently necessary, in order to be able to begin an ending to the plague. The solution here, in terms of the resentment and possible eventual renunciation of participation by the have-nots is, for the haves to do what they promised: to stop their arms races and to start reducing the plague within themselves. One could also hope for a wider adherence to the NPT, beginning with France, which now has a government much more interested in peace and disarmament (and somewhat less interested in "la grandeur a la francaise") than its predecessors.

It bears noting that the translation, by Bruce Adkins, is quite good and contributes to the readability of the book.

MEASURES FOR INCREASING IAEA SAFEGUARDS EFFECTIVENESS

C.R. HATCHER
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ABSTRACT

The effectiveness of International Atomic Energy Agency (IAEA) safeguards depends not only on the quality of IAEA inspection and independent verification of declared nuclear material and facility use, but also on the perception of and reaction to IAEA safeguards by the nations who make up the international community. Because perceptions and reactions often involve nontechnical as well as technical factors, it has proven difficult to describe IAEA safeguards effectiveness in quantitative technical terms. This study uses a flow diagram to examine how IAEA inspections and the resulting verification statements lead to the main political objectives of IAEA safeguards, assurance and deterrence. Based on this approach, a figure of merit called the IAEA safeguards effectiveness ratio is defined, and measures for increasing IAEA safeguards effectiveness are identified and discussed.

I. INTRODUCTION

A. Background

Active support of International Atomic Energy Agency (IAEA) safeguards has been and remains one of the key elements of U.S. nonproliferation policy. Yet, during the past two years, increasing concern has been expressed in the U.S. about the limits of IAEA safeguards effectiveness. This concern and the resulting inquiry and debate have been given extensive coverage in the press and are the subjects of several letters to the Journal of the INMM.[1-3] In following the debate, it becomes apparent that one of the reasons why there is such diversity of opinion regarding the effectiveness of IAEA safeguards is that widely different criteria are used for judging effectiveness.

This report examines the subject of IAEA safeguards effectiveness and suggests an approach for determining a figure of merit, called the effectiveness ratio. The approach provides a framework for examining the complex interaction between the technical and nontechnical factors involved in IAEA safeguards, and may be used for evaluating the impact (on effectiveness) of future safeguards options and initiatives.

The effectiveness of IAEA safeguards can be viewed as the degree to which IAEA safeguards meet their intended objectives. Thus, to address IAEA safeguards effectiveness, one must first examine the stated objectives.

B. Objectives of IAEA Safeguards

For the purposes of this study, the most useful statement of intended IAEA safeguards objectives is the one given by H. Grümm in 1980[4] and later included in the IAEA/SG information pamphlet INF/3 (Ref. 5).

> "The main political objectives of IAEA safeguards are:
>
> To assure the international community that States are complying with their non-proliferation and other 'peaceful use' undertakings;
>
> To deter (a) the diversion of safeguarded nuclear materials to the production of nuclear explosives or for other military purposes and (b) the misuse of safeguarded facilities with the aim of producing unsafeguarded nuclear material."

It is generally accepted that assurance provided by IAEA safeguards contributes to reduced motivation for nations to acquire nuclear weapons and that deterrence acts as a barrier to dissuade states from diverting material or misusing facilities.

An earlier version of IAEA safeguards objectives can be found in INFCIRC/153 (Ref. 6), which contains the often quoted statement:

> "...the objective of safeguards is the timely detection of diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons or of

> other nuclear explosive devices or for purposes unknown, and deterrence of such diversion by the risk of early detection."

Timely detection does not represent an intended objective in the same sense that assurance and deterrence do. The IAEA must have (and must be perceived to have) the capability for timely detection of diversion of significant quantities of nuclear material in order to provide meaningful assurance and deterrence. In this regard, timely detection is a means to an end, not the desired objective. If IAEA safeguards are completely successful in providing adequate assurance and deterrence, there may never be an occasion for the detection of a diversion.

The INFCIRC/153 statement of objectives was a significant step in defining the principal technical factors that contribute to deterrence, and it led to the quantification of detection goals.[7] However, this statement of objectives does not recognize nontechnical factors, and it fails to consider both the possibility of facility misuse and the goal of assurance. The INF/3 statement of objectives provides a more comprehensive basis for identifying technical and nontechnical factors that influence IAEA safeguards effectiveness than is provided by the INFCIRC/153 statement of objectives.

C. IAEA Safeguards Approach

Table I shows, in simplified form, the basic approach for implementing IAEA safeguards. There are five sequential steps: (1) the IAEA charter and approach for providing international safeguards must be accepted by the member states; (2) having an accepted charter, the IAEA then drafts agreements with each member state defining how IAEA safeguards are to be conducted in that country; (3) the member state provides information on nuclear facilities and materials to the IAEA, as called for in step 2; (4) the IAEA independently verifies (by on-site inspection) that the information provided by the state is accurate and complete; and (5) the IAEA makes statements regarding its verification of declared nuclear material and facility use, as well as on the general status of IAEA safeguards implementation.

Each of the steps outlined in Table I is essential for the overall effectiveness of IAEA safeguards. Because the steps follow sequentially, step 5 (IAEA statements) is the final product that demonstrates how successfully all of the steps have been carried out. Therefore, to evaluate effectiveness, one can examine whether IAEA safeguards verification statements lead to the intended objectives of assurance and deterrence.

TABLE I

IAEA SAFEGUARDS APPROACH[a]

Step	Milestone	Principal Documents and Activities
1	General IAEA charter and approach	-Statutes of the IAEA (1956) Ref. (8) -INFCIRC/66 (1965) Ref. (9) -INFCIRC/153 (1970) Ref. (6) -INF/1,2,3 (1980-81) Refs. (7,10,5)
2	Agreements between the IAEA and states	-Safeguards Agreement -Subsidiary Arrangements Facility Attachments[b]
3	Information provided by states on facilities and materials	-Design Information Questionnaire (DIQ) -Inventory Change Report (ICR) -Material Balance Report (MBR) -Physical Inventory Listing (PIL) -International Transfer Report (ITR)
4	IAEA verification that states are complying with safeguards agreements	-Inspection Plan -Pre-op Logistics -On-Site Inspection MC and A, C and S -Inspection Report
5	IAEA statements regarding independent verification and safeguards implementation	-Summary to State -Safeguards Implementation Report -IAEA Papers and Publications -Diplomatic Communications

[a] This table is similar to information presented by Carlos Büchler of the IAEA at the "Advanced International Training Courses on State Systems of Accounting for and Control of Nuclear Materials," Santa Fe, New Mexico, 1981 (see Ref. 11).

[b] Some recycling occurs between steps 2 and 3, e.g., Facility Attachments are negotiated following receipt of the Design Information Questionnaire.

II. ANALYSIS

A. Paths to Assurance and Deterrence

Figure 1 shows the paths connecting IAEA verification statements to the main political objectives of IAEA safeguards, assurance and deterrence. Following on-site inspections, the IAEA must make a statement that it was either able or unable to verify declared nuclear material and facility use. The fact that the IAEA summarizes highly complex findings using a binary description has been criticized by some, but this approach has precedent in many successful institutions, including judicial systems throughout the world. IAEA verification statements are initially made to the state authorities whose facility was inspected and are later made in generalized form to the international community via the annual Safeguards Implementation Report. Two types of responses to IAEA verification statements are possible: either the statements are accepted at face value, or they are not accepted at face value, as illustrated by the paths marked 1, 2, 3, and 4 in Fig. 1.

Path 1 corresponds to the most frequent situation in which the IAEA states that it was able to verify declared material and facility use, and these statements are not seriously questioned or discredited. Path 1 is the only path leading directly to both assurance and deterrence.

Path 2 occurs when the IAEA indicates that it was unable to verify declared material or facility use and the state involved cooperates with the IAEA so that corrective action (to enhance IAEA independent verification) can be taken by either the IAEA or the state. Path 2 leads directly to deterrence, but does not lead to assurance until

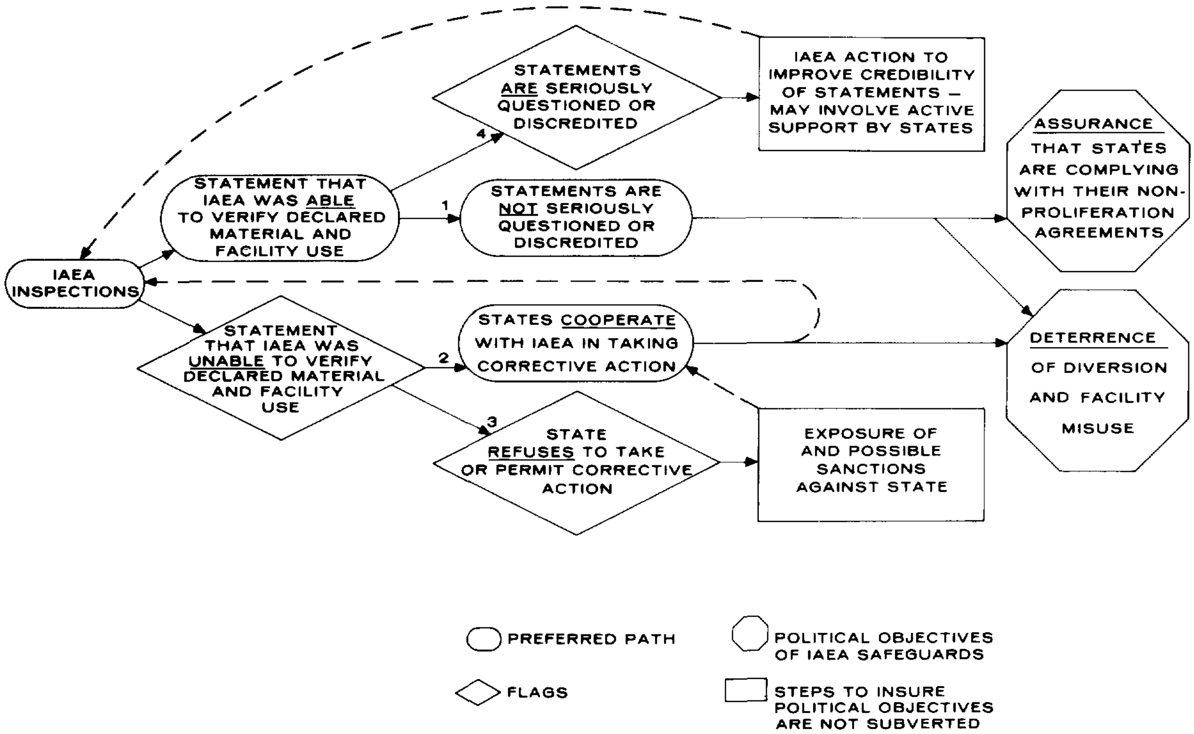

Fig. 1. Diagram of paths leading from IAEA inspections and the resulting verification statements to the main political objectives of IAEA safeguards, assurance and deterrence.

subsequent inspections (indicated by the dashed line) result in a path 1 response.

In path 3, the IAEA indicates that it was unable to verify declared material or facility use and the state involved refuses either to take corrective action or to permit IAEA corrective action. To ensure that the objectives of IAEA safeguards are not subverted, a number of measures are available to the IAEA, including withholding technical assistance to the state, suspending the privileges of IAEA membership, and informing the Security Council and General assembly of the U.N. Because path 3 is the result to be expected if a state has actually diverted nuclear material, the IAEA must be prepared to take immediate action when a path 3 response is indicated.

Path 4 results when the IAEA states that it was able to verify declared material and facility use and these statements are seriously questioned or discredited in the international community. Path 4 might occur if national safeguards authorities discredit IAEA safeguards in a public forum or if some publicized action by a state or group of states implies that IAEA safeguards are considered to be ineffective. In order to ensure that IAEA safeguards objectives are not subverted, the IAEA must respond with whatever action is required to restore its credibility.

Paths 1 and 2 are considered to be the preferred paths. Although path 2 does not lead directly to assurance, it does lead to normal evolutionary improvements in safeguards procedures, so that subsequent inspections at the facility in question should result in path 1 transactions.

Both paths 3 and 4 have the short term effect of reducing safeguards effectiveness; however, with appropriate action, paths 3 and 4 can be prevented from subverting IAEA safeguards objectives. Normally, transactions along paths 3 and 4 should be infrequent, and if this is not the case, it indicates that there is a significant problem with IAEA safeguards effectiveness.

B. The IAEA Safeguards Effectiveness Ratio

We define N_1, N_2, N_3, and N_4 as the number of transactions per year that flow through paths 1, 2, 3, and 4 shown in Fig. 1. The effectiveness ratio is defined as

$$E_r = \frac{N_1 + N_2}{N_0 + N_1 + N_2 + N_3 + N_4} = \frac{N_1 + N_2}{N_0 + N_T} ,$$

where N_T is the total number of inspections that the IAEA makes in one year, and N_0 is the additional number of inspections that the IAEA would make if there were no financial, legal, or operational restrictions on its inspection activity. The effectiveness ratio E_r is simply the number of inspection statements per year that are accepted at face value, divided by the total number of inspections per year that the IAEA would perform if there were no restrictions on its inspection activity. E_r can be maximized by minimizing the sum of $N_0 + N_3 + N_4$.

Table II presents an analysis of the critical factors (N_0, N_3, and N_4) that limit the IAEA safeguards effectiveness ratio E_r. The central column of Table II lists possible causes that contribute to nonzero values of N_0, N_3, and N_4; the right-hand column lists measures that could be used to decrease N_0, N_3, and N_4. In Table II, measures (a) and (a') correspond to possible cause (a); measure (b) corresponds to possible cause (b), etc. The information in Table II describes the current situation in IAEA safeguards with reasonable accuracy, but is not intended to be highly detailed or all inclusive.

Each measure for decreasing the critical factors listed in Table II will increase the effectiveness ratio E_r, provided that a decrease brought about in one critical factor is not offset by an increase in other critical factors. With careful implementation and timing, the measures in

TABLE II

ANALYSIS OF FACTORS THAT LIMIT THE IAEA SAFEGUARDS EFFECTIVENESS RATIO E_r

Critical Factor N_i	Possible Causes for $N_i > 0$	Corresponding Measures for Decreasing N_i
N_0	(a) The combination of increasing number and complexity of facilities under IAEA/SG and limited IAEA/SG operating budgets.	(a) Increase IAEA/SG operating budgets.
		(a') Develop more efficient IAEA/SG approaches through advanced technology, improved logistics, stronger SSACs, etc.
	(b) Refusal of a few nonweapons, non-NPT states to accept full-scope safeguards.	(b) Encourage all nonweapons states to accept full-scope IAEA/SG.
	(c) Restrictions imposed by some Safeguards Agreements and Subsidiary Arrangements in both NPT and non-NPT countries.	(c) Update Safeguards Agreements and Subsidiary Arrangements to reflect facility changes, improved IAEA/SG approaches, etc.
N_3	(d) Lack of trained personnel to design and implement improved SSAC procedures.	(d) Improve SSAC capability through personnel training.
	(e) State's unwillingness to accept procedures not specified in the Safeguards Agreement or Subsidiary Arrangements.	(e) Update Safeguards Agreements and Subsidiary Arrangements.
		(e') Improve IAEA/State communication, and stress importance of mutual cooperation and flexibility.
	(f) State/IAEA disagreement on necessity of improving SG measures.	(f) Familiarize state authorities with SG philosophy, practice, and experience in other similar nations.
	(g) State's view that SG improvement would be be discriminatory.	(g) Develop IAEA/SG approaches that are less intrusive and more compatible with existing facilities and procedures.
		(g') Provide greater transparency of IAEA/SG operations to demonstrate IAEA/SG fairness and objectivity.
	(h) State's de facto withdrawal from SG Agreement, including possible diversion or facility misuse.	(h) Make de facto withdrawal unattractive by specifying severe sanctions and penalties.
N_4	(i) Insufficient technical credibility of IAEA independent verification statements.	(i) Provide greater transparency of IAEA/SG operations to demonstrate capability of detecting diversion and facility misuse.
		(i') Strengthen IAEA verification through use of more and better IAEA equipment, inspector training, improved SSAC performance, etc.
		(i") Reduce difficulty of IAEA verification through consolidation of material and facilities at state or regional level.
	(j) Unrealistic expectations for role of IAEA/SG.	(j) Define and communicate IAEA role more widely using attractive, easy-to-understand methods and language.
	(k) Politically motivated actions that cast doubt on IAEA/SG effectiveness.	(k) Develop means for decoupling politically motivated actions from the question of IAEA/SG effectiveness.

Table II should not significantly increase any of the critical factors, and therefore can be expected to generate an overall increase in the effectiveness ratio.*

C. Measures for Increasing IAEA Safeguards Effectiveness

Nations with different technological, political, economic, and cultural histories are likely to view the needs for changing or improving IAEA safeguards in different ways. Using the model under discussion, some nations will place first priority on decreasing one critical factor, such as N_4, while others may place first priority on decreasing N_0 or N_3 and fail to see much importance in decreasing N_4. As a consequence, measures listed in Table II that have the effect of simultaneously decreasing two or more critical factors would be expected to have wider support among the IAEA member states than measures that decrease only one critical factor.

Table III, which is a regrouping of information in Table II, divides measures for increasing IAEA safeguards effectiveness into "plural measures" and "singular measures," depending on the number of critical factors affected. The wording of the measures in Table III has been broadened to include closely related measures in Table II, as indicated by the letters (a'), (d), etc.

Plural Measures: The plural measures for increasing IAEA safeguards effectiveness shown in Table III are, as expected, widely supported and largely noncontroversial in nature. Furthermore, the plural measures are consistent with current activity intended to improve IAEA safeguards effectiveness. For example, under the U.S. Program of Technical Support to IAEA Safeguards, a major effort was initiated in 1977 to provide the IAEA with improved safeguards technology by supplying instruments, software, personnel training, consulting, and technical assistance. Since then, several other nations, including the U.S.S.R., Canada, Germany, Japan, Great Britain, and Australia, have also started technical assistance programs. The IAEA established a separate section for safeguards training in 1980 and has developed a comprehensive set of inspector training courses. In addition, the IAEA is planning significant expenditures during the next five years for containment and surveillance equipment and nondestructive assay equipment to be used in its independent verification activity. Thus, a great deal of effort has been and continues to be spent on measure A listed in Table III by both the IAEA and certain member states. It is of critical importance that this effort continue and that emphasis be placed on key technical problems, such as (1) the need for safeguards training for state and facility personnel in developing countries and (2) the need for both R&D and consensus in safeguards approaches for bulk facilities, including reprocessing and enrichment plants.

TABLE III

MEASURES FOR INCREASING IAEA SAFEGUARDS EFFECTIVENESS

		Critical Factors Affected†		
	Plural Measures	N_0	N_3	N_4
A.	Improve safeguards technology and personnel training at international, state, and facility levels.	a'	d g	i'
B.	Improve IAEA/State interaction, including communication, cooperation, and mutual understanding.		e' f	j
C.	Update Safeguards Agreements and Subsidiary Arrangements as needed and as conditions conditions permit.	c	e	
D.	Increase transparency of IAEA/SG operations.		g'	i
	Singular Measures			
E.	Increase IAEA/SG operating budgets.	a		
F.	Encourage all nonweapons states to accept full-scope IAEA/SG.	b		
G.	Make de facto withdrawal from Safeguards Agreements unattractive by specifying severe sanctions and penalties.		h	
H.	Reduce difficulty of IAEA verification through consolidation of material and facilities at state or regional level.			i"
I.	Develop means of decoupling politically motivated actions from the question of IAEA/SG effectiveness.			k

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†Lower case letters (a', d, i', etc.) under N_0, N_3, and N_4 denote corresponding measures listed in Table II.

For many years, the IAEA has emphasized improving IAEA/State System communication, cooperation, and mutual understanding (measure B in Table III). IAEA activity in this area extends not only to meetings and negotiations that are part of the IAEA's independent verification process, but also to IAEA technical committees and advisory groups and to safeguards training courses for state and facility personnel. Still, the most common reason for difficulties in implementing IAEA safeguards remains the need for better communication between IAEA and state personnel. Hence, this effort should be continued by the IAEA and strongly supported by the member states.

Measure C in Table III, updating of Safeguards Agreements and Subsidiary Arrangements

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*We have not yet attempted to determine an empirical value of E_r, but it would be interesting to tabulate E_r as a function of calendar year, type of facility, geographical region, etc.

(including Facility Attachments), is another area that has been actively pursued by the IAEA. This measure is necessary when nuclear facilities are built or modified, when the IAEA wishes to alter its safeguards approach (such as by adding containment and surveillance equipment), or when Safeguards Agreements are to be brought into line with the Non-Proliferation Treaty (NPT).

The IAEA has been somewhat more cautious in its efforts to increase the transparency[12] of its safeguards operations (measure D in Table III). Clearly this is an area that calls for caution because of the need to protect proprietary and confidential information about the facilities and processes involved. The technology used in IAEA safeguards has been described in IAEA publications[13] and in the open literature.[14] The Safeguards Implementation Report annually summarizes (in general terms, without identifying states or facilities) the status of IAEA safeguards, including accomplishments and difficulties encountered. Still, IAEA effectiveness would be increased if more information concerning inspection and verification results were made part of the public record.

Singular Measures: The singular measures for increasing IAEA safeguards effectiveness shown in Table III are, by comparison with the plural measures, less widely supported and more controversial in nature. Furthermore, some of the singular measures listed involve political considerations that extend beyond the currently accepted role of IAEA safeguards. This is not to imply that singular measures should not be pursued, but rather that the main initiative and follow-through necessary for pursuing the singular measures probably will have to come from sources other than the IAEA. For example, it is unlikely that the IAEA will allocate a larger fraction of its resources for IAEA safeguards operations (one possible approach to singular measure E) because of the understandable desire on the part of developing countries to use competing resources to foster the transfer of nuclear technology. However, the technical support to IAEA safeguards initiated by the U.S. and other countries with large national nuclear programs has already begun to have a positive impact on IAEA safeguards operations. In effect, the technical support programs subsidize the development of improved IAEA safeguards technology, so that internal IAEA resources can be more efficiently applied to safeguards operations.

International plutonium storage, which would fall under singular measure H, is one of the more interesting institutional concepts arising from the International Nuclear Fuel Cycle Evaluation (INFCE). Although this subject has been studied by an IAEA advisory committee, international plutonium storage is unlikely to move forward unless greater incentives can be provided for states to become party to such an agreement.

In general, it appears that the singular measures listed in Table III will require new types of institutional arrangements which are just beginning to emerge. These new institutional arrangements may depend on bilateral and multilateral agreements, and in some cases could lead to a stronger role for IAEA safeguards.

III. SUMMARY

IAEA safeguards effectiveness depends not only on the technical quality of IAEA independent verification of declared nuclear material and facility use, but also on the perception of and reaction to IAEA safeguards by the nations who form the international community. Because perceptions and reactions generally involve nontechnical as well as technical factors, it is impossible to describe IAEA safeguards effectiveness completely in terms of technical performance criteria.

The model shown in Fig. 1 offers an alternative approach for examining IAEA safeguards effectiveness. Although the model is simpler than the actual situation, it allows one to summarize technical and nontechnical factors that influence IAEA safeguards effectiveness, as illustrated in Table II. Finally, by analyzing the measures for improving IAEA safeguards effectiveness shown in Table III, it becomes clear that considerable progress is being made on plural measures and that new institutional approaches are needed to address some of the singular measures.

An essential consideration when selecting measures for improving IAEA safeguards effectiveness (that has not been dealt with in this study) is the cost of implementation and operation. Although of fundamental importance, cost comparisons are used primarily for evaluating specific, well-defined alternatives rather than for providing general guidance. For example, in selecting ways to implement measures listed in Table III, cost comparisons should be a prime consideration.

The model shown in Fig. 1, which was developed primarily for the purpose of discussing IAEA safeguards effectiveness, also illustrates a number of other points that are worth recognizing. IAEA safeguards are by no means perfect, but they contain several features that compensate for their lack of perfection. Although the use of technology can make independent verification a more objective process, there will always be a need for negotiation and compromise. Differences in point of view because of technical, political, economic, and cultural experiences are an inherent part of IAEA safeguards that must be recognized in the negotiation process.

By not accepting IAEA verification statements at face value, nations are generally sending a constructive message to the IAEA and to the international community that, in their view, IAEA safeguards procedures should be modified. As a consequence, IAEA safeguards are constantly evolving in an effort to satisfy and balance the needs of the international community. Member states should recognize that the IAEA cannot maintain its politically impartial role (which is essential if the IAEA is to provide assurance and deterrence) if the IAEA is dominated by a single state or a group of states with special interests. States should also recognize that while the IAEA gains strength by responding to constructive criticism, overdrawn criticism to which the IAEA cannot respond only weakens the credibility and effectiveness of IAEA safeguards.

It is hoped that this look at IAEA safeguards from a different perspective will stimulate new thought on the subject and lead to better appreciation of the strengths and limits of current institutional arrangements, as well as clarify measures for improving IAEA safeguards effectiveness.

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ANTICIPATED AMOUNTS OF NUCLEAR MATERIALS UNDER IAEA SAFEGUARDS (1981-1990)

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To assess the scope of nuclear activities subject to safeguards in the future, the System Studies Section of the Department of Safeguards of the IAEA maintains a computerized data base file where data on nuclear fuel cycle facilities under operation, under construction, and planned, collected from open publications, are stored and updated.

A set of computerized programmes has been worked out to forecast both the number of nuclear facilties of different types and the amounts of nuclear materials that may come under safeguards in the future.

Simplified models simulating the flows of nuclear materials associated with the operation of power reactors have been adopted for the forecasting of the amounts of nuclear materials.

The calculation has dealt only with those types of power reactors for which the operational experience exists and for which a model approach based on that experience could be reasonably applied (PWRs, BWRs, PHWRs and GCRs).

Two stages of calculations have been performed:

- assessment of amounts of nuclear materials discharged from power reactors prior to 1982;
- estimation of anticipated amounts of discharge up to 1990 both from operating and future power reactors.

Assessment of historical discharge prior to 1982

The data on nuclear electricity generated by power reactors published in Nucleonics Week have been used for these calculations.

Two different models were used for LWRs and on-load reactors.

- Light Water Reactors

Using the data on electricity generated and design core loading the average burnup is calculated. The amount of plutonium contained in discharged fuel is a product of a design discharge fuel weight and a plutonium production rate. The burnup of the fuel remaining in a core is calculated separately for each section of a core (2 remaining sections for a PWR and 3 for BWR) by summing up the average burnup and historical burnup of an individual section. Using these data on burnup and design data on enrichment, the plutonium production rate is calculated as a function of both parameters.

The total error of calculation of the sum of plutonium in discharged fuel and in core is assessed to be within 20%. It includes the error of burnup calculation, the error of plutonium production rate estimation and the error associated with the deviations of the realistic values of discharged fuel from the design values.

- On-load power reactors.

Using the data on electricity generated and design burnup the amount of discharged fuel is calculated. The latter is multiplied by the plutonium production rate ($0.9235 \cdot x^{0.6946}$, where x is BURNUP (GWt.D/t) to give the plutonium content in discharged fuel.

Plutonium remaining in a core is calculated as a product of a design core inventory and plutonium production rate corresponding to 50% of design burnup.

The total error of estimation is assessed to be within 25%.

Estimation of the anticipated amounts of discharged nuclear materials.

The following assumptions are adopted for LWRs. The refuelling of a reactor occurs at the end of a calendar year. For a PWR 1/3 of the design burnup is assumed at the first discharge, 2/3 at the second and full design burnup at the

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third discharge. For a BWR: the first discharge occurs at 1/4, the second at 1/2, the third at 3/4, and the fourth at full design burnup.

The programme draws on the design data for an individual reactor and generates these parameters and appropriate plutonium production rates in accordance with the table above. Along with plutonium values in discharged fuel and in core for every future year until 1990, the programme also generates the values of natural uranium demanded for a first core (two years before the startup), the amount of LEU for the first core (enrichment service to transfer the above natural uranium into 3% enriched uranium one year before the startup), LEU and LEU fuel fabrication demands for refuelling and cumulative amounts of discharged fuel.

For on-load power reactors a load factor of 0.8 is assumed, and calculation of fuel discharged and plutonium in it and in a core is calculated for that load factor and design burnup. Also calculated are the amounts of natural uranium demands (one year before the start-up) and U-nat fuel fabrication demands (the year of start-up) and demands of these materials for refuelling.

With those models applied, the forecast of the amounts of nuclear materials associated with operation of power reactors has been done for 92 operating reactors, 91 reactors under construction and 52 planned reactors of 30 non-nuclear weapon states.

The status of startup dates of the future power reactors is as of 31 December 1981.

The results are given on figures 1-3 separately for the three cases:

- operating reactors;
- reactors under operation and construction;
- reactors under operation, construction and planned.

Figure 1 shows the natural uranium estimated to be under safeguards associated with on-line fuelled reactors, from 1981 to 1990. It shows the cumulative sum of the natural uranium being fabricated into fresh fuel, uranium in on-line fuelled reactors, and depleted uranium in spent fuel, as a function of time.

Figure 2 shows the low enriched (3%) uranium anticipated to be under safeguards in the light water reactor (LWR) fuel cycle. It shows the cumulative sum, as a function of time, of low enriched uranium undergoing conversion and fabrication of fresh fuel, uranium in the reactors, and uranium contained in the spent fuel.

Figure 3 shows the anticipated amounts of plutonium in discharged fuel and in the cores of on-line fuelled and light water moderated power reactors.

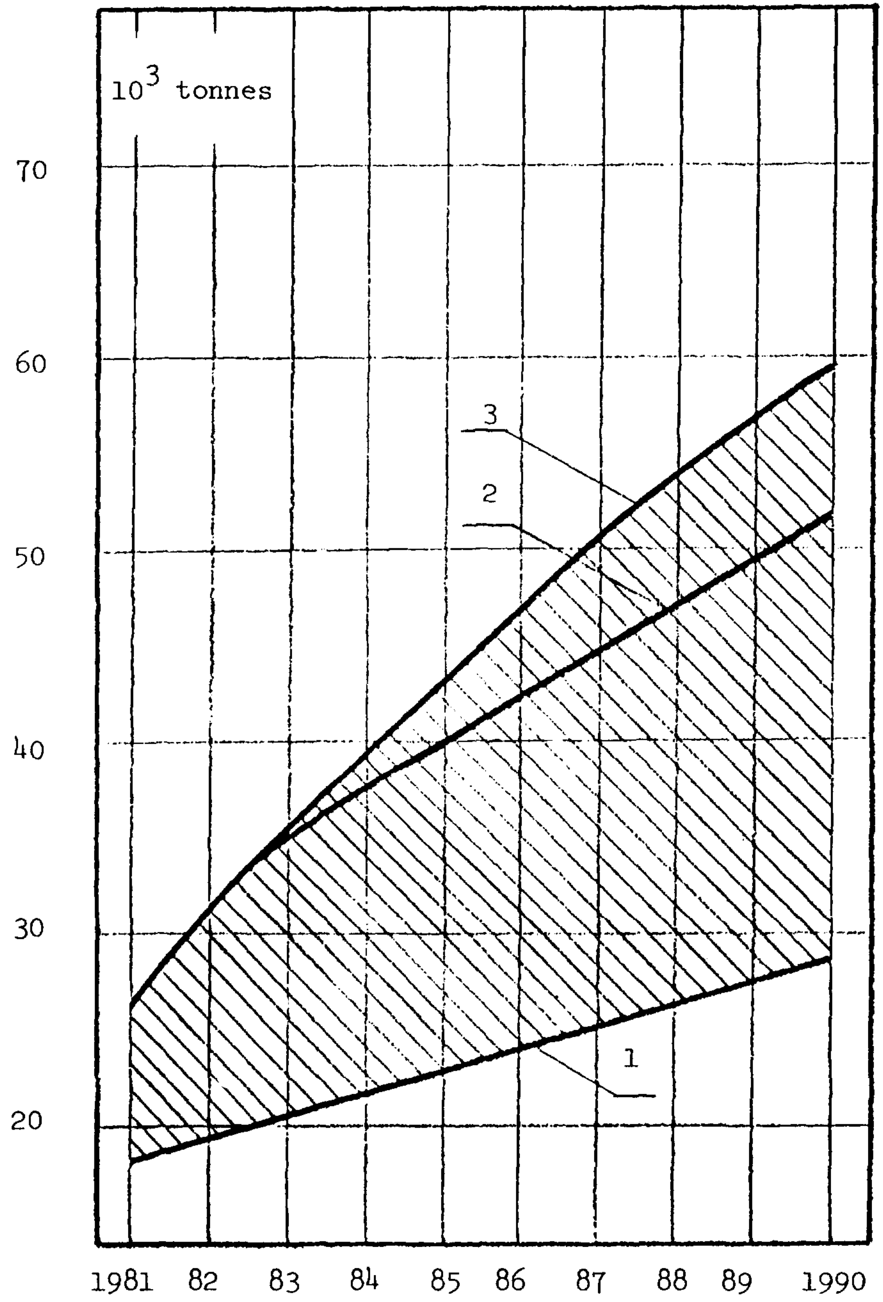

Figure 1. Anticipated amounts of unirradiated and irradiated uranium for on-line fuelled reactors under safeguards. 1. Operating reactors, 2. reactors under construction, 3. reactors now planned.

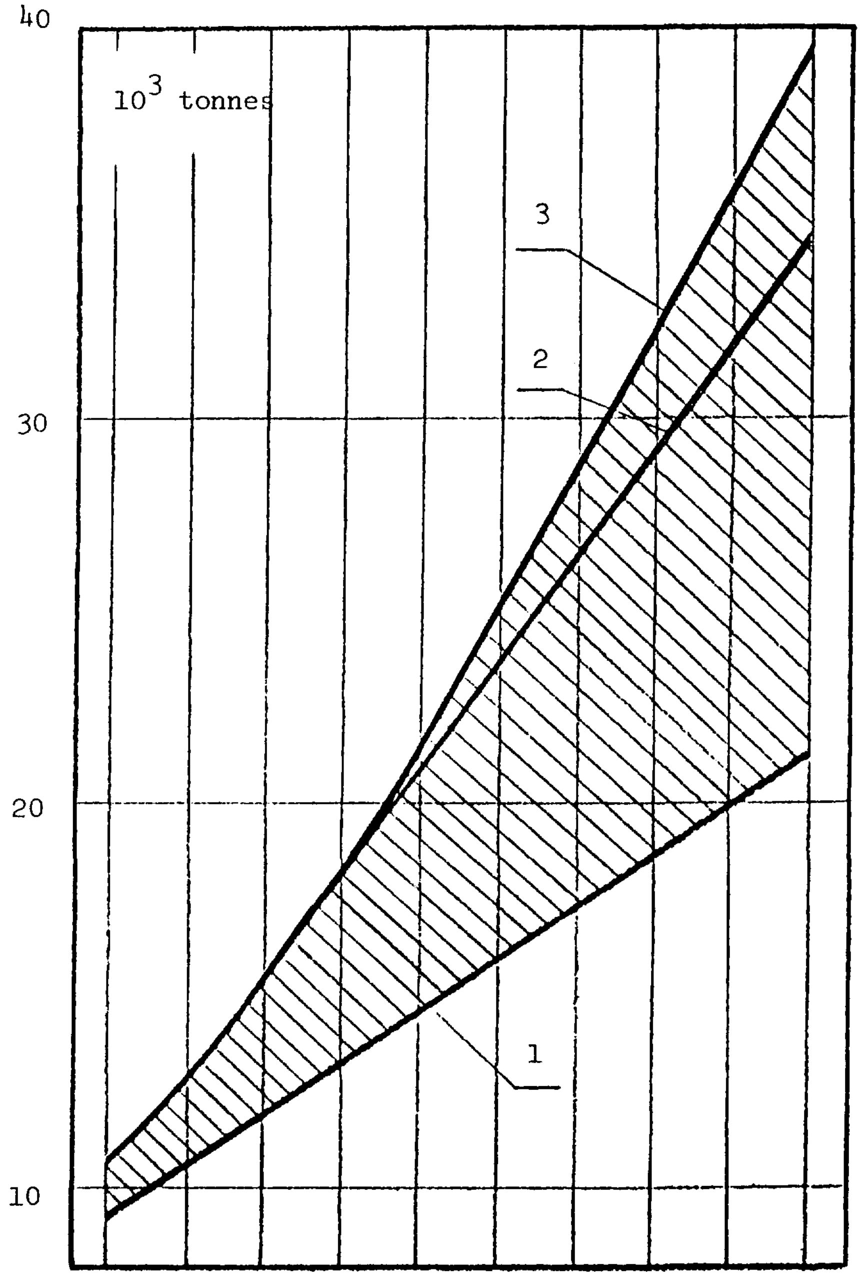

Figure 2. Anticipated amounts of unirradiated and irradiated low enriched uranium for LWR's. 1. Operating reactors, 2. reactors under construction, 3. reactors now planned.

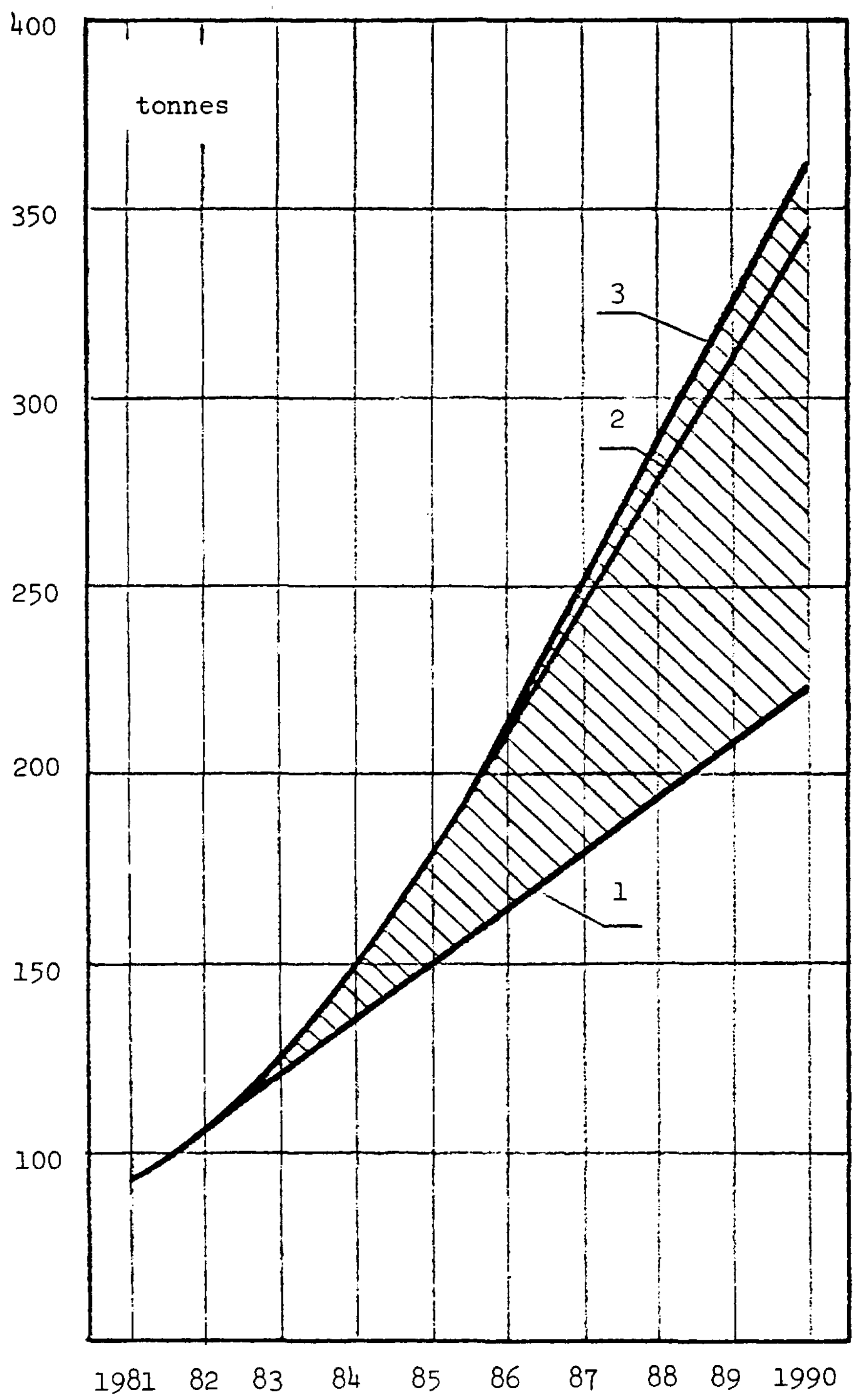

Figure 3. Anticipated amounts of plutonium (total) under safeguards.
1. operating reactors, 2. reactors under construction,
3. reactors now planned.

ATTRIBUTES MODE SAMPLING SCHEMES FOR INTERNATIONAL MATERIAL ACCOUNTANCY VERIFICATION

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Abstract

This paper addresses the question of detecting falsifications in material balance accountancy reporting by comparing independently measured values to the declared values of a randomly selected sample of items in the material balance. A two-level strategy is considered, consisting of a relatively large number of measurements made at low accuracy, and a smaller number of measurements made at high accuracy. Sampling schemes for both types of measurements are derived, and rigorous proofs supplied that guarantee desired detection probabilities. Sample sizes derived using these methods are sometimes considerably smaller than those calculated previously.

I. Introduction

This paper considers the problem of deriving measurement strategies and sample sizes for the purpose of the verification of a material balance or declared inventory by an international safeguards authority such as the International Atomic Energy Agency (IAEA). Because the IAEA does not have the resources to independently measure all items and thereby determine its own material balance, it requires the facility operator to report the values of his own measurements and then verifies that these reported numbers are in fact correct by making independent measurements on a randomly sampled subset of the reported items. This structure of reporting and verification defines two general strategies for an adversary wishing to divert material from a material balance. He may report an unfalsified material balance (accurately reporting his own measurements) so the diverted material will show up as declared "material unaccounted for", or he may falsify reported measurements to understate receipts or overstate shipments and inventories, thereby reducing the declared material unaccounted for.

In this paper we are concerned with the detection of the second type of strategy. In particular, we are concerned with the detection of falsifications which are large enough to be detected if the inspector decides to independently measure the item whose reported contents has been falsified. Such a falsification will be called a "defect" and the item will be said to be "defected". Falsifications by smaller amounts must be detected using material balance statistics involving many measurement data. Sampling for the purpose of detecting defects is sometimes referred to as "attributes mode" sampling.

In the model adopted here, the material balance is made up of a number of "strata", each of which is composed of items which have similar physical and chemical compositions, so that they can be measured by the same methods. It is assumed here that the inspector has at his disposal two measurement techniques for each stratum of material. The first is easily performed but has relatively poor accuracy and precision; its purpose is to detect large falsifications. Because it is not adequate to detect small falsifications, a second level is used, where measurements are performed with higher accuracy and precision. We will call these level one and level two measurements, respectively (these types of measurements are sometimes called "attributes measurements" and "variables measurements in the attribute mode").

The multi-level scheme has a number of advantages. Generally, the technical criteria on which inspection objectives are based specify that the system be capable of the detection, with a specified probability, of a specific minimal quantity of material diverted, which will be called the goal quantity, G. In order to make up a goal quantity, the diverter may use a small number of large falsifications, or a larger number of smaller falsifications. Using the easily performed level one measurements minimizes the effort needed to detect the first strategy; if these are performed, the sample size of the level two measurements can be made smaller, because it need only detect the second strategy, involving more defected items. The level two measurements also serve as follow-up actions when marginally significant data result from a level one measurement. Thus there are actually three sample sizes calculated for each stratum: a level one sample size to detect large defects, a level two sample size resulting from false alarms of level one measurements, and a level two sample size to detect small defects.

The purpose of this paper is to derive sampling schemes and sample sizes which will guarantee detection of a strategy of diversion through defects of a goal quantity of material with a specified probability while minimizing the number of items sampled.

In section two, a condition is derived for the detection schemes for individual strata which guarantees that the derived detection probabilities will hold even if the total falsification is spread among many strata. In section three, level one measurement strategies are considered. In section four, the basic results for level two measurements are derived. Section five contains the proofs of some inequalities referred to in previous sections. Results are summarized and compared with previous techniques in section six, a final section contains a numerical example.

II. The Multi-Stratum Condition

In the following sections, sample sizes and detection schemes will be computed for each individual stratum, based on the number of items in the stratum, the nuclear material contents of the stratum, and other parameters, independent of the characteristics of other strata. The formulas will guarantee that if an entire goal quan*tity is diverted from a single stratum*, detection will occur with the specified probability. However, it is also desirable to be able to show that if the goal quantity is split among strata, the specified probability will continue to hold. This is possible if the detection probability, as a function of the amount diverted, obeys a simple formula which we derive here. This idea was previously noted in a paper by Hough et al.(1)

The following notation will be used throughout this paper; additional notation is defined as needed:

i: subscript indicating stratum number.

β: non-detection probability (computed or actual)

βo: desired non-detection probability

G: goal quantity of nuclear material (e.g. kgs. of plutonium)

D: total amount of defect of falsification in a stratum (e.g., kgs. of plutonium)

Suppose we have a number of strata, and for each stratum we have a sampling plan and measurement strategy such that

$$\beta_i(D_i) \leq \beta_o^{D_i/G}$$

That is, the non-detection probability in the i^{th} stratum, as a function of the total falsification in that stratum D_i, is less than $\beta_o^{D_i/G}$. Then for any set of falsifications totaling a goal quantity G,

$$\Sigma_i D_i = G$$

we have an overall non-detection probability:

$$\beta = \Pi_i \beta_i(D_i) \leq \Pi_i \beta_o^{D_i/G} = \beta_o^{\Sigma_i D_i/G} = \beta_o$$

Therefore, if we prove that the non-detection probability for a sampling plan has the property

$$\beta(D) \leq \beta_o^{D/G} \qquad (1)$$

the diverter cannot do better than β_o by spreading his diversion over strata.

III. Level One Sampling Schemes

The purpose of level one sampling is the detection of a small number of large defects totalling one goal quantity with the desired detection probability (or non-detection probability). It is assumed in this section that the largest amount by which the reported value of an item can be falsified is its nominal or declared contents. The diversion strategy dealt with in this section is that in which a minimal number of items are falsified, where the amount of each falsification is the item *contents*. For example, four cans of PuO_2 powder whose nominal contents were two kgs of plutonium would be claimed to be full when actually empty, making up the goal quantity of 8 kgs. of plutonium. Thus it is assumed (in this section only) that if a defected item is measured by the level one measurement, detection will occur with probability one.

A. Hypergeometric Sampling

The following additional notation will be used:

j: subscript indicating item number

N: number of items in a stratum

m: number of defected items

n_1: number of items sampled by level one technique

A: declared nuclear material contents of an item

U: *smallest integer greater than or equal* to; U(1)=1, U(1.1)=2

We will use the term "hypergeometric" sampling to refer to a standard scheme (see references 1 and 2) in which, from a population of N items, the number sampled is

$$n_1 = U(N(1 - \beta_o^{A/G})) \qquad (2)$$

The diverter, to obtain a quantity of material D, must defect $m(D) = U(D/A)$ items. The probability that none of these will show up in the sample of size n_1 is

$$\beta(D) = \Pi_{j=1}^{m(D)} (1 - n_1/(N-j+1))$$

$$\leq (1 - n_1/N)^{m(D)} \qquad (3)$$

$$\leq (1 - n_1/N)^{D/A}$$

substituting (2)

$$\leq (\beta_o^{A/G})^{D/A} = \beta_o^{D/G}$$

The hypergeometric sampling scheme therefore obeys the condition given by formula (1). The word "hypergeometric" is used because the number of defected items in the sample follows a hypergeometric distribution.

B. Fractional Sampling

Formula (2), before rounding, may yield sample sizes less than one, and it may be desirable to sample the stratum on a random basis only. We will show that the following procedure may be used: (1) Calculate

$$P_s = N(1 - \beta_o^{A/G}) \qquad (4)$$

(2) Assuming $P_s \leq 1$ the stratum is sampled with probability P_s; it is ignored with probability $1-P_s$. (Many programmable calculators have random number generators built in, or can be programmed to produce random numbers. These generators generally produce uniformly distributed independent pseudo random numbers between zero and one; sampling would take place if the number generated was less than P_s.)
(3) If it is sampled, one item is chosen at random from the stratum and measured with the level one technique.

To show that this procedure satisfies condition (1), we note that if a total falsification of D is made in the stratum, $U(D/A)$ items are falsified. The conditional probability of detection, given that the stratum is sampled, is therefore $U(D/A)/N$. The overall detection probability is therefore

$$1 - \beta(D) = N(1 - \beta_o^{A/G})(U(D/A)/N)$$

$$= U(D/A)(1 - \beta_o^{A/G})$$

therefore

$$\beta(D) = 1 - U(D/A) + U(D/A)\beta_o^{A/G}$$

using lemma 4 of section V with $a = U(D/A)$, $b = \beta_o^{A/G}$, we have

$$\beta(D) \leq (\beta_o^{A/G})^{U(D/A)} \leq \beta_o^{D/G}$$

C. Binomial Sampling

The above schemes should be adequate to cover most practical situations. There is however, a general approach, applicable in almost any situation, which may be useful if (a) there is a significant variation in the material contents in items is the stratum; (b) there is no fixed population of items, but a continuous stream of items to be verified, as might be encountered in a continuous inspection regime.

Under this scheme a probability of sampling is calculated for each item; the probability is, of course

$$\begin{aligned} P_j &= 1 - \beta_o^{A_j/G} \quad \text{if } A_j \leq G \\ &= 1 - \beta_o \quad \text{if } A_j \geq G \end{aligned} \qquad (5)$$

where A_j is the nuclear material contents of item j. If there is a fixed number of items to be sampled, and the contents of each item is the same, then the sample size will be a binomially distributed random variable. To show that the scheme satisfies condition (1), suppose a set of K items, indicated by index j* are defected, whose total contents is D:

$$\Sigma_{j*=1}^{K} A_{j*} = D$$

then the non-detection probability is

$$\beta(D) = \Pi_{j*=1}^{K} (1-P_{j*}) = \beta_o^{\Sigma_{j*}A_{j*}/G} = \beta_o^{D/G}$$

Consider the case where the nuclear material contents of all items are the same ($A_j = A$ for all j) and A is very small compared with G. Then

$$P_j = P = 1 - \beta_o^{A/G}$$

$$= 1 - e^{A \log \beta_o/G}$$

$$\simeq 1 - (1 + A \log \beta_o/G)$$

$$= - A \log \beta_o/G$$

Since P will be small, it is appropriate to use the Poisson approximation to the binomial. In a stratum of size N, the number of samples will be Poisson distributed with expected value $\lambda = NP = NA \log \beta_o/G$.

This scheme can be implemented in the same manner as that for fractional sampling, by generating a random number using a calculator for each item and comparing it to P_j.

IV. Level 2 Sampling

In order to detect strategies of partial or small defects, a number of level two measurements are used based on a calculated sampling plan. The level two measurements are also used as follow-up actions in case of anomalous results from the level one measurements. Detection can therefore occur in two modes, corresponding to two independently generated sets of level two measurements:

(1) the sample chosen based on the level two sampling plan may contain a defected item; (2) the level one measurement can be anomalous resulting in its remeasurement by the level two technique.

A. Derivation of Level Two Sample Sizes

We will use the following additional notation:

s: amount by which the reported value of an item is defected or falsified

σ: standard deviation of the level one measurement technique

$\bar{\sigma}$: σ/A; relative standard deviation of level one technique

p: number of standard deviations exceeding which the difference between the declared value and the results of the level one measurement is anomalous

n_2: sample size for level two measurement to detect partial defects

β_1: probability that no level one measurement is anomalous

β_2: probability that a defected item will appear in the sample of size n_2

ϕ: cumulative normal distribution function

log: natural logarithm

We now derive a formula for n_2 adequate to fulfill condition (1). It will be assumed that hypergeometric sampling is used as the level one sampling technique, but the derivation using the other forms would be almost identical. A conservative approximation of the probability that no anomalous level one measurements will be observed is first derived:

β_1 = 1 - Pr (anomalous result|defected item in level one sample)

x Pr (defected item in level one sample)

The second probability is shown to be at least

$$1 - (1-n_1/N)^m$$

in equation (3), where m is the number of defected items. The first probability depends upon the correlation between level one measurements. If the measurement errors are completely independent ("random errors"), the probability is

$$1 - [\phi(p-s/\sigma)]^h$$

where h is the number of defected items appearing in the sample. If the measurement errors are completely correlated ("systematic measurement errors") the probability is

$$1 - \phi(p-s/\sigma) = \phi(s/\sigma-p)$$

We will adopt this last expression as being conservative, since it is always smaller. Therefore

$$\beta_1 \leq 1 - \phi(s/\sigma-p)[1-(1-n_1/N)^m] \qquad (6)$$

If the amount of falsification is D = ms, and formula (2) is used for n_1, we have

$$\beta_1 \leq 1 - \phi(s/\sigma-p)[1-\beta_o^{AD/Gs}] \qquad (7)$$

Using equation (3) again, we have, for the probability β_2,

$$\beta_2 = (1-n_2/N)^{D/s} \qquad (8)$$

The overall non-detection probability is then $\beta=\beta_1\beta_2$. Note that this depends upon s, which the diverter may choose to maximize β. The main result of this section is the following. Suppose we define

$$f(\beta_o,p,\bar{\sigma}) = \max_{c\geq 0}\Big\{- c\log(\beta_o) + c\log\left[1-\phi(c-p) + \phi(c-p)\beta_o^{1/c\bar{\sigma}}\right]\Big\} \qquad (9)$$

And suppose that n_2 is chosen according to

$$n_2 \geq \frac{N\bar{\sigma}A}{G} f(\beta_o,p,\bar{\sigma}) \qquad (10)$$

Then if $\beta = \beta_1\beta_2$, we will show that, regardless of the value of s,

$$\beta \leq \beta_o^{D/G}$$

Proof: Substitution of (9) and $\sigma = \bar{\sigma}A$ into (10) yields

$$(n_2/N) \geq \max_{c\geq 0}\Big\{- \frac{c\sigma}{G} + \frac{c\sigma}{G}\log\left[1 - \phi(c-p) + \phi(c-p)\beta_o^{A/c\sigma}\right]\Big\}$$

letting $\sigma c=s$, and ϕ stand for $\phi(s/\sigma-p)$,

$$(n_2/N) \geq \max_{s\geq 0}\Big\{- \frac{s}{G}\log\beta_o + \frac{s}{G}\log\left[1 - \phi + \phi\beta_o^{A/s}\right]\Big\}$$

using lemma 1 from section 5

$$\log(1-n_2/N) \leq - \max_{s\geq 0}\{\text{bracketed term}\}$$

$$-\log(1-n_2/N) \geq \max_{s\geq 0}\{\text{bracketed term}\}$$

$$0 \geq \max_{s \geq 0} \left\{ -\frac{s}{G} \log \beta_o + \frac{s}{G} \log \left(1 - \phi + \phi \beta_o{}^{A/s}\right) + \log(1-n_2/N) \right\}$$

using lemma 2 from section 5,

$$0 \geq \max_{s \geq 0} \left\{ - G^{-1} \log\beta_o + G^{-1} \log\left(1 - \phi + \phi\beta_o{}^{A/s}\right) + s^{-1} \log(1-n_2/N) \right\}$$

$$(D/G)\log\beta_o \geq \max_{s \geq 0} \left\{ (D/G \log\left(1 - \phi + \phi\beta_o{}^{A/s}\right) + (D/s)\log(1-n_2/N) \right\}$$

raising to the power e,

$$\beta_o{}^{D/G} \geq \max_{s \geq 0} \left\{ \left(1 - \phi + \phi\beta_o{}^{A/s}\right)^{D/G} (1-n_2/N)^{D/s} \right\}$$

using lemma 3 (with $a = \phi$, $b=\beta_o{}^{A/s}$, $c=D/G$)

$$\beta_o{}^{D/G} \geq \max_{s \geq 0} \left\{ \left(1 - \phi + \phi\beta_o{}^{AD/Gs}\right) (1-n_2/N)^{D/s} \right\}$$

substituting (7) and (8),

$$\beta_o{}^{D/G} \geq \beta_1\beta_2 = \beta.$$

B. Numeric Values of the Function f; Choosing p-Values

Table 1 gives the calculated values of expression $f(\beta_o,p,\bar{\sigma})$ for various values of β_o, p, and $\bar{\sigma}$. The values of f increase with $\bar{\sigma}$, but the dependence is very weak. Because it is very seldom that values of $\bar{\sigma}$ greater than .2 would be encountered in practice, and because smaller values make very little difference, the $\bar{\sigma}$=.2 table can be used exclusively. Figure 1 is a graph of f with $\bar{\sigma}$ = .2.

It may be that the value of the parameter p (the critical value of the level one test) may be fixed by other considerations; however it may also be regarded as a free parameter which can be chosen to minimize effort. In the latter case, it can be noted that increasing p will decrease the number of anomalous results from the level one measurements due to false alarms, leading to a decrease in the number of resultant second level measurements required as follow-up actions.

The expected number of such measurements is

$$n_f = N(1 - \beta_o{}^{A/G})\ \phi(-p) \qquad (11)$$

However, the sample size n_2 from equation (10) increases with increasing p because f is an increasing function of p. Since the two samples are chosen independently, there is the possibility that the two will overlap. The expected total number of level two measurements is therefore

$$n_{2t} = n_2 + n_f - n_1 n_f/N \qquad (12)$$

The values of p that minimize this total can be established computationally for various values of the parameters A/G, β_o, and $\bar{\sigma}$. However, as a general rule, the dependence of this optimal value of p on A/G and β_o is small. A reasonable guide for choosing p can be based on the value of $\bar{\sigma}$, as follows.

$\bar{\sigma}$	best p
≤.015	3
.015-.04	2.5
.04-.1	2
>.1	1.5

Computations show that total level 2 sample sizes will not exceed $2n_2$ (i.e., $n_{2t} \leq 2n_2$). Where p-values of 2.5 or 3 are chosen in the above table, total level 2 sample sizes will not exceed 1.25 n_2.

V. Supporting Proofs.

Lemma 1. If $x \geq y$ then $\log(1-x) < -y$

proof: $x-1 \geq \log(x)$

$x \geq \log(1+x)$

$-x \geq \log(1-x)$

so $\log(1-x) \leq -x \leq -y$

Lemma 2. If $\max f(x) \leq 0$ then $\max_{x>0} (f(x)/x) \leq 0$

proof: If $\max f(x)/x > 0$ then there would be some $x_o > 0$ and $y > 0$

such that

$$\frac{1}{x_o} f(x_o) = y > 0$$

but then $f(x_o) = x_o y > 0$

this contradicts $\max_{x>0} f(x) \leq 0$.

Lemma 3. If $0 \leq a,b,c \leq 1$
then $1 - a + ab^c \leq (1-a+ab)^c$

proof: $(1-a)(1-b) \geq 0$

$1-a+ab-b \geq 0$

$1-a+ab \geq b$

so

$(1-a+ba)^{c-1} \leq b^{c-1}$ for $0 \leq a,b,c \leq 1$

Consider $f(b;a,c) = (1-a+ab)^c - (1-a+ab^c)$

$$\frac{df}{db} = ca\left((1-a+ab)^{c-1} - b^{c-1}\right)$$

since c,a ≥ 0, and the term is brackets is negative,

$$\frac{df}{db}(b;a,c) \leq 0;\ 0 \leq a,b,c \leq 1$$

however, $f(1;a,c) = 0$ for all $0 \leq a,c \leq 1$

therefore, $f(b;a,c) \geq 0$ for all $0 \leq a,b,c < 1$

therefore, $(1-a+ab)^c \geq 1-a+ab^c$

Lemma 4. If $a \geq 1$ and $0 < b \leq 1$
then $b^a \geq 1 - a + ab$

Proof. Let $f(b;a) = b^a - ab + a - 1$

Then $f(1;a) = 0$ for all a

$$\frac{df}{db} = ab^{a-1} - a = a(b^{a-1} - 1) \leq 0$$

for $a \geq 1$ and $0 < b \leq 1$.

Therefore $f(b;a) \geq 0$ for $a \geq 1$ and $0 < b \leq 1$.

VI. Summary Remarks

The sampling strategies discussed in this paper may be summarized as follows. The entire material balance is first divided into strata, for each of which a sampling scheme is determined. Generally, formula (2) can be used to calculate the sample size for the level one (attributes) measurement. If this size turns out to be one, formula (4) can be used to calculate a probability that a single item will be sampled from the stratum. In special circumstances it may be useful to use formula (5) to determine a probability of sampling for each item.

The level two (variables measurement in the attributes mode) sampling strategy begins with a determination of the critical value of the level one measurement (the number of standard deviations at which the level one measurement result is defined to be anomalous). If this is not fixed by other considerations, it can be chosen according to the table in IV.B. Once this critical value is chosen, formula (10) is used to calculate the level two sample size. In addition to these level two measurements, it is assumed that a level two measurement is made as a follow-up action to an anomalous result of a level one measurement. The total expected number of level two measurements is given in Equation (12); it will not exceed twice the sample size calculated in (10).

For all of these schemes it is shown that (1) the desired detection probability will result if an entire goal quantity is diverted as defects from the stratum, (2) the desired detection probability will continue to hold if the goal quantity is split among strata.

A previous paper by this author$^{(3)}$ had reported a table of numeric values for level two sampling similar to those given in table 1. Although they were based on a less general proof and a different calculation than described here, the resultant numeric values were virtually identical to those in this paper except for very large σ and β (no differences exceed 8%). As was noted before$^{(3)}$ these schemes result in considerably smaller level two sample size than those that are derived from schemes presently in use (see, for example, reference 2, section 8.4.1 as regards variables sizes in the attributes mode). The formula generally adopted is

$$n_2' = U\left(N(1 - \beta_o^{4\bar{\sigma}A/G})\right)$$

The logic behind this formula is that the level two measurement need be able to detect falsifications no larger than $4\sigma A$; larger falsifications are presumably detectable with the attributes measurement with high probability and low false alarm rate. This reasoning is neither carefully justified nor overly conservative. Presumably the value of what we call p is taken to be about two (although this is not stated or recommended in procedures) yielding a false alarm probability of 2.3% and a built-in nondetection probability (when the falsification is just above $4\sigma A$) of 2.3%. These values are small, but not negligible. What the logic ignores is the overlapping detection capability of the two systems in the critical range of a few σ; this is taken into account in the present calculation.

VII. Example.

Consider a stratum of 100 cans of PuO_2 powder, each weighing approximately 2.5 kg., for which the inspector has an NDA technique that can estimate plutonium content to 9% (one sigma). The inspector can also weigh and sample the can. The inspectors goal quantity is 8 kg. of plutonium, and his desired detection probability is .9. We have

$N = 100$

$A = 2.5 \times .88 = 2.2$ kg plutonium per item

$\beta_o = 1-.9 = .1$

$G = 8$

$\bar{\sigma} = .09$

The level one (attributes) sample size from formula (2) is

$$n_1 = U(46.9) = 47$$

Therefore, 47 items would be selected at random from the hundred to be measured by the NDA technique. The value of p (the number of standard deviations at which the measured value is rejected) is chosen as 2 from the table at the end of IV.B. Thus if the declared value differs from the NDA value by more than 18% (two times the sigma of the NDA measurement) the value is rejected, and the can is weighed and sampled.

The weighing and sampling (level two, or variables in attributes mode) sample size is calculated from equation (10) and table 1; in this case f(.1, 2, .09) is 3.22. The sample size n_2 is therefore 7.97, which we round up to 8. These eight samples for weighing and sampling are chosen independently and in addition to the previous 47. In addition, we will have to do weighing and sampling for the items rejected by the NDA measurement. The expected number of these measurements is given by equation 11 as 1.1.

Note that the formulation currently in use would yield a sample size for weighing and sampling of $n_2' = 21$ and this does not incorporate measurement of the NDA false alarms.

References

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2. IAEA Safeguards Technical Manual, Part F "Statistical Concepts and Techniques," Vol. III, IAEA-174, Vienna (1978).

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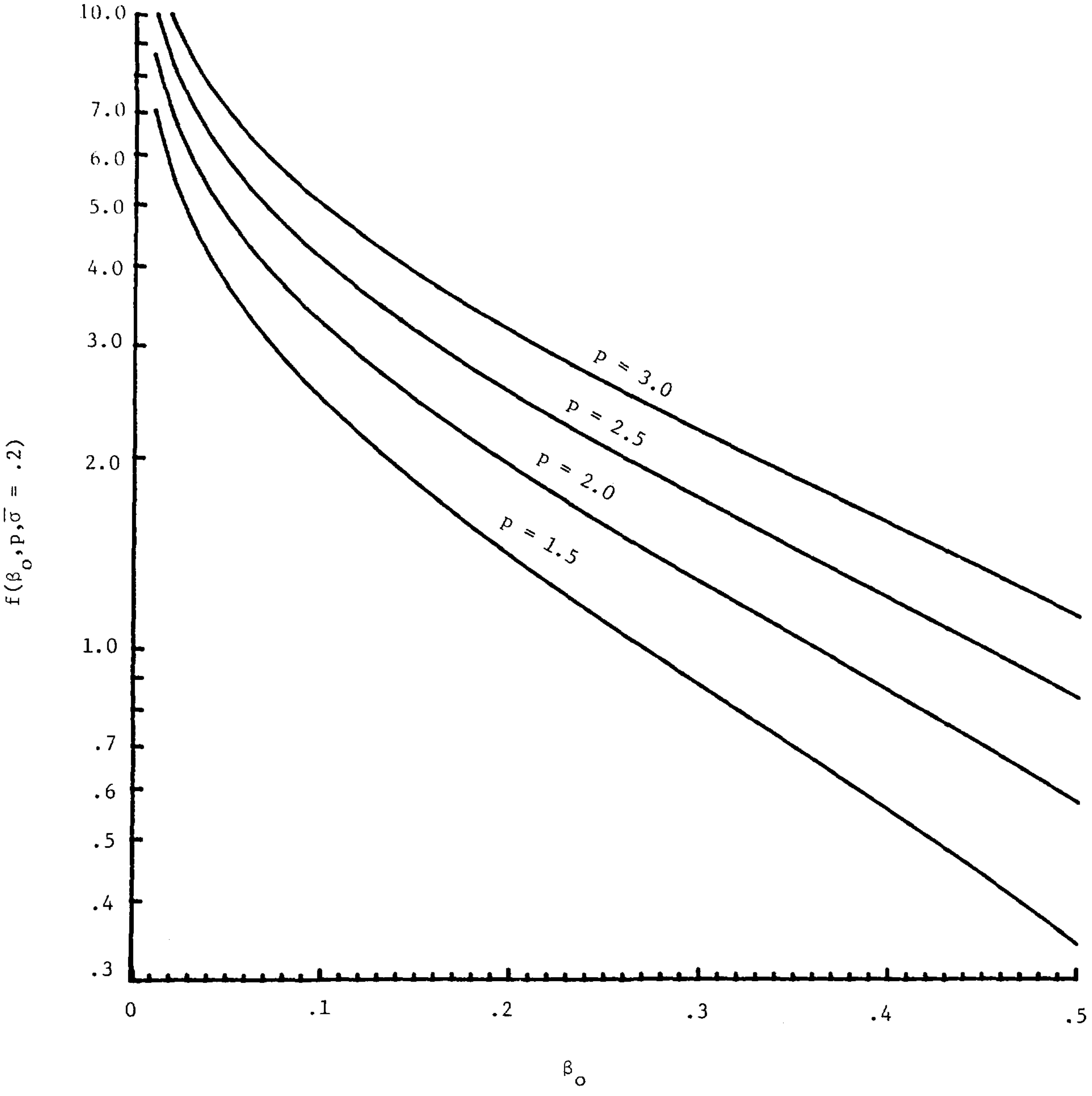
β_o	p	$f(\beta_o,p,.2)$	β_o	p	$f(\beta_o,p,.1)$	β_o	p	$f(\beta_o,p,.05)$	β_o	p	$f(\beta_o,p,.01)$
.50	1.5	.34	.50	1.5	.33	.50	1.5	.33	.50	1.5	.33
.20	1.5	1.39	.20	1.5	1.39	.20	1.5	1.39	.20	1.5	1.39
.10	1.5	2.45	.10	1.5	2.45	.10	1.5	2.45	.10	1.5	2.45
.05	1.5	3.68	.05	1.5	3.68	.05	1.5	3.68	.05	1.5	3.68
.50	2.0	.57	.50	2.0	.55	.50	2.0	.55	.50	2.0	.55
.20	2.0	1.93	.20	2.0	1.92	.20	2.0	1.92	.20	2.0	1.92
.10	2.0	3.23	.10	2.0	3.22	.10	2.0	3.22	.10	2.0	3.22
.05	2.0	4.69	.05	2.0	4.69	.05	2.0	4.69	.05	2.0	4.69
.50	2.5	.83	.50	2.5	.79	.50	2.5	.78	.50	2.5	.78
.20	2.5	2.51	.20	2.5	2.49	.20	2.5	2.49	.20	2.5	2.49
.10	2.5	4.06	.10	2.5	4.04	.10	2.5	4.04	.10	2.5	4.04
.05	2.5	5.78	.05	2.5	5.77	.05	2.5	5.77	.05	2.5	5.77
.50	3.0	1.12	.50	3.0	1.05	.50	3.0	1.04	.50	3.0	1.04
.20	3.0	3.15	.20	3.0	3.10	.20	3.0	3.10	.20	3.0	3.10
.10	3.0	4.95	.10	3.0	4.92	.10	3.0	4.92	.10	3.0	4.92
.05	3.0	6.93	.05	3.0	6.91	.05	3.0	6.91	.05	3.0	6.91

Table 1

Figure 1


10.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
.7
.6
.5
.4
.3
$f(\beta_o, p, \bar{\sigma} = .2)$
p = 3.0
p = 2.5
p = 2.0
p = 1.5
0
.1
.2
.3
.4
.5
β_o

DEVELOPMENT OF AN IMPROVED MONITOR FOR PORTAL DETECTION OF THE UNAUTHORIZED REMOVAL OF SPECIAL NUCLEAR MATERIAL

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ABSTRACT

A study was made of alternative designs for the portal detection of special nuclear material. Changes in the detector, signal-processing, and alarm logic components improved detection sensitivity and make the system less prone to false alarms. The resulting performance complies with the criteria for allowable frequency of false alarms specified by the Nuclear Regulatory Commission.

INTRODUCTION

Part of the Entry Control R&D Program at Sandia National Laboratories deals with the development of equipment that would prevent the unauthorized removal of special nuclear material (SNM). When we evaluated commercial monitors, we found that, while all suppliers could comply with the applicable Department of Energy (DOE) guideline attached to AEC-2405, their devices did not exhibit adequate sensitivity to shielded SNM. Early entry-control techniques relied upon metal detectors not only to detect weapons, but also to indicate the presence of metallic shielding. This approach was of limited use because metal detectors are not sensitive to some shielding made of composite materials such as lead-loaded polyethylene. Because of this inadequacy, we undertook a study of different concepts of detecting SNM that would increase sensitivity and thus reduce the shielding problem. We evaluated three commercial portal monitors and constructed a prototype monitor for comparison. The prototype construction incorporated design changes in the detector, signal-processing, and alarm components resulting in a more stable and sensitive system. Its performance also complies with the more stringent false-alarm-rate (FAR) criteria specified by the Nuclear Regulatory Commission Regulatory Guide 5.27.

TEST METHODS

To evaluate alternative designs, we developed standardized test methods for comparing the commercial and prototype systems. The development of test methods was based on a desire to achieve a stable and predictable FAR.

We found that stability and predictability can be achieved if the monitor measures only radiation and excludes the effects of other systematic problems such as noise. Two tests were applied to determine how well the monitors measured only radiation--the chi-square test and modification of the F Test.[1] Price[2] suggests that if the chi-square P value is between 0.02 and 0.98, the device for measuring radiation is functioning properly. Because radioactive emissions are described by Poisson behavior, the F test is also useful; we required the ratio of variance to the arithmetic mean to fall between 0.75 and 1.25. Such a criterion guarantees that, on the average, the observed FAR is that which is statistically expected. The two tests are related so that our F criteria gives a chi-square P value between 0.074 and 0.913.

The evaluation procedure was based on an analysis of 1024 observations of monitor count-rate data obtained with a multichannel analyzer operating in the multichannel scaling mode. These data were first analyzed as to chi-square fit. Then successive subsets of 64 observations were subjected to the modified F Test. Finally, the expected Poisson distribution was calculated by using the observed mean and sigma as the square root of that mean. The expected and observed data distributions were then plotted overlay fashion as shown in a plot from the prototype monitor (Figure 1). The subset analysis with the modified F was done because this analysis became the basis for a unique new alarm module design (to be discussed later).

The test procedures were used for background measurements and for measurements of test sources. The probability of source detection was then inferred from tables of the

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standardized normal distribution for cases where both the chi-square and modified tests were valid. A detection threshold of 3.1 sigma was used to yield a FAR of 1/1000. Table 1 shows typical measured values of mean and variance for the three commerical radiation detection units, designated A, B and C.

Table 1

BACKGROUND RADIATION MEASUREMENTS

COMMERCIAL MONITOR	MEAN(cps)	VARIANCE	RATIO
A*	6312	88 512	14.02
B	9825	94 443	9.61
C	602	1253	2.08

DEVELOPMENT PROGRAM

We chose organic scintillators for detectors because they offer higher portal efficiency per dollar than does NaI(Tl). The specific scintillator chosen was plastic; thus the baseline performance of Unit B was established for comparison since it is also based on a plastic scintillator. Then we made changes in the detector, signal-processing, and alarm logic components to improve detection sensitivity and make the system less prone to false alarms.

BASELINE PERFORMANCE

A setup procedure was used to maximize the performance of each component. First, the optimum bias voltage for the photomultiplier tube (PMT) was determined by the method suggested by Price.[2] If the PMT is used in the absence of a scintillator, bias voltage can be increased slowly to determine the onset of PMT noise. The optimum bias is then slightly below the noise point. Optimum voltage was found to be 1.3KeV for the Hamamatsu R-878 PMT used in Unit B.

Next, the main amplifier was adjusted to preclude clipping of the detector signals. The NIM equipment standard provides for a 10-V maximum amplitude; the amplifier gain was set to prevent excessive clipping at this level. Third, the detectors were balanced by observing multichannel analyzer pulse-height response to a ^{60}Co source for each detector and then adjusting PMT focus so that all detectors responded with similar pulse-height. It was important to place the source at the exact location on each detector since pulse-height response is a function of placement for large detectors. Following balance, the amplifier gain was again checked and readjusted.

Finally, because of the sensitivity of the pulse-height function with respect to position, the single channel analyzer window was set between the 10-V maximum and some lower limit. The lower limit was first adjusted to give zero counts in the absence of PMT bias. PMT bias was then applied and data taken while raising the lower limit until the chi-square and modified F tests were satisfied. The unmodified curve shown in Figure 2 is the baseline performance of Unit B.[4] The high enriched-uranium (HEU) sources used were metallic right-circular cylinders with greater than 93% ^{235}U content. The sources were placed at the indicated locations along the centerline of the portal monitor.

DETECTOR IMPROVEMENTS

During the study we found that the capability for light collection of the commercial detectors was not as good as it could be. Since light collection is directly related to sensitivity, we investigated several concepts that would improve the design and developed a 5.08 x 20.32 x 80-cm scintillator slab with a light pipe transition to the PMT.[5] In addition, we bonded the PMT permanently to the light pipe with Dow Corning 3140RTV.* The PMT bond is a good optical match to the light pipe and precludes detector damage that occurs with presently used silicone grease bonding methods.

SIGNAL PROCESSING IMPROVEMENTS

We evaluated two general methods of detector signal processing in conjunction with portal detection sensitivity. We compared the presently used method of pulse-height analysis to that of pulse-shape discrimination, which had not been applied to portal detection technology. We found that pulse-shape discrimination performs better because it is a narrow-band process and thus has excellent noise limiting characteristics. Broad-band noise pulses that are outside the band of radiation-induced pulses are removed, thereby increasing the signal-to-noise ratio.

Signal processing is further enhanced by dynamically compressing the PMT signal where several orders of magnitude of linear response are compressed into a few orders of magnitude of output. Compression was accomplished by modifying the PMT divider chain.[4] The compressed range closely matches the input range of the pulse-shape discrimination circuits and allows processing of small-amplitude pulses. Small detector signals propagate through the PMT at a very high gain; larger signals are

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*As reported by Avenhaus, et. al[3]. Other values are from this study.

*Bonding available from Dow Corning Corporation, Midland, MI 48640 compressed, thereby preventing amplifier overload. Impedance matching in the detector signal path was also used to prevent spurious pulse reflections. Each detector terminates in the system impedance and then feeds into a simple resistive power divider designed to maintain the chosen impedance. The power dividers and integral detector units, including dynamic compression, are available from Bicron Corporation[6] as an ESC-2052 detector set.

Performance of the prototype monitor was measured in stages to demonstrate the effects of each design change. The addition of pulse-shape discrimination to the commercial unit gave the performance shown in Figure 2 with a 3g HEU test source.

In Unit B there are two large detectors mounted one to each sidewall. The Sandia prototype uses four of the new detectors, two in each side wall. The combined performance of pulse-shape discrimination and the new detectors is shown in Figure 2 with a 1-g HEU test source.

The addition of dynamic compression makes no significant difference in the 1-g test source response. For shielded material, however, the improved portal with dynamic compression will detect 75 g of ^{238}U shielded with 1.25 cm of lead at a probability of 0.9. Without dynamic compression, the probability of detection was 0.5. The unmodified commercial unit cannot detect the shielded test source.

ALARM LOGIC COMPONENT IMPROVEMENTS

The final step in any portal detection system is resolution of detector signal for possible alarm. In keeping with acceptable statistical practice, we devised a new alarm logic based on the modified F test. This logic not only ensures that the expected 0.1 percent FAR is achieved with a 3.1-sigma alarm threshold, it also provides a unique self-check of portal operation. Operational failure is indicated when the expected tolerance between the variance and mean is not observed. The alarm module is programmed to keep track of personnel passages and alarm history. A serial data output (RS232) of the passage and alarm history is provided on the rear panel. Two typical examples of output are shown in Figure 3.

Two alarm thresholds are used as indicated by the LIKELY and SEVERE alarm tabulations. The LIKELY threshold is 3.1 sigma, which gives FAR of 1 per 1000 passages. The SEVERE threshold is 4.0 sigma, giving FAR of 3.17 per 100,000 passages. Both alarms are provided so that either may be used independently of the other, or so that correlation between both alarms can be done. Simple tables are provided as data output, allowing the operator to quickly determine level of confidence on alarm information; that output gives the required number of alarms which must be observed in order to achieve the indicated levels of confidence. The alarm module is now available from TSA Systems[7] as a Model 420.

SUMMARY

Considerable improvement has been made to existing portal technology by increasing system sensitivity and stability. The improved portal monitors are easier to operate because of the automatic self-check alarm logic. The stability of the FAR gives the operator a greater sense of confidence in the assessment of an actual alarm. Perhaps most important, however, is that portal monitors incorporating the improved modifications can be more effective components of safeguards systems.

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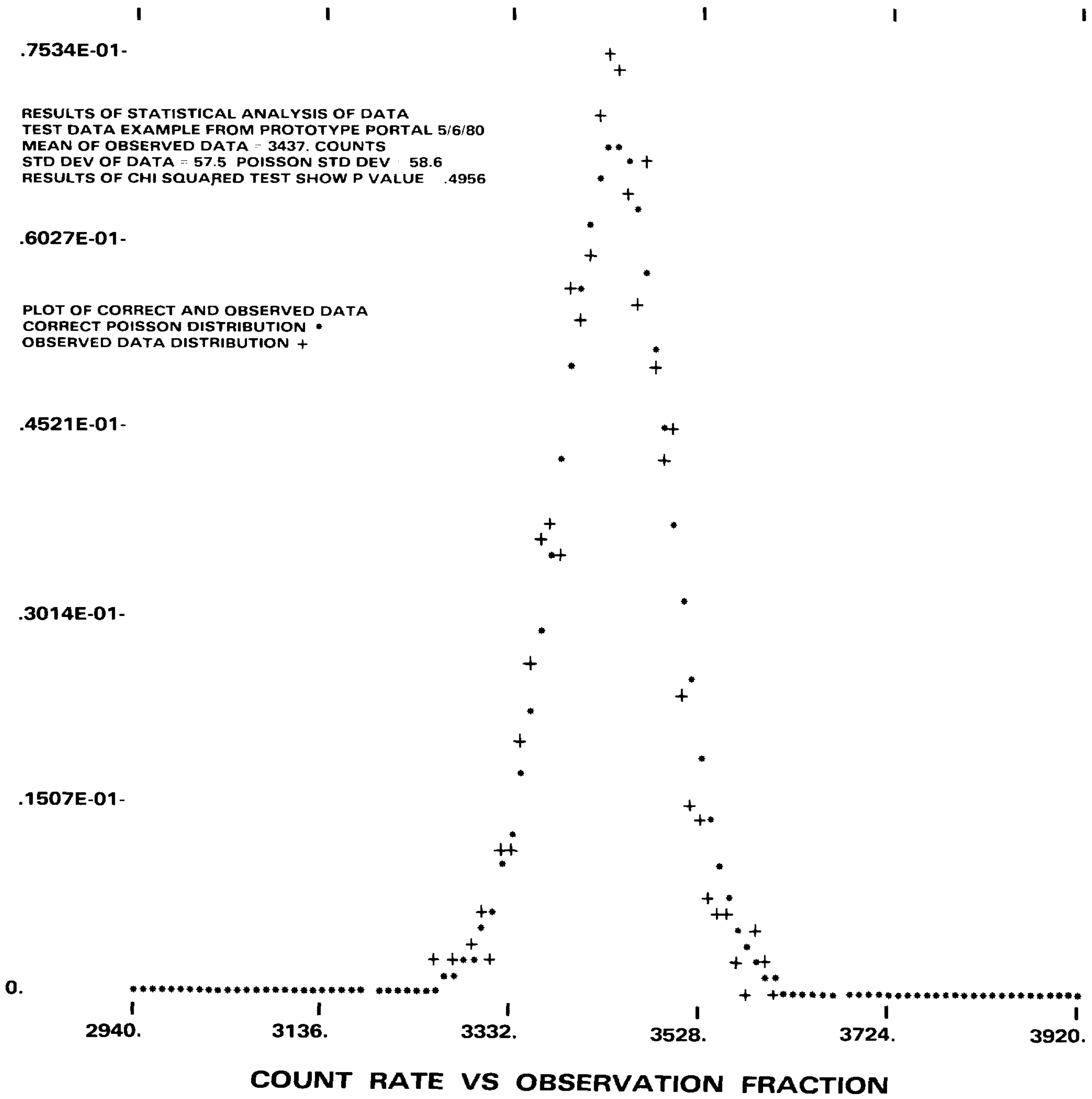
6. Available from: Bicron Corporation, 12345 Kinsman Road, Newbury, OH 44065

7. Available from: TSA Systems Incorporated, P. O. Box 1920, Boulder, CO 80306



```
RESULTS OF STATISTICAL ANALYSIS OF DATA
TEST DATA EXAMPLE FROM PROTOTYPE PORTAL 5/6/80
MEAN OF OBSERVED DATA = 3437. COUNTS
STD DEV OF DATA = 57.5  POISSON STD DEV   58.6
RESULTS OF CHI SQUARED TEST SHOW P VALUE   .4956

PLOT OF CORRECT AND OBSERVED DATA
CORRECT POISSON DISTRIBUTION *
OBSERVED DATA DISTRIBUTION +
```

Figure 1

EXPERIMENTAL RESULTS

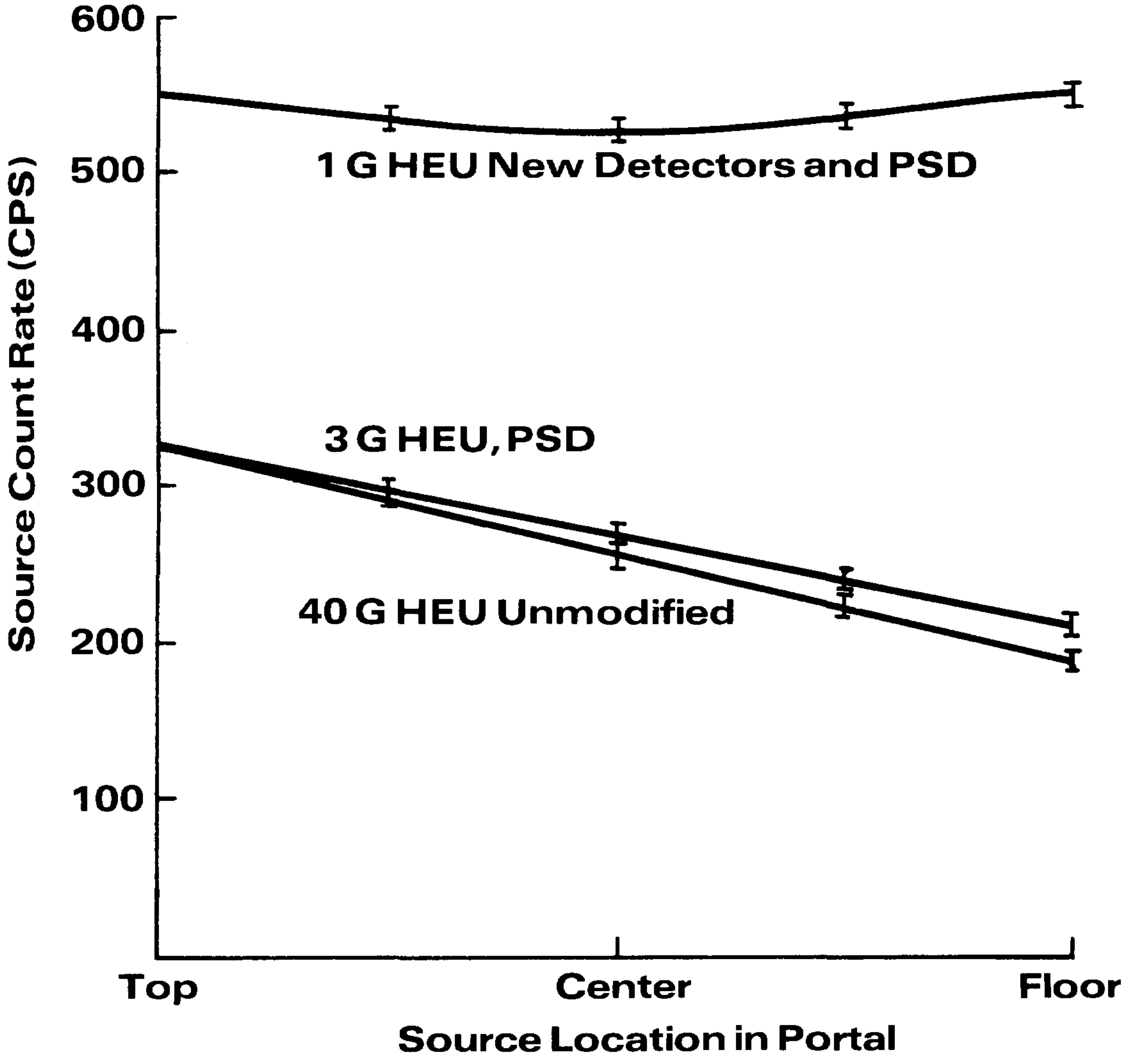


Figure 2

ALARM MODULE OUTPUT

```
NUMBER OF PASSAGES               2849

OBSERVED LIKELY ALARMS              2

REQUIRED ALARMS FOR:
  54%    4    68%    4
  78%    4    91%    6
  95%    6    99%    8

OBSERVED SEVERE ALARMS              0

REQUIRED ALARMS FOR:
  54%    0    68%    0
  78%    0    91%    0
  95%    0    99%    0

SNM/BACKGROUND ALARMS

HIGH BACKGROUND
  LIKELY ALARMS          0
  SEVERE ALARMS          0

LOW BACKGROUND
  LIKELY ALARMS          0
  SEVERE ALARMS          0

VARIANCE TEST            0

TERMINAL DUMP            3

BACKGROUND ANOMALIES                0
```

TYPICAL SCENARIO
2849 TOTAL PASSAGES

```
NUMBER OF PASSAGES                    23697

OBSERVED LIKELY ALARMS                   41

REQUIRED ALARMS FOR:
  54%    26    68%    27
  78%    28    91%    31
  95%    32    99%    37

OBSERVED SEVERE ALARMS                    2

REQUIRED ALARMS FOR:
  54%     1    68%     1
  78%     1    91%     2
  95%     2    99%     3

SNM/BACKGROUND ALARMS

HIGH BACKGROUND
  LIKELY ALARMS          0
  SEVERE ALARMS          0

LOW BACKGROUND
  LIKELY ALARMS          0
  SEVERE ALARMS          0

VARIANCE TEST            0

TERMINAL DUMP           28

BACKGROUND ANOMALIES                      0
```

18 SOURCE MOVEMENTS
2 OF WHICH WERE SEVERE
23697 TOTAL PASSAGES

Figure 3

A STATISTIC SENSITIVE TO DEVIATIONS FROM THE ZERO-LOSS CONDITION IN A SEQUENCE OF MATERIAL BALANCES

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Abstract

The CUMUFR (cumulative sum of standardized MUF-residuals) statistic is proposed to examine materials balance data for deviations from the zero-loss condition. The time series of MUF-residuals is shown to be a linear transformation of the MUF-time series. The MUF-residuals can directly be obtained by applying the transformation or they can be obtained, approximately, by the application of a Kalman filter to estimate the true state of MUF. A modified sequential test with power one is formulated for testing the CUMUFR statistic. The detection capability of the proposed examination procedure is demonstrated by an example, based on Monte Carlo simulations, where the materials balance of the chemical separation process in a reference reprocessing facility is considered. It is shown that abrupt as well as protracted loss patterns are detected with rather high probability when they occur after a zero-loss period.

1. Introduction

In near-real-time materials accountancy a time series of MUF-observations has to be examined for deviations from the zero-loss condition. On the analogy of adaptive Kalman filters, where the sequence of measurement residual realizations is monitored to indicate whether the mathematical model has to be adapted because it does no longer describe the real system satisfactorily, it is proposed that the examination for deviations from the zero-loss condition is based on the time series of MUF-residuals.

It is shown that the sequence of MUF-residuals can be obtained from the time series of MUF values by a linear transformation. An algorithm to determine the transformation matrix is given. It is also demonstrated that the MUF-residuals can be calculated approximately by the application of a Kalman filter to estimate the true state of MUF.

The safeguards problem is to test the hypothesis of no loss of material against the alternative hypothesis of material loss. This test problem which is commonly stated for the time series of MUF's is formulated for the time series of MUF-residuals and the CUMUFR statistic, respectively.

A sequential test with power one is proposed to test the CUMUFR statistic. The test with power one which has been developed by H. Robbins and D. Sigmund |1|, is modified to be satisfactorily applicable to the test problem in the case of the CUMUFR statistic.

The detection capability of the CUMUFR statistic tested by the modified sequential test with power one is demonstrated by Monte Carlo simulations for the materials balance of the chemical separation process in a reference reprocessing facility with a throughput of 1000 t heavy metal per year.

2. Formulation of the Safeguards Problem

Let I_i be the measured inventory at the beginning of the i-th balance period, T_i the measured net transfer (receipts minus shipments) in the same period, and I_{i+1} the measured inventory at the end of the i-th period. I_{i+1} is assumed to be also the beginning inventory of the i+1-st balance period. The "Material Unaccounted For" (MUF) is given by $MUF_i=I_i+T_i-I_{i+1}$ for i=1,...,n.

Let the measurement errors be independent, normally distributed random variables with zero mean and known variance and let them be denoted by

η_i : random error in measuring the inventory
ν_i : systematic error in measuring the inventory
ε_i : random error in measuring the net transfer
δ_i : systematic error in measuring the net transfer.

Then the true value of MUF_i is equal to the expected value of MUF_i which is denoted by $E(MUF_i)$. We have

$$MUF_i = E(MUF_i)+\eta_i+\nu_i+\varepsilon_i+\delta_i-\eta_{i+1}-\nu_{i+1}$$

for i=1,...,n.

Let the n-dimensional random vector

$$\underline{MUF}_n := \begin{pmatrix} MUF_1 \\ \cdot \\ \cdot \\ \cdot \\ MUF_n \end{pmatrix}$$

be distributed according to the multivariate normal distribution $N(\underline{\mu}^M, \underline{\underline{\Sigma}}^M)$, where $\underline{\mu}^M$ is the vector of the expected value and $\underline{\underline{\Sigma}}^M$ the covariance matrix, see e.g. |2|.
Given observations on the random variables $MUF_1,\dots,MUF_n$ (taken at consecutive time points) and $\underline{\underline{\Sigma}}^M$ known, then the safeguards problem is usually formulated as a test problem for MUF. In this case we have to test the simple hypothesis of no loss of material:

$$H_o : \mu_i^M = \dots = \mu_n^M = 0$$

against the composite alternative of material loss:

$$H_1 : \mu_1^M = L_1, \dots, \mu_n^M = L_n ; \quad \sum_{i=1}^{n} L_i > 0.$$

If we assume e.g. a constant loss situation, the alternative hypothesis may be written as

$$H_1 : \mu_1^M = \dots = \mu_{m-1}^M = 0$$

$$\mu_m^M = \dots = \mu_n^M = L, \quad 1 \leq m \leq n, \quad 0 < L < \infty.$$

Note that both the point of change, m, and the size of the change, L, are unknown in safeguards.

Now let the safeguards situation be considered as a stochastic process which is described by the time series of MUF-values. This process is called normal when no loss occurred in the balance periods considered. In safeguards we are interested to detect deviations from the normal situation whenever they occur.

Let the MUF-residuals be defined as

$$MUFR_i := MUF_i - E(MUF_i | MUF_1, \dots, MUF_{i-1})$$

for i=1,...,n. Explicitly the vector of MUF-residuals is given as

$$\underline{MUFR}_n := \begin{pmatrix} MUFR_1 \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ MUFR_n \end{pmatrix} = \begin{pmatrix} MUF_1 \\ MUF_2 - E(MUF_2 | MUF_1) \\ \cdot \\ \cdot \\ \cdot \\ MUF_n - E(MUF_n | MUF_1, \dots, MUF_{n-1}) \end{pmatrix}$$

The cumulative sum of observations is a common statistic in the inference about the point of change in mean in a sequence of random variables, see e.g. |3|. This is, as will be shown later, the appropriate statistic for a sequential test with power one which is proposed for the data evaluation.

Let us denote the variance of $MUFR_i$ by σ_i^2 for all i=1,...,n and let us consider the time series

$$\frac{MUFR_1}{\sigma_1}, \dots, \frac{MUFR_n}{\sigma_n}$$

as observations. The test statistic, we are interested in, is then given as

$$CUMUFR_j := \sum_{i=1}^{j} \frac{MUFR_i}{\sigma_i} \quad , \ j=1,\dots,n.$$

3. Exact Calculation of MUF-residuals

We want to obtain the distribution of MUF_i conditioned on $MUF_1,\dots,MUF_{i-1}$ for i=2,...,n.

Let the random vector $\underline{X}$ be distributed according to the multivariate normal distribution $N(\underline{\mu}, \underline{\underline{\Sigma}})$ where $\underline{\mu}$ is the vector of the expected value and $\underline{\underline{\Sigma}}$ the covariance matrix.

Further let us partition $\underline{X}$ into subvectors:

$$\underline{X} = \begin{pmatrix} \underline{X}_1 \\ \underline{X}_2 \\ \underline{X}_3 \end{pmatrix}$$

where $\underline{X}_i$ is of p_i components, i=1,2,3 and $p_1+p_2+p_3=n$.

The mean vector is partitioned into subvectors, that

$$\underline{\mu} = \begin{pmatrix} \underline{\mu}_1 \\ \underline{\mu}_2 \\ \underline{\mu}_3 \end{pmatrix}$$

where $\underline{\mu}_i := E(\underline{X}_i)$, i=1,2,3. And the covariance matrix is partitioned into submatrices, such that

$$\underline{\underline{\Sigma}} = \begin{pmatrix} \underline{\underline{\Sigma}}_{11} & \underline{\underline{\Sigma}}_{12} & \underline{\underline{\Sigma}}_{13} \\ \underline{\underline{\Sigma}}_{21} & \underline{\underline{\Sigma}}_{22} & \underline{\underline{\Sigma}}_{23} \\ \underline{\underline{\Sigma}}_{31} & \underline{\underline{\Sigma}}_{32} & \underline{\underline{\Sigma}}_{33} \end{pmatrix}$$

where $\underline{\underline{\Sigma}}_{ij} := E(\underline{X}_i . \underline{X}_j')$, i,j=1,2,3, and the transposed of $\underline{X}$. is denoted by $\underline{X}'$. Let $\underline{x}_i$ be the realization of $\underline{X}_i$, i=1,2,3. Then we know according to a theorem of Anderson |6| that the conditional distribution of $\begin{pmatrix}\underline{X}_2\\ \underline{X}_3\end{pmatrix}$ given $\underline{x}_1$ is normal with mean

$$\begin{pmatrix}\underline{\mu}_{2.1}\\ \underline{\mu}_{3.1}\end{pmatrix} := E\left\{\begin{pmatrix}\underline{X}_2\\ \underline{X}_3\end{pmatrix}\middle|\ \underline{x}_1\right\} = \begin{pmatrix}\underline{\mu}_2\\ \underline{\mu}_3\end{pmatrix} + \begin{pmatrix}\underline{\underline{\Sigma}}_{21}\cdot\underline{\underline{\Sigma}}_{11}^{-1}\\ \underline{\underline{\Sigma}}_{31}\cdot\underline{\underline{\Sigma}}_{11}^{-1}\end{pmatrix}\cdot(\underline{x}_1-\underline{\mu}_1) \qquad (1)$$

and covariance matrix

$$\begin{pmatrix}\underline{\underline{\Sigma}}_{22.1} & \underline{\underline{\Sigma}}_{23.1}\\ \underline{\underline{\Sigma}}_{32.1} & \underline{\underline{\Sigma}}_{33.1}\end{pmatrix} :=$$

$$= E\left\{\left[\begin{pmatrix}\underline{X}_2\\ \underline{X}_3\end{pmatrix} - \begin{pmatrix}\underline{\mu}_{2.1}\\ \underline{\mu}_{3.1}\end{pmatrix}\right]\cdot\left[\begin{pmatrix}\underline{X}_2\\ \underline{X}_3\end{pmatrix} - \begin{pmatrix}\underline{\mu}_{2.1}\\ \underline{\mu}_{3.1}\end{pmatrix}\right]'\ \middle|\ \underline{x}_1\right\}$$

$$= \begin{pmatrix}\underline{\underline{\Sigma}}_{22} & \underline{\underline{\Sigma}}_{23}\\ \underline{\underline{\Sigma}}_{32} & \underline{\underline{\Sigma}}_{33}\end{pmatrix} - \begin{pmatrix}\underline{\underline{\Sigma}}_{21}\\ \underline{\underline{\Sigma}}_{31}\end{pmatrix} \cdot \underline{\underline{\Sigma}}_{11}^{-1}\cdot(\underline{\underline{\Sigma}}_{12}\quad \underline{\underline{\Sigma}}_{13}) \qquad (2)$$

where $\underline{\underline{\Sigma}}_{ij}^{-1}$ is the inverse matrix of $\underline{\underline{\Sigma}}_{ij}$, i,j=1,2,3.

From (1) and the definition of the MUF-residuals follows that MUFR_i is a linear function of $\underline{\text{MUF}}_{i-1}$. In the case of the null hypothesis we can write

$$E(\text{MUF}_i|\text{MUF}_1,\dots,\text{MUF}_{i-1}) =$$

$$= \beta_{i1}.\text{MUF}_1+\dots+\beta_{i,i-1}.\text{MUF}_{i-1},\ i=2,\dots,n.$$

The coefficients β_{ij} are usually called "partial regression coefficients".
Then we have

$$\underline{\text{MUFR}}_n = \underline{\underline{B}}.\underline{\text{MUF}}_n$$

with

$$\underline{\underline{B}} = \begin{pmatrix} 1 & 0 & 0 & \cdots & 0\\ -\beta_{21} & 1 & 0 & \cdots & 0\\ \vdots & & \ddots & \ddots & \vdots\\ \vdots & & & \ddots & 0\\ -\beta_{n1} & \cdots & & -\beta_{n,n-1} & 1 \end{pmatrix}$$

From equation (2) we see that the conditional variance

$$\sigma^2_{ii.1,\dots,i-1} :=$$

$$E\{[\text{MUF}_i - E(\text{MUF}_i|\text{MUF}_1,\dots,\text{MUF}_{i-1})]^2|\text{MUF}_1,\dots,\text{MUF}_{i-1}\}$$

is independent of the observations. Thus, it is identical to the unconditioned variance of MUFR_i for i=2,...,n. According to a theorem of Feller |4| we know further that MUFR_i is independent of $(\text{MUF}_1,\dots,\text{MUF}_{i-1})$. When MUFR_i is independent of $\underline{\text{MUF}}_{i-1}$ then it is also independent of any linear combination of $\underline{\text{MUF}}_{i-1}$ for all i=2,...,n, see e.g. |2|.

Therefore, the MUFR_i, i=1,...,n, are mutually independent normally distributed random variables. Thus, the covariance matrix is diagonal and we can write

$$\underline{\underline{\Sigma}}^R := \underline{\underline{B}}.\underline{\underline{\Sigma}}^M.\underline{\underline{B}}' = \begin{pmatrix} \sigma^2_{11} & & & 0\\ & \sigma^2_{22.1} & & \\ & & \ddots & \\ 0 & & & \sigma^2_{nn.1,\dots,n-1} \end{pmatrix}$$

where σ^2_{ij} is the ij-th element of $\underline{\underline{\Sigma}}^M$.

The MUFR_i, i=1,...,n, have minimal variance, because we know according to a theorem of Anderson |2| that of all linear combinations $\underline{\alpha}'_{i-1}.\underline{\text{MUF}}_{i-1}$, the combination $\underline{\beta}'_{i-1}.\underline{\text{MUF}}_{i-1}$ minimizes the variance of $\text{MUF}_i-\underline{\alpha}'_{i-1}.\underline{\text{MUF}}_{i-1}$, where $\underline{\beta}'_{i-1} := (\beta_{i1},\dots,\beta_{i,i-1})$, i=2,...,n; see K.B. Stewart |11|.

Now we can determine the distribution of CUMUFR_n. We know that the n-dimensional random vector $\underline{\text{MUFR}}_n$ is distributed according to $N(\underline{\underline{B}}.\underline{\mu}^M,\ \underline{\underline{\Sigma}}^R)$. Let the mean vector $\underline{\underline{B}}.\underline{\mu}^M$ be denoted by $\underline{\mu}^R$ and let Θ_n be defined as $\Theta_n := \sum_{i=1}^{n} \frac{\mu_i^R}{\sigma_i}$, where the variance of MUFR_i is denoted by σ_i^2, i=1,...,n. Then CUMUFR_n is distributed according to $N(\Theta_n, n)$.

To calculate the MUF-residuals we want to obtain the partial regression coefficients β_{ij}. In order to do that let us treat the distribution of

$\begin{pmatrix}\underline{X}_2\\ \underline{X}_3\end{pmatrix}$ given $\underline{x}_1$ as a multivariate normal distribution. Then we find, according to equation (1) and (2) that the conditional distribution of $\underline{X}_3$ given $\underline{x}_1$ and $\underline{x}_2$ is normal with mean

$$\underline{\mu}_{3.1,2} := E(\underline{X}_3 | x_1, x_2) =$$

$$= \underline{\mu}_{3.1} + \underline{\underline{\Sigma}}_{32.1} \cdot \underline{\underline{\Sigma}}_{22.1}^{-1} \cdot (\underline{x}_2 - \underline{\mu}_{2.1}) \tag{3}$$

and covariance matrix

$$\underline{\underline{\Sigma}}_{33.1,2} := E\{(\underline{X}_3 - \underline{\mu}_{3.1,2}) \cdot (\underline{X}_3 - \underline{\mu}_{3.1,2})' | \underline{x}_1, \underline{x}_2\} =$$

$$= \underline{\underline{\Sigma}}_{33.1} - \underline{\underline{\Sigma}}_{32.1} \cdot \underline{\underline{\Sigma}}_{22.1}^{-1} \cdot \underline{\underline{\Sigma}}_{23.1} \; . \tag{4}$$

Using equation (1) and (3) a recursion formula can be developed:

$$\beta_{ij} =$$

$$\frac{\sigma^2_{ij.1,\ldots,j-1}}{\sigma^2_{jj.1,\ldots,j-1}} - \sum_{k=1}^{i-j-1} \frac{\sigma^2_{i,j+k.1,\ldots,j+k-1}}{\sigma^2_{j+k,j+k.1,\ldots,j+k-1}} \beta_{j+k,j};$$

$i=2,\ldots,n$, $j<i$

where $\sigma^2_{ij.1,\ldots,j-1}$ is the conditional covariance of (MUF_i, MUF_j) given the observation of $\underline{MUF}_{j-1}$ and $\sigma^2_{ij.0} := \sigma^2_{ij}$ the ij-th element of $\underline{\underline{\Sigma}}^M$.
Using equation (2) and (4) a recursion formula for the conditional covariances can be developed:

$$\sigma^2_{ij.1,\ldots,k} =$$

$$\sigma^2_{ij.1,\ldots,k-1} - \frac{\sigma^2_{ik.1,\ldots,k-1} \cdot \sigma^2_{jk.1,\ldots,k-1}}{\sigma^2_{kk.1,\ldots,k-1}} \text{ for}$$

$i,j = k+1,\ldots,n$; $j \leq i$; $k=1,\ldots,n-1$.

4. Approximate Calculation of MUF-Residuals

We want to obtain the MUF-residuals approximately by using a Kalman filter model for the time series of MUF's. Before we define a specific Kalman filter the general Kalman filter model is described briefly.

The standard discrete-time Kalman filter state and observation model can be written as |5|:

State: $\underline{X}_{i+1} = \underline{\underline{\Phi}}_{i+1,i} \cdot \underline{X}_i + \underline{\underline{G}}_{i+1,i} \cdot \underline{W}_i$

Observation: $\underline{Z}_{i+1} = \underline{\underline{H}}_{i+1} \cdot \underline{X}_{i+1} + \underline{V}_{i+1}$

where $i = 0,1,\ldots,$ is the discrete-time index.

$\underline{X}_.$: state process; random n-vector

$\underline{\underline{\Phi}}_{.,.}$: state transition matrix; nxn-matrix

$\underline{\underline{G}}_{.,.}$: disturbance transition matrix, nxp-matrix

$\underline{W}_.$: state disturbance; random p-vector

$\underline{Z}_.$: observation process; random m-vector

$\underline{\underline{H}}_.$: observation matrix, mxn-matrix

$\underline{V}_.$: observation error; random m-vector

The state disturbance $\underline{W}_i$ and the observation error $\underline{V}_i$ are assumed to be distributed according to $N(\underline{0}, \underline{\underline{\Sigma}}_i^W)$ and $N(\underline{0}, \underline{\underline{\Sigma}}_i^V)$, respectively, and $\underline{W}_.$ and $\underline{V}_.$ are both assumed to be uncorrelated in time:

$$E(\underline{W}_i \cdot \underline{W}_j') = \begin{cases} \underline{\underline{\Sigma}}_i^W & : i = j \\ 0 & : i \neq j \end{cases}$$

$$E(\underline{V}_{i+1} \cdot \underline{V}_{j+1}') = \begin{cases} \underline{\underline{\Sigma}}_{i+1}^V & : i = j \\ 0 & : i \neq j \end{cases}$$

for $i=0,1,\ldots$. The state vector $\underline{X}_o$ is assumed to be distributed according to $N(\underline{\mu}_o, \underline{\underline{\Sigma}}_o)$. It is further assumed that $\underline{X}_o$, $\underline{W}_.$ and $\underline{V}_.$ are independent of each other.

To specify the model we have to know the matrices $\underline{\underline{\Phi}}_{i+1,i}$, $\underline{\underline{G}}_{i+1,i}$, $\underline{\underline{H}}_{i+1}$ and also $\underline{\underline{\Sigma}}_i^W$, $\underline{\underline{\Sigma}}_{i+1}^V$ for all $i=0,1,\ldots$ and $\underline{\mu}_o$, $\underline{\underline{\Sigma}}_o$. The idea is that the state described by $\underline{X}_i$ at time i, is unknown and cannot directly be observed. Only $\underline{Z}_i$ can directly be determined by measurement. Let $\underline{X}_i$ be distributed according to $N(\underline{\mu}_i, \underline{\underline{\Sigma}}_i)$ for $i=1,2,\ldots$. Then we want to estimate $\underline{\mu}_i$, $\underline{\underline{\Sigma}}_i$ on the basis of the observed $\underline{Z}_i$. In Kalman filter theory these estimates are defined as:

$$\hat{\underline{\mu}}_i := E(\underline{X}_i | \underline{Z}_1, \ldots, \underline{Z}_i)$$

$$\hat{\underline{\underline{\Sigma}}}_i := E\{(\underline{X}_i - \hat{\underline{\mu}}_i) \cdot (\underline{X}_i - \hat{\underline{\mu}}_i)' | \underline{Z}_1, \ldots, \underline{Z}_i\}$$

for all $i=1,2,\ldots$. It can be shown that $\hat{\underline{\mu}}_i$ is a minimum variance unbiased linear estimate for $\underline{\mu}_i$.

The Kalman filter algorithm propagates $\hat{\underline{\mu}}_i$ and $\hat{\underline{\underline{\Sigma}}}_i$ from time i to time i+1 in a recursive way. But this algorithm needs to be started from a known condition ($\underline{\mu}_o$, $\underline{\underline{\Sigma}}_o$, $\underline{\underline{\Sigma}}_o^W$), in which the two matrices $\underline{\underline{\Sigma}}_o$, $\underline{\underline{\Sigma}}_o^W$ must be symmetric and positive semi definite. In Kalman filter theory it is assumed that the parameters $\underline{\mu}_o$ and $\underline{\underline{\Sigma}}_o$ are known a priori. The starting condition is then formulated as

$$\underline{\hat{\mu}}_o := \underline{\mu}_o$$

$$\underline{\underline{\hat{\Sigma}}}_o := \underline{\underline{\Sigma}}_o \ .$$

The parameters $\underline{\mu}_o$ and $\underline{\underline{\Sigma}}_o$ are not necessarily known a priori in reality. In this case an assumption has to be made for ($\underline{\mu}_o$, $\underline{\underline{\Sigma}}_o$) in which the ignorance is usually described by $\underline{\underline{\Sigma}}_o = \infty . \underline{\underline{I}}$, where $\underline{\underline{I}}$ is the identity matrix.

The observation residual (sometimes called the "innovation") is defined in Kalman filter theory as:

$$R_i := \underline{Z}_i - H_i . \underline{\hat{\mu}}_i^- \quad , \quad i=1,2,\ldots$$

where $\underline{\hat{\mu}}_i^- := E(\underline{X}_i | \underline{Z}_1, \ldots, \underline{Z}_{i-1})$. It can be shown that $\underline{X}_i$ and $\underline{V}_i$ conditioned on $\underline{Z}_1, \ldots, \underline{Z}_{i-1}$ are jointly normal and thus $\underline{Z}_i$ conditioned on $\underline{Z}_1, \ldots, \underline{Z}_{i-1}$ is normal with mean

$$E(\underline{Z}_i | \underline{Z}_1, \ldots, \underline{Z}_{i-1}) = E\{(\underline{\underline{H}}_i . \underline{X}_i + \underline{V}_i) | \underline{Z}_1, \ldots, \underline{Z}_{i-1}\} =$$

$$= \underline{\underline{H}}_i . \underline{\hat{\mu}}_i^-, \ i=1,2,\ldots$$

We see that the MUF-residuals are a special case of the general definition of the observation residual in Kalman filter theory . The conditional mean and the conditional covariance matrix, respectively, is given as:

$$E(\underline{R}_i | \underline{Z}_1, \ldots, \underline{Z}_{i-1}) := E\{(\underline{Z}_i - \underline{\underline{H}}_i . \underline{\hat{\mu}}_i^-) | \underline{Z}_1, \ldots, \underline{Z}_{i-1}\} = 0,$$

$$E(\underline{R}_i . \underline{R}_i' | \underline{Z}_1, \ldots, \underline{Z}_{i-1}) :=$$

$$= E\{(\underline{Z}_i - \underline{\underline{H}}_i . \underline{\hat{\mu}}_i^-) . (\underline{Z}_i - \underline{\underline{H}}_i . \underline{\hat{\mu}}_i^-)' | \underline{Z}_1, \ldots, \underline{Z}_{i-1}\} =$$

$$= E\{(\underline{\underline{H}}_i \underline{X}_i - \underline{\underline{H}}_i \underline{\hat{\mu}}_i^- + \underline{V}_i) . (\underline{\underline{H}}_i \underline{X}_i - \underline{\underline{H}}_i \underline{\hat{\mu}}_i^- + \underline{V}_i)' | \underline{Z}_1, \ldots, \underline{Z}_{i-1}\} =$$

$$= \underline{\underline{H}}_i . \underline{\underline{\Sigma}}_i^- . \underline{\underline{H}}_i' + \underline{\underline{\Sigma}}_i^V$$

for i=1,2,..., where

$\underline{\underline{\Sigma}}_i^- := E\{(\underline{X}_i - \underline{\hat{\mu}}_i^-) . (\underline{X}_i - \underline{\hat{\mu}}_i^-)' | \underline{Z}_1, \ldots, \underline{Z}_{i-1}\}$. The latter covariance matrix is computed in the Kalman filter algorithm. We know (see section 3) that the unconditioned covariance matrix of the residual is the same as the conditional covariance matrix. Thus, the realization of the residuals and the covariance matrix of the residuals can be obtained via the application of a Kalman filter.

Let us now define a Kalman filter model for the time series of MUF's in order to obtain the MUF-residuals. Let us assume the following model:

State:

$$\widetilde{MUF}_{i+1} = \widetilde{MUF}_i$$

Observation:

$$MUF_{i+1} = \widetilde{MUF}_{i+1} + \eta_{i+1} + \nu_{i+1} + \varepsilon_{i+1} + \delta_{i+1} - \eta_{i+2} - \nu_{i+2}$$

for i=0,1,...,n.

It should be noted that, in contrast to the direct determination of the residuals, the determination with the help of a Kalman filter model requires to introduce a state variable $\widetilde{MUF}_o$ which is distributed according to (μ_o^M, Σ_o^M) and μ_o^M, Σ_o^M is assumed to be known a priori. It can be shown, however, that the following filter model

state:

$$\underline{X}_{i+1} = \underline{\underline{I}} . \underline{X}_i$$

Observation:

$$\underline{Z}_{i+1} = \underline{\underline{I}} . \underline{X}_{i+1} + \underline{V}_{i+1} \ ,$$

with the starting condition ($\underline{\mu}_o^X$, $\underline{\underline{\Sigma}}_o^X$) set to $\underline{\mu}_o^X = \underline{0}$, $\underline{\underline{\Sigma}}_o^X = \infty . \underline{\underline{I}}$, leads to $\underline{\hat{\mu}}_1^X = \underline{Z}_1$ and $\underline{\underline{\hat{\Sigma}}}_1^X = \underline{\underline{\Sigma}}^V$.

I.e. under this assumption for the starting condition the Kalman filter algorithm produces exactly the same estimates (after one realization is available) as we would get in that case in which no a priori information is available and e.g. a maximum likelihood estimate is used. In the case of the MUF filter model the starting condition is assumed to be $\mu_o^M = 0$, $\Sigma_o^M = \infty$. It can be shown that in this case the MUF-residuals and the corresponding variances, computed via the application of the Kalman filter algorithm, converge asymptotically to the exact values which are determined by the linear transformation of the time-series of MUF's.

Let $\widetilde{MUF}_i$ be distributed according to $N(\mu_i^M, \Sigma_i^M)$, i=1,...,n. Then we are interested to obtain an estimate for the parameters (μ_i^M, Σ_i^M), which are denoted by $\hat{\mu}_i^M$ and $\hat{\Sigma}_i^M$, respectively, based on the observed values of $MUF_1, \ldots, MUF_i$.

Note that this filter model is not in standard form because the sequence of observation errors is correlated in time, which is caused by the systematic errors ν_i and δ_i which are correlated by definition, and the random error η_{i+2} which appears at time i+1 and at time i+2. In order to circumvent that problem the original state equation has to be augmented by the correlated observation errors which have to be written in the form of a state equation:

$$\eta_{i+1} = 0 \cdot \eta_i + 1.\eta_{i+1}$$

$$\nu_{i+1} = \Phi^I_{i+1,i} \cdot \nu_i + 1.W^I_i$$

$$\delta_{i+1} = \Phi^T_{i+1,i} \cdot \delta_i + 1.W^T_i$$

for i=0,1,2,... . The values for $\Phi^I_{i+1,i}$, $\Phi^T_{i+1,i}$, W^I_i and W^T_i have to be determined in a way that the specified properties of the systematic errors are still valid and at the same time the requirements for a state equation are satisfied.

The observation can then be written as:

$$MUF_{i+1} = \left[1.\widetilde{MUF}_{i+1} + 1.\eta_{i+1} + (1-\Phi^I_{i+1,i}).\nu_{i+1} + 1.\delta_{i+1}\right] + (\varepsilon_{i+1} - W^I_{i+1} + \eta_{i+2})$$

When we identify

$$\underline{X}_{i+1} := \begin{pmatrix} \widetilde{MUF}_{i+1} \\ \eta_{i+1} \\ \nu_{i+1} \\ \delta_{i+1} \end{pmatrix}$$

$$\underline{\underline{\Phi}}_{i+1,i} := \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & \Phi^I_{i+1,i} & 0 \\ 0 & 0 & 0 & \Phi^T_{i+1,i} \end{pmatrix}$$

$$\underline{\underline{G}}_{i+1,i} := \underline{\underline{I}},$$

$$\underline{W}_i := \begin{pmatrix} 0 \\ \eta_{i+1} \\ W^I_i \\ W^T_i \end{pmatrix}$$

$$\underline{Z}_{i+1} := MUF_{i+1},$$

$$\underline{\underline{H}}_{i+1} := (1 \quad 1 \quad \{1-\Phi^I_{i+2,i+1}\} \quad 1),$$

$$\underline{V}_{i+1} := \varepsilon_{i+1} - W^I_{i+1} - \eta_{i+2},$$

we have a filter model* in which the observation error $\underline{V}_i$ is uncorrelated in time.

Note that the state disturbance $\underline{W}_i$ and the observation error $\underline{V}_i$ are correlated now, which is described by the covariance matrix $\underline{\underline{\Sigma}}^{WV} := E(\underline{W}_i . \underline{V}_i')$ for i=1,...,n. This causes no problem because a generalized Kalman filter algorithm |6| can be used where $\underline{W}_.$ and $\underline{V}_.$ are assumed to be correlated.

Let us assume that $\widetilde{MUF}_.$ describes the true state of MUF. in a constant or zero-loss situation. Then the Kalman filter algorithm calculates a minimum variance unbiased linear estimate $\hat{\mu}^M_.$ for the mean of the true state and also $\hat{\Sigma}^M_.$, the error variance of that state. At the same time we obtain, approximately, the realization of the MUF-residuals and the variance of the residuals.

The residual can be interpreted as the algebraic difference between the actual observation value and the prediction of that value based on past observation data. This makes clear, intuitively, why the sequence of residual realizations is known |5,6| to be sensitive to changes in the real system which invalidate the mathematical model the filter is based on. This fact is used in adaptive Kalman filters, e.g. |5|. Because the examination of a sequence of material balance data for a deviation from the zero-loss condition is a similar problem, the time series of residuals was proposed here to be the basis of the evaluation |7|.

It should be noted that we arrived at the sequence of MUF-residuals as a possible statistic for the evaluation of the time series of MUF values on the analogy of adaptive Kalman filters, where during the operation of the filter the actual residual sequence realization is monitored to indicate situations where the mathematical model does no longer describe the real system satisfactorily and has, therefore, to be adapted. It is interesting to note that other authors came to the same statistic following different ways. The difference statistic D_n which has been proposed by J.L. Jaech |9| to reduce the influence of systematic errors as well as the ITMUF statistic which has been proposed by A.J. Woods et al |10| for the detection of a single large loss are identical to the MUFR statistic. Also the weighted average and the innovations sequence introduced by Stewart |11| and |12| considering only random errors is identical to the sequence of $MUFR_1$,... . The advantage here, however, is that the sequence of MUF-residuals and the corresponding variance can be calculated for a general covariance structure on the observed MUF's recursively or by using a Kalman filter to estimate the true state of MUF.

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*This Kalman filter has been developed by J.P. Shipley |8|.

When we use that filter model in order to obtain the MUF-residuals we get, as a by-product, also a minimum variance unbiased linear estimate for the mean of the true state of MUF. This can be assumed as a constant-loss estimator.

5. Sequential Test with Power One

In safeguards the time when loss occurs, the loss period and the loss-rate in that period are unknown. We want to detect a loss whenever it occurs as soon as possible with a high probability of detection and low false alarm probability. A test with these properties is of interest.

A Wald-type sequential test will, when no loss occurs, accept the hypothesis H_o after some time steps. But the loss detection must continue, so the test has to be restarted by eliminating all the previously acquired observations and resetting the thresholds to their value at the beginning of the test. Thereby we have the disadvantage that the overall false alarm probability is not controlled.

The so-called sequential test with power one, which has been developed by H. Robbins and D.Siegmund |1| does not have an acceptance region for H_o. Thus, the test needs not to be restarted when the hypothesis H_o holds. This test has been proposed for application in safeguards by J.P. Shipley |13| and D.D. Cobb |14|.

The sequential test with power one has been developed for independent observations which are distributed according to $N(\mu,1)$. The test statistic is the cumulative sum of observations. The tested hypotheses are, $H_o:\underline{\mu\leq 0}$ and $H_1:\underline{\mu>0}$. This test guarantees that $\beta = 0$ for $\underline{\mu>0}$ and α is bounded for $\underline{\mu\leq 0}$.

This sequential test applied to the time series of MUF's would satisfy the requirements for the safeguards problem. However, the strong correlation of succeeding MUF-values, even in the case of random errors only, invalidates the required independence of observations.

The standardized MUF-residuals, $\frac{\text{MUFR}_n}{\sigma_n}$, do have this required property.In order to decide whether this sequential test can be applied to the standardized MUF-residuals we have to transform the safeguards problem into a test problem for the MUF-residuals.

Let us consider an example to illustrate the properties of the alternative hypothesis. Let us assume: n=5 and

$$\underline{\underline{\Sigma}}^M = \begin{pmatrix} 1 & -0.3 & 0.1 & 0.1 & 0.1 \\ -0.3 & 1 & -0.3 & 0.1 & 0.1 \\ 0.1 & -0.3 & 1 & -0.3 & 0.1 \\ 0.1 & 0.1 & -0.3 & 1 & -0.3 \\ 0.1 & 0.1 & 0.1 & -0.3 & 1 \end{pmatrix}$$

We obtain

$$\underline{\underline{B}} = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 \\ 0.3 & 1 & 0 & 0 & 0 \\ -0.01 & 0.3 & 1 & 0 & 0 \\ -0.15 & -0.05 & 0.3 & 1 & 0 \\ -0.19 & -0.2 & -0.04 & 0.33 & 1 \end{pmatrix}$$

and $$\underline{\underline{\Sigma}}^R = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 0.91 & 0 & 0 & 0 \\ 0 & 0 & 0.91 & 0 & 0 \\ 0 & 0 & 0 & 0.89 & 0 \\ 0 & 0 & 0 & 0 & 0.86 \end{pmatrix}$$

Let the alternative hypothesis in the case of the MUF sequence be given by a loss vector $\underline{L}$:

$$\underline{\mu}^M = \underline{L} = \begin{pmatrix} 1 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix}$$

Then we get

$$\underline{\mu}^R = \underline{\underline{B}}.\underline{L} = \begin{pmatrix} 1 \\ 0.30 \\ -0.01 \\ -0.15 \\ -0.19 \end{pmatrix}$$

and the mean Θ_n of CUMUFR_n given in vector representation:

$$\underline{\Theta} = \begin{pmatrix} 1 \\ 1.31 \\ 1.30 \\ 1.15 \\ 0.94 \end{pmatrix}$$

Note:

(i) a loss (i.e. a positive shift in the mean value of MUF) is transformed into a shift of the mean of the MUF-residuals. Thus, the MUF-residuals are sensitive to a loss.

(ii) a single loss in period i causes not only a shift in the mean of MUFR_i but also in all the following MUF-residuals. So the shift in the mean of the cumulative sum is a function of i (i.e. CUMUFR_n is not an unbiased estimate for the amount of loss).

(iii) The shift in the mean of the MUF-residuals can change its sign. It can be shown that this is also true for the shift in the mean of CUMUFR. As a consequence it can not be decided whether a single observed shift is caused by a loss or gain of material. However, an analysis of the time series of observations will allow such a discrimination.

Let us for a moment consider the case where only random measurement errors are assumed in closing the materials balance and let all the measurement errors be independent. Let the correlation coefficients corresponding to the covariance matrix $\underline{\underline{\Sigma}}^M$ be denoted by ρ_{ij}. Then we can show that

$$\rho_{ij} = \begin{cases} 1 & : j=1 \\ 0 \div -0.5 & : j=i\pm 1 \\ 0 & : \text{otherwise} \end{cases} \qquad i,j=1,\ldots,n$$

Where $\rho_{ij}=0$, $j=i\pm1$ occurs in a strongly throughput dominated regime (i.e. the throughput measurement error is much larger than the inventory measurement error). And $\rho_{ij}=-0.5$, $j=i\pm1$ occurs in a strongly inventory dominated regime. Then the elements of the transformation matrix B can be shown to be all positive. Note that in this case, a single loss causes a monotonically increasing positive shift in the mean of CUMUFR.

In terms of the CUMUFR_n statistic the safeguards problem is to test the simple hypothesis:

$$H_o : \underline{\Theta} = \underline{0}$$

against the composite alternative:

$$H_1 : \underline{\Theta} \neq \underline{0} \; .$$

We know that the sequential test with power one, as introduced by H. Robbins and D. Siegmund, looks only for a positive shift in the mean. We have seen, however, that a loss causes solely a positive shift in the mean of the time series of CUMUFR's only in that case in which the systematic errors are neglected. In general, when also systematic errors have to be considered, a single loss causes a positive shift in the mean, which is increasing, only in the first few consecutive time steps after the loss occurred. Afterwards the shift is monotonically decreasing and becomes negative finally. The negative shift is then increasing with an asymptotical behaviour.

If we would apply a test which looks only for a positive shift in the mean of the time series of CUMUFR's to detect e.g. a loss, which occurs a rather long time after an undetected small loss, we would find that the detection capability is almost zero, because the undetected loss caused an increasing negative shift in the mean before the next loss occurred.

Besides the sequential test with power one H. Robbins and D. Siegmund |1| have developed a sequential test with uniformly small error probabilities for independent observations which are distributed according to $N(\mu,1)$ where μ is an unknown parameter, $-\infty<\mu<\infty$. The test statistic is the cumulative sum of observations denoted as S_n. The tested hypotheses are, $H^- : \underline{\mu} < \underline{0}$ versus $H^+ : \underline{\mu} > \underline{0}$, $\underline{\mu} = \underline{0}$ being excluded. The test procedure is

$$\begin{aligned} &\text{accept } H^- &&: S_n \leq -b_n \\ &\text{reject } H^- &&: S_n \geq b_n \\ &\text{no decision:} && -b_n < S_n < b_n \end{aligned}$$

where the threshold b_n is given as

$$b_n = \{(n+M)\left[A^2 + \ln(\tfrac{n}{M} + 1)\right]\}^{1/2} ; \; A^2 = -2 \ln \alpha, \; M>0.$$

Then we have according to H. Robbins et al |1|

$$P_{\underline{\mu}}\{\text{accept } H^-\} \leq \frac{\alpha}{2} \text{ for } \underline{\mu} > 0,$$

$$P_{\underline{\mu}}\{\text{accept } H^+\} < \frac{\alpha}{2} \text{ for } \underline{\mu} < 0,$$

$$P_{\underline{\mu}}\{|S_n| \geq b_n \text{ for some } n \geq 1\} \begin{cases} < \alpha & : \underline{\mu} = \underline{0} \\ = 1 & : \underline{\mu} \neq \underline{0}. \end{cases} \tag{5}$$

In our case we have a modified test problem:

$$H_o : \underline{\mu} = \underline{0}$$

$$H_1 : \underline{\mu} \neq \underline{0}.$$

By the modification of the test procedure to

$$\begin{aligned} &\text{reject } H_o &&: |S_n| \geq b_n \\ &\text{no decision} &&: |S_n| < b_n \end{aligned}$$

we get a sequential test which looks for positive and negative shifts in the mean and can be used to test the CUMUFR_n statistic. This test is a sequential test with power one as can be seen from (5).

It should be noted that the CUMUFR_n statistic is similar to the $\mathrm{CUMUF}_n := \sum_{i=1}^{n} \mathrm{MUF}_i$ statistic which, for a given reference time and a fixed false alarm probability, leads to the maximum detection probability for the most pessimistic loss pattern at the end of that reference time as has been shown by R. Avenhaus and J.L. Jaech |15|. Thus, of all loss patterns within the fixed reference time that, which can be detected with the lowest probability, will best be detected when CUMUF, taken at the end of that reference period, is tested. But it should be kept in mind that this approach does maximize the detection probability at the end of a given reference time without taking into account the timeliness aspect which is of most concern here.

6. Example

Let us consider the chemical separation process for plutonium of a reference reprocessing facility design with a throughput of 1000 tons heavy metal per year described in |16|. The reference facility is designed to operate 200 days per year. For simplification the chemical separation process is divided into five process areas: head-end, 1st plutonium cycle, 2nd plutonium cycle, 3rd plutonium cycle and plutonium concentration. The materials balance is closed in a one day time interval.

The analysis relies on a rather simple plant operation and measurement simulation model. That is, the in-process inventory is summarized in five inventory batches which correspond to the above mentioned five process areas. Transfers occur batchwise, where 3 input batches of high active feed, 2 output batches of plutonium product and 1 waste batch are operated per day in steady state. The facility is operated strictly stationary, i.e. the inventory of the five areas is constant and the unmeasured inventory (inventory of process equipments, pipes etc.) does not contribute to MUF. The measurements are simulated batchwise, where a multiplicative measurement error model is used. Random - η, ε - as well as systematic measurement errors - δ - are considered. No recalibration of measurement instruments is foreseen; thus, the systematic errors in measuring the inventory cancel in the materials balance. The measurement errors are assumed to be independent of each other and normally distributed with zero means and known variances σ_η^2, σ_ε^2 and σ_δ^2.

	plutonium inventory (kg)	σ_η (relative)
head-end	196.5	.01
1. Pu-cycle	7.6	.01
2. Pu-cycle	50.	.005
3. Pu-cycle	134.	.005
Pu-concentration	62.5	.005

Table 1: Plutonium inventory and the corresponding in-process measurement errors

	plutonium/batch (kg)	σ_ε (relative)	σ_δ (relative)
input	16.73	.01	.01
output	25.	.002	.002
waste	.2	.25	.25

Table 2: Input and output batch data and the corresponding measurement errors

In Table 1 and Table 2 the data for the measured plutonium inventories and transfers and the corresponding measurement errors are given.

Different loss patterns are considered, given in Table 3, to demonstrate the detection capability of the proposed evaluation procedure. It is assumed that the first loss occurs in the 31st balance and that the accumulated loss is ≈ 20 kg's in all loss patterns.

Case	Loss Pattern
A	block loss (total loss in one period)
B	step loss; loss rate increases by 0.55 kg/balance
C	uniform loss; loss rate ≈ 2 kg/balance
D	uniform loss; loss rate ≈ 1 kg/balance
E	uniform loss; loss rate ≈ 0.7 kg/balance
F	uniform loss; loss rate ≈ 0.5 kg/balance
G	uniform loss; loss rate ≈ 0.3 kg/balance
H	uniform loss; loss rate ≈ 0.2 kg/balance

Table 3: Loss Patterns

The equation for the threshold of the power one test contains two parameters "M" and "A" to adjust for detection sensitivity and false alarm probability, respectively. In this evaluation the value M = 50 was used and the parameter "A" was fixed by the false alarm probability α which was chosen to be <0.05.

Results

A Monte Carlo simulation was used to investigate the detection sensitivity of the proposed evaluation procedure. In each run 200 materials balances were calculated, and 10,000 runs were made for each Monte Carlo simulation.

At first the actual false alarm probability (α_{200}) was established from 10,000 zero-loss runs, yielding $\alpha_{200} \sim 0.01$. The reason for the improvement is that the theoretical false alarm probability is valid for an infinite large number of balances whereas here only 200 balances are considered.

The results concerning the detection probability for different loss patterns are given in Fig. 1. They show that the detection probability for the same amount of loss is strongly dependent on the loss pattern. The detection probability increases for an increasing loss rate. This was to be expected because the MUF-residuals should be sensitive to the degree of the deviation from the zero-loss condition. For loss patterns with rather small loss rates the detection probability would be increased when the test would run for more than 200 balances. In Fig. 2 $E(CUMUFR_j)$

is plotted for the hypothesis H_1 taking the loss pattern of case G as an example. We see that the negative shift of the mean becomes significant in later periods which would contribute to detection probability.

For comparison the detection probability of a fixed-length test which covers 200 balances is also given in Fig. 1. In this case $CUMUF_{200}$ is tested with an assumed false alarm probability $\alpha = 0.05$. The standard deviation of $CUMUF_{200}$ is determined to be $\sigma_{200} \approx 100$ kg. The detection probability yields ≈0.08 for all loss patterns. The independence from the loss pattern is obvious, because in the case of a fixed-length test the detection probability is only dependent on the amount of loss.

The MUF-residuals are defined as the difference between the actual measured MUF and the prediction of that value based on previous MUF-observations. Thus, the variance of the MUF-residuals should decrease with an increasing number of materials balances. For the example considered, the standard deviation of the MUF-residuals is plotted in Fig. 3. We find that the standard deviation is decreasing rather rapidly in the first periods and is decreasing afterwards with an asymtotical behaviour. The decreasing standard deviation of the MUF-residuals should influence the detection probability of losses which occur in the very first balances. This influence was investigated by assuming a block loss of 15 kg's which occurs in different balances. The result of the Monte Carlo simulations is presented in Fig. 4. As expected, the detection probability is significantly improved when the loss occurs in later material balances. Therefore, the evaluation procedure which is based on the time series of MUF-residuals is most effective for loss patterns which occur after about 10 to 20 clean (zero-loss) material balances.

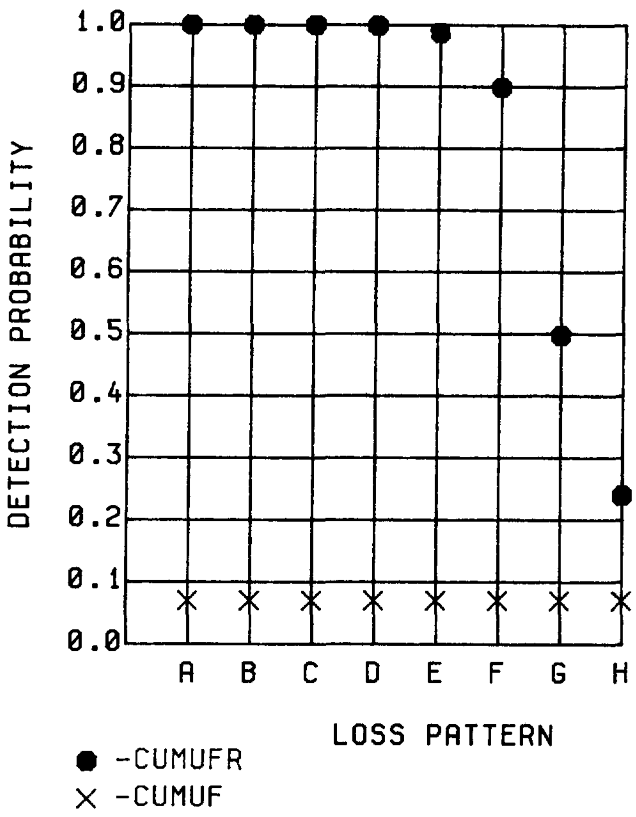

Fig. 1: Detection probability for different loss patterns with a constant accumulated loss of ≈ 20 kg's plutonium

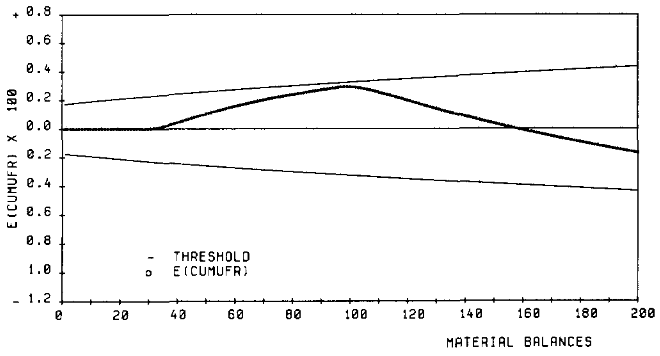

Fig. 2: The mean value of $CUMUFR_j$ in the case of loss pattern case G as hypothesis H_1

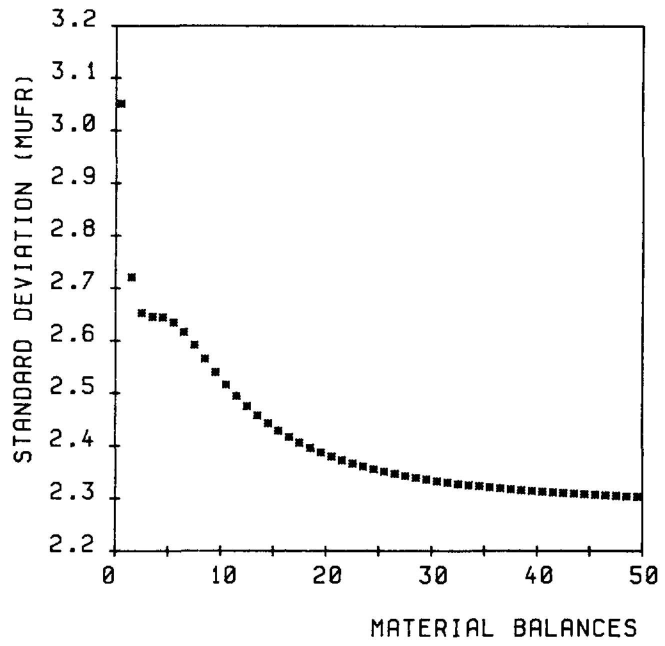

Fig. 3: Standard deviation of the MUF-residuals

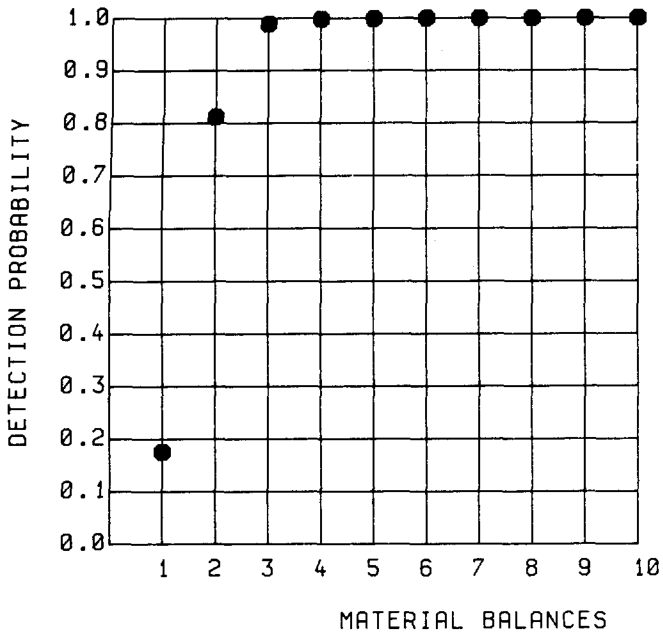

Fig. 4: Detection probability for a block loss of 15 kg plutonium versus the number of the balance in which the loss occured.

7. Conclusions

It is assumed that in safeguards a significant deviation from the zero-loss condition, whenever it occurs, has to be detected with high probability as soon as possible. Testing the CUMUFR statistic by a modified sequential test with power one is the proposed evaluation procedure. The basic MUF-residuals (MUFR) time series can be obtained from the time series of MUF observations by a linear transformation or, approximately, by the application of a Kalman filter to estimate the true state of MUF.

For the loss patterns considered the proposed evaluation procedure is shown to be by far superior to a test of the CUMUF$_{200}$ statistic in regard to the timeliness aspect and also the detection probability. The latter would lead to the maximum detection probability in that case, see |15|, in which the 200 balance periods are considered as a reference time and the optimum loss pattern for a potential diverter within that reference period is used. Note that this is the optimum evaluation procedure for a different safeguards problem in which a reference time is given and the probability to detect a loss within that period at the end of the reference time is to be maximized.

It is further shown that the detection probability is, for the same amount of loss, strongly dependent on the loss pattern. Low loss rates, even if they remain constant for a long time, yield a lower detection probability than a higher loss rate which holds only for a short period.

This evaluation procedure is most sensitive to loss patterns which occur after about 10 to 20 clean material balances. This is a drawback of using the MUF-residuals. Because they are defined as the difference between the actual MUF-value and the prediction of that value based on previous MUF observations, a certain amount of historical information is necessary to obtain a residual with a reasonable small variance.

It should be noted that in practical application for safeguards, follow-up actions have to be initiated when the null hypothesis is rejected to investigate what caused the rejection.

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