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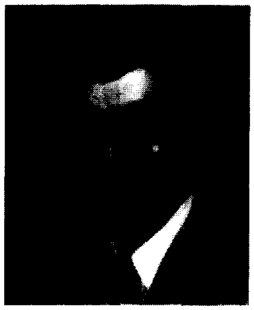
A Challenge for Our Members



I trust you will agree with me that our professional society has a tremendous growth potential in today's environment. As the premier international organization involved in the management of nuclear materials, we should aggressively pursue growing issues such as waste management, environmental restoration, weapons dismantlement, non-proliferation of weapons of mass destruction, and the attendant transportation needs. Sure, we have been active in these topics, but I suggest we could be more proactive.

Each of the above has an upward vector for concern. As an example, not very many years ago, the concerns for non-proliferation were resting in a few select governmental organizations. Today there is a proliferation of organizations involved in non-proliferation. Almost every government organization that exists now has a group dedicated to non-proliferation. I do not imply in any way that this is bad. I only use this as an example of the upward vector on this topic. Consider environmental restoration, which, until recently received little attention and was underfunded, is today being aggressively pursued.

We are a professional society with excellent credentials in core competencies that naturally allow us to provide an international service for these growing issues. And these issues will be around for a long time. Will we be able to maintain our premier posture to serve these communities? I certainly hope so. However, there are some indicators that we may want to think about. Have you considered, for example, the "professional age" of our membership? A recent survey of our members, conducted by Bruce Moran of our membership committee, revealed some interesting facts. Bruce labels the results as preliminary since only one-third of our membership had responded at the time of this report, yet 75 percent of the membership that responded have more than 10 years experience in the nuclear materials management field, with 36 percent having more than 20 years experience. Also, 50 percent of the respondents have been INMM members for more than 10 years. Do these numbers tell a story? I believe they do.

Thus, I would like to offer a challenge to our membership. This challenge is to: (a) sign up to support actively one of our technical divisions, and (b) recruit a new member. The strength of the Institute will depend entirely on the strength of our technical divisions. New blood in these divisions fosters new insights, new directions and expanding expertise. New members in the Institute are an absolute must. Consider the company or institution where you work. No doubt the management philosophy asserts that continued enhancement in strength and capabilities requires the addition of new, competent staff. Our Institute is no different. I hope that you accept the challenge.

It is with sadness that the INMM has learned of the sudden death this fall of Russian Ambassador Igor Palenykh, who along with Gen. William Burns, was our plenary speaker at our last annual meeting.

Also, Tom Shea of the International Atomic Energy Agency, and past chair of the Vienna Chapter, suffered a mild heart attack. Tom is back at work and appears to be on the road to recovery.

As always, your comments or questions are welcome. As you read this *Journal*, our Technical Program Committee will be actively putting together the program for our next annual meeting in Scottsdale, Ariz. There is an air of excitement for some of us since this is the first year of the Institute's new structure, under which all of the technical divisions will be the formal focal points of our sessions. We anticipate this will improve the way we do business.

Also, in the near future, each member will be asked to fill out a questionnaire on the role the Institute should play in education and training. Please take the time to share your thoughts with us.

Dennis Mangan, Chair
Institute of Nuclear Materials Management
Sandia National Laboratories
Albuquerque, New Mexico, U.S.A.

New Approaches to Safeguarding

As usual, this issue contains several technical papers on different subjects. Manfred Zendel describes the approach the IAEA has developed for verifying the materials at facilities that fabricate mixed uranium/plutonium fuels, using traditional methods and more advanced and automated equipment. These facilities are among those which process safeguards-sensitive materials and require considerable effort on the part of the agency and the facility operators. This is one of several papers which are to be published in the *Journal* describing the Agency's approaches to safeguarding different classes of nuclear facilities.

The paper by Leslie Fishbone and Theodor Teichmann describes how the IAEA or others might compare the zone approach for the back end of the fuel cycle to the present facility-oriented approach, as it regards the safeguards effort involved and the effectiveness achieved. While the zone approach has proven to be cost-effective for the Canadian natural uranium fuel zone from conversion and fabrication up to the insertion in a reactor, the potential advantages for spent fuel and plutonium fuel zones are less obvious. Nevertheless, they merit consideration.

We ran short on technical papers this time, in spite of my frequent appeals in this column. An officer of the Institute came to the rescue and obtained the papers by Margaret Barham and Brian Lanning, which had been presented recently at a meeting of our Central Chapter. Barham's paper describes the approach taken in developing a training course for the auditors who are to perform the evaluations of the material control and accounting procedures (MC&A) at the Department of Energy's (DOE) nuclear facilities. The DOE publishes its MC&A and physical protection requirements in the "DOE Orders," referenced in the paper. For those who may not be familiar with the DOE safeguards system, "physical protection" refers to the procedures designed to admit authorized individuals to the facility and to prevent access through force or deceit. "Material accounting" has its traditional meaning. "Material control" refers to those measures such as containment and surveillance, which are designed to deter or to promptly detect unauthorized activities by those who have access to the sensitive materials. Lanning's article clearly explains how to determine the error components from "paired measurements" — an old subject in a new light.

As Lawrence Bruckner explains, we published the unedited version of his paper in the last issue. I am most grateful to him for submitting this correction. 1993 promises to be an exciting year for arms reduction and for safeguards subjects in general. Please keep us informed, and have a good year.

William A. Higinbotham
Brookhaven National Laboratory
Upton, New York, U.S.A.

The International Workshop on Calorimetry

International Workshop on Calorimetry participants: (seated, from left) Teresa L. Creamers, LANL, USA; Walter Strohm, EE&G Mound, USA; Sergio Guardini, CEC-JRC, Italy; H. Kapulla, KFK, Germany. (Middle row, from left) Jerry Wetzel, EG&G Mound, USA; Lee A. Refalo, SRS, USA; Raymond Gunnick, LLNL, USA; Gerry P.D. Verracchia, EURATOM, Luxembourg; John A. Mason, ANTECH, UK; Paul Barberl, CEA SACLAY, France; Michael C. Axelrod, LLNL, USA; Tran Mahn Tuan, CEA SACLAY, France; Thomas E. Sampson, LANL, USA; Gilbert Bortels, CEC-JRC, Italy; John Lightfoot, BNFL, UK; Guiseppe Grassi, CEC-JRC, Italy. (Back row, from left) V.A. Wichers, ECN, Netherlands; Brian Metcalfe, ANMCO Harwell, UK; Gary Vassallo, CEC-JRC, Italy. Not pictured: Vincenzo Vocino, Donato D'Adamo and Bruno Remorini, each of the CEC-JRC, Italy.

An international workshop on calorimetry was conducted at the Pre-PERLA Laboratory of the Commission of European Communities' (CEC) Joint Research Centre (JRC), March 23-27, 1992, in Ispra, Italy.

This workshop was sponsored by the JRC and the U.S. Department of Energy, Office of Safeguards and Security (DOE/OSS)[1] as a continuation of the EURATOM/DOE "Agreement for Cooperation in Safeguards Research and Development." The workshop was organized by the JRC; the Institute for Safety Technology, Ispra, Italy; and by EG&G Mound Applied Technologies, USA.

The workshop was convened to evaluate the current status of the calorimetric assay of plutonium and tritium and to make recommendations for further development and implementation. The calorimetric assay of plutonium and tritium is used for accountability measurements by every DOE facility having significant amounts of these materials. Calorimetric assay also is used for safeguards verification measurements during inspections by DOE field offices. The experience is significantly different in Europe and with the International Atomic Energy Agency (IAEA). Calorimetric assay has had only limited use for the measurement of plutonium-contaminated waste in France and for safeguards plutonium verification measurements by inspectors in the United Kingdom. EURATOM and IAEA do not currently use calorimetric assay in inspections.

There are efforts under way, however, to use calorimetric assay routinely for plutonium accountability measurements in the United Kingdom and for tritium accountability measurements at the JRC. This workshop was especially timely as it provided recommendations to nuclear materials control and safeguard authorities and to instrument developers for the effective implementation of this technology now emerging in Europe. It is hoped that the results of this workshop will also be useful to the IAEA and EURATOM.

The workshop was structured to provide papers concerning all aspects of the calorimetric assay of plutonium and tritium and laboratory demonstrations of a variety of calorimeters as well as demonstrations of gamma-ray plutonium isotopic measurement systems. Twenty-two people from eight different countries attended the workshop, including seven people from four DOE laboratories.

The atmosphere was informal, and discussions occurred freely during all parts of the workshop. Papers were presented by users of calorimetric assay from Europe and especially from the United States, by potential users from Europe, and by both European and U.S. developers. The papers provided a broad spectrum of viewpoints incorporated into the workshop evaluations and recommendations.

Five calorimeter systems from Europe and the United States were

included in the laboratory demonstrations as well as three gamma-ray plutonium isotopic systems using the MGA plutonium isotopic analysis code developed in the United States and tested at the JRC. Plutonium-238 heat standards certified by EG&G Mound Applied Technologies were available, as well as the PERLA PuO_2 standards.

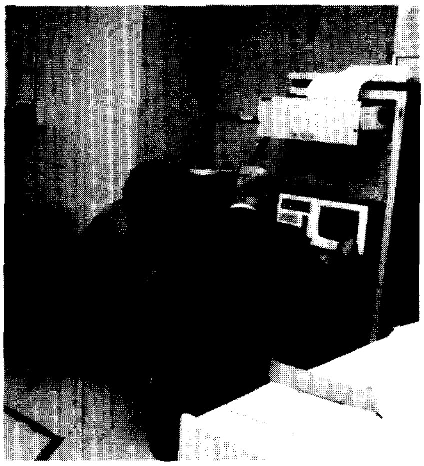
From the papers, the laboratory demonstrations and from the continuing discussions, the workshop developed an evaluation of the current status of calorimetric assay as well as recommendations for further development and for effective implementation. Briefly, the evaluations and recommendations were:

- Calorimetric assay of plutonium is more accurate and precise than neutron correlation methods but has a longer measurement time.
- Calorimetric assay of plutonium and tritium should be used by plant operators for accountability measurements.
- The calorimetry, passive neutron correlation counting (PNCC) and gamma-ray plutonium isotopic measurements should be used as a safeguards verification measurement system.

[1]The International Safeguards Branch of DOE/OSS is now in the International Safeguards Division of the DOE Office of Arms Control and Nonproliferation.

[2]Now with Wackenhut, Central Training Academy, Albuquerque, New Mexico, U.S.A.

[3]Mound is operated by EG&G Mound Applied Technologies for the United States Department of Energy under Contract No. DE-AC04-88DP43495.



Participants observe some of the five calorimetric systems demonstrated at the recent calorimeter workshop.

- An international measurement infrastructure including training of plant operators and inspectors in NDA technology, certified standards and exchange programs should be developed.

The workshop participants further recommended that another workshop be convened at a later date — and perhaps annually — to follow up on the implementation of calorimetric assay throughout the international nuclear community.

A report on the workshop is being prepared. The report will contain detailed evaluations and recommendations and will be distributed in Europe and in the United States.

Walter W. Strohm[2]
EG&G Mound Applied Technologies[3]
Sergio Guardini
CEC/JR

Chapters: Central Region

The Central Region Chapter of the Institute of Nuclear Materials Management held its annual meeting on Oct. 29 - 30, 1992. Thirty-one persons representing 14 sites or organizations attended the meeting, held at the Hurstbourne Hotel and Conference Center, Louisville, Ky.

The purpose of the chapter's annual meeting is to provide a forum for nuclear materials management and safeguards professionals to discuss nuclear materials management and safeguards approaches and equipment being implemented by their organizations as well as to discuss regional concerns.

The goal of the meeting is to give staff persons who do not have the opportunity to be involved in other INMM activities a chance to become involved in the exchange of nuclear materials management and safeguards information. Only three of the meeting's 13 technical paper presenters held management positions.

The annual meeting began with technical presentations and ended with the business meeting. Major items of business were the annual report of the treasurer and the installation of new members to the executive committee. Those completing terms on the executive committee were: Walter W. Strohm, chair; Donald R. Fidler, secretary; and Jill N. Cooley and Colleen C. Gradle, members-at-large. It was noted that John Lemming retains the post of past-chairman because the five chairs who followed Lemming left the Central Region before completing their terms.

Awards of appreciation were presented to Strohm and Fidler for their years of service to the chapter. The following new executive committee members began or continued their terms of office at the annual meeting:

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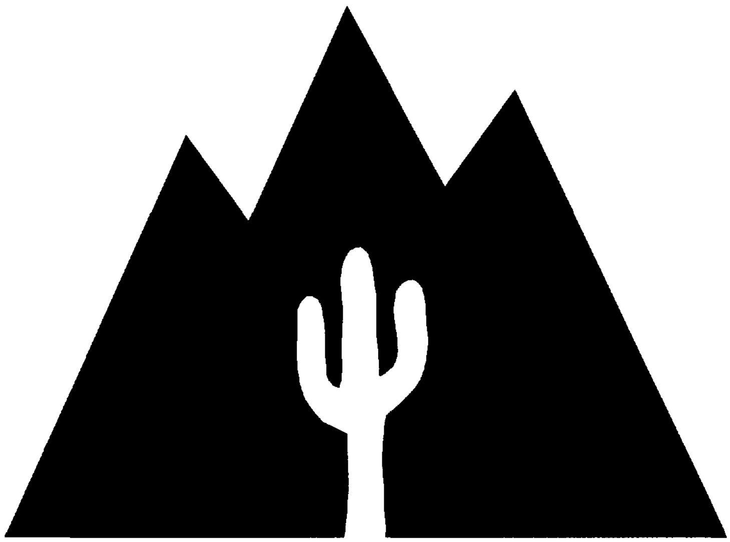


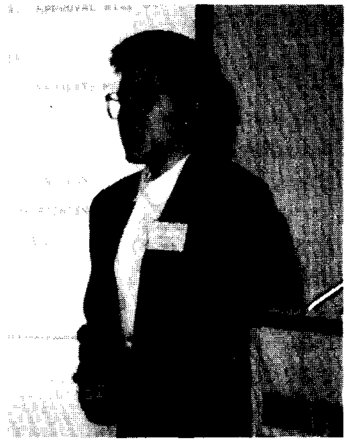
The INMM 34th Annual Meeting

July 18-21, 1993

The Scottsdale Princess Hotel

Scottsdale, Arizona

INMM
SAFEGUARDS
TRANSPORTATION
WASTE MANAGEMENT
INSTITUTE OF NUCLEAR MATERIALS MANAGEMENT



Above left: John L. Hehmeyer, EG&G Mound Applied Technologies, makes a presentation. Above: Michele R. Smith, U.S. Department of Energy, addresses the Central Region gathering. Left: Walter W. Strohm receives an award of appreciation from Central Region Chapter Chair Connie P. Hall.

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Connie P. Hall, chair; David S. Shisler, vice chair; Bruce W. Moran, secretary; John W. Wachter, treasurer; and Jere Bracey. Russ Johns, Wanda Mitchell and Ray Seiler, members-at large.

The annual meeting committee was composed of John Wachter, arrangements, and Bruce Moran, technical program. Session chairs were Theodore S. Sherr, U.S. Nuclear Regulatory Commission (NRC), and Garland R. Proco, U.S. Department of Energy (DOE), Field Office-Oak Ridge. The meeting program was as follows:

• Opening remarks, Connie P. Hall, chapter chair, and Bruce W. Moran, program chair.

• "United States Support to the Commonwealth of Independent States," Theodore S. Sherr, U.S. Nuclear Regulatory Commission, Rockville, Md.

• "The DOE and NRC Nuclear Materials Management and Safeguards System (NMMSS) — What It Is and What It Isn't," Evelyn McKamey, Martin Marietta Energy Systems, Oak Ridge, Tenn.

• "User Friendly Computer Applications — Is There Such a Thing?" Jeffrey P. Crabb, Martin Marietta Energy Systems, Paducah, Ky.

• "Computerized PICAS Ledger Program," Carol A. Ewing and Barry L. Adair, Martin Marietta Energy Systems, Paducah, Ky.

• "Monitoring Human Error with Control Charts by Exploiting Existing Data Collection Systems," Mary Ann French and Dewey L. Whaley, Nuclear Fuels Services, Erwin, Tenn.

• "The Role of the CTA in MC&A Training," Walter W. Strohm, Wackenhut Services Inc., Albuquerque, N.M.

• "NMC&A Auditor Training," Margaret A. Barham, Martin Marietta Energy Systems, K-25 Site, Oak Ridge, Tenn.

• "Training Program for MC&A," John L. Hehmeyer, EG&G Mound Applied Technologies, Miamisburg, Ohio.

• "DOE Measurement Control Policy Initiatives," Michele R. Smith, U.S. Department of Energy, Germantown, Md.

• "Estimate of Shipper/Receiver Measurement Variances Using Analysis of Variance," Brian M. Lanning, Martin Marietta Energy Systems, Portsmouth, Ohio.

• "The Safeguards Measurement Evaluation Program — A Sample Exchange Program," M. Irene Spaletto, U.S. Department of Energy, New Brunswick Laboratory, Argonne, Ill.

• "Nondestructive Assay Measurements in Support of Portsmouth Gaseous Diffusion Plant's HEU Suspension Project," Richard L. Mayer, Martin Marietta Energy Systems, K-25 Site, Oak Ridge, Tenn.

• "Field Measurements to Support IAEA Procedures Development for Fuel Assembly and Fuel Rod Active Length Verification," Wendell L. Belew, Martin Marietta Energy Systems, K-25 Site, Oak Ridge, Tenn.

On Feb. 17, the Central Region Chapter will sponsor a technical session on waste management and transportation at the WATTec Conference held annually in Knoxville, Tenn. WATTec is a national conference and exhibition sponsored by the technical and professional societies of eastern Tennessee to provide a forum for the exchange and dissemination of information on current national issues involving science and technology.

The Winter Executive Meeting will be held preceding the Central Region Chapter technical session at the WATTec Conference. The next annual meeting will be held in Oak Ridge, Tenn., on Oct. 28-29, 1993. The meeting will coincide with the 50th Anniversary of the city of Oak Ridge.

Bruce W. Moran
Chapter Secretary
Martin Marietta Energy Systems
Oak Ridge, Tenn., U.S.A.

Division Report: IS & NP

On Nov. 3, 1992, the INMM International Safeguards Division (ISD) met at the Commission of European Communities (CEC) Joint Research Centre (JRC) in Ispra, Italy.

Fifteen members of the International Safeguards community, from the IAEA, CEC-JRC-Ispra, Australia, France, Germany, the Netherlands, Sweden, the United Kingdom and the United States participated in the meeting.

The chair opened the meeting with recent information from the INMM Executive Committee regarding the roles of the International Safeguards & Non-proliferation (IS&NP) and Arms Control & Verification (AC&V) Divisions, which have been redefined, resulting in the former IS&NP Division becoming the International Safeguards Division (ISD). In the discussion that followed, it was generally recognized that the activities of the group would remain essentially the same as originally intended.

The international safeguards sessions of the 1993 INMM Annual Meeting were discussed. It was agreed that the division would propose that the first three international safeguards sessions be devoted to the numerous issues that have emerged since the events in Iraq, and other significant world events, and their impact on the application of safeguards on a worldwide basis. All participants agreed to encourage their colleagues at their organizations to submit papers.

The international safeguards panel held at the 1992 INMM Annual Meeting was discussed in detail, and it was agreed to consider convening a similar panel in one of the 1993 sessions.

In the course of these discussions on "administrative matters" the participants discussed a range of current international safeguards topics and issues, including:

• the recent suggestions regarding "streamlined" and alternate safeguards approaches,

• the concept of "transparency," particularly as related to differences in the application of safeguards,

• "lessons learned" from the Iraq case; in particular with respect to unreported (clandestine) facilities and associated "new measures" related to detection of such facilities, and

• increased rights for inspectors to access places also outside nuclear facilities and beyond strategic points inside nuclear facilities.

The participants further discussed:

• access to all places at all times and what restrictions would be acceptable and what can be learned from the CWC

• additional information relevant to safeguarding, including information on a state's nuclear program and its operation (one purpose being that the IAEA could have better knowledge when planning its inspection program)

• limited restrictions for visas (sufficient number of designated inspections),

• make fuller use of a State System of Accounting for and Control of Nuclear Material (SSAC) and criteria such a SSAC must meet in order to carry out some of the safeguards activities IAEA inspectors perform today,

• aspects of discriminations (political or technical), and

• "independent verification" in a safeguards regime where the IAEA carries out much less verification than some under the current regime.

On Dec. 8, 1992, the ISD met at the Nuclear Materials Control Center (NMCC) in Tokyo. Sixteen members of the International Safeguards Community from Japan and the United States participated in the meeting. The chair began with a briefing on recent activities of the ISD, including the meeting at JRC-Ispra.

The international safeguards sessions of the 1993 INMM Annual Meeting were again discussed. It was suggested that a panel could be held at the 1993 INMM Meeting to address the subject of "Inspection Modes" — more specifically, to cover the many subject areas surrounding inspections not in the "routine" category. The meeting participants considered this to be a good topic because of the many opinions regarding limitations and procedures.

The possibility of scheduling the next division meeting immediately before or after the May 1993 ESARDA Symposium in Rome was discussed. Such a meeting would allow for a significant number of participants from Europe as well as from other continents. This possibility will be discussed with ESARDA officials, and the result will be provided to the division participants.

Cecil S. Sonnier, Chair
Paul Ek, Vice Chair
International Safeguards and Non-proliferation Division

Division Report: MC & A Technical

The MC & A Technical Division and the Pacific Northwest Chapter of INMM will host a "Workshop on Long-Term Special Nuclear Material Storage — Inventory Extension," April 18-21, 1993, in Richland, Wash. The workshop will explore implementation strategies for the recently issued U.S. Department of Energy (DOE) guidelines and provide insights on the design of new long-term storage facilities or cost-effective modifications to existing facilities.

For program information, contact Don Six, Westinghouse Hanford Co., (509) 376-7820. For registration information, call INMM Headquarters, (708) 480-9573.

Committees: N14 Standards

The annual N14 Committee meeting was held Nov. 6, 1992, at the U.S. Nuclear Regulatory Commission (NRC) in Rockville, Md. Minutes of the meeting are in preparation and will be mailed to individuals on the N14 roster.

Twelve new members were voted onto the N14 Committee, making a total of 74 members.

The ANSI Executive Standards Council approved the reaccreditation of ASC N14 under its expanded scope, effective Aug. 6, 1992. The approved scope reads as follows:

"Standards for the packaging and transportation of fissile and radioactive materials, non-nuclear hazardous materials including waste and mixed materials, but not including movement or handling during processing and manufacturing operations."

Highlights of the N14 standards are:

• ANSI N14.6 - 1986 — Special Lifting Devices for Shipping Containers

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Committees: Government-Industry Liaison

The INMM Government-Industry Liaison Committee held an open meeting on "Government Safeguards and Security Initiatives for Nuclear Facilities" on July 23, 1992, during the week of the 1992 INMM Annual Meeting in Orlando, Fla. Four invited speakers from the U.S. Nuclear Regulatory Commission (NRC) and the U.S. Department of Energy (DOE) presented overviews of their agencies' initiatives in nuclear safeguards and security. An informal discussion among the speakers and the roughly 30 attendees followed each presentation.

Elizabeth Ten Eyck, Deputy Director of the NRC Division of Safeguards and Transportation, provided an update on NRC rulemaking, guidance and other activities. Ten Eyck discussed the status of the rules on physical fitness, day firing qualifications, fitness for duty, licensees' announcement of inspections, amendment to 73.40(a) on protection objectives and MC&A enrichment. She also summarized new guidance on physical inventory summary reports and on physical protection plan format and content. Ten Eyck concluded her presentation with an overview of the safeguards event reporting program and an announcement of the joint DOE-NRC Physical Protection Technology Update. Winnie Lehman, from the DOE Office of Safeguards and Security (OSS), gave an overview of the office's equipment standardization program and the National Industrial Security Program (NISP).

A DOE and operating contractor working group has begun the standardization program by considering items for common procurement and associated performance specification for a pilot program. NISP addresses the protection of information, not nuclear material, and has the dual goals of enhancing security while making it less costly.

Glenn Podonsky, DOE Deputy Assistant Secretary for Security Evaluations (SE), presented the SE oversight functions, types of inspections and current emphasis. Its short-term goals include promoting effective resource allocation, developing tools and methodologies for inspections and assessing insider protection systems. Effective insider protection requires integrated systems of physical security hardware, protective force and procedural and accounting controls.

David Meyers, a program analyst with DOE/OSS, reviewed current department initiatives in materials control and accountability. The department's activities include strategic planning, measurement control, materials control, DOE orders and manuals, CTA training, and physical inventory guidance/criteria. DOE/OSS has recently completed new guidance and criteria that reduce the frequency of performing nuclear material inventories based on the use of alternative assurance and control measures.

Most attendees were quite pleased with this informal session on government programs. For the first time, this meeting was held on the morning following the annual meeting's technical sessions. Attendance was significantly higher than at the most recent committee meetings.

Several persons from diverse organizations volunteered to help plan future meetings sponsored by the Government-Industry Liaison Committee. We will soon begin considering discussion topics and invited speakers for next year's sessions. The ideas of all INMM members are welcome.

John C. Matter, Chair
Sandia National Laboratory
Albuquerque, New Mexico, U.S.A.

Committees: N14 Standards

Continued from page 11

Weighing 10,000 Pounds (4500kg) or More for Nuclear Materials. This standard was approved by the N14 Committee. The final draft is being edited prior to submittal to ANSI for approval.

• ANSI N14.19 — Ancillary Features of Irradiated Shipping Casks. This standard will be withdrawn and a new scope and standard will be prepared.

• ANSI N14.24 — Barge Transport of Radioactive Materials. This standard has been approved by the N14 Committee. The final draft is being edited prior to submittal to ANSI for approval.

• ANSI N14.27 — Carrier and Shipper Responsibilities and Emergency Response Procedures for Highway Transportation Accidents Involving Truckload Quantities of Radioactive Material.

This standard was approved by the N14 Committee. The final draft is being edited prior to submittal to ANSI for approval. Planning has started on an extensive revision, which includes the scope. The project is expected to be completed by Jan. 1, 1997.

• ANSI N14.30 - 1992 — Design, Fabrication and Maintenance of Semi-Trailers Employed in the Highway Transport of Weight-concentrated Radioactive Loads. This standard was approved by the Board of Standards Review, effective Oct. 1, 1992.

A detailed report on N14 Standards will be provided in the next report.

John W. Arendt, Chair
ANSI N14 Committee

Tributes to two dangerous thinkers

Dangerous Thoughts, Memoirs of A Russian Life
Yuri Orlov
Wm. Morrow and Co.
New York, New York 1991

Memoirs
Andrei Sakharov
Alfred A. Knopf
New York, New York 1990

Moscow and Beyond
Andrei Sakharov
Alfred A. Knopf
New York, New York 1990

Progress, Coexistence and Intellectual Freedom
Andrei Sakharov
W. W. Norton
New York, New York 1968

My Country and The World
Andrei Sakharov
Alfred A. Knopf
New York, New York 1975

Sakharov Remembered, A Tribute by Friends and Colleagues
Sidney D. Drell and Sergie P. Kapitza, Editors
American Institute of Physics
New York, New York 1991

Events in the former Soviet Union should be of particular interest to INMM members because their careers and lives have been profoundly influenced by what has taken place there. The existence of the Soviet Union as our giant, superpower adversary, with its armored divisions at the gates of Western Europe, necessitated the creation of a complex of U.S. Department of Energy (DOE) facilities with the capacity to design, test and produce thousands of warheads in order to achieve a nuclear standoff. Now that the challenge has largely disappeared, a new complex of facilities, far more modest in scale, is planned for the early decades of the next century. In addition, a number of INMM members have been, or soon will be, engaged in providing nuclear safeguards assistance to the former Soviet Union or in implementing arms control agreements between the United States and some of the former Soviet republics.

Russian history has been tumultuous during the past 75 years. In the time since the Russian Revolution, the world has seen this giant among nations — occupier of one-sixth of the world's land area and stretching, like our country, between the world's two great oceans — undergo upheavals, repression and physical devastation on a scale unequalled anywhere else in the modern world. Beginning with the 1917 toppling of the Czarist monarchy, Russia has experienced, in succession, socialist and communist revolutions, a bloody civil war, a six-decade-long tyranny established by the criminals and mass murderers who rose to power during the civil war, and perpetuated at the end by corrupt party hacks, and a massive invasion by Nazi Germany, which produced enormous devastation and claimed more than 15 million lives.

Now, within a short span of time, this system has effectively undergone a total political and economic collapse. For us, this has produced the enormous benefit of an end to the Cold War, which will allow us to reallocate resources once earmarked for defense.

It can be argued that the most important factor in the collapse of the Soviet system was the failure of its command economy, with its built-in contradictions and enormous inefficiencies. As a consequence of this colossal failure, the citizens of the former Soviet Union now rank 45th in the world in per capita income, 30th in life expectancy and worse than 50th in infant mortality.

An equally important factor in bringing about the fundamental political changes that have taken place was the dedicated efforts of the many thousands of human rights activists and political dissidents. Risking the loss of their livelihood, their freedom and even their lives, the dissidents strove to inform the Soviet public of the crimes and repressions committed by Soviet leaders and of the corruption and social injustices inherent in the system. These individuals, most of whom remain unknown in the West, are indeed the heroes of our time. An important consequence of these political changes is that, in contrast to the situation that existed when the Soviet state was born, where the worst and most ruthless elements in Russian society had seized power, the political initiative is now in the hands of individuals who have a firm commitment to democratic principles and a policy of nonviolence. Accordingly, there is genuine hope that stable democratic institutions can at last evolve and function in the former Soviet Union.

Of the many activists who strove to bring about this profound change in the Soviet system, two are particularly well known in the United States, Yuri Orlov and Andrei Sakharov. Orlov has recounted the story of his life as a physicist and political activist in one book, *Dangerous Thoughts, Memoirs of A Russian Life*, and Sakharov in two, *Memoirs*, and *Moscow and Beyond.* Sakharov produced a number of other works, including his landmark 1968 essay "Progress, Coexistence and Intellectual Freedom," and the collection of essays *My Country and The World.*

A number of books have already been published of Sakharov's life and work, including the collection of essays edited by Drell and Kapitsa, *Sakharov Remembered, A Tribute by Friends and Colleagues* and others are sure to follow.

Dangerous Thoughts, Memoirs of A Russian Life is a vivid account of life in the Soviet Union as experienced by an individual who dared attempt to reform the system. Orlov began life in a small village situated between Moscow and Smolensk. Almost like a tale from the remote past, his story begins with an account of how, at age 4, while returning through the snow from a market town in a horse-drawn sleigh with his grandmother, they were pursued and surrounded by a pack of wolves who attempted to pull down their horse. They barely made it back to the village unscathed. It is interesting to note that this same individual is now in residence at a major American university and participating in a fundamental physics experiment at one of our national laboratories. He came of age during World War II, during which he served as a laborer in a factory in Eastern Russia producing T-34 tanks and then as an artillery lieutenant in the closing months of the war.

One common theme that runs through both the Orlov and Sakharov memoirs is the description of the extreme difficulties Soviet citizens have lived with during the last 70 years. Shortages of basics were an everyday burden. Soviet housing conditions would be regarded as intolerable anywhere in the West, with entire families often sharing only one room, with a communal kitchen and primitive toilet facility shared by many families. The only bathing facilities were often public bath houses located miles away.

Their accounts also bring home the human cost of the collectivization of farms, and the terror of the 1930s, which impacted many relatives and friends, as did the enormous casualties suffered during the war. On the basis of information assembled in recent years by human rights advocates in the Soviet Union, the total cost of their own government's tyranny sums to a grand total of 65 million lives.

After the war, Orlov studied at the Moscow State University, specializing in physics, and upon graduation, secured a post in the Institute for Theoretical and Experimental Physics (ITEP) in Moscow. At this point a promising career lay ahead of him, and had he chosen not to challenge the political system, he could have enjoyed a privileged existence as a member of the intellectual elite.

Orlov's first challenge to this system occurred in 1956, after the famous denunciation of the crimes of Stalin by Kruschev at the 20th Party Congress. A meeting was called at the ITEP, the purpose of which was clearly to obtain from the staff professions of loyalty to those in power, but Orlov used the occasion to support Kruschev's charges and criticize the repressive nature of the communist government.

This forthright action cost Orlov his ITEP post and also earned him the "dissident" label and the KGB surveillance that goes with it. He moved to Yerevan, in Soviet Armenia, where he remained for 16 years, achieving distinction as an accelerator designer, and winning election as a corresponding member of the Armenian Academy of Science.

In 1972, Orlov returned to Moscow, where he eked out a living giving private lessons. He also became increasingly involved with human rights activities, especially regarding the fate of individuals arrested and prosecuted by the government for various anti-state activities. During the next several years he carried out two actions which earned him the wrath of the

Continued on page 14

Continued from page 13
authorities. The first, in 1973, was a letter to Brezhnev containing 13 questions aimed at the basic principles on which the system rested. Orlov's second bold act of defiance occurred three years later when he helped create the Public Group to Support Compliance With The Helsinki Accords in the U.S.S.R., an organization dedicated to collecting and disseminating information on human rights cases in the Soviet Union that constituted violations of the Helsinki Accords, to which the U.S.S.R. was a signatory.

Shortly after the organization of this group in February 1977, Orlov was arrested, tried for anti-state activities and sentenced to seven years in a labor camp and five additional years of exile. He was incarcerated for slightly more than six years, and his account of the rigors of the prison system and the constant mistreatment he suffered at the hands of those who ran it is chilling, especially when one realizes that this fate was shared by tens of millions of others. He was released in 1984, only to be sent into exile in a small village in Siberia near the Lena River. After two years of difficult, but more tolerable existence there, he was suddenly flown back to Moscow and deported from the Soviet Union. In the years since 1984 Orlov has campaigned on behalf of other political prisoners in the Soviet Union, most of whom were released by 1988. He has also campaigned for political reforms, and has again been able to practice his profession of physics both in the United States and in Europe.

The reader will find *Dangerous Thoughts* a moving personal odyssey of an honest and courageous individual who strove to reform his country's political system. The last chapter, entitled "What Is to Be Done?" (named after a famous article written by Lenin) provides an excellent assessment of the current political situation in the former Soviet Union.

Andrei Sakharov was a remarkably gifted individual who, during his lifetime, pursued three careers, achieving great distinction in each. As a young theoretical physicist he was assigned to work in the Soviet nuclear weapons program, where he soon became, and remained for two decades, their foremost designer of thermonuclear devices. At the end of this time he was expelled from the weapons program for his political activities and returned to research in fundamental physics, producing a number of important papers which were characterized by their deep insight and originality of thought. During this time he became increasingly involved with a wide range of political and humanitarian concerns, becoming, during the last years of his life, the most influential voice for political reform in the Soviet Union.

In the texts of *Memoirs* and *Moscow and Beyond*, which total about 850 pages, Sakharov provides a detailed history of his personal life, his work and his political and humanitarian activities. Further material is provided by those who knew him in *Sakharov Remembered.* In view of his achievements, such a quantity of material is to be expected.

Sakharov was born in Moscow in 1921 into a family that belonged to the old Russian intelligentsia. His father was a physics teacher who played a key role in Andrei's early intellectual development. He obtained his degree in physics from Moscow State University in 1942 and then worked as an engineer in a munitions factory for the duration of the war. After the war he was accepted as a graduate student at the Lebedev Physical Institute in Moscow where he studied with the noted physicist Igor Tamm, obtaining his degree in 1947. His gifts as a theoretical physicist were already apparent, particularly his deep insight which often enabled him to arrive at an original approach to a problem that had eluded others. In 1948, Tamm included Sakharov in a group of young physicists who were organized to study the possibility of constructing a thermonuclear device. In 1950, Sakharov moved to the "Installation," a secret laboratory dedicated to the development of nuclear weapons, where he worked until his security clearance was withdrawn in 1968.

Many readers of this review will be interested in Sakharov's account of the Soviet thermonuclear weapons program, although it is necessarily devoid of technical details. What is clear is that Sakharov, with his gifts as a theorist, contributed most, if not all, of the key ideas which led to the development of devices which could be delivered by ballistic missiles. In 1955, the Soviet government, in order to enhance creativity through competition, established a "Second Installation" to insure that weapons development would proceed as fast as possible. During this time, Sakharov's creativity extended into other areas as well. He originated several ideas for controlled thermonuclear fusion and for producing superstrong magnetic fields, and after 1965, produced important work in the fields of cosmology, particle physics and gravity. His contributions to the Soviet defense program during this time were recognized by election to the prestigious Soviet Academy of Sciences, the Stalin prize and three Hero of Socialist Labor awards. These awards and his reputation probably protected him, a few years later, from the fate that overtook Yuri Orlov and enabled Sakharov to play a key role in the reform of Soviet society.

During these years, Sakharov's political views continued to evolve. He was first concerned with the health effects of fallout from above-ground testing on the population, attempting in vain to persuade the government to minimize and then eliminate such tests. Eventually, this campaign had a major influence on the adoption of the Limited Test Ban Treaty, which banned such tests. Sakharov was also concerned with environmental matters, in particular the massive pollution of Lake Baikal, which was then occurring. He also involved himself in opposing those associated with the charlatan Trofim Lysenko who had, with his pseudoscience, essentially destroyed the discipline of biology in the Soviet Union and persecuted many honest and competent scientists. As the crimes of the Stalin era became widely known during the "Kruschev Thaw," Sakharov became increasingly more convinced of the fundamental flaws in the Soviet system. This culminated in the publication of his essay, "Reflections on Progress, Peaceful Coexistence and Intellectual Freedom" in 1968, which received wide circulation in both the Soviet Union and abroad. The publication of this fundamental criticism of the system led to his dismissal from the "Installation" and weapons programs, and he returned to the Lebedev Institute of Moscow.

At this juncture Sakharov, in addition to continuing work on fundamental science problems, became deeply involved in the human rights movement, in particular, going to the defense of the "prisoners of conscience" who were persecuted by the regime. At this time he also campaigned vigorously on behalf of the Crimean Tartars, who had been expelled from their homes by Stalin during the war and deported to a remote part of the country. No subsequent regime permitted the Tartars to return to their homeland. In 1972, Sakharov met and married Elena Bonner, a well-known political dissident and civil rights activist. By 1975 Sakharov had acquired such stature that he was awarded the Nobel Peace Prize.

In 1980, after opposing the war in Afghanistan, he was deported to the city of Gorky. In 1984, his wife was also sentenced to internal exile. While in Gorky he found it necessary to go on hunger strikes three times to force the regime to recognize the rights of his family, the most important of these was when it was necessary for Elena Bonner to travel abroad for heart surgery to save her life. Finally, in December 1986, Mikhail Gorbachev revoked the exile and they were permitted to return to Moscow.

For the next three years, until his death at the end of 1989, with the stature and moral authority he commanded, he played a key role in political events.

Sakharov's death at a comparatively young age and at a crucial juncture in the history of his country is particularly regrettable. Orlov summarizes this in his epitaph, "Sakharov had already transformed Russian history. Had he lived, he would have transformed it again. For near the end of his life, almost overnight, he developed into a brilliant, committed politician, not only leading tough battles in the Congress, but meeting with industrial workers and drafting a new constitution that I would call a 'constitution of human rights.' The only public figure acceptable to all parts of his too-vast country, Sakharov had become just the person to lead a decaying nation exhausted with itself, yet still capable of responding to great honesty, great professional achievement, great suffering and great precision of thought."

It is difficult to overstate the profound influence Sakharov had on the fundamental political transformation that took place in his country during the past few years and its significance to the new and better world order that will follow.

The reader who would like a view into these exciting and momentous events will find the Orlov and Sakharov materials worthwhile.

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Additional Considerations Regarding the Choice of Measurement Control Check Frequency

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ABSTRACT

In a previous paper, factors involved in the choice of frequency of instrument measurement control checks were presented. Unfortunately, some discussions were inadvertently omitted from the paper during the process of review, editing and printing. That material is presented here.

I. INTRODUCTION

In a previous paper,[1] important factors involved in the choice of a sampling interval or frequency of instrument measurement control checks were presented. The factors were the costs of performing a measurement control test, the cost of not detecting a problem, the system characteristics, throughput, regulatory requirements and specifications, and graded safeguards. It was seen that costs could be expressed in different units. There were dollar costs, costs due to exposure, costs from lost production time and costs due to credibility.

Unfortunately, some discussions were inadvertently omitted during the process of review, editing and printing. The omitted material included valuable suggestions made by the reviewers and enhancements made by the author. In the following section these omissions are presented.

II. ADDITIONAL CONSIDERATIONS

1. Stricter Requirements. There has been a long history of quality control and assurance activities at nuclear facilities. However, the new quality culture, which is developing in the United States sets even stricter requirements for all aspects of the facility's operations, including assurance of quality measurements. Additionally, there is strong emphasis on the need to strive for "continual improvement." Thus, documentation needs to be in place to assure that sampling interval choices are defensible and current.

2. Team Approach. Consideration of the factors presented earlier[1] involves essentially a cost/risk/benefit analysis. Thus, it is important that the choice of measurement control check frequency be made by a team that is knowledgeable about the measurement requirements, the system capability, the material to be measured and statistics.

3. Failure Response. Every measurement system will eventually fail a measurement control check either by chance or because of a real problem with the system This is to be expected and should not cause unnecessary alarm. However, each failure requires a response. The nature of the response should be described in a documental failure response plan. The plan must clearly distinguish between response to failures that are of statistical significance only and response to failures that are of both statistical and practical significance.

4. Computer Software. If costs of making a measurement control check and the costs of failing to detect a problem can be converted to a common unit, such as dollars, one can determine an optimal sampling interval mathematically. There is at least one commercially available computer software code that will do this. This code is based on a model by Montgomery[2] and is included in the software package SPC-PC II marketed by Quality America, 7650 E. Broadway, Tucson, Ariz. (The author has no experience with the code.)

III. CONCLUSION

Discussions which were omitted from the originally published version of a paper on the choice of sampling interval for instrument measurement control checks were presented.

A copy of the complete paper is available from the author, Lawrence A. Bruckner, Statistics Group, MS F600, Los Alamos National Laboratory, Los Alamos, Mew Mexico, U.S.A.. 87545

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Analysis of the Zone Approach for Plutonium Facilities*

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ABSTRACT

In order to examine the effect of different inspection strategies on inspection effort, an analysis was carried out of the zone approach for the international safeguards verifications of a model nuclear fuel cycle. The fuel cycle includes the fabrication of mixed-oxide fresh fuel for nine light-water reactors and one experimental breeder reactor and the subsequent reprocessing of the spent fuel. There are thus two zones to be considered, a plutonium zone and an irradiated fuel zone. The zone approach entails many fewer verifications of nuclear material flows between different material balance areas (facilities) than the facility-oriented approach, and it requires an annual simultaneous physical inventory verification (PIV) and monthly simultaneous interim inventory verifications for timeliness at all the facilities. Therefore, the zone approach yields "snapshots" of the disposition of the nuclear materials at the time of the simultaneous inventory verifications, but less verified information than a facility-oriented approach encompassing frequent flow verification.

I. INTRODUCTION

In the zone approach,[1] facilities in a nuclear fuel cycle are grouped into zones, with special regimes of inspections for the purposes of international safeguards verifications. Within a zone, which encompasses nuclear materials of a single category, flows between different material balance areas (MBAs) or facilities need not be verified. This first feature of the zone approach results in a savings of inspection effort compared to a facility-oriented approach but also yields less verified information about the disposition of nuclear material than an approach encompassing frequent flow verification. The second feature of the zone approach is the requirement of a (nearly) simultaneous physical inventory verification (PIV) of the nuclear material in all the MBAs and simultaneous interim inventory verifications for timeliness. These simultaneous inventory verifications partially compensate for the loss of verified flow information. Thus the safeguards verifications are conducted as though the zone were a single MBA.

However, the next conceivable step, making the zone into a de jure MBA, is not taken. Reports continue to be issued to the International Atomic Energy Agency (IAEA) by the State System of Accounting for and Control of Nuclear Material (SSAC), with the information originating at the facilities, concerning all inter-MBA flows.

This zone approach can lead to efficiencies in IAEA safeguards inspection requirements, though with some loss of verified knowledge about the disposition of nuclear material. The most essential flow verifications[2] are retained since they occur at the zone boundaries.

In this paper, the zone approach is studied for the plutonium facilities of an advanced nuclear fuel cycle. (An underlying report by Fishbone and Teichmann,[3] gives all of the details including the effect of lengthening the timeliness goals for direct-use material.) In a previous work, details of the approach were studied for the low-enriched uranium (LEU) zone of a fuel cycle.[4,5] The present work extends the LEU analysis to the "back-end" facilities as well as to power reactors that use mixed-oxide (MOX; plutonium plus uranium) fuel. The significant zones in the present study are the irradiated fuel zone comprising the reactors and spent fuel pools and the head end of the reprocessing plant, and the plutonium zone, starting at the reprocessing plant input accountability tank, embracing the fuel fabrication facilities, and terminating when the MOX fuel assemblies enter the reactors. These zones are shown in Figure 1 and discussed somewhat further below (Section II).

The goal is to understand the relative effectiveness and efficiency of the zone approach in comparison to the facility-oriented approach for the zones containing irradiated and unirradiated direct use material. This provides a better foun-

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dation for deciding on the possible degree of application of the zone approach to plutonium facilities.

The IAEA has already applied elements of a zone approach, primarily simultaneous PIVs, to the conversion, and fabrication, plants and the reactor fresh-fuel storage areas of the natural-uranium fuel cycle of Canada. This has been done because of the huge resource requirements that would be needed for full flow verification at all of the facilities involved in fuel production.[6-8] The accumulating experience in Canada suggests that the zone approach be studied carefully for potential application in other situations. More limited experience exists for the application of the zone approach to the LEU facilities in the Republic of Korea.[9]

II. FUEL CYCLE

The fuel cycle under study here consists of nine light-water reactors (LWRs), one experimental breeder reactor (XBR), one spent-fuel reprocessing plant, one plutonium nitrate-to-oxide conversion plant and two MOX reactor fuel fabrication plants. One of the MOX plants is automated; the other is conventional. Necessary as well in the fuel cycle, but not studied here, are enrichment and fabrication facilities for LEU fuel. The fuel-cycle flows are listed in Table 1.

Figure 1 shows the fuel flows among the facilities and also the zone structure of the fuel cycle. In connection with Figure 1 two aspects of the zone boundaries deserve comment. These remarks follow from the principle[3] that zones should encompass nuclear materials of similar safeguards significance, e.g. material categories.[1] This principle leads to a fresh-fuel zone, an irradiated-fuel zone and a plutonium zone. The boundary between the fresh-fuel zone and the irradiated-fuel zone is at the reactor cores. The boundary between the irradiated-fuel zone and the plutonium zone is at the input accountability tank of the reprocessing plant.

III. INSPECTION ACTIVITIES

The method of analysis was to compile lists for each facility type of the inspection activities necessary for a facility-oriented safeguards approach. It could be argued, justifiably, that the IAEA's existing strategy contains many "fuel-cycle" aspects, particularly the emphasis on verifications in facilities handling unirradiated direct-use material, particularly plutonium.[10] This is not the issue here: the nomenclature "facility" or "facility-oriented" approach is used for precision and for purposes of comparison.

The IAEA inspection approach for the nuclear material in the zone would combine materials accountancy, containment and surveillance. Materials accountancy would play the central role in the bulk-handling facilities (reprocessing, conversion and MOX fuel-fabrication plants), while containment and surveillance measures would predominate in the reactors. Diversion scenarios per se are not discussed; rather, it is assumed that the verification activities in the facility approaches are adequate to detect and deter an appropriate set of diversion scenarios.

The IAEA Safeguards Criteria for inspection goal attainment follow from the primary safeguards objectives and constitute both implementation and evaluation criteria. The criteria prescribe in a detailed way the verifications to be conducted at different facility types for the various kinds of nuclear material. The prescriptions include alternative verification measures in several situations and random sampling fractions for different material types. The actual values of the parameters used in this analysis generally follow the latest IAEA Safeguards Criteria.[1] However, certain verifications assumed for the "maximal" facility-oriented approach go beyond those required by the latest criteria. This assumption should be borne in mind in reviewing the comparisons cited later.

For bulk-handling facilities, sample sizes for verification were calculated for this analysis by a one- or two-level attributes sampling scheme.[11,12] Generally speaking, this means that the level-one test is a gross-attributes test designed to detect, at a high probability, whole-item defects in sufficient number to equal one significant quantity (SQ) of nuclear material. For items containing at least one SQ, as for example, MOX fuel assemblies, the sampling fraction would equal the desired detection probability. The level-two test requires a smaller sample size to detect the same goal quantity spread in smaller (partial) defects among a larger number of items. The more complicated procedure for bias-defect sampling was not used; this assumption also qualifies the ultimate comparisons.

For each inspection activity there is a time (inspection effort) requirement that depends on the amount of nuclear-material inventory or flow involved through the calculated sample sizes. Additionally, empirical "progress ratios" to account for variations in plant sizes and activities were used. The inspection effort estimates were based on information as was available from published Agency reports,[5] together with rough guesses made to illustrate how such an analysis would be performed for the actual facilities in a particular state. The numbers for the automated MOX plant are even rougher estimates. Generally, the types of inspection are physical inventory verifications (PIVs), flow verifications (FVs) and interim inventory verifications (IIVs) required to meet timeliness goals. To facilitate the zone approach analysis, the inspection activities were further divided into groups corresponding to flow verifications at different key measurement points (KMPs). Given these groupings, reasonable fractions of the total administrative and auditing time for the inspection regime were allocated to each of these groups. There is some arbitrariness in the division of inspection activity times because:

1. some IAEA inspections serve several purposes;
2. IAEA inspections are continuous at some facilities; and
3. the data were not always suitably disaggregated.

Table 2 gives the estimated inspection effort (based on the rough estimates described above), according to the detailed grouping for all of the facilities under consideration. The inspection activity times are summed for each inspection type at each facility over the entire fuel cycle to give an annual total for the facility-oriented approach. The effort per facility was also uniformly augmented by one-sixth to account for training.

IV. ZONE-APPROACH INSPECTION-EFFORT ANALYSIS

Given inspection activity times for the facility approach, the analysis proceeded by determining the inspection effort required for each particular intra-zone flow verification. The effect of progressive elimination of each such verification was found by subtraction from the total for the facility approach, with adjustments where necessary. Only the actual verification time was subtracted, not the time for associated administration and auditing. Verifications of the inter-zone flows cannot be eliminated without sacrificing the ability to determine if there are diversions of bulk materials.[2] These include verifications of the nuclear material content of irradiated-fuel assemblies at the feed side of the reprocessing plant and of fresh assemblies inserted into the reactors, particularly the MOX assemblies. All other inter-facility and inter-MBA flow verifications within the plutonium zone are supplementary to these. (This is not equivalent to the policy statement of saying that some supplementary verifications are deemed too important to forego.) Verifications of such minor flows as wastes would also be required if the materials in question leave the zone or are no longer subject to routine inventory verification or if safeguards upon them are to be terminated.[13]

Thus, according to the zone approach, verifications need not be done on certain inter-MBA flows within the facilities (equivalently, at certain KMPs for such facilities with single-MBA safeguards structures), on the flow of spent fuel from the reactor storage pools to the reprocessing plant, on the flow of plutonium nitrate from the reprocessing plant to the conversion plant, and on the flow of plutonium oxide from the conversion plant to the MOX fuel-fabrication plants. The finished fuel assemblies must be verified somewhere, but this could be done at the reactors as well as at the fabrication plants. Similar considerations would apply to the uranium flows within the zone from the reprocessing plant to the MOX fuel fabrication plants.

Eliminating flow verifications does not mean eliminating interim inventory verifications to satisfy the timeliness goal. Since the same inspection visit can serve for both purposes, calculating the efficiency gains from elimination of flow verifications must be done with great care.

V. FLOW-VERIFICATION ELIMINATION

The results for the inspection effort saved upon elimination of flow inspection activities appear in Table 3. The results suggest that the fuel cycle inspection effort requirements might be significantly reduced from the total for the "maximal" facility approach by combining "intermediate" cases into the "maximal" application of the zone approach. From the total of 3,216 man-days of inspection effort, a total estimated reduction of nearly 38% is conceivably possible. It is important to keep in mind that these absolute numbers are very sensitive to the underlying assumptions about individual inspection activity times and should be regarded skeptically. On the other hand, changes based on the hypothesized deletion of flow verifications would tend to give the correct trends if the deletions were carried out.

VI. SIMULTANEOUS PIV AND IIVS

Compensating in part for the reduced verified information about the flows are the (nearly) simultaneous PIV and IIVs for timeliness over all the MBAs in each zone. (These simultaneous inspections do not mean simultaneous LWR refuelling.) These provide excellent "snapshots" of the nuclear materials in the fuel cycle and thus provide assurance about the locations and amount of nuclear material over entire zones at a single time. They thereby also provide coverage against concealment of diversion by "borrowing" nuclear material from other MBAs. In the absence of exact simultaneity, so-called "bridging" measures could be employed based on containment and surveillance.

The approximate inspector requirements for the annual PIV appear in Table 4 by facility; the requirements are lower for IIVs. Table 5 then gives the fuel cycle total given the assumption that (one of the) IIVs is performed at the reactors at the time of the zone PIVs at the bulk-handling facilities (BHFs).

Such simultaneous inspections create a "peaking" problem in regard to the number of inspectors needed. The requirement is 53 inspectors for a zone-wide simultaneous PIV in the model fuel cycle, with a reduction of 11 possible if the reactor inspections immediately follow those of the BHFs. Thirty-three inspectors are required for a simultaneous IIV, which would include a core-opening PIV at one reactor; a reduction of 14 is possible if the reactor inspections immediately follow those of the BHFs. This peaking problem probably requires an additional inspection effort (person-days of inspection, PDI) which can only be quantified by a detailed examination of any actual situation.

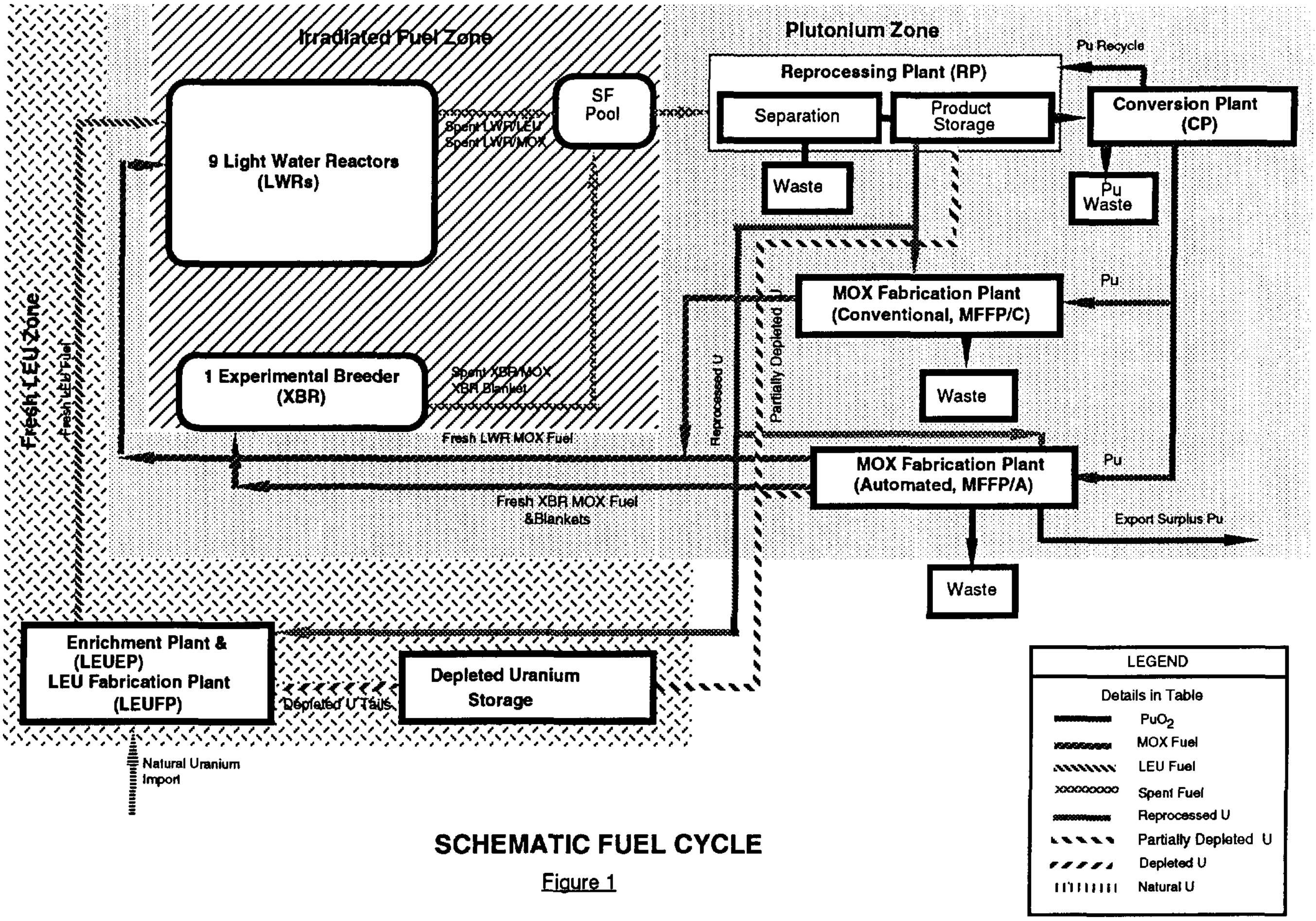
VII. DISCUSSION AND CONCLUSIONS

The quantitative estimate of the results[a] is presented here solely to show how the procedure described here should be used in conjunction with representative agency inspection effort data in deciding whether or not to change the approach for a specific national fuel cycle. Instituting a zone approach for this fuel cycle would result in the elimination of several flow verifications that are required for a facility approach,

[a] Of the inspection effort accompanying a significant change in the IAEA safeguards inspection approach for a model nuclear fuel cycle relying heavily upon the thermal recycle of plutonium.

Table 1
Summary Fuel Cycle Data

Facility/Material	tU/a	%235	kg Pu/a	% fissile
MOX Fueled LWRs				
Fresh LEU Input	169.3	3.2		
Fresh LWR MOX Input	62.6	1.0	4187.0	61.0
Spent LEU Output	161.1	1.0	1521.0	
Spent LWR MOX Output	61.2	0.4	3186.0	
MOX Fueled XBR				
Fresh XBR/MOX Input	1.8	1.0	768.0	61.0
Fresh Axial Blanket Input	1.9	0.4		
Fresh Radial Blanket Input	4.4	0.4		
Spent XBR/MOX Output	1.8	0.4	526.0	43.0
Spent Axial Blanket Output	1.8	0.4	37.0	95.0
Spent Radial Blanket Output	4.4	0.4	88.0	95.0
Reprocessing Plant				
Spent LEU Input	161.1	1.0	1521.0	
Spent LWR/MOX Input	61.2	0.4	3186.0	
Spent XBR/MOX Input	1.8	0.4	526.0	43.0
Spent Axial Blanket Input	1.8	0.4	37.0	95.0
Spent Radial Blanket Input	4.4	0.4	88.0	95.0
Recycle from Conversion			28.0	
U03 Output	230.3			
Pu(N03)4 Output			5324.0	
Pu Waste			62.0	
Conversion Plant				
Pu(N03)4 Input			5324.0	
Pu02 Output			5262.0	
Recycle to Reprocessing			28.0	
Pu Waste			34.0	
MOX Fuel Fabrication Plants (2)				
Reprocessed Uranium Input	65.1	1.0		
Reprocessed Plutonium Input			5262.0	61.0
Depleted Uranium Input (for blankets)	6.3	0.4		
LWE/MOX Output	62.6	1.0	4185.0	61.0
XBR/MOX Output	1.8	0.4	768.0	61.0
Blankets	6.3	0.4		
Plutonium Export			279.0	61.0
Import				
LWR LEU	856.9	0.7		



SCHEMATIC FUEL CYCLE

Figure 1

with a concomitant savings in inspection effort.

Were the zone approach to be considered for an actual fuel cycle situation, the analysis of potential savings should be redone with actual values for inspection activity times.

In all cases, the elimination of a flow verification represents a savings in inspection effort that comes with some reduction in verified information about the disposition of nuclear material in the fuel cycle. So-called "primary" verifications — those of dissolved spent fuel at the reprocessing plant and of fresh MOX fuel for the reactors — have not been considered candidates for elimination in this analysis, so basic information necessary for safeguards purposes would not be lost.[2] The verifications that could be eliminated according to the zone approach for the fuel cycle are of course vital for a facility approach.

On the other hand, material balance considerations suggest[14] that a zone material balance based on simultaneous PIVs and verification of inter-zone flows would provide a more sensitive test for (zone) material unaccounted for (MUF) than would a collection of facility material balances. However, it should be noted that more elaborate MUF combinations have been devised to deal with specified diversion strategies (*loc. cit.*), and that in such circumstances operators may be able to take advantage of them with knowledge of the zone system.

A possible misunderstanding is to presume that the "maximal" facility-oriented approach discussed here represents the existing IAEA inspection approach at all facilities. This is certainly not the case: The "maximum" savings cited here should be understood to apply to a hypothetical inspection approach (as well as a hypothetical fuel cycle), though by no means an unreasonable one. One example of the difference is that the maximal facility-oriented approach encompasses verifications of all spent fuel shipped from LWRs to the reprocessing plant. The IAEA currently seeks to verify only shipments of partially filled casks. The inspection effort savings estimated in this work are based on a model, commercial-scale fuel cycle. It is an important policy question to decide on the desirability of the elimination of any flow verifications, while attaining a reasonable balance-between verified information (i.e., the safeguard's effectiveness) and the inspection resources required (i.e., the safeguard's efficiency), given the significance of the nuclear material involved. Of course, the answer might differ from that implicit in the acceptance of a zone approach for indirect-use LEU or for other situations.

Table 2
Maximal Facility Approach Inspection Effort Summary
Person-Days of Inspection (PDI)

9	Light Water Reactors		
	Interim Inventory Verifications	3	
	MOX Fuel Receipt Verifications	5	
	MOX Fuel Timeliness Verifications	1	
	Spent Fuel Shipment Verifications	14	
	Physical Inventory Verification	22	
	Subtotal (without and with training)	9 x 45	53
1	Expenmental Breeder Reactor		
	Interim Inventory Verifications	38	
	MOX Fuel Receipt Verifications	24	
	Spent Fuel Shipment Verifications	24	
	Physical Inventory Venfication	6	
	Subtotal (without and with training)	92	108
1	Reprocessing Plant		
	Interim Inventory Verifications	165	
	Spent Fuel Receipt Verifications	71	
	Dissolver Transfer Verifications	365	
	Plutonium Product Transfer Verifications	248	
	Uranium Product Transfer Verifications	16	
	Plutonium Nitrate Transfer Verifications	127	
	Uranium Product Shipment Verifications	10	
	Waste Flow Verifications	75	
	Physical Inventory Venfication	59	
	Subtotal (without and with training)	1136	1326
1	Conversion Plant		
	Interim Inventory Verifications	88	
	Plutonium Nitrate Receipt Verifications	125	
	Powder Transfer Venfications	121	
	Powder Shipment Verifications	53	
	Scrap Recovery Flow Verifications	9	
	Waste Flow Verifications	8	
	Physical Inventory Verification	18	
	Subtotal (without and with training)	422	493
1	MOX Fuel Fabrication Plant (Conventional)		
	Powder Receipt Verifications	72	
	Powder and Rod Transfer Venfications	90	
	Assembly Shipment Verfications	72	
	Powder Interim Inventory Verifications	63	
	Assembly Interim Shipment Verifications	63	
	Physical Inventory Venfication	64	
	Subtotal (without and with training)	424	495
1	MOX Fuel Fabrication Plant (Automated)		
	Powder Receipt Verifications	36	
	Powder and Rod Transfer Verifications	36	
	Assembly Shipment Verfications	36	
	Powder Intenm Inventory Verifications	60	
	Assembly Interim Shipment Verifications	60	
	Physical Inventory Verification	43	
	Subtotal (without and with training)	271	317
	Fuel Cycle Total (without and with training)	2750	3216

Table 3
Fuel Cycle Inspection Efforts for Different Safeguards Approaches

Approach	Total Effort (PDI)	Savings (PDI)	%Reduction
Maximum Facility Approach	3216		
Elimination of Spent Fuel Shipments Verifications at LWRs and XBR	3035	181	5.6
Elimination of Spent Fuel Receipt Verifications at the Reprocessing Plant	3139	77	2.4
Elimination of Plutonium Nitrate Shipment Verifications at the Reprocessing and Conversion Plants	2930	143 143	4.5 4.5
Elimination of Plutonium Nitrate Powder Transfer Verification at the Conversion Plant	3143	73	2.3
Elimination of Powder Shipment Flow Verification at Conversion	3157	59	1.8
Elimination of Scrap Recover Flow Verification at the Conversion Plant	3206	10	0.3
Elimination of Powder Receipt Verification at both MOX Fabrication Plants	3100	116	3.5
Elimination of the Powder and Rod Transfer Flow Verifications at both MOX Fabrication Plants	3093	123	3.8
Maximum Zone Approach	2008	1208	37.6

Verifications of entire flow strata by unattended equipment are currently being demonstrated in a mixed-oxide fabrication plant.[14] If the continuity of knowledge can be maintained after measurement verification of the items in these strata,[15, 16] then this situation represents a probably better alternative to saving inspection effort than does the zone approach. "Probably" qualifies the statement because the unattended verification equipment is very expensive and is suitable mainly for entirely new facilities.

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Table 4
Inspector Effort Required at Plutonium Plants for the Physical Inventory Verifications

Plant Type	Inspection Effort Application
Reprocessing Plant	Twelve inspectors for six days ≈ 72 PDI
Conversion Plant	Six inspectors for four days ≈ 24 PDI
Conventional MOX Fuel Fabrication Plant	Fourteen inspectors for five days Fabrication Plant ≈ 70 PDI
Automated MOX Fuel Fabrication Plant	Ten inspectors for five days ≈ 50 PDI
MOX Fuelled LWR	Four inspectors for three days in two shifts* ≈ 24 PDI
MOX Fuelled XBR	Three inspectors for two days ≈ 6 PDI

*Two shifts because of the expected rate of refuelling activities. One shift for all other plants.

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Table 5
Inspector Requirements for Simultaneous PIVS and IIVS

Plants	Inspection Type	
	PIV	IIV
Light-Water Reactors (9)	4[a]	1[a]
Experimental Breeder Reactor	3	2
Bulk Handling Facilities	42	19
Fuel Cycle Total	53[b]	33[c]

[a] For each LWR
[b] 53 = 42 + 2 + 9 x 1, i.e., IIVs at the reactors
[c] 33 = 19 + 4 + 8 x 1 + 2, i.e., including a PIV at one reactor each inspection

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Experiences and Trends in Safeguarding Plutonium Mixed Oxide (MOX) Fuel Fabrication Plants

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ABSTRACT

Safeguard approaches for manually operated MOX fuel fabrication plants are compared to recent approaches adopted for automated fuel fabrication plants. Near real time accountancy (NRTA), in-line non-destructive assay (NDA) instrumentation and advanced containment and surveillance (C/S) systems for automated plants are described. The balance between high capital investments and achievable inspection effort reductions, minimization of radiation exposure and intrusiveness, improvements in timely detection efficiency and effectiveness of safeguards are discussed.

The need for close cooperation between the operator, the state and the inspectorate in implementing safeguards approaches in future plants is stressed.

Other technological developments which may become available in the future could enable the Agency to perform remote certification of certain operator actions by on-line data communication between facilities and a central inspection control unit.

INTRODUCTION

The purpose of this paper is to review the Agency's experience in safeguarding different types of MOX fuel fabrication plants with various throughputs and to outline trends for future plants.

Technological developments in measurements techniques and in the area of containment and surveillance have improved the verification capabilities of the Agency during the recent years. Major advances in data processing capabilities allow for an increase in transparency and timeliness in accounting for nuclear material. As necessary, the Agency updates its safeguards approaches in cooperation with the operator and state authorities to take advantage of these developments.[1]

1. MOX PLANTS UNDER SAFEGUARDS

MOX fuel fabrication plants are highly safeguards-sensitive facilities using direct-use materials (plutonium in MOX, in pure oxide as well as in solutions.) At present there are four operating MOX plants under IAEA safeguards located in Belgium, Germany and Japan. Another plant will become operational in the near future. The increasing demand for MOX fuel has triggered planning and construction of new MOX plants, e.g., in France (MELOX), United Kingdom (BNFL), Belgium and Japan. MOX fuel is produced for light water reactors (LWR), advanced thermal reactors (ATR) and fast breeder reactors (FBR).

1.1 General plant description

The MOX fuel fabrication plants under consideration have different characteristics as shown in Table 1. They differ in size, storage arrangements for feed and product, process modes (e.g., different scrap recovery processes on differences in the conversion of solutions and powders), and the degree of automation of the plant. In all instances production flow starts with feed powder (MOX, pure PuO_2, pure UO_2), which is blended according to the customer's specification. The specified powder is pressed into pellets which are then sintered. The pellets are loaded into fuel pins from which assemblies are produced. The nuclear materials are in the form of pure powders and pellets, scrap, process hold-up, pins, assemblies and small amounts of solutions.

Modern plants are increasingly automated to decrease both personnel exposure and production costs. A consequence of automation is a limitation on direct access to nuclear material for both the operator and the inspectorate. New approaches had to be developed. The plants under construction or recently commissioned are highly automated with safeguards verification instrumentation built in.

1.2 Conventional plants

Early MOX plants were primarily a manual operation using conventional glovebox techniques. Process areas and storage areas for feed intermediate products and assemblies are physically separated. This requires a relatively high number of material movements between storage and process areas as well as multiple manual handling of the nuclear material. Large portions of the plants were devoted to R& D work and to gain experience with the fabrication of MOX fuel.

1.3 Automated plants

Modern plants are designed to produce fuel assemblies in full automated (hands-off) process. At present, the plutonium fuel production facility (PFPF) in Japan is the only operating automated MOX plant.[2] Raw MOX powder is shipped from a nearby conversion plant to the storage in PFPF. The MOX powder is transferred, as required, to the process by an automated transfer machine. All nuclear material in the process glove boxes are handled remotely in transport containers and are removed from the gloveboxes at the end of an operation day. Due to the remote operation and the high radiation field, the process areas as well as the plutonium storages for feed assemblies are not normally accessible.

The Siemens MOX II plant[3] which is in the final construction phase, uses a different principle of handling nuclear materials. The transport of PuO_2 and MOX powders is effected in pipes which connect individual silos from the powder reception store to the process. It also includes an internal automated dry scrap recovery capability. Furthermore, the facility has its own wet recovery plant, and waste treatment capability. The pellets are produced in practically two identical lines and are stored on trays in automated temporary stores. Assemblies are fabricated within a minimum time span prior to shipment to minimize the needs to provide storage for the assemblies.

2. SAFEGUARDS APPROACHES

The development of an implementation scheme ("Safeguards Approach") for safeguarding a facility is an iterative and dynamic process involving the agency, the state authority and the operator. The approach specifies the necessary inspection activity to be carried out in order to provide assurance that nuclear materials are properly accounted for. An effective safeguards approach has been to be consistent with the safeguards criteria. Each approach is specifically adapted to the facility, taking into account to the extend possible:

- design features,
- technical feasibility of safeguards measures,
- diversion assumptions,
- availability of resources, and
- intrusiveness to plant operation.

Furthermore, the approach should take due account of the effectiveness of the safeguards system of the state to minimize unnecessary duplication of activities.

2.1 Conventional approach

The conventional approach is designed to detect both abrupt or protracted removals or losses of nuclear material across a material balance period (MBP). The final safeguards conclusion is derived after the evaluation of an operator's accountancy system and the corresponding independent verifications for the MBP. The key activities are:

1. verification of transfers in and out of a plant,
2. a yearly physical inventory verification (PIV) to close the MBP,
3. interim inventory verifications to confirm on a monthly basis that 8 kg of Pu or more in not missing from a plant,
4. the application and use of C/S measures, and
5. other activities include a book audit, follow-up actions, verification of an operator's measurement system and actions to cope with unforeseen circumstances.

The verification is based on random sampling plans which use a medium detection probabilities (DP) for interim inspections and a high DP for PIVs/inventory change verifications when calculating sample sizes.

2.1.1 Verification of transfers

Verification of transfers of nuclear materials in and out of a plant requires an inspector's presence unless receipt and shipment items can be kept identifiable and available for verification during a subsequent inspection within the timeliness period.

A MOX plant receives feed powder or solution, which is usually verified and sealed at the shipper's location, and the verification effort upon receipt can be limited to seal verification. Receipts not verified prior to shipment are to be verified by NDA/DA for gross, partial and bias defects based on a sampling plan using a 90% DP.

The verification of shipments, mainly fuel assemblies is performed with special high level neutron coincidence (HLNC) equipment. Occasionally fuel pins are shipped which are verified by high resolution gamma spectrometry (HRGS) and HLNC. In some facilities, product assemblies are accumulated in a separate storage. They are verified during the monthly inspection and are placed under C/S until shipment. Other facilities require immediate verification and packing of each assembly. The shipping container is sealed by the inspector. This requires continuous presence by inspectors.

2.1.2 Physical inventory verifications

The verification of the operator's physical inventory taking (PIT) by inspectors is a core activity for the standard safeguards approach. PIVs are carried out under shutdown conditions. The plant has to be cleaned out and all nuclear materials have to be in accountable form. Preparing for and providing assistance during the physical inventory verification requires a substantial effort from the operator.

Materials under successful C/S are remeasured with a low DP for gross and partial defects. The process inventory is verified by sampling from the glovebox inventories with sample sizes calculated using a 90% DP. The items selected for verification are identified, weighed and sampled into pre-tared vials for subsequent NDA or DA. The samples are bagged out, sent to the analytical laboratory for weighing and samples treatment as required. The amount of plutonium in the sample vials is determined by passive neutron coincidence counting (NCC) with an inventory sample counter (INVS) by HRGS. In some facilities, the complete item (e.g., powder can) is bagged out for verification by HLNC, which reduced the need for sampling.

In general, several inspector/operator teams have to work in parallel to complete the process sampling in time to assure that continuity of knowledge during the selection is preserved. This lease to a peak load of inspectors needed solely for the purpose of the PIV.

2.1.3 Interim inventory verifications

Interim inventory verifications are carried out to confirm on a monthly basis that 8 kg of plutonium or more is not missing from a facility. At the time of an interim inventory verification, the inspection is being carried out in an operating facility with material in the process. Ongoing process operations may not enable the operator to present the process inventory itemized form and verification based on a random sampling plan may not be feasible. For such cases, and in an attempt to minimize interference in plant operation and the expenditure of inspection resources, the agency implements facility or process specific procedures that detail the verification necessary to achieve the timeliness goal. These procedures are developed by the inspectors and then submitted for technical review and subsequent management approval by the Department of Safeguards.

To the extent possible, the facility-specific timeliness procedure are required to incorporate generic criteria (e.g. random sampling with a DP of 50%). However, the primary objective is to make optimum use of automated instrumentation, ongoing flow verification and any other features associated with a specific process. The effectiveness of a facility specific timeliness procedure can only be judged after sufficient implementation experience has been gained. An example of a facility specific timeliness procedure, which was implemented on a trial basis but later terminated, is given below.

2.1.3.1 Follow-up and balancing of mixes (FBOM) scheme

The desire to reduce the effort needed for the verification of the production lines and to minimize intrusion in the production process led to the development of the FBOM scheme.[4] The FBOM scheme is described as a dynamic verification scheme. the concept portrays the process as a "black box." All material, organized into identifiable units called mixes, is verified as it enters and exits the process. The idea is that if individual mixes transit the process area within a month then timeliness is achieved through a running real-time balance of mixes. Under the FBOM scheme, there are no verifications of material in the process.

Practical problems were encountered during the implementation, e.g., mixes could not be differentiated to the extent necessary, limits for the "out of balance" for individual mixes and concentration of mixes exceeded agreed limits and a large number of mix balances could not be closed within the required time period. The operator's objective to minimize intrusions into the process was not achieved because in-process verifications are required to recover from balance and differentiability failures. The FBOM scheme led to an annual expenditure of inspection manpower which was 75 percent higher than that expended to safeguard a similar plant under the standard approach. The cumulative exposure sustained by operators and inspectorate personnel for the inspection effort was three times higher than that for similar plans. As a consequence, the agency has recently stopped the use of the FBOM scheme.

2.1.4 Application of C/S measures

C/S measures are applied and evaluated to assure the integrity of verified materials. Metal seals are applied on storage locations or containers. The inspector receives most of his radiation dose during seals application (attachment/detachment and check). Recently, the agency has been using variable coding seal systems (VACOSS) on storage cubicles which can be verified by a party line from outside of the storage. This remote verification approach reduced the radiation burden both to operators and inspector.

Surveillance is used to confirm the absence of any interferences with the verified materials. Successful application of C/S measures greatly reduced the remeasurement effort required. The use of C/S is optimized when the operators separates static materials from materials anticipated to be used soon in the process.

2.1.5 Other activities

Book audit activities performed monthly include the examination and reconciliation of accountancy and operating records, the comparison of operators' records with state reports and the updating of the book inventory. The verification of operators' measurement system, e.g. pellet sampling at the rod loading station needs to be performed four times a year. Indirect use materials, e.g., UO_2 powders for blending, are normally verified only during a PIV and require only a minor inspection effort.

2.2 Modern approach: The NRTA scheme

NTRA stands for a specific safeguard scheme which requires the operators to provide at regular intervals and under normal plant conditions a snapshot of the distribution of material in the plant. The agency then verifies the inventory and strikes material balances (MB) between successive snapshots. With the implementation of an NRTA system, the approach becomes dynamic and assurance accumulates over time. The NRTA scheme enhances timely detection by subdividing a yearly MBP into separate (e.g. monthly) MBPs. The sequential statistical analysis of material unaccounted for (MUF) and operator-inspector differences (D) provide the information necessary to verify the operator's declarations in a timely manner.

2.2.1 NRTA scheme at PFPF

The NRTA scheme used at PFPF,[4] the first of its kind used in a fuel fabrication plant, is based on a verification network. The operators provided early information on the proposed design of the facility to the agency. As a result, verification instrumentation could be adequately incorporated into the final design on the basis of a mutual agreement between operator and inspectorate. While the NRTA capability provides a comprehensive and refined approach for accountancy verification, the network also comprises in-line NDA instrumentation and C/S systems. The in-line NDA equipment is used to verify the plutonium content by measuring the Pu-240 effective content of feed containers, process containers, pins, assemblies and holdup. These are HLNC type detectors tailored to specific applications.

2.2.1.1 Verification of transfers

Verification of transfers to and from the plant (feed powders and assemblies) are performed at a 100 percent level using the in-line NDA instrumentation and unattended mode. Typically, a period of one month is covered and the inspection activity is reduced to data collections and evaluation, and review of C/S to confirm movements and to identify measured items.

2.2.1.2 PIV

PIVs become less important under an NRTA scheme because the implementation of the NRTA scheme is equivalent to carrying out quasi PIVs at regular intervals with the advantage that such verifications could be done under operating conditions. The main difference from the interim inspection is the use of a higher DP in calculation of sample sizes.

Remote verification of nuclear material eliminates the need for items to be handled manually and minimizes the number of process samples to be bagged out. This reduces radiation exposure, paper work for material control, contamination risks and waste disposal requirements.

2.2.1.3 Interim inspection

Monthly inspections are carried out to verify the complete inventory. Application of NDA instrumentation integrated into the storage and process combined with surveillance reduces greatly the interference in normal plant operation. Process material and stored materials can be verified in an unattended mode during night shifts or weekends, This is achieved by a sample plan annunciator system (SPAN) which produced a safeguarded sample plan. Selected samples are revealed to the operator at a controlled time, recording the date and time of the announcement. The selected item is retrieved by the automatic transfer system from its storage position and transported to the respective measurement position with a known and reproducible transport time. The item is identified by CCTV cameras which are triggered by radiation. Inspector presence and access to the process is required for only a small fraction of items subject to sampling for DA/HRGS, for the measurement of process hold-up and to collect the measurement data.

2.2.1.4 Use of C/S

The application of C/S measures plays an important role in the application of unattended verification. C/S measures are used to:

- identify the items to be measured
- confirm their correct position in the counter during measurement
- trace their movements
- assure storage integrity.

The review of C/S data is done remotely and without interference in plant operation. Access to the plant area is required only for servicing purposes; some extra effort is also needed to authenticate the operators provided C/S systems.

2.2.1.5 Other activities

Machine-readable operators information facilitates the book audit. The additional inspection activity of running the NRTA analysis could be considered as a reconciliation of operating and accountancy records. The verification of an operator's measurement system, e.g., sampling at the pellet stage is replaced by in-line NDA instrumentation.

2.2.2 NRTA scheme and Siemens MOX II

The NRTA scheme proposed for the new automated Siemens MOX plant is similar to the one used at PFPF. However, operation scheme at Siemens dictates a quasi-continuous (e.g. daily) presence of inspectors to verify incoming feed materials and finished assemblies. Unattended NDA systems are used for the pellet tray storage, all other systems are used in the attended mode. Nuclear materials are verified by HLNC-type instrumentation in combination with HRGS and by process sampling or by seal verification.

All collected verification data, C/S data and accountancy data provided by the operators are handled within the central evaluation system. The NRTA data reduction and analysis routine of the central evaluation system enables the agency to perform a monthly material balance evaluation, i.e., to test whether to MUF and D values are within acceptable limits.

2.2.2.1 Verification of transfers

The verification of receipts in the form of PuO_2 canisters is performed on a 100% basis by an HLNC type detector with an

HRGS mounted adjacent to the neutron detector. All PuO_2 receipts are subject to sampling for DA on a statistical sampling plan. The selected cans are marked at time of receipt and will be sampled for bias defects once the cans are transferred to the process.

All fuel assemblies are verified in a fuel assembly NCC detector before they are loaded into shipping containers. Subsequently, these containers are sealed.

2.2.2.2 Interim inspection

The status of the previously verified material that has been placed under C/S measures is confirmed by evaluating the applied C/S devices, i.e., verification of seals, review of video recordings, etc. Unsealed materials in vaults are verified by HLNC and HRGS. Process materials (except pellet storage) are sampled. The samples are sent via a pneumatic system to the laboratory and subsequently measured by INVS and HRGS in the inspector's measurement room. Rods and quivers filled with rods are verified by special NCC equipment and HRGS. The inventory of the pellet stores is determined by measuring all pellet trays entering or leaving the stores. They pellet tray measurement stations operate continuously in unattended mode to collect HLNC and electromechanical data. The data is read monthly from the collection computer onto diskette and transferred to the central evaluation computer for subsequent evaluation.

2.2.2.3 Use of C/S

The C/S measures that are foreseen to be applied can be summarized as follows:

Metal seals will be used to assure integrity of previously verified material in vaults, quivers and shipping containers, and it indicate tampering measurement devices, e.g., on probes for level measurements or on loadcells (powder silos).

A multicamera system with CCTV camera covering various areas, e.g., PuO_2 input store, entrance/exit of pellet storage will be used. The surveillance data will be transmitted via a protected data link to the central inspector's room for recording.

2.3 Approach differences and cost considerations

The manually operated plants have much higher safeguards manpower requirements compared to the automated plants. The schemes for the automated plants enhance the timely detection of any missing nuclear material and reduce:

- intrusiveness in plant operation,
- operating costs,
- radiation exposure to personnel,
- risk for contamination accidents, ans
- waste.

The costs of implementing the different approaches differ significantly. Staff costs are the main cost factor for the agency in the safeguards application of manually operated plants and are covered by a regular inspection budget. Capital costs for safeguards equipment and its installation in the new plants are exceeding the agency's financial resources. Its amortization may take several years. The agency's budget in not a long-term budget and its financial resources available to invest for future savings are very limited. As a result, the agency has to find short-term solutions if it is asked to contribute financially on an equal basis. Costs can be reduced for the agency with

Table I
General plant characteristics

	PPFF	PFPF	Belgo-nuclaire	Siemens MOXI	Siemens MOXII
Start of operation	1972	1987	1973	1980	[1993]
Near Real Time Accountancy	NO	YES	NO	NO	YES
Present capacity [tMOX/y]*	10	5	40	35	[110]
Main Fuel Product	ATR	FBR	LWR	LWR	LWR
Routine Frequency of inspection	once per month	once per month	continuous	continuous	continuous
Remarks	(1),(2)	(1),(3)	(1),(2)	(1),(2),(5)	(1),(4)

*See references (3), (6) and (7)

(1) Typical Pu/(Pu+U) (w/o) for ATR, LWR :~3%; FBR:19~30%~.
(2) Facility produced also FBR type before 1988.
(3) An ATR line is under construction with a capacity of 40 [tMOX/y].
(4) Facility could produce FBR fuel (equivalent capacity: 10 [tMOX/y]).
(5) Formerly known as ALKEM.

the help of operators and the state by the use of operator-provided equipment (subject top authentication), and by plant designers taking into account the specific requirements of safeguards. Contributions from individual support programs is another important factor in the agency's realization of individual safeguards projects.

3. TRENDS

The use of MOX fuel is increasing. Construction of new commercial fabrication plants with throughputs of more than 100 tMOX/y are planned to meet the projected MOX fuel requirements. The use of plutonium within a closed nuclear fuel cycle may play a potentially key role in nuclear disarmament. Advances in nuclear disarmament may increase the amount of available plutonium that has to be dealt with by hundreds of tons. The most logical way to reduce plutonium stocks is to fabricate it into MOX fuel to be burned in commercial reactors. By this means, the stock of weapons plutonium would be consumed within the fuel cycle safeguarded by the agency. Recycling of plutonium will also save uranium resources and could reduce waste storage problems.

The increased effectiveness and the reductions in cost and radiation exposure which are expected to accompany future developments will become possible only by relying increasingly on remotely controlled operations/inspections. Remote verification could be realized by using on-line data communication between a facility and a central inspection control unit. In-line NDA verification data and C/S data could be transmitted together with NRTA accountancy data, and analytical data from automated sample analyzers. All the data could be evaluated on line by the inspection control unit. The activation of instruments could be performed remotely. A further step may become possible when technological development in the area of artificial intelligence will permit the use of robots with detection capabilities for continuous inspections of non-access areas.

4. CONCLUSIONS

MOX fuel fabrication plants are highly safeguards-sensitive facilities and their numbers are expected to increase considerably in the near future. The safeguards schemes designed for "manual" plant operations are cumbersome, manpower-intensive and not very cost effective. It can be envisaged that to reduce intrusiveness in plant operations, minimize radiation doses and enhance safeguards efficiency and effectiveness, future emphasis will increasingly be placed on the introduction of NRTA verification networks. However, to accomplish this while the financial resources available to the agency remain limited, the use of equipment provided by other sources will become necessary, and approached for the authentication of such equipment will become a prominent theme in the future. Another novel and increasingly important feature of future safeguards schemes will be the early involvement of the agency during the planning stages of a plant so that an efficient and cost-effective integration of safeguards features into the final plant design can be accomplished smoothly.

Cooperation among all parties involved is essential to implement credible safeguards measures at the plants of the future.

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Materials Control and Accountability Auditor Training

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ABSTRACT

As the Department of Energy (DOE) works to standardize the training for individuals performing materials control and accountability (MC&A) functions, the need for a definition of the appropriate training for MC&A auditors has become apparent. In order to meet the DOE requirement for individual training plans for all staff performing MC&A functions, the following set of guidelines was developed for consideration as applicable to MC&A auditors. The application of these guidelines to specific operating environments at individual DOE sites may require modification to some of the tables. The paper presents one method of developing individual training programs for an MC&A auditor or for an MC&A audit group based on the requirements for internal audits and assessments included in DOE Order 5633.3, Control and Accountability for Nuclear Materials.

I. INTRODUCTION

As the Department of Energy (DOE) works to standardize the training for individuals performing materials control and accountability (MC&A) functions, the need for a definition of the appropriate training for MC&A auditors has become apparent. The responsibilities of the MC&A auditor in a changing environment include assisting the site in ensuring the maintenance of the required level of safeguards for the nuclear materials stored, processed, or handled at the site. The rapid rate of change currently in progress makes this a challenge for all auditors, particularly relatively new auditors. Providing an appropriate level of training for new auditors and ensuring the currency of the skills for experienced auditors requires a flexible training program that can be modified to meet changes in the operating environment and missions at the site. This paper provides tools and guidelines to assist in developing the DOE required individual training plans for MC&A auditors or MC&A audit groups. The application of these guidelines to specific operating environments at individual DOE sites may require modification to some of the tables. The basis for the training needs for the MC&A audit function are the requirements for internal audits and assessments included in DOE Order 5633.3, Control and Accountability for Nuclear Materials. The tables provide the detailed information and can be used as worksheets in the development of evaluations to determine the specific training requirements for the site MC&A auditors. The DOE Order 5633.3 includes the following definitions:

Audit
The process of reviewing and evaluating compliance with applicable directives and regulations and/or the examination of records or accounts to check their accuracy.

Assessment
An appraisal to evaluate the effectiveness of an activity/operation or to determine the extent of compliance with required procedures and practices; and/or to perform an evaluation of a material control and accounting (MC&A) anomaly or material discrepancy indicator.

The DOE also uses the terms surveys and inspections to refer to activities included in the above definitions. For this paper, all inspection, evaluation, appraisal and review activities will be referred to generically as audits. The term audit was chosen simply to match the term auditor which is generally understood. The term assessor may eventually replace auditor but common usage still refers to those performing assessments and evaluations as auditors. Also throughout the paper, the term auditor(s) will refer to the individual or group of individuals performing audits.

II. TRAINING NEEDS IDENTIFICATION

The first task in defining the specific training needs for MC&A auditors is an evaluation of the job responsibilities and the DOE requirements for audits with the understanding that at each location, the auditor may have additional duties either within MC&A or in related safeguards organizations. Man-

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agement should ensure the non-audit assignments given to the MC&A auditor do not compromise their independence. The second task is to match these general tasks or responsibilities with the skills required to perform each task. The third task requires matching skills to various training sources. Table 1 identifies those skills an MC&A auditor needs to conduct the required audits.

The guidelines developed and included in this paper are comprehensive and for each auditor(s) an evaluation must be conducted to determine which tasks will be performed by the auditor(s) and which will be purchased from technical experts. Table 2 identifies those skills frequently acquired from technical support organizations. The specific determination of the combination of tasks to be included in the definition of the auditor(s)'s roles and responsibilities will vary depending on the operating environment at the site and the availability of technical experts, particularly statisticians and computer security specialists.

The general requirement for audits is defined in DOE Order 5633.3, Chapter I Section 5:

• Each facility shall establish a program to assess its control and accountability systems and procedures and to assure the integrity and quality of these systems.

• No distinctions are made among the tasks required based on either the category of the materials or on the frequency requirements for the audits.

3. REQUIREMENTS

Review of the draft of 5633.3A does not indicate shrinkage in the internal audit requirements for MC&A but rather indicates an increase in the number of performance tests. A distinction between MC&A internal assessments and MC&A internal audits is drawn in the draft 5633.3A. The site specific implementation of these new requirements will vary but the impact on the specific training requirements is limited. Table 1 presents information that is valid for the DOE complex under the current DOE Order 5633.3.

Site specific evaluation of the MC&A internal audit function may include audit requirements from additional DOE orders based on the responsibilities assigned to the MC&A audit group. Any additional requirements should be compared and cross-referenced to the list of skills prior to determining the training needs for individuals assigned to perform these additional audits.

Table 3 includes the specific DOE order reference requiring MC&A audits. The table also includes cross references to Table 1, Matrix of MC&A Audit Skills, for each requirement.

4. DEVELOPMENT OF INDIVIDUAL TRAINING PLANS

After determining which MC&A audit functions will be performed by the individual auditor or audit group, it is necessary to conduct a skills assessment and determine which of the needed skills each auditor possesses. The skills assessment should be conducted for each member of the audit group and the overall needs identified. The nature of the work assignment may permit specialization with coverage for the group provided by different individuals. MC&A management must decide the level of coverage for each type of audit work to determine how many auditors must be trained to perform each required audit.

The next step is the development of individualized training plans. The training plans must identify specific skill needs for each individual and then prioritize these skills to assist in developing a training schedule. The prioritization should consider the technical support services available as well as the cost of training to provide the maximum coverage of the required skills to minimize the training costs. The long-term plan should reflect a cost-benefit analysis of reliance on technical support organizations versus development of in-house expertise. These plans should also consider the individual career goals of the individual auditor to permit development towards long-term career goals wherever practical.

5. SKILL ACQUISITION

Table 4 adds sources of training to the matrix of MC&A audit skills listed as Table 1. The sources for skills are listed as central training academy (CTA), formal education, professional training, job experience and site-specific training. These sources are explained in the following paragraphs.

CTA. There are numerous sources of training for auditors but the major provider of training specifically designed for MC&A auditors is the CTA. The CTA has two courses that are directly applicable for MC&A auditors, MCA150 - MC&A Inspection Procedures and MCA103 — Introduction to Performance Testing. A follow-on course to MCA150, MCA351 — Advanced MC&A Inspection Techniques, has been proposed but the general format and structure for this class has not been finalized. The other courses listed provide additional training in MC&A functions that provide skills necessary to MC&A auditors:

MCA101: Introduction to Materials Control and Accountability
MCA110: Basic Nuclear Materials Accounting
MCA130: MC&A Statistics for Managers — This course is under development.
MCA140: Basics of MC&A Measurements — This course is under development.
MCA144: Measurement Control Programs in MC&A — This course is under development.

The courses under development will be completed based on funding and priorities set by the CTA and the availability of subject matter experts to participate in the adjunct faculty teams formed by the CTA for each course. The references in Table 4 are based on discussions with CTA staff to identify skills scheduled to be included in each of these courses.

Table 1
Matrix of Skills

Specific Skill

I. ACCOUNTING
   - A. Generally Accepted Accounting Principles (GAAP)
   - B. Inventory procedures
   - C. Reconciliation processes
   - D. Internal controls
     1. Identify controls
     2. Evaluate controls
     3. Recommend improvements

II. PERFORMANCE TESTING
   - A. Develop tests
   - B. Conduct tests
   - C. Evaluate results

III. OVERALL PROGRAM REQUIREMENTS DEFINITION
   - A. Familiarity with DOE Order 5633 Series
   - B. Other safeguards orders
   - C. Understand relevant facility policies and procedures
   - D. General understanding of health, safety and environmental regulations

IV. COMPUTER SYSTEMS
   - A. System development methodologies
   - B. System development testing
   - C. Methods of internal control available for testing through the computer
   - D. Disaster recovery
   - E. Computer security
   - F. Configuration control systems

V. AUDIT
   - A. System analysis – suggest areas for improvement in economy and efficiency
   - B. Planning
   - C. Effective observation techniques
   - D. Understanding of various types of audit evidence and relative merits of each
   - E. Development of sufficient documentation
   - F. Reporting/follow-up
   - G. Develop effective check lists for compliance audits

VI. INTEGRATED SAFEGUARDS
   - A. Understanding of graded safeguards approach
   - B. Risk analysis used to develop overall audit schedule
   - C. Risk analysis used to develop specific audit program
   - D. Develop integrated audit approach
   - E. Evaluate effectiveness of defense in depth
   - F. Evaluate effectiveness of the MC&A program as part of total safeguards package

VII. STATISTICS
   - A. Ability to develop sound random samples
   - B. Review control charts and evaluate appropriateness of calculation of control limits
   - C. Evaluate results from tests based on statistical samples
   - D. Determine when to use statistical vs. judgmental samples
   - E. Evaluate validity of statistically based internal control systems
   - F. Evaluate adequacy of statistically based measurement controls

VIII. TECHNICAL – CHEMISTRY OR ENGINEERING
   - A. Understand appropriate facility specific terminology
   - B. Communicate with technical operating staff
   - C. Evaluate impact on MC&A controls of proposed changes in processing methodologies
   - D. Understand limitations on controls based on engineering or other technical constraints
   - E. Evaluate analytical results requested as part of verification/confirmation programs
   - F. Evaluate precision and accuracy limits for various destructive and nondestructive assay methodologies
   - G. Evaluate overall effectiveness of measurement control program

IX. PERSONAL/PROFESSIONAL SKILLS
   - A. Ability to work as member of the MC&A team
   - B. Maintain objective, independent attitude
   - C. Negotiation/persuasion techniques
   - D. Strong sense of ethics and willingness to carry through on identified issues to ensure appropriate disposition
   - E. Effective listening
   - F. Communication
     1. Verbal
     2. Written

Table 2
Skills Commonly Purchased From Technical Organizations*

IV. COMPUTER SYSTEMS
   A. System development methodologies
   B. System development testing
   C. Methods of internal control available for testing through the computer
   D. Disaster recovery
   E. Computer security
   F. Configuration control systems

VI. INTEGRATED SAFEGUARDS
   E. Evaluate effectiveness of defense in depth

VII. STATISTICS
   A. Ability to develop sound random samples
   B. Review control charts and evaluate appropriateness of calculation of control limits
   E. Evaluate validity of statistically based internal control systems
   F. Evaluate adequacy of statistically based measurement controls

VIII. TECHNICAL – CHEMISTRY OR ENGINEERING
   D. Understand limitations on controls based on engineering or other technical constraints
   E. Evaluate analytical results requested as part of verification/confirmation programs
   F. Evaluate precision and accuracy limits for various destructive and nondestructive assay methodologies

*These skills are a subset of those listed in Table 1 and the numbering from Table 1 has been maintained.

Table 3
List of Defined MC&A Audit Requirements

1. Task: Establish a program to assess control and accountability systems and procedures, and to assure the integrity and quality of these systems
   DOE Order Reference: 5633.3 I.5
   Skills Needed for Task*: III; V.B; VI.B, C
2. Task: Document the internal review and assessment program
   DOE Order Reference: 5633.3 I.5.a
   Skills Needed: V.E, F, G; IX.F
3. Task: Maintain auditor(s) independence from process operation
   DOE Order Reference: 5633.3 I.5.a
   Skills Needed: IX.B, D
4. Task: Assess the effectiveness of the MC&A system in deterring, preventing, detecting, and responding to the unauthorized removal of SNM
   DOE Order Reference: 5633.3 I.5.a
   Skills Needed: II.A, B, C; V.A
5. Task: Audit the selection, maintenance, calibration, and testing functions to assure proper equipment and system performance
   DOE Order Reference: 5633.3 I.5.b
   Skills Needed: VIII.A-G
6. Task: Audit the system of checks and balances, including separation of duties and responsibility
   DOE Order Reference: 5633.3 I.5.b
   Skills Needed: I.A, D; IV.B,C
7. Task: Audit to identify irregularities and to detect or prevent tampering with materials or MC&A system components
   DOE Order Reference: 5633.3 I.5.b
   Skills Needed: IV.C; VI.F
8. Task: Audit change controls, including authorization requirements to prevent unauthorized or inappropriate modification of system components, procedures, or data
   DOE Order Reference: 5633.3 I.5.b
   Skills Needed: I.D; IV.A, F
9. Task: Audit procedures and/or checks to assure the reliability and accuracy of MC&A data and information
   DOE Order Reference: 5633.3 I.5.b
   Skills Needed: I.D; IV.E; VII

9a. Task: Audit physical inventories conducted
   Skills Needed: I.B; VII

9b. Task: Audit physical inventory reconciliation program
   Skills Needed: I.C

9c. Task: Audit controls that limit access to the accounting system and nuclear materials accounting data
   DOE Order Reference: 5633.3 II.2.d
   Skills Needed: IV.E

10. Task: Conduct tests to provide verification of procedures and practices to show that material controls are effective
   DOE Order Reference: 5633.3 I.5.c
   Skills Needed: II
11. Task: Assess procedures for emergency conditions and for periods when MC&A system components are inoperative
   DOE Order Reference: 5633.3 I.S.d
   Skills Needed: II; IV.D; VI.E
12. Task: Assure that the individuals responsible for performing measurements have sufficient knowledge to perform the measurements in an acceptable manner
   DOE Order Reference: 5633.3 II.4.c
   Skills Needed: III.C; V.D
13. Task: Provide assurance that measurement personnel are qualified and requalified according to a training plan to ensure demonstration of acceptable levels of proficiency before performing measurements
   DOE Order Reference: 5633.3 II.4.c
   Skills Needed: V.D

*Skills needed are listed in Table 1 (*Continued on page 36*)

Table 3

(Continued from page 35)

14. Task: Conduct audits to provide assurance that only qualified measurement methods are used for accountability purposes
DOE Order Reference: 5633.3 II.4.b
Skills Needed: VIII.G

15. Task: Audit measurement systems to ensure maintenance of measurement methods that can provide nuclear material values for all nuclear materials on inventory
DOE Order Reference: 5633.3 II.4.d.2
Skills Needed: VIII.F

16. Task: Provide assurance of the effectiveness of the measurement control program
DOE Order Reference: 5633.3 II.4.e
Skills Needed: VII.B, F; VIII.G

17. Task: Assess the material control indicators to provide assurance that losses and unauthorized removals of nuclear materials are detected
DOE Order Reference: 5633.3 II.6
Skills Needed: VII

18. Task: Audit materials access program to assure that only properly authorized personnel have access to nuclear materials, to accountability data and information, and to data generating equipment
DOE Order Reference: 633.3 III.2.a, b, c
I.D; IV.E; VI.A, E, F

19. Task: Evaluate material containment program including the following areas: Material Access Areas; Material Balance Areas; Materials in Storage; Materials in Use or Process; Transfers
DOE Order Reference: 5633.3 II.4
Skills Needed: I.D; II; VI.F

20. Task: Ensure effectiveness of the program for detection and assessment of the unauthorized removal of nuclear materials: Daily Administrative Checks; Tamper-indicating Devices; Portal Monitors; Waste Monitors
DOE Order Reference: 5633.3, III
Skills Needed: II; VI.D, E, F; VII; VIII

Formal Education. Table 4 references for formal education are to college level courses in the related field (i.e., for Sections I and V, Accounting and Audit, these skills can be obtained through accounting course work or a degree in accounting, finance or a related field). The skills for Section IV, Computer Science, would require a degree in computer science or a significant number of computer science courses. In Section VII, Statistics, a limited number of courses may provide the required level of expertise. Section VIII, Technical, would be satisfied with a degree in a physical science or engineering or selected course work as determined by the type of operations conducted at the site. In evaluating the appropriateness of specific courses, it may be necessary to obtain guidance from individuals in the relevant field.

Professional Training. There are a multitude of professional training organizations providing workshops or training classes in specific skills. These training sources may be more expensive than other options but provide the opportunity to target specific skills with limited time commitments.

Job Experience. Relevant job experience could include working with experienced MC&A auditors or in another MC&A field, i.e., materials accounting. Experience as an accountant, internal auditor, programmer, system analyst, chemist, engineer or statistician would be another effective source of training for an MC&A auditor.

Site-Specific Training. The general employee training provided at each site provides a good basic understanding of the safety, health and environmental concerns at the site. The effectiveness of this training related to MC&A must be evaluated at each site. Each MC&A organization must provide training in the site accountability system and many provide additional training for MC&A staff and/or operating area staff. These courses should be evaluated as a resource for training new MC&A auditors.

6. CONCLUSION

The information presented in the tables is detailed and comprehensive and initially presents a picture of an unreachable target for training new MC&A auditors. But, as the site specific information is factored in along with the skills possessed by the MC&A auditors, the resulting training needs can be prioritized and the training plans for individual auditors developed to meet the needs of both the organization and the individual.

Margaret A. Barham made the transition from internal auditing to nuclear materials control and accountability (NMC&A) in August 1990. The initial job responsibilities included developing, documenting and implementing the NMC&A internal audit program for the Department of Energy (DOE) Oak Ridge K-25 Site (managed by Martin Marietta Energy Systems) and developing a comprehensive set of programmatic documentation for the K-25 Site NMC&A program.

Prior to working in internal audit (three years for Martin Marietta Energy Systems and one year for Rockwell Hanford Operations, Richland, Wash.), the author worked in finance for Rockwell Hanford Operations for three years. The author is in the process of transferring to a new position in the Safeguards Studies Group at Martin Marietta Energy Systems to work on various projects for DOE and the Nuclear Regulatory Commission. The author is a Certified Internal Auditor and Certified Public Accountant.

Table 4
Matrix of Skills and Sources for Training

Specific Skill	CTA Training	Formal Education	Professional Training	Job Experience	Site-Specific Training
I. ACCOUNTING					
A. GAAP-Accounting Principles	MCA110	•			
B. Inventory Procedures	MCA110				
C. Reconciliation Processes	MCA110	•			•
D. Internal Controls					
1. Identify controls			•	•	•
2. Evaluate controls			•	•	
3. Recommend improvements			•	•	
II. PERFORMANCE TESTING					
A. Develop tests	MCA103			•	
B. Conduct tests	MCA103			•	
C. Evaluate results	MCA103			•	
III. OVERALL PROGRAM REQUIREMENTS DEFINITION					
A. Familiarity with DOE Order 5633 Series Reading	MCA110, MCA101			•	Required Reading
B. Other Safeguards Orders				•	Required Reading
C. Understand relevant facility policies and procedures				•	
D. General understanding of health, safety and environmental training regulations			•	•	Site Access Gen. Employ-eeTraining
IV. COMPUTER SYSTEMS					
A. System development methodologies		•	•	•	
B. System development testing		•	•	•	
C. Methods of internal control available for testing through the computer			•	•	
D. Disaster recovery		•	•	•	
E. Computer security		•	•	•	
F. Configuration control systems		•	•	•	
V. AUDIT					
A. System Analysis suggest areas for improvement in economy and efficiency	MCA351 (proposed)	•		•	
B. Planning	MCA150			•	
C. Effective observation techniques			•	•	
D. Understanding of various types of audit evidence and relative merits of each		•	•	•	
E. Development of sufficient documentation		•	•	•	
F. Reporting/follow-up	MCA150		•		
G. Develop effective check lists for compliance audits	MCA351 (proposed)			•	
VI. INTEGRATED SAFEGUARDS					
A. Understanding of Graded Safeguards Approach	MCA101				
B. Risk Analysis used to develop overall audit schedule	MCA351 (proposed)			•	
C. Risk Analysis used to develop specific audit program	MCA150			•	

(*Continued on page 38*)

Table 4

(Continued from page 38)

Specific Skill	CTA Training	Formal Education	Professional Training	Job Experience	Site-Specific Training
D. Develop integrated audit approach	MCA351 (proposed)				
E. Evaluate effectiveness of defense in depth	MCA103				
F. Evaluate effectiveness of the MC&A program as part of total safeguards package	MCA351 (proposed)				
VII. STATISTICS					
A. Ability to develop sound random samples		•			
B. Review control charts and evaluate appropriateness of calculation of control limits	MCA140 (development)	•		•	
C. Evaluate results from tests based on statistical samples	MCA130	•		•	
D. Determine when to use statistical vs. judgmental samples	MCA130	•		•	
E. Evaluate validity of statistically based internal control systems		•		•	
F. Evaluate adequacy of statistically based measurement controls		•			
VIII. TECHNICAL CHEMISTRY OR ENGINEERING					
A. Understand appropriate facility specific terminology				•	•
B. Communicate with technical operating staff	MCA144 (development)	•		•	
C. Evaluate impact on MC&A controls of proposed changes in processing methodologies				•	
D. Understand limitations on controls based on engineering or other technical constraints	MCA144 (development)	•		•	
E. Evaluate analytical results requested as part of verification/confirmation programs	MCA144 (development)	•		•	
F. Evaluate precision and accuracy limits for various destructive and nondestructive assay methodologies	MCA144 (development)			•	
G. Evaluate overall effectiveness of measurement control program	MCA351 (proposed)			•	
IX. PERSONAL PROFESSIONAL SKILLS					
A. Ability to work as member of the MC&A team					
B. Maintain objective, independent attitude					
C. Negotiation/persuasion techniques			•		
D. Strong sense of ethics and willingness to carry through on identified issues to ensure appropriate disposition					
E. Effective listening			•		
F. Communication Verbal Written					
Verbal		•	•	•	
Written		•	•	•	

Estimating Shipper/Receiver Measurement Error Variances by Use of ANOVA

■
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■

ABSTRACT

Every measurement made on nuclear material items is subject to measurement errors which are inherent variations in the measurement process that cause the measured value to differ from the "true" value. In practice, it is important to know the variance (or standard deviation) in these measurement errors, because this indicates the precision in reported results. If a nuclear material facility is generating "paired" data (e.g., shipper/receiver) where party 1 and party 2 each make independent measurements on the same items, the measurement error variance associated with both parties can be extracted. This paper presents a straightforward method for the use of standard statistical computer packages, with analysis of variance (ANOVA), to obtain valid estimates of measurement variances. Also, with the help of the P-value, significant biases between the two parties can be directly detected without reference to an F-table.

INTRODUCTION

In an ideal nuclear material measurement environment, the item we are measuring will equal the true value of the item. However, measurement errors, which are the result of variations in man, machine, method and environmental influences, usually prevent the two from agreeing. Because measurement errors are inherent to the measurement process, a very important nuclear material control problem is the estimation of the variability in measurement errors. Knowing the variability in measurement errors allows the precision of the particular measurement method, which expresses the typical disagreement of repeated measurements of a single item by the method, to be determined.

The intent of this paper is to show how analysis of variance (ANOVA) can be easily applied to shipper/receiver (S/R) data, or more generally, "paired" data from two methods to estimate the inherent measurement error variability of both parties. Statistical theory is used to establish that the mean square error (MSE) from the ANOVA for paired data is an unbiased estimator of the true measurement error variance for both parties. The derivation of this equivalence is given in the Appendix.

DEFINITIONS AND BEST DATA GATHERING TECHNIQUE TO USE

A parameter that quantifies the variability in measurement errors is the variance. We will term this the measurement error variance and denote it as σ^2_ε. Typically, there are two techniques for estimating σ^2_ε:

1. Repeat measurements on a "known" standard.
2. Single measurements on production material items by two methods (e.g., S/R).

Technique 2 is preferred because the operator does not know what the true value should be. When an operator knows about what the value should be, as he will with standards, it will be extremely difficult for him to be uninfluenced by this knowledge when determining a value for the standard. Consequently, measurement error variances tend to be underestimated. Precision estimates with production material, as obtained when shippers and receivers each measure materials, are immune from such influences. Therefore, more realistic estimates of the uncertainties associated with the measurement method can generally be derived from the actual production materials themselves.

The data obtained from technique 2 are denoted "paired" data. In general, when n items are each measured once for the same characteristic by two methods or parties (methods and parties being interchangeable), we say the data are paired. Specifically, with S/R data, there are n production material containers that are each weighed once by the shipper and the receiver, where shipper and receiver represent the two methods. Because paired data are quite common (S/R data) or can be made so (see Example 2), they are extremely valuable for obtaining valid estimates of the methods measurement error variance.

ANOVA TECHNIQUE AND METHODOLOGY FOR PAIRED DATA

The ANOVA (analysis of variance) is a powerful technique that allows for the separation of the different sources of variation in our data set. An excellent discussion of classical analysis of variance can be found in Bowen and Bennett.[1] For the general paired data layout (see Table A in Appendix), we

Table 1
Two-Way ANOVA for paired data

Source	DF	SS	MS	F	P-Value
Methods	N-l	SSl	MSl	MSl/MSE	
Items	n-l	SS2	MS2	M52/MSE	
Error	(N-l)(n-l)	SSE	$MSE = S^2_\varepsilon$		
Total	2n-1	SST			

have what is known as a two-way crossed ANOVA with one observation per cell. Computer printouts of ANOVA results for paired data have the format of Table 1, although some of the nomenclature may be slightly different.

Source refers to the sources of variation (Methods, Items, and Measurement Error), and for each source, **DF** refers to the degrees of freedom, **SS** to the Sum of Squares, **MS** to the Mean Square, **F** to the F statistic, and **P-value*** measures whether F is statistically large. The sum of squares Methods (SSl) measures the variability between the two method means (e.g., S/R means), the sum of squares Items (SS2) measures the variability between item means, while SSE is the sum of squares due to measurement error. SST is a measure of the overall variability in the data. Each mean square is the sum of squares for the source of variation divided by the degrees of freedom for the source. The F is the ratio of the source Mean Square to the Mean Square Error (MSE).

MSE is an unbiased estimate of the common measurement error variance, σ^2_ε, for both methods *assuming they have equal variances*. (See proof in Appendix.)

In nuclear material applications, the equality of variance assumption may not be valid. In this case, the notation that follows will be needed to derive separate estimates of each parties variances:

Let

$S^2_{\varepsilon 1}$ = observed measurement error variance for Method 1 (Ml). Estimates $\sigma^2_{\varepsilon 1}$, the true measurement error variance for Ml.

$S^2_{\varepsilon 2}$ = observed measurement error variance for Method 2 (M2). Estimates $\sigma^2_{\varepsilon 2}$, the true measurement error variance for M2.

S^2_ε = observed measurement variance for both parties (MSE from ANOVA). Estimates σ^2_ε, the common measurement error variance for both parties.

S^2_T = observed variance in the true values of the items, = (MS2 - MSE)/2 from ANOVA. Estimates σ^2_T.

S^2_1 = observed variance among the Ml values. Estimates $\sigma^2_T + \sigma^2_{\varepsilon 1}$.

S^2_2 = observed variance among the M2 values. Estimates $\sigma^2_T + \sigma^2_{\varepsilon 2}$.

Table 2
Possible situations and actions leading to different estimates of the measurement error variances

Situation Leading to Various Estimates of $\sigma^2_{\varepsilon 1}$ and $\sigma^2_{\varepsilon 2}$		Action to Estimate Variance
1:	assume $\sigma^2_{\varepsilon 1} = \sigma^2_{\varepsilon 2}$	set $S^2_{\varepsilon 1}$, and $S^2_{\varepsilon 2}$ = MSE
2:	assume $\sigma^2_{\varepsilon 1} \neq \sigma^2_{\varepsilon 2}$	set $S^2_{\varepsilon 1} = S^2_1 - S^2_T$ $S^2_{\varepsilon 2} = S^2_2 - S^2_T$
2A:	either $S^2_{\varepsilon 1}$ or $S^2_{\varepsilon 2}$ is negative after performing Action 2.	call it zero and the other 2(MSE)
2B:	P-Value for S^2_T is greater than 0.75 or S^2_T is negative from ANOVA#.	set $S^2_{\varepsilon 1} = S^2_1$ $S^2_{\varepsilon 2} = S^2_2$

A large P-value or negative value of S^2_T indicates the true item to item variance is negligible.

This notation is utilized in Table 2, which provides a listing of the most common situations that can lead to different variance estimates, as well as the mathematical actions that will provide the best estimates of these variances.

EXAMPLES OF ESTIMATING MEASUREMENT ERROR VARIANCE AND BIAS OF TWO METHODS USING ANOVA

Two examples follow which illustrate how to use paired data with the ANOVA technique to (1) estimate the common measurement error variance for the shipper's and receiver's measurement method, and establish if a bias exists, and (2) compare two operator's measurement precisions within a facility.

*The term "P-Value" may be mentioned by different names for different statistical packages (e.g., "P," "Sig.Level," "Prob.," "PR > F").

Table 3
Data Input for example 1

Response	Container	Party
13.08	1	1
13.14	2	1
13.08	3	1
13.18	4	1
13.19	5	1
13.22	1	2
13.24	2	2
13.15	3	2
13.20	4	2
13.17	5	2

an unbiased estimate of the true variance for both the shipper's and the receiver's measurement process for weighing production cylinders. The standard deviation of the measurement error, S_e, which is often defined as the "precision," is $\sqrt{0.00201}$ or 0.04483.

(b) To determine whether a bias exists, we obtain the P-value, which is the probability of incorrectly concluding a bias exists between the two parties (i.e., the observed α-level). If the P-value for one Party is suitably small (≤ 0.05 or 0.1, or $\leq$ whatever has been pre-chosen as α by the experimenter), this indicates the two party averages are statistically different.

The P-value (0.0941) indicates that the bias between the two parties is statistically significant, i.e., the two sample means are further apart than we would expect from measurement errors alone. An investigation as to the cause appears warranted. Notice that the P-value has allowed us to make a decision about the significance of the bias without consulting the standard F table. A very nice attribute, indeed!

Table 4
Computer ANOVA output for example 1.

Source	DF	SS	MS	F	P-Value
Parties	1	.00961	.00961	4.781	.0941
Containers	4	.0084	.0021	1.045	.4836
Error	4	.00804	.00201		
Total	9	.02605			

Example 1

Shipper/Receiver data for the weight of 5 filled UF6 containers are as follows:

Container	Ml (shipper)	M2 (receiver)
1	13.08	13.22
2	13.14	13.24
3	13.08	13.15
4	13.18	13.20
5	13.19	13.17
Mean	13.134	13.196

(a) If past experience indicates the two-party measurement error variances are equal, what is the estimate of the common measurement variance, σ^2_ε?

(b) Does a bias exist between the shipper's and receiver's results (i.e., are the two parties true means statistically different)?

To perform the ANOVA, the majority of statistical packages require that the values being compared all reside in a single variable. A second and third variable supply the item and method information via identifiers, 1, 2, etc. Table 3 shows the data file format for Example 1. The ANOVA results are in Table 4.

Solution (a) Situation 1 from Table 2 applies, so the observed measurement error variance equals 0.00201. This is

*The data for example 2 are given also in reference 1 [p. 820] where the authors apply Grubb's method to the data.

Example 2

To compare the precision of two newly hired operators, the same 18 containers of production material were weighed once by each operator on the same scale. (Assume the same measurement operation is carried out by both individuals during the same time frame so that the same environment is created for both). Since no prior data exist for these new operators, it will be prudent to assume they have different measurement error variances, i.e., $\sigma^2_{\varepsilon1} \neq \sigma^2_{\varepsilon2}$.

(a) What are the best estimates of the "within-operator" measurement error variances?

(b) Assuming that S^2_T is negative, estimate the measurement error variances.

The data and ANOVA results are listed in Table 5 and Table 6.

Solution. (a) Situation 2 from Table 2 applies to this data since we could not assume equal measurement error variances.

From Action 2, $S^2_{\varepsilon1} = S^2_1 - S^2_T$ and $S^2_{\varepsilon2} = S^2_2 - S^2_T$

From the ANOVA,
$S^2_T = (5.90958 - 3.27515)/2 = 1.31721.$

Table 5

Data for example 2

Container	Operator 1	Operator 2
1	75.44	73.96
2	77.46	75.98
3	72.22	74.15
4	75.85	75.98
5	74.28	77.44
6	76.82	77.61
7	74.24	70.30
8	77.87	80.27
9	75.32	78.75
10	76.17	73.70
11	73.21	77.93
12	75.65	74.70
13	76.93	73.38
14	72.36	73.67
15	79.15	76.01
16	75.90	77.01
17	77.03	76.71
18	75.90	73.71
	$S^2_1 = 3.4330^*$	$s^2_2 = 5.7517^*$

Table 6

ANOVA for example 2

Source	DF	SS	MS	F	P-Value
Operator	1	.0081	.0081	.00247	.9614
Container	17	100.46289	5.90958	1.804	.1169
Error	17	55.6776	3.27515		
Total	35	156.1486			

This estimates the variance in the true container weights, σ^2_T, i.e., the "product" variance. At this point, if S^2_T is negative or the P-value for container is > 0.75, we perform Action 2B. Since P-value = 0.1169, we proceed with Action 2.

Therefore,

$S^2_{\varepsilon 1} = 3.4330 - 1.31721 = 2.1158$, and

$S^2_{\varepsilon 2} = 5.7517 - 1.31721 = 4.4345$.

Notice that (2.1158 + 4.4345)/2 = 3.27515 is the ANOVA estimate of the *common* measurement error variance, which is valid only if you can assume $\sigma^2_{\varepsilon 1} = \sigma^2_{\varepsilon 2}$. Since precision worsens as the value of the standard deviation (or variance) increases, operator 2 is less precise than operator 1. Although a formal test for equality of variance should be performed, the assumption of variance heterogeneity (unequal precision) appears plausible. If the purpose of the investigation was to choose a "winner," it appears to be operator 1. If the purpose was to find areas of improvement, it is with operator 2.

Note: If $S^2_{\varepsilon 1}$ or $S^2_{\varepsilon 2}$ had been negative, we would perform Action 2A by setting the negative estimate equal to zero and the other becomes MSE multiplied by two.

(b). This is situation 2B, thus

S^2 = (A) = 3.433 and

$S^2_{\varepsilon 2}$ = (B) = 5.7517.

ASSUMPTIONS

It is assumed that the item values are limited to a small enough range so that (l) any bias existing between the two parties remains constant and (2) the magnitude of the measurement error variance does not depend on the magnitude of the items measured — otherwise a single variance does not exist for each party. These assumptions can be examined by preparing a "residual" plot via the ANOVA routine or by lotting the n differences (D_i values from Table A in the Appendix) against time order on a trend chart. If the plotted points (on either chart) appear randomly distributed, the assumptions are valid. If non-random trends exist, consult a statistician. In Jaech's paper, "Statistical Methods in Nuclear Materials Control,"[2] there is an example of a set of paired data violating the assumptions. Finally, as with all estimation procedures, the larger the sample size (number of items measured), the more precise the estimate of $\sigma^2_{\varepsilon 1}$ and $\sigma^2_{\varepsilon 2}$.

CONCLUSION

Experience shows that no matter how good two parties measurement processes are, a measurement taken on the same item by each party (e.g., shipper and receiver) will usually disagree because of measurement errors. Knowing the variance (or standard deviation) in these measurement errors, we can quantify the inherent precision of each measurement method and thus judge the adequacy of the method. This paper has shown how to use a familiar statistical technique known as ANOVA to easily obtain the best estimate of the shipper's and receiver's measurement error variances. More generally, when n items are each measured once for the same characteristic by two "methods" (methods may be shipper and receiver,

*Using the routine sample variance formula we get

$$S^2_1 = \frac{(75.44)^2 + \ldots + (75.90)^2 - \{(75.44 + \ldots + 75.90)^2/18\}}{17} = 3.4330$$

$$S^2_2 = \frac{(73.96)^2 + \ldots + (73.71)^2 - \{(73.96 + \ldots + 73.71)^2/18\}}{17} = 5.75$$

scale 1 and 2, operator 1 and 2, procedure 1 and procedure 2, or any two sources), the technique will work equally well. Secondly, by use of a helpful statistic known as the P-value, an "on-the-spot" assessment of the statistical significance of the bias between the two methods is obtained without having to track down a table of significant F values before a conclusion can be made.

APPENDIX

1. Table A is a schematic of a typical paired data layout.

Item	Method 1	Method 2	Mean	Diff. $(I_{i1} - I_{i2})$
1	I_{11}	I_{12}	$\bar{I}_1$	D_1
2	I_{21}	I_{22}	$\bar{I}_2$	D_2
.	.	.	.	.
.	.	.	.	.
n	I_{n1}	I_{n2}	$\bar{I}_n$	D_n
Mean	$\bar{T}_1$	$\bar{T}_2$	$\bar{S}$(grand average)	$\bar{D}$

Table A Notation

The symbol I_{11} represents the measurement of item 1 under method 1 and I_{12} the measurement of item 1 under method 2. In general, the first subscript to an I indicates the item observed and the second subscript the method under which the observation is made.

Let n = # of items, i = 1, 2,..., n

N = # of methods, j= 1,2.

2. ANOVA breakdown of total variation.

In ANOVA terminology,

SSTotal = SSItem + SSMethods + SSError

or,

SSMethod + SSerror = SSTotal - SSItem (A)

Since the variation within an item is made up of method differences and measurement error, we can write,

SSWithin = SSMethod + SSError. (A1)

Rearranging terms,

SSError = SSWithin - SSMethod. (B)

3. Proof that the estimate of ANOVA MSError is an unbiased estimator of the true measurement error variance.

By use of notation from Table A,

$$\text{SSwithin item i} = \sum_{j=1}^{2} (I_{ij} - \bar{I}_i)^2 = \frac{(I_{i1} - I_{i2})^2}{2}. \quad (1)$$

The pooled within item variation,

$$\text{SSwithin,} = \sum_{i=1}^{n} \frac{(I_{i1} - I_{i2})^2}{2}. \quad (1A)$$

$$\text{SSmethod} = n\sum_{j=i}^{2} (\bar{T}_j - \bar{S})^2 = \frac{n(\bar{T}_1 - \bar{T}_2)^2}{2}. \quad (2)$$

From (B) above we have,

$$\text{SSerror} = \sum_{i=1}^{n} \frac{(I_{i1} - I_{i2})^2}{2} - \frac{n(\bar{T}_1 - \bar{T}_2)^2}{2}. \quad (3)$$

Now let $D_i = I_{i1} - I_{i2}$.

$$\text{Then } \bar{D} = {}^1/_n \sum_n D_i = \bar{T}_1 - \bar{T}_2. \quad (4)$$

$$\text{Hence, SSerror} = {}^1/_2 [\sum_n D_i^2 - n\bar{D}^2]. \quad (5)$$

It is easy to see that (5) is just

$${}^1/_2 [\sum_n D_i^2 - (\sum_n D_i)^2/n]. \quad (6)$$

From the ANOVA table, SSerror has (N-1)(n-1) degrees of freedom. Taking N=2,

$$\text{MSerror} = \frac{\text{SSerror}}{(n-1)} = {}^1/_2 * \frac{\sum_n D_i^2 - [(\sum_n D_i)^2/n]}{(n-1)}. \quad (7)$$

The ratio to the right of ½ is the simple variance of the D_i values, S^2_{diff}. Thus (7) = ½ * (s^2_{diff}).

It is well known,[4] that

$$E[S^2diff/2] = \frac{\sigma^2_{\varepsilon 1} + \sigma^2_{\varepsilon 2}}{2} \quad (8)$$

Thus,

$$E[\text{MSerror}] = \frac{\sigma^2_{\varepsilon 1} + \sigma^2_{\varepsilon 2}}{2} \quad (8A)$$

Now if $\sigma^2_{\varepsilon 1} = \sigma^2_{\varepsilon 2} = \sigma^2_{\varepsilon}$, then $E[\text{MSerror}] = \sigma^2_{\varepsilon}$. (9)

Thus (8) and (9) are equivalent and (9) implies the ANOVA MSerror is an unbiased estimator of σ^2_{ε}.

For $\sigma^2_{\varepsilon 1} \neq \sigma^2_{\varepsilon 2}$ see Jaech[4] and Grubbs.[3]

ACKNOWLEDGMENT

I wish to thank Dr. Henry Thomas and Mr. David Shisler for their helpful suggestions concerning the preparation of the paper.

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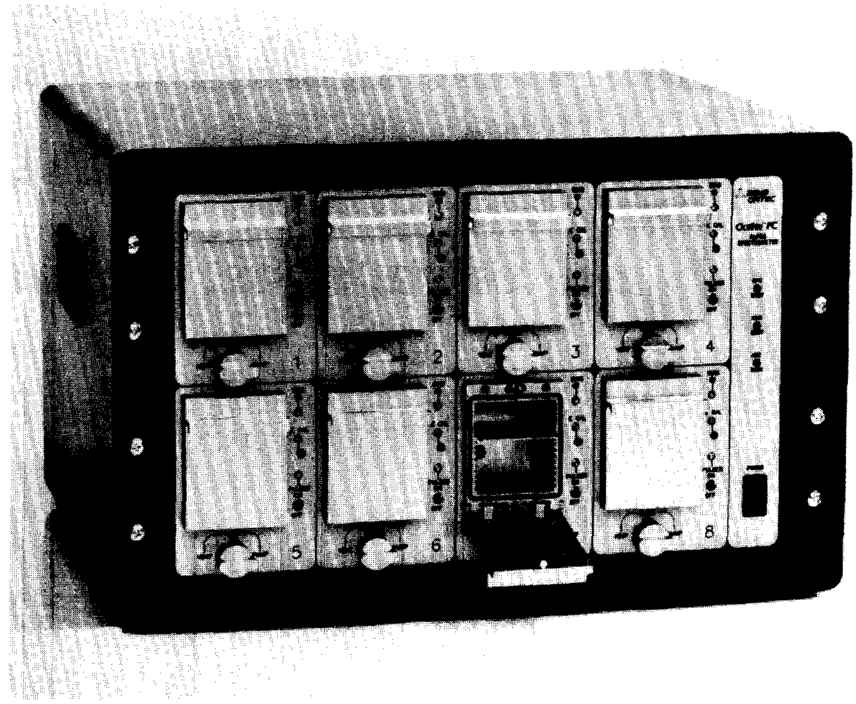

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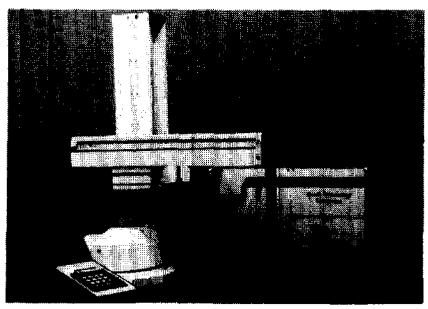

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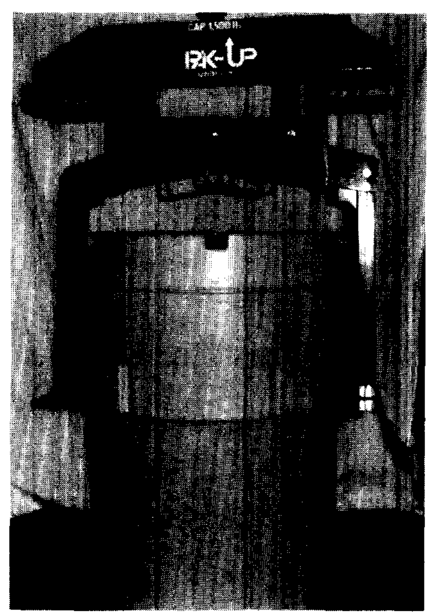

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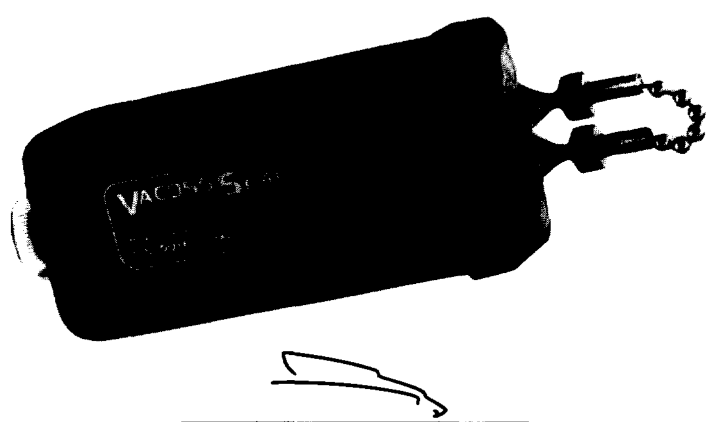

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