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1993 International Target Values for Uncertainty Components in Fissile Isotope and Element Accountancy for the Effective Safeguarding of Nuclear Materials 19
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An Improved Binomial Approximation to the Hypergeometric Density Function 36
John L. Jaech

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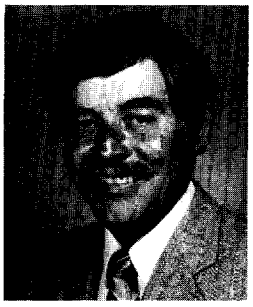
Nuclear Materials Management Appearing More Often in Today's Environment



I find it interesting how much more frequently the words *nuclear materials management* are commonly used in today's environment. As government agencies and the public address the impact of the post-Cold War era and the concern for nuclear proliferation, various programs, study documents and white papers have emerged that address the recognized need for effective control of nuclear materials, particularly plutonium.

As I read some of these documents, at times I get the feeling that *nuclear materials management* could be a new concept in the authors' minds. Interestingly enough, the "new" technologies identified in these documents as being needed for effective materials management were the subject of many of our annual meeting sessions over the past years.

On the other hand, there are many ongoing programs on nuclear materials management in which members of our Institute play a leading role. As all of us address the nuclear proliferation issues, knowledge in the breadth of technologies required is becoming ever more important. And the needed technologies, represented by the leading experts in their fields, are embraced within our six technical divisions international safeguards, materials control and accountancy, non-proliferation and arms control, transportation, physical protection, and waste management). This makes our annual meeting an even more important event — an opportunity to convey to others the expertise of our Institute. Also, our annual meeting provides the opportunity for cross-fertilization among the technologies, as well as a forum for technology transfer. And remember, it is difficult to accuse one of reinventing the wheel if your wheel has not been published. We hope you responded favorably to our annual meeting *Call For Papers.*

At the last executive committee meeting, held in October 1993, the committee voted to enhance the importance and recognition of senior members of the Institute. On page 7 of this issue is an article on these changes, as well as changes affecting our sustaining members.

Should you have any comments or suggestions, please feel free to contact me at (505) 845-8710.

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

INMM SAFEGUARDS TRANSPORTATION WASTE MANAGEMENT presents a spring workshop on

Long-term storage of special nuclear materials: safety, operations and safeguards interface

Oak Ridge, Tennessee

During May 1994, INMM's Materials Control and Accountability Technical Division will be hosting the second workshop on long-term storage of special nuclear materials.

The goal of the workshop is to identify and pursue resolution of potential conflicts between operations, safety, MC&A and physical protection interests for long-term storage facilities. Workshop teams composed of operations, safety and safeguards personnel will visit storage facilities of different designs within the Oak Ridge complex, identify retrofits necessary to convert the facility for long-term storage and define specifications for a new facility designed for storage of similar materials. A Q clearance will be required for all participants (L clearances on a limited basis).

Preliminary agenda:

- *Review of recommendations from previous meeting*
- *Identification of issues*
- *Discussion of issues (teams)*
- *Presentation of Oak Ridge storage configurations*
- *Team visit and assessment of storage configuration*
- *Team reports*
- *Team development of solutions to long-term storage issues*
- *Panel discussion on issues resolution (team leaders)*
- *Develop joint report of recommendations (team leaders)*

For additional information, please contact INMM headquarters at (708) 480-9573.

New Non-proliferation Policy Helps, But We Still Have a Long Way to Go

On July 16, 1945, I was one of those who observed the explosion of the first nuclear device. I was scared stiff and remained so for many years as the United States and the Soviet Union produced and deployed ever more powerful nuclear weapons. It was a very dangerous period for humanity. At long last, sanity prevailed over paranoia. The Cold War is over, but many thousands of thermonuclear warheads are still aimed at each of us.

Finally, the two adversaries are cooperating in reducing their deployed nuclear weapons, beginning to dismantle the warheads and discussing seriously how to get rid of the threat posed by weapons of mass destruction.

On Sept. 27, 1993, President Clinton announced a new non-proliferation and export control policy which will probably affect many of those involved in safeguards [See Chair's Message in the October 1993 issue of *JNMM*.]. Note that the United States and other nations still have a long way to go before the world will be entirely free from the fear of mass destruction. It will take many years to agree on how to dismantle the warheads and provide assurance to everyone that the materials are accounted for and verified.

A feature article in this issue discusses some of the issues to consider in deciding what to do with the plutonium that is to be removed from warheads. It will also take a long time to convert the excess quantities of highly enriched uranium to low-enriched uranium and to use them as fuel in power reactors without depressing the already low prices for natural uranium and for enrichment. These are subjects that affect many nations, not just the United States and Russia. They are challenging subjects and more pleasant to confront than a nuclear arms race.

On the technical side of this *JNMM* issue, we have the latest International Target Values for the Uncertainty Components in Fissile Isotope and Element Accountancy which limit the sensitivity of verification based on material accounting, and a paper on sampling plans by our expert, John Jaech. We received several other contributions, which are under review or were reviewed and, hopefully, will be revised in time for the next issue.

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

What Should We Do With the Plutonium?

The question of what to do with the plutonium from dismantled nuclear weapons presents an opportunity for creative and comprehensive thinking in the various dimensions of public policy potentially affected by the issue. The consensus goal is to eliminate the potential for weapon use. This can be accomplished by destroying the plutonium or by treating and disposing it outside the human environment.

Destruction can be accomplished in nuclear power reactors that produce electricity, thereby offsetting, in the value of the electricity produced, some of the extraordinary costs incurred in producing the plutonium. Disposal would involve placement in a deep geological formation, presumably within the framework of regulations established by the U.S. Nuclear Regulatory Commission and the technologies and facilities being developed by the Office of Civilian Radioactive Waste Management in the U.S. Department of Energy (DOE). Before any disposition option is selected, the plutonium would be held in highly secure storage for a period of time.

Various nuclear reactor technologies might be used to destroy the plutonium, and the DOE has an evaluation under way of five principal options. Alternative technologies might also be used to prepare the plutonium for disposal. The significant feature of these options for destruction or disposal is their remarkable diversity in terms of factors such as cost and schedule to achieve deployment, environmental impacts, creation of jobs, potential worker and public health effects, and impact on national energy supply markets and policy. Such benefits and liabilities must be characterized for each option so that the options can be compared for their benefit in reducing the risk of future use of the plutonium in weapons.

Such a risk reduction can be accomplished in stages. The first stage is simply to dismantle the weapon and keep the plutonium in secure storage in its weapon configuration. The second stage is to deform the configuration and maintain secure storage. Obviously, neither of these actions severely inhibits reconstitution of the weapons threat, although the threat is greatly reduced in comparison with deployed weapons. The investment in each action is significant, however, and secure storage of plutonium is highly expensive. An attendant issue is the question about the number of storage sites that should be provided. Single-site storage minimizes costs but focuses the target of terrorist or obstructionist action; multiple sites diversify the targets but increase storage costs.

The next stage is to condition the plutonium for destruction in reactors or for disposal. Conditioning for reactors would involve use of the plutonium in mixed-oxide fuels manufactured in existing fuel fabrication plants for existing reactors, or siting, licensing, constructing and operating of a new fuel fabrication plant that uses technology suitable for a new, future generation of reactors. The existing reactors would be poor consumers of the plutonium, but this option would avoid the costs and issues of new facilities. Use of new reactor technology with effective plutonium consumption capability would require investment in a large array of nuclear fuel cycle facilities. This option would commit the United States to a new generation of nuclear power as a significant element of future electric energy supply.

Implementing this option would stimulate a spectrum of economic activity, raise questions of federal encroachment in the energy marketplace and give nuclear power opponents new targets. It would also proliferate human health risks and diversify the types of radioactive wastes for disposal. These effects should be evaluated and compared with those for alternative strategies for managing the plutonium and assuring adequate energy supply.

Whether conditioned initially for reactor consumption or disposal, the plutonium eventually becomes a concern for disposal. The reactor route produces used nuclear fuel that can be sent to disposal in an intact form or can be chemically processed to recover uranium and plutonium, with fission products as the waste. The direct disposal route requires conditioning technology which assures that the plutonium does not create disposal safety issues and is not recoverable for future use in weapons. Only the technology for chemically processing used fuel from existing reactors is proven, and it is not in use in the United States. Fission product wastes from past defense production operations in the DOE complex are expected to be converted into a glass form for disposal, but the feasibility of tying the plutonium conditioning requirements to this technology requires evaluation. A dedicated facility and technology for plutonium conditioning might be necessary.

The route chosen for plutonium management could be affected or dictated by disposal program policy and safety requirements. The disposal safety regulations are comprehensive and stringent. Also, plans to dispose of wastes other than used fuel from existing power reactors and defense wastes will raise significant issues concerning waste repository design and capacity, potential for nuclear criticality, nuclear safeguards, security, waste retrievability, and safety performance standards compliance.

At minimum, the duration and cost

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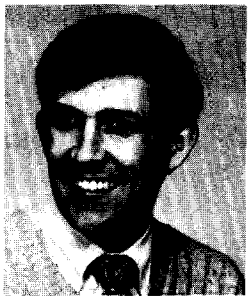
INMM Senior Membership Program is Revised



Bruce Moran

Paul Ebel

At the request of the INMM Executive Committee, the Membership Committee reviewed the senior membership program. This program is of concern because only a small number of those members eligible have applied to become senior members. The argument frequently heard against becoming a senior member is that no value is provided for the additional $15 per year.

The counter argument is made that senior status should reflect a person's extra dedication to INMM, and one measure of that dedication is the willingness to contribute more to INMM financially. Both arguments have merit, and the rationale from both was considered when assessing potential revisions to the senior membership program.

Members of the Membership and Professional Recognition committees established a joint task force to address this issue. The objective of the Membership Committee is to promote membership and participation in INMM, as well as promote services to best meet the members' needs. The objective of the Professional Recognition Committee is to recognize long and dedicated service to INMM and the field of nuclear materials management.

The INMM's Meritorious Service and Distinguished Service awards acknowledge significant contributions by individuals to the field of nuclear materials management, but INMM has been seeking a more general way to recognize broad and long-term dedication provided by members. The senior membership level was identified as a means to recognize this support because the level is underutilized and appropriately described in the INMM constitution and bylaws.

The task group recommended that senior membership recognize not only those members who have at least 10 years of nuclear materials management experience, but should also recognize those members who consistently contribute professionally to INMM's programs. Consistent contributions to INMM are not limited to INMM Executive Committee members, division officers and committee chairs, but include members active in committees and regional chapters, technical session chairs, and members who consistently present technical papers at INMM-sponsored meetings, seminars and workshops. Consistent contributions should be defined as personal efforts supporting aspects of INMM's programs during each of the last five years and indications that the person will continue to actively contribute. Once a person attains the status of senior member, they will maintain that status until they discontinue membership in INMM.

No advantages were identified that could fairly provide value for the senior membership dues differential. The task group also felt that senior membership eligibility should not be based on an individual's willingness to pay additional money to INMM. (The $15 differential paid by the current senior members does not significantly affect INMM's budget.) Therefore, elimination of the differential was recommended.

On Oct. 20, 1993, the INMM Executive Committee approved the recommendations of the joint task group for revisions to the senior membership Program. Effective next membership year (beginning Oct. 1, 1994), the senior member dues differential will be eliminated, and effective immediately, new senior member applicants must meet the professional contributions requirement.

At the beginning of each membership year, senior member applications will be distributed to the membership. The applications will be reviewed by the Membership and Professional Recognition committees, and qualified applicants will be recommended to the Executive Committee for approval. Applicants will be notified of their selection status in late spring, and successful applicants will be awarded senior member status at the INMM Annual Meeting that year. It is hoped that this increased recognition of contributing individuals will encourage more INMM members to become active in INMM activities, committees, technical divisions and regional chapters.

If you believe that you qualify to become a senior member of INMM, please complete the application on the left and mail it to INMM headquarters, 60 Revere Dr., Suite 500, Northbrook, IL 60062, by April 1, 1994. Successful applicants will receive senior member status at the 35th Annual Meeting, July 17-20, 1994, in Naples, Fla.

Bruce Moran, Chair
INMM Membership Committee
Martin Marietta Energy Systems
Oak Ridge, Tennessee, U.S.A.

Paul Ebel, Chair
INMM Professional Recognition Committee
BE Inc.
Barnwell, South Carolina, U.S.A.

Committees: N14 and N15

ANSI Highlights

The ANSI board of directors approved on Sept. 9, 1993, the following policy on metric usage: "Units of the International System of Units, the modernized metric system, are the preferred units of measurement in American National Standards."

Other Highlights

The Office of Management and Budget (OMB) is issuing a revised version of OMB Circular A-110, "Federal Participation in the Development and Use of Voluntary Standards." The circular was revised to foster greater agency use of voluntary standards, particularly in light of recently stated national objectives, and increase the effectiveness of the circular.

The U.S. Department of Energy issued DOE 1300.2A, Department of Energy Technical Standards Program, on May 19, 1992. This DOE order encourages the use of voluntary standards (nongovernment standards), and the participation in nongovernment standards bodies and in the development of standards.

N14 Committee

The annual N14 meeting was held in Rockville, Md., on Nov. 4, 1993. Minutes of the meeting will be distributed to N14 members, and highlights of the meeting minutes will be included along with the N14 Standards status in the April issue of *JNMM*.

The N14 policy on metrics was adopted at this meeting: "Use metric units when possible with customary units in parentheses as appropriate."

N15 Committee

The N15 Committee is still without a chairperson and a secretary. Anyone wishing to serve in these positions or desiring additional information should contact Barbara Scott at INMM headquarters, (708) 480-9573, or John Arendt at 109 Caldwell Dr., Oak Ridge, TN 37830; (615) 483-1401. The person selected for each position will be thoroughly trained in ANSI and N15 procedures.

N15 Standards currently listed in the *1993 Catalog of American National Standards* are:

ANSI N15.10-1987 — *Unirradiated Plutonium Scrap – Classification.*

ANSI N15.11-1983 — *Audit Opinions on Nuclear Material – Balance Reports.*

ANSI N15.15-1974(R1981) — *Nuclear Materials – Assessment of The Assumption of Normality (Employing Individual Observed Values).*

ANSI N15.18-1988 — *Nuclear Materials – Mass Calibration Techniques for Control.*

ANSI N15.19-1989 — *Nuclear Materials Control – Volume Calibration Techniques.*

ANSI N15.20-1975(R1987) — *Nondestructive Assay Systems – Guide to Calibrating.*

ANSI N15.22-1987 — *Nuclear Materials – Plutonium-Bearing Solids - Calibration Techniques for Calorimetric Assay.*

ANSI N15.28-1991 — *Nuclear Materials Control – Guide for Qualification and Certification of Safeguards and Security Personnel.*

ANSI N15.35-1983 — *Nondestructive Assay by Counting Passive Gamma Rays – Guide to Preparing Calibration Material.*

ANSI N15.36-1983 — *Nuclear Materials – Nondestructive Assay Measurement Control and Assurance.*

ANSI N15.37-1981 — *Nondestructive Assay Systems for Nuclear Material Control – Guide to Automation.*

ANSI N15.38-1982 — *Auditing Nuclear Materials Safeguard Systems – Generic Standard.*

ANSI N15.41-1984 — *Derivation of Measurement Control Programs – General Principles.*

ANSI N15.54-1988 — *Instrumentation – Radiometric Calorimeters – Measurement Control Program.*

ANSI requires that standards must be reviewed every five years for reaffirmation, revision or withdrawal. Failure to maintain standards within 10 years of their approval results in automatic withdrawal by ANSI. A complete report on N15 Standards will be included in the April issue of *JNMM*.

Yvonne Ferris, chair of N15.36 — *Nuclear Materials – Nondestructive Assay Measurement Control and Assurance* writing group is in the process of completing the final draft for N15 balloting.

We want to increase the N15 balloting by adding members at large. If you wish to serve on this committee, contact Scott or Arendt. As a voting member, you will be required to review and vote on proposed standards.

Your support and participation in the N15 committee is welcome and needed.

John Arendt
INMM/ANSI Nuclear Standards Representative
Oak Ridge Associated Universities
Oak Ridge, Tennessee, U.S.A.

Chapters: Central

The Central Region held its annual meeting at the Garden Plaza Hotel in Oak Ridge, Tenn., Oct. 28-29, 1993. Forty-four people representing 10 facilities within the region attended. The goal of the meeting was to provide an opportunity for staff people who do not have the chance to attend other INMM activities to become involved in the exchange of nuclear materials management and safeguards information.

The meeting opened with technical presentations and concluded with a business meeting. Major items of business were the presentation and discussion of the treasurer's annual report, review of the prior year's activities, establishment of a committee for the 1994 annual meeting site selection, and reporting of ballot (constitution and bylaws changes) and election results.

Those completing terms on the Central Region Executive Committee were Chair Connie Hall and Members at Large Jere Bracey and Russell Johns. John Lemming retains the post of past-chair because the next six chairs are no longer members of the INMM Central Region.

The result of the members-at-large election was very close: only 10 votes separated the first and last place candidates (of four candidates). The revised constitution and bylaws of the Central Region will be published in the Central Region *Annual Meeting Proceedings*. Members of the Central Region Executive Committee beginning or continuing their terms of office at the meeting are (end of term in parantheses):

Chair: David Shisler (1995)
Vice Chair: John Hehemeyer (1995)
Secretary: Bruce Moran (1995)
Treasurer: John Wachter (1995)
Members at Large:
Wanda Mitchell (1994)
Raymond Seiler (Chris Pickett, acting) (1994)
Terry Lewis (1995)
Tina Barnette (1995)

The annual meeting committee was composed of Wachter, arrangements, and Moran, technical program. Session chairs were Frank Martin, Martin Marietta Energy Systems, and Carleton Bingham, U.S. Department of Energy, New Brunswick Laboratory.

In other news, on Feb. 23, 1994, at the annual WATTec Conference in Knoxville, Tenn., the Central Region will conduct a technical session on technology transfer. This is INMM's fifth year of participation in WATTec, a national conference and exhibition sponsored by the technical and professional societies of East Tennessee to provide a forum for the exchange and dissemination of information on current national issues involving science and technology. The winter Executive Committee meeting will be held during the lunch break of this Central Region technical session.

Bruce Moran
INMM Central Region Secretary
Martin Marietta Energy Systems
Oak Ridge, Tennessee, U.S.A.

Divisions: Physical Protection

The Physical Protection Division met July 18, 1993, during the INMM 34th Annual Meeting in Scottsdale, Ariz. Only 10 people attended the division meeting, but it was a great meeting nonetheless. Guest speaker Basil Steele from Sandia National Laboratories did an excellent job. Later, during the annual meeting, a number of people indicated that for the next annual meeting they would try to make their travel arrangements to include the Sunday division meetings. In 1994, the Physical Protection Division's meeting will again be held on the first day of the INMM Annual Meeting, Sunday afternoon, July 17, at the Registry Hotel in Naples, Fla.

All Physical Protection Division members and others interested in the division should assist with the following efforts:

1. Make suggestions for future workshop topics.

2. Identify people willing to serve as organizers of workshops and as workshop chairs. Usually these people have strong input into the possible locations and times for the workshops.

3. Solicit papers for publication in *JNMM*.

4. Now that the division has the major responsibility for the physical protection sessions at the annual meeting, we should all be thinking about the general and specific topics we would like to cover at the annual meeting, and we should start soliciting for papers to fill those sessions.

5. Make suggestions for education, training or other aspects of continued professional development.

6. The divisions were formed to promote better technical exchange, allow more people to become involved in the operation of INMM, and increase personal recognition and member satisfaction. Suggestions about how to

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Physical Protection

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achieve these goals are always welcome.

The division planned a physical protection workshop for spring of 1994. A definite topic has not been chosen, but possibilities include:

- Insider protection,
- Thermal detectability,
- Video compression,
- Entry control and contraband detection,
- Security personnel training,
- Intrusion detection systems,
- Positive personnel identification,
- Safeguards and security - concepts and analysis,
- Protection program planning,
- Evaluation methodology and analysis,
- Video and infrared assessment systems,
- Information surety systems,
- Uses of computers in security, and
- Making safeguards and security technologies applicable to environmental and waste management needs.

Those members who attended the last annual meeting in Scottsdale and indicated an interest in the Physical Protection Division have already received a questionnaire regarding the planned workshop. Input from others is also welcome. However, since decisions about the workshop are in progress, input is needed as soon as possible.

J.D. Williams, Chair
INMM Physical Protection Division
Sandia National Laboratories
Albuquerque, New Mexico, U.S.A.

Divisions: International Safeguards

On July 18, 1993, the INMM's International Safeguards Division (ISD) met at the Princess Hotel in Scottsdale, Ariz., during the INMM 34th Annual Meeting. Forty members of the international safeguards community, from the IAEA, CEC/EURATOM, CEC/JRC-Ispra, Australia, Canada, France, Germany, Japan, Netherlands, People's Republic of China, Sweden, United Kingdom and the United States participated in the meeting.

Chair Cecil Sonnier opened the meeting with an expression of regret from the vice chair, Paul Ek of SKI, Sweden, who could not attend. Recent changes to the ISD panel for the annual meeting program were announced. The chair distributed copies of the new INMM Division Charter and explained the Institute's intent regarding the current formulation.

Considerable time was devoted to discussions on a potential ISD workshop in 1994. A subset of the multiple topics formulated and discussed by the ISD in previous meetings was sought as the basis for a workshop.

It was concluded that the next ISD meeting should concentrate discussion on the subject of transparancy, which was recognized as a complex topic consisting of many of the items in the topic list of the ISD. The next ISD meeting was scheduled for the afternoon of March 18 and the morning of March 19, 1994, in Vienna after the IAEA Symposium. Further, it was agreed that draft short-form papers on the subject of transparancy could be prepared and provided to the ISD chair for distribution. This would allow the distribution of all drafts in advance of the March meeting in Vienna, and provide a sound basis for discussions.

As in past meetings of the ISD, numerous current international safeguards topics were discussed. It was recognized that many factors must be considered before the introduction of the variety of changes currently under consideration, as well as the vast array of new technology which may support these changes.

Cecil Sonnier, Chair
INMM International Safeguards Division
Sandia National Laboratory
Albuquerque, New Mexico, U.S.A.

Roger Case, Secretary
INMM International Safeguards Division
Sandia National Laboratory
Albuquerque, New Mexico, U.S.A.

Member News

Carl Gertz, project manager of the Department of Energy's Yucca Mountain Site Characterization, was named to head the task force on Assisted Self-Assessment of Tank Farms Management at the Hanford Site in Richland, Wash. The task force, formed in early September, is composed of people from both inside and outside the Hanford organization and will study the tank situation at the site through the end of 1993. It will then make recommendations to the DOE and other stakeholders on the high-priority waste tank situation.

Gertz's assignment at Hanford began Oct. 18, 1993, and is a temporary position. He is still technically the Yucca Mountain project manager.

Two new sustaining corporate members were approved. INMM welcomes Battelle Pacific Northwest Laboratory of Richland, Wash., and the U.S. Nuclear Regulatory Commission in Washington, D.C.

Plutonium

Continued from page 4

of the repository licensing process would be affected by the need to address and resolve such issues; progress and confidence in the disposal program of the DOE's Office of Civilian Radioactive Waste Management might also be affected. To minimize these issues and costs, the disposal regulations might be used to specify the conditioning technologies to be used for plutonium and for used fuels that are the responsibility of the DOE.

Another interaction between disposal and plutonium management strategy concerns disposal capacity. Under current law, the capacity of the first deep geologic repository is limited to 70,000 metric tons of uranium or similar material. This limit was imposed in the spirit of political equity to assure that there would be at least two repositories. Existing reactors will produce a total of about 87,000 metric tons of used fuel. A decision to consume the plutonium in new reactors could trigger action toward siting, characterizing and licensing the second repository. Within this option is the possibility that disposal of wastes other than used fuel from existing power reactors will be directed at the second repository to avoid adverse impacts on the current disposal program.

Consideration of options for disposition of plutonium from nuclear weapons must clearly rise above protagonists of narrow issues. Much is at stake, and the issues and options are complex. Leadership, vision and evaluation that addresses all of the complexities must be provided and sustained.

John Bartlett
Analytic Science Corp.
Reading, Massachusetts, U.S.A.

Correction

An incorrect contact was given for those who want to be on the distribution list of the Department of Energy's standards newsletter, *Standards Forum.*

Interested people should contact Don Spellman at the DOE Lead Standardization Activity, c/o Performance Assurance Project Office, P.O. Box 2009, Oak Ridge, TN 37831-8065 U.S.A.; (615) 574-7891.

John G. Keliher, director of the Office of Intelligence and National Security, and Hiroyoshi Kurihara, INMM Japan Chapter treasurer and executive director of the Power Reactor and Nuclear Fuel Development Corp., sign an agreement at U.S. Department of Energy headquarters in September 1993. The agreement calls for cooperation in research and development concerning nuclear material control and accounting measures for safeguards and non-proliferation. It also covers development, testing and evaluation of technology, equipment and procedures to improve nuclear materials control. (Photo courtesy of the DOE.)

INMM Constitution and Bylaws

(with amendments as approved by the membership in June 1993)

CONSTITUTION

ARTICLE I — NAME

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

ARTICLE II — PURPOSE

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

a. The advancement of nuclear materials management in all its aspects.

b. The promotion of research in the field of nuclear materials management.

c. The establishment of standards, consistent with existing professional norms.

d. The improvement of the qualifications and usefulness of those engaged in nuclear materials management and safeguards through high standards of professional ethics, education, and attainments, and the recognition of those who meet such standards.

e. The increase and dissemination of information through meetings, professional contacts, reports, papers, discussions, and publications.

ARTICLE III — MEMBERSHIP

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

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

ARTICLE IV — OFFICERS

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

Section 2. There shall be an Executive Committee which shall be composed of the officers of the Institute, the immediate past Chair of the Institute, and four (4) Members-at-large elected from the membership of the Institute. In addition, the Chair of each Institute Chapter chartered outside the United States and having fifty (50) or more members shall be an Ex-Officio member of the Executive Committee. If a Chapter Chair is unable to attend a given meeting of the Executive Committee, that Chair may designate a member of the Chapter as proxy who will assume all rights and privileges of the office for the subject meeting.

Section 3. The Chair of the Institute shall be the Chair of the Executive Committee.

ARTICLE V — MEETINGS

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

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

ARTICLE VI — AMENDMENTS

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

Section 2. Proposed amendments may be originated by:

a. The Executive Committee upon approval of the proposed amendment by a majority of the members of that committee.

b. Fifteen (15) members in good standing who submit a proposed amendment in writing over their signatures to the Executive Committee through the Chair of that Committee.

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

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

BYLAWS

ARTICLE I — MEMBERSHIP

Section 1. GRADES

The constituted membership of the Institute shall consist of Regular Members, Student Members, Emeritus Members, Sustaining Members, and Honorary Members. Regular Members shall have the particular designations of Members, Senior Members, or Fellows. Except as otherwise provided in these Bylaws, Regular Members shall be equally entitled to all rights and privileges of the Institute. Student Members, Emeritus Members, and Honorary Members shall have all rights and privileges of Institute membership; except that they shall have no voting

privileges in matters affecting the Institute as a whole, nor may they hold any governing office of the Institute.

Section 2. MEMBERS

a. A Member, at the time of admission or advancement to that grade, shall be at least twenty-one (21) years of age and of good character and:

(1) Shall have a bachelor's or higher degree in a subject relevant to safeguards, and shall be employed in or related to the management of nuclear materials or nuclear safeguards; or

(2) Have been engaged in the practice of safeguards or nuclear materials management long enough to have demonstrated competence and understanding of a professional nature.

b. In addition to meeting all of the requirements of Section 2.a, a Member, before admission or advancement to that grade, shall be:

(1) Qualified, under instruction and supervision, to undertake the planning and carrying out of work involving application of the principles of nuclear materials management; or

(2) Qualified, under supervision, to teach subjects relating to nuclear materials management approved by the Executive Committee.

c. A Student Member who:

(1) Completes fulfillment of the requirements of Section 2.a.(1) of these Bylaws; or

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

Section 3. SENIOR MEMBERS

a. A Senior Member at the time of advancement to that grade, shall be at least thirty (30) years of age, shall have been a Regular Member of the Institute for at least three (3) continuous years, shall be actively engaged professionally in nuclear materials management (temporary unemployment excepted), and shall have had at least ten (10) years of active experience in one or more nuclear materials management positions indicative of growth in competence and achievement. Graduation in an appropriate curriculum of an accredited educational institute approved by the Membership Committee shall be considered the equivalent of four (4) years of the requisite ten (10) years of professional experience.

b. In addition to meeting all of the requirements of Section 3.a of these Bylaws, a member shall, in order to be advanced to the grade of Senior Member,

(1) Be professionally engaged in a technical, administrative, or consultative position in nuclear materials management and in that capacity shall have had responsible charge for at least two (2) years of work requiring application of nuclear materials management principles, or

(2) Be a teacher of a subject or subjects related directly to the nuclear materials management field and, as such, be capable of teaching a major course in one or more branches of that field, and shall have had responsible charge for at least two (2) years in a field approved by the Membership Committee, or

(3) Be a person engaged in nuclear materials management (or in a closely allied field) who by the development of nuclear materials management principles or procedures, or by proficiency in nuclear engineering or in closely allied subjects, or as an executive of a technical or operating enterprise of large scope, or as an executive with major responsibility for physical protection of nuclear material, has attained a standing equivalent to that required for the Senior Member grade under Section 3.b.(1) and (2) of these Bylaws, or

(4) Be a person who holds, in good standing, in a cognate professional engineering, technical, or scientific society of national scope in any country, a grade of membership for which the qualifications indicate a standing equivalent to that required for Senior Member under Section 3.b.(1) and (2) of these Bylaws.

Section 4. FELLOWS

a. A Fellow, at the time of such designation, shall be a Senior Member actively engaged professionally in nuclear materials management as previously defined in Section 3 of this Article. In addition, such member shall have established a specific record of contribution to the profession, had at least fifteen (15) years of active experience in the profession, and have been in good standing in the grade of Senior Member for at least five (5) consecutive years immediately prior to the date of the proposal for advancement to the grade of Fellow.

b. A member who, on becoming a Senior Member, held in good standing in a cognate professional engineering, technical, or scientific society of national scope in any country, a grade of membership for which the qualifications indicate a standing equivalent to that required for the grade of Senior Member herein, may have such years of prior membership in that equivalent grade, to a maximum of four (4), considered as part of the five (5) years in the Senior Member grade requisite to advancement to the grade of Fellow.

c. The total of the number of Fellows at the time of their advancement, excluding those who have resigned or become Emeritus Members, shall never exceed five percent (5%) of the regular membership. Fellows of the Institute shall be assessed the same dues as Senior Members.

d. In addition to meeting all of the requirements of Section 4.a of these Bylaws, a Senior Member shall, in order to be advanced to the grade of Fellow,

(1) Have attained distinction in the planning or operation of nuclear materials management work, or of work in a related technical, administrative, consultative, or pedagogic field; and shall have been in full and responsible charge of the work involved for at least

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five (5) years, or,

(2) Have attained distinction by reason of original work in the development or exposition of the theory, principles, or techniques of nuclear materials management, or of significant work in an allied technical, administrative, consultative, or pedagogic field; or as an alternative, shall have attained distinction as an executive in charge of nuclear materials management work of large scope, or in charge of the application of nuclear materials management principles in important projects.

Section 5. STUDENT MEMBERS

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

Section 6. EMERITUS MEMBERS

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

Section 7. SUSTAINING MEMBERS

a. Since many private corporations or divisions thereof, governmental agencies, and other collective groups share the objectives outlined in Article II of the Institute of Nuclear Materials Management Constitution and may wish to make financial contributions on a regular basis to encourage and assist the endeavors involved in meeting these objectives, such contributing groups, upon their application, may be recognized by designation as Sustaining Members. The monies collected from these dues shall be restricted for use in technical activities of the Institute such as standards, technical committees, technical staff, and special publications.

b. Each Sustaining Member shall designate and be represented by an individual employed by or associated with it who is also qualified under Article 1, Section 2.a. and b. of these Bylaws; and such individual shall, on behalf of the Sustaining Member organization, have all the rights and privileges of a Regular Member. Sustaining Members shall be privileged to send a number of their employees to sponsored meetings of the Institute at a reduced rate.

Section 8. HONORARY MEMBERS

Honorary Members shall be prominent political, governmental, scientific, academic, or other figures usually from outside of the membership of the Institute who have rendered acknowledged eminent service to nuclear materials management or to the allied arts and sciences. Such membership may be granted only by the Executive Committee. Honorary Members shall not be assessed dues.

ARTICLE II — ADMISSION, ADVANCEMENT, TRANSFER, RESIGNATION, REINSTATEMENT, AND EXPULSION OF MEMBERS

Section 1. ADMISSION

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

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

Section 2. REJECTION

If an application fails to have the approval of all members of the Membership Committee, it shall be declared as rejected by the Membership Chair who shall then forward it, with the noted deficiencies, to the Executive Committee through its Chair. The Executive Committee shall review the application and the reasons for rejection and make such other examination of the applicant's qualifications as it may deem advisable. If, then, a majority of the members of the Executive Committee sustains the rejection, the Chair of

the Executive Committee shall direct the Treasurer to notify the applicant of the rejection and to return the originally submitted membership fee to the applicant along with the notice of rejection. If, after the review by the Executive Committee of the application, the reasons for rejection, and such other examination of the applicant's qualifications as it may deem advisable, a majority of the committee shall sustain the application, the applicant shall be declared to be a member and shall be so advised by the Membership Chair as provided in Section 1 of this Article.

Section 3. DUES
Membership dues for each Institute year beginning on October 1 shall be due and payable in October. The Executive Committee shall establish dues for the various grades of membership, and such procedures as are appropriate for their billing and collection, and shall determine when a member will be suspended for non-payment of dues.

Section 4. SENIOR MEMBERS
Members of the Institute may apply for the grade of Senior Member at any time upon becoming eligible. Each such applicant shall certify that the requirements of Article 1, Section 3 of these Bylaws have been met and shall provide such additional information as prescribed by the Membership Committee. The Membership Committee shall consider each application for advancement to Senior Membership submitted to it under the provisions of Article 1, Section 3. If, following the above consideration, the Committee shall approve said application, then, upon payment of the applicant of any transfer fee, increase in dues, or other charges prescribed in the Bylaws, the Secretary shall enroll said applicant as a Senior Member of the Institute.

Section 5. FELLOWS
a. The grade of Fellow may be attained only by advancement from the grade of Senior Member, and may not be attained by application. A proposal for the advancement of a Senior Member to the grade of Fellow shall be originated by five (5) or more Members of the Institute who shall provide data sufficient in their judgment to substantiate the qualifications of their candidate with respect to the requirements of Article 1, Section 4 of these Bylaws. Such proposals shall be submitted to the Secretary who shall refer them to the Fellows Committee for its consideration.

b. If the Fellows Committee finds such candidate fully qualified for the grade of Fellow, and that such advancement to that grade would be in the best interest of the Institute, it shall so certify the nomination and forward its recommendation to the Executive Committee. If the nomination receives the favorable vote of two-thirds of the members of the Executive Committee, the candidate shall be made a Fellow of the Institute.

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

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

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

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

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ARTICLE III — ELECTION OF OFFICERS AND MEMBERS-AT-LARGE

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

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

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

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

Section 5. The Secretary shall mail a ballot listing the names of the candidates and the offices or positions to which they have been nominated to each member in good standing not later than May 15 of each year. The ballot shall bear a notice to the effect that the marked ballot shall be returned to the Secretary before June 15. The Secretary shall supply with the ballot an envelope within which the marked ballot shall be sealed. The sealed ballot shall be returned to the Secretary in an outer envelope bearing the member's signature. In marking the ballot the member may write in the name of another member as a candidate for an office or position and vote for that member, if that name is not listed on the ballot forwarded by the Secretary to the member.

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

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

Section 8. All officers shall serve without remuneration.

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

ARTICLE IV — DUTIES OF OFFICERS AND COMMITTEES

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

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

Section 3. The Vice Chair shall assist the Chair in all matters referred and, in the absence of the Chair, shall perform all of the duties of that office.

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

a. Give due advance notice of all meetings of the Institute to each member.

b. Mail to each member ballots for the election of officers and other elective positions and for proposed amendments to the Constitution and Bylaws.

c. Notify each member of the results of elections and of the voting on

proposed amendments.

d. Record the names of new members on the roll of members and advise new members of their acceptance into membership by the Institute.

e. Perform such other duties as the office shall require or as shall be assigned by the Executive Committee.

f. Surrender to a successor all books, records, correspondence, and documents of the Institute.

Section 5. The Treasurer shall collect and disburse the funds of the Institute. Approval of the Institute's budget by the Executive Committee shall constitute authority to the Treasurer to disburse appropriate funds provided that such individual disbursements shall have been vouchered by the responsible Chair or individual designated by the Executive Committee. The Treasurer shall also:

a. Present a financial report to the Executive Committee at the end of each fiscal year and at other times as requested by the Chair.

b. Receive applications for membership and membership fees from the Secretary and forward applications for membership to the Chair of the Membership Committee.

c. Advise any rejected applicant for membership of such rejection and return to the applicant the membership fee originally submitted with the application.

d. Issue to each member a notice of dues payable. Such notice shall show the due date on or before which payment is to be made.

e. Perform such other duties as the office may require or as assigned by the Executive Committee.

f. Surrender to a successor all funds and property of the Institute.

Section 6. The Secretary and the Treasurer may delegate any of their aforementioned duties to the Executive Director with the approval of the Executive Committee.

Section 7. The Executive Committee shall be the governing body of the Institute and as such, shall have full power to conduct, manage, and direct the business and affairs of the Institute in accordance with its Constitution and Bylaws. It shall:

a. Maintain a book of minutes of all proceedings at its meetings.

b. Interpret and execute the provisions of the Constitution and Bylaws.

c. Fill any vacancy in any office of the Institute or Executive Committee except that of Chair.

d. Select and appoint a Statutory Agent with a business address in the State of Ohio in which the principal office of the Institute is located.

e. Select and appoint a Membership Committee composed of the Secretary, Treasurer, and at least one other Member-at-large and designate the Chair of that Committee. Neither the Secretary nor the Treasurer shall be the Chair.

f. Select and appoint a Program Committee composed of a Chair and at least one other member and designate the Chair of that Committee.

g. Select and appoint a Nominating Committee composed of a Chair and at least one other member and designate the Chair of that Committee.

h. Select and appoint a Fellows Committee of at least three Senior Members or Fellows and designate the Chair of that Committee.

i. Select and appoint other committees as may be appropriate for conducting Institute business.

Section 8. The Executive Committee shall meet at least twice each operating year upon due notice to its members at the call of the Chair or upon the written request of a majority of the members of the Committee directed to the Chair of the Committee. In the absence of a quorum, which shall be five members of the Executive Committee, called meetings of the Executive Committee shall adjourn to a date. In the absence of both the Chair and Vice Chair at an Executive Committee or Institute meeting, the Executive Committee shall elect a temporary Chair.

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

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

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

Section 12. All appointed committees shall maintain a record of all proceedings and otherwise provide for their own operation.

Section 13. Members of committees appointed by the Executive Committee shall serve for a term of one year or until their successors have been appointed.

Section 14. The Fellows Committee shall review all nominations for advancement to the grade of Fellow, shall evaluate each candidate for such advancement to assure that the requirements of Article I, Section 4 of these Bylaws are met, and shall recommend such candidates for advancement as they deem appropriate.

ARTICLE V — TECHNICAL DIVISIONS

Section 1. The Executive Committee may, at its discretion, create and establish Technical Divisions dedicated

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to specific major disciplines and activities of the Institute as defined by the Executive Committee.

Section 2. Each Division may structure its own membership and, at its own discretion, create a board of directors for its administration. Actions and activities by any Division requiring Institute approval shall be presented to the Executive Committee by the Division Chair for consideration and action.

Section 3. The Chair of each division shall be appointed by the Executive Committee and shall serve until a successor is appointed. Division Chairs shall be responsible for the structure and organization of their Division as defined under Section 2 of this Article. Each Chair shall also provide the Executive Committee, for their approval, a proposed Charter consisting of a general statement under which their Division will operate; and shall be responsible for the direction and operation of the respective Division according to its separate Charter.

Section 4. The Executive Committee shall require and receive regular reports from each Division Chair on the activities and accomplishments of the Division. The Executive Committee shall, from time to time, review and reevaluate each Division; and may terminate, combine, or redefine the general charter of any of the Divisions as may be required.

ARTICLE VI — MEETINGS

Section 1. At regular meetings of the Institute the order of business shall be established by the Chair. The rules of order in the conduct of meetings not specifically provided in these Bylaws shall be Robert's "Rules of Order." A quorum shall consist of the members in attendance.

ARTICLE VII — CHAPTERS

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

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

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

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

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

ARTICLE VIII — AMENDMENTS

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

1993 International Target Values for Uncertainty Components in Fissile Isotope and Element Accountancy for the Effective Safeguarding of Nuclear Materials

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Abstract

Following a 1988 recommendation of the International Atomic Energy Agency (IAEA) Standing Advisory Group on Safeguards Implementation (SAGSI), the IAEA convened a Consultants Group meeting in June 1991 to provide expert advice on international standards of measurements applicable to safeguards data. As a result, International Target Values (ITVs) were chosen to describe uncertainty components in fissile element and isotope accountancy and were defined on the model of the 1987 and 1988 European Safeguards Research and Development Association (ESARDA) Target Values. The draft ITVs were submitted to several national and international technical panels, including ESARDA/WGDA, ESARDA/WGNDA, INMM 5.1 Committee, ISO/TC85/SC5/WG3, and the Japanese Ad Hoc Technical Group on International Standards of Measurements.

The results of this world-wide review were incorporated in the present report of the IAEA Consultants Group Meeting of June 1993. The 1993 ITVs in this report describe the within- and between-inspection uncertainty components that are expected to be achievable under current industrial and inspection conditions in fissile element and isotope accountancy measurements. Sixteen different nuclear materials of major significance to safeguards are considered. Separate ITVs are defined for the major measurement steps including bulk measurement, sampling, isotope and element assays for NDA and DA procedures. The propagation of these components defines the ITVs for uncertainties in the determinations of masses of fissile element and isotope for selected combinations of measurement methods. These ITVs are directly comparable to the uncertainties observed in actual operator's and inspector's accountancy data. The present report explains why target values are needed, how the concept evolved, and how they relate to the operator's and inspector's measurement systems. The 1993 ITVs are intended to be used by plant operators and safeguards organizations, as a reference of the quality of measurements achievable in nuclear material accountancy, and for planning purposes. They should not be used in place of performance values in statistical tests of operator-inspector differences, nor for licensing or regulatory purposes. The report acknowledges the progress made in accountancy and verification measurements since the 1988 ESARDA Target Values were published and points out the areas where further improvements can be expected in the future.

Introduction

Safeguarding nuclear material involves a quantitative verification of the accountancy of fissile materials by independent measurements. The effectiveness of these verifications depends to a great extent upon the quality of the accountancy measurements achieved by both the facility operator and the safeguards inspectorate. For this reason a typical model of Safeguards Agreements[1] stipulates that: "The agreements should provide that the system of measurements on which the records used for the preparation of reports are based,

shall either conform to the latest standards or be equivalent in quality to such standards." Although the above requirement was directed to the facility operators, it applies equally well to the safeguards inspectorates.

In the absence of relevant international standards of measurements, the IAEA defined in the 1970s a set of international standards of nuclear material accountancy,[2] which lists the "expected measurement accuracy associated with the closing of a material balance" at five different types of nuclear facilities. However, these values have never been reviewed despite numerous technological changes since their adoption by consensus by a group of experts designated by their governments. Safeguards officials and evaluators, and also plant measurement specialists, would need both more current and more informative references regarding the desirable precision and accuracy to be achieved in the measurements of the volume or mass of a material and in the sampling, elemental and isotopic assays for the various nuclear materials encountered in the nuclear fuel cycle.

The Working Group on Techniques and Standards for Destructive Analysis (WGDA) of the ESARDA pioneered the way in 1979 by presenting a list of "target values" for the uncertainty components in destructive analytical methods[3] to the safeguards authorities of Euratom and of IAEA. Revised estimates were prepared in collaboration and published as the 1983 Target Values[4] after four years of extensive discussion and consultation with and within operators' laboratories and safeguards organizations. The international acceptance of the concept grew further with the next review which involved, in addition to the ESARDA/WGDA and IAEA, the active participation of the members of two specialized committees of the Institute of Nuclear Materials Management (INMM). The 1987 Target Values, published as a result of this review,[5] define, like the previous editions, the values of the random and systematic error parameters to be aimed for in elemental and isotopic analyses of the most significant types of materials using common destructive analytical methods. The same groups took a new step when they agreed to define with the 1988 edition[6] the values of the random error parameter to be met in the elemental assays as a result of sampling. Unfortunately, it was not possible at this time to include values for the systematic components in the sampling uncertainties.

This paper establishes the concept of international target values (ITVs) and includes estimates of the random and systematic error uncertainties originating from the measurements of volumes or masses of nuclear materials. The scope of ITVs was also extended to include a consideration of the nondestructive assay methods (NDA) that have won acceptance as accountancy verification tools.

As in earlier publications, the values listed in this paper have been derived from an evaluation of actual measurement data. Three sources of this information were considered. The most relevant and complete set of measurement data comes, without question, from the information gathered by safeguards inspectorates during the statistical evaluation of the measurements reported by the facility operators and the results of independent measurements performed on the same materials by the inspectors.[7,8] Secondly, these data, as shown later, must be complemented or confirmed by an examination of the results of laboratory intercomparisons[9-12] or measurement quality evaluation programs.[13-27] Lastly, and whenever possible, the proposed ITVs have been supported on the basis of in-depth analyses of the uncertainties derived from individual measurement processes as published by measurement specialists.[28-31]

It is also important to note that an increasingly broader audience took part in the discussion of the successive versions of the ESARDA and the ITVs. The ESARDA/WGDA held joint meetings with the ESARDA Working Group on NDA methods (ESARDA/WGNDA) as a part of the discussion of the 1993 version. The IAEA included the topic in its current work plan and held two Consultants Group meetings[32,33] with the participation of a representative from a large European reprocessing plant, Brazilian and Japanese national nuclear authorities, and representatives of ESARDA, INMM, the International Organization for Standardization (ISO), the European Community (EC) and IAEA inspectorates. In total, close to 500 specialists from nearly 100 laboratories, nuclear plants and national authorities in about 20 different countries were involved in the discussion of the 1993 ITVs. The ITVs have been endorsed by the ANSI/INMM Committee 5.1 on Analytical Chemistry Laboratory Measurement Control, ISO/TC851/SC5/WG3 on Accountancy Analytical Methods in Nuclear Spent Fuel Reprocessing, and the ESARDA Working Groups on DA and NDA. They will be submitted to the IAEA Standing Advisory Group on Safeguards Implementation (SAGSI).

The 1993 ITVs bear a date like the previous ESARDA Target Values, since experience has shown that the quality of measurements varies with time as methods are improved or developed in response to technical or social demands. ITVs also reflect the current understanding of the structure of the uncertainty components in nuclear material accountancy measurements. Accordingly, they are likely to change as this understanding improves or varies.

As with the previous lists, the 1993 ITVs should be achievable from today forward under the conditions normally encountered in typical industrial laboratories or during actual safeguards inspections. They do not represent the ultimately achievable measurement uncertainties which could be obtained under exceptional or ideal laboratory conditions, or with most recently developed methods.

Major changes in the nuclear fuel cycle have occurred since the 1988 edition. Chemical processing and fuel fabrication plants currently operate at or near full capacity. New and larger plants came into operation, multiplying the throughput by a projected factor of 4 at COGEMA in La

Hague, France[34,35] or by a factor of 3 at Belgonucléaire in Dessel, Belgium,[36] for example The burnup of reprocessed spent fuels and the specific activity of the retrieved plutonium continued to increase, often reaching over 35,000 MW days/ton and 4 TBq/g (110 Ci/g), respectively. At the same time, the limits of personnel radiation exposure, and the volume and radioactivity level of the releases to the environment were drastically reduced, sometimes by a factor 10 or more.[35,37] Intense efforts are also being made in the nuclear industry to continue to decrease the production of radioactive wastes.

Considerable resources have been invested for the installation of new analytical facilities with greater radiation protection shielding and the development of analytical procedures with remote and automatic handling,[38-40] which allow more or faster analyses with less radiation exposure and reduced radioactive effluents and wastes. Measurements with instruments like high-level neutron coincidence counters (HLNCC), K-edge X-ray absorptiometer and fluorescence analyzers (HKED) are used routinely by inspectors at the plants not only to detect partial defects but also to verify the flow and balance of nuclear materials. These techniques, or similar ones developed for safeguards purposes, also find applications in plant process control. The 1993 ITVs reflect a significant improvement by a factor of 2 to 2.5 in the accuracy achievable in practice in the analyses of uranium products and spent fuel solutions. The 1993 list should, therefore, still be a motivating goal for beginner laboratories and a reasonable but effective reference for experienced laboratories and safeguards evaluators.

Safeguards Accountancy Verification Measurements

As evident from the title of this paper and its introduction, the principal application of the ITVs will continue to be in safeguards activities. The safeguards verification data also form the main measurement information on which the ITVs are based. A description of the origin of the safeguards data is therefore relevant.

Figure 1 describes the basic measurement scheme followed in safeguards accountancy verifications. For each inspection, j, the inspector selects, in accordance with a random sampling plan, the items or batches of nuclear materials to be verified by an independent measurement. The inspector then compares the result of his verification measurement, Y_{ij}, to the result, X_{ij}, which the operator has obtained on the same batch or item i, and which the operator has declared to the inspectorate. The ability of the inspector to detect whether the difference, d_{ij}, is significantly different from zero depends upon the overall uncertainties in the results X_{ij} and Y_{ij}. Figure 1 identifies the major steps of the measurement process where uncertainties can arise. Figure 1 reflects more immediately the situation where both the operator and the inspector use a destructive analytical method (DA) for the elemental and isotopic assays. However it is also, with some modification, directly relevant to the use of an NDA method, which is frequently the case for the inspector. Nevertheless, it is recognized that a model more specific to NDA may be needed to take into account differences between NDA and DA methodologies.

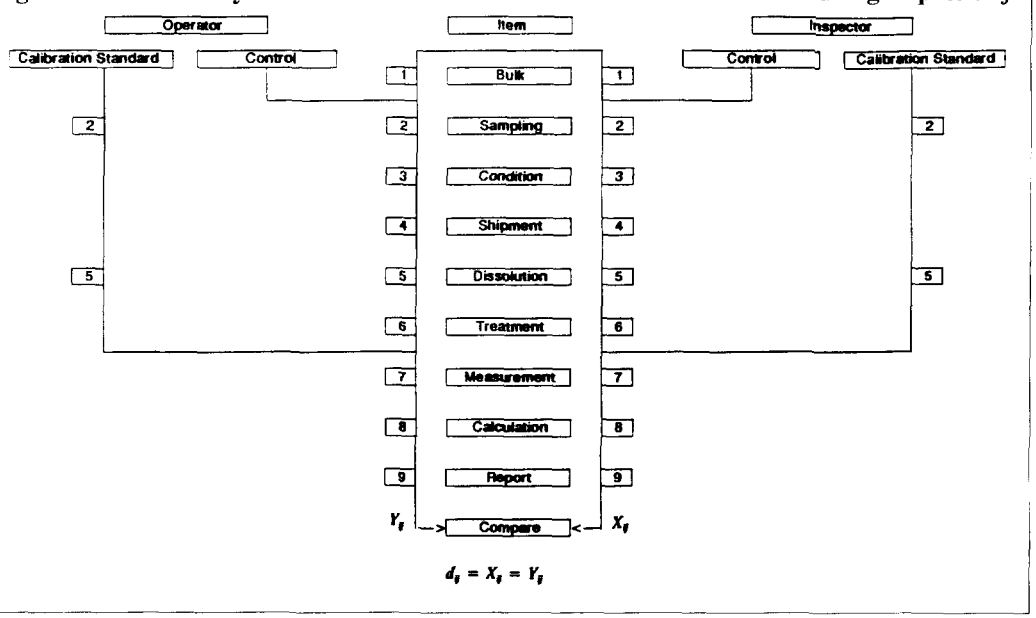
Step 1 corresponds to the measurement of the volume or mass of the item or batch of material. This so-called bulk measurement, when needed, takes place in the plant area. Uncertainties due to bulk measurement errors will be considered for the first time in this paper.

Step 2, the sampling, involves removing a representative fraction of the material from its container for the purpose of the analystical measurement. This step is also done in the plant area.

Step 3 points out the precautions that must be taken in the way the withdrawn sample is conditioned and packaged at the sampling station so that its isotopic and elemental compositions do not change in an uncontrolled way during its transport to the position or laboratory where it will be measured.[41]

Step 4, the shipment, is the transport itself of the sample

Figure 1: Accountancy and Verification Measurement Scheme for Item *i* during inspection *f*



to the location where it can be measured. This is never a trivial operation, even when the distance is very short, as in the case of an NDA measurement, which is done practically on the spot.

Step 5, the dissolution, is specific to destructive analytical measurements using a wet chemical procedure.

Step 6, the treatment, is intended to bring the sample into the optimal geometrical, physical and/or chemical form for the measurement.

Step 7 represents the measurement itself. Step 8, the calculation, involves transforming the result of the physical or chemical measurement obtained in the preceding step into an estimate of the elemental concentration c_{ij} or the isotope abundance *fij* of the fissile element or isotope of interest and combining these with the result of the bulk measurement w_{ij} to yield a measure of the mass of fissile isotope X_{ij} in item or batch *i*, or $X_{ij} = w_{ij} \sum c_{ij} \sum fij$. It is in this step that uncertainties in the physical or chemical model used to describe the measurement come into play along with the uncertainties of the calibration process. Figure 1 points out that most often the reference materials used to calibrate the measurement method are, especially for DA, also subject to a sequence of steps before they are measured. This sequence will usually be different and simpler than the process to which the actual sample is subjected. Although not shown on Figure 1, bulk measurements need also to be calibrated. The uncertainties in the measurements of element concentrations and isotope abundances considered in the earlier target values and the present version of the ITVs refer to the combined effects of the uncertainties in steps 3 to 8 occurring after the taking of the sample in step 2.

Step 9, the reporting of the results, is purely clerical but unfortunately it can be a source of mistakes. Of course, the goal for step 9 should be to have no mistakes at all. Thus, no additional uncertainty from the clerical reporting of the results is included in the ITVs proposed in this document.

Quality control should be introduced at every stage of the process, starting with bulk measurements. Quality control on sampling can be done by taking replicate samples after different mixing times or taking samples from a number of items of the same batch of bulk materials. Quality control materials or samples can be introduced at specific steps to verify the quality of the whole process or any part of it, including the conditioning and shipment steps. Figure 1 is an example where control materials are used independently by the operator and the inspector to check the quality of the processes following the bulk measurement. Quality control measures should be documented in a suitable quality assurance program.[42-44]

NOTE: When NDA is used, the attention focuses most on the measurement (step 7) as the preceding steps have less impact or may even be omitted. For example, bulk measurements and sampling are not needed if the NDA method allows direct measurement of the total amount of fissile element or isotope contained in a whole item or batch of nuclear material, as with various neutron counters or calorimeters.

Evaluation of Safeguards Accountancy Verification Measurements

The safeguards inspectors examine the operator–inspector data pair differences to determine whether these exceed values which would be expected as a result of the uncertainties in the operators' and inspectors' measurements. The inspectors need to know for this purpose the magnitude of the major uncertainties in the actual data collected during their verification activities.

The two types of measurement uncertainties that play an important role in planning for inspections and in drawing inferences from inspection data stem from the random errors on one side and the systematic errors on the other.[45-48] Simply stated, the effects of random errors are reduced by repeated sampling and analysis while systematic errors continue to persist, and their effects are independent of the number of analyses performed under a fixed set of conditions. Thus, random error components can also be understood as those affecting single items. For example, in NDA, single item counting statistics and measured background correction uncertainties are typical random error sources. However, inter-item differences when assaying a population (a batch, a stratum) will also appear as a random component. Systematic error components are those affecting groups or classes of items, like those interpreted with the same calibration curve, or normalized with the same normalization experiments, or affected by the same background subtraction. However, uncertainties in the certified values of reference materials used in the calibration curve setting, nuclear data uncertainties, as well as instrumental biases will also appear to have a systematic character.

A systematic error is regarded by some to be synonymous with a calibration error. In some applications, this may be the dominant source of uncertainty. However, calibration information is not always available, nor are shifts in the calibration always taken into account. Further, other sources of systematic errors, resulting, for example, from uncorrected interfering effects, may contribute significantly to the overall uncertainty. For example, mismatches between actual samples and calibration materials or the settling of powders during storage or shipments can be the sources of undetected errors in NDA measurements. The resulting uncertainties will usually be expected to have a systematic character. However, under actual inspection conditions these effects can also appear as random uncertainties. Also, in methods using internal calibration procedures, the uncertainty linked to the calibration is essentially of a random rather than systematic nature. Examples of this are the plutonium isotopic analysis by high resolution gamma spectrometry (HRGS)[29] and isotope dilution mass spectrometry (IDMS)

using two isotope tracers.[49]

A basic assumption is that the random and systematic components of the measurement uncertainties are characteristics of the type of material, its chemical and physical form and of the method of measurement. A further assumption is that for a given inspection, the systematic component is constant, but this component may vary from one inspection to another, for both the operator and the inspector. Consequently, the inspectors group the data pairs originating from one inspection, j, by material balance areas (MBA) and by strata of materials of similar characteristics.[47] For a given MBA and stratum, call $d_{ij} = (X_{ij} - Y_{ij})/X_{ij}$, and the operator-inspector difference d_{ij} for item i in inspection j, with $i = 1, 2, \ldots, m_j$ and $j = 1, 2, \ldots, K$. To simplify the presentation, relative differences are treated here. In practice, absolute differences, $(X_{ij} - Y_{ij})$, are also used. The assumed error model is $d_{ij} = \Delta + \Delta_j + \varepsilon_{ij}$, where Δ is the mean difference over the K inspections, while Δ_j is the change in the systematic error observed during inspection j, and ε_{ij} is the random error affecting the measurement of item i during inspection j.

Δ_j and ε_{ij} both have expectation zero (mean). In a one-way analysis of variance of the operator-inspector differences, d_{ij}, the within-inspection mean square gives an estimate of the variance, $s^2(\varepsilon)$, of the random component, ε_{ij}, while the between-inspection mean square, after removing the contribution of the random component, provides an estimate of the variance, $s^2(\Delta)$, of the changes of the systematic component, Δ_j, from one inspection to another. Alternatively, one may estimate the between-inspection parameter by calculating the variance of the inspection mean differences and correcting for the random component. The model used in the analysis of variance assumes that random uncertainties are the same for all items in the stratum and across all inspections; it also assumes that the between inspection term, Δ_j, has the same probability distribution for all inspections. The reader should consult references 45-48 for more accurate and detailed descriptions of the model.

Separate paired comparisons of this type are done for bulk measurements, element concentrations and isotope abundances, as well as for the masses of fissile elements and isotopes. After screening out outliers, one obtains, for each type of measurement, an estimate of the sum of the actual variance components for the operator's and inspector's measurement systems: $s^2(\varepsilon) = RAN(O)^2 + RAN(I)^2 - 2r(\varepsilon)RAN(O)xRAN(I)$, and $s^2(\Delta) = BIF(O)^2 + BIF(I)^2 - 2r(\mathrm{D})BIF(O)xBIF(I)$, where $RAN(O)$ and $RAN(I)$ are the standard deviations of the "within-inspection" uncertainty for the operator and the inspector respectively, $r(\varepsilon)$ is the Pearson correlation coefficient between the operator's and the inspector's random errors,[50] $BIF(O)$ and $BIF(I)$ are the standard deviations of the "between-inspection-fluctuation" component, in the operator's and inspector's measurements respectively, and $r(\Delta)$ is the Pearson correlation coefficient between the operator's and inspector's between-inspection-fluctuations.[50]

Independent evidence shows that the uncertainties of operator's and inspector's data have similar magnitudes when both are obtained with similar methods. This is particularly the case when both operator and inspector use DA. In such an instance, the values

$$RAN(O) \cong RAN(I) \cong \frac{s(\varepsilon)}{\sqrt{2}}$$

and

$$BIF(O) \cong BIF(I) \cong \frac{s(\Delta)}{\sqrt{2}},$$

provide good estimates of the standard deviations of the uncertainty components of the measurement of each separate party which are independent of each other, with $r(\varepsilon) = r(\Delta) = 0$. In other situations, operator's DA results may be compared with much less precise and/or much less accurate inspector's results obtained, for example, by some NDA methods. If, for example: $RAN(I) \geq 3RAN(O)$, and $BIF(I) \geq 3BIF(O)$, then, at the limit $RAN(I) \cong s(\varepsilon)$ and $BIF(I) \cong s(\Delta)$.

In such a case, $RAN(0)$ and $BIF(0)$ must be derived from a comparison with inspector's measurements obtained by DA. Various other statistical techniques are used to derive separate estimates of the operator's and inspector's uncertainty parameters from a statistical evaluation of the actual data pairs d_{ij}.[46,51] The result of these evaluations are tables of performance values which have been published on the basis of current inspection experience with DA and NDA.[53] These values are generally updated once a year.

Use of Safeguards Performance Values for Inspection Purposes

The above performance values are used in planning inspections and in drawing inferences based on the declared values of the operator and on the measured values of the inspector. From an inspection planning viewpoint, they allow calculation of sample sizes for NDA and for DA verification methods that are optimal with respect to achieving the desired level of potential defect probability, with the minimum number of samples.[54,55] With respect to their usage in drawing inferences, there are several aspects.

First, they serve to define alarm levels, or reject limits, such that if a given data pair difference, d_{ij}, exceeds the limit L in absolute value, it is identified as a discrepancy, where L is defined by the equation:

$$L = 3\left[s^2(\Delta) + s^2(\varepsilon)\right]^{1/2}$$

In practice, the data pair differences may be calculated on either an absolute or relative basis, as was mentioned following the equation in the preceding section. Of course, for

a homogeneous stratum, it makes no difference whether absolute or relative differences are calculated.

In addition to defining attribute tests reject limits as just described, performance values are also used in calculating the standard deviation of the so-called $\hat{D}$ statistic, which may be applied to a given stratum or to a collection of strata, e.g. all strata comprising an inventory or all strata in a material balance. For a given stratum, $\hat{D}$ is an estimate of the bias in the operator's declared total amount for the stratum, where the bias may be due to a combination of causes, including but not limited to, falsifying data to hide diversion. For a single stratum, the standard deviation of $\hat{D}$ is given by the equation:

$$SD = N\left[s^2(\Delta) + \frac{s^2(\varepsilon)}{n}\right]^{1/2} \bullet \bar{x}$$

where N is the total number of items in the stratum, n is the number of verfied items, $\bar{x}$ is the average declared mass of fissile element or isotope per item in the stratum.

In extending $\hat{D}$ to include several strata, the algebraic sum of individual strata values is found. For example, the estimated bias in an inventory may be denoted by DINV, and the estimated bias in a material balance MUF value by DMUF. The respective deviations, denoted by SDINV and SDMUF in this discussion, are computed as extensions of the above equation, again using performance values. The details of computing SDINV and SDMUF are documented[55a]. It is noted that systematic errors that affect more than one stratum are taken into account. Also, in the case of SDMUF, a distinction is made between the standard deviation of DMUF under the null hypothesis of no data falsification and under the alternate hypothesis of data falsification.

If the inflated variance of DMUF under the alternate hypothesis is ignored to simplify this discussion, then M_o given by the equation below is the value of DMUF that would be detected with probability (1-ß) if the false alarm probability is α.

$$M_o = \left(t_\alpha + t_\beta\right)SDMUF,$$

where t_α and t_β are the normal distribution factors corresponding to a detection probability (1-ß) and a risk of false alarm α, respectively.

M_o may be regarded as a measure of the detection capability of the safeguards verification system at the specified probabilities when the verificaiton data are applied in the variable mode. For completeness of discussion, it is noted that one may also combine the tests of significance on DMUF and on MUF into a single test involving (MUF $-\hat{D}$). This may be regarded as the inspector's estimate of MUF since it is the reported MUF corrected for the estimated bias. Again, details of this test are documented.[55b]

Discrepancies in amounts of fissile element or isotope, statistically significant material balance differences exceeding a specified fraction of a safeguards *significant quantity* (SQ)[57] and SDMUF exceeding a value consistent with the International Standards of Accountancy[2] are the object of further investigations by the safeguards authorities.

The inspector will also compare the material balances or the MUF declared by the operator with an uncertainty derived from the performance values observed in actual operator-inspector differences at the given MBA, when these exist, rather than from the operator's declared performance. Thus, the balance of material declared to be present at the plant in a given stratum at the time of a particular inspection will be compared to a standard deviation, SB, given by the following equation:

$$SB = N\left[\overline{BIF(O)^2} + \frac{\overline{RAN(O)^2}}{n(O)}\right]^{1/2} \bullet \bar{x}$$

where N is the number of items in the material balance, $n(O)$ is the number of items that the operator has measured in this stratum, $BIF(O)$ and $RAN(O)$ are the performance values derived by the inspector from operator-inspector pair differences for the given stratum and facility, and $\bar{x}$ is the average declared mass of fissile element or isotope per item in the stratum.

The estimation of performance values from the statistical evaluation of the operator-inspector pair differences constitutes a verification of operator's declared uncertainties. This function of the verification measurement system becomes particularly important when safeguarding very large nuclear material throughputs because timely detection of anomalies requires that the operator makes available the process data needed to maintain a near real time material accountancy (NRTMA) of the MUF.

Limits of the Safeguards Performance Values

The users of the performance values must remain aware of a number of limits in their meaning or content. Plant operational and economic constraints may inflate the variance components of the operator-inspector differences significantly compared with the expected capability of current measurement technology. The safeguards inspector must indeed verify that the uncertainties in the plant measurement system are not deliberately inflated in order to reduce the detection capability of the verification measurements. The latter concern increases with the throughput of the plant. There will therefore always be a need for target values providing an accepted measure of the capability of current measurement technology under reasonably economic and operational conditions encountered in the industry. Conversely, paired comparisons do not detect the measurement errors or uncertainties that are common to the operator and inspector. For example, if both use the same reference material for calibration, the uncertainty of the certified value of the reference

material will appear as a common systematic component in both results. The common component can also be of a random nature; random sampling errors are common, for instance, when the operator and the inspector measure the same sample or separate aliquots of the same sample.

These common components do not affect the uncertainties of the differences between operator's and inspector's measurements on a single stratum. They can, however, hinder the detection of differences with the true amount of material. On the other hand, the use of performance values can lead to underestimation of the total uncertainties in the operator's declarations or in the material balance differences over the plant. Thus, independent measurement evidence, free from such common mode uncertainties, is needed.

The user of the performance values must also know that the estimate of the between-inspection effects, $s(\Delta)$, becomes less precise as the random uncertainty component, $s(\varepsilon)$, increases.[46] When the inspector's uncertainties are large compared to the operator's values, it becomes difficult to obtain a precise estimate of the operator's uncertainties, and vice versa. This is frequently the case when the operator's data come from DA measurements while the inspector measures by NDA. The paired comparisons can lead to an overestimation of the random uncertainties of the operator's DA measurements, and at the same time, to a poor estimate of the between-inspection effects in the inspector's NDA results. As a further complication, estimates of these parameters will be affected when the operator's values are based in part on nominal or average values. A separate evaluation of the performance of individual measurement methods is necessary to guard against such potential problems.

Results of Laboratory Intercomparisons

Laboratory intercomparisons also offer a documented set of experimental data relevant in defining target values. The most useful information stems from experiments where the participants analyze very well-characterized materials or measure well-known volumes or masses of nuclear materials in industrial tanks or containers, and where their results are directly compared to the certified composition of the materials or to the certified value of the quantities subject to the test. Permanent or periodic measurement evaluation programs have a greater value for our present purpose than one-shot intercomparison experiments, because the participants tend to follow more closely their routine measurement procedure when the intercomparison samples are submitted sufficiently and frequently.[14-27]

Mass measurements are rather straightforward, so that actual inspection data probably provide sufficiently reliable estimates of their uncertainties. The measurements of volumes of solutions in industrial tanks using pneumatic level indicators is a more complex procedure and have been the object of several scientific experiments with international participation. The results of these experiments have been reported[58-61] and were used in the discussion of the relevant target values. The uncertainties to be expected in the use of tracer techniques for volume measurements have been evaluated in the same or similar experiments.[62-65]

Unfortunately, there exists no permanent measurement evaluation program regarding the quality of sampling procedures. Interlaboratory experiments on the quality of sampling of industrial nuclear materials have been rare and limited to the estimation of the random component of the sampling uncertainties.[66] Actually, in most reports of such experiments, the interlaboratory participation concerned more the evaluation of the quality of the elemental assay than the sampling itself.

There are numerous references of interest regarding one-shot intercomparisons of the quality of elemental and isotopic assays by DA.[11,12,66-68] There are yet, however, too few reports of extensive NDA intercomparisons.[9,18,70,71] The evaluations of such one-shot experiments are usually much more elaborate than those of actual inspection data or those of permanent measurement evaluation programs. They provide, therefore, a better insight into the structure of the sources of measurement uncertainties. Unfortunately, they are often published with long delays and rarely present a current picture. Another frequent drawback of interlaboratory comparisons is that they too rarely involve the measurements of actual industrial materials under industrial conditions. The report of the interlaboratory certification of working reference materials for NDA of plutonium materials[71] perhaps constitutes an interesting exception.

For these reasons some degree of caution was taken in using the results of these evaluations in the preparation of this paper.

Reports of Validation of Measurement Methods

It is a standard practice of the metrological and analytical laboratories to submit new measurement methods to an experimental validation. However, the reports of such tests have been too frequently overoptimistic and can rarely be checked against independent references. The most trustworthy studies of this type are certainly those that identify the basic metrological parameters of the measurement process, estimate the contributions of the uncertainties occurring in these elementary steps, and compare the expected performance with the results of actual measurements of well known amounts of materials.[28-31, 62-65, 72-82]

The reports of most recent experimental developments in isotope dilution mass spectrometric assay of spent fuel solution using large size dried (LSD) spikes,[83] metal spike,[84] internal standard[49] and total evaporation techniques (TET)[85] were considered with particular interest because the analyses of spent fuel dissolver solutions at large reprocessing plants should be of the highest possible accuracy.

Meaning of the 1993 International Target Values for Uncertainty Components

The 1993 International Target Values (ITVs) for Uncertainty Components take into account actual practical experiences and should be achievable today under the conditions normally encountered in typical industrial laboratories or during safeguards inspections.

They were selected on the basis of a critical discussion of the inspectorates' performance evaluations of actual historical data, and their comparison with the 1987 and 1988 ESARDA Target Values as well as complementary experimental evidence provided by interlaboratory measurement evaluation programs, demonstrations of measurement methods and instrumentation, and information provided by individual laboratories.

The 1993 ITVs do not represent the ultimately achievable performance of a measurement system which would be obtained under exceptional or ideal laboratory conditions. However, they reflect reasonably well the progress observed during the past several years in the routine performance of accountancy and verification measurements.

Performance values are described by a range of values of the parameters measuring the uncertainties observed during actual industrial operations and safeguards inspections.[52] This range is sometimes said to represent the state of the practice. The uncertainties achieved under ideal conditions by research laboratories or laboratories producing and certifying primary reference materials can be represented by another range of values which may be taken to illustrate the state of the art in analytical measurements. At a given time, the two ranges of values can overlap to various degrees depending upon the nature of the measurement and the spread of analytical technology advances at that time. The ITV for a given type of measurement is a single value that has been selected to be a goal of acceptable level achievable in practice.

Structure and Content of the 1993 International Target Values

The 1993 ITVs are presented in tabular form according to material types (or strata) which are encountered in nuclear facilities under safeguards and are subject to accountancy measurements. Tables 1.1 to 1.14 (p. 31-35) cover 14 categories of materials of major importance in safeguards. These tables provide the values of significant uncertainty parameters in a measurement for safeguards purposes. They concern primarily the determination of the amounts of uranium (total element), plutonium (total element) and ^{235}U (total isotope), but also provide information on the target values proposed for the measurements and processes required to determine total element or isotope amounts, namely bulk measurements, sampling, concentration measurements and the assays of the ^{235}U isotope abundance.

Separate tables provide a list of ITVs for plutonium isotope assays (Table 2, p.35) and the codes for the measurement methods used in Tables 1 and 2 (Table 3, p.35). Two parameters characterize the quality which should be aimed for in a specific measurement of a given material using a specified method at a single laboratory: RAN is the relative standard deviation of the repeatability[86] to be expected in the random uncertainty components encountered during a single inspection, and BIF is the relative standard deviation of the changes in the systematic errors which may occur between inspections. Attempts were made to include in these parameters all uncertainty components that determine the potential difference between the measured and the true value assuming that the operator's and inspector's measurements are completely independent. For example, the values specified for the element and isotope concentration measurements take into account all uncertainties generated in Steps 3-8 of Figure 1 and the uncertainties in the reference data and materials used in calibration following the taking of the sample. It has not yet been possible to propose ITVs for the term BIF applicable to sampling.

The combination of the RAN and BIF parameters,

$$s_R = \left(\overline{RAN}^2 + \overline{BIF}^2\right)^{1/2},$$

should be equivalent to the relative standard deviation of the reproducibility of the measurement, as it is defined in the relevant ISO standard,[86] when it is applied to the measurement of a single laboratory.

For a given material and a given combination of DA methods, the ITVs for the mass of element or isotope is equal to the square root of the sum of the squares of the ITVs for the relevant individual components, i.e., bulk measurement, sampling, element concentration and isotope abundance, after rounding to the nearest 0.05% unit. For example, in the first line of Table 1.1, the ITVs for the determination of the mass of ^{235}U isotope are derived as follows:

$$RAN = \left(\overline{0.05}^2 + \overline{0.10}^2 + \overline{0.05}^2 + \overline{0.20}^2\right)^{1/2} = 0.235$$

rounded to RAN = 0.25; and

$$BIF = \left(\overline{0.05}^2 + \overline{0.00}^2 + \overline{0.05}^2 + \overline{0.20}^2\right)^{1/2} = 0.212$$

rounded to BIF = 0.20.

Applications of ITVs

The ITVs are values for uncertainties achievable in routine measurements involved in the determination of the amount of nuclear materials for materials accountancy and safeguards verification purposes. They are intended to be used as a reference by plant operators, state systems and international safeguards organizations only. The ITVs are not developed to serve licensing or other regulatory objectives. They should

also not be used in place of performance values in estimating the statistical significance of operator-inspector differences or MUF.

The expected relative standard deviation for the total amount of nuclear material may be read directly from the tables for certain combinations of material types, measurement methods and conditions. For example, according to Table 1.7, the overall random uncertainty to be expected for a DA measurement of the total plutonium mass is 0.45% for one laboratory. The expected relative standard deviation, SDR, of the uncertainties of random character in the difference between operator and inspector estimates of the total plutonium mass by DA in a spent fuel solution should be:

$$SDR = \left(2 \times \overline{0.45}^2\right)^{1/2} = 0.64\%.$$

It is also possible to calculate the parameters for other combinations of methods from the standard deviations listed in the tables for individual uncertainty components by adding the squares of the components and taking the square root of the sum. If, for example, in Table 1.7, the mass of the input solution is measured rather than its volume, the ITV standard deviations for Pu-total would be calculated by summing the squares of the weighing, sampling and IDMS components as follows:

$RAN = (0.05^2 + 0.3^2 + 0.2^2)^{1/2} = 0.36\%$; and
$BIF = (0.05^2 + 0.2^2)^{1/2} = 0.21\%$

assuming $RAN = BIF = 0.05\%$ for the weighing of the tank with a load cell. The reader is advised to consult reference 87 for a description of the application of ITVs to various situations which may be encountered in actual verifications.

Future Developments

The intention is to update the ITV tables regularly in order to incorporate the latest information that may come from inspectorates' performance evaluations based on actual historical data, interlaboratory measurement evaluation programs, demonstration of new measurement methods and instrumentation, and experimental qualification of recommended sampling procedures.[88-98] Suitable measurement data are needed in particular to define ITVs for the uncertainty component of systematic character in sampling procedures. Models more specific to the NDA measurement processes are being developed by the ESARDA/NDA Working Group to monitor the sources of major uncertainties in actual inspectors' measurements.

The experts who took part in this work will follow attentively how recent developments in bulk measurements[60,61] and elemental assays[82,85,99] of spent fuel solutions improve the accuracy of the accountability of large throughputs and inventories of nuclear materials at large plants coming now under safeguards. In preparation of the next revision of the ITVs, the IAEA inspectorate should identify the areas where further improvements would be desirable and possible. The next revision of the ITVs should provide the opportunity to invite more experts from Eastern Europe, South America, Asia and Africa to participate in the discussion and updating of the international target values.

References

1. International Atomic Energy Agency. *The Structure and Content of Agreements Between the Agency and States Required in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons.* INFCIRC/153 (corrected), para. 55 (1972).

2. International Atomic Energy Agency. *IAEA Safeguards Glossary.* IAEA/SG/INF/1 (Rev. 1): 27(1987).

3. De Regge, P. "1979 Target Values for uncertainty components of destructive analysis methods." Minutes of the meeting of the ESARDA/WGDA in Brussels, April 23-24, SCK, Mol, Belgium (1979).

4. De Bièvre, P. et al. "1983 Target Values for uncertainty components in fissile element and isotope assay." *ESARDA Bulletin* 6: 1 (1983)

5. De Bièvre, P. et al. "1987 Target Values for uncertainty components in fissile isotope and element assay." *Proceedings, AIEA Symposium on Nuclear Safeguards Technology*: 649-662 (1987).

6. De Bièvre, P. et al. "Random uncertainties in sampling and element assay of nuclear materials; target values." *ESARDA Bulletin* 13: 8 (1987).

7. Kuhn, E. et al. "The ESARDA Target Values: are they achievable in safeguards measurements." Transactions American Nuclear Society winter meeting: 221-222 (1989).

8. De Bièvre, P. et al. "The European Commission's safeguards analytical measurements laboratory network." *Proceedings, 13th Annual ESARDA Symposium*: 107 (1991).

9. Morel, J. et. al. "Intercomparison of Plutonium Isotopic Composition Measurements by X- and Gamma-Ray Spectrometry; Results from the PIDIE Exercise." Rep. LPRI 91/278-MARS, DAMRI, CEA, Saclay (1991).

10. Harry, R.J.S. *Plutonium Isotopic Determination Inter-comparison Exercise.* Rep. ECN-RX-90-044, Netherlands Energy Res. Foundation, Petten, The Netherlands (1990).

11. Verdingh, V. et al. "Interlaboratory comparison exercise for the determination of uranium by potentiometric titration." *Proceedings, 13th Annual ESARDA Symposium*: 195-201 (1991).

12. Bickel, M. et al. "Interlaboratory comparison exercise for the determination of uranium by potentiometric titration (second phase)." *Proceedings, 15th Annual ESARDA Symposium*: 643 (1993).

13. Houin, C. "French program for analytical quality control in the safeguards field." *Proceedings, 9th Annual ESARDA Symposium*: 381 (1987).

14. De Bièvre, P., Wolters, W.H. "The regular European interlaboratory measurement evaluation program." *Proceedings,*

9th Annual ESARDA Symposium: 125-128 (1987).

15 De Bièvre, P., Mayer, K. "How well can we measure uranium and plutonium on an interlaboratory basis?" Presented at the Conference on Methods and Applications of Radioanalytical Chemistry, Kona, Hawaii (1991).

16. Mayer, K. et al. "Results of REIMEP 89 on UO_2 powder, UO_2 pellets, uranyle nitrate." *Proceedings, 13th Annual ESARDA Symposium*: 203-213 (1991).

17. Beyrich, W. et al. "DOD Evaluation of REIMEP Round UF_6/1987." Presented at the ESARDA/WGDA Meeting, Salamanca, Spain (1989).

18. Aparo, M., Cresti, P. "REIMEP 1987, An Interlaboratory ^{235}U Enrichment Determination by Gamma Measurement on Solid UF_6 Sample." Rep. RT/COMB/87/15, ENEA, Casaccia (1988).

19. De Bolle, W. et al. "REIMEP 1992 - Uranium Hexafluoride. Preparation and Characterization of the Material." *Proceedings, 15th Annual ESARDA Symposium*: 639 (1993).

20. Mayer, K. et al. "Performance Values of the Assay of Fissile Material as Derived from REIMEP." *Proceedings, 15th Annual ESARDA Symposium*: 465 (1993).

21. CETAMA. "Programme d'Evaluation de la Qualité du Résultat d'Analyse dans l'Industrie Nucléaire (EQRAIN)." Program No 4, 1990-1991. Nitrate d'Uranyle, Rep. TEC 92-1, CEA, Fontenay-aux-Roses (1992).

22. CETAMA. "Programme d'Evaluation de la Qualité du Résultat d'Analyse dans l'Industrie Nucléaire (EQRAIN)." Program No 4, 1990-1991. Nitrate de Plutonium, Rep. TEC 92-2, CEA, Fontenay-aux-Roses (1992).

23. Pérolat, J.P. "Programme d'Evaluation de la Qualité du Résultat d'Analyse dans l'Industrie Nucléaire - Bilan de Cinq Programmes." *Proceedings, 15th Annual ESARDA Symposium*: 453 (1993).

24. Cacic, C.G. "Safeguards Measurement Evaluation Program." Phase I, Final Report, Rep. NBL-319, USDOE (1988).

25. Mitchell, W.G. "Measurement technology at selected DOE facilities: a status report." *JNMM*, Vol. XX, 4 (1992) 32-42.

26. EG & G Mound Applied Technologies. "Calorimetry Exchange Program Annual Data Report for 1988." Rep. MLM-MU-89-68-0003, EG & G Miamisburg, O (1989).

27. EG & G Mound Applied Technologies. "Calorimetry Exchange Program Annual Data Report for 1990." Rep. MLM-MU-91-63-0005, EG & G, Miamisburg, O (1991).

28. Ottmar, H., Eberle, H. "The Hybrid K-edge/K-XRF Densitometer, Principles, Design, Performance." Rep. KfK 4590, KfK, Karlsruhe (1991).

29. Gunnink, R., MGA. "A Gamma Spectrum Analysis Code for Determining Plutonium Isotopic Abundances." UCRL-LR-103220, 1, 2, LLNL, Livermore, Calif. (1990).

30. Kuhn, E. et al. "The NBL-Potentiometric Titration of Uranium; Experience of the Safeguards Analytical Laboratory." Rep. IAEA/RL/62, IAEA, Vienna (1979).

31. De Bièvre, P. *Isotope Dilution Mass Spectrometry in Trace Metal Analysis in Biological Specimens*. Biomedical Publication, Foster City, Calif. (1985).

32. IAEA. Consultants Group Meeting on International Standards of Measurements, Vienna (1991).

33. IAEA. Consultants Group Meeting on International Target Values, Vienna (1993).

34. *Journal Officiel de la République Française*. NC 4669 and NC 4672, (1981).

35. Sorel, F. "Face aux Rayonnements: la Radioprotection à COGEMA LA HAGUE — Organisations et Moyens." COGEMAGAZINE, No. 47: 26 (1993).

36. *French Nuclear Newsletter*: 8, 11 (1987).

37. "Annual report and accounts 85-86." *British Nuclear Fuels*. Risley, Warrington: 27 (1986).

38. Menlove, H.O. et al. "Remote-controlled NDA systems for feed and product storage at an automated MOX facility." *Proceedings, INMM 30th Annual Meeting*: 267 (1989).

39. Miller, M.C. et al. "Remote-controlled NDA systems for process areas in a MOX facility." *Proceedings, INMM 30th Annual Meeting*: 274 (1989).

40. Krellmann, J. "Plutonium Processing at the Siemens Hanau Fuel Fabrication Plant." *Nuclear Technology* 102: 18 (1993).

41. Bagliano, G. et al. *The Safeguards Analytical Services*. STR-69, Rev.2, IAEA, Vienna (1986).

42. American Society for Quality Control. *Quality Management and Quality System Elements for Laboratories*. ANSI/ASQC Standard Q2-1991, ASQC Wisconsin (1990).

43. Ratliff Jr., T.A. *The Laboratory Quality Assurance System*. Van Nostrand Reinhold, New York (1990).

44. American National Standards Institute Inc. *Measurement Control Program — Analytical Chemistry Laboratory*. ANSI/N 15.51-90, ANSI, New York (1990).

45. Hough, G. et al. "Qualification of Measured Data for Safeguards Use." *Proceedings, ESARDA Specialists' Meeting*: 13 (1982).

46. Jaech, J.L., Russell, M. "Estimation of Systematic Error Parameters." Proceedings, 4th International Conference on Facility Operators-Safeguards Interface: 72 (1991).

47. Jaech, J.L. *The Generalized Difference Statistic*. STR-278, IAEA, Vienna (1992).

48. De Grandi, G. et al. "Software, data structures, and data evaluation algorithms for a verification data managements system." *Proceedings, 6th Annual ESARDA Symposium*: 199 (1984).

49. Callis, E.L.. "High Precision (≤ 0.01 %), uranium isotope ratio measurements by thermal ionization mass spectrometry utilizing a double spike technique." *Proceedings, Conference on Analytical Chemistry in Nuclear Technology*: 115-123 (1982).

50. International Organization for Standardization. *Statistics, Vocabulary and Symbols*. ISO 3534 — 1977: 266, Geneva (1977).

51. IAEA. *IAEA Safeguards: Statistical Concepts and*

Techniques. IAEA/SG/SCT/4, Section 4.6.3, IAEA, Vienna (1988).

52. Jennekens, J. IAEA, Vienna, personal communication to P. De Bièvre, 25 August 1992.

53. Jaech, J., Russell, M. *Algorithms to Calculate Sample Sizes for Inspection Sampling Plans*. STR-261, Rev. 1, IAEA, Vienna (1991).

54. IAEA. *Safeguards Criteria* 1991-1995, Dept. of Safeguards, IAEA, Vienna (1992).

55. IAEA. *IAEA Safeguards Glossary*. IAEA/SG/INF/1 (Rev.1), IAEA, Vienna: 38 (1987).

55a. IAEA. *IAEA Safeguards Statistical Concepts and Techniques*. IAEA/SG/SCT/4, IAEA, Vienna: 78 (1989).

55b. IAEA. *IAEA Safeguards Statistical Concepts and Techniques*. IAEA/SG/SCT/4, IAEA, Vienna: 117 (1989).

56. IAEA. *IAEA Safeguards Glossary*. IAEA/SG/INF/1 (Rev.1), IAEA, Vienna: 35 (1987).

57. IAEA. *IAEA Safeguards Glossary*. IAEA/SG/INF/1 (Rev.1), IAEA, Vienna: 23 (1987).

58. Carchon, E., de Regge, P, Franssen, F. *Reprocessing Input Tank Calibration Exercise (RITCEX)*. Rep. BLG 588, 1, 2 (1985).

59. Bokelund, H. et al. "An International Collaborative Exercise on the Calibration of a Model Reprocessing Plant Accountancy (CALDEX) Tank Using Lutecium Tracer." Meeting minutes, ESARDA/RIV Work Group, October 1993, Ispra, Italy.

60. Cauchetier, P. "Calibration of an accountability tank using bubbling pressure measurements." *Proceedings, 15th Annual ESARDA Symposium*: 243 (1993).

61. M. Neuilly. "Calibration of UP 2-800 (La Hague) accountability tank." *Proceedings, 15th Annual ESARDA Symposium*: 249 (1993).

62. Hein, H.J., Lausch, W., Schwertner, W. *Volumetric Assay in an 800-Liter Ring Slab Using a Lithium-Magnesium-Uranium Tracer*. Rep. JOPAG/10.82-PRG-56 (1982).

63. Trincherini, P.R. *Volume and Mass Measurement in the Input Accountability Tank of the Reprocessing Plant by the IDMS Tracer Technique*. Rep. EUR 12623 EN, Joint Research Centre, Ispra, Italy (1990).

64. Reed, W.J. et al. *Special Meeting of ESARDA/RIV Work Group on Tracer Calibration Exercise of CALDEX Project*. March 1991, Harwell, UK, and Nov. 1991, Pierrelatte, France.

65. Cauchetier, P. "Experience with the use of a lutetium tracer at a spent fuel solution accountability tank." TAMELAB Meeting, Ispra, Italy (1992).

66. Verdingh, V. et al. "Repeatability and Reproducibility of Gravimetric Uranium Determinations in UO2 Pellets." CEC, *Nuclear Science and Technology*: Com. 4182 (1985).

67. Beyrich, W. et al. "The role of interlaboratory comparison analyses for nuclear safeguards delineated by the results of the experiments JEX-70, and IDA-72." Presented at the Eighteenth Conference on Analytical Chemistry in Nuclear Technology (1974).

68. Beyrich, W. et al. *The IDA 80 Measurement Evaluation Program on Mass Spectrometric Isotope Dilution Analysis of Uranium and Plutonium*. Vol. I, KfK 3760, EUR 7990e, and Vol. II, KfK 3761, EUR 7991e, Karlsruhe (1984).

69. Guardini, S. et al. "ESARDA performance values of non destructive assay techniques applied in safeguards." *Proceedings, 4th International Conference on Facility Operations-Safeguards Interface*: 448 (1991).

70. Guardini, S. "Performance Values of Non-Destructive Assay (NDA) Techniques Applied to Safeguards: The 1993 Evaluation by the ESARDA NDA Working Group." *Proceedings, 15th Annual ESARDA Symposium*: 469 (1993).

71. S. Guardini et al. *Quality Control Provisions Applied in the Preparation and Characterization of Pu-bearing PERLA Standards*. Rep. EUR 13038 EN, Joint Research Center, Ispra, Italy (1990).

72. Kuvik, V. et al. The MacDonald and Savage titrimetric procedure scaled down to 4 mg sized plutonium samples. Part 1. Basic potentiometric procedure, *Anal. Chim. Acta* 256: 163-176 (1992).

73. Aggarwal, S.K. et al. Comparative Study of ^{239}Pu, ^{240}Pu and ^{241}Pu spikes for determining plutonium concentrations by isotope dilution thermal ionization mass spectrometry. *International Journal of Mass Spectrometry and Ionic Processes* 71: 221-231 (1986).

74. Laszlo, G. et al. "Optimal sample to tracer ratio for isotope dilution mass spectrometry: the poly isotope case." *Proceedings, 13th Annual ESARDA Symposium*: 219 (1991).

75. Holland, M.K. et al. *The New Brunswick Laboratory Controlled Potential Coulometric Method for the Determination of Plutonium*. Rep. NBL-299, USDOE, Argonne, Ill. (1981).

76. Wagner, H.G. et al. "On-Site Analytical Measurements for Input Accountancy Verification in a Large Reprocessing Plant by Hybrid K-Edge." *Proceedings, 4th International Conference on Facility Operations-Safeguards Interface*: 164 (1991).

77. Ibid. "NDA of PuO_2 Powder Samples." 449.

78. Ibid. "Field Experience of EURATOM with LLNL-MGA Code for Pu Gamma Spectroscopy." 299.

79. Davidson, D. et al. "A new high-accuracy combined neutron/gamma counter for in glove-box measurements of PuO_2 and MOX safeguards samples." Proceedings, 15th ESARDA Annual Symposium: 585 (1993).

80. Ensslin, N. et al. "Some target assay uncertainties for passive neutron coincidence counting." *JNMM* XIX: 610 (1990).

81. Sampson, T.E. *Precision of Gamma-Ray Measurements of the Effective Specific Power and Effective ^{240}Pu Fraction of Plutonium*. Rep. LA-UR-92-883, LANL, Los Alamos Nat. Lab. (1992).

82. American National Standards Institute Inc. *Pu-bearing Solids Calibration Techniques for Calorimetric Assay*. ANSI 15.22-1987, ANSI, New York (1987).

83. Donohue, D. et al. "Spent fuel accountability measure-

ments by IDMS using a common large-size dried spike (LSD)." *Proceedings, 15th Annual ESARDA Symposium*: 491 (1993).

84 De Bièvre, P. et al."Solid spikes from CBNM for Input Analysis." *Proceedings, 13th Annual ESARDA Symposium*: 229 (1991).

85. Callis, E.L. "High precision isotopic analyses of uranium and plutonium by total sample volatilization and signal integration." *International Journal of Mass Spectrometry and Ionic Processes* 103: 93 (1991).

86. International Organization for Standardization. *Statistics, Vocabulary and Symbols.* ISO 3534 — 1977: 266, 276 (1977).

87. Deron, S. "How to use the ESARDA target values for sampling and element assay." *ESARDA Bulletin* 13: 17 (1987).

88. American Society for Testing and Materials. "Standard Practice for Sampling Nuclear Materials in Multi-Container Lots." *Annual Book of ASTM Standards*: C970-87 (1991).

89. Ibid. "Standard Practice for Sampling Liquid Uranium Hexafluoride." C1052-85.

90. Ibid. "Standard Practice for Sampling Uranium Ore Concentrate." C1075-86.

91. Nuclear Regulatory Commission. *Considerations for Sampling Nuclear Materials for SNM Accounting Measurements.* Rep. NUREG/CR-0087, Washington, D.C. (1987).

92. Nuclear Regulatory Commission. *Methods for the Accountability of Reprocessing Plant Dissolver and Waste Solutions.* Rep. NUREG/CR-0515, Washington, D.C. (1978).

93. Nuclear Regulatory Commission. *Methods for the Accountability of Uranium Dioxide.* Rep. NUREG-75/010, Washington, D.C. (1975).

94. Atomic Energy Commission. *Methods for the Accountability of Plutonium Dioxide.* Rep. WASH 1335, Washington, D.C. (1974).

95. Atomic Energy Commission. *Methods for the Accountability of Plutonium Nitrate Solutions.* Rep. WASH 1282, Washington, D.C. (1974).

96. International Organization for Standardization. *Guidelines for the Sampling of Plutonium Dioxide.* ISO 11482 (in preparation).

97. International Organization for Standardization. *Guidelines for the Sampling of Plutonium Nitrate Solutions.* ISO/TC85/SC5/WG3/N277E/3 (in discussion).

98. International Organization for Standardization. *Guidelines for the Sampling of Uranyle Nitrate Solutions.* ISO 11598 (in preparation).

99. Ottomar, H. et al. "Striving for improved accuracy in reprocessing input measurements by X-ray densitometry." *Proceedings, 15th Annual ESARDA Symposium*: 261 (1993).

TABLES 1.1-1.14

1993 International Target Values for Uncertainty Components in Measurements of Amount of Nuclear Material for Safeguards Purposes

(% relative standard deviation)

NOTE: RAN: Relative standard deviation of the repeatability of the measurement of a single laboratory within one inspection

BIF: Relative standard deviation of the between inspection uncertainty component for a single laboratory

Table 1.1

Material Type: $LEUF_6$

Measurement Method				Bulk		Sampling		U Conc.		^{235}U Abundance		U Total		^{235}U Total		Pu Conc.		Pu Total		NOTES
Bulk	U	^{235}U	Pu	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	
LCBS	GRAV	TIMS		0.05	0.05	0.10		0.05	0.05	0.20	0.20	0.10	0.05	0.25	0.20					
LCBS	GRAV	GSMS		0.05	0.05	0.10		0.05	0.05	0.05	0.05	0.10	0.05	0.15	0.10					
		PMCN								5.0	2.0									1/
		PMCG								3.0	2.0									1/

Notes: 1/ Measurement time 300 sec.

Table 1.2
Material type: U Oxide Powders (LEU)

Measurement Method				Bulk		Sampling		U Conc.		^{235}U Abundance		U Total		^{235}U Total		Pu Conc.		Pu Total		NOTES
Bulk	U	^{235}U	Pu	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	
EBAL	GRAV	TIMS		0.05	0.05	0.20		0.10	0.10	0.20	0.20	0.25	0.10	0.30	0.25					1/
EBAL	TITR	TIMS		0.05	0.05	0.20		0.10	0.10	0.20	0.20	0.25	0.10	0.30	0.25					1/
EBAL	GRAV	LMCN		0.05	0.05	0.20		0.10	0.10	0.50	0.50	0.25	0.10	0.55	0.50					2/
EBAL	TITR	LMCN		0.05	0.05	0.20		0.10	0.10	0.50	0.50	0.25	0.10	0.55	0.50					2/
		PMCN								2.50	1.50									3/
		PMCG								1.80	1.50									3/, 4/

Notes:
1/ U concentration measurement requires weight change correction because of sample instability
2/ Gamma spectrometry under laboratory conditions
3/ Measurement time 300 sec
4/ Including calibration against reference materials certified to 0.3% or better, and uncertainties in the correction of container wall absorption of 0.5% or less.

Table 1.3
Material Type: U Oxide Pellets (LEU)

Measurement Method				Bulk		Sampling		U Conc.		^{235}U Abundance		U Total		^{235}U Total		Pu Conc.		Pu Total		NOTES
Bulk	U	^{235}U	Pu	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	
EBAL	GRAV	TIMS		0.05	0.05	0.05		0.05	0.05	0.20	0.20	0.10	0.05	0.20	0.20					3/
EBAL	TITR	TIMS		0.05	0.05	0.05		0.10	0.10	0.20	0.20	0.10	0.10	0.25	0.25					3/
EBAL	GRAV	LMCN		0.05	0.05	0.05		0.05	0.05	0.50	0.50	0.10	0.05	0.50	0.50					1/ 3/
EBAL	TITR	LMCN		0.05	0.05	0.05		0.10	0.10	0.50	0.50	0.10	0.10	0.50	0.50					1/ 3/
		PMCN								2.5	1.5									2/

Notes:
1/ Gamma spectrometry under laboratory conditions
2/ Measurement time 300 sec.
3/ The uncertainties in U Total and U235 Total may be larger for pellets containing Gd because of sampling errors due to larger pellet-to-pellet variability.

Table 1.4
Material Type: U Scrap

Measurement Method				Bulk		Sampling		U Conc.		^{235}U Abundance		U Total		^{235}U Total		Pu Conc.		Pu Total		NOTES
Bulk	U	^{235}U	Pu	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	
EBAL	TITR	TIMS										1.0	0.70	1.5	1.0					1/,3/
EBAL	TITR	TIMS										5.0	5.0	7.0	7.0					2/,3/
EBAL	TITR	LMCN										1.0	0.70	1.5	1.0					1/,3/
EBAL	TITR	LMCN										5.0	5.0	7.0	7.0					2/,3/
		PMCN								5.0	5.0									4/

Notes:
1/ Homogeneous scrap
2/ Heterogeneous scrap
3/ The values given are representative of average performance observed on historical data. No estimates are given for the individual characteristics; sampling errors are the main contribution to the overall errors observed.
Scrap can contain various levels of interfering impurities which could result in larger measurement errors. NDA measurements not requiring sampling are preferable for heterogeneous scrap.
4/ Measurement time 300 sec.

Table 1.5
Material Type: Fuel Rods

Measurement Method				Bulk		Sampling		U Conc.		^{235}U Abundance		U Total		^{235}U Total		Pu Conc.		Pu Total		NOTES
Bulk	U	^{235}U	Pu	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	
		UNCL												2.5	2.5					1/
		AWCC												2.0	1.0					1/,3/
		PMCN								2.0	1.0									1/,4/
			AWCC																	2/,4/

Notes:
1/ U Fuel Rods
2/ MOX Fuel Rods
3/ Measurement time 600 sec.
4/ Measurement time 300 sec.

Table 1.6
Material Type: Fuel Assemblies

Measurement Method				Bulk		Sampling		U Conc.		^{235}U Abundance		U Total		^{235}U Total		Pu Conc.		Pu Total		NOTES
Bulk	U	^{235}U	Pu	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	
		UNCL												2.5	2.5					1/
		AWCC												2.0	1.0					1,3/
		PMCN								2.0	1.0									1/,4/
			HLNC															1.5	1.0	2/,4/

Notes:
1/ U Fuel Assemblies
2/ MOX Fuel Assemblies
3/ Measurement time 600 sec.
4/ Measurement time 300 sec.

Table 1.7
Material Type: Reprocessing Input Solution (LWR)

Measurement Method				Bulk		Sampling		U Conc.		^{235}U Abundance		U Total		^{235}U Total		Pu Conc.		Pu Total		NOTES
Bulk	U	^{235}U	Pu	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	
DIPT	IDMS	TIMS	IDMS	0.30	0.20	0.30		0.20	0.20	0.20	0.20	0.45	0.30	0.50	0.35	0.20	0.20	0.45	0.30	1/
DIPT	HKED		HKED	0.30	0.20	0.30		0.20	0.20			0.45	0.30			0.60	0.30	0.75	0.35	2/

Notes:
1/ U and Pu assay using common spike
2/ Target values for HKED for one-hour counting time

Table 1.8
Material Type: LEU Nitrate, Pu Nitrate, and LEU/Pu Nitrate Solutions

Measurement Method				Bulk		Sampling		U Conc.		^{235}U Abundance		U Total		^{235}U Total		Pu Conc.		Pu Total		NOTES
Bulk	U	^{235}U	Pu	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	
DIPT	TITR	TIMS		0.30	0.20	0.10		0.10	0.10	0.20	0.20	0.35	0.20	0.40	0.30					1/
EBAL	TITR	TIMS		0.05	0.05	0.10		0.10	0.10	0.20	0.20	0.15	0.10	0.25	0.25					1/
DIPT	KEDG			0.30	0.20	0.10		0.20	0.20			0.35	0.30							1/, 8/
DIPT			TITR	0.30	0.20	0.20										0.15	0.15	0.40	0.25	2/, 4/
DIPT			IDMS	0.30	0.20	0.20										0.20	0.20	0.40	0.30	2/
DIPT			KEDG	0.30	0.20	0.20										0.20	0.20	0.40	0.30	2/,5/,8/
DIPT			KEDG	0.30	0.20	0.20										0.60	0.50	0.70	0.55	2/,6/,8/
DIPT	TITR	TIMS	TITR	0.30	0.20	0.20		0.10	0.10	0.20	0.20	0.35	0.20	0.40	0.30	0.20	0.20	0.40	0.30	3/,4/
DIPT	IDMS	TIMS	IDMS	0.30	0.20	0.20		0.20	0.20	0.20	0.20	0.40	0.30	0.45	0.35	0.20	0.20	0.40	0.30	3/
DIPT	XRF	TIMS	XRF	0.30	0.20	0.20		0.50	0.50	0.20	0.20	0.60	0.55	0.65	0.55	0.50	0.50	0.60	0.55	3/
DIPT	HKED	TIMS	HKED	0.30	0.20	0.20		0.20	0.20	0.20	0.20	0.40	0.30	0.45	0.35	0.60	0.30	0.70	0.35	3/,7/,8/

Notes:
1/ Uranyl nitrate solutions
2/ Pu nitrate solutions
3/ Mixed U/Pu solutions with U/Pu ratio between 1 and 100
4/ Coulometry expected to give equivalent performance as potentiometric titration
5/ KEDG with x-ray tube and optical cells
6/ KEDG with radioisotope transmission sources
7/ for LWR-type solutions
8/ Measurement time 600-1200 sec.

Table 1.9
Material Type: Pu Oxide

Measurement Method				Bulk		Sampling		U Conc.		^{235}U Abundance		U Total		^{235}U Total		Pu Conc.		Pu Total		NOTES
Bulk	U	^{235}U	Pu	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	
EBAL			GRAV	0.05	0.05	0.10										0.10	0.10	0.15	0.10	
EBAL			TITR	0.05	0.05	0.10										0.15	0.15	0.20	0.15	1/
EBAL			INVS	0.05	0.05	0.10										2.0	1.5	2.0	1.5	2/
			HLNC															1.0	0.50	2/

Notes:
1/ Coulometry expected to give equivalent performance as potentiometric titration
2/ Measurement time 300 sec.; with mass spectrometric isotopic analysis

Table 1.10
Material Type: FBRR MOX (> 10% Pu)

Measurement Method				Bulk		Sampling		U Conc.		^{235}U Abundance		U Total		^{235}U Total		Pu Conc.		Pu Total		NOTES
Bulk	U	^{235}U	Pu	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	
EBAL	TITR	TIMS	TITR	0.05	0.05	0.50		0.20	0.20	0.20	0.20	0.55	0.20	0.60	0.30	0.20	0.20	0.55	0.20	1/,2/
EBAL	GRAV	TIMS	TITR	0.05	0.05	0.50		0.10	0.15	0.20	0.20	0.50	0.15	0.55	0.25	0.20	0.20	0.55	0.20	1/
EBAL	XRF	TIMS	XRF	0.05	0.05	0.50		0.50	0.50	0.20	0.20	0.70	0.50	0.75	0.55	0.50	0.50	0.70	0.50	
EBAL	IDMS	TIMS	IDMS	0.05	0.05	0.50		0.20	0.20	0.20	0.20	0.55	0.20	0.60	0.30	0.20	0.20	0.55	0.20	
EBAL			INVS	0.05	0.05	0.50										1.95	1.5	2.0	1.5	2/
			HLNC															2.0	1.0	2/,3/

Notes:
1/ Coulometry expected to give equivalent performance as potentiometric titration.
2/ Measurement time 300 sec.; with mass spectrometric isotopic analysis.
3/ Better measurement performance to be expected for material in standardized containers.

Table 1.11
Material Type: LWR MOX (< 10% Pu)

Measurement Method				Bulk		Sampling		U Conc.		^{235}U Abundance		U Total		^{235}U Total		Pu Conc.		Pu Total		NOTES
Bulk	U	^{235}U	Pu	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	
EBAL	TITR	TIMS	TITR	0.05	0.05	0.50		0.20	0.20	0.20	0.20	0.55	0.20	0.60	0.30	0.20	0.20	0.55	0.20	1/
EBAL	GRAV	TIMS	TITR	0.05	0.05	0.50		0.10	0.15	0.20	0.20	0.50	0.15	0.55	0.25	0.20	0.20	0.55	0.20	1/
EBAL	IDMS	TIMS	IDMS	0.05	0.05	0.50		0.20	0.20	0.20	0.20	0.55	0.20	0.60	0.30	0.20	0.20	0.55	0.20	
EBAL			INVS	0.05	0.05	0.50										1.95	1.50	2.00	1.50	2/
			HLNC															4.00	1.00	2/,3/

Notes: 1/ Equivalent performance expected for coulometric procedures instead of potentiometric titration.
2/ Measurement time 300 sec.; with mass spectrometric isotopic analysis.
3/ Better measurement performance to be expected for material in standardized containers.

Table 1.12
Material Type: MOX Scrap

Measurement Method				Bulk		Sampling		U Conc.		^{235}U Abundance		U Total		^{235}U Total		Pu Conc.		Pu Total		NOTES
Bulk	U	^{235}U	Pu	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	
EBAL	TITR	TIMS	TITR									5.0	0.50	5.0	0.55			5.1	0.50	1/
EBAL	IDMS	TIMS	IDMS									5.0	0.50	5.0	0.55			5.0	0.50	1/
EBAL			INVS															7.0	5.0	1/,2/
			HLNC															7.0	3.0	1/,2/

Notes: 1/ The values given are representative of average performance observed on historical data. No estimates are given for the individual characteristics; sampling errors are the main contribution to the overall errors observed. Scrap can contain various levels of interfering impurities which could result in larger measurement errors.
2/ Measurement time 300 sec.

Table 1.13
Material Type: U Metal (HEU)

Measurement Method				Bulk		Sampling		U Conc.		^{235}U Abundance		U Total		^{235}U Total		Pu Conc.		Pu Total		NOTES
Bulk	U	235 U	Pu	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	
EBAL	GRAV	TIMS		0.05	0.05	0.05		0.05	0.05	0.02	0.02	0.10	0.10	0.10	0.10					
EBAL	TITR	TIMS		0.05	0.05	0.05		0.10	0.10	0.02	0.02	0.10	0.10	0.10	0.10					
EBAL	GRAV	LMCN		0.05	0.05	0.05		0.05	0.05	0.10	0.10	0.10	0.10	0.15	0.10					1/
EBAL	TITR	LMCN		0.05	0.05	0.05		0.10	0.10	0.10	0.10	0.10	0.10	0.15	0.15					1/
		PMCN								0.50	0.50									2/
		PMCG								0.50	0.50									2/

Notes: 1/ Gamma spectrometry under laboratory conditions
2/ Measurement time 300 sec., calibration against reference materials certified to 0.3% or better, and uncertainties in the correction of container wall absorption of 0.5% or less.

Table 1.14
Material Type: U-Al (HEU)

Measurement Method				Bulk		Sampling		U Conc.		^{235}U Abundance		U Total		^{235}U Total		Pu Conc.		Pu Total		NOTES
Bulk	U	^{235}U	Pu	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	RAN	BIF	
EBAL	TITR	TIMS		0.05	0.05	0.20		0.10	0.10	0.05	0.05	0.25	0.10	0.25	0.10					
EBAL	TITR	LMCN		0.05	0.05	0.20		0.10	0.10	0.20	0.20	0.25	0.10	0.30	0.25					1/
		PMCN								1.0	1.0									2/
		PMCG								1.0	1.0									2/

Notes: 1/ Gamma spectrometry under laboratory conditions
2/ Measurement time 300 sec. calibration against reference materials certified to 0.3% or better, and uncertainties in the correction of container wall absorption of 0.5% or less.

Table 2
Plutonium Isotope Assay of PuO_2 and MOX

Isotope Ratio	Method (1)					
	TIMS		HRGS (2)		LMCA (3)	
	RAN	BIF	RAN	BIF	RAN	BIF
$^{238}Pu/^{239}Pu$	1.5	1.0	2.0	2.0	1.0	1.0
$^{240}Pu/^{239}Pu$	0.1	0.05	1.0	1.0	0.7	0.7
$^{241}Pu/^{239}Pu$	0.2	0.2	1.0	1.0	0.7	0.7
$^{242}Pu/^{239}Pu$	0.4	0.3	(4)	(4)	(4)	(4)

(1) Typical values for high burn up plutonium

(2) Measurement time 3 x 100 sec.

(3) Measurement time 3 x 1000 sec. with 0.5 g amount of plutonium

(4) The $^{242}Pu/^{239}Pu$ isotope ratios are not measured by gamma spectrometry but may be estimated by isotopic correlations with relative standard deviations of 5 % for the random and between-inspection uncertainty components.

Table 3
Coding of Measurement Methods

Measurement	Code	Technique
Bulk	LCBS	Load-Cell Based Weighing System
	EBAL	Electronic Balance
	DIPT	Dip Tubes
U Assay	GRAV	Gravimetry
	TITR	Titration
	IDMS	Isotope Dilution Mass Spectrometry
	KEDG	K-Edge Densitometer
	HKED	Hybrid K-Edge/K-XRF Densitometer
	XRF	X-Ray Fluorescence
Isotopic Analysis	TIMS	Thermal Ionisation Mass Spectrometry
	GSMS	Gas Source Mass Spectrometry
	PMCN	Portable Multichannel Analyzer, NaI-detector
	PMCG	Portable Multichannel Analyzer, GeLi-detector
	LMCN	Laboratory Multichannel Analyzer, NaI-detector
	HRGS	High Resolution Gamma Spectrometry
	LMCA	Laboratory Multichannel Analyzer
Total ^{235}U	FRSC	Fuel Rod Scanner
	AWCC	Active Well Coincidence Counter
	UNCL	Uranium Neutron Coincidence Collar
Pu Assay	GRAV	Gravimetry
	TITR	Titration
	COUL	Coulometry
	KEDG	K-Edge Densitometer
	HKED	Hybrid K-Edge/K-XRF Densitometer
	IDMS	Isotope Dilution Mass Spectrometry
	HLNC	High Level Neutron Coincidence Counter
	INVS	Inventory Sample Coincidence Counter

Note: Measurement codes correspond to the codes adopted in the IAEA Safeguards Manual, Part SMO, SMO 7.1, Annex 1, IAEA, Vienna (1992-09-30).

An Improved Binomial Approximation to the Hypergeometric Density Function

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Abstract

The hypergeometric probability density function is applicable when sampling is from a finite population in attributes inspection. It is often convenient to approximate this exact function with a binomial function. This paper develops a binomial approximation that differs from the standard function generally used. It is demonstrated that this new approximation is much superior to the standard function.

Introduction

In developing the sampling plan used by the International Atomic Energy Agency (IAEA) in their inspections, it was necessary to calculate the nondetection probablity as a function of the number of defects and the probability that a defect is properly classified as a defect given that it has been measured. The exact expression for this involves summing a large number of terms, each term containing as one of the factors a probability calculated by the hypergeometric probability density function. The calculation of the nondetection probability is greatly simplified upon approximating the hypergeometric function with a binomial density function.

However, in some regions of interest in inspection sampling plans, the parameter values were of a size that caused the commonly used, or standard, binomial function to be a poor approximation to the hypergeometric. This situation motivated the development of an alternate binomial approximation to the hypergeometric function. It is the purpose of this paper to present this alternate function and compare it with the standard function. The alternate binomial function is shown to be superior to the standard function and may be used in any situation in which hypergeometric probabilities (sampling from a finite population without replacement) may be approximated by the simpler binomial probabilities (sampling with replacement).

Hypergeometric Density Function

Let: N = number of items in the population
n = number of items in the sample
D = number of defects in the population
d = number of defects in the sample

The exact probability that the randomly selected (without replacement) sample of n items will contain d defects is given by the hypergeometric probability density function:

$$h(d) = \frac{\binom{D}{d}\binom{N-D}{n-d}}{\binom{N}{n}} \tag{1}$$

Standard Binomial Approximation

The standard binomial approximation to $h(d)$ is

$$b_0(d) = \binom{n}{d} p_0^d (1-p_0)^{n-d} \tag{2}$$

where

$$p_0 = \mathrm{D}/\mathrm{N} \tag{3}$$

This is the approximation assuming that $D \geq n$. If $D < n$, it is better to interchange the roles of D and n. This fact is not always mentioned. For example, to quote from the book identified by the U.S. Nuclear Regulatory Commission

*This work was begun while the author was a CFE at the International Atomic Energy Agency and was completed under contract with the IAEA.

(NRC) as the "reference manual of statistical methodology for nuclear material management practitioners,"[1] the following statement is made: "When N is 'large' relative to 'n', however, the binomial *pdf* provides a satisfactory approximation to the hypergeometric *pdf* for computing probabilities when sampling is without replacement. A widely accepted definition of 'large' is $N > 50$ and $n/N \leq 0.10$ ... ." Note that nothing is said about the value of D. On the other hand, the corresponding IAEA reference document does distinguish between which approximation to use depending on the relative sizes of n and D.[2] However, no criterion is given as to how small n and D must be relative to N, nor is the minimum value for N specified.

Alternate Binomial Approximation

The alternate approximation takes the form of Equation 2, with p_0 and n replaced by p_1 and n_1, found by equating the first two moments of the hypergeometric function to the first two moments of the binomial function and solving for p_1 and n_1. The equations to solve are:

$$n_1 p_1 = n D / N \tag{4}$$

$$n_1 p_1 (1 - p_1) = (N - n) n D (N - D) / N^2 (N - 1) \tag{5}$$

The easily derived solutions are:

$$p_1 = 1 - (N - n)(N - D) / N(N - 1) \tag{6}$$

$$n_1 = nD / Np_1 \tag{7}$$

Since n_1 will most likely not be an integer, the factor

$$\binom{n}{d}$$

in Equation 2 takes on its more general meaning,

$$\binom{n}{d} = \Gamma(n+1) / \Gamma(d+1)\Gamma(n-d+1), \tag{8}$$

where Γ denotes the gamma function.

In summary, the alternate binomial approximation is written as follows:

$$b_1(d) = \frac{\Gamma(n_1 + 1)}{\Gamma(d+1)\Gamma(n_1 - d + 1)} p_1^d (1 - p_1)^{n_1 - d} \tag{9}$$

where p and n_1 are given by Equations 6 and 7, respectively, and where $\Gamma(a)$ denotes the gamma function.

$$\Gamma(a) = \int_0^\infty e^{-t} t^{a-1} dt \tag{10}$$

Recall that if a is an integer, then

$$\Gamma(a) = (a - 1)! \tag{11}$$

Note that p_1 and n_1 are symmetric in n and D in the sense that the values of n and D may be interchanged without affecting the approximation.

It is noted that $b_1(d)$ is a true probability density function (*pdf*) only if n_1 is an integer. In this event, all terms are positive for $0 \leq d \leq n_1$ and they sum to 1, necessary conditions for a function to be a *pdf*.

If n_1 is not an integer, as will usually be the case, $b_1(d)$ is not truly a *pdf* because it yields negative results for alternate terms once d exceeds (n_1+1). To circumvent this difficulty, define $b_1(d) = 0$ for $d > (n_1+1)$. The sum of $b_1(d)$ for $d = 0$ to the largest integer contained in (n_1+1) will be very nearly 1, so the difficulty identified here is only of academic interest, unless one's interest is in the extreme right hand tail of the distribution (i.e., very small probabilities). In this event, it will be necessary to calculate probabilties using the exact *pdf*, $h(d)$.

Study to Compare $h(d)$, $b_0(d)$, and $b_1(d)$

Exact probabilities of observing d defects for given values of N, n and D were calculated using $h(d)$, Equation 1. Approximate probabilities were also calculated by the two binomial approximations, $b_0(d)$ and $b_1(d)$, Equations 2 and 9, respectively.

For a given case, values were assigned to N, n and D. The 168 cases run consisted of a subset of the 294 combinations of N, n and D.

N = 20, 40, 80, 160, 320, 640
n/N = 0.05, 0.10, 0.15, 0.20, 0.30, 0.40, 0.50
D/N = 0.05, 0.10, 0.15, 0.20, 0.30, 0.40, 0.50

Because of the interchangeable roles of n and D, not all of the above 49 combinations of n and D need be run for a given N. Rather, for a given N and n, only those combinations for which $D \geq n$ need be run. Thus, the total number of cases is

$$6(7 + 6 + 5 + \ldots + 1) = 168$$

For a given case, after calculating $h(d)$, $b_0(d)$, and $b_1(d)$, a *figure of merit* was computed for each of the approximations $b_0(d)$ and $b_1(d)$ as follows:

$$FM0 = \sum_d |h(d) - b_0(d)| / h(d)m \quad (12)$$

$$FM1 = \sum_d |h(d) - b_1(d)| / h(d)m \quad (13)$$

where the sum is taken over those terms for which $h(d) \geq L$, and where m is the number of terms in the sum. The largest term in each sum is also found and designated as MAX0 and MAX1 respectively.

For $L = 0.01$, summary Table 1 gives FM0 and FM1 values and Table 2 gives MAX0 and MAX1 values. The quality of the $b_1(d)$ approximation relative to the $b_0(d)$ approximation is quite apparent from both tables; $b_1(d)$ is much closer to $h(d)$ than is $b_0(d)$.

Adequacy of Approximations

As was previously mentioned, it is generally agreed that $b_0(d)$ is an acceptable approximation to $h(d)$ if $n \leq 0.10N$ and $N \geq 50$, irrespective of the value of D. From Table 1, it is seen that for $n = 0.10N$ and $N = 40$, with D ranging from $0.10N$ to $0.50N$, the mean FM0 value is 0.082. For $N = 80$, it is even larger at 0.088; for $N = 60$, it is still larger at 0.093. The means for $N = 320$ and $N = 640$ are 0.078 and 0.066 respectively. (It is noted that FM0 is not a smooth function of any of the parameters because of the way it is calculated with $L = 0.01$. In one case, the smallest value of $h(d)$ may just exceed 0.01 and in another, it may be slightly smaller than 0.01. Since MAX0 tends to occur at the small values of $h(d)$, the reason for the lack of smoothness in FM0, as well as in FM1, MAX0, and MAX1, is apparent.)

From Tables 1 and 2, it is seen that FM0 and MAX0 are not dependent on $max(n, D)$. Hence, more insight can be gained on the quality of $b_0(d)$ by averaging the FM0 and MAX0 values over $max(n, D)$ for given $min(n, D)$ and N. Tables 3 and 4 are the results of these averaging processes.

The reason that FM0 and MAX0 is 0 for $N = 20$ and $min(n, D) = 0.05N$ or 1 is that for $min(n, D) = 1$, the binomial and hypergeometric distributions give the same result; it doesn't matter whether sampling is with or without replacement.

For $min(n, D) = 0.10N$ and $N \leq 160$, the mean FM0 value is 0.086. Thus, using FM as the criterion for judging the adequacy of an approximation, Table 1 can be used to determine the region in which $b_1(d)$ is an adequate approximation

Table 1: FM0 (Approximation 1): FM1 (Approximation 2)

		max (n, D)													
		.05N		.10N		.15N		.20N		.30N		.40N		.50N	
min(n, D)	N	FM0	FM1	FM0	FM1	FM0	FM1	FM0	FM1	FM0	FM1	FM0	FM1	FM0	FM1
.05N	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	40	.013	.001	.014	.001	.067	.018	.049	.018	.033	.018	.027	.019	.026	.021
	80	.097	.008	.039	.008	.024	.008	.045	.007	.031	.011	.047	.015	.038	.016
	160	.035	.004	.038	.004	.048	.005	.031	.006	.035	.007	.045	.011	.042	.012
	320	.036	.002	.048	.003	.042	.003	.042	.005	.041	.006	.046	.008	.033	.006
	640	.045	001	.037	.002	.033	.002	.033	.002	.037	.004	.038	004	.036	.005
.10N	20			.028	.002	.161	.037	.110	.037	.071	.038	.057	.040	.054	.043
	40			.087	.017	.050	.016	.103	.013	.067	.022	.103	.038	.083	.031
	80			.085	.008	.109	.012	.066	.011	.076	.015	.098	.023	.093	.026
	160			.110	.007	.092	.008	.093	.010	.091	.013	.101	.018	.072	.014
	320			.081	.004	.071	.004	.071	.005	.081	.008	.083	.010	.078	.011
	640			.078	.003	.076	.003	.058	.003	.060	.004	.060	.005	.065	.006
.15N	20					.135	.036	.090	.035	.180	.050	.128	.042	.119	.061
	40					.129	.017	.092	.021	.106	.027	.153	.040	.220	.113
	80					.159	.017	.105	.015	.116	.017	.142	.027	.176	.047
	160					.130	.011	.125	.011	.119	.013	.100	.013	.122	.020
	320					.121	.006	.113	.007	.117	.009	.099	.009	.112	.013
	640					.093	.003	.097	.004	.082	.005	.080	.006	.086	.007
.20N	20							.294	.057	.154	.045	.258	.123	.201	.069
	40							.156	.020	.182	.030	.156	.037	.226	.073
	80							.232	.027	.226	.032	.139	.022	.175	.037
	160							.171	.013	.157	.014	.167	.020	.125	.018
	320							.138	.007	.143	.010	.142	.011	.115	.012
	640							.116	.004	.124	.006	.106	.007	.113	.008
.30N	20									.282	.054	.441	.147	.224	.071
	40									.332	.057	.262	.053	.244	.057
	80									.252	.028	.275	.038	.344	.060
	160									.213	.017	.222	.022	.208	.025
	320									.214	.012	.209	.015	.173	.016
	640									.172	.007	.164	.009	.156	.011
.40N	20											.541	.189	.262	.080
	40											.444	.081	.271	.057
	80											.426	.053	.396	.058
	160											.309	.027	.359	.038
	320											.241	.016	.261	.021
	640											.209	.011	-	-
.50N	20													.764	.179
	40													.776	.163
	80													.478	.066
	160													.432	.044
	320													.314	.025
	640													-	-

Table 2: MAX0 (Approximation 1); MAX1 (Approximation 2)

		max (n, D)													
		.05N		.10N		.15N		.20N		.30N		.40N		.50N	
min(n, D)	N	MAX0	MAX1	MAX0	MAX1	MAX0	MAX1	MAX0	MAX1	MAX0	MAX1	MAX0	MAX1	MAX0	MAX1
.05N	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	40	.025	.001	.025	.002	.170	.049	.114	.047	.064	.044	.040	.041	.026	.037
	80	.252	.023	.074	.020	.031	.017	.130	.013	.055	.021	.126	.028	.082	.031
	160	.057	.009	.095	.007	.139	.009	.066	.008	.081	.017	.129	.038	.096	.026
	320	.080	.004	.151	.005	.118	.007	.106	.014	.105	.016	.120	.023	.083	.013
	640	.134	.002	.093	.006	.087	.006	.090	.007	.111	.012	.107	.011	.097	.012
.10N	20			.050	.003	.425	.105	.267	.101	.140	.094	.086	.086	.056	.078
	40			.175	.043	.062	.036	.306	.028	.122	.042	.285	.087	.179	.068
	80			.223	.012	.330	.020	.150	.017	.176	.037	.290	.082	.215	.058
	160			.363	.017	.274	.015	.244	.030	.239	.035	.273	.050	.183	.031
	320			.203	.013	.190	.013	.198	.016	.247	.027	.243	.026	.217	.028
	640			.238	.006	.222	.009	.157	.006	.187	.011	.174	.011	.184	.014
.15N	20					.283	.094	.140	.084	.539	.094	.303	.059	.187	.118
	40					.329	.023	.132	.042	.221	.041	.350	.094	.547	.422
	80					.513	.034	.261	.034	.327	.027	.451	.097	.468	.164
	160					.407	.038	.333	.032	.342	.028	.287	.033	.329	.047
	320					.411	.026	.358	.023	.340	.026	.302	.019	.320	.032
	640					.270	.008	.280	.009	.223	.008	.217	.010	.241	.012
.20N	20							.938	.125	.308	.078	.772	.392	.442	.162
	40							.402	.038	.426	.085	.437	.062	.550	.184
	80							.682	.069	.649	.088	.334	.038	.466	.082
	160							.492	.039	.493	.035	.560	.066	.219	.031
	320							.388	.017	.472	.030	.441	.032	.310	.021
	640							.344	.007	.365	.013	.314	.012	.321	.014
.30N	20									.691	.101	1.126	.410	.442	.102
	40									1.089	.182	.718	.099	.467	.092
	80									.817	.084	.851	.104	1.023	.209
	160									.590	.034	.724	.057	.585	.046
	320									.674	.026	.647	.031	.479	.026
	640									.539	.013	.488	.015	.435	.018
.40N	20											1.814	.684	.458	.124
	40											1.285	.240	.609	.111
	80											1.446	.191	1.169	.176
	160											1.003	.065	1.137	.112
	320											.775	.028	.796	.038
	640											.595	.019	-	-
.50N	20													3.009	.634
	40													2.392	.641
	80													1.431	.199
	160													1.389	.125
	320													.940	.041
	640													-	-

Table 3: FM0 values averaged over Max(n,D)

	N					
min(n, D)	20	40	80	160	320	640
0.05N	0	0.033	0.046	0.039	0.041	0.037
0.10N	0.080	0.082	0.088	0.093	0.078	0.066
0.15N	0.130	0.140	0.140	0.119	0.112	0.088
0.20N	0.227	0.180	0.193	0.155	0.135	0.115
0.30N	0.316	0.279	0.290	0.214	0.199	0.107
0.40N	0.402	0.358	0.411	0.334	0.251	0.209
0.50N	0.764	0.776	0.478	0.432	0.314	-

Table 4: MAX0 values averaged over Max(n,D)

	N					
min(n, D)	20	40	80	160	320	640
0.05N	0	0.066	0.107	0.095	0.109	0.103
0.10N	0.171	0.188	0.231	0.263	0.216	0.194
0.15N	0.290	0.316	0.404	0.340	0.346	0.246
0.20N	0.615	0.454	0.533	0.466	0.403	0.336
0.30N	0.753	0.791	0.897	0.633	0.600	0.487
0.40N	1.136	0.947	1.308	1.070	0.786	0.595
0.50N	3.009	2.392	1.431	1.389	0.940	-

to $h(d)$ by identifying those values of $min(n, D)$, $max(n, D)$, and N for which FM1 ≤ 0.086. It is noted that with a few exceptions, FM1 is always ≤ 0.086, and usually by a large amount. The exceptions occur at the following parameter values:

min (n, D)	max (n, D)	N	FM1
0.15N	0.50N	40	0.113
0.20N	0.40N	20	0.123
0.30N	0.40N	20	0.147
0.40N	0.40N	20	0.189
0.50N	0.50N	20	0.179
0.50N	0.50N	40	0.163

The first two cases represent perturbations in the sense that they are surrounded by FM1 values that are much smaller. Hence, they may be ignored. In fact, the only region in which $b_1(d)$ may be judged to be of questionable adequacy is when N is small, say ≤ 20, and when both n and D approach $0.50N$. Even here, the approximation is not bad, for $N = 20$ and for all practical purposes, $b_1(d)$ may be used throughout the entire region characterized in Table 1 if FM is the adequacy criterion.

If MAX is the criterion, then the mean MAX0 value from Table 4 is 0.213 for $min(n, D) = 0.10N$ and $N \leq 160$. From Table 2, MAX1 is always ≤ 0.213 with the following exceptions:

min (n, D)	max (n, D)	N	FM1
0.15N	0.50N	40	0.422
0.20N	0.40N	20	0.392
0.30N	0.40N	20	0.410
0.40N	0.40N	20	0.684
0.40N	0.40N	40	0.240
0.50N	0.50N	20	0.634
0.50N	0.50N	40	0.641

Not surprisingly, these are the same instances identified by the FM criterion with one exception. Thus, by either criterion, $b_1(d)$ is judged to be an adequate approximation to $h(d)$ throughout the entire region characterized in Tables 1 and 2, with the approximation being of slightly questionable quality only for $N = 20$ and n and D both near $0.50N$.

The Case of n and/or $D > 0.50N$

The study included values of n and/or D only up to $0.50N$. However, in effect, this covered the entire range of n and D values because of symmetry in the hypergeometric distribution. That is, if n and/or D exceed $0.50N$, then the hypergeometric probabilities, and the binomial approximations as well, may be computed by defining n', D', and d' as functions of N, n, D, and d. Specifically, the following correspondences are made:

Case 1
If $n > 0.50N$ and $D > 0.50N$, define

$$n' = N - n$$
$$D' = N - D$$
$$d' = d - (n + D - N)$$

Case 2
If $n > 0.50N$ and $D \leq 0.50N$, define

$$n' = N - n$$
$$D' = D$$
$$d' = D - d$$

Case 3
If $n \leq 0.50N$ and $D > 0.50N$, define

$$n' = n$$
$$D' = N - D$$
$$d' = n - d$$

The roles of n and D are simply reversed from those in Case 2.

Use of Binomial Approximations in IAEA Sample Size Calculations

The IAEA algorithms used in calculating sample sizes for inspection sampling plans are documented.[3] One part of the algorithm calls for calculating the nondetection probability, β, as a function of the number of defects, D, and the probability, q, that a defect is properly classified as a defect, if measured. The exact expression for the nondetection probability is

$$\beta = \sum_d h(d)(1 - q)^d \qquad (14)$$

This indicated summation can be greatly simplified by replacing $h(d)$ by $b_1(d)$ of Equation 9. Call the approximate nondetection probability β_1 to distinguish it from the exact value ß.

$$\beta_1 = \sum_d b_1(d)(1 - q)^d \qquad (15)$$

Assume that n_1 is an integer so that β_1 may be written

$$\begin{aligned}\beta_1 &= \sum_d \binom{n_1}{d} p_1^d (1-p_1)^{n_1-d}(1-q)^d \\ &= (1-p_1)^{n_1} \sum_d \binom{n_1}{d}\left[\frac{p_1(1-q)}{(1-p_1)}\right]^d \\ &= (1-p_1)^{n_1}\left[1+\frac{p_1(1-q)}{(1-p_1)}\right]^{n_1} \\ &= (1-p_1 q)^{n_1},\end{aligned} \tag{16}$$

which is a much simpler result that is the exact formula for ß in Equation 14.

Clearly, the corresponding result if $b_0(d)$ were used instead of $b_1(d)$ is, for $D \geq n$,

$$\beta_0 = (1-p_0 q)^n \tag{17}$$

when p_0 is D/n. If $D < n$ then simply interchange D and n in Equation 17 and in the definition of p_0. The values of ß, β_0, and β_1 were calculated for 14 actual examples. Table 5 summarizes the results.

Table 5: Comparison of Exact Hypergeometric Probabilities with Approximate Probabilities

N	D	n	q	ß	β_0	β_1
87	80	33	0.03203	0.3727	0.2905	0.3727
54	52	5	0.06734	0.7152	0.7056	0.7152
157	152	18	0.07431	0.2608	0.2405	0.2608
100	90	20	0.10	0.1513	0.1221	0.1513
100	90	30	0.02	0.5798	0.5246	0.5798
50	47	8	0.05	0.6803	0.6598	0.6803
30	27	5	0.233	0.3075	0.2802	0.3076
116	110	12	0.10	0.3024	0.2841	0.3024
200	60	30	0.006	0.9474	0.9433	0.9474
116	80	12	0.30	0.0609	0.0529	0.0610
116	10	12	0.90	0.3625	0.3606	0.3634
20	3	6	0.75	0.4508	0.4344	0.4529
200	10	83	0.3714	0.1855	0.1341	0.1857
200	60	31	0.003819	0.9651	0.9622	0.9651

Table 5 again demonstrates the clear superiority of $b_1(d)$ over $b_0(d)$. It also demonstrates the very close agreement between ß, calculated using $h(d)$, and β_1, calculated using $b_0(d)$.

Summary

The $b_1(d)$ approximation to $h(d)$ is clearly superior to the commonly used $b_0(d)$ approximation. It is judged to be adequate for all values of n and D and for $N \geq 20$. However, if N is less than 20 when both n and D are near $0.50N$, the approximation should be used with some caution.

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References

1. Bowen, W.M., Bennett, C.A. (eds.). "Statistical Methods for Nuclear Material Management." NUREG/CR-4604: 49 (1987).
2. "IAEA Safeguards Statistical Concepts and Techniques." IAEA/SG/SCT/4: 18-20 (1989).
3. Jaech, J. L., Russell, M. "Algorithms to Calculate Sample Sizes for Inspection Sampling Plans." IAEA STR-261, Rev. 1 (1991).

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