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INMM Cooperates Worldwide

In the last issue of the *Journal*, I commented that the INMM had been asked by the International Atomic Energy Agency (IAEA) in Vienna to provide support and cooperation for its Symposium on International Safeguards scheduled for March 14-18, 1994. The request came from then-Deputy Director General of Safeguards, Jon Jennekens, during our Executive Committee Meeting at the last Annual Meeting in Orlando.

The IAEA subsequently established a Symposium Program Committee composed of members of the IAEA and representatives from the four cooperating organizations: the American Nuclear Society (ANS), the European Safeguards Research and Development Association (ESARDA), the Russian Nuclear Society and the INMM. Les Fishbone, who is on assignment at the IAEA from Brookhaven National Laboratories, is scientific secretary of the Symposium and chair of the Program Committee. Les will hold this position until August 1, when his assignment ends. At that time, he will be replaced by Jim Larrimore, who is also chair of the INMM Vienna Chapter.

The last IAEA Symposium on Safeguards occurred on Nov. 10-14, 1986, in Vienna. There were 296 participants representing 28 countries. There were 137 papers presented, along with 24 poster papers. The scientific secretary was Jim Lovett, and the scientific co-secretary was John Jaech, both of whom are well-known in the INMM. The Vienna Chapter of the INMM headed a social event for the participants.

The 1994 Symposium will be the seventh held by the IAEA. Up until the last one, the symposium was held every four years. Budget constraints, however, have precluded any symposium since 1986, nearly seven years ago.

The 1994 Symposium Program Committee first met in December of last year and established a general list of topics to be discussed. As a result, an "Information Sheet" on the symposium was prepared and distributed to all member states of the IAEA. The importance of the symposium on the information sheet is highlighted by the following: "IAEA safeguards are in a particularly dynamic situation because of the recent, continuing experience with inspections under United Nations Security Council resolutions; the political changes in several regions of the world; and the technological changes in the underlying peaceful nuclear fuel cycle."

The information sheet continues: "The symposium … is intended to be broadly based. Papers are invited for presentation or poster on all aspects of international safeguards implementation and development, subject to the fundamental constraint that papers should represent new work …"

Topics for which papers are invited include strengthened and more cost-effective safeguards, experiences in safeguards implementation, experiences in safeguards verification activities, integrated safeguards systems, material accountancy, measurement by sampling and destructive or nondestructive assay, safeguards statistics and data processing, safeguards for plutonium facilities, containment and surveillance technology, safeguards for uranium fuel fabrication and enrichment facilities, safe-

Six new INMM members from the Russian Federation are welcomed by INMM Chair Dennis L. Mangan. The delegation visited Sandia National Laboratories during a tour of U.S. laboratories. Pictured (left to right) are Vladimir Kositsin, Igor Ivanovich Bumblis, Aleksandr V. Izmailov, Eugeni N. Shilkin, Dennis L. Mangan, Yuri G. Volodin and Yuri N. Barmakov.

Chair's Message
continued from previous page

guards for reactors and spent fuel storage facilities, and safeguards approaches. An advertisement flyer for the symposium states the following: "Participation in the symposium, whether or not a paper will be presented, must be through designation of the Government of a Member State of the IAEA or by an International Organization invited to participate. Participation forms and forms for submission of a paper may be obtained from the IAEA (Vienna International Center, P.O. Box 100, A-1400, Vienna, Austria; telephone, 43-1-23601863; fax, 43-1-234564, attention: Jim Larrimore) or the appropriate National Authority (DOE or DOS). Completed forms are to be returned to the IAEA by Aug. 15, 1993.

This symposium will be an exciting one, and I encourage those in the international safeguards field to give consideration to supporting it. The INMM is proud to be a cooperative organization.

On another topic, Cecil Sonnier of Sandia National Laboratories, who is chair of the INMM International Safeguards Division, underwent open-heart surgery on May 2, 1993. He is on his way to a strong recovery, which is good news for all of us.

On my recent trip to Vienna, I observed that our Vienna Chapter is going strong under the excellent leadership of Jim Larrimore. I had the opportunity to attend the chapter's luncheon meeting, along with more than 50 other attendees. The featured speaker was Robert Kelly, deputy leader of UNSC 687 Action Team, who spoke on "Iraq Inspection Experience — A Personal View." Bob gave an exceptional presentation.

I hope to see you in July in Scottsdale, Ariz., for our Annual Meeting. As always, should you have any questions or comments, please feel free to contact me at 505/845-8710.

Dennis Mangan, Chair
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The Ebb and Flow of Nuclear Materials Management

This issue contains three technical articles. I tried to encourage some of those who recently presented interesting papers to U.S. chapters to submit them, but without success.

Two of the technical papers continue the valuable contributions from the IAEA. The third is a description of the neural network technique with illustrations of how it might be used for safeguards applications.

The latter reminded me of the fall of 1945, when I was at Los Alamos. The war was over and many scientists were collecting information which might be useful to them after they went back to their universities or to other assignments. John von Newmann asked me if the electronics experts would explain to him about the prospects for developing digital computers. We said that we would be happy to do so, if he would explain digital computers to us. The way that he did this was to describe the work a scientist had done before the war using the large nerves in frog's legs, which remain operating for awhile after excision. The signal moves through a nerve fiber at a certain speed. At a synapse, one or more nerves connect to the one or more following nerves. The signal may be simply transferred or two signals coming in may be needed to send one on, or one may negate the other, standard logic circuits. It turns out that a neural network composed of only a few of these elements can be taught to respond in a specific way to a specific stimulus. The system is a conditioned reflex! John wasn't then planning to design such a system. He had made some calculations with the U.S. Army's ENACT, an electronic calculator, by programming the subroutines on a patch board. His great idea, was to store the program as well as the data in the computer. What he wanted to know was how difficult it would be to store data and programs in acoustic delay lines, for example, and to perform the computer operations contained in the programs. We were able to provide reasonable estimates for the speeds and costs for such electronic analogues of the frog's delay lines and logic circuits. The first commercial electronic computer was very much like the neural network. Now it is reversed. The computers have become much faster and more efficient. The neural network technique uses special programs and in the future will probably also employ additional fast digital circuits designed specifically for such applications.

It was about 20 years ago that I was persuaded to become the technical editor. That means beating the bush for contributions, reading them, deciding who might be competent reviewers, sending the reviewer's comments and often mine to the contributor, and trying to keep everyone happy. This is not always easy, but there have been few complaints.

In spite of the editing, not every technical article is entirely clear and useful to others. Other technical journals regularly print letters to the editor and responses from the original authors. INMM members either don't read the articles carefully or are too apathetic to comment. This time, I am pleased to say, we have such a technical discussion. The editor preferred to title these "INMM Comment." I consider such discussions to be very important and hope that this will stimulate you to follow through in the future.

One important country recently decided not to obtain nuclear weapons and another indicated that it intends to obtain them. South Africa signed the NPT a year ago and placed all of its nuclear materials and facilities under IAEA safeguards. On March 24, President F. W. de Klerk announced that South Africa had constructed six gun-type nuclear weapons and had dismantled them and the facilities that had been used to design and build them, before signing the NPT. The HEU is to be blended down to LEU. At about the same time, North Korea cancelled its agreement to accept IAEA safeguards. Argentina and Brazil decided several years ago to forego peaceful nuclear explosives, but several important countries are not NPT signatories and have nuclear weapons. In the meantime, the U.S.A. and Russia are discussing what to do with their huge stockpiles of unneeded HEU and plutonium. Nuclear materials management will become ever more important for world security.

For the last year, the editor of the *Journal* at INMM headquarters has been Charles Laughlin. Charles recently accepted a position with a large publishing company in Chicago. He has been a pleasure to work with. I wish him well on his new assignment with another publishing company.

Dr. William A. Higinbotham
Brookhaven National Laboratory
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Questions Raised by Paper on the Add-a-Source Method

In the July 1992 *JNMM* paper "Passive Neutron Waste-Drum Assay With Improved Accuracy And Sensitivity For Plutonium Using The Add-A-Source Method," the author, H.O. Menlove, clearly describes the instrument, the add-a-source method intended to characterize "matrix effects," and the means developed to improve measurement sensitivity. The paper explains that the add-a-source "matrix correction factor" is based on the same type of neutron detection as passive plutonium measurements, specifically coincidence detection. Hence, fairly good assay accuracy seems credible under assumptions of near-uniform distribution of both hydrogen and plutonium in the matrix.

But the cited *JNMM* paper includes two unfortunate misleading claims:

(1) "The errors introduced from matrix materials in 200-L drums have been reduced by one order of magnitude by using the add-a-source technique"; and (2) "If neutron-shielding material is present in the drum, the AS procedure picks up the condition with good sensitivity." Both claims are substantial exaggerations.

The quoted error-reduction claim depends very strongly on the homogeneity assumptions stated above. Yet in the *JNMM* paper these homogeneity assumptions are neither stated nor implied in the context of the claim, which appears in both the abstract and the introduction. In fact, the introduction explicitly states that waste materials are heterogeneous (not homogeneous). For waste matrices that contain moderate-to-large quantities of hydrogen and in which hydrogen and/or plutonium could be distributed very nonuniformly, the add-a-source waste-drum assay (for fixed plutonium content) would vary widely as a function of hydrogen and plutonium distributions. In fact, the unqualified error-reduction claim is not only misleading but is demonstrably a gross exaggeration.

Similarly, the shielding-detection claim applies to some scenarios but not to other highly credible scenarios, hence — because it is unqualified — it also is an exaggeration.[1] In particular, it would not apply to the scenario of a 200-L drum filled with material of moderate hydrogen density (approximately one-third that of solid polyethylene) which surrounds a medium-sized object — the object comprising a standard can of plutonium oxide and a surrounding close-fitting solid polyethylene shield of medium thickness (approximately 6–8 cm). The diameter of the object would be substantially less than the diameter of the drum. Therefore, because of neutron scattering, the add-a-source method — which in its present form could be employed in both a coincidence mode and an uncollimated transmission measurement mode — would fail to detect the presence of the dense polyethylene shielding.

This scenario is important because the plutonium assay would be within normal range (less than 200 g), even though the can concealed in the drum could contain several kilograms of plutonium.[2] Thus, despite impressive claims of error-reduction and shielding detection capabilities, the add-a-source technique (in its present form) could not be expected to register an anomaly for this "obvious" gross concealment scenario.

This nondetectable concealment problem exists, for 200-L waste drums or larger waste objects, with respect to all currently employed neutron waste monitoring techniques. The problem exists also with respect to the current mode of operation of the segmented gamma scanner — an "obvious" concealment scenario being the (off axis) inclusion of a compact lead-shielded can of plutonium oxide.

Nevertheless, Department of Energy safeguards regulations (DOE Order 5633.3) require that facilities employ, in material access areas, waste monitoring equipment that is capable of detecting the inclusion of excessive amounts of plutonium or highly enriched uranium. In order to assure capability to meet waste monitoring regulations, it is necessary to examine options for modifications to existing waste packaging procedures and waste monitoring techniques.

Modifications that have been suggested for application in material access areas include the following:

- All waste containers must be no thicker (in diameter) than 200-L waste drums, and more relevant monitoring techniques must be used.
- All waste containers must be ≤ 25 cm thick (less than half the diameter of a 200-L drum). For example, waste containers could be 75 cm wide, 200 cm long, 20 cm thick.
- Current neutron and gamma ray waste assay instruments should be upgraded to perform transmission measurements with suitable collimation and continuous data recording, in order to scan for a large- or medium-sized shielded region within the waste object.
- Real-time radiography (RTR) should be used.

Which of these would be most feasible and effective? Which approaches would U.S. experts recommend for use in monitoring nuclear waste in material access areas in other parts of the world?

Helen Hunt
Consultant
Princeton, New Jersey U.S.A.

References

1. The same error occurs in the more recent report by the same author (with co-authors): P.M. Rinard, E.L. Adams,

JNMM Comment
continued from previous page

H.O. Menlove, J.K. Sprinkle Jr., "The Nondestructive Assay of 55-Gallon Drums Containing Uranium and Transuranic Waste Using Passive-Active Shufflers," *Los Alamos National Laboratory Report LA-12446-MS*, November 1992, pp. 31 & 33.

2. Experimental results for shielding scenarios are reported by N.J. Nicholas, K.L. Coop, R.J. Estep, "Capability and Limitation Study of the DDT Passive-Active Neutron Waste Assay Instrument," *Los Alamos National Laboratory Report LA-12237-MS*, May 1992, pp. 16-17; also in reference 1, pp. 31 & 33.

Howard Menlove Responds

Helen Hunt's letter to the editor, "Waste Assay and Screening," makes several valid points, but she grossly exaggerates the heterogeneous waste problems when applying the add-a-source correction technique. Hunt has a valid point in that the article, "Passive Neutron Waste-Drum Assay With Improved Accuracy and Sensitivity for Plutonium Using the Add-a-Source Method," should have included more qualifications for the matrix conditions and plutonium distributions. The add-a-source paper under discussion represents an initial exposition on the technique and is by no means the final paper on the subject.

The add-a-source accuracy improvements are obtained for homogeneous matrix conditions as well as for *most* heterogeneous conditions. For example, the following heterogeneous matrix conditions satisfy the add-a-source correction stated in my paper:

1. A 200-L drum containing a random mixture of pieces (4-8 cm) of iron, aluminum and polyethylene. Figure 6 in the paper includes a drum of this type (top of figure) and the add-a-source correction was as valid for this heterogeneous sample as for the homogeneous mixtures.

2. *Any* heterogeneous mixture of glass, metal machine parts, and tools.

3. A heterogeneous mixture of paper, plastic bags, rubber gloves and HEPA filters. Example of these cases are given in Fig. A-2 of "WDAS Operation Manual Including the Add-A-Source Function" (*Los Alamos National Laboratory Report LA-12292-M*, April 1992).

4. A drum containing a heterogeneous mixture of compacted glove-box components including plastic, glass, stainless steel and machine parts.

5. A drum containing cleanup items such as rags, paper towels, PVC bags, plus metal parts and tools. Such mixtures of materials are include in *Los Alamos National Laboratory Report LA-12292-M* (April 1992).

Of course, one can make up mixtures that would cause inaccurate add-a-source corrections, such as a drum with the bottom portion filled with water and the top portion relatively dry.

However, waste drums do not normally contain liquids for reasons of safety and potential leakage, and drums with liquids do not contain high SNM content for reasons of criticality safety.

My above examples of heterogeneous wastes did not address the plutonium localization, that is, the "plutonium lumping" problem. For nonhydrogenous wastes, plutonium localization is not a problem for passive-neutron assay and the assay error from uncertainties in the position of plutonium can be estimated to be less than ±5% from Figs. 2 and 3 in the add-a-source paper. For practical organic wastes (for example, PVC bags, rags and rubber gloves), the hydrogen density is less than 0.02 g H/cm^3 and the plutonium localization problem is not serious. However, for high-hydrogen matrix conditions, the positioning uncertainty increases because of variable shielding of the fast neutrons getting out of the drum. This effect can be measured and corrected by using multiplicity counting for significantly high quantities of plutonium (>l g).

Hunt greatly exaggerates the amount of hydrogen contained in normal waste materials. The highest hydrogen loading that we found in a MOX fabrication facility's waste drums was ~0.018 g H/cm^3 (rubber glove and PVC bags), which is much less than Ms. Hunt's example of *moderate* hydrogen loading (0.047 g H/cm^3). Full water density corresponds to 0.11 g H/cm^3. These exaggerated hydrogen densities in turn exaggerate the problems related to localized plutonium distributions and

CH_2 diversion shields embedded in hydrogenous wastes. Also, Hunt's examples of the size of the CH_2 shield in the container for diverting several kilograms of PuO_2 are too small for standard containers and repackaging would be required to obtain her small diameters (6–8 cm).

We have recently performed tests with a CH_2 shield thickness of 7.6 cm surrounding a sample can with a diameter of 12 cm. The total diameter of the cylindrical shield was 29 cm and it was placed at various radial and vertical positions inside the 57-cm-diameter drum (55-gallon). This shield reduced the singles neutron signal from the PuO_2 by only a factor of 2.9, and the coincidence rate was reduced by a factor of 8. Because the detector is undermoderated, the initial shielding material gives no attenuation in the neutron signal. Thus a thicker shield would be required to give the attenuations referred to by Hunt. The presence of this shield could be detected by the multiposition add-a-source method.

The following techniques can be used with the passive neutron hardware to determine if localized shielding exists in a waste drum:

1. Multiposition add-a-source measurements to scan the drum. The hardware and software to implement this are currently in use with the Los Alamos passive-neutron drum assay system.

2. Add-a-source neutron transmission measurements using the detector bank on the opposite side of the drum from the ^{252}Cf source. Tests on this approach are underway at Los Alamos and preliminary results flag the case of a localized shield in the drum.

3. Neutron multiplicity measurements where the ratio of triples to doubles changes as the shielding increases. Higher efficiency detector systems are under design to improve the counting statistical precision need for the multiplicity counting.

In summary, whereas this development is still a work in progress, tests clearly show that both homogeneous and heterogeneous materials are corrected using the add-a-source method. The multiposition add-a-source has been tested recently on potential problem heterogeneous mixtures such as a 200-L drum with the bottom half filled with compacted polyethylene bags and the top half filled with concrete blocks and rubble. The add-a-source corrected result was within a few percent of the true value for the case of the plutonium being distributed throughout the drum. On the other hand, if all of the plutonium were located in the polyethylene-bag region or in the concrete rubble region, the matrix-related error increased to about 7%. All of the uncertainties are small when dealing with waste disposal measurements.

In choosing the technical approach for measuring waste drums, the technical complexity and assay time should be kept to a minimum for reasons of cost and reliability. For example, to know the particular size and location of a metal wrench in the drum is a liability if the wrench does not impact the assay. The liability is because of the overhead in data storage, review and archiving. The solutions to the safeguards diversion problem in wastes are relatively simple compared with the array of environmental questions for waste drums.

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Committees: N14 Standards

Recent activities of the INMM N14 Standards Committee include:

ANSI N14.1-1990 — *Packaging of Uranium Hexafluoride for Transport.* Randy Reynolds, N14.1 chair, has sent a letter to the Writing Group with a list of proposed changes and has requested input on any additional changes. A revised agenda, listing items to be considered for incorporation or change to the standard was sent to N14.1 committee members on April 16. The preliminary schedule for N14.1-1995 is:

- fall 1993, Writing Group meeting;
- early 1994, N14 balloting;
- mid-1994, resolve negative ballots; and
- late 1994, submit to ANSI for approval and publishing.

ANSI N14.2 — *Tiedowns for Transport of Fissile and Radioactive Containers Greater than One-Ton Truck Transport* (in process). The revised draft standard, May 5, 1993, was received for N14 balloting from the Writing Group chair. N14 balloting has begun with a closing date of July 15, 1993.

ANSI N14.5-1987 — *Leakage Test of Packages for Shipment.* This standard is due to be updated in 1993. If the international standard, which is in preparation, is acceptable to the U.S. regulatory agencies and the N14 committee, it will be adopted in lieu of N14.5-1987. If not, N14.5-1987 will be updated. This decision will be made in late 1993. An extension to Dec. 31, 1995, for revision of N14.5 has been received from ANSI. A draft international standard was received for preliminary review. N14 balloting of this standard will be accomplished in the fourth quarter of calendar year 1993.

ANSI N14.6 — *Special Lifting Devices for Shipping Containers Weighing 10,000 Pounds (4500 kg) or More for Nuclear Materials.* The Writing Group has considered comments and has completed the revision. This revised standard N14.6-1993 has been forwarded to ANSI for approval and publishing.

ANSI N14.7 — *Guide to the Design and Use of Shipping Packages for Type A Quantities of Radioactive Materials.* It has been determined that an existing draft can be used for final development of the draft. A plan and schedule has been prepared.

ANSI N14.10 — *Guide for Liability.* The scope has been revised. The need for the standard is being determined. If needed, a writing group will be formed and a draft will be prepared. Estimated completion date is June 1996.

ANSI N14.19-1986 — *Ancillary Features of Irradiated Shipping Casks.* A letter ballot to withdraw this standard was sent to N14 members with a closing date of April 1, 1993. Ballots are currently being evaluated.

ANSI N14.23 — *Design Basts for Resistance to Shock and Vibration of Radioactive Material Packages Greater than One-Ton in Truck Transport.* Comments have been received by the Writing Group and are currently being considered. A writing group meeting has been rescheduled for mid-June for development of a final draft which is tentatively scheduled to be completed by Aug. 1, 1993.

ANSI N14.24 — *Barge Transport of Radioactive Materials.* A new chair of the Writing Group is still being sought. This standard was updated with editorial changes and sent to ANSI for reaffirmation. Planning on a revised standard is tentatively scheduled for completion by Jan. 1, 1993.

ANSI N14.25 — *Tiedowns for Rail Transport of Fissile and Radioactive Material Containers.* This project will start after N14.2 is completed. PINS will be submitted including a schedule for completion.

ANSI N14.26 — *Guidance on Quality Control Activities as They Relate to the Inspection, Preventive Maintenance and Post-Incident Testing of Packages Used for the Shipment of Radioactive Material.* Work is continuing on preparation of a draft document. This draft is 90 percent complete.

ANSI N14.27 — *Carrier and Shipper Responsibilities and Emergency Response Procedures for Highway Transportation Accidents Involving Truckload Quantities of Radioactive Material.* This standard will be reaffirmed with editorial changes in 1993. After reaffirmation, planning will start on an extensively revised standard. A new scope will be prepared and a new standard developed. The completed draft has been submitted to ANSI for approval.

ANSI N14.30 — *Design, Fabrication and Maintenance of Semi-Trailers Employed in the Highway Transport of Weight-Concentrated Radioactive Loads.* This standard was approved by ANSI on Oct. 1, 1992, and was published in January 1993. It is available for sale from ANSI for $40 per copy.

Numerical Model Development: The ANSI N14 subcommittee works for development of a numerical model for thermal evaluation of UF_6 cylinders is in process and data is being obtained and analyzed. A first draft will be available in late 1993.

Standard Matrix: Plans to revise Standard Matrix for Light-Water Reactor Spent-Fuel Transportation are in progress.

N14 Procedures Manual: Updates for the N14 Procedures Manual were mailed to manual recipients.

N14 Membership: There are currently four people who have requested membership and who are awaiting balloting. In addition, recommendation to fill the vacancies for the American Institute of Chemical Engineers and the American Industrial Hygiene Association have not been received.

There are currently 80 members, including eight alternates. There are also 30 individuals designated "For Information Only" on the N14 roster.

Second International Mixed Waste Symposium: A paper, "Potential for National Consensus Standards for the Packaging and Transportation of Mixed Waste," has been prepared for presentation at the symposium. The symposium is being held Aug. 16-18, 1993, in Baltimore. The authors are J.W. Arendt, N14 Chair, and J.R. Clark, vice president, E.R. Johnson Associates Inc.

N14 Annual Meeting: The next N14 annual meeting is scheduled to be held Nov. 4, 1993, and will be hosted by the Department of Energy. A letter was sent to N14 roster members and nonmembers requesting input on subject matter, presentations and speakers that would be of interest to meeting attendees and would assist in making the meeting both informative and productive. Two responses were received this month.

N14 Record Retention: A policy for N124 record retention is being drafted. Resource material has been obtained from ANSI. This policy will be considered for the INMM Secretariat policy for both N14 and N15.

ISO/DIS 10276 Trunnions for Spent Fuel Element Transport Packages: An ISO working group response to comments submitted by the United States was received and distributed to a select group of N14 reviewers. These comments are being evaluated and a U.S. position is being developed for use at a working group meeting in London June 9-10, 1993.

John W. Arendt
Chair, ANSI N14 Committee
Consultant
Oak Ridge, Tennessee U.S.A.

Committees: Bylaws

By the time your read this you will have received the annual ballot for INMM officers and Executive Committee members for the upcoming year. On this ballot were two amendments to the bylaws having to do with fees. The current bylaws require that dues for Senior Members be set at a higher rate than regular members and that Sustaining Member employee meeting fees be set at the member rate.

From experience with the membership program, the annual meetings and the various workshops, we believe that the interests of the members can best be served if the Executive Committee is permitted to make these determinations on an annual basis as they do in all other fees and dues matters. Amendments to remove these requirements from the bylaws were therefore approved by the Executive Committee at its spring meeting in Boston, and we hope that you supported its decision when you sent back your ballot to INMM headquarters earlier this summer.

Several other amendments have been approved during the past two or three years, but the bylaws have not been reprinted for sometime. In the near future, you should receive an updated printing for your files.

Roy Cardwell
Chair, Bylaws Committee
Consultant
Lenoir City, Tennessee U.S.A.

Divisions: MC&A
Summary of INMM Long-Term SNM Storage — Inventory Extension Workshop

The INMM Long-Term SNM Storage — Inventory Extension workshop was held April 18-21, 1993, in Richland, Wash. The workshop included five half-day sessions devoted to the topic of the long-term storage of spent nuclear materials.

Session I: Long-Term Storage Policy and Guidance

This session featured five speakers. Four of the speakers represented DOE and the fifth speaker was from the NRC. The session was in panel format with participation from the floor, and it covered facets of the storage issue including vault configuration, location (above vs. below ground), size, type (working vs. storage), and safeguards and security systems. Guidance and regulations from DOE-EM, SA, SA, DP as well as an NRC perspective on the impacts should IAEA inspections be imposed on a DOE facility were provided.

Discussions by the workshop participants following the presentations were lively and pointed out the timely nature of the workshop topic and the need for improved coordination between DOE components at the national level.

Session II: Technology and Inventory Frequencies

Session II focused on the benefit that surveillance technology can offer in reducing the contact and access requirements to stored nuclear materials. The session highlighted the one technical system, the vault safety and inventory system (VSIS), which is currently operating. Speakers from various national laboratories introduced technical systems which are either in the maturing or the emerging stage of development.

A breakout session followed the presentation. Attendees were asked to brainstorm new ideas for technologies to extend inventories and to determine how much extension was enough and why. The topic of inventory extension attracted the most attention. Frequency periods determined by factors other than material type and category were suggested such as, custodian turnover, radiation exposure (ALARA), and real-time surveillance equating to continuous inventory.

Session III: Integration of Safeguards and Security Information Management

A panel of subject matter experts discussed the technical and regulatory direction of the next generation of safeguards and security information, management systems. After the presentations, lively panel/floor discussions centered on the merit of integrating safeguards and security data into a unified information management system.

Several points emerged from the floor discussions: system integration is ripe for serious consideration, types of data to be integrated is unclear, and integration will not be a trivial task. This topic generated so much energy that it was the consensus of the participants to support another INMM workshop focusing on this topic.

Session IV: The Challenge of Securing Long-Term Storage

Five invited presentations were given in this session ranging from what was transpiring in the Complex 101 arena to future storage plans at various DOE sites. From the tone of the presentations, one could see the various stages of long-term storage development throughout the complex. Some sites, like Hanford, are initiating storage action by consolidating material, reducing protected areas, repairing/replacing systems, revising existing facilities, changing work procedures and planning facility replacement. Other sites are beginning to consider the subject of storage in a context other than process lag storage.

Two storage time frames emerged from the discussions.

• Intermediate storage using existing facilities for a period between now and the time when a properly designed storage facility is constructed. The time frame was considered to be less than 20 years.

• Long-term (intermediate by DOE definition) storage using new facilities until a final disposition is achieved, This time frame was estimated to range from 20 to 100 years.

Session V: The Bottom Line: Safeguards and Security Design Concepts for a New Long-Term Storage Facility

A breakout session was organized for this period. Four groups were assigned to formulate user/design requirements for an ideal long-term storage facility. A summary report was presented by each group at the conclusion of the breakout session.

Summary requirements from the groups included:

• robotic material handling,

• underground location,

• retrievable storage,

• passive or biological protection where feasible,

• stable product form,

• reliable long-term storage canister,

• recognition of the need for limited product shipping/receiving and repackaging/processing capability,

• modular storage design,

• reliable measurement and accountability systems designed for ease of upgrade over time,

• software and systems documented to quality assurance levels,

• definition of acceptable risk, and

• reliable real-time surveillance methodology permitting a continuous inventory policy whereby mass is imputed to canister (unless a canister state change is detected, a computer inventory of the canister is equated to physical inventory).

Don Six, general chair, and Larry McRae, technical program chair, are pleased with the results of the meeting. The technical content was outstanding. The energy and interest generated by the meeting were evidence of the need for the workshop. Don and Larry would like to thank those who participated as panel moderators, session chairs and breakout leaders. Due to the larger than planned turnout (93 registered attendees versus 40-50 planned), the meeting rooms were strained but the workshop was a financial success for the INMM.

Several papers from this workshop are planned for inclusion in a future issue of *JNMM*.

Don Six
Westinghouse Hanford Co.
Richland, Washington U.S.A.

Chapters:
Jennekens Gives Farewell Address to Vienna Chapter

Departing Deputy Director General for IAEA Safeguards Jon Jennekens flanked by Vienna Chapter Chair James Larrimore and Treasurer Peggy Scott.

When Jon Jennekens arrived in the mid-1980s as the deputy director general of the International Atomic Energy Agency's Department of Safeguards, he announced that one of his goals was to learn the name of every one of the more than 500 employees on his staff. In the course of his April first address to the Vienna chapter, Jennekens referred to almost everyone of the audience by name. If he had not achieved his goal, he had certainly come very close.

In reviewing his tenure as Safeguard's DDG, Jennekens gave surprisingly little time to the headline grabbing events with which he was concerned — the inspections in Iraq and the more recent problems with the Democratic People's Republic of Korea. Instead he dealt more with internal issues such as the conditions of travel, the status of safeguards clerks and technicians, and problems concerning agency reluctance to compensate staff injured on duty travel. Referring to the agency's relations with Euratom, he felt that there had been some improvement during the time he had headed the department, but that they were still not as good as he would have wished.

Jennekens will probably be most remembered for his great interest in the people on his staff. Not only did he learn their names, but he showed a sincere concern for their well-being. He now heads for his home in Ottawa and retirement after four decades in public service, but we doubt that the international safeguards community has seen the last of him. We wish him well.

His successor, Bruno Pellaud of Switzerland, assumed his new duties at the beginning of May.

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Rethinking the Environmental Paradigm

Trashing The Planet
Dixy Lee Ray with Lou Guzzo
Regnery Gateway: Washington, D.C., 1990

Environmental Overkill
Dixy Lee Ray with Lou Guzzo
Regnery Gateway: Washington, D.C., 1993

Since World War II, the United States has achieved impressive accomplishments in regard to safeguarding the environment and protecting members of the public from several genuine hazards. Emissions of pollutants from motor vehicles and industrial plants have been reduced substantially, and major improvements made in air and water quality. Only a few years ago substances such as DDT and herbicides containing 2,4D were in wide use, and dangerous materials such as Paris Green, bichloride of mercury and rodent poisons containing thallium could easily be obtained and used. But these hazards have been greatly reduced.

Along with these major benefits, however, there have been other, less welcome developments. The long vendetta against nuclear power and its virtual abandonment as a future source of energy, coupled with our politically driven failure to come to grips with the technically tractable problem of dealing with nuclear waste will impact our economy and the quality of life in future decades. Other troubling events include the overreactions of the public, legislators and regulatory agencies in dealing with materials such as chrysotile asbestos, Alar, dioxins and innumerable other substances perceived to be carcinogens. Most recently, the apparent acceptance by the news media, some segments of the public and certain officials, of the assertion by environmental activists that drastic and enormously costly changes in our technology and way of life must occur to avoid catastrophic global warming raises the question of whether our society has indeed taken leave of its reason.

These concerns, and others equally important, are addressed in the books *Trashing The Planet* and *Environmental Overkill*, by Dixy Lee Ray and Lou Guzzo. These provocative and interesting works are particularly significant. When comparing these publications against the enormous volume of material published recently that deals with environmental questions, they stand alone in daring to defy conventional mores by questioning the wisdom and utility of the measures adopted and proposed by activists claiming to protect the environment and public.

Most INMM members need no introduction to Dixy Lee Ray. In addition to a distinguished career on the zoology faculty of the University of Washington, she has served as governor of the state of Washington, chairman of the Atomic Energy Commission and assistant secretary of state in the U.S. Bureau of Oceans. Many members will recall her keynote address at the 29th Annual Meeting of the INMM in Las Vegas in 1988, "The Role of Plutonium as a Resource Now and in the Future." In that address she stated her views on the potential value of nuclear energy to our country's future.

These two books are probably polemics, in the best sense of the term, in that they state one side of a case with reasoned arguments and present a great deal of factual material. Both publications strongly support the conclusion that while many environmental safety measures have been justified in the name of preserving the environment and protecting the public, a number of ill-considered measures have been conducted or proposed with little or no scientific justification that will be destructive to our national interests.

Although the selected topics differ, both authors explore the political and economic forces driving the environmental movement, discuss the movement's social and economic consequences and raise a number of individual topics and examples. While discussions of the political origins of the environmental movement contain no surprises for those who have followed events in this area, the authors illustrate the frightening reality of how persistent efforts from a small number of determined and clever individuals have led to the creation of programs and a government apparatus that consumes enormous resources and intrudes into the lives of citizens in countless ways. The principal players in this scenario have been:

1. Activist leaders who have exerted profound influence on followers, the public at-large, the media, legislators and, through the courts, government policy. While many leaders and members of these organizations favor sensible measures for the preservation of the environment and public welfare, certain of the most charismatic leaders possess visions of a future utopia and agendas for action which can only be described as bizarre. Ray and Guzzo quote a number of their public statements, for example:

- "A global climate treaty must be implemented, even if there is no scientific evidence to back the greenhouse effect."
- "We have to offer up scary scenarios, make simplified, dramatic statements and make little mention of any doubts we may have. Each of us has to decide what the right balance is between being effective and being honest."
- "Scientists who work for nuclear power energy have sold their soul to the devil. They are either dumb, stupid or highly compromised. ... Free enterprise

really means rich people get richer. And they have the freedom to exploit and psychologically rape their fellow human beings in the process ... Capitalism is destroying the earth. Cuba is a wonderful country. What Castro's done is superb."

• "Childbearing [should be] a punishable crime against society, unless the parents hold a government license. ... All potential parents [should be] required to use contraceptive chemicals, the government issuing antidotes to citizens chosen for childbearing."

2. The news media, with a keen sense of what attracts and holds the interest of the public, consistently resorts to sensationalism in reporting activists' claims at face value and ignoring responsible scientific judgements. As a result, media reports have sometimes led to near-hysteria by the public, as was the case with the Three Mile Island accident, the Love Canal problem and the current controversy over the health effects of electromagnetic fields.

3. Several years ago a member of Congress remarked that "In politics, the perception is the reality." In view of this, members of legislative bodies can scarcely be faulted for responding vigorously to pressures from environmental groups and widespread anxiety on the part of the public.

4. It is in the interest of the organizations charged with environmental protection to adopt an extreme position in categorizing the perceived hazards and creating and enforcing regulations to project an image of vigilance, to forestall campaigns against them, such as legal action by activist groups, and to obtain the maximum possible level of funding. This has often led to the setting of maximum permissible levels of a large number of substances in the environment or in food and water which is many levels below those found to produce any discernible health effects in humans or animals. The authors present several examples where government agencies have released information which greatly exaggerated the threat of particular environmental or health hazards with the obvious intention of obtaining increased levels of funding.

5. Every time a new environmental concern emerges and new regulations are passed, a new industry is created made up of lawyers, consulting firms and companies which find, analyze, remove and dispose of hazardous substances while engaging in litigation over the perceived consequences of the hazard. Hence a constituency has been created that profits by the creation and rigorous enforcement of ever more regulations.

The burden of complying with environmental regulations is substantial and includes:

• The direct costs incurred in complying with regulations. An example is the extremely high costs of removing asbestos or lead paint from buildings, and the enormous inflation in recent years of the cost of removing and disposing of refuse.

• The paperwork burden of complying with the maze of regulations has substantially increased costs for most businesses and industries as well as government agencies. The consequent increase in the costs of goods and services has placed the United States at a competitive disadvantage with respect to many other countries.

• Many regulations enacted recently are severe and often harshly enforced. For example, under the Montreal Protocol, which regulates the use of the chlorofluorohydrocarbons (CFCs) that are believed to cause the depletion of ozone in the upper atmosphere, the transportation of a refilled freon cylinder carries a penalty of five years' imprisonment. The creation of a body of domestic law impacting all Americans through international environmental treaties, while necessary in certain instances, is a matter of serious concern.

At the level of the individual citizen, the impact of current environmental regulations can be seen in the possible plight of the owner of an older home in the Northeastern states. In the Northeast, homes are usually heated by fuel oil which is stored in an in-ground tank. In most areas, if such a tank develops a leak, an environmental enforcement agency is notified, the tank is removed from the ground along with all contaminated soil. This procedure leaves homeowners with giant craters in their yards and bills amounting to several thousands of dollars — even in instances where the ground water in the area has already been rendered unfit to drink by other pollution. In addition, if the house utilizes a heating system insulated with asbestos and the paint and plumbing contain lead, further liabilities may exist. Lending institutions are now sensitive to these potential liabilities and engage consulting firms to inspect a property before issuing a mortgage. As a result, the homeowner may find it essentially impossible to dispose of a property without remediation procedures that may consume most of the property's value.

It is possible to comment on only a few of the environmental issues raised by the authors.

The most important issue is the policy adopted with respect to asbestos. The first and most important consideration is that the name asbestos is a generic term applied to several dissimilar minerals. Two of these minerals of the so-called amphibole variety, crocodilite and amosite — blue and brown, respectively in color — are indeed extremely dangerous and constitute about five percent of the total asbestos which has been mined and used. Their widespread use in shipbuilding in World War II led to devastating health problems among exposed workers. However, the remaining 95 percent of the asbestos utilized is the white mineral chrysotile with a chemical composition and crystal structure different from the amphiboles. Extensive epidemiological studies in areas of Quebec where chrysotile is mined have not disclosed any health problems associated with exposure to it; the fibers are probably no more hazardous than most other mineral dusts. It is a common constituent of rocks in parts of the United States, and the weathering of these rocks releases substantial amounts of fibers into the environment. Chrysotile asbestos has had endless uses in brake linings, insulation, acoustic tiles, etc., and has been ubiquitous in the American environment for at least half a century. If the material is undisturbed in buildings, the concentration of fibers in the air usually does not exceed that found in outside air in many parts of the country. Conversely, removal of the asbestos usually leads to an increased concentration of airborne fibers. Thus the rationale for a nationwide program for the removal of all asbestos from schools and public buildings at a cost of billions of dollars is not evident. One could speculate what government policy might be if the mineral chrysotile had not been grouped generically with other, dangerous minerals under the name asbestos a century ago. Most states have laws regulating race horses; common sense prevents us from applying them to sawhorses.

The Alar, Love Canal and dioxin controversies are discussed in some detail. Very briefly:

- The only evidence that Alar can produce tumors in animals originated in a test performed in 1977 and was totally discredited later. Subsequent tests on animals produced no tumors at levels equivalent to the consumption of more than 10,000 pounds of apples each day for 70 years by a human being.
- While the construction of housing developments in the Love Canal area, where chemical wastes had previously been buried, was a matter of concern and required remediation efforts, subsequent epidemiological studies did not show any evidence for adverse health effects or chromosome damage among people living in the area.
- While dioxins are a legitimate concern and demonstrably toxic to certain species of animals, their toxicity to humans appears to have been greatly exaggerated. People exposed during the massive dioxin spill 17 years ago in Seveso, Italy, and workers in American plants who have also been exposed have shown no adverse health effects other than a skin condition known as chloracne, which soon disappears with treatment.

The discussions of the greenhouse effect and global warming are among the most interesting sections of the two books. Some salient points discussed are:

- Current models are still too crude to describe adequately observed or possible future climatic phenomena.
- The principal greenhouse gas in not carbon dioxide but water, which accounts for most of the greenhouse effect. Water enters into climatic phenomena in several fundamental ways — the enormous capacity of the oceans to store thermal energy and to transport it from one area to another, the ability of clouds and snow cover to reflect solar energy back to outer space and its high heat of vaporization, which drives most storms. In current climatic models water is the "wild card"; its behavior cannot be completely predicted.
- The carbon dioxide budget in the environment is not well understood, but it is known that the quantity produced each year by human activities is only a very small fraction of that which is produced and exchanged during naturally occurring processes.
- If any global warming at all has occurred during the past several decades it is very small, no more than half a degree. This is far smaller than the naturally occurring temperature fluctuations that have occurred in Europe during the past two millennia.

In short, there is no evidence that a global warming trend has set in or that the release of carbon dioxide into the atmosphere by human activities will produce such a trend. The adoption of drastic, costly and far-reaching policies advocated by environmental activists to deal with what may be a slowly developing or even non-existent problem cannot be justified until solid scientific evidence is proved to exist.

The two books, *Trashing The Planet* and *Environmental Overkill*, by Ray and Guzzo represent sane and moderate approaches to our environmental problems. They initiate what should be a responsible dialogue on environmental issues in which decisions to establish programs, enact regulations and allocate resources are based on scientific evidence rather than conjecture and mass hysteria. Perhaps in this way they will help, in the course of saving our planet, to save us from ourselves.

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Safeguarding Reprocessing Plants: Principles, Past Experience, Current Practice and Future Trends

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Abstract
Under Article 6(c) of all comprehensive International Atomic Energy Agency (IAEA) safeguards agreements, verification procedures are to concentrate on those stages in the nuclear fuel cycle involving the production, processing, use or storage of nuclear material from which nuclear weapons could readily be made. In that context, the most intensive IAEA safeguards are applied at chemical processing plants and other facilities at which separated plutonium is stored, processed or used. The principles underlying the design, implementation and evaluation of IAEA safeguards at chemical reprocessing plants are explored in this paper. The interrelation between the elements of the safeguards approach for such plants is examined, including design verification, extensive use of containment and surveillance, including operations monitoring in certain of the process areas, near-real-time accountancy and conventional accountancy measures. Reference is made to IAEA experience, and current practice is examined at length. New reprocessing plants of large throughput and/or having novel design features are under construction, and the measures currently in use will require extensive effort to provide effective and efficient safeguards implementation.

I. Introduction

The intensity of IAEA safeguards measures applied in a facility depends upon the ease with which the nuclear materials processed, stored or used in that facility could be employed for the production of nuclear weapons. Thus, of the many different types of facilities in which IAEA safeguards are applied, facilities which store, process or use highly enriched uranium, uranium-233 or plutonium separated from fission products are subject to the most intensive IAEA safeguards measures.

In this paper, we present an analysis of the factors affecting safeguards implementation in reprocessing plants, a compilation of plants where IAEA safeguards have been or will be applied, a description of current practice and the challenges foreseen for strengthening and streamlining current practice and applying safeguards at new facilities.

II. Factors Affecting Safeguards Implementation

In this section, we define a "reprocessing complex" in terms of the operations typically carried out and the chemical technology employed. Then we summarize the inspection requirements used for planning and evaluation purposes. Next, the principal factors affecting safeguards implementation in a given setting are identified. Following that, the elements of the safeguards approach for reprocessing plants are presented, establishing the principles for design and implementation of safeguards at these plants. Finally, inspector staffing requirements and deployment arrangements are described.

1. Reprocessing Plant Characteristics

A chemical reprocessing plant complex may include spent fuel transport-cask storage and unloading areas, spent fuel storage ponds, a mechanical cell for shearing fuel assemblies or a cell for chemically decladding fuel elements, dissolution and clarification cells, a chemical separations and purification area, acid and organic recovery systems, uranium and plutonium oxide conversion areas, plutonium and uranium product storage, waste storage areas and waste conditioning, and analytical and operations testing laboratories. Fuel fabrication facilities may also be sited at the same complex. Many of these activities involve separated plutonium and thus require intensive safeguards.

While a variety of reprocessing technologies have been explored over the years, the plants submitted to IAEA safeguards thus far have been based on the Purex process. In this process, fuel materials are dissolved in hot nitric acid, and

TABLE 1

SAFEGUARDS IMPLEMENTATION CRITERIA FOR REPROCESSING PLANTS (INFCIRC-153)

<table>
<tr><th colspan="2">ACTIVITIES PERFORMED</th></tr>
<tr><th>FLOW VERIFICATIONS</th><th>INTERIM AND PHYSICAL INVENTORY VERIFICATION</th></tr>
<tr><td>Frequency of Inspections: Continuous</td><td>Frequency of Inspections: Monthly IIV/Yearly PIV</td></tr>
<tr><td><u>Examination of Records and Reports</u>

Facility accounting records are compared with Inventory Change Reports (ICRs), Material Balance Reports (MBRs) and any other special reports provided by the State to the IAEA. Records are checked for consistency.</td><td><u>Examination of Records and Reports</u>

Itemized Inventory List is compared for consistency with the Material Balance Report and Physical Inventory Listing. Inventory Change Reports and Material Balance Reports are compared for consistency.</td></tr>
<tr><th colspan="2">SPENT FUEL</th></tr>
<tr><td><u>Receipts</u>

<u>If Shipped Verified and Sealed;</u> The Seal is verified maintaining continuity of knowledge.

<u>If Shipped unverified or unsealed;</u> The spent fuel is item counted and verified with medium detection probability for gross defects.[1]

<u>Shipments</u>

<u>If not to be verified on receipt;</u> The spent fuel is item counted and verified with medium detection probability for gross defects and sealed.

<u>If to be verified on receipt;</u> The spent fuel is item counted and measures taken to ensure that the cask contents are not altered before shipment.

<u>Transfers to the Mechanical Cell;</u> All transfers are item counted and verified by serial number.</td><td><u>Spent Fuel under Dual C/S</u>

<u>PIV;</u> Both C/S systems are evaluated. If seals are used, verify with low detection probability.

<u>IIV (for timeliness);</u> Only one device need be evaluated if it is conclusive positive. If seals are evaluated, verify with low detection probability.

<u>Spent Fuel under Single C/S</u>

<u>PIV;</u> Spent fuel is item counted and surveillance is evaluated or seals are verified using low detection probability.

<u>IIV (for timeliness);</u> The C/S device is evaluated. Seals, if used, are verified with low detection probability.[1]

<u>Spent Fuel not under C/S</u>

<u>PIV;</u> Spent fuel is item counted and verified with medium detection probability for gross defects.

<u>IIV (for timeliness);</u> Spent fuel is item counted and verified with low detection probability for gross defects.</td></tr>
</table>

the undissolved particles are then removed prior to chemical processing. Next, plutonium and uranium are separated from fission products through liquid-liquid interactions in which the Pu and U are transferred between aqueous solutions (nitric acid) and organic solutions (typically comprised of tributyl phosphate in a kerosene carrier). Successive separation stages provide a highly decontaminated Pu/U stream, which is subsequently partitioned into separate Pu and U streams for further purification and concentration, leading to the final solution products, typically plutonium and uranyl nitrate. These are then converted to oxide powders for storage or subsequent processing.

2. Inspection Requirements for Reprocessing Plants

Safeguards activities are designed and implemented so as to detect a diversion of one *significant quantity* of nuclear material either removed abruptly or in a protracted manner. For plutonium, one significant quantity (SQ) is defined to be 8 kg Pu. The timing interval related to protracted diversion possibilities is one year, for abrupt diversion of separated plutonium, one month, and for plutonium in spent fuel, three months.

The principal requirements for safeguards implementation are summarized in Table 1. These criteria have evolved over the years and reflect technical considerations against possibilities for diversion and concealment, and the verification capabilities available to the IAEA. The current criteria will be revised in 1995 for the period from 1996–2000.

3. Factors Affecting Safeguards System Design

IAEA safeguards at a reprocessing plant are designed and carried out in such a manner as to satisfy the criteria currently in effect. The specific arrangements employed at a given reprocessing plant depend on a range of considerations, including:

a. the type of safeguards agreement (i.e., whether it is based on a comprehensive safeguards obligation involving all nuclear facilities and materials within a state, or limited to a given project or to specific equipment or materials covering the entire facility or a specified portion or portions thereof);

b. whether or not the plant has been built or has been operated before safeguards are applied. This may occur in states which do not have comprehensive safeguards agreements, when safeguards are applied, discontinued and then reapplied when safeguarded spent fuel is to be processed. When safeguards are applied to a plant already in operation or one that has operated in the past, a significant effort is required to confirm its history;

c. the scale and specific design features of a plant (for

TABLE 1 (continued)

PLUTONIUM/URANIUM PROCESS SOLUTIONS/PRODUCT COMPOUNDS	
Dissolver Solution to Process: Each transfer is verified by volume or weight measurements, sampling and analysis for Pu and U with a capability to detect measurement biases and C/S is maintained to detect all transfers. Completion of Dissolution: Operating Records (Charts) are checked after all dissolutions to verify that dissolution was completed. Product Transfers to Storage: All transfers of Pu and HEU product material from the process are verified with the capability to detect measurement biases. Pu Transfers from facility: Material is item counted and verified with high detection probability for gross, partial and bias defects, and transfers are made under seal or inspector observation. Pu Transfers by Pipeline from facility: For transfers by pipeline, verification can be omitted if the PIVs and IIVs (for timely detection) are performed simultaneously. Uranium Transfer from facility: Transfers not under seal are item counted and: Verified with medium detection probability for gross, partial and bias defects (LEU), verified with medium detection probability for gross and partial defects (NU) and verified with medium detection probability for gross defects (DU). Transfers under seal, verified before shipment or after receipt: Seal verification is performed with low detection probability. The material is item counted and verified with medium detection probability for: Gross, partial and bias defects (LEU), gross and partial defects (NU) and gross defects (DU).	PU PIV: Verified with high detection probability for gross, partial and bias defects. IIV (Timeliness): Product material in storage not under C/S is verified with medium detection probability for gross and partial defects. In-process inventory is verified using approved facility-specific procedures. NU and LEU Verified with medium detection probability for gross and partial defects. DU Verified with medium detection probability for gross defects.
WASTE MATERIALS	
Material not under C/S: Transfers are verified with high detection probability for Pu and medium detection probability for uranium (for gross defects).	Material not under C/S PIV: Verified with high detection probability for Pu and medium detection probability for uranium (for gross defects). IIV (Timeliness): Verified with medium detection probability for gross defects. Material under C/S IIV (Timeliness): The C/S system is evaluated, items are item counted and seal verification is performed with low detection probability. NOTE: Waste material is verified to the extent that the total amount of unverified inventory changes are below 0.5 SQ per Material Balance Period for each material type.
SPECIAL NOTES	
	Unverified nuclear material cannot exceed 0.6 SQ for any material type (IIV). Unverified material for each nuclear material type cannot exceed 0.3 SQ (PIV).

example, a small plant with manual controls calls for very different safeguards arrangements than a new commercial scale plant with extensive plant computerization); and

d. the intensity of the radiation background (while introducing an element of diversion-resistant self-protection, the intense radiation imposes requirements for safeguards measures to be performed remotely, within the biologically shielded areas of the plant).

4. *Elements of the Safeguards Approach*

IAEA safeguards implementation at reprocessing plants consists of a combination of nuclear material accountancy and containment/surveillance measures for design verification, the verification of plant operations and the verification of inventory changes and interim and annual physical inventories.

4.1 *Design Information Examination and Physical Verification.* This process is undertaken for the following purposes:

a. to establish that the design information provided by the state is complete, accurate and consistent;

b. to verify that the facility is constructed, operated and maintained in accordance with the design information provided. The provision, examination and verification of design information begins with the conceptual design of a plant and extends over its whole life, including decommissioning. Extensive physical verification activities are carried our during plant construction, during cold and hot plant commissioning, during shut downs for plant modifications and maintenance and, to the extent practicable, during plant operations;

c. to gain an understanding of the facility to confirm its declared peaceful purpose;

d. to conclude that the facility operator will be capable of operating the facility in accordance with the information provided, specifically in relation to procedures for the control and accounting of nuclear materials;

e. to serve as the basis for the design and implementation of a safeguards approach for the plant, to detect a diversion or undeclared reprocessing activities; and

f. to serve as a reference basis for normal plant operational patterns, and for abnormal or anomalous conditions when those patterns are not observed in practice.

4.2 *Nondestructive Assay (NDA) and Containment and Surveillance (C/S) Measures.* These measures are used extensively to verify the amounts of plutonium and uranium and to maintain continuity of knowledge of the verified amounts, particularly in item-control areas of the plant for spent fuel and for plutonium oxide or mixed plutonium-uranium oxide (MOX) product.

4.3 *Plant Operations Monitoring.* Plant-specific proce-

TABLE 2. REPROCESSING PLANTS SUBJECT TO IAEA SAFEGUARDS

PLANT NAME	LOCATION	CAPACITY	OPERATIONAL STATUS	SAFEGUARDS STATUS
EUROCHEMIC	MOL, BELGIUM	0.5 t/d LWR FUEL; MTR FUEL	OPERATED FROM 1966 - 1974	SAFEGUARDS APPLIED AFTER PLANT SHUT-DOWN
RADIOCHEMICAL LABORATORY	NYONGBYONG, DEMOCRATIC PEOPLES REPUBLIC OF KOREA	CONFIDENTIAL	CONFIDENTIAL	NPT SAFEGUARDS
UP2, UP3	CAP DE LA HAGUE, FRANCE	8 t/d LWR FUEL (COMBINED)	IN OPERATION	LIMITED SAFEGUARDS NWS VOLUNTARY OFFER LASCAR INVOLVEMENT
WIEDERAUF-ARBEITUNGS ANLAGE KARLSRUHE (WAK)	KARLSRUHE, GERMANY	0.2 t/d LWR FUEL	OPERATED FROM 1971 - 1991	NPT SAFEGUARDS
WIEDERAUF-ARBEITUNGS ANLAGE WACKERSDORF (WAW)	WACKERSDORF, GERMANY	3.5 t/d LWR FUEL	CANCELLED	PLANNING, R&D LASCAR INVOLVEMENT
NO NAME GIVEN	EL THUWAITA, IRAQ	CONFIDENTIAL	DESTROYED 1991	VIOLATION
PREFRE REPROCESSING PLANT	TARAPUR, INDIA	0.5 t/d CANDU FUEL	COMMISSIONED IN 1982	ONLY WHEN SAFEGUARDED FUEL IS REPROCESSED
EUREX	SALUGGIA, ITALY	0.1 t/d LWR FUEL	SHUT-DOWN	NPT SAFEGUARDS
ITREC	ROTONDELLA, ITALY	0.02 t/d Th FUEL	SHUT-DOWN	NPT SAFEGUARDS
PETRA	ISPRA ITALY	EXPERIMENTAL: TRU WASTE R&D	AWAITING COMMISSIONING	NPT SAFEGUARDS
TOKAI REPROCESSING PLANT	TOKAI-MURA, JAPAN	0.7 t/d LWR/ATR FUEL	IN OPERATION	NPT SAFEGUARDS
ROKKASHO REPROCESSING PLANT	ROKKASHO-MURA, JAPAN	4 t/d LWR FUEL	UNDER CONSTRUCTION	NPT SAFEGUARDS LASCAR INVOLVEMENT
CHEMICAL PROCESS FACILITY	TOKAI-MURA, JAPAN	FAST REACTOR R&D REPROCESSING PLANT	1982 - 1987	NPT SAFEGUARDS
RECYCLE ENGINEERING TECHNOLOGY FACILITY (RETF)	TOKAI-MURA, JAPAN	LMR FUEL REPROCESSING	UNDER LICENCE REVIEW	NPT SAFEGUARDS
NUCLEAR FUEL SERVICES (NFS)	WEST VALLEY, USA	1.5 t/d LWR FUEL	RETIRED 1972	TRAINING + R&D
THERMAL OXIDE REPROCESSING PLANT (THORP)	SELLAFIELD, UNITED KINGDOM	6 t/d LWR FUEL	IN COMMISSIONING	LIMITED SAFEGUARDS NWS VOLUNTARY OFFER LASCAR INVOLVEMENT
FAST REACTOR FUEL REPROCESSING PLANT	DOUNREAY, UNITED KINGDOM	0.04 t/d LMR FUEL	IN OPERATION	LIMITED PERIOD (1980-82) NWS VOLUNTARY OFFER TRAINING + R&D

dures are employed to provide authenticated data for the nuclear materials accountancy measures described below, and to confirm that plant operations are consistent with operator declarations. Plant-specific systems are used particularly in the head-end process area, the chemical separations and purification process areas (especially for the contactors and evaporators), the plutonium solution storage area, the plutonium conversion area and, in the future, high-level waste-conditioning plants.

These systems may incorporate solution level, density, temperature and concentration measurements, together with engineering flow sheet analyses to provide estimates of the inventories in the chemical plant, including those in the dissolvers, clarifiers, contactors and evaporators.

4.4 *Interim Inventory Verifications (IIV).* These are carried out to meet verification timeliness requirements. They combine findings from physical inventory verifications, inventory change verifications during a material balance period, and the verification activities carried out specifically for IIV.

For medium- and large-scale plants, near-real-time accountancy (NRTA) is applied to enhance verification sensitivity and to reduce the number of IIV verification measurements required. The manner in which data are collected and the frequency for deriving NRTA balances depend on the scale of the plant. For new plants, on-line data acquisition is foreseen, which will permit balance closings whenever desired.

4.5 *Subcampaign Material Balances.* These may be computed at large plants for the contiguous reprocessing of fuels from a single reactor, permitting a shipper/receiver difference to be evaluated on a client basis.

4.6 *Annual Material Balance Evaluations.* At least once per year, plant operators are required to shut down their plants, clean out the process areas and collect all nuclear materials at specially designated measurement points. The inventory is then measured and the combined material balance over a one-year (maximum) period is evaluated and reported to the IAEA. Physical inventory verification, together with inventory change verification, enables the IAEA to verify the material-unaccounted-for (MUF) declared by the operator, and to evaluate operator and inspector errors associated with the inventory and inventory changes and the resulting MUF value.

4.7 *Cumulative Material Balances.* These are computed over the life of the facility to ensure long-term verification stability.

5. Inspector Staffing and Deployment

Reprocessing plants operate around the clock, and thus the requirement for safeguards inspectors at medium- or large-scale plants is for 24-hour coverage, seven days per week. Additional inspectors are needed to cover such activities as book auditing, camera servicing, in-plant measurements, sample taking and preparations for sample shipments to the IAEA Safeguards Analytical Laboratory, and on-site inspection data evaluation. During shutdown periods the requirements are reduced considerably.

In addition to field activities, at IAEA headquarters inspectors (and Agency support staff) carry out detailed analyses of the inspection data to produce the inspection reports and statements to the state.

About 600 person-days[2] of inspection are needed for shift coverage, and approximately 100 person-days for additional activities, for typical medium-sized reprocessing plants operating for 200 days per year. The total number of inspectors needed to meet this commitment depends on whether those inspectors are based in Vienna, in a regional office within the country where the facility is located, or reside in the vicinity of the plant and work at an inspection center at the plant site. The trend has been towards greater decentralization.

5.1 *Inspector Expertise.* Two categories of inspectors are used at reprocessing plants, taking into account overall Agency staff utilization efficiency requirements. These may be called *reprocessing inspectors*, whose normal obligations are focused on one or more reprocessing plants, and *supplemental inspectors* assigned for one or more person days of inspection when their normal duties permit. The qualities required of *reprocessing inspectors* reflect the wide range of technologies employed. A good working team can be set up if there is an adequate mix of expertise in more than one of the following fields:

a. reprocessing chemistry, chemical engineering and related reprocessing technology (inspectors with these skills are always in need);

b. nondestructive assay and destructive laboratory assay techniques;

c. computer literacy, including limited programming skills;

d. report writing and communications skills;

e. management, training and planning skills; and

f. safeguards rules, regulations and common practice.

5.2 *Training.* A comprehensive training program is needed to establish and maintain the knowledge and skills of *reprocessing inspectors*, particularly for those inspectors who do not have industrial experience in reprocessing plants. The skills and knowledge needed by *supplemental inspectors* is less demanding, encompassing only the broader aspects of reprocessing technology and facility-specific inspection practices. Inspector scheduling is normally arranged such that there is always at least one *reprocessing inspector* in the area, available to assist *supplemental inspectors* as needs develop. The training commitment necessary to support *reprocessing and supplemental inspectors* is thus quite extensive, especially in view of the high turnover of staff. General and specialized courses are provided related to reprocessing, particularly in the United Kingdom.

TABLE 3. APPROVED MEASUREMENT METHODS/EQUIPMENT FOR REPROCESSING PLANTS

MATERIAL FORM	VERIFICATION	APPROVED METHOD
SPENT FUEL	GROSS DEFECT	ICVD (CERENKOV DETECTION) GRN1 (NEUTRON DETECTION) CPMU (CUTIE PIE) HSGM (HIGH SENSITIVY γ MON.) SFAT (SPENT FUEL ATTRIBUTE TESTER)
MEASURED DISCARDS, WASTE	GROSS DEFECT	PMCG (MCA W/ Ge DETECTOR) PMCN (MCA W/ NaI DETECTOR) DA (DESTRUCTIVE ASSAY)
DISSOLVER SOLUTION	GROSS/PARTIAL /BIAS DEFECT	ELTM (ELECTROMANOMETER OR H_2O MANOMETER) + DA (IDMS, ISOTOPE DILUTION MASS SPECTROMETRY), OR HKED (HYBRID K-EDGE DENSITOMETER)
PLUTONIUM NITRATE	GROSS/PARTIAL /BIAS DEFECT	ELTM (ELECTROMANOMETER OR H_2O MANOMETER), + KEDG (K-EDGE DENSITOMETER), OR + DA (DESTRUCTIVE ASSAY),
URANYL NITRATE	GROSS/PARTIAL /BIAS DEFECT	ELTM (ELECTROMANOMETER OR H_2O MANOMETER) + DA (DESTRUCTIVE ASSAY)
PLUTONIUM OXIDE POWDER, OR MIXED PLUTONIUM/ URANIUM OXIDE POWDER (MOX)	GROSS/PARTIAL /BIAS DEFECT	*GROSS:* HLNC (HIGH LEVEL NEUTRON COINCIDENCE ASSAY) PMCG (MCA W/ Ge DETECTOR) OR PMCN (MCA W/ NaI DETECTOR) *PARTIAL:* HLNC (HIGH LEVEL NEUTRON COINCIDENCE ASSAY) + HRGS (HIGH RESOLUTION γ ASSAY), OR INVS (INVENTORY SAMPLE COINCIDENCE ASSAY) + HRGS (HIGH RESOLUTION γ ASSAY) *BIAS:* DA (DESTRUCTIVE ASSAY)
URANIUM OXIDE POWDER	GROSS/PARTIAL /BIAS DEFECT (BIAS DEFECT FOR LEU ONLY)	*GROSS:* PMCN (MCA W/ NaI DETECTOR) PMCG (MCA W/ Ge DETECTOR) *PARTIAL:* PMCN (MCA W/ NaI DETECTOR) + EBAL (ELECTRONIC BALANCE + STANDARD IAEA WEIGHTS) *BIAS:* DA (DESTRUCTIVE ASSAY)

Note: selections among alternative methods may be determined by the availability of equipment or plant-specific factors making one choice preferable to others.

IV. Past Experience

Table 2 shows the chemical reprocessing plants where IAEA safeguards have been, are currently, or will be applied. In some cases, safeguards application has been on a partial basis, as under voluntary safeguards agreements in nuclear weapons states. In other cases, extensive safeguards-related R&D activities are underway or have been carried out.

V. Current Practice

In this section, the verification activities currently applied are summarized.[3] Measurement systems currently approved for routine inspection use in reprocessing plants are shown in Table 3. Table 4 summarizes the techniques most widely applied in the analysis of inputs to and product outputs from reprocessing plants. The measurement uncertainties are taken from a forthcoming IAEA publication.[4] They describe the measurement performance that is expected under normal conditions.

1. Design Verification

Design verification is expected to be achievable under routine verification conditions.

In reprocessing plants currently under IAEA safeguards,

TABLE 4. ANALYTICAL TECHNIQUES AND EXPECTED MEASUREMENT ERRORS

MEASUREMENT POINT	MEASUREMENT TECHNIQUE	MEASUREMENT	ERROR STD. DEV. (% REL)	
			RANDOM	SYSTEM.
INPUT SOLUTION	ISOTOPE DILUTION MASS SPEC.	PU-CONCENTRATION U-CONCENTRATION U-235 ABUNDANCE	0.4 0.3 0.3	0.2 0.2 0.2
	ISOTOPE DILUTION MASS SPEC. (USING LSD-SPIKE)[6]	PU-CONCENTRATION U-CONCENTRATION U-235 ABUNDANCE	0.2 0.2 0.2	0.1 0.1 0.2
	HYBRID K-EDGE DENSITOMETER	PU-CONCENTRATION U-CONCENTRATION	0.6 0.5	0.3 0.35
PU OUTPUT SOLUTION	TITRATION/COULOMETRY	PU-CONCENTRATION	0.15	0.15
	K-EDGE DENSITOMETER	"	0.20	0.20
PUO_2	TITRATION/COULOMETRY	PU-CONCENTRATION	0.15	0.15
	HLNC	TOTAL PU	1.0	0.5
U OUTPUT SOLUTION	TITRATION/COULOMETRY	U-CONCENTRATION	0.1	0.1
	K-EDGE DENSITOMETER	"	0.2	0.2
	MASS SPECTROMETRY	U-235 ABUNDANCE	0.2	0.2

the design information has been verified. Additional design verification activities should be carried out when there are plant modifications or when operator access is required inside the biological shield for repairs. Implementation arrangements for continued design verification over the life of existing plants and decommissioning are under discussion.

2. Verification of Plant Operations

2.1 *Verification of Transfers to the Mechanical Cell.* C/S is maintained to detect all transfers of spent fuel from the spent fuel pond to the mechanical cell. Observed movements are cross checked with operator declarations and in-cell gamma monitor readings. The serial number of each fuel assembly is identified in the cell prior to shearing.

2.2 *Verification of Shearing and Dissolution.* Shearing of the bottom end of each fuel assembly is monitored and visual observation of the chopped fuel assembly bottom is carried out to ensure that the assembly cannot go back to the pond without unacceptable contamination. Completion of dissolution is verified by assuring that the standard dissolver solution density is achieved, as established during plant commissioning.

2.3 *Monitoring of Operator Instrumentation.* Strip charts and data logged by operator computers are examined to confirm that operations are consistent with operator declarations. Limited authentication measures are applied.

3. Inventory Change Verification

3.1 *Verification of Spent Fuel Receipts.* All spent fuel receipts are verified by item counting and Cerenkov glow, or gross gamma detection, with random medium detection probability. Casks leaving the facility are checked before they are removed from the unloading pond to verify that they are empty.

3.2 *Verification of Input Accountancy.* Input declarations from the reactors are calculated values based on the quantities of nuclear material in the fresh fuel assemblies and nuclear loss and production calculations made over the exposure history of each fuel assembly. The calculated values are corrected for ^{241}Pu decay over the period from final discharge from the reactor core to the time that input accountability measurements are made.

Each batch of dissolver solution is verified in the input accountability tank prior to being transferred to the process. This verification consists of volume measurements and sampling for analysis of Pu (all batches) and U (random medium basis) to detect bias defects. The calibration of the input accountancy tank is checked annually and a recalibration is performed when necessary.

Sample preparations at the facility, the shipping of samples to the IAEA Safeguards Analytical Laboratory, and sample analysis and evaluation, can take up to three months. Therefore, a preliminary evaluation is made using a density correlation[5] to estimate the uranium content. The Pu/U ratio de-

TABLE 5. REPROCESSING-RELATED R&D UNDER IAEA MEMBER STATE SUPPORT PROGRAMMES

TOPIC	STATUS
TOOLS AND TECHNIQUES FOR DESIGN INFORMATION VERIFICATION	ACTIVE
MAINTAINING CONTINUITY OF KNOWLEDGE ON VERIFIED DESIGN INFORMATION	ACTIVE
WORKSHOP: VERIFICATION DURING PLANT COMMISSIONING TO CONFIRM PHYSICAL DESIGN VERIFICATION AND TO ESTABLISH REFERENCE BASE FOR COMPARISON DURING NORMAL PLANT OPERATIONS	ACTIVE
FEASIBILITY OF ADVANCED METHODS OF MATHEMATICAL ANALYSIS APPLIED TO DESIGN VERIFICATION AND NRTA AUTHENTICATION ANALYSIS	ACTIVE
VIBRATION ANALYSIS OF SHEARING	PRE-STARTUP
FEASIBILITY OF NOBLE GAS ISOTOPE CORRELATION FOR INDEPENDENT MEASUREMENT OF PU INPUT, AND C/S MONITORING OF SHEARING	ONE ACTIVE, ONE UNDER CONSIDERATION
FEASIBILITY OF COMBINED NDA/DA OF CURIUM FOR INPUT VERIFICATION, VERIFICATION OF PU IN LEACHED HULLS, AND VERIFICATION OF PU IN CONDITIONED WASTE	UNDER CONSIDERATION
HYBRID K-EDGE/K-XRF FOR INPUT MEASUREMENTS	ACTIVE
UNATTENDED VERIFICATION OF TANK VOLUME MEASUREMENTS AND SAMPLING	ACTIVE
APPLICATION OF NRTA/ADJUSTED RUNNING BOOK INVENTORY METHOD IN HEAD-END PROCESSING AREAS OF REPROCESSING PLANTS	ACTIVE
AUTHENTICATION OF OPERATOR MONITORING SYSTEMS BY EXPERT SYSTEMS ANALYSIS	PRE-STARTUP
SOLUTION MASS VERIFICATION TECHNOLOGY	ONE ACTIVE, ONE UNDER CONSIDERATION
REPROCESSING/CONVERSION PLANT NRTA SAFEGUARDS DESIGN SPECIFICATIONS	ACTIVE
DIAGNOSTIC ANALYSIS OF NRTA ALARMS	STARTUP
ADAPTATION AND APPLICATION OF HAZOP/HAZAN METHODS TO SAFEGUARDS	ACTIVE
PROBABALISTIC ANALYSIS OF SAFEGUARDS EFFECTIVENESS FOR REPROCESSING PLANTS	ACTIVE

clared by the shipper (the reactor), adjusted to reflect historical data for each reactor, is used to obtain a preliminary estimate of the Pu content.

Input accountability values are compared with shipper declarations. Problems exist in the SRD comparisons due to batch mixing and to inaccurate burn-up calculations, particularly for Boiling Water Reactors.

3.3 *Verification of Waste Streams.* Verification of transfers to waste or to measured discards is required for gross defects. Over a material balance period, unverified transfers must not exceed one-half of one SQ for each material type.

Waste materials must be measured and conditioned to be nonretrievable before safeguards can be terminated on the plutonium and uranium contained. At present, however, no practical verification methods exist for leached hulls and filters, and these materials are maintained as retained waste. High level liquid waste (HLLW), which contains most of the nuclear material in retained waste, also must be analyzed for the presence of plutonium.

3.4 *Verification of Plutonium Product Output.* All transfers of the final plutonium product solution (i.e., plutonium nitrate, $Pu(NO_3)_4$) from the process material balance area are verified for bias defects by volume measurement, sampling and analysis — mainly by K-edge densitometry and additionally, on a random basis, by destructive analysis.

Volume calibration of the output accountancy tank is checked each year and a recalibration is performed if necessary.

3.5 *Verification of Plutonium Product Shipments.* All transfers of plutonium product material from the plutonium nitrate storage tanks to a conversion facility are verified by volume measurement, sampling and analysis for gross, partial and bias defects, usually by X-ray fluorescence (XRF) and destructive analysis. This verification can be performed at either the shipping or receiving tanks, provided that C/S is maintained during such transfers (usually by inspector observation of tank levels).

3.6 *Verification of Uranium Solution or Product Powder Shipments.* Shipments of uranium from the facility are verified by volume measurement (for solutions) or by weighing (for oxide powders), with medium detection probability for gross and partial defects for low-enriched and natural uranium, and for gross defects for depleted uranium.

4. Interim Inventory Verification (IIV)

Interim inspection activities are carried out at a time (called the cut-off time) when the Pu product evaporator has just been emptied. During shutdown, any convenient time may be chosen.

4.1 *Examination of Records and Reports.* Facility accountancy records are examined for correctness and consistency with the operating records and supporting documents. Inventory change and material balance reports submitted by the state to the Agency are compared with the previously examined facility accountancy records.

4.2 *Spent Fuel Verification.* The spent fuel pond inventory is verified by comparing the operator's declaration of transfers to and from the pond area with that observed through surveillance.

4.3 *Verification Activities in the Head-End.* The in-process inventories in the head-end and in the process MBA are verified by an approved facility-specific method. Head-end batches present at the cut-off time are identified, tracked until their arrival in the input accountancy tank, and verified as inventory and as flow to the process MBA.

4.4 *Verification Activities in the Separations and Purification Area*. Near-real-time accountancy (NRTA) measures are applied on a monthly basis to the process MBA based on operator declarations of flow and inventory. All flows to or from the process MBA are verified. Samples are taken from the major Pu-containing inventory tanks on a random medium basis for authentication of the operator declarations. The sequence of monthly NRTA MUFs is analyzed for indications of possible losses of plutonium, which might result from innocent causes or in the event of a diversion.

4.5 *Verification Activities in the Plutonium Nitrate Storage Area.* The $Pu(NO_3)_4$ stored in product tanks is verified by volume measurement and sampling for gross and partial defects by K-edge densitometry. An NRTA analysis with authentication is also carried out for this storage.

TABLE 6. FACTORS AFFECTING SOLUTION MASS MEASUREMENTS

The accuracy of a measurement of the amount of nuclear material present in solution in a given tank or series of tanks will be influenced by the following factors:

1) Tank design and materials; supporting structures; piping for transfers of solutions, ventilation, reagent addition, air pulsation or sparging; power trains for mechanical homogenization; pneumatic lines for solution level and density measurements; and electronic cabling for temperature measurements and other types of instrumentation;

2) Tank operational procedures, including provisions for sampling, solution transfers, drainage, homogenization and ventilation;

3) Physical and chemical phenomena, including density, acidity, viscosity, surface tension, volatility/chemical reactivity, thermal expansion, polymerization, presence of undissolved solids or immiscible liquids;

4) The solution measurement system, including sensors with support utilities (e.g., dip tubes with controlled instrument air or nitrogen supply) and transducers; signal conditioning; data transmission and logging.

5) Initial tank calibrations and re-calibrations providing reliable calibration curves, including determinations of the random and systematic uncertainties associated with those determinations, including acceptance testing and normal operations.

6) Sampling systems, including provisions for assuring that samples are representative and well characterized; provisions for protecting the integrity of samples and methods, procedures and evaluations of sampling error anticipated in routine use of the tank; and

7) Sample concentration measurements to determine the elemental and isotopic composition of nuclear material species present in the solution in the tank at the time of measurement, and methods, procedures and evaluations of random and systematic uncertainties associated with the concentration measurements.

5. Physical Inventory Verification (PIV)

One PIV is carried out per calendar year at intervals not exceeding 14 months. Before the PIV, the operator cleans out the process vessels and piping by successive rinsing and flushing and transfers the recovered materials to calibrated tanks. The entire plant inventory is measured or otherwise confirmed by the operator, constituting the physical inventory taking (PIT). The result of this is a preliminary list of inventory items (LII), which serves as the basis for IAEA verification.

Upon completion of the PIT, the operator analyzes the material balance over the period from the previous PIT and subsequently submits his declaration to the national safeguards authority. The national safeguards authority, when satisfied with the material balance report, submits an official Material Balance Report to the IAEA, which includes the official Physical Inventory Listing (PIL), based on the LII.

5.1 *Examination of Records and Reports.* The facility accountancy records are examined for correctness and consistency with the operating records and supporting documents. Inventory Change and Material Balance Reports submitted by the state to the Agency are compared with the previously examined facility accountancy records.

5.2 *Spent Fuel Verification.* For PIV, the spent fuel pond inventory is verified through successful surveillance and item counting of the spent fuel assemblies, plus random low verification for gross defects. If spent fuel is stored in closed containers, two-stage sampling is applied; containers are selected with 10% detection probability ($\beta = 0.9$), and then assemblies in the selected containers are verified by identification and Cerenkov glow or gross gamma detection on a random medium basis.

5.3 *Verification of the Plutonium and Uranium Inventory.* Plutonium solutions in process vessels as well as in storage tanks are verified with high detection probability ($\beta = 0.1$) for gross, partial and bias defects. Uranium solutions and product powders are verified with medium detection probability for gross and partial defects for low enrichment and natural uranium and for gross defects for depleted uranium. Plutonium waste is verified with high detection probability for gross defects. (Note that up to 0.3 SQ of each material type, i.e., 2.4 kg Pu, may remain unverified according to present requirements.)

VI. Future Trends

Approximately one quarter of the total IAEA inspection effort is devoted to plutonium processing facilities, the amount depending from year to year on the operating schedules of the existing plants. While substantial technical progress has been realized in establishing credible safeguards systems, efforts continue to address some remaining problems. However, none of these problems has precluded inspection goals from being attained, but improvements are needed to improve the technical credibility of the safeguards applied, or to lower the costs of safeguards implementation without adversely affecting safeguards effectiveness. Some of the present problem areas are identified below:

- Measurement biases on solution measurements persist at levels in excess of 1% (i.e., 10 times the expected levels of performance).
- In some cases, it is not possible to assure that samples taken for the IAEA are not altered prior to shipment to the Agency's Safeguards Analytical Laboratory.
- Following recommendations from the IAEA board of governors, continuing verification of design information of operating plants will require significant effort and may interfere with plant schedules. Limitations caused by radiation will inhibit the extent of physical verification.
- Investigations are continuing into expanded use of unattended verification arrangements, telecommunications and resident inspector deployment as possible efficiency measures.
- Improvements are required in the analysis of shipper/receiver differences (see annex).

In addition to these activities focused on existing facilities, in the coming years, Agency safeguards will be applied at a few new reprocessing plants, particularly in Japan. Efforts related to new plants are described below.

1. Safeguards Implementation at New Reprocessing Plants

The basic concepts regarding IAEA safeguards implementation in large-scale reprocessing plants were investigated recently, under an arrangement referred to by the acronym LASCAR (for LArge SCAle Reprocessing).[7,8] France, Germany, Japan, the United Kingdom, the United States, Euratom and the IAEA examined potential verification arrangements for the spent fuel areas, the main chemical process area and the product storage areas. While LASCAR

TABLE 7: VERIFICATION MEASUREMENT METHODS FOR ON-SITE IAEA ANALYTICAL LABORATORIES

PROCESS AREA	SAMPLING POINT	INSTRUMENT OR METHOD	CONCENTRATION MEASUREMENT	SAMPLE FRACTION	GOAL ACCURACY
HEAD END	INPUT TANK	HYBRID K-EDGE DENSITOMETER (HKEDG)	Pu U	100 % 50 %	≤ 1 % ≤ 0.5 %
SEPARATION	BUFFER/FEED TANKS	ISOTOPE DILUTION MASS SPECTROMETRY (IDMS)	Pu U	25 % 2 %	≤ 0.2 % 0.2 %
SEPARATION	SCRUB AND WASTE TANKS	Pu(VI) SPECTRO-PHOTOMETRY	Pu	< 20 %	≤ 25 %
Pu PURIFICATION	COLLECTION AND FEED TANKS	HKEDG IDMS	Pu Pu	50 % ≤ 10 %	1 % ≤ 0.2 %
	PuN TANKS	KEDG IDMS	Pu Pu	25 - 100 % 10 - 90 %	0.2 % 0.1 %
	WASTE TANKS	Pu(VI) SPECTRO-PHOTOMETRY	Pu	< 10 %	≤ 25 %
U PURIFICATION	UN TANKS	K-EDGE DENSITOMETER (KEDGG)	U	≤ 10 %	0.2 %
	UO_3 CANS UO_3 CANNING	NDA (MEASUREMENTS MADE IN PLANT) KEDG	U U	≤ 10 % 1 %	< 5 % 0.2 %
MOX CONVERSION	U, Pu N TANKS	KEDG	U Pu	< 10 % 50 %	0.2 % 0.2 %
		IDMS	Pu	20 %	≤ 0.2 %
	MOX CANISTERS MOX CANNING	NDA (MEASUREMENTS MADE IN PLANT) KEDG	Pu Pu	100 % 25 %	1 % ≤ 0.2 %

was a significant success, a considerable effort will be required to translate the recommendations into specific working arrangements for the new large scale plants. Also, reprocessing plants other than those considered by LASCAR will or may come under IAEA safeguards in the future (see Table 2).

New reprocessing facilities that are currently being designed or constructed pose challenges in the application of safeguards principally because of the large quantities of nuclear material involved, the complexity of the plants and their remote locations. Existing verification equipment or procedures may be inadequate or inappropriate or highly inefficient, especially in large-scale plants. For example, new reprocessing plants may employ continuous dissolvers, centrifugal contactors and continuous evaporators, requiring new inspection procedures. Moreover, the scale of some of the new facilities is expected to be much larger than that of existing plants subject to IAEA safeguards. In the plants addressed through LASCAR, for example, the plutonium throughput, in-process inventory and storage capacity will be 10-to-50 times that encountered in existing plants under IAEA safeguards. These facilities will require extensive Agency effort and will strain the limits of Agency verification capabilities.

2. R&D and Implementation Support Planning For New Reprocessing Plants

New safeguards techniques and equipment are required that are cost effective and eliminate anticipated vulnerabilities or shortcomings. R&D is carried out for the IAEA by Member State Support Programs. Table 5 identifies the R&D tasks currently active in Australia, Euratom, Japan, the United Kingdom and the United States, and additional R&D topics under consideration.

Our R&D planning must consider the following factors:

• implementation must be synchronized with plant construction schedules,

• current and projected inspection requirements must be met (see Table 1),

• LASCAR recommendations will be honored and

• the required sequence of tasks necessary to address each need and the resources available within Member State Support Programmes.

When a requirement is identified on the basis of reducing intrusiveness, improving cost effectiveness or addressing potential vulnerabilities, one or more tasks may be proposed to address each need. The tasks generally would follow logical stages: concept development (of one or more alternative approaches), evaluation of alternatives, technology development and evaluation, system procurement, system qualification and evaluation, training, and maintenance.

Each task must be planned in accordance with the plant construction and commissioning schedule. The relationships between tasks must be identified and progress closely monitored to ensure that when a new plant commences operations, an effective and efficient safeguards system will be in place.

3. Anticipated Problems for Safeguards Implementation in New Facilities

At the present time, the following issues remain unresolved:

- The costs for implementing safeguards at new reprocessing plants will be substantial, requiring additional resources for staff, equipment and operations.
- Solution mass measurement technology is not sufficient for the needs anticipated, noting that 0.1% of throughput may be greater than one significant quantity of plutonium. Table 6 shows the factors affecting the accuracy of solution mass measurements.
- Monitoring of process operations will be required in real-time, with comparisons of the observed operations with operator declarations and predictions of normal plant behavior. This is a more intrusive arrangement than currently employed, and one likely to require more frequent inspector enquiries than at present.
- Resident inspectors will substantially reduce the inspector staffing requirements. Basing inspectors in remote areas will require attractive arrangements.
- On-site analytical laboratories may be shared by Agency analysts and national safeguards analysts to offset the costs that both would bear if separate laboratories were established. The capabilities foreseen for on-site laboratories are shown in Table 7. Such a laboratory should be equipped to provide verification measurements of the main nuclear material streams and strata with accuracies of the order of 0.1%. These measurements will be needed to complement less accurate but more frequent measurements done by faster and simpler methods. If the accuracy is comparable to that obtained at the IAEA Safeguards Analytical Laboratory, shipments of samples to SAL will be needed infrequently for quality control and authentication purposes, and for the resolution of discrepancies, or in the event of failure of the equipment in the on-site laboratory. The working arrangements will require that the Agency analysts are able to obtain independent measurement results.
- Specialized verification systems will tax the Agency's ability to ensure reliable safeguards implementation (design, procurement, authentication, operation, maintenance).
- The policies and specific guidelines for authentication of operator instruments and for the termination of safeguards on measured discards require further development.

VII. Conclusions

In the case of safeguards as applied to a reprocessing plant, the effectiveness of IAEA technical safeguards measures is determined by the Agency's ability to detect the diversion of plutonium or uranium from the declared reprocessing plant inventories, and to detect undeclared reprocessing operations, should such a diversion or misuse occur. The effectiveness of a given safeguards application depends on the relative strengths and limitations of the measures employed, beginning with design verification and building up through the various applications of containment and surveillance and nuclear materials accountancy at the facility in question. Other possibilities are available to supplement these routine verification activities, including special inspections if suspicions warrant. Thus, no single safeguards measure, whether it be anomaly detection through containment and surveillance, or material balance evaluation involving the analysis of material-unaccounted-for, adequately represents the capability or the system to detect diversion or undeclared reprocessing.

Safeguards in new reprocessing plants will differ from current implementation arrangements in several ways. First, the emphasis on design verification will be more evident, over the entire life of a plant. Second, for large scale facilities, there will be a greater need for assuring that operations are carried out as declared, which will require extensive use of installed instrumentation. Operator instruments will be used more than at present, and authentication provisions will be incorporated from the outset. Third, with the increased data requirements and budgetary pressures limiting future staff growth, on-site inspection centers will be needed, with on-line logging of verification data and on-site data analysis and reporting capabilities. Where possible, resident inspector arrangements may be adopted to facilitate specialization and to increase inspector efficiency. And fourth, on-site analytical laboratories may be employed to minimize the number of samples requiring shipment to the IAEA Safeguards Analytical Laboratory in Seibersdorf, Austria. Such laboratories will provide improved verification sensitivity and dramatically improve verification timeliness.

The principal objective of this paper has been to describe safeguards implementation at current reprocessing plants and the complications anticipated in meeting future demands. On the whole, the safeguards provisions employed today are acceptable, with certain improvements required. For the future, the complications identified are being addressed, although the demands will certainly tax the existing conceptual base and the implementation framework.

References

1. In IAEA safeguards terminology, low, medium and high detection probability refer to the probability for committing errors of the second type, b, chosen for planning purposes to be 0.9, 0.5, and 0.1, respectively.

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FRACTAL ANALYSIS OF SHIPPER/RECEIVER DIFFERENCE SERIES

Shipper/Receiver Difference analyses are carried out to verify the amounts of nuclear materials transferred between facilities, and thereby to detect diversion concealment through over declarations of shipments or under declarations of receipts. For spent fuels, however, the shipper is the reactor, and the amounts of plutonium and uranium in spent fuel assemblies are calculated on the basis of the initial contents and nuclear loss and production over the exposure history of the assembly in the reactor. Substantial shipper/receiver differences are observed in practice. Fractal analyses reduce the random effects and permit useful SRD analyses.

At the beginning of the century, a hydrologist named Hurst was concerned with the problem of reservoir control. To come up with an optimum discharge policy, the influx of water had to be modeled. Hurst measured how the reservoir level fluctuated around its average over time. As expected, the range of this fluctuation would change depending on the length of time used for measurement. If the series were a random walk-like sequence then the range would increase with the square root of time. To standardize the measure over time, Hurst created a dimensionless ratio - *the rescaled range* - by dividing the range by the standard deviation of observations. *Hence, the analysis of random processes and of time series with the help of the behavior of the rescaled range is called rescaled range (R/S) analysis.* Hurst found that most natural phenomena, including river discharges, follow a "biased random walk" trend with noise. The strength of the trend and the level of noise can be measured by how the rescaled range scales with an exponent (H) of time, noting that H = 0.5 corresponds to Brownian motion.

A more modern twist in Hurst's investigations is that of the connection to fractal sets. Mandelbrot studied time series, which he called fractional Brownian motion, a generalization of the classical Brownian motion. He found interesting interpretations of the Hurst exponent. For example, the fractal dimension of a time series showing a stable Hurst exponent H is equal to 1/H. Thus, the parameter H is a measure of the roughness of a series at small scales. It is also related to the correlation between two increments of the process.

A time sequence plot of almost any SRD series shows a noise-like process as if produced by some random mechanism. In analyzing an SRD series, it is first described as tersely as possible. (The Box-Jenkens analysis, for example, would attempt to describe a time series with a small number of coefficients defining a filter, which in turn transforms white noise into a series statistically identical to the underlying one.) Next, its structure, buried in its noise-like appearance, is revealed. SRD series can contain information about the various fuels and reactor types with which they are associated.

In work carried out thusfar, the R/S analysis of two SRD data sets suggests that:

- there are unique and stable Hurst coefficients for each series; and
- process campaigns and reactor fuel types seem to show distinct structures in the R/S transform.

The most useful aspect of the R/S analysis might be its discerning capability for fuel and reactor types in the SRD series.

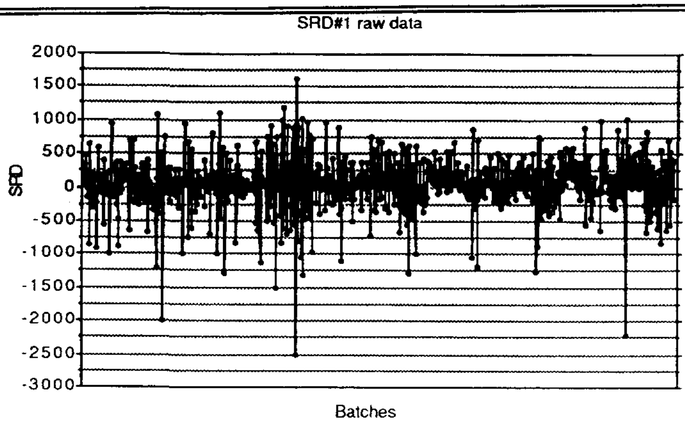

Figure 1. An unmodified SRD sequence, expressed in arbitrary units.

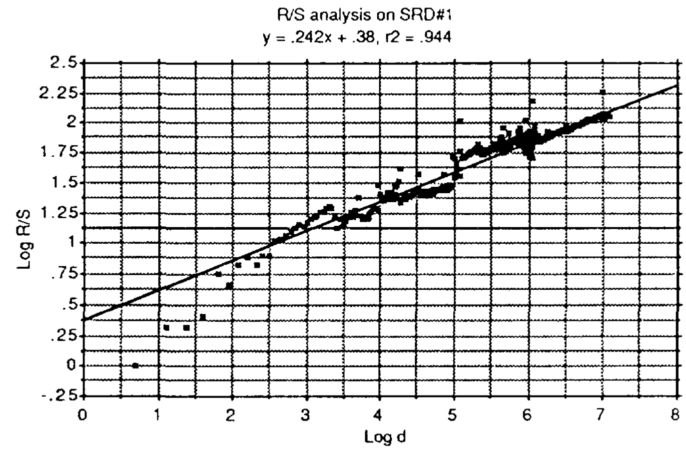

Figure 2. The R/S transform of the SRD sequence shown in Figure 1 gives an H estimate of .242, which corresponds to a fractal dimension about twice that of normal Brownian motion, or a random walk with small steps. Another SRD sequence yielded a fractal dimension of 2.36.

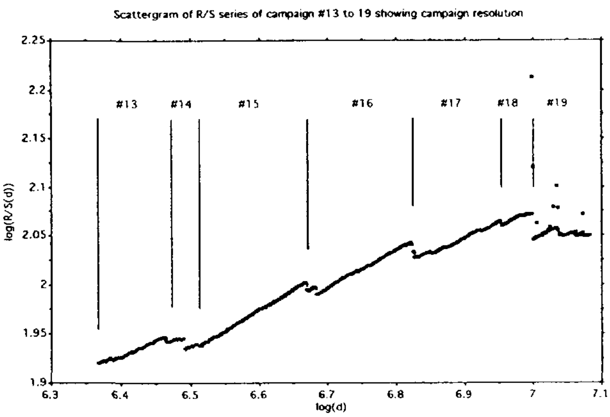

Figure 3. The ability of the R/S transform to resolve different campaigns in the original SRD sequence is shown; jumps in the R/S sequence tend to mark the beginning of a new campaign.

Current Trends in the Implementation of IAEA Safeguards

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Abstract

A practical goal, embodying the principle that a minimum amount of material is required in order to manufacture a nuclear explosive device, is that safeguards activities should enable the timely detection of the diversion of a significant quantity of nuclear material. It is important to note that the safeguards activities are not restricted to the International Atomic Energy Agency (the agency) but impose obligations on both state (and consequently on facility operators) and the agency. The beneficiaries are member states of the world community which have enhanced confidence in the competence and probity of states with safeguards agreements. Neither safeguards nor the nuclear industry have remained stationary. As new techniques have been developed, they have found applications, and as new challenges were encountered, the system has responded, for example, through improved measurements; through new or improved techniques for the operator, state or agency; and through new regulations.

This paper details approaches, procedures and techniques developed for new complex nuclear facilities. Trends toward increasing efficiency and effectiveness, and developments leading to more automated analysis and collection of data and the development of nondestructive assay methods are examined. Also important are trends in the presentation of safeguards results to the states and the general public.

It is concluded that the existence of new situations has been recognized and procedures, equipment and new techniques have been introduced. These introductions, whether by operator, state or agency, have enabled the agency to maintain the assurance of state compliance to the obligations of safeguards agreements, despite the increasing complexity of the nuclear industry and the increasing amounts of material to be safeguarded.

The most significant trends now being considered, those requiring the provision of assurances that there are no undeclared activities or material which ought to have been declared under the terms of the agreement, pose new challenges to all parties. The high level of cooperation experienced in the current climate gives cause for confidence that the challenges will be overcome successfully.

I. Introduction

The goal of safeguards, in very general terms to provide assurance that nuclear material, certain non-nuclear material, facilities and equipment are used only as defined in a safeguards agreement; more specifically, this means providing assurance that the nuclear material covered by a safeguards agreement is not diverted from peaceful use. A practical goal, embodying the principle that a minimum amount of material is required in order to manufacture a nuclear explosive device, is that the safeguards activities should enable the timely detection of the diversion of a significant quantity of nuclear material.

It is important to note that the safeguards activities are not restricted to the agency but impose obligations on both the state (and consequently on facility operators) and the agency. The beneficiaries are member states of the world community which have enhanced confidence in the competence and probity of states with safeguards agreements.

The goal, as outlined above, has not changed since the introduction of safeguards, but neither safeguards nor the nuclear industry have remained stationary. As new challenges were encountered, the system has responded, for example, through improved measurements; new or improved techniques by the operator, state or agency; and through new regulations.

The stimuli for these changes have also come from diverse sources. Improved measurement methods required by the operators of large facilities have also been applied for safeguards verification, and devices (such as neutron coincidence counting equipment) which were primarily developed to enable safeguards verification have found important uses in nuclear facilities. The development of on-line computer systems has had a marked influence both in plant-control and in many of the agency's activities, while the need to ship samples for verification has influenced the promulgation of national legislation for the safe transfer of radioactive materials.

It has always been an aim of the agency to be cost-effective, and steady improvement has been achieved whether measured in effort per significant quantity or in goal attainment related to the amount of effort expended. A problem in recent years has been the marked decrease in available budget and it has been necessary to reduce some aspects of implementation. The reduction in inspection efforts has been on aspects that added least to the overall confidence and in many cases the effects were minimized through administrative arrangements, such as the assignment of longer inspection tours for individual inspectors. There has, however, been a compensatory trend — the development of regional safeguards systems.

The agency has an obligation to base its conclusions on its own activities and cannot simply repeat verdicts supplied by national and regional multinational systems. This requirement does not eliminate the possibility of controlled integration with such systems and a recently developed partnership approach which ensures the ability of the agency to draw valid conclusions is being implemented in conjunction with the Euratom Safeguards Directorate.

In certain circumstances, savings can be achieved through the implementation of a "zone approach." It is not suggested that in all possible cases the creation of a "zone" is cost effective. Every case must be considered individually, but it has been possible to introduce several "zones" with consequent savings in resources and in financial outlay.

There are frequent suggestions that a fuel cycle approach could result in efficient, economic safeguards and studies are in progress to assess the impact of possible modifications to the existing systems. It is not possible, at this time, to define such studies as a "trend," but there may well be possibilities for the future.

II. New Approaches, Procedures and Techniques

There are several factors that determine the need for the development of new safeguards approaches, procedures and techniques:

- the application of safeguards at new complex nuclear facilities — such as advanced nuclear reactors, MOX fuel fabrication, enrichment and reprocessing plants;
- the requirement that the agency achieve a high degree of effectiveness and efficiency in applying safeguards; and
- the need to minimize the intrusiveness into facility operation and to minimize the exposure of the operator and the inspector to ionizing radiation when carrying out safeguards inspections.

During the last several years, the concept of zone approach continued to attract the attention of the agency, and the number of implemented zone approaches has grown during the last 10 years from one to four. This concept treats a set of facilities or material balance areas (MBAs) within a state with regard to a given type or category of nuclear material as a "zone." An inspection scheme implemented in the framework of zone approach consists of physical inventory verifications (PIVs) carried out simultaneously at all the MBAs included in the zone and of verifying the nuclear material flows into and out of the zone. The role of the zone approach is to improve the cost effectiveness of measures related to verification of domestic transfers of nuclear material and to provide assurance against the borrowing of nuclear material within the zone. Currently, zone approaches are implemented for the natural uranium and low-enriched uranium fuel cycle facilities in one state and the natural uranium fuel cycle facilities in another state and for a group of facilities handling plutonium and high-enriched uranium in one state. It could be the case, however, that the zone approach in its current form is only an intermediate step in the development of a comprehensive approach based on correlating the information from nuclear fuel cycle MBAs.

A principle of random selection of nuclear material items for verification has been used in safeguards for a long time; a new trend is an expansion of this principle. A new feature of modern safeguards is a concept of the short notice random inspection (SNRI) regime. This concept has been widely used in developing the 1991-95 Safeguards Criteria; implementation of the SNRI regime was envisaged for increasing the effectiveness in verification of domestic transfers of natural and low-enriched uranium and for the confirmation of the absence of the borrowing of nuclear material. These two requirements have not yet been fully met in practice due to the difficulties in arranging for the necessary inspection regimes. The agency, however, has gained to date some positive experience of using the SNRI or similar regimes in other areas of safeguards implementation, namely, the application of SNRI for the confirmation of operator declarations on refuelling at multiunit on-load reactors, performance of limited frequency unannounced access inspections of the cascade areas at enrichment plants for confirmation of the absence of the unreported production of direct-use material, and selection of some nuclear installations with small quantities of nuclear material for inspection on a random basis.

In the last several years some problems of verification for timely detection purposes were under close consideration by the agency. The subject relates mostly to large facilities processing direct-use material in bulk form, where material in the process area is difficult to access for verification. Development of safeguards approaches with the objective of meeting the timeliness requirements revealed the following trends for such facilities:

- a requirement for the operator to maintain nuclear material accountancy in a timely manner — one example being a near real time accountancy (NRTA);
- development of methods and techniques for remote or

unattended verification of nuclear material flows within the facility;

- a tendency of usage by the inspector of the operator's measurement equipment or usage of joint equipment by the inspector and operator under the condition that such equipment is authenticated by the agency; and
- an extensive application of containment/surveillance (C/S) measures.

The growing number of nuclear material stores under safeguards, especially long-term stores of spent fuel, where nuclear material is difficult to access, results in increasing application of C/S measures and in the need to improve the effectiveness and reliability of these measures. The latter requirements led to a wide introduction of dual C/S systems i.e., systems consisting of two independent components which are not subject to a common tampering or failure mode. As of the end of 1992, there were about 20 dual C/S systems in operation. Another trend which deserves mention is the replacement of optical surveillance film cameras with video cameras and the introduction of nuclear material flow monitors combined with other C/S systems. At of the end of 1992, there were more than 150 video systems, six core discharge monitors and 26 spent fuel bundle counters installed in safeguarded facilities.

The permanent demand for upgrading the effectiveness and efficiency of agency safeguards has led to rapid development of safeguards equipment for nondestructive assay (NDA). This, together with the improved methods of statistical analysis and planning of verification activities, has led to an increased role of NDA verification in agency safeguards. The current trends in the application of NDA methods could be described as follows:

a. *Verification of spent fuel*

Significant progress has been achieved in the development and implementation of new devices for Cerenkov glow observation under normal illumination conditions. This instrument is currently most frequently used for verification of spent fuel and is considered to be almost nonintrusive. There are several other NDA instruments which could be used in situations where the use of the Cerenkov viewing devices is not appropriate (e.g., where spent fuel has low burn-up or long cooling time): spent fuel attribute tester (SFAT), irradiated fuel measuring system (GRNI), high-range underwater monitor (Cutie-Pie), etc. Those instruments are, however, more intrusive than to the Cerenkov viewing device.

b. *General purpose attribute tester*

Testing the nuclear material items for gross defects is currently one of the most frequent verification activities. A portable, low-resolution gamma-ray measurement device (HM-4) was frequently used for this purpose. The main advantage of this device is its portability. However, it has certain limitations and is being replaced in many inspections by the portable multichannel analyzer (PMCA).

c. *Verification for partial and bias defect*

Verification for partial and bias defects usually requires more than one measurement operation (e.g., weighing or volume determination plus determination of element/isotope content). There is a wide variety of NDA instruments developed for accurate quantitative measurement of nuclear material. Most of them are used for partial defect tests. Significant progress has been achieved in developing instruments based on the principle of fission neutrons coincidence measurement (e.g., active well coincidence counter (AWCC)). These instruments — used in passive (plutonium measurement) or active (uranium measurement) mode and coupled with precise measurement of isotopic composition by gamma spectrometry — provide generally good accuracy and in certain conditions can be used for bias defect tests in lieu of destructive analysis.

Table I displays the trends in utilization of destructive analysis (DA) and NDA measurements for the period 1987–1991.

Table I
Utilization of Destructive Analysis (DA) and Nondestructive Analysis (NDA) Measurements During 1987-1991

Inspections in which NDA measurements were used	**1987**	**1988**	**1989**	**1990**	**1991**
• Low resolution gamma ray measurement	508	618	640	600	458
• Gamma ray measurement with portable multichannel analyzer	194	207	305	302	471
• High resolution gamma spectrometry	52	59	49	57	82
• Neutron coincidence measurement	128	193	199	198	191
• Cerenkov glow observation	249	312	366	372	436
DA results reported	3,600	3,040	2,890	2,900	2,830

III. Safeguards Effectiveness and Presentation of Results

The results of safeguards effectiveness evaluation have been included in the Safeguards Implementation Report (SIR), which has been presented since 1977 to the board of governors. The evaluation is performed in accordance with the Safeguards Criteria, which specify the scope, the normal frequency and the quality of the verification activities considered by the secretariat to be necessary for fulfilling the agency's responsibilities under safeguards agreements. The evaluation results are displayed as various grades of inspection goal attainment for safeguarded facilities, inspected during the year and, for certain parameters, at the level of an entire state.

The current trend in safeguards effectiveness evaluation could be characterized by the increasing transparency of this process. The Safeguards Criteria have been made available to member states initially for information and then, at the time of the development of the 1991–95 Safeguards Criteria, for comment.

It is important that the achievements and problems of safeguards implementation and their relative significance are clearly understood. Significant efforts have been made during the last several years in order to improve the presentation of information to the board of governors, member states and the general public.

These efforts have resulted in a new and generally well-received presentation of the SIR to the board, in a growing number of briefing meetings on safeguards implementation issues with the missions of member states, in meetings with individual SSACs to discuss results achieved and problems encountered and in articles in open literature such as the quarterly *IAEA Bulletin* and the *IAEA Yearbook*. At the same time, there have been several technical issues considered at meetings of the board of governors. These trends are in line with the fact that implementation of international safeguards is a joint venture by the IAEA and member states and illustrates that the effectiveness of safeguards depends to a large extent on cooperation between the agency and the members of the world community. It is to be regretted that a simultaneous negative trend has been the reduction in the number of consultants meetings hosted by the agency due to recent severe budgetary restrictions.

The 1991 events in Iraq have shown that the possibility of clandestine activities, either totally separate or covertly linked with safeguarded facilities, exists and should be considered. Attention, therefore, is given to proposals for strengthening the safeguards system through wider reporting of transfers of nuclear material and equipment and through special inspections when these are necessary and appropriate and for a need for a strengthened and comprehensive evaluation of safeguards implementation.

Openness and transparency are playing an increasingly important role in the international safeguards regime and a current trend is the requirement for safeguards activities to include giving assurance of the completeness of a state's declaration on initial inventories of nuclear material coming under safeguards, assurance that there are no undeclared nuclear activities in states with comprehensive safeguards agreements and the consideration of a more active role for SSACs in the mutual implementation of safeguards.

IV. Conclusion

The existence of new situations has been recognized and new procedures, equipment and techniques have been introduced. These introductions, whether by operator, state or agency, have enabled the assurance offered by the agency on the states compliance with safeguards agreements to be maintained despite the increasing complexity of the nuclear industry and the increasing amounts of material to be safeguarded.

The most significant trends now being considered, those requiring the provision of assurances that there are no undeclared activities or material which ought to have been declared under the terms of the agreement, pose new challenges to all parties. The high level of cooperation experienced in the current climate gives cause for confidence that the challenge will be successfully overcome.

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The Role of Neural Networks in Safeguards and Security*

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Abstract
Interpreting data from nuclear safeguards and computer security systems is a tedious and time-consuming task. It typically requires the examination of large amounts of data for unusual patterns of activity. Neural networks provide a flexible pattern-recognition capability that can be adapted for these purposes. In this paper we describe a methodology for performing anomaly detection and consistency checking in safeguards and security data.

Introduction
Data acquisition and control systems used in chemical processing plants, storage facilities for nuclear materials, and weapons dismantlement facilities all have the potential to generate large amounts of data. Because of the complexity and diversity of the data, efficient automatic algorithms are necessary to make interpretations and ensure secure and safe operation. New, advanced systems are needed to analyze the information gathered from process monitors so that humans can direct their attention to possible problems and assist with on-site interpretations.

Such systems must be capable of detecting anomalies. The monitoring system should be robust enough to detect, assess, and respond to a non-normal situation. It should be able to help safeguards inspectors verify that material has not been diverted. Furthermore, it should be able to detect movement of unexpected amounts of material in unexpected directions.

Historically, we have relied on physical security and access controls for the assurance of material security. With potential hacker[1] and insider[2] threats and emerging transparency issues, these traditional methods are no longer adequate. On-line, real-time analysis techniques are now needed to ascertain plant security; in the future these techniques will be required to recognize normal operations at dismantlement and storage facilities and to respond to non-normal (anomalous or inconsistent) conditions in a *timely* and *effective* manner. Efforts to develop the capabilities just described have succeeded in that effective prototype anomaly detection algorithms using neural networks have been applied to several different situations. In this paper we describe the neural network methodology we have used in three applications.

Neural Networks
Neural networks are based on a mathematical model that is derived from cell biology. These networks are organized into layers consisting of several neurons (nodes) connected together with adjustable weights. Each layer performs a particular function. The input layer processes the data being presented to the network. The hidden layers, one or more, encode "features" in the data, and the output layer holds the response of the network to a given input. This is illustrated in Fig. 1, where the neurons are shown as black dots and the weights are shown as lines connecting the dots.

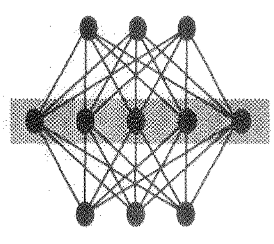

Fig. 1. A neural network.

Two phases of operation are required: the learning phase and the testing and recall phase. Learning consists of presenting a stimulus (an input vector) to the input layer together with a desired response. The network then calculates

*This work was supported by the U. S. Department of Energy, Office of Safeguards and Security and Office of Arms Control and Non-proliferation.

a result using the current weights and given input values. This "answer" is next compared with the desired response. If a difference of sufficient magnitude exists, the weight values are adjusted. As this learning process is repeated with more vectors, the weights will converge, and the network is said to be trained.

During the recall phase, similar examples are presented to the network to test whether the training was adequate. The difference between the desired and actual output is a measure of success, with differences of smaller magnitude representing greater success than those of larger magnitude.

Neural networks have been applied to a variety of problems in function approximation, prediction, pattern matching, filtering, optimization, and classification. Examples of their successes include reading handwritten zip codes, predicting thermal power in nuclear power plants, controlling accelerators, recognizing the shape of a gun from an airport X-ray, compressing images, recognizing human faces and speech, recognizing targets with sonar, playing backgammon, diagnosing circuit board faults, rating municipal bonds, and controlling robot arms. Given the diversity (and presumed incompleteness) of this list, it is not surprising that anomaly detection for nuclear safeguards and security is another area for application. In this paper, we exploit the ability of neural networks to model a normal situation and detect an abnormal one while classifying input values.

Our approach is based on the hypothesis that non-normal activity would involve unusual patterns of behavior. With this understanding we can build a model for anomaly detection that is based on the same hypothesis as that used in computer intrusion detection: exploitation of system vulnerabilities involves non-normal system use. That is, if we can build a model of normal, or expected system behavior (normal movement of material, normal dismantlement of weapons, normal placement of materials in a storage vault), then we can detect non-normal or unsecure behavior.

To successfully model a process with a neural network, a good set of observables must be chosen. These observables must in some sense adequately span the space of representable normal events, so that a signature metric can be built for normal operation. In this way, a non-normal event, one that does not fit within the signature, can be detected. Examples of information that could be combined in a model are location and size of spikes in sensor data from gamma-ray and neutron detectors, plant control system information (robot position, binary device states), statistical information taken from video images, and time-of-day information.

There are many different architectures for neural networks. Network designers must choose not only a numerical approach, but they also must decide on the function of the network and which components will be included in the input and output vectors. The type of network one uses depends on the application. The types of networks that we have found to be useful in anomaly detection are described in the following sections. These are classification networks that use input values to predict a categorical output. For example, given symptoms and lab results, determine the most likely disease.

Back Propagation

At present, the most popular network for many problems is a feedforward back propagation network.[3] It is also one of the easiest to understand. The network is composed of input and output layers and one or more hidden layers of neurons; information flows in a single direction. Information vectors are presented to the network one at a time. If the output of the network is incorrect, the weights are adjusted so that the error is reduced and so that future responses are more accurate.

We can describe this process mathematically. The output y_i of the ith neuron is given by

$$y_i = sig\left(\sum_j W_{ij} y_j + \Theta_i \right) ,$$

where y_j is the output of the jth neuron in a layer immediately below the one in which the ith neuron is located. The W_{ij} are weights of connections between layers, and the θ_i are thresholds determined by least-mean-squares minimization. The sigmoid function *sig* (called a transfer function) is defined by

$$\mathrm{sig}(x) = 1/2\ [1 + \tanh(x)]$$

The form of this function is chosen to mimic the response of a biological neuron to a stimulus. Let E be a cost function

$$E = \frac{1}{2} \sum_{p=1}^{M} \left[f(\mathbf{x_p}) - \Phi(\mathbf{x_p}) \right]^2 ,$$

where x_p is an input training vector, $f(x_p)$ is the training output for the input vector x_p and $\phi(x_p)$ is the network output for the training input x_p. The summation is over all training points. M is the number of times that any training point is shown to the net. For convenience, we have assumed a single output, although there can be multiple outputs. The learning algorithm is simply the numerical technique for the minimization of E. Common minimization methods, for instance, are gradient descent, conjugate gradient and Newton's method.[4] Fig. 2 illustrates a portion of this algorithm, showing several inputs, a single neuron in a hidden layer and a single output.

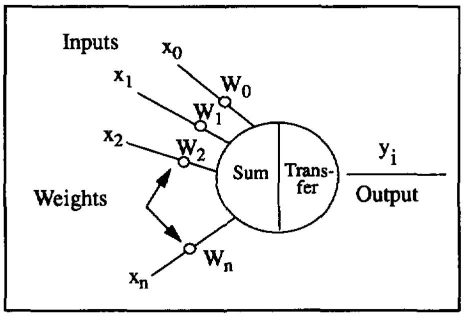

Fig. 2. A single neuron and its inputs and output.

During learning, information is propagated back through the network and used to update the weights. Because information is presented to the network to train it, it is often called *supervised* learning.

Back propagation networks have some problems. When used for classification, they tend to place an anomalous item into a category into which it best fits without recognizing its anomalous character. They also give no measure of goodness of fit when performing classification. Another paradigm, the Self-Organizing Map (SOM) is often used in conjunction with back propagation. The next section describes this algorithm and shows how it can be used to not only classify data but provide a measure of abnormality as well.

Self-Organizing Maps

Categorizing data is a fundamental and frequent activity in many applications. The SOM neural network is one methodology that addresses this area by creating a two-dimensional feature map of the input data. If two input vectors are close in some sense, they will be mapped into the same area of the feature map. This map, or Kohonen layer, was devised by Teuvo Kohonen.[5] A key difference between the SOM and many other networks is that the SOM learns without supervision, hence the term self-organizing.

The SOM typically has two layers: a self-organizing layer and an input layer that is fully connected to it. During training, a Euclidean distance is computed between the input vector and a weight vector associated with each neuron in the Kohonen layer. If the input vector has n values and is given by

$$\mathbf{X} = (x_1, x_2, \ldots, x_n),$$

then each Kohonen neuron will also have n weight values and can be written as

$$W = (w_1, w_2, \ldots, w_n).$$

The Euclidean distance D_i is computed for each of the m Kohonen neurons:

$$D_i = \|X - W_i\| = \sqrt{(X_1 - W_{i_1})^2 + (X_2 - W_{i_2})^2 + \ldots + (X_n - W_{i_n})^2}.$$

The neuron with the weight vector closest to the input vector (that is, having the smallest D_i) is the winner. Neighboring neurons then adjust their weights to be closer to this same input-data vector. This adjustment is the learning mechanism. Thus, input vectors are grouped into areas represented by areas of the Kohonen layer. This algorithm is illustrated in Fig. 3.

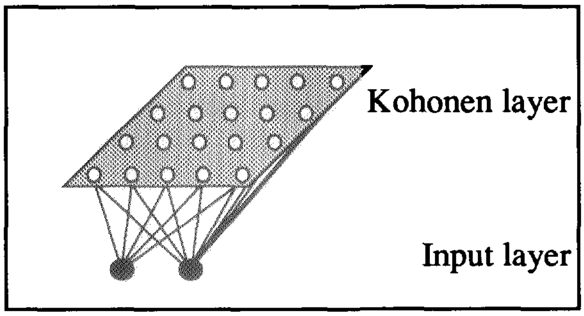

Fig. 3. Self-organizing map (shown with partial connections).

During the testing phase, the neuron whose weight vector is nearest to the input vector is called the winner and has an output of 1.0, while the other Kohonen neurons have an output of 0.0. An anomalous input vector will still have a winner, but the distances will be larger than those for non-anomalous inputs because presumably the anomaly is not close to anything. It is this feature that we exploit when detecting anomalies.

The SOM described above can be used as a preprocessor when combined with other categorization networks, such as the back propagation type mentioned earlier. Because of the features and advantages described above, the network can be trained to place (that is, process) the input vector into a particular category, as illustrated in Fig. 4. This classified-input result can then be used as input to another network for further manipulation.

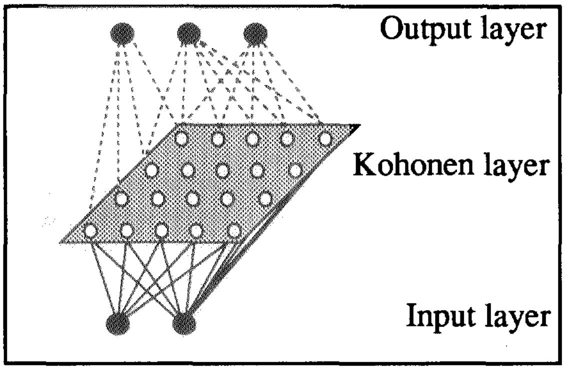

Fig. 4. Self-organizing map with categorization (shown with partial connections).

In the following section we describe the application of categorical SOM neural networks to three problems in safeguards and security.

Applications

An ideal anomaly detector for a complex system must be capable of detecting a wide variety of anomalies. It should address two problems: distinguishing normal events from abnormal events and classifying the abnormal events by type (for example, material flow in wrong direction, fuel rod burnup too low, cpu usage too high, file being executed by the wrong user). These requirements are difficult for a variety of reasons:

- Typical real-time activity may vary from day to day;
- There may be different types of activity on different parts of the system; and
- Data collected for analysis by an inspector are usually voluminous, making the modeling activity complex.

For simplicity, we focus on only the first of the two problems: detection. Other papers have addressed the diagnosis problem.[6,7] Our approach to detection assumes that system operation consists of two stochastic processes: normal and abnormal (or misuse).[8]

Computer Security

Our first example was first described in Ref. 9. Related applications are found in Refs. 10, 11 and 12. We present a summary of that work here and then show how the same technique can be applied to two other areas of interest to safeguards. This example is a simple distributed system- activity problem consisting of three users on three computers performing a small number of functions (printing, executing, and transferring files). The three users each have a unique pattern of simulated activity in the functions they perform, the computers they are using, and the files they access. Because of the simplicity of the data set, one can simulate both normal activity and anomalies of various types without a large resource requirement.

The anomaly detection problem here is to read a single audit record and determine which user generated it. If the predicted user is different from the user identification in the audit record, then this is flagged as an anomaly. Furthermore, if the prediction is not a "strong" one, that is, the classification was not made with high certainty, then this information is also flagged as possibly anomalous. The types of anomalies that were created in a test file to represent improper actions by users include sending a file to the "wrong" (meaning unusual or unauthorized) machine, executing a program on the wrong machine, printing or executing files that exceed size limits, and printing the wrong file.

A hybrid SOM/back propagation neural network processed this audit information and modeled each user's activity. The network was trained on a set of 120 simulated audit records containing the information for the distributed system described above. The input records indicated the type of operation, the machine identification, the program identification, and the size of the file. The output neuron gave a user identification. After training, the network was tested with another data set containing 135 records, 17 of which were anomalies. For each member of the test set, we plotted the Euclidean distance from the winning neuron's weight vector to the input vector as shown in Fig. 5. The anomalous events are indicated by greater distance from the x axis and marked by arrows. These graphs represent, for each user, a measure of abnormality of each audit record, with the larger values being more abnormal. The y axis gives distance (the abnormality measure), and the x axis gives the number of the audit record.

This example shows that one can model simulated information flow with a neural network and locate anomalous events by exploiting the calculations inherent in an SOM. To direct attention to the most abnormal events, one might consider establishing a threshold value and examining first those data points that are above that tolerance. Our next example is a very similar problem, but consists of flows of a completely different nature. We will examine the flow of material and the detection of anomalies in a chemical processing plant.

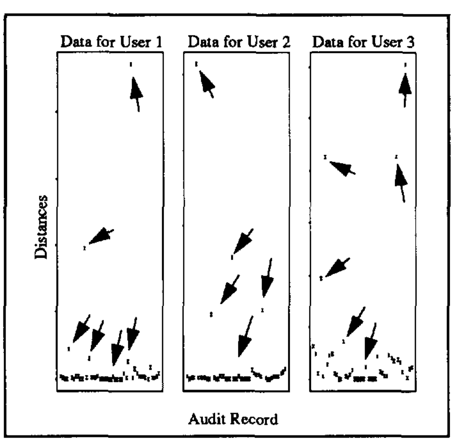

Fig. 5. Anomalies in computer security data.

Chemical Processing Plant

The problem of anomaly detection in materials control systems is analogous to the computer security problem. Techniques used to ascertain plant conditions must not only recognize normal facility operations but also be able to respond to non-normal (anomalous) conditions. Being able to make this division requires having a good understanding of the underlying processes. With this understanding we can build a model for anomaly detection that is based on the same hypothesis as that used in computer security audit analysis: exploitation of plant vulnerabilities involves non-normal operation. Neural networks and, in particular, SOM neural networks can be used to enhance the real-time materials control aspects of safeguards systems.

In this section, we expand on ideas found in Refs. 13 and 14. The problem described in this work is one of a chemical processing plant with three tanks and several valves or other binary devices. Material is transferred from one tank to another as valves are opened and closed. Material can be transferred in a small number of specific patterns and can leave the system in specific ways. Thus, material transfers follow very specific patterns of activity. Simulated data were used as a training set and were based on data from a chemical processing plant. The plant process monitoring system consists of a set of instruments and sensors installed to collect data and send them to a computer for processing and storage. Readings from the tanks represent volumes, and readings from the valves, pumps, and steam jets represent on/off or open/closed status.

In these papers, predictive back propagation neural networks are used to predict the volume of liquid in tanks found in a chemical processing plant and thereby predict the amounts of material lost. This technique works well with simulated data and is presently being applied to actual data. It is not difficult to restate this as a classification problem and there are multiple ways in which to do so. One such method, which we discuss in this section, is to build a network that uses as input the current valve states and categorizes the direction of material movement in each of the tanks: material increasing, material decreasing, or no change. Other possibilities, not discussed here, would be (1) to extend this to a combination categorization, as just described, plus prediction of amount of change in volume; (2) given tank volume changes, to categorize which binary devices should be open (or on); and (3) use an SOM network that is not combined with back propagation to cluster the tank transfers of material or cluster the tank transfers with the valve state changes. Any of these methods would be appropriate categorization statements of the problem to use to detect anomalies and provide useful information to an inspector.

For our prototype problem, we built an SOM/back propagation network as shown in Fig. 6. The input records indicated valve state (7 neurons, values 0 or 1), while the output neurons indicate the direction of material movement for each tank (3 neurons, values -1, 0, or 1). There are 2 hidden layers, a Kohonen layer having 20 neurons, and a back propagation having 14 neurons.

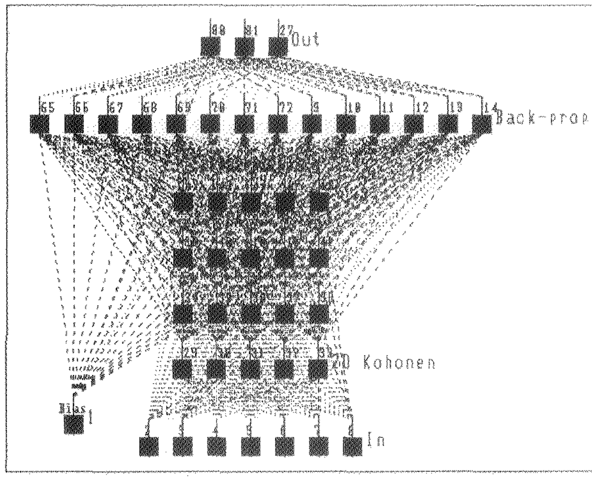

Fig. 6. SOM/back propagation neural network for a chemical plant.

The number of training records was 9600, representing 274 transfers of material from one tank to another. After training, the network was tested with another set containing 2200 samples, representing 24 transfers, three of which were anomalous. Using the same procedure as described in the computer security example, we plotted the Euclidean distance from the winning Kohonen neuron's weight vector to the input vector, as shown in Fig. 7, with the anomalous events indicated by greater distance from the x axis and marked by arrows. (The circled points are a single anomalous transaction.) These graphs indicate the abnormality of each record from the plant, with the larger values being more abnormal. The y axis gives distance (the abnormality measure), and the x axis gives the number of the plant-control-system record.

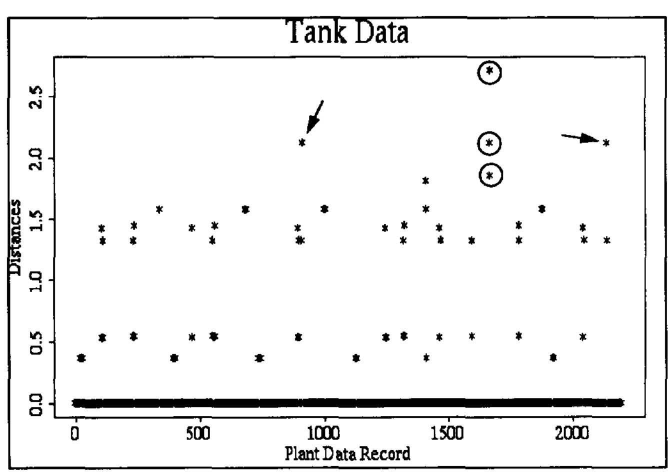

Fig. 7. Anomalies in chemical plant data.

The first and third anomalies, marked with arrows, were transactions in which material left a tank and did not appear anywhere else in the system. The second anomaly, a circled set of values, involved a valve being open when it should not have been. The normal transactions appear as data points at zero until material is transferred, and then they appear as vertical columns of dots. The network correctly classified all 2200 samples and provided abnormality information.

If this were a report generated from an actual plant, it would indicate that attention should be directed to records showing the largest distances first, as these are the most anomalous. Thus, this neural network gives us a tool to help the inspector decide where attention is most urgently needed or where plant operation deviates from plant design.

Nuclear Reactor

The third anomaly detection example involves data from the Canadian CANDU reactor.[15,16] We provide a brief description of that work and show how the Kohonen net technique can be applied to locate anomalies. The CANDU reactor can be accessed from both ends of the core for refueling; fresh fuel can be pushed in one side and spent fuel discharged on the other. This has the advantage that refueling can be performed without shutting down the reactor but has the disadvantages of requiring constant monitoring of the fueling process and causing heightened concern over the possible diversion of spent fuel. A sketch of a typical reactor face is shown in Fig. 8. Loading direction alternates, checkerboard fashion, on the face on the reactor.

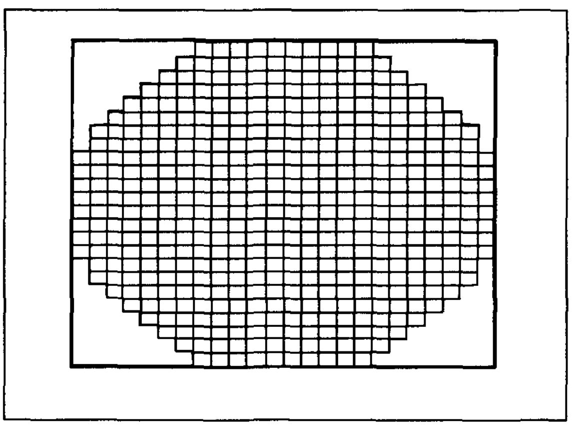

Fig. 8. Channel map for a typical face of a CANDU reactor.

Safeguarding this fuel involves monitoring each cylindrical uranium bundle as it is pushed through the reactor. Because the refueling is continuous, the safeguards inspector needs modern, high-performance tools to provide continuous monitoring and to assist with the review process. Core discharge monitors (CDMs) provide an effective method for gathering data for a safeguards system.[17] Each CDM uses radiation detectors to monitor activity in the reactor core and the fuel storage areas. Thus, they can detect when a refueling cycle is taking place. Fig. 9 shows the relationship of the detectors to the reactor core.

Ref. 15 addresses the problem of providing automated analysis to help safeguarding agencies assess the accuracy of facility declarations. The neural network paradigm was used to learn reactor geometry and refueling patterns. Specifically, this report describes procedures for predicting burnup and for predicting from which of eight areas on the reactor face a bundle was pushed. The eight regions are shown in Fig. 10.

Data for building a neural network that makes this prediction were collected over a period of one month, corresponding to about 170 fuel discharge events. Although the data came from a shuffling activity during reactor start-up trials rather than normal refueling, it was still possible to train a neural network to classify the data into regions. The 10 actual inputs to the network were 5 values from each of the two CDMs on one face of the reactor. The output was a number from 1 to 8, representing the area of the face of the reactor. The data set was divided into two parts, one for training and one for testing. The training set consisted of only 63 vectors and the test set only 89.

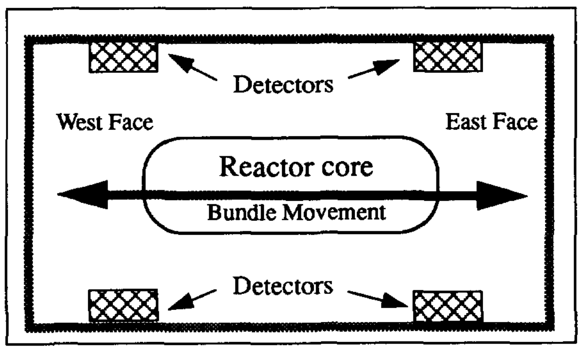

Fig. 9. Location of core discharge monitor detectors with respect to the reactor core.

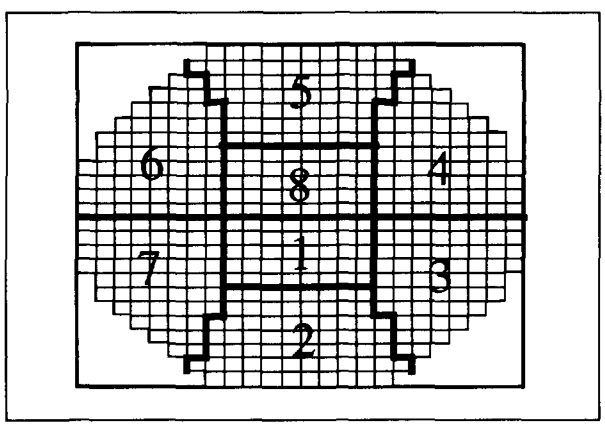

Fig. 10. Eight region map for CANDU reactor face.

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We applied the SOM/back propagation algorithm to this data set and used it to identify anomalies. We added one data point to the end of the data set that contains values that are out of range for typical pushes from that region of the reactor face. The results are shown in Fig. 11. In this figure the normal values are indicated by asterisks, while the anomalies are shown as triangles. The hand-introduced anomaly is on the far right and has a distance value of about 2.0. One can see that, as in Fig. 5 and Fig. 7, the anomalies generally have larger distance values than non-anomalous values and provide an effective means of interpreting data normality. Anomalies in this example indicate an inconsistency in the data, rather that diversion of material. One would expect that all pushes from a given sector on the face of the reactor would generate data that are similar. Due to the insufficiency of the data set and the shuffling activity that was taking place, the data were not as similar as one would expect. In spite of this, the network was able to correctly classify 85% of the data in the test set. With an adequate data set from a normal refueling cycle, the classification would have been more accurate, allowing true anomalies, such as the one added to the end of the data set, to be more distinct.

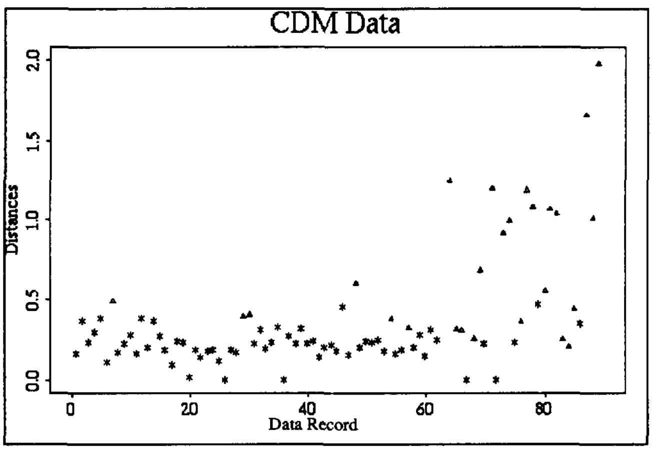

Fig. 11. Core discharge monitor data showing anomalies.

For this application, the neural network methodology was used, not just to look for anomalies that might indicate diversion of material, but also to provide information on normal or expected operations. It also can be used to predict burnup, check for consistency between channels, and compare the number of bundle pushes and power levels shown in the operator log with values that are predicted by the network based on core discharge monitor and other system data.

Conclusions

The examples described above illustrate the important role that neural network technology can play in safeguards and security. The examples should be considered prototypical anomaly detection networks and not finished products by any means. A final product, scaled up from a prototype, that has been properly designed, tested, and installed is quite likely to be much larger, more complicated, and more robust. For example, it is believed that real world problems such as speech recognition are very complex and may require networks with as many as 10^5 weights. A common scale-up problem in real applications is computing time; training time may be prohibitive. An approach that may help to alleviate this problem is to disperse the tasks of the network over several smaller networks. All three examples in this paper would be amenable to this type of design.

Building a neural network to perform a real world safeguards problem will be quite different from writing a piece of software in C or Fortran. The developer can focus on the structure of the network and the analysis of the data to be used for training without having to initially write code. With a good neural network development tool (and they are now readily available), the development becomes first an analytical task (studying the data and understanding it) and then a creative task (building the network). There are many parameters from which to choose to tailor the network to a particular application (for example, one may choose the transfer function, learning rule, or the learning rates), but one can frequently start with system defaults and modify them as needed. A reasonable way to begin is to first build a small prototype using simulated data, as we have done here, and then extend it to a more realistic size. At implementation time, we may want to consider a combination hardware and software approach, as neural network chips are becoming readily available.

The neural network approach described here provides an effective methodology for the detection of anomalies and data inconsistencies in safeguards and security data in situations where more direct data analysis may not be practicable. Because there are no known formulas for neural network configuration, some tuning is required to choose the optimal number of neurons in the hidden layers. Once this is established, an appropriate threshold must also be chosen for distinguishing the anomalies. A weakness in the neural network approach is that there are no specific rules available after training that can be used to trace the cause of an anomaly, although this has been addressed elsewhere.[6,7] This can sometimes be accomplished by other means such as using a network design that produces a particular output upon detection of an anomaly of a particular type. In general, traceability is difficult with neural networks. A further weakness is that the network might require retraining periodically to adapt to system changes or recalibration.

Another issue that one must face when using neural networks is obtaining an adequate set of training data. It is difficult to quantify the amount of training data required for good results. The quantity depends on the complexity of the records and the number of "features" embedded in the data. One should have sufficient data to ensure good coverage in the multidimensional space that is being modeled. It is not sufficient merely to have megabytes of numbers from a plant. A good understanding of the underlying processes that produced the data is also essential.

Neural networks are quite good at detecting normal and abnormal patterns of activity. An efficient final application might include several specialized networks, each trained to detect different types of anomalous events. These combined with an expert system for diagnosis and some statistical calculations for observing, say, daily or weekly volume activity would constitute an effective anomaly detection system. New, advanced systems such as these are needed to process the information gathered from monitors so that inspectors can focus on the most urgent problems.

There are challenging, real problems in the safeguards and security area that are appropriate for solution with the techniques described here. Although we have focused in this paper on anomaly detection, there are many others areas appropriate for neural network solutions. One might consider using a neural network for predicting when a process might become unstable, or how much material should be produced at a given step of a process.

Neural networks offer important new computational structures in their ability to learn and adapt and in their massively parallel nature. Considerable work is being done internationally both in the theoretical support of this field and in devising new applications, and hardware implementations are becoming available, making future implementations faster. Neural networks should be considered an addition to; and not a replacement of, our existing "toolbox" of mathematical and computer science techniques for building effective and efficient safeguards systems.

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