JNMM

JOURNAL OF
THE INSTITUTE OF
NUCLEAR MATERIALS MANAGEMENT

Volume XVII, Number 1 • October 1988

CONTENTS

Volume XVII, Number 1 • October 1988

PAPERS

EDITORIALS

INMM NEWS

DEPARTMENTS

On the Cover:
View of La Hague reprocessing plant from Erqueville Village, France. Photo courtesy COGEMA.

JNMM is published four times a year by the Institute of Nuclear Materials Management, Inc., a not-for-profit membership organization with the purpose of advancing and promoting efficient management and safeguards of nuclear materials.

SUBSCRIPTION RATES: Annual (U.S., Canada and Mexico) $100.00, annual (other countries) $135.00; (shipped via air mail printed matter); single copy regular issues (U.S. and other countries) $25.00; single copy of the proceedings of the annual meeting (U.S. and other countries) $65.00. Mail subscription requests to *JNMM*, 60 Revere Drive, Suite 500, Northbrook, Illinois 60062 U.S.A. Make checks payable to INMM.

ADVERTISING, distribution and delivery inquiries should be directed to *JNMM*, 60 Revere Drive, Suite 500, Northbrook, Illinois 60062 U.S.A. or contact Greg Schultz at (312) 480-9573, telex 910-221-5870, telecopy (312) 480-9282. Allow eight weeks for a change of address to be implemented.

ISSN 0893-6188

SOCIETY OF NATIONAL ASSOCIATION PUBLICATIONS

INMM
INSTITUTE OF NUCLEAR MATERIALS MANAGEMENT

Time Advances All But the Odds

The first annual meeting of the INMM that I attended was held in the Stardust Hotel in Las Vegas in 1969. It is interesting to look back and to compare that meeting with the recent meeting, also in Las Vegas, in June. Electronic developments have made the slot machines more colorful and more difficult to understand, but the player's odds have not improved.

The annual meetings have increased in size. In 1969 there were three days of single sessions compared to three days with many parallel sessions in 1988. Attendance has increased by about a factor of five, and now includes a large number of members from Europe and Asia, an important advance.

Since readers of the Journal will have the June proceedings by now, and many attended the meeting, the following is a brief summary of the proceedings of 1969 for comparison. There were five exhibits then, one of which was the mobile non-destructive assay laboratory which Los Alamos had just prepared to visit nuclear facilities in the U.S. Official speakers included an Atomic Energy Commission member, James Ramey, and the heads of the two AEC safeguards offices, Delmar Crowson and Russ Wischow.

Allan Labowitz of the AEC Division of International Affairs discussed the nuclear non-proliferation treaty, which was soon to be adopted, and predicted that containment of proliferation would require significant nuclear arms control agreements among the five nuclear weapon states. John Jennikens and J.C. McManus, of Canada, presented a paper on IAEA inspection policies which is as relevant today as it was then.

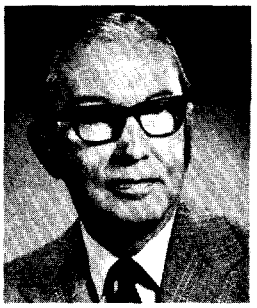
Materials accounting was generally assumed to be synonymous with domestic and international safeguards, although there was one paper on seals. No one was worrying about nuclear waste disposal in 1969, although more attention was being paid to measuring waste discards. The most disturbing papers were on transportation. Highly valuable shipments had gone astray and the U.S. government agencies were attempting to develop credible requirements for safeguards and safety.

The number of nuclear facilities and the amounts of material have increased greatly since 1969, as many of the speakers predicted. The IAEA and national safeguards programs have also evolved and improved, as was then hopefully predicted, and a start has finally been made on containing "vertical" proliferation.

Since 1969 the Institute has expanded to encompass all of the elements of domestic and international safeguards, waste management, and transportation. It has also become a truly international organization. It has two very active chapters overseas, one in Vienna and one in Japan. Each of these has an annual meeting at which papers are presented which should be of interest to many other members.

The Ninth Annual Meeting of the Japan Chapter was held on June 2, 1988 in Tokyo. There were four invited papers and 12 contributed papers on a wide variety of safeguards subjects of great interest. J.H. Jennekins, Deputy Director General of the IAEA, was the first speaker. There were papers on transportation, radioactive waste management, safeguards techniques for gas centrifuge and laser isotope enrichment plants, hull monitors, C/S for spent fuel storage, and near-real-time accounting. The proceedings were published in an attractive volume, topped with the INMM logo. The Japan chapter has set a high example for the rest of us.

Dr. William A. Higinbotham
Brookhaven National Laboratory
Upton, New York



Where Will Safeguards Be Tomorrow?

Fellow members and friends of the INMM, this year our Institute will sponsor its 30th Annual Meeting. During the preceding years, the Institute has been instrumental in the development of safeguards technology. The term "safeguards" was first used on November 15, 1945 in a joint statement by President Truman of the United States, Prime Minister Attlee of Great Britain and Prime Minister King of Canada calling on all nations to join them in eliminating nuclear weapons and offering to share the benefits of nuclear energy, subject to appropriate "safeguards." In those early years I am sure that no one envisioned the safeguards systems that are in place today. The question is "Where or what will 'safeguards' be tomorrow?" You and I as members of the INMM have an opportunity to play an important role in answering that question.

The goals of the INMM as stated in Article II of the INMM constitutions are to advance nuclear materials management, to promote research in the field of nuclear materials management, to establish standards consistent with professional norms, to improve qualifications of those engaged in nuclear materials management, and to increase the dissemination of information through meetings, professional contacts and publications. These goals can only be realized if *you* will become involved. The INMM is a volunteer organization and exists only in and through its members. If you wait to

see what the Institute is, or what it can do for you, it may not be the organization that you wanted it to be. If for some reason you cannot now become involved in a committee, standards writing group, or professional meeting, please evaluate what the INMM means to you and drop me a line at EG&G Mound Applied Technologies, P.O. Box 3000, Miamisburg, Ohio 45343. I look forward to hearing from you.

John F. Lemming
EG&G Mound Applied Technologies
Miamisburg, Ohio

The Second US/FRG Workshop on Near-Real-Time Accounting for Reprocessing Plants

The second technical workshop on near-real-time accounting in an industrial scale reprocessing plant was held in Los Alamos December 7-9, 1987. Papers from the Workshop are featured in this issue of the *Journal.* The workshop was organized within the context of the US DOE-FRG/BMFT agreement in the field of international safeguards. The workshop was initiated by the Los Alamos National Laboratory and the DWK, which has responsibility for construction and operation of a planned industrial scale reprocessing plant in the FRG. The workshop objective was to review the state-of-the-art in near-real-time accounting and develop a common understanding among experts from the participating countries to identify problems requiring additional work.

The topic of near-real-time accounting (NRTA) for large scale reprocessing plants has been under discussion within the international safeguards community for at least ten years. Within the last few years the studies have evolved from theoretical designs to actual testing of the concept under plant operating conditions. The first workshop held in Hannover in May 1986 resulted in descriptions of plant experience gained in the FRG at Karlsruhe, in the UK at Dounreay, and in Japan at Tokai. All of these experiments demonstrated the general applicability of NRTA and also identified areas requiring further technical development. The results indicated that implementation of NRTA would be highly facility specific.

The second workshop was held to review new work in NRTA that has been performed since the first workshop. Over 50 experts from 5 different countries and 2 safeguards inspectorates were in attendance (See list at end of this article). The workshop participants included plant designers, instrument designers, systems engineers, statisticians, and representatives from both IAEA and

Table I: Topics Covered at Workshop on NRTA for Reprocessing

Experiments

T. Jones, UK: Experimental Work at Dounreay; *M. Delange:* Experience at COGEMA on Comulative Flux; *T. Nakai:* Collection of Field Test Data of NRTA at TRP; *J. Lausch:* Recent Development of Internal Nuclear Material Control at WAK; *J. Lovett:* Process Monitoring; *F. Walford:* Some Personal Thoughts on NRTMA; *M. Ehinger:* Process Monitoring Data and NRTA Verification; Process Monitoring Experiments at ORNL

Calibration of Equipment

M. Aparo: Volume Calibration; *I. Lausch:* Calibration Exercises at the Accountancy Tank of WAK; *T. Nakai:* Calibration of the Input Accountancy Tank; *A. Hakkila:* Comments on the Matrix Effect on Calibration of X-Ray Densitometers

Process Simulation

M. Canty, Hein: Simulation of Triple Tank Systems in the Wackersdorf Reprocessing Plant; *E. Leitner, R. Weh, M. Canty:* Evaluation of Book Inventory Data of WAK and Comparison with Simulated Data of the Wackersdorf Reprocessing Plant; *M. Aparo:* A Feasibility Study on NRTA Implementation to EUREX Pilot Reprocessing Plant: Process Flow Sheet and Measuring System Simulation; *A. Hakkila:* Contribution of Contactor Inventory to NRTA Measurement Uncertainties; *J. Barnes:* Column Inventory; *A. Beyerlein:* Column Inventory

Data Treatment, Statistics, and Other Topics

J. Lausch, R. Beedgen: Statistical Analysis of WAK Accountancy Data; *B. Jones:* Statistical Tests of Near-Real-Time Materials Accounting Data; *H. Nishimuri:* Statistical Analysis of NRTA Field Test Data; *R. Avenhaus, E. Leitner, R. Weh:* Measurement Error Components in the Analytical Determination of Pu Concentration; *H. Kawamoto:* The JNFS Reprocessing Plant; K. Ikawa: NRTA Analysis System at PNC

Verification

U. Wenzel: Considerations on On-Site Verification of Safeguarded Material by Destructive Assay; *R. Haas:* Monitoring In-Field Data Euratom Developments in the Field of Unattended and Authenticated Data Logging; *T. Jones:* Verification of NRTA Data; *R. Foulkes:* Verification of NRTMA Data at THORP; *J. Lovett:* Use of Process Data to Reach Safeguards Conclusions; *R. Avenhaus, E. Leitner:* Verification of Accountancy Data in a Triple Tank *System; F. Franssen:* RBI and Process Monitoring; On-Site Verification Using RBI

Euratom with expertise in both systems studies and inspections.

The workshop was organized to cover five topics (Table I.). The first session reviewed the status of experiments demonstrating NRTA and process monitoring; the second session discussed work in calibration of equipment required for NRTA; the third session reviewed work on inspector verification of operator's data. The results of each of the sessions are briefly reviewed.

In the session on recent experiments, Maurice Delange of COGEMA described significant new work on the cumulative flux technique. This technique is based on Running-Book Inventory and differs markedly from NRTA approaches being developed in the FRG, the UK, and Japan. The work in the UK at Dounreay as described by Terry Jones, in Tokai as described by T. Nakai, and at WAK as Described by J. Lausch did not produce the quantum leap in new information that occurred at the Hannover meeting. However, these new approaches to decreasing the biases observed in earlier experiments should prove valuable to other workers.

A series of papers on process monitoring more clearly defined the role of process monitoring in both domestic and international safeguards. It was apparent that process monitoring will play an important role in both process operations and domestic safeguards in some States, but its role, if any, in international safeguards probably will be limited to those functions that can be used in a surveillance mode.

The session on calibration of equipment showed that excellent work is being done on volume calibration including development of weigh tanks and improvements in calibration techniques. However, more work needs to be done in calibration of other measurement devices.

The session on process simulation pointed out that computer simulation will be important in understanding how a reprocessing facility operates as well as in designing processes and safeguards systems. Los Alamos data on the contribution of column inventory to overall measurement uncertainties provided evidence that the verification problem for solvent extraction contractors may not be a serious concern.

The discussions on data treatment indicated that statisticians have developed numerous statistical procedures for analysis of NRTA data. Frank Walford of UKAEA suggested that it may be time to stop developing new statistical procedures and instead identify the one or few statistical procedures that will be of the most value for NRTA analysis and verification.

The session on verification demonstrated that considerable work has been done in this area since the Hannover meeting 1-1/2 years ago. Franssen of the Agency presented his thoughts on on-site verification versus verification away from the facility and concluded that some mix of on-site verification using installed instruments and shipment of some samples to Seibersdorf would be an optimal verification approach. The overall impression from these discussions was that the area of verification needs a better definition of what needs to be verified and a simplification of proposed verification procedures. This should be a major area of work for the coming years.

Comments from the participants indicated that the workshop was of great benefit to all and that a follow-up workshop should be held in 1-1/2 years.

E. A. Hakkila and R. G. Gutmacher; Safeguards Systems; Los Alamos National Laboratory; Los Alamos, New Mexico U.S.A.

R. Weh; Deutsche Gesellschaft; fuer Wiederaufarbeitung von Kernbrennstoffen mbH Hannover, Federal Republic of Germany

List of Attendees

Aparo, Massimo, ENEA, Italy

Augustson, Ronald, Los Alamos National Laboratory, USA

Baker, Michael P., Los Alamos National Laboratory, USA

Barnes, James W., Los Alamos National Laboratory, USA

Beedgen, Rainer Dr., Kernforschungszentrum Karlsruhe, FRG

Beyerlein, Adolph, Clemson University, USA

Canty, Morton J., Kernforschungsanlage Julich, FRG

Dean, Guy, CEA, France

Delange, Maurice, Cogema Groupe CEA, France

Dionisi, Mario, ENEA, Italy

Eccleston, George; Los Alamos National Laboratory, USA

Ehinger, Michael, Oak Ridge National Laboratory, USA

Emrich, Frank Dr., Nukem GmbH, FRG

Foulkes, Robert W., BNFL, United Kingdom

Franssen, Fredy, IAEA, Austria

Gutmacher, Ralph G., Los Alamos National Laboratory, USA

Haas, Rudolf, EURATOM; Luxembourg,

Hakkila, E. Arnold; Los Alamos National Laboratory, USA

Hammon, Wolfgang Dr., Nukem GmbH, FRG

Hirons, Thomas J., Los Alamos National Laboratory, USA

Ikawa, Koji, JAERI, Japan

Jackson, James, Los Alamos National Laboratory, USA

Jones, Barry J., BNFL, United Kingdom

Jones, Terry J., UKAEA-Dounreay, United Kingdom

Kawamoto, Hayao, JNFS, Japan

Kawata, Tomio, Oak Ridge National Laboratory, USA

Keepin, G. Robert, Los Alamos National Laboratory, USA

Lausch, Joachim, Wiederaufarbeitungsanlage Karlsruhe, FRG

Leitner, Erwin, DWK, FRG

Lovett, James, IAEA, Austria

Physical Protection

Markin, Jack T., Los Alamos National Laboratory, USA

McRae, Larry, Westinghouse Hanford, USA

Menlove, Howard, Los Alamos National Laboratory, USA

Nackaerts, Herman, EURATOM, Luxembourg

Nakai, Toshiro, PNC, Japan

Nishimura, Hideo, NMCC, Japan

Petit, Andre, Cogema, Groupe CEA, France

Picard, Richard R., Los Alamos National Laboratory, USA

Pillay, K.K.S., Los Alamos National Laboratory, USA

Rachev, Anton, IAEA, Austria

Sellinchegg, Dieter, IAEA, Austria

Smith, C. N., Nuclear Regulatory Commission, USA

Smith, Darryl B., Los Alamos National Laboratory, USA

Stewart, William E., E. I. DuPont & Nemours, USA

Strittmatter, Richard B., Los Alamos National Laboratory, USA

Tape, James W., Los Alamos National Laboratory, USA

Uchikaoshi, Seiji, NMCC, Japan

Van Der Stricht, Etienne, EURATOM, Luxembourg

Walford, Frank J., UKAEA, Harwell, United Kingdom

Weh, Rudolf, DWK, FRG

Wenzel, Ulrich, IAEA, Austria

Whetten, John, Los Alamos National Laboratory, USA

Williams, Thomas L., DOE/Savaannah River Plant, USA

Wirfs, Larry, Nuclear Regulatory Commission, USA

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

- Workshop, "Intergrated Safeguards,", at the Marriott Hotel, Albuquerque, N.M., October 17-20, 1988.
- Workshop, "The Use of Computers in Security," at the Garden Plaza Hotel, Oak Ridge, Tenn., April 3-5, 1989.
- Workshop, "Detecting Outsiders and Insiders by Integrating the Elements of Delay, Intrusion Detection, and Entry Control into Physical Security Systems," tentatively scheduled for the fall of 1989 in the mid-East Coast area.
- Workshop, "Package Search Techniques," is currently being considered, but has not been tentatively scheduled. Such a workshop would concentrate on better and more effective methods of searching packages which enter restricted areas. If you have an interest in such a workshop please contact Donald Kasum, Nuclear Regulatory Commission (301) 492-3379.

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

General

The Technical Working Group on Physical Protection had a very well attended and successful series of technical presentations at the 29th Annual INMM Meeting which was held in Las Vegas, Nevada June 26-29, 1988. A Working Group Steering Committee Meeting was held at the close of one of the sessions. The items discussed were:

1. Next year's annual meeting. Attendees were encouraged to start planning to present papers. Suggestions for session topics, speakers, and moderators are welcome.
2. Whether the Working Group was serving the needs of its members.
3. The INMM *Journal* and the need for more papers from the Technical Working Group Members.
4. Future Workshops.

Integrated Safeguards

This workshop will be held at the Marriott Hotel in Albuquerque, N.M., October 17-20, 1988. This workshop will focus on administrative, technical and operational problems relating to interaction of safeguard systems. The program will provide participants with the opportunity to present, discuss and exchange information on the problems associated with this topic. The workshop is jointly sponsored by the INMM Materials Control and Accountability and Physical Protection Working Groups. The co-Chairmen are Jack Markin, Los Alamos National Laboratory (505) 667-7777 and Ivan Waddoups, Sandia National Laboratories, (505) 844-1649. Registration ($275 for non-members and $225. for INMM members) will be accepted at the workshop.

The Use of Computers in Security

The second workshop on the Use of Computers in Security is scheduled to be held April 3-5, 1989 at the Garden Plaza Hotel in Oak Ridge, Tenn. G.W. Morrison, (615) 574-2797, Martin Marietta Energy Systems, Y-12 Plant, Oak Ridge, Tenn. is the Workshop Chairman. Separate from this Workshop, but of interest to some of the attendees; a classified, non-INMM sponsored, physical security discussion is scheduled to be held at the Y-12 Plant April 6-7, 1989.

continued on page 42

Reflections on the 1988 INMM Annual Meeting and Thoughts for the 30th Annual Meeting in 1989

For the last four years, each Annual Meeting technical program has exceeded the previous year in the number of presentations. The 1988 Annual Meeting was no exception, again, with a record-breaking 204 papers and 28 sessions! The Final Program weighed in at a record-breaking 80 pages, featuring 195 abstracts. The Proceedings, now being distributed, also breaks existing records at 1,008 pages. Here is a summary of the technical program status for the last five years:

Year:	'88	'87	'86	'85	'84	'83	'82
Papers:	204	172	132	129	96	61	55

In addition to our usual powerful array of presentations in "traditional" technical program activities, the Technical Program Committee has continued to innovate with new ideas and "sparklers." We have also taken some risks. One such risk is to reduce the Plenary Session to one prominent speaker rather than the traditional four or five. This allows us to focus in on one event to start off our "show" and also allows us extra time Monday morning for needed additional technical sessions. If you attended the Las Vegas meeting you could not help but be overwhelmed by Dixy Lee Ray's superb talk. Several people told me that it was the best keynote talk the Institute has had in the last 15 years! That may be somewhat of an exaggeration, for we have had some great ones, but Dixy really did make our day this time. The risk paid off well. Incidentally, the text of Dixy's talk will be included in the January 1989 issue of the *Journal*, along with the Annual Safeguards Roundtable Interview, in which Dixy made some interesting and provocative comments.

Some highlights of this year's program were the sessions on the National Academy of Sciences review of DOE's MC&A activities, the DOE safeguards and security orders and guides, safeguards technology for nuclear processing, and factors in effective human performance.

We have continued to encourage participation from a broad spectrum of the community. This has resulted not only in a large number of papers but in variety as well as in quality. This year we had a session on technology transfer with input from non-safeguards areas to stimulate thought and broaden perspective. I understand that there is and will be a continuing significant increase in technology transfer emphasis and activity especially in the DOE Defense Program sector. Again, INMM has taken a leadership role in promoting and providing a forum to become informed, to share the experiences of others, and to discuss issues in a professional atmosphere. We also had a session on quality assurance in research and development. This topic is getting increased attention as better understanding of QA's real meaning and potential rewards in "non-traditional" areas is achieved. Look for other technical and professional organizations to follow the Institute's lead.

Looking forward to the 1989 Annual Meeting, we plan to continue with innovative topics to stimulate the INMM family, and to maintain our visibility and prominence as a useful resource in the community. We plan to address such subjects as arms control and treaty verification, and the application of the Non-proliferation Treaty as a model for international inspectorate for chemical weapons! An extensive series of sessions is planned for the radioactive waste management topic stemming from some very positive renewed interest and support by DOE's Civilian Radioactive Waste Management Office. Again, efforts will be made to increase the participation from the "real world" parties — the utilities and the facilities operating personnel.

The Committee continues to attempt to attract the right kinds of quality papers for the Annual Meeting so as to make the INMM a focal point and a foundation for the discussion and presentation of controversial and innovative activities in a truly professional atmosphere as well as a means of transferring technology and information.

I am still looking for the Committee to prepare some guidelines for speakers to help improve or facilitate the presentations. One of the most common complaints we get from attendees is that they could not read the slides, the speaker ran over the alloted time (which prevented the listener from going next door to hear the speaker in the other session), and the speaker overwhelmed them with data and failed to make his/her point! We plan to address these issues for the 1989 meeting.

If the 1988 Annual Meeting technical program was a success it was due to all the participants whether they took an active or an indirect part in the year-long process. The administrative work done by the INMM Executive Office (OMSI) in coordinating the entire meeting activities from inception to completion was again outstanding. Further, I would like to thank the speakers (and authors) without whom there would be no program, the session chairmen who mastered the idiosyncrasies of the speakers, and all those who helped in their own way to make the Technical Program work. I would like to especially recognize the talanted Technical Program Committee, noted below, who just sparkled in their enthusiasm while devoting so much of their time and effort:
Committee: C. Pietri, Chairman, R. Al-Ayat, J. Arendt, K. Byers, J. Craig, W. Lamb, N. Roberts, C. Sonnier, J. Tape, L. Thomas, J. Williams, R. Cardwell, Chairman, Posters/Demonstrations

Awards

INMM Chairman Charles M. Vaughan presented awards at a banquet held on Tuesday, June 28 at the INMM 29th Annual Meeting. Five

INMM members were recognized for four decades of outstanding contributions of the safeguards and nuclear materials management field and to the Institute.

Receiving the status of Fellow of the Institute of Nuclear Materials Management were Kenneth E. Sanders and Harley L. Toy. Both are long standing INMM members.

Dr. Sanders, a Senior Member of the INMM, has been active in the nuclear safeguards profession since 1972 and currently works to strengthen International Atomic Energy Agency (IAEA) safeguards under the U.S. nonproliferation policy for the U.S. Arms Control and Disarmament Agency (ACDA). Dr. Sanders has served as a technical consultant for quality assurance to the IAEA for the last eight years and as an invited lecturer at Department of Energy (DOE) nonproliferation courses.

Dr. Sanders' nominators called him "one of the very few individuals in the U.S. government's non-proliferation community who combines the expertise in nuclear technology with a thorough knowledge of relevant domestic, foreign and national security policies."

Harley L. Toy has been with Battelle Columbus Laboratories (BCL) more than 35 years. He now serves as Manager of Nuclear Services, supervising maintenance of the BCL nuclear license and its regulatory compliance, nuclear support services and radiological safety. He also served as Nuclear Manager and Supervisor of the Technical Support Group for many years. He is the author of numerous manuals and papers on INMM and licensing administration.

Dr. Toy is a charter member of the INMM. From 1963-70 he served as INMM Secretary, an office through which all administrative activities were coordinated in those formative years of the organization. Dr. Toy served the Institute as Vice-Chairman in 1971-72 and Chairman in 1973-74.

William C. Myre was awarded the INMM Meritorious Service Award for 1988 in recognition of his contributions in physical security and in the management of DOE and Department of Defense (DOD) nuclear security programs at Sandia National Laboratories. He has completed 38 years with Sandia.

In 1977 Mr. Myre became the Director of the Nuclear Security Systems Directorate. Under his direction, the physical security program was the largest research and development program of its kind in the West. Mr. Myre has been a member of the INMM since 1977 and served on the Long Range Planning Committee. He has also served as an editorial advisor to the *Journal of Nuclear Materials Management*. The award cited his "support of the Institute, his staff and the nuclear industry in the promotion of technical exchange and technology transfer."

A Distinguished Service Award was presented to Dr. Haruo Natsume. Dr. Natsume is a member of the Japan Chapter of INMM. He served as a member-at-large of the chapter's executive committee from 1978-82.

Dr. Natsume received the award for his "early and significant nuclear research in Japan, and (for) his outstanding contribution to international safeguards technology through the development and application of destructive and nondestructive measurement techniques." In 1954 Dr. Natsume was responsible for separating and determining fission-product nuclides of the rare-earths in radioactive fallout of the Bikini Nuclear Explosion Test. His fellow chapter members said that his techniques and procedures have been the key technology in operating the Safeguards Analytical Laboratory of the Nuclear Materials Control Center in Japan (NMCC).

George W. Evans was the recipient of another Distinguished Service Award. He is Corporate Manager of Safeguards and Security with Martin Marietta Energy Systems, the current contractor for the Oak Ridge Y-12 Plant. Mr. Evans has been employed there for 44 years, holding various positions before being named to his current position in 1986. He currently supervises work at five plants.

"George is probably the longest experienced security manager in a U.S. nuclear facility," his nominators said. "His advice and opinions are sought after and respected by all of us in the business." They said that Mr. Evans' contributions to efficient and proper nuclear materials management began with his first job in chemical recovery and have continued throughout his career. The Distinguished Service Award recognizes his contributions to the nuclear weapons program, both in operations and management, as well as his contribution to nuclear safeguards and security.

Charles Pietri, Chairman
INMM Technical Program Committee
U.S. Department of Energy
Argonne, Illinois

Correction

Correction to the book review entitled "IAEA in Perspective Credibility vs. Perfection", a review of Lawrence Scheinman's *The International Atomic Energy Agency and World Nuclear Order.*

A sentence in the second paragraph of the first column of page 8 of the January 1988 issue of *JNMM* should read as follows: "With regard to the last point, the IAEA's safeguards function is of most relevance to the industrialized states, while technical assistance is of most relevance to underdeveloped states".

The underlined words were inadvertently omitted from the published version.

Leslie G. Fishbone
Brookhaven National Laboratory

Production and Verification of Materials Measurement Data For Near Real Time Materials Accountancy (NRTMA) In THORP

R.W. Foulkes
British Nuclear Fuels plc
Risley, Warrington
United Kingdom

ABSTRACT

The safeguards strategy developed for THORP and the corresponding design features have recently been described in a paper to the ANS 3rd International Conference[1]. Because of the large in-process plutonium inventory, BNFL decided to adopt NRTMA for its own purposes as a materials accountancy and control tool, with the expectation that it would serve to provide the safeguards inspectorates with short term assurance against diversion. The essential extra step in adapting NRTMA to safeguards is to provide the inspectorates with the means of verifying the accountancy data. Whilst the development of statistical techniques has produced a powerful method of analyzing and interpreting the data, the important question of verification has received less attention. This paper describes the techniques that will be available to safeguards inspectors in THORP. It is important to appreciate that the designer can do no more than provide the physical means of verification; the degree of assurance gained will depend on the design of inspection strategies, which is the business of the inspectorate.

2. THE ESSENTIALS OF A NRTMA SYSTEM

A practicable system in a commercial plant requires:

i) The inspectorates will make use of materials measurement data generated by the operator's instruments.

ii) The method of determining in-process inventory must be rapid and non-intrusive, and make acceptable demands on an inspector's time.

iii) The technology used to measure materials flow and inventory must be sufficiently transparent to allow verification, without compromising sensitive information.

iv) There must be an effective methodology for analyzing and interpreting the accountancy data, and for investigating anomalies.

In this paper it is assumed that (i) is accepted, since it would be completely impracticable to include an independent measurement capability for the inspectorates, with so many and varied measurements involved. The paper addresses items (ii) and (iii), and describes the practical aspects of throughput and inventory measurement, data handling, and verification. Statistical treatment of the data (iv) is the subject of a separate paper.

3. GENERAL DESCRIPTION OF THE MATERIALS MEASUREMENT SYSTEM

NRTMA will be applied only to plutonium; hence, in-process inventory will be measured in the highly active cycle (fission product removal and partition of Pu and U), the plutonium purification cycle, plutonium nitrate evaporation and product receiving tanks. Input measurement will be made at the input accountancy tanks located in the head end. The plant areas to be covered by NRTMA and the relationship with the remainder of the Chemical Separation Plant is shown schematically in Figure 1. Table 1

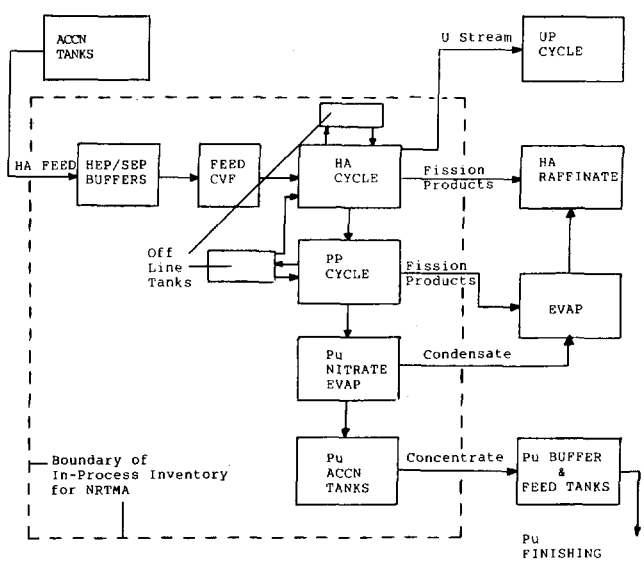


Figure 1. Schematic of Chemical Separation Plant Showing Boundary of In-Process Inventory.

Table 1
Distribution of Plutonium Inventory and Method of Measurement

Item(s)	Typical Inventory (kg)	% of total	How Measured
Main buffer tanks (3)	375	63.4	Accountancy tank sample analysis + buffer tank level
In-line tanks (6)	14.5	2.5	Tank level + model estimate of concentration
Columns (11)	9	1.5	Process model
Pipework and small items	8	1.3	Calculated volume + model estimate of concentration
Pu Evaporator System	35	5.9	Process model
Pu Concentrate Accountancy Tanks (2)	150	25.4	Weight + design product concentration
	591.5	100.0	

shows the typical inventories expected within each plant area, and summarizes the methods of establishing the inventory in each. In the following paragraphs the main plant area functions and the materials measurement techniques are briefly described.

3.1 Input Accountancy Tanks

The input accountancy tanks (2 off) will be vertical cylinders with dished ends, having a volume of 23m^3 and a tare weight of about 54t. Each tank will be suspended on four tie bars, which will pass through the biological shield and be attached to a weighing system above the cell and outside the highly active area. In addition to the weighing facility, each tank will be equipped with a conventional volume measurement capability, based on dip tubes, and will have liquor homogenization and sampling facilities.

3.2 HEP/SEP Buffer Tanks

These comprise three vertical cylindrical, 75m^3, tanks which provide the decoupling between the Head End Plant (predominantly batch processes) and the Chemical Separation Plant (continuous processes). These tanks normally hold the major proportion (circa 60%) of the total plutonium inventory. The tanks operate in sequence, each tank being filled by three accountancy tank batches, 'bonded' for conditioning and sampling, and then transferred forward to the Chemical Separation Plant as required. The inventory of plutonium in these tanks will be determined from the volume of liquor held, and the concentration of plutonium in the liquor. The concentration will be established for a full tank by using the batch feed data from the accountancy tanks.

3.3 HA Feed CVF

Liquor from one of the HEP/SEP buffer tanks is pumped up to a Constant Volume Feeder (CVF). This operates at an approximately constant level with a continuous overflow back to the same buffer tank. Liquor from the CVF is then carefully metered into the HA cycle. Since the CVF operates around a constant level, then for a given plutonium concentration its inventory remains constant. Plutonium concentration changes would normally only occur when changes (e.g. fuel type or history) to the plant feed are made. The daily flow of liquor through the CVF is much greater than the CVF capacity; hence the concentration of plutonium in the CVF is the same as that being fed to it from the HEP/SEP buffer. The inventory in the CVF will be obtained from the feed concentration together with the constant level reading in the CVF.

3.4 Highly Active (HA) Cycle

The feed from the HA Feed CVF passes to two pulsed columns where the majority of the fission products are separated from the uranium and plutonium. The fission products are sent to the HA Raffinate Tanks. A proportional sampler is provided on the line to the HA Raffinate Tanks so that the amount of plutonium leaving in this stream can be checked. The uranium and plutonium are then separated in two further-pulsed columns. The plutonium bearing aqueous stream is washed with organic in another pulsed column before being fed to the valency adjustment step prior to the Product Purification Cycle. Instrumentation is provided to detect and prevent the slippage of significant quantities of plutonium to the uranium stream. The HA cycle contains a number of ∞ 1m^3 tanks which act as on-line buffers to give some decoupling between the various columns.

The pulse column mechanical design and the complex interactions between mass transfer, chemical reaction, and hydrodynamic effects occurring within the columns are such as to preclude the assessment of column inventory by direct measurement. Process models have been developed for the columns which enable performance to be predicted and inventories to be calculated. The accuracy of these models for inventory purposes need not be great; the HA cycle is expected to contain only 2.3% of the total plutonium inventory of which only 0.8% is normally in the columns with the remainder in the on-line buffers and interconnecting pipework.

The models will be used to generate a database from which inventories of the columns and connecting vessels and pipework can be derived. The HEP/SEP buffer analysis will enable the feed concentration to be obtained and this, together with the feedrate derived from the HA CVF, should enable the appropriate inventories to be calculated. The models will give the in-column inventory directly while the pipework and in line vessel inventories will be derived from predicted stream compositions and known liquor volumes.

3.5 Plutonium Purification (PP) Cycle

The aqueous product stream from the HA cycle is fed through the valency conditioning step to a small on-line buffer. As required, the liquor is passed into two pulsed columns which remove the final traces of fission products and uranium. An additional pulsed column is used to re-

move organic traces before the liquor is fed to the evaporator feed tanks.

This section of the plant is estimated as holding circa 2.6% of the total plutonium inventory. The proposed in-plant inventory derivation is the same as the HA cycle, viz pulsed column inventories from process modelling with subsequent downstream tanks/pipework estimated from the calculated output composition plus level measurement in the tanks. Since all tanks with significant inventories can be sampled, the validity of the model predictions can be cross checked.

The raffinate stream leaving the PPL column is monitored by on-line instrumentation as it flows into a raffinate pumping tank from which it is transferred to the Salt Free Evaporator.

3.6 Plutonium Nitrate Evaporator System

The evaporator is used to concentrate the purified plutonium nitrate solution to 300g Pu/l prior to accountancy measurement and storage. This section of the plant consists of an evaporator feed vessel, the evaporator callandria and recirculation leg. The evaporator operates continuously, but the discharge of the concentrate to the accountancy tanks is a batch transfer controlled from a gamma absorptiometer.

The evaporator system design and operation are complex, and it is not possible to measure the inventory directly. However, the total evaporator system has been the subject of a detailed process model, which has been used to study the process control and performance aspects of the evaporator. The model has also been used to study the plutonium inventory of the evaporator system throughout its normal operating cycle. It is proposed that the results of the model are used to establish the in-process inventory for this section of plant.

Results from the process model show that the total plutonium inventory of the evaporator system varies within a very small range throughout its operating cycle. It is very insensitive to flowsheet concentration, and should vary by no more than ± 5% over the whole range of throughput and concentration. It is proposed that mean predicted figure will be used as the in-process inventory estimate. The figure is a function of the set point of the gamma monitor, and model results will be provided for a range of set points.

3.7 Plutonium Concentrate Accountancy Tanks

Plutonium nitrate concentrate from the evaporator is transferred in a series of circa 1-2 litre batches to one of two 500l accountancy tanks. Approximately 167 l are transferred each day (Reference Fuel Flowsheet). The tanks will be harp-shaped tabular, suspended by two hanger rods carrying the tank weight back to a weighing system outside the active cell. As with the input tanks, there will be a back-up volume measurement capability and homogenization and sampling facilities.

When the material balance is taken it is likely that one accountancy tank will be filling while the other is in the homogenization, sample and transfer phase. The inventory of the filling tank will have to be inferred either from weight and density measurement (to give composition) or by assuming the evaporator outlet concentration and the tank level. For the tank in the accountancy phase, sample results will be available.

For the process models referred to in the preceding paragraphs to be valid, the plant must be in a steady operating state close to the state assumed in the modelling. A number of reference state models will be produced to cover the expected range of operating conditions. Results of modelling show that the plant will take a maximum of 24 hours to re-establish steady state operation following a step change in feed conditions, and this is the time that would have to be allowed, following such a change, before taking an in-process inventory.

Measurement instrument read-outs will be scanned at regular intervals by the computer data handling system. Inventory taking should therefore be a relatively simple and rapid process, with all the necessary conversions of raw data and reference to process models being carried out within the main plant information computer.

4. VERIFICATION

Verification, to be fully effective, must start during construction, and continue through to commissioning. In the following paragraphs verification is considered as being carried out in three phases, viz. pre-commissioning, during commissioning, and routinely during plant operation.

4.1 Pre-commissioning

The purpose of verification prior to commissioning is to verify that the material flow routes are exactly as declared and key measurement points cannot be by-passed, instrument sensors are correctly located to measure what they should measure, and that there are no built-in diversion routes. Some design features, particularly those in the highly active areas, can be verified only before active commissioning. After that stage they become inaccessible, to the operator as well as the inspectorate, either because of permanent physical barriers or very high background radiation.

In the case of THORP the following aspects of plant design have been identified, where verification could be profitably applied.

i) Accountancy tanks and associated pipework, including wall boxes.
ii) Instrumentation and associated cabling and pipework, with the possibility of applying seals to some items (see 4.3).
iii) The sample withdrawal and transport system.
iv) Data handling systems software, at the quality assurance stage (see 4.3).

The key to success and economy of effort lies in timely recognition of what needs to be verified and in sensible programming. The work should be planned such that the operator cannot make clandestine changes after verification, and as far as possible should be planned to coincide with the operator's own pre-commissioning checks, to ensure that no important point of detail is overlooked.

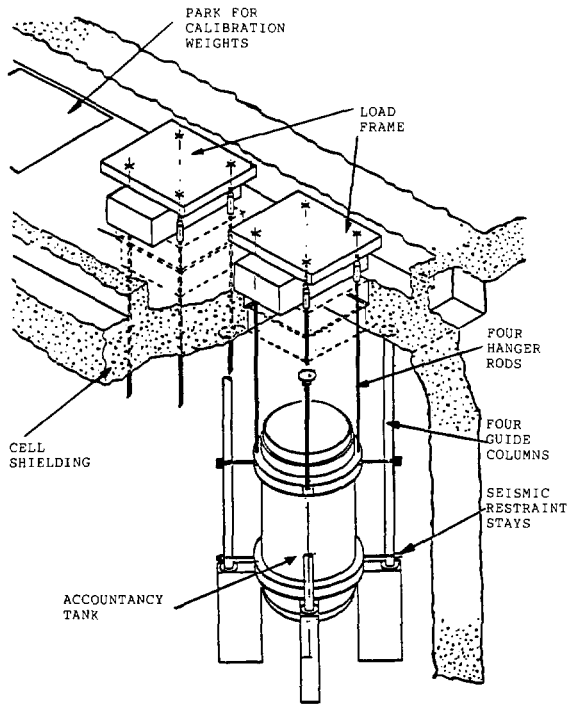


Figure 2. Input Accountancy Tank General Arrangement.

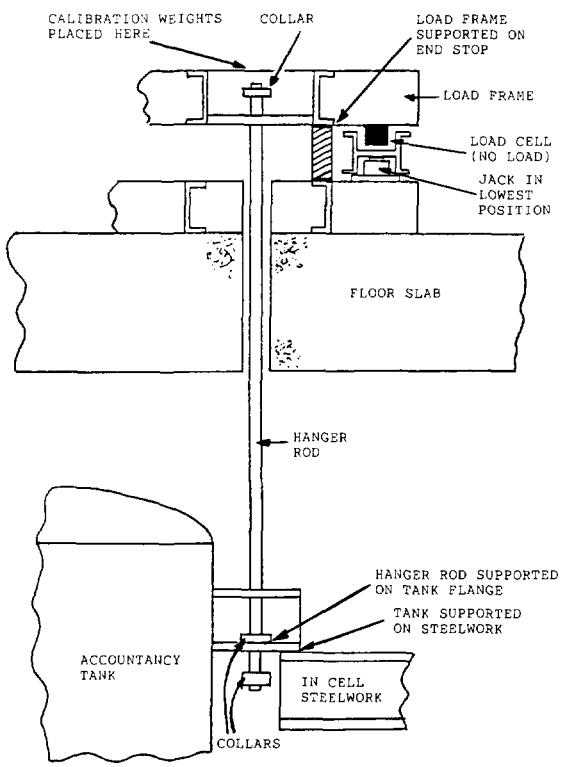


Figure 3. Accountancy Tank Weighing System, Position 1. Tank and Load Frame supported clear of load cell.

4.2 Commissioning and Calibration

From a safeguards point of view, the most important activity during commissioning is the initial calibration of the accountancy measurement instrumentation and validation of the process models to be used in establishing in-process inventory. It is important for the inspectorates to be involved in any calibration activity, but in some cases the initial calibration provides a once-only opportunity to verify the zero inventory condition.

- (i) Accountancy Tank Weighing Systems

The weighing equipment fitted to the input and output accountancy tanks has been designed so that the variable components are located outside the active cell, and will be accessible for verification at any time.

The general arrangement of the input tank weighing system is shown in Figure 2. The outcell part of the weighing system comprises a load frame which, when weighing is not in progress, rests on an end stop. Beneath the load frame is a lifting frame supported by four jacks. Sandwiched between the lifting frame and the load frame are four load cells. The load frame is connected to the tank by hangers which pass through the cell roof. By selecting positions of the jacks, the system can be put into various positions which allow:

i. Load cell calibration at zero load and with test weights.

ii. Determination of the tare weights of the load frame, the hanger rods, and the tank.

iii. Measurement of the net weight of the liquor in the tank.

Figures 3 and 4 show the system with jacks in the lowest and highest positions. Full range calibration of the system is achieved by placing standard weights on the load frame. The parts of the system beneath the load frame will be enclosed in a metal box, for protection against damage or dust. This cover will be removed for initial settling of clearances which can be verified, and will be closed and sealed. Verification of the no load case and tare weights can be readily verified, and calibration can be verified using incremental standard weights belonging to the inspectorates. The tare weight of the empty tank, however, can be verified only during this initial calibration; thereafter it will always contain a small heel of liquor. This is largely irrelevant for throughput measurement since batches of liquor transferred to the chemical process will be determined by weight difference.

The product output accountancy tanks employ a different weighing system which measures the correcting force necessary to maintain the tank in a reference null displacement position. Although the actual weighing mechanism is different, the basic approach of locating the critical components outside the cell is maintained. The system is designed so that the tare weight of the tank and the hanger system are counterbalanced during initial setting

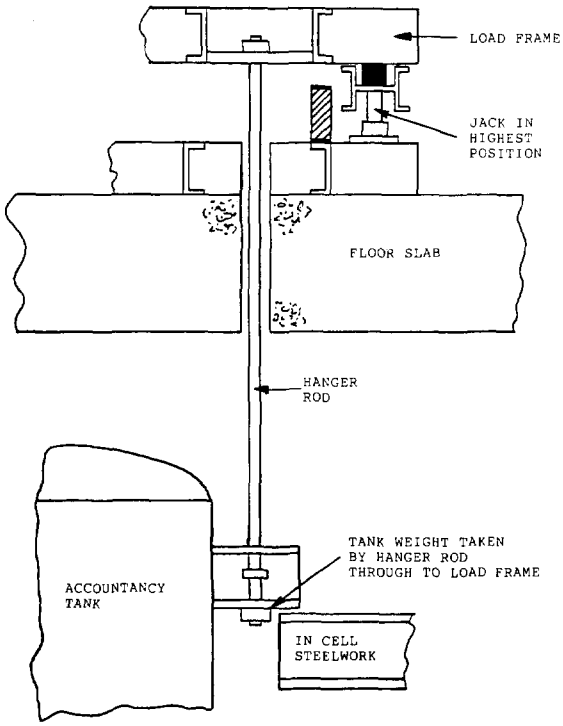


Figure 4. Accountancy Tank Weighing System, Position 4. Load Frame, Hanger Rods, and Tank Weights on Load Cell.

up, and the system therefore detects only the liquor weight. After the initial setting, the system is calibrated by placing standard weights on a loading platform. As with the input tanks, there will always be a small heel, and it will not be possible to return to the empty tank condition, after the initial calibration. After initial calibration the out cell weighing mechanism will be enclosed in a tamper proof cover.

- (ii) Volume Measurement Systems

  Volume measurement will be based on the use of dip tubes to measure the level of liquor in a tank. The system produces a pressure signal which is converted into an electrical signal by means of a transducer. The gas pipework connected to the dip tubes is designed to allow the injection of test pressures to check the response of the electrical side. Hence calibration and verification of that part of the system should be relatively easy. Calibration of the complete system, to include the relationship between liquor depth and volume will be achieved by the addition of accurately known incremental volumes of inactive liquor and observing the response of the instruments. This can be adequately verified by allowing an inspector to observe the procedure. Calibration by this method will be a lengthy procedure which can be very infrequently undertaken. However, changes in calibration associated with tank geometry should be very small, and could not, in any case, be systematically applied by an operator, in order to falsify the measurement.

- (iii) Process Models

  There are two possible approaches to verifying the process models. One approach is to allow scrutiny of the models by the inspectorates. Alternatively it should be possible to validate the models from data gathered from the operating plant. The operator will need to do this, in any case, for his own operational purposes.

  The pulsed column model has been validated externally at a UK university. It is commercially sensitive, revealing detailed information about column design and operating parameters. However, the best approach, which will be employed by the operator, will be to check the response of the columns under a number of plant conditions. In general, if the model correctly predicts column behaviour, the material inventory should be correct, and a simplified, less sensitive physical inventory model could then be used for safeguards purposes. In any case, the columns are expected to account for only $1\frac{1}{2}\%$ of the total inventory, and the maximum variation in hold-up in the columns should amount only to a few hundred grammes.

  The evaporator hold-up, circa 6% of the total inventory, is more significant, but is expected to vary by no more than $\pm$ 5% (relative) over the normal operating range. The evaporator model is also commercially sensitive, but it is expected that a simplified version can be produced to enable the inspectorates to carry out simple calculations which can be compared with plant behaviour. A first order check on hold-up may be possible when the evaporator is started, initially or following an extended shut down, by determining the quantity of plutonium transferred to the evaporator system to reach the control take-off concentration of 300 g/l.

4.3 Routine Operation

The THORP process control system will be a hierarchical system, with the plant information computer (PIC) at the highest level, providing management with collated data from different areas of the plant, and small programmable controllers at the lowest level. The heart of the system is a distributed control system for the chemical processes, integrated on a multi-highway network. The system is illustrated schematically in Figure 5. The PIC will not perform any control functions; it will be purely an information gathering computer, and will be the key machine for all reports and long term data storage. The PIC will store immediate and short term historical data for plant operation, and longer term data for accountancy and site license purposes. There will be a facility for downloading longer term data onto tape.

It is expected that the plant information computer will be the normal source of data for the inspectorates, either on tape, or more probably via a direct link giving read-only access to the computer. It is recognized that the inspecto-

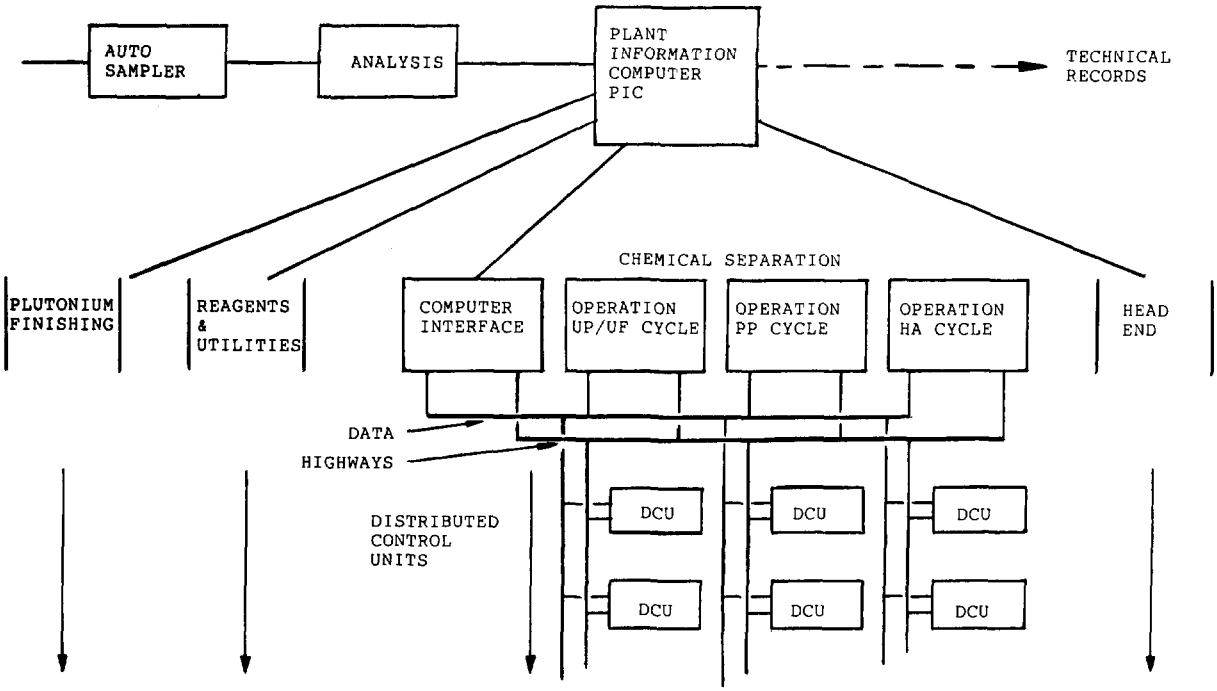


Figure 5. Process Control System Schematic, showing detail for the Chemical Separation Section

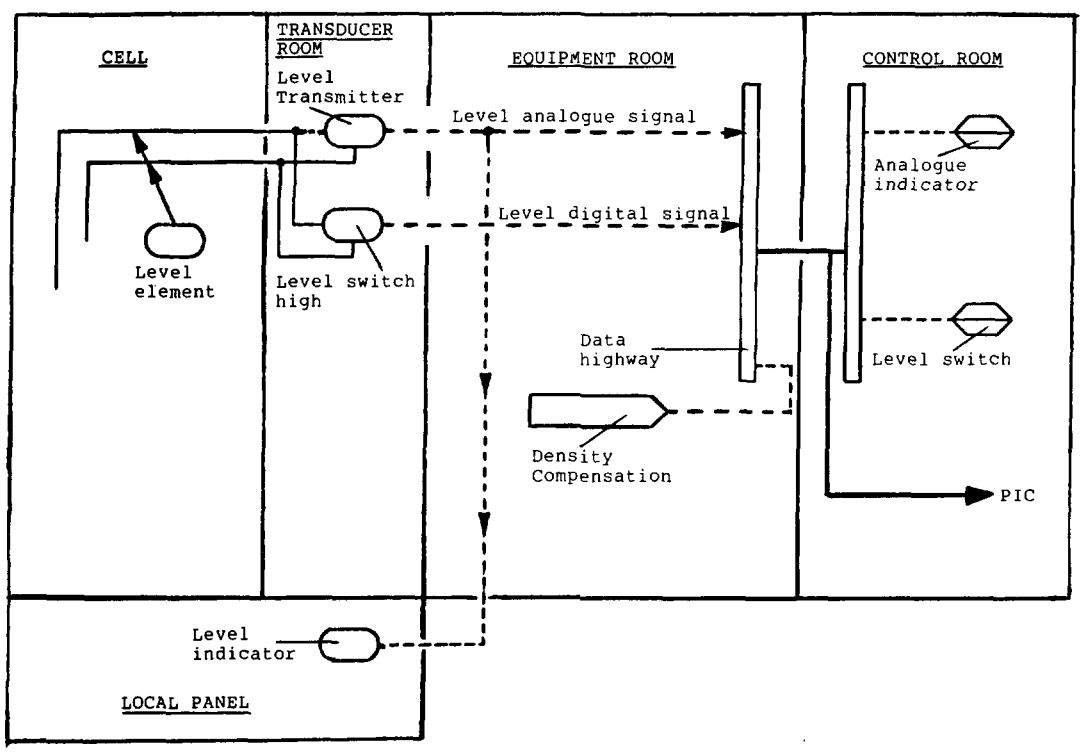


Figure 6. HEP/SEP Buffer Level Instrument Loop (Simplified) Showing Local Indicator

rates will be concerned at the possibilities for corrupting data within the computerized data handling system. THORP will employ "off the shelf" software for the plant controlling functions and THORP specific software for data processing. It will be recalled (para 4.1) that the data processing software will be offered for initial validation during the pre-commissioning period. Thereafter, occasional re-validation will be possible by comparison with a reference copy which will be held at the Sellafield site.

The data gathering and verification facilities available from the electronic data processing (edp) system should give the inspectorates high confidence in the integrity of the operator's data. Further assurance will be gained from direct hard-wired read-outs, independent of the e.d.p. system, at all the key throughput and inventory measurement points. Figure 6 is a schematic showing the essentials of the instrument loop for liquor level measurement in the large buffer vessels between the head end and separation plant (HEP/SEP). Gas pressure signals from the dip tubes are fed to transducers where the gas pressure is converted to an electric signal. All the transducers will be located in a separate room where they can be sealed against tampering, either individually or by sealing the room. Immediately after the transducer room there will be a hard-wired tapping to an instrument situated in a local panel. These instruments will be accessible at all times for random checking, and if necessary a data logging facility could be included.

With reference to sample analyses, the only fully reliable method of verification that is universally acceptable is independent analysis by the inspectorates, although it is known that a number of alternative techniques (e.g. 'blind' analysis) are being examined. In THORP it is assumed that the inspectorates will be supplied with samples for on-site analysis using NDA techniques such as K-edge densitometry or for export to their own laboratories.

5. SUMMARY

The design policy has been to provide the inspectorates with a diversity of verification opportunities. It is the Company view that a well designed inspection strategy which makes optimum use of these facilities will provide safeguards assurance compatible with inspection goals.

Superficially, the range of verification activities proposed in this paper may appear to be intrusive, but should not be. The pre-commissioning and commissioning activities will be important confidence building steps in the verification process. If carried out thoroughly, they should make it possible for the inspectorates to use accountancy data direct from the operator's data base, needing only occasional recourse to direct verification at the local instruments.

Robert Foulkes received a BSc in mathematics and physics from the University of London in 1953. His early work was with ICI Ltd, Birmingham UK, on research in support of the enrichment project at Capenhurst. He joined UKAEA (and subsequently BNFL) at Capenhurst in 1961 where he was engaged in diffusion and centrifuge enrichment plant management. He transferred to BNFL's headquarters at Risley in 1977, where he has been responsible for developing safeguards systems for new plants. He has been involved in a number of international safeguards activities, and is currently developing safeguards systems for the Thermal Oxide Reprocessing Plant (THORP), under construction at Sellafield.

Near Real Time Materials Accountancy at BNFL: Past, Present and Future

Barry J. Jones
British Nuclear Fuels plc
Risley, Warrington
United Kingdom

ABSTRACT

In recent papers[1,2] it has been shown that Near Real Time Materials Accountancy (NRTMA) is vastly superior to conventional accountancy in the following respects:

- *more timely detection of abrupt losses;*
- *much higher probability of detection of abrupt losses or gross accountancy errors;*
- *much greater control of protracted losses, biases and systematic measurement errors.*

It seems an appropriate time to reflect on how these conclusions were reached and what implications they may have for the future of NRTMA.

This paper is not statistical in the technical sense; it considers the direct practical applications of this work in the operation of any specified plant.

THE PAST

How it all Began

A literature search, covering the past decade, shows many papers on NRTMA. A variety of plant models and test procedures have been examined. Because sufficient details of the plant models have not always been given, and because results have been largely based on extensive Monte Carlo simulation, it has been difficult to make direct comparisons. Against the background that there did not seem to be a clear consensus about the best test procedure, BNFL, stimulated by a paper[3] given by Pike and Woods at the IAEA Symposium on Nuclear Safeguards Technology (1982), chose to first examine the properties of Page's test applied to the SITMUF sequence[4]. As work has continued, confidence in this choice has increased.

Calculate instead of Simulate

One early difficulty was that evaluations using Monte Carlo simulation methods carried with them a high computing overhead. Furthermore, sampling error sometimes led to unclear conclusions. This was especially a problem when investigating low-likelihood events such as false alarms. For example[5], an attempt was made to estimate, by simulation, the false alarm rate for the (H, K) pair (2,1.1), for a campaign of 21 balance periods. The simulation was repeated ten times with 10,000 runs in each. The number of false alarms in these runs were 454, 501, 454, 457, 487, 480, 511, 493, 512 and 495. Here the range for False Alarm Probability (FAP) goes from 4.5% to 5.1%. It appears that the FAP is somewhere near 5%, perhaps a little less.

In fact it was fortunate that the range was this narrow. The expected experimental error, based on a 95% confidence interval, in an estimate of a probability close to 5% is

$$\pm 1.96 \times \sqrt{(95 \times 5)/10000}\% = \pm 0.43\%$$

Of course, this error would be correspondingly larger if a smaller number of simulation runs were used. For example, if the estimate is based on only 1,000 runs, the expected error would be ±1.35%.

BNFL's first innovation was the replacement of Monte Carlo methods by direct calculation[5]. This allowed FAPs to be calculated quickly and accurately for chosen values of the Page's test parameters, H and K, and for any campaign length. For the case above, the calculated value of the FAP was 4.98%. Conversely, if the campaign length and FAP are specified, then a family of (H,K) pairs can be derived. Examples of (H,K) pairs for FAP of 5% and a campaign of 40 balance periods are given in Table 1.

Table 1
(H,K) Pairs for 5% False Alarms
in a 40 Balance Period Campaign

H	K
0.0	3.01580
1.0	2.03090
2.0	1.25080
3.0	0.83963
4.0	0.60949
5.0	0.46061
6.0	0.35582
7.0	0.27704
8.0	0.21440
9.0	0.16212
10.0	0.11674
11.0	0.07609
12.0	0.03876

Calculation of Response to Materials Loss

The method originally developed to calculate the parameters H and K for a given FAP, when no loss is occurring, was then extended to allow investigation of the response of Page's test to any pattern of abrupt and/or protracted loss[6].

However, because the behaviour in response to loss is plant specific, a basic shorthand was adopted to characterize plants. It is likely that plant behaviour may be masked by the random variability of the data, of which the most important source is measurement uncertainty. For each balance period, the following terms were defined:

I the standard deviation of the inventory measurement error (kg);
T the standard deviation of the throughput measurement error (kg.)

If H and K are chosen to give a specified FAP for a certain campaign length (in terms of number of balance periods), then the response of the test procedure depends fundamentally on the values of I and T. Since I and T depend on the physical properties of the plant and its measurement system, the method allows the effect of the plant design on the performance of the NRTMA system to be calculated. At the conceptual stage of plant design, I and T can be estimated using an elementary model in order to compare basic design options. As the design advances, so the modelling of the data capture and processing system can be made more sophisticated and more subtle design options evaluated. This simple approach was used to evaluate a number of THORP design options using, as a yardstick, the ability of the NRTMA system to detect abrupt loss.

The Dilemma of a Single Test

Work until now had concentrated on the detection of abrupt loss. It had been found that if a high probability of detection was sought in the period of the loss then an (H,K) pair should be selected from the appropriate contour such that H was small. When the study was widened to examine the detection of protracted loss it was found that a large H was the best choice[7]. Herein lies a dilemma; it might seem that there is no best choice of the parameters H and K to give a versatile test to detect both abrupt and protracted losses. In principle this dilemma could be overcome by running two separate tests, with suitably chosen (H,K) pairs so that the overall FAP achieved the nominal value. It has been found, by experiment, that two such tests do not perform independently and that the components cannot be chosen in the straightforward way appropriate for independent tests.

The Joint Test

For any specified loss scenario, there will be a particular (H,K) pair which gives the best chance of detecting the loss. In practice it will not be known what loss scenario to expect and therefore it will be impossible to choose an (H,K) pair which is "best" in this sense.
Moreover, a test which performs well against abrupt loss does badly against slow protracted loss and vice versa. This difficulty could be resoled by finding a test procedure sufficiently versatile to protect simultaneously against a wide range of loss scenarios.

BNFL's second innovation was the conception of the joint test[7]. A computer program was developed to allow detection probability to be calculated for the application of two tests, in turn, at each period. This program allows the FAP to be controlled to any specified level for any two component joint test. In addition the performance of the joint test can be calculated for any loss scenario.

THE PRESENT

An Act of Faith

Up until now the study of NRTMA in BNFL had been pursued with an element of faith, and a belief in its potential benefits. Some authors[8] held the view that NRTMA did give improved timeliness of detection but that this timeliness could be gained only at the expense of a reduction in the power to ultimately detect a loss of a given size.

Comparison of NRTMA with Conventional Accountancy

This seemed an appropriate time to make a theoretical comparison of sensitivity and timeliness of the two accountancy systems[1]. The investigations were carried out using data from a model with characteristics similar to those which British Nuclear Fuels expects of its new Thermal Oxide Reprocessing Plant (THORP).
To quote from the conclusions of the paper[1]:

> ". . . a joint Page's test is sufficient and necessary for the detection of both abrupt and protracted losses. Furthermore, it is clear that NRTMA is superior to conventional accountancy for both of these types of loss.
>
> For an abrupt loss, the join test has a higher probability of detection by the end of the campaign and, if the loss occurs early in the campaign, the joint test will detect it much earlier.
>
> If the loss is protracted, the overall power of NRTMA is virtually identical to that of conventional accountancy. However, the joint test will respond more quickly and give an early opportunity to an operator to investigate the cause of the alarm and to take appropriate action."

Probability of Ultimate Detection

The paper[1] includes a veiled apology for the fact that; using NRTMA, the probability of ultimate detection of a protracted loss is marginally less than it would have been using conventional accountancy.

Perhaps there is a penalty for using NRTMA after all!

Expected Loss

A very recent paper[2] which reports a study of the effect of balance frequency on the sensitivity and timeliness of NRTMA points out that:

> ". . . for the practical purpose of materials control, the probability of ultimate detection of protracted loss has no relevance; what matters is that loss of material should be minimized."

If an apology is needed, then it should be for not making this fundamental observation sooner. It was shown that, even with a modest number of balance periods, a dramatic reduction in the average loss occurs by using NRTMA. These developments make it possible to further exploit the potential of NRTMA for controlling materials loss.

Some Points of Clarification

In the introduction, a conscious decision was made to identify the concept of a gross accountancy error with an abrupt loss and a systematic measurement error with a protracted loss. This is an important idea and is a realistic approach since such errors of accounting or failures in the measurement system will show up in the test procedure just as if they are losses. (An error may equally well show up as an apparent gain of material.)

To run a statistical accountancy and control system, it is necessary to incorporate knowledge of the precision of the plant measurement system into the test procedure. The question which remains is how knowledge of so-called systematic errors should be incorporated, if at all. (Certainly it should be recognised that gross accounting errors can never be so incorporated.) There are two fundamentally different approaches — modelling or detecting.

The approach, favoured by BNFL, is to say that a test procedure should aim to *detect* any anomaly in a sequential data stream. The statistical techniques proposed in this paper are able to detect the occurrence of accounting errors and systematic measurement errors as well as genuine losses of material. There is a risk that modelling of systematic errors will introduce extra uncertainty into the test procedure, thus reducing its sensitivity.

THE FUTURE

To date, work has been aimed towards developing the best possible testing procedure for detecting anomalies in materials accountancy data. When a test procedure is used as part of a materials control system, it will be the "effect" which will be observed when the test signals an alarm and the operator will want to know the possible "causes". Therefore, before test procedures can be used for practical purposes of materials control, further development is necessary.

Suppose a joint test is designed for a particular plant. When materials accountancy data is processed and subjected to the NRTMA test procedure, there will come a time when an anomaly will be signalled. There is no easy way of attributing this "effect" to a specific "cause". The anomaly could have resulted from a variety of loss scenarios or it could be just a false alarm. The problem which remains to be addressed is that of resolution of such anomalies.

REFERENCES

1. Barry J. Jones, "Comparison of Near Real Time Materials Accountancy Using SITMUF and Page's Test with Conventional Accountancy", Proceedings of the Ninth Annual ESARDA Symposium on Safeguards and Nuclear Material Management, 255, (1987)
2. Barry J. Jones, "Near Real Time Materials Accountancy Using SITMUF and a Joint Page's Test: Dependence of Response on Balance Frequency", Proceedings of the Third American Nuclear Society Conference on Facility Operations — Safeguards Interface, ---, (1987)
3. D.J. Pike & A.J. Woods, "Statistical Methods in Nuclear Material Accountancy", Proceedings of the IAEA International Symposium on Nuclear Safeguards Technology (Vol 2), 359, (1982)
4. A.J. Woods & D.J. Pike, "Statistical Methods in Nuclear Material Accountancy", Proceedings of the Fifth Annual ESARDA Symposium on Safeguards and Nuclear Material Management, 369, (1983)
5. Barry J. Jones, "Near Real Time Materials Accountancy; Calculation of the Parameters Used on Page's Test", ESARDA Bulletin, 7, 19, (1984)
6. Barry J. Jones, "Calculation of Diversion Detection Using the SITMUF Sequence and Page's Test: Application to Evaluation of Facility Designs", Proceedings of the Seventh Annual ESARDA Symposium on Safeguards and Nuclear Material Management, 365, (1985)
7. Barry J. Jones, "Calculation of Diversion Detection Using the SITMUF Sequence and Page's Test: Response to Abrupt and Protracted Diversion", Proceedings of the IAEA International Symposium on Nuclear Material Safeguards (Vol 1), 402, (1986)
8. E. Leitner, R. Weh, R. Avenhaus & M. Canty, "What is the Price of Timeliness", Proceedings of the Ninth Annual ESARDA Symposium on Safeguards and Nuclear Material Management, 235, (1987)

Barry Jones received his BA in Chemistry from Oxford University in 1969 and, after further research there, his BSc in 1970. He joined the Production Division of the UKAEA at its Capenhurst Works in 1970, shortly before it became part of British Nuclear Fuels Limited. He developed plant items for both the diffusion and centrifuge enrichment plants. In 1974 he became manager responsible for providing an operational service to owners of centrifuge and component test-rigs. In 1978 he moved to Risley to work on safeguarding the Company's many new plants, in particular the Thermal Oxide Reprocessing Plant (THORP) now under construction. Since 1984 his major commitment has been the development of NRTMA for use as a materials control aid by plant operators and as a safeguards tool.

A Feasibility Study on NRTA Implementation to EUREX Pilot Reprocessing Plant: Process Flow Sheet and Measuring System Simulation

M. Aparo, M. Dionisi, P. Zeppa
MEPIS Division, ENEA Fuel Cycle Department, C.R.E. Casaccia
F.V. Frazzoli, R. Remetti, C. Portale
University of Rome "La Sapienza", Dep. Energetica
Italy

ABSTRACT

A NRTMA system is to be applied at the EUREX pilot reprocessing plant when it reprocesses spent fuel from the TRINO LWR. In order to estimate the performance of this accounting system, a computer simulation of the processes was developed. The simulation system, relevant plant design data, and the anticipated NRTMA results are predicted.

1. INTRODUCTION

Nuclear Material Accountability, supported by Containment and Surveillance measures, is a fundamental means for an effective International Safeguard implementation in nuclear plants.

Accountability is based on verification that the difference between a material quantity entering a given material balance area and the quantity leaving that area in a given period of time corresponds to the amount of material actually present at the moment of the inspection, taking into consideration the beginning inventory amount.

The acronym MUF (Material Unaccounted For) is, at present, a technical term generally used to define the result of the above material balance and its value, in ideal conditions, should be equal to zero. Ideal values are never found in practice; the causes non-zero values can be identified in the following:

1. Increasingly unmeasurable material losses (deposition, precipitation, variable holdups)
2. Physical inventory and material flow measurement errors
3. Measurement recording and reporting errors
4. Unauthorized material diversion.

The aim of accountability is to find out if, among the MUF components, an actual diversion is present.

The closing of a material balance and the MUF determination requires, in the present practice, the shut-down of plant operation for a Physical Inventory Taking (PIT) once or twice a year.

In the recent years International Safeguards responding to the needs of timeliness in detecting diversion and concealing activities, devoted R&D efforts on a new Dynamic Accountability procedure (NRTMA) with particular concern with reprocessing plants [1, 2, 3].

A rational application of the NRTMA technique is considered to be a powerful tool for the inspectors to detect a diversion and a practical and economical advantage for the Operators.

ENEA, knowing that the new approach calls for field experiments, has performed a feasibility study of a NRTMA system to be applied to the EUREX pilot reprocessing plant and a computer program, based on simulated plant generated data, has been developed.

The research activities are carried out in the frame of the Italian Support Programme to IAEA Task D.01 (Development and Demonstration of NRTA in Nuclear Material control).

The program includes:

- Nuclear Material flows simulation through the main plant process units;
- Physical Inventory simulation according to the process model generated material flows;
- material Balance evaluation.

This paper provides a survey of aspects of the plant, the measuring system, and the mathematical modelling.

2. EUREX PILOT REPROCESSING PLANT OVERVIEW

The EUREX plant is a multipurpose pilot plant, located in the northern part of Italy, for reprocessing of MTR and LWR fuel elements.

It became operational in October 1970, and up to now 506 MTR and 72 CANDU fuel elements have been processed, using both tertiary amine (TCA) and TBP as extractants.

Basically the process consists of two extraction and strip cycles carried out in mixer settler batteries.

In the near future TRINO LWR fuels will be processed and a coprocessing flow-sheet will be adopted using TBP or alternatively Amides as extractants.

The use of the coprocessing flow-sheet, which is the object of the NRTMA analysis reported in the present work, is connected with expected operational and Safeguards ad-

vantages: the product obtained constituted by a solution of Pu and U in a given ratio is ready for conversion to MOX and is of reduced strategic importance.

3. COMPUTER SIMULATION PROGRAM

In order to verify the performance of a NRTMA system to be applied at the EUREX plant a simulation program has been developed.

The program flow-chart is shown in Fig. 1.

An initial interactive procedure allows the user to specify the material balance frequency, the number of material balances to be considered and the presence of a possible diversion (for the time being the diversion can be simulated only in the output accountancy tank).

The program provides plots of the inventory, as a function of time, in each component of the plant and graphs of the MUF and CUMUF behaviours.

4. DYNAMIC MODEL OF THE PROCESS SECTION OF THE EUREX PILOT REPROCESSING PLANT

A simulation of the EUREX Pilot Reprocessing Plant operating with a modified Purex flowsheet has been developed in order to provide data to be processed by the measurement simulation section of our computer code.

The simulated data should accurately represent the dynamic behaviour of in-process holdup and of Pu flowing through the process, under normal operating conditions.

Fig. 2 shows a block diagram of the simulated EUREX process section.

EUREX operates in a batch type process. After the chemical adjustment, the 1AF stream from the feed adjustment tank enters the feed tank. The 1AF feed stream is a solution of plutonium nitrate (2.5 g/l) and approximately 100 times as much uranyl nitrate, in 2M HNO_3. After the feed tank is filled, the content is pumped to the first cycle mixer settlers extraction unit where an early fission products codecontamination is carried out.

The aqueous and the organic waste streams (1AW, 1CW) are transferred to the respective collecting tanks and the first cycle product stream (1CP) is sent, after chemical adjustment performed in F-405 tank, to the butter tank F-406.

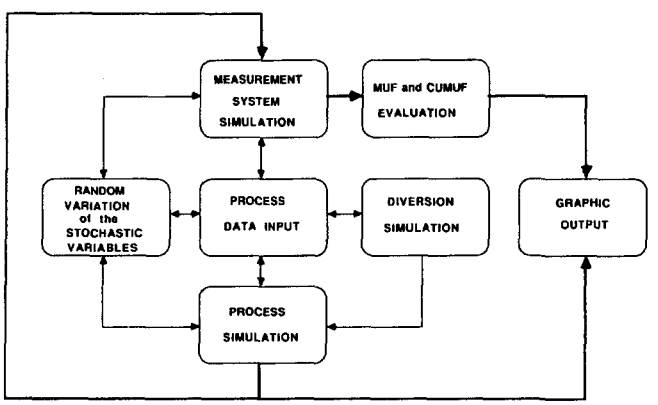


Figure 1. Program Flow-Chart

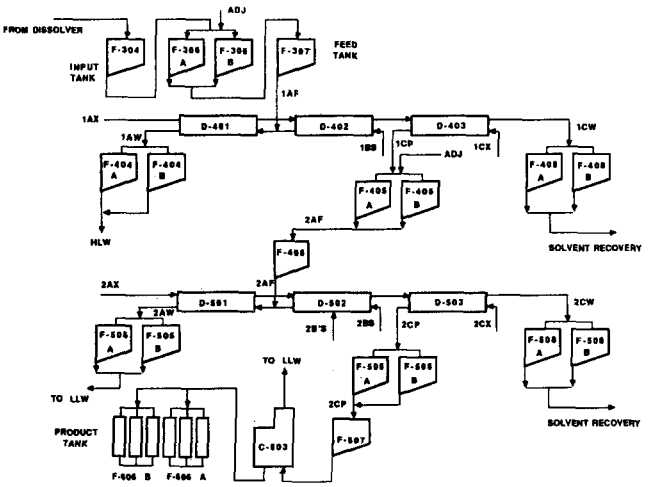


Figure 2. Block Diagram of the simulated EUREX process section

Table I EUREX plant flow-sheet characteristics

Idenfication	Flow-rate l/h	Streams Description	Pu g/l	U g/l	HNO_3 M	TBP %
1AX	6	Input organic 1° Cycle	—	—	—	30
1AF	2.2	Feed 1° Cycle	2.5	250	2	—
1AW	3.51	Aqueous waste 1° Cycle	$2\ 10^{-4}$	$4.8\ 10^{-4}$	2.2	—
1CW	6	Organic waste 1° Cycle	$1\ 10^{-5}$	$1\ 10^{-2}$	$5\ 10^{-4}$	—
1CX	9	Reducing strip (HAN = 0.1M)	—	—	0.01	—
1CP	9	Product 1° Cycle	0.6	59	0.144	—
1BS	1.5	Scrub 1° Cycle	—	—	3	—
2AX	10	Input organic 2° Cycle	—	—	—	30
2AF	13.5	Feed 2° Cycle	0.41	40.5	2	—
2AW	17.3	Aqueous waste 2° Cycle	$2\ 10^{-5}$	$6\ 10^{-5}$	1.8	—
2CW	10.2	Organic output 2° Cycle	—	50	0.033	30
2CX	2	Reducing strip (HAN = 0.3M)	—	—	0.3	—
2CP	2	Product 2° Cycle	2.7	17.8	0.52	—
2BS	2	Scrub 2° Cycle	—	—	0.5	—
2B'S	2	Scrub 2° Cycle	—	—	2	—

Table II. In process hold-up in tanks and extration equipments of EUREX plant flow-sheet

Identification	Volume (l)	Items Description	Pu g/l
F-307	360	Feed 1°Cycle	2.5
F-404	180	Aqueous waste 1°Cycle	$2\ 10^{-4}$
F-408	350	Organic waste 1°Cycle	$1\ 10^{-5}$
F-405	35	Product adjustment 1°Cycle	0.41
F-406	35	Feed 2°Cycle	0.41
F-505	100	Aqueous waste 2°Cycle	$2\ 10^{-5}$
F-508	350	Organic output 2°Cycle	—
F-506	40	Product 2°Cycle	2.7
F-507	40	Feed Evaporator	2.7
C-603	14	Evaporator	100
F-606	125	Output	100
D-401	54.4	Codecontamination battery 1°Cycle (8 st.)	
D-402	68	Scrub battery 1°Cycle (10 st.)	
D-403	108.8	Strip battery 1°Cycle (16 st.)	
D-501	74.8	Codecontamination battery 2°Cycle (11 st.)	
D-502	74.8	Coscrub battery 2°Cycle (11 st.)	
D-503	108.8	Partial partition battery 2°Cycle (16 st.)	

The 2AF stream feeds the second cycle mixer settlers extraction unit where, after a further fission products codecontamination, an Uranium partial stripping is performed. The organic stream (2CW) contains a fairly high amount of uranium (50 g/l). The second cycle product stream (2CP) is collected in a buffer tank before being transferred to the C-603 concentrator and the concentrated product is then collected in the output accountancy tank for interim storage.

Table I lists typical plutonium concentrations and volumetric flow rates in the EUREX flow sheet.

Nominal in-process holdups in tanks and extraction equipments are given in Table II.

4.1 — The Dynamic Model

Flow rates of SNM streams into and out from the work stations and Pu concentrations of external streams entering these stations are treated as stochastic variables as described in [2].

To represent random variations in the process, if x(t) is the value of a stochastic variable at time t, then its value at time tΔt is given by the algorithm:

$$x(t+\Delta t) = x(t) + x_n\ r\ G \qquad (1)$$

where r is a random variable uniformly distributed between (−1,1), G indicates Normal Distribution.

$$\text{if} \quad \text{abs}[x(t+\Delta t) - x_n] \geq 2\ \sigma\ x_n \quad \text{then} \quad x(t+\Delta t) = x_n$$

σ is the relative standard deviation of variations in process variables. At the moment we have assumed $\sigma = 0.05$ for all stochastic variables.

We assume that the time dependance of all flow rates and Pu concentrations are approximately constant over sufficiently short time intervals Δt.

4.2 — Tanks

For an instantaneous and perfectly mixed tank, Pu concentrations and volumetric holdups are determined by the relationship of mass and volume conservation according to:

$$d\ [V(t)\ C_T(t)] / dt = q_{in}(t)\ C_{in}(t) - q_{out}(t)\ C_T(t) \qquad (2)$$

$$d\ V(t) / dt = q_{in}(t) - q_{out}(t) \qquad (3)$$

where:
V — liquid volume in the tank;
C_{in}, C_T — input and in tank Pu concentrations, respectively;
q_{in}, q_{out} — input and output volumetric flow rates.

4.3 — Solvent Extraction Contractors (Mixer Settlers)

Simulation of the solvent extraction contractors generally requires sophisticated mathematical models able to describe the time dependance of the Pu inventory. In this preliminary approach a simplified dynamic model, neglecting the effects of many complex parameters, has been developed, leading to a series of assumptions the most common of which are:

a) perfect mixing in the mixer;
b) instantaneous material transfer between the two phases in the mixer;
c) total volumetric holdup constant both in mixer and in settler;
d) ratio of the two phases holdup volume in the mixer is in direct proportion to the volumetric flow rates;
e) no mass transfer in the settler;
f) no concentration gradient in each phase of the settler.

• Mixer

A schematic diagram of a single stage mixer settler is shown in Fig. 3.

Most of the evidence suggests that the mixers, which must be well stirred in order to achieve efficient mass transfer, can be modeled as perfectly mixed tanks.

For each Δt increment the set of equations, required for mass conservation, as as follows:
Mass conservation:

$$q^A_{in}(t)\ C^A_{in}(t) + q^O_{in}(t)\ C^O_{in}(t) = q^A_M(t)\ C^A_M(t) + q^O_M(t)\ C^O_M(t) \qquad (4)$$

where A and O indicate aqueous and organic phase, subscript M refers to mixer.
Equilibrium stage condition:

$$C^O_M(t) = m\ C^A_M(t) \qquad (5)$$

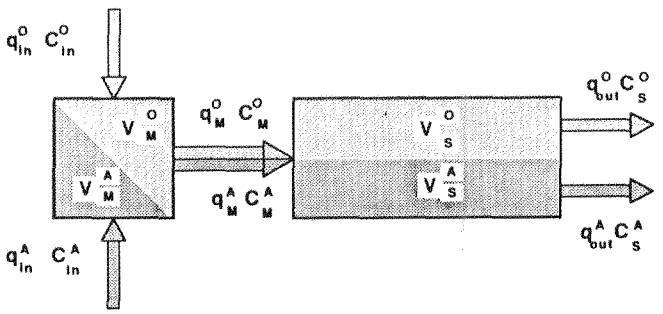


Figure 3. Schematic Diagram of a Mixer Settler Stage

The parameter m is chosen in order to ensure that the separation factors foreseen by the reference flow-sheet are achieved.

From eq. (4) and (5):

$$C^A_M(t) = \frac{q^A_{in}(t)\ C^A_{in}(t) + q^O_{in}(t)\ C^O_{in}(t)}{q^A_M(t) + m\ q^O_M(t)} \quad (6)$$

where:

$$q^A_M(t) = q^A_{in}(t)\ [1 + K^A\ (C^A_M(t) - C^A_{in}(t))] \quad (7)$$

$$q^O_M(t) = q^O_{in}(t)\ [1 + K^O\ (C^O_M(t) - C^O_{in}(t))] \quad (8)$$

K^A and K^O are parameters which take into account volume transfer between the two phases.

The phase volumetric holdups are given by:

$$V^A_M(t) / V^O_M(t) = [\ q^A_{in}(t)/q^O_{in}(t) + q^A_M(t)/q^O_M(t)\ ] / 2 \quad (9)$$

assuming the total holdup to be constant:

$$d\ V^{TOT}_M / dt = 0 \quad (10)$$

• Settler

Evaluation of the flow rates, Pu concentrations and phase volumetric holdups in the settler are carried out by a dynamic model whereas the time behaviour for process variables in the mixer is determined by studying successive equilibrium stages. In fact, after evaluating the new equilibrium conditions for the mixer at time t, the settler concentration response for each phase and the relative holdups are determined by assuming the concentrations and flow rates leaving the mixer to be constant between t and $t + \Delta t$.

The following relationships, modelling each settler phase as perfectly mixing tank, are used:

Mass conservation

$$d\ [V^A_S\ C^A_S] / dt = q^A_M(t)\ C^A_M(t) - q^A_{out}(t)\ C^A_S(t) \quad (11)$$

$$d\ [V^O_S\ C^O_S] / dt = q^O_M(t)\ C^O_M(t) - q^O_{out}(t)\ C^O_S(t) \quad (12)$$

Phase volumes conservation:

$$d\ V^A_S / dt = q^A_M(t) - q^A_{out}(t) \quad (13)$$

$$d\ V^O_S / dt = q^O_M(t) - q^O_{out}(t) \quad (14)$$

4.4 — Evaporator

The evaporator operates in three successive steps:

i) filling step — during this step the evaporator is modelled as a simple vessel; when the nominal volume, V_n, has been reached the concentration process starts;

ii) concentration step — the process is carried out at "constant volume"; the amount distilled, q_{dist}, is integrated by a continuous feed of intermediate product, q_{in}.

iii) product transfer step — the evaporation process is considered to be completed when an intermediate product batch has been processed; final concentrated product is then transferred to the final output accountancy tank.

The evaporation unit has been modelled, as a first approach, using the following relations;

i) Filling

$$dV_E(t) / dt = q_{in}(t) \quad (15)$$

ii) Concentration

$$dV_E(t) / dt = q_{in}(t) - q_{dist}(t) \quad (16)$$

where $q_{in}(t)$ and $q_{dist}(t)$ are stochastic variables.

For both i) and ii) steps the following relations are used:

$$dM_E(t) / dt = q_{in}(t)\ C_{in}(t) \quad (17)$$

$$C_E(t+\Delta t) = M_E(t+\Delta t) / V_E(t+\Delta t) \quad (18)$$

where M_E is the Pu mass contents in the evaporator.

iii) Product transfer

Only a stochastic type transfer efficiency is used to model the product transfer step.

5. PRELIMINARY RESULTS FOR THE REFERENCE PROCESS

The simulated time dependence of the Pu holdups from startup to the end of the second batch in the first and the second extraction cycles rose for about 25 hours and then settled at 70 g. in the first and 40 g. in the second cycle.

The evaporator feed tank shows a steady increase for the first 100 hours when it stabilizes at 108g.

6. MEASURING SYSTEM SIMULATION MODEL

Implementation of NRTMA requires measurements of in-process inventory in addition to the measured receipts and removals.

In our case, such in-process inventory is assumed to be evaluated, as far as tanks are concerned, by existing pro-

cess instrumentation and by a simplified dynamic model for solvent extraction systems and evaporator.

The inventory in minor process components such as pipes is, at this moment, fully neglected. Furthermore, taking advantage of batch-type process characteristics, in-process inventory is carried out after emptying the concentrator in order to avoid measurements or model evaluation of such a component. Each tank is assumed to be equipped with probes for volume and concentration measurements. Measured values are obtained on the basis of the true material flow data generated by the program section described in the previous paragraphs.

The program is subdivided in three subroutines which simulate inventory, input and output measurements following the same model.

The measured value M of a "true quantity" μ is given by

$$M = \mu (1+\epsilon+\delta) + d \qquad (19)$$

where ϵ is the relative error due to instrument precision (simulated random error), $-\delta$ is the error due to instrument calibration (simulated systematic error) and d is a factor that takes into account instrument calibration drift. Both errors ϵ and δ are assumed to be independent and normally distributed with mean zero and variances σ_ϵ^2 and σ_δ^2 respectively.

In the measuring system simulation a value of ϵ is sampled for each measurement whereas a value for δ is periodically sampled with the frequency of instrument recalibration. The parameter d is a linear function of the time and is set to zero at each instrument recalibration. The uncertainties for both volume and concentration measurements, used in the investigation (see Table III) are grouped into four classes of tanks; the values have been taken from literature and from EUREX plant operators suggestions.

Table III. Typical measurement errors in EUREX in-process inventory

	Measurement	Method	σ_r(%)	σ_s(%)
Input Tank	Volume	Differential Pressure Gauge	0.3	0.3
	Concentration	Isotopic Dilution Mass Spectrometry	0.6	0.3
Intermediate Tanks	Volume	Differential Pressure Gauge	0.5	0.5
	Concentration	Potentiometric Titration	0.4	0.4
Waste Tanks	Volume	Differential Pressure Gauge	1	1
	Concentration	TTA extration/α counting	4	2
Product Tanks	Volume	Differential Pressure Gauge	0.3	0.3
	Concentration	Isotopic Dilution Mass Spectrometry	0.6	0.3

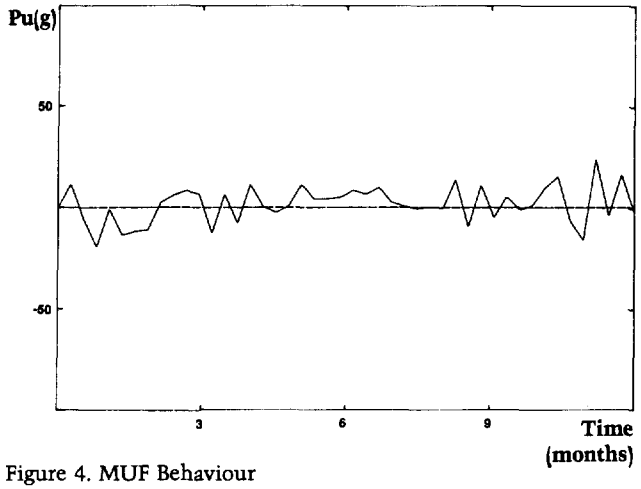


Figure 4. MUF Behaviour

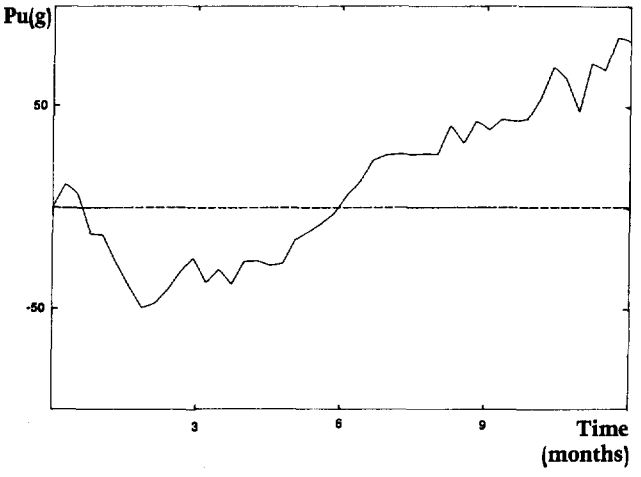


Figure 5. CUMUF Behaviour

7. MATERIAL BALANCE

Measured values of net material transfer and initial and final in-process inventories are combined to evaluate material balance. The balance frequency, i.e. the time interval between two consecutive material balances, has been chosen 8 days.

The behaviours of MUF and CUMUF in one year are shown in Figs. 4 and 5 respectively.

No statistical test has been implemented so far to infer whether or not a diversion has occurred.

8. CONCLUDING REMARKS

The work reported in this paper has to be considered a preliminary study of a Near Real Time Accountancy procedure to be applied to a reference coprocessing flow-sheet which will be used for LWR spent fuel reprocessing at the ENEA EUREX Pilot Plant. The ongoing activities are focused on the dynamic simulation of the Pu distribution within the process unit and on the MUF and CUMUF behaviours in selected material balance time intervals.

Due to the peculiarity of both EUREX plant lay-out and coprocessing chemical flow-sheet suitable and specific sta-

tistical tests for Near Real Time Accountancy data evaluation have to be defined.

The simulation model, in its present version, can give, with fairly good reliability, the holdups variation during the in-process inventories; nevertheless some integrations are foreseen in the future.

Extended studies aimed at investigating the systematic errors, arising from real plant operation activities, due to instruments calibration and drift, data evaluation or transcription, will be performed. Different diversions scenarios as well as supplementary statistical tests will also be examined.

ACKNOWLEDGMENTS

The authors wish to thank Mr. A. Moccia and Mr. G. Bardone for their valuable help and contributions in the preparation of this paper.

REFERENCES

1. R. Weh, E.A. Hakkila, M.J. Canty
"Results of a Technical workshop on Near Real Time Material Accounting for Reprocessing Plant"
Nuclear Safeguards Technology (IAEA SM 293/53 — 1986)
2. E.A. Hakkila, et al.
"Coordinated Safeguards for Materials Management in a Fuel Reprocessing Plant
Los Alamos Scientific Laboratory Report LA — 6881 (1977)
3. M.J. Canty, et al.
"Simulation of Nuclear Fuel Reprocessing for Safeguards"
KfK — 3439 (1983)

Max Aparo received his Degree in Nuclear Engineering from the University of Rome in 1980. He obtained an ENEA postgraduation fellowship in the field of research and development on Non Destructive Techniques for the assay of Special Nuclear Material.

In 1983 he joined the ENEA Fuel Cycle Department where he became involved in reprocessing plant Safeguards. Mr. Aparo took a leave of absence from ENEA for 9 months to join, as scientist visitor, the Non Destructive Techniques group of the Los Alamos National Laboratory. Mr. Aparo is the Italian representative in the ESARDA NDA Working Group.

Mario Dionisi received his Degree in Nuclear Engineering from the University of Rome in 1983.

From 1983 to 1986 he was involved in reprocessing plant Safeguards on a fellowship of The University of Rome and, in cooperation with JRC Ispra, on the Input Measurement System in a reprocessing plant. In 1986 he joined the ENEA Fuel Cycle Department where he works in The Instrumentation and Automatization Laboratory. Mr. Dionisi is the Italian representative in the ESARDA RIV (Reprocessing Input Verification) Working Group.

Paolo Zeppa received his Degree in Nuclear Engineering from the University of Rome in 1983.

From 1984 to 1985 he was an ENEA postgraduation fellow in the field of neutron measurement techniques for Safeguards purposes. In 1986 he joined the ENEA Fuel Cycle Department where he works in The Instrumentation and Automatization Laboratory in the field of Non Destructive Techniques of Special Nuclear Material.

Franco Vittorio Frazzoli received his Degree in Physics from the University of Rome in 1965.

Since 1973 he has been a Professor at The University "La Sapienza" of Rome, where he teaches Nuclear Physics.
He carried out activities of experimental scientific research involved with the application of Nuclear Radiations to Nuclear Engineering. In particular in the field of Safeguards, he studied the application of Analytical Techniques to Nuclear Fuel Cycle Plants.

Romolo Remetti received his degree in Nuclear Engineering from the University of Rome in 1982.

Since then he has carried out activities of experimental scientific research in the application of Nuclear Analytical Techniques to Reprocessing and Fabrication Plants. He is now completing his P.H.D. in Engineering at the University of Rome studying process controls and simulation of the Nuclear Plants.

Carmelo Portale received his Degree in Nuclear Engineering from the University of Rome in 1987.

Since then he has studied process controls and simulation of Reprocessing Plants.

cess instrumentation and by a simplified dynamic model for solvent extraction systems and evaporator.

The inventory in minor process components such as pipes is, at this moment, fully neglected. Furthermore, taking advantage of batch-type process characteristics, in-process inventory is carried out after emptying the concentrator in order to avoid measurements or model evaluation of such a component. Each tank is assumed to be equipped with probes for volume and concentration measurements. Measured values are obtained on the basis of the true material flow data generated by the program section described in the previous paragraphs.

The program is subdivided in three subroutines which simulate inventory, input and output measurements following the same model.

The measured value M of a "true quantity" μ is given by

$$M = \mu (1 + \epsilon + \delta) + d \qquad (19)$$

where ϵ is the relative error due to instrument precision (simulated random error), $-\delta$ is the error due to instrument calibration (simulated systematic error) and d is a factor that takes into account instrument calibration drift. Both errors ϵ and δ are assumed to be independent and normally distributed with mean zero and variances σ_ϵ^2 and σ_δ^2 respectively.

In the measuring system simulation a value of ϵ is sampled for each measurement whereas a value for δ is periodically sampled with the frequency of instrument recalibration. The parameter d is a linear function of the time and is set to zero at each instrument recalibration. The uncertainties for both volume and concentration measurements, used in the investigation (see Table III) are grouped into four classes of tanks; the values have been taken from literature and from EUREX plant operators suggestions.

Table III. Typical measurement errors in EUREX in-process inventory

	Measurement	Method	σ_r(%)	σ_s(%)
Input Tank	Volume	Differential Pressure Gauge	0.3	0.3
	Concentration	Isotopic Dilution Mass Spectrometry	0.6	0.3
Intermediate Tanks	Volume	Differential Pressure Gauge	0.5	0.5
	Concentration	Potentiometric Titration	0.4	0.4
Waste Tanks	Volume	Differential Pressure Gauge	1	1
	Concentration	TTA extration/α counting	4	2
Product Tanks	Volume	Differential Pressure Gauge	0.3	0.3
	Concentration	Isotopic Dilution Mass Spectrometry	0.6	0.3

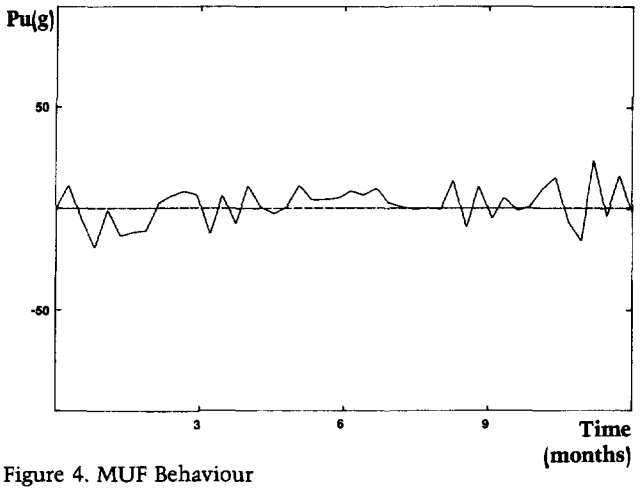


Figure 4. MUF Behaviour

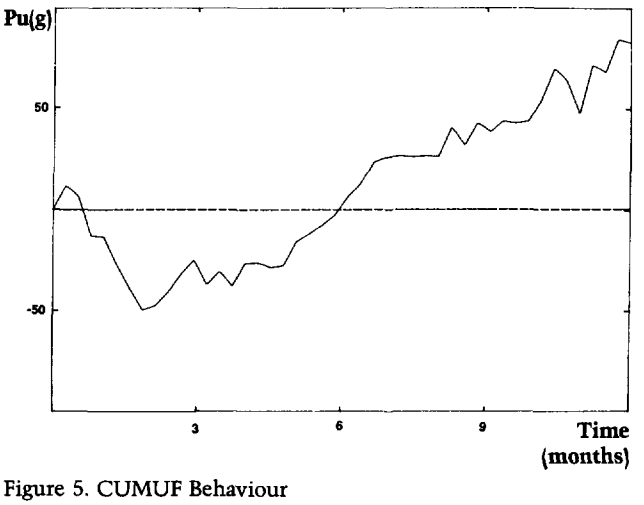


Figure 5. CUMUF Behaviour

7. MATERIAL BALANCE

Measured values of net material transfer and initial and final in-process inventories are combined to evaluate material balance. The balance frequency, i.e. the time interval between two consecutive material balances, has been chosen 8 days.

The behaviours of MUF and CUMUF in one year are shown in Figs. 4 and 5 respectively.

No statistical test has been implemented so far to infer whether or not a diversion has occurred.

8. CONCLUDING REMARKS

The work reported in this paper has to be considered a preliminary study of a Near Real Time Accountancy procedure to be applied to a reference coprocessing flow-sheet which will be used for LWR spent fuel reprocessing at the ENEA EUREX Pilot Plant. The ongoing activities are focused on the dynamic simulation of the Pu distribution within the process unit and on the MUF and CUMUF behaviours in selected material balance time intervals.

Due to the peculiarity of both EUREX plant lay-out and coprocessing chemical flow-sheet suitable and specific sta-

tistical tests for Near Real Time Accountancy data evaluation have to be defined.

The simulation model, in its present version, can give, with fairly good reliability, the holdups variation during the in-process inventories; nevertheless some integrations are foreseen in the future.

Extended studies aimed at investigating the systematic errors, arising from real plant operation activities, due to instruments calibration and drift, data evaluation or transcription, will be performed. Different diversions scenarios as well as supplementary statistical tests will also be examined.

ACKNOWLEDGMENTS

The authors wish to thank Mr. A. Moccia and Mr. G. Bardone for their valuable help and contributions in the preparation of this paper.

REFERENCES

1. R. Weh, E.A. Hakkila, M.J. Canty
"Results of a Technical workshop on Near Real Time Material Accounting for Reprocessing Plant"
Nuclear Safeguards Technology (IAEA SM 293/53 — 1986)
2. E.A. Hakkila, et al.
"Coordinated Safeguards for Materials Management in a Fuel Reprocessing Plant
Los Alamos Scientific Laboratory Report LA — 6881 (1977)
3. M.J. Canty, et al.
"Simulation of Nuclear Fuel Reprocessing for Safeguards"
KfK — 3439 (1983)

Max Aparo received his Degree in Nuclear Engineering from the University of Rome in 1980. He obtained an ENEA postgraduation fellowship in the field of research and development on Non Destructive Techniques for the assay of Special Nuclear Material.

In 1983 he joined the ENEA Fuel Cycle Department where he became involved in reprocessing plant Safeguards. Mr. Aparo took a leave of absence from ENEA for 9 months to join, as scientist visitor, the Non Destructive Techniques group of the Los Alamos National Laboratory. Mr. Aparo is the Italian representative in the ESARDA NDA Working Group.

Mario Dionisi received his Degree in Nuclear Engineering from the University of Rome in 1983.

From 1983 to 1986 he was involved in reprocessing plant Safeguards on a fellowship of The University of Rome and, in cooperation with JRC Ispra, on the Input Measurement System in a reprocessing plant. In 1986 he joined the ENEA Fuel Cycle Department where he works in The Instrumentation and Automatization Laboratory. Mr. Dionisi is the Italian representative in the ESARDA RIV (Reprocessing Input Verification) Working Group.

Paolo Zeppa received his Degree in Nuclear Engineering from the University of Rome in 1983.

From 1984 to 1985 he was an ENEA postgraduation fellow in the field of neutron measurement techniques for Safeguards purposes. In 1986 he joined the ENEA Fuel Cycle Department where he works in The Instrumentation and Automatization Laboratory in the field of Non Destructive Techniques of Special Nuclear Material.

Franco Vittorio Frazzoli received his Degree in Physics from the University of Rome in 1965.

Since 1973 he has been a Professor at The University "La Sapienza" of Rome, where he teaches Nuclear Physics.
He carried out activities of experimental scientific research involved with the application of Nuclear Radiations to Nuclear Engineering. In particular in the field of Safeguards, he studied the application of Analytical Techniques to Nuclear Fuel Cycle Plants.

Romolo Remetti received his degree in Nuclear Engineering from the University of Rome in 1982.

Since then he has carried out activities of experimental scientific research in the application of Nuclear Analytical Techniques to Reprocessing and Fabrication Plants. He is now completing his P.H.D. in Engineering at the University of Rome studying process controls and simulation of the Nuclear Plants.

Carmelo Portale received his Degree in Nuclear Engineering from the University of Rome in 1987.

Since then he has studied process controls and simulation of Reprocessing Plants.

cess instrumentation and by a simplified dynamic model for solvent extraction systems and evaporator.

The inventory in minor process components such as pipes is, at this moment, fully neglected. Furthermore, taking advantage of batch-type process characteristics, in-process inventory is carried out after emptying the concentrator in order to avoid measurements or model evaluation of such a component. Each tank is assumed to be equipped with probes for volume and concentration measurements. Measured values are obtained on the basis of the true material flow data generated by the program section described in the previous paragraphs.

The program is subdivided in three subroutines which simulate inventory, input and output measurements following the same model.

The measured value M of a "true quantity" μ is given by

$$M = \mu (1+\epsilon+\delta) + d \qquad (19)$$

where ϵ is the relative error due to instrument precision (simulated random error), $-\delta$ is the error due to instrument calibration (simulated systematic error) and d is a factor that takes into account instrument calibration drift. Both errors ϵ and δ are assumed to be independent and normally distributed with mean zero and variances σ_ϵ^2 and σ_δ^2 respectively.

In the measuring system simulation a value of ϵ is sampled for each measurement whereas a value for δ is periodically sampled with the frequency of instrument recalibration. The parameter d is a linear function of the time and is set to zero at each instrument recalibration. The uncertainties for both volume and concentration measurements, used in the investigation (see Table III) are grouped into four classes of tanks; the values have been taken from literature and from EUREX plant operators suggestions.

Table III. Typical measurement errors in EUREX in-process inventory

	Measurement	Method	σ_r(%)	σ_s(%)
Input Tank	Volume	Differential Pressure Gauge	0.3	0.3
	Concentration	Isotopic Dilution Mass Spectrometry	0.6	0.3
Intermediate Tanks	Volume	Differential Pressure Gauge	0.5	0.5
	Concentration	Potentiometric Titration	0.4	0.4
Waste Tanks	Volume	Differential Pressure Gauge	1	1
	Concentration	TTA extration/α counting	4	2
Product Tanks	Volume	Differential Pressure Gauge	0.3	0.3
	Concentration	Isotopic Dilution Mass Spectrometry	0.6	0.3

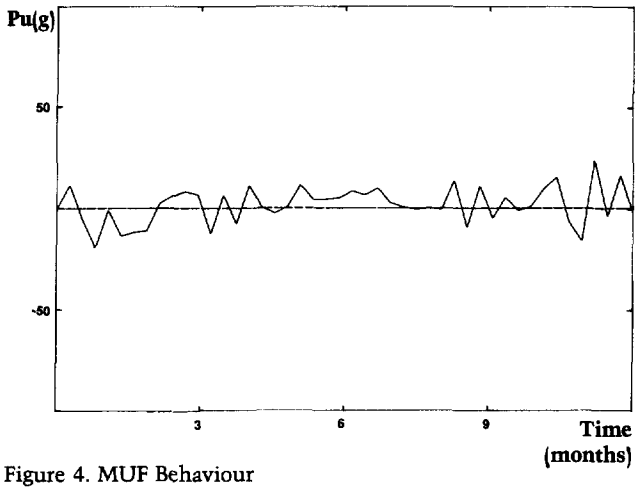


Figure 4. MUF Behaviour

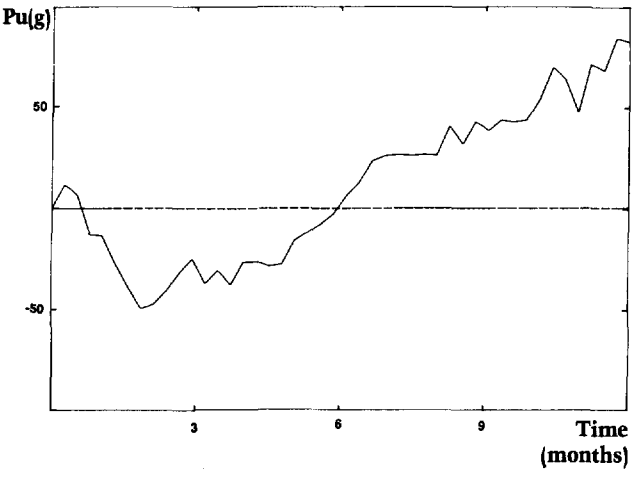


Figure 5. CUMUF Behaviour

7. MATERIAL BALANCE

Measured values of net material transfer and initial and final in-process inventories are combined to evaluate material balance. The balance frequency, i.e. the time interval between two consecutive material balances, has been chosen 8 days.

The behaviours of MUF and CUMUF in one year are shown in Figs. 4 and 5 respectively.

No statistical test has been implemented so far to infer whether or not a diversion has occurred.

8. CONCLUDING REMARKS

The work reported in this paper has to be considered a preliminary study of a Near Real Time Accountancy procedure to be applied to a reference coprocessing flow-sheet which will be used for LWR spent fuel reprocessing at the ENEA EUREX Pilot Plant. The ongoing activities are focused on the dynamic simulation of the Pu distribution within the process unit and on the MUF and CUMUF behaviours in selected material balance time intervals.

Due to the peculiarity of both EUREX plant lay-out and coprocessing chemical flow-sheet suitable and specific sta-

tistical tests for Near Real Time Accountancy data evaluation have to be defined.

The simulation model, in its present version, can give, with fairly good reliability, the holdups variation during the in-process inventories; nevertheless some integrations are foreseen in the future.

Extended studies aimed at investigating the systematic errors, arising from real plant operation activities, due to instruments calibration and drift, data evaluation or transcription, will be performed. Different diversions scenarios as well as supplementary statistical tests will also be examined.

ACKNOWLEDGMENTS

The authors wish to thank Mr. A. Moccia and Mr. G. Bardone for their valuable help and contributions in the preparation of this paper.

REFERENCES

1. R. Weh, E.A. Hakkila, M.J. Canty
"Results of a Technical workshop on Near Real Time Material Accounting for Reprocessing Plant"
Nuclear Safeguards Technology (IAEA SM 293/53 — 1986)
2. E.A. Hakkila, et al.
"Coordinated Safeguards for Materials Management in a Fuel Reprocessing Plant
Los Alamos Scientific Laboratory Report LA — 6881 (1977)
3. M.J. Canty, et al.
"Simulation of Nuclear Fuel Reprocessing for Safeguards"
KfK — 3439 (1983)

Max Aparo received his Degree in Nuclear Engineering from the University of Rome in 1980. He obtained an ENEA postgraduation fellowship in the field of research and development on Non Destructive Techniques for the assay of Special Nuclear Material.

In 1983 he joined the ENEA Fuel Cycle Department where he became involved in reprocessing plant Safeguards. Mr. Aparo took a leave of absence from ENEA for 9 months to join, as scientist visitor, the Non Destructive Techniques group of the Los Alamos National Laboratory. Mr. Aparo is the Italian representative in the ESARDA NDA Working Group.

Mario Dionisi received his Degree in Nuclear Engineering from the University of Rome in 1983.

From 1983 to 1986 he was involved in reprocessing plant Safeguards on a fellowship of The University of Rome and, in cooperation with JRC Ispra, on the Input Measurement System in a reprocessing plant. In 1986 he joined the ENEA Fuel Cycle Department where he works in The Instrumentation and Automatization Laboratory. Mr. Dionisi is the Italian representative in the ESARDA RIV (Reprocessing Input Verification) Working Group.

Paolo Zeppa received his Degree in Nuclear Engineering from the University of Rome in 1983.

From 1984 to 1985 he was an ENEA postgraduation fellow in the field of neutron measurement techniques for Safeguards purposes. In 1986 he joined the ENEA Fuel Cycle Department where he works in The Instrumentation and Automatization Laboratory in the field of Non Destructive Techniques of Special Nuclear Material.

Franco Vittorio Frazzoli received his Degree in Physics from the University of Rome in 1965.

Since 1973 he has been a Professor at The University "La Sapienza" of Rome, where he teaches Nuclear Physics.
He carried out activities of experimental scientific research involved with the application of Nuclear Radiations to Nuclear Engineering. In particular in the field of Safeguards, he studied the application of Analytical Techniques to Nuclear Fuel Cycle Plants.

Romolo Remetti received his degree in Nuclear Engineering from the University of Rome in 1982.

Since then he has carried out activities of experimental scientific research in the application of Nuclear Analytical Techniques to Reprocessing and Fabrication Plants. He is now completing his P.H.D. in Engineering at the University of Rome studying process controls and simulation of the Nuclear Plants.

Carmelo Portale received his Degree in Nuclear Engineering from the University of Rome in 1987.

Since then he has studied process controls and simulation of Reprocessing Plants.

Volume Calibration and Instrument Testing at ENEA Central Research Laboratory, Casaccia

M. Aparo, M. Dionisi
ENEA Fuel Cycle Department
CRE Casaccia, Italy
S. Suda
Brookhaven National Laboratory
Upton, New York U.S.A.

ABSTRACT

The Italian Nuclear and Alternative Energy Commission (ENEA) has established a testing facility for volume measurement instruments and techniques at its Central Research Laboratory in Casaccia. The testing apparatus consists of a scale model of the ENEA ITREC pilot reprocessing plant input accountability tank made of clear acrylic (Methylmithacrilate) which permits observation of the test conditions and relationships among alternative volume measurement instruments. For the test reported in this paper, the IAEA Ruska Electromanometer system was installed in the tank and used as a reference for assessing the performance of alternative upgraded volume instruments. In this paper we present results of the tests conducted in the summer of 1987 under a joint ITA-USA-IAEA task.

TESTING OBJECTIVES

The experimental activities reported in the present paper are carried out in the framework of a joint ITA-USA-IAEA field test of volume measurement instruments.

The Italian Support Program to the Agency is directed toward activities concerning optimization of process control instrumentation, methods and techniques. The activities carried out under Italian support task (ITA-D.04) entitled, "Field test of advanced instrumentation for level and density measurements in an accountability vessel", were aimed at conducting a series of cold tests in an experimental set up at the ENEA-CASACCIA laboratory using several types of volume measurement instruments for six different experimental tests.

In response to the Italian request for the loan of the IAEA Ruska electromanometer system and installation assistance, the USA Support Program offered to participate (Task A.152) in the installation of the equipment and in the planning and management of the field tests for instrument systems characterization as well as in the evaluation of the results.

The general objective of the joint task was to assess the performances of alternative upgraded volume instrumentation systems relative to the Ruska electromanometer system.

EXPERIMENTAL SETUP

In order to test the performance of advanced instrumentation for level and density measurements, and to investigate error sources during calibration runs and successive volume determinations, an experimental setup was designed and constructed at CASACCIA COMB-MEPIS laboratory. The main component is a clear, acrylic tank (Methylmethacrilate) shown in Figure 1, which has the same shape as the input accountancy tank installed at ENEA ITREC pilot reprocessing pant. This scaled-down input tank has a total height of 120 cm and a maximum capacity of 38 litre. A series of instrument systems for level, weight, density and temperature measurement were installed in the tank for use in performing calibration runs as well as operational volume determinations.

The instruments for level measurements tested were:

- Time Domain Reflectometer (TDR)
- RF level transmitter (capacitance probe)
- Pneumatic system connected to:
  a) Conventional water filled U-Tube manometer
  b) DRUCK pressure gage
  c) RUSKA electromanometer

A brief description of the instrument systems follows.

The Time Domain Reflectometry technique for level measurement is based on the propagation of an incident pulse train through a circuit or a cable under examination, followed by observation of the reflected signal due to any impedance change along the signal path. Mismatch locations, which for level measurement are due to the change of dielectric constant at the air-liquid interface, can be thus determined by recording, with respect to time, the position of the reflected wave form.

The TDR system has been so far characterized by poor precision (about 2%), mainly due to manual reduction of the TDR signatures. Recently, using an automated data acquisition and evaluation system, important improvements in the TDR system performance have been obtained. As reported in a previous paper (1), the automatic system comprises a microprocessor unit, interfaced to a PC-MS DOS based, with a software program for determining inflexion points.

RF level transmitter refers to a Drexelbrook Level Trans-

mitter system composed of a teflon insulated sensing element connected with a Cote-Shield electronic unit is similar to the theory of a capacitance electronic unit, but with an important circuit addition. While a pure capacitance system sees the variation of the capacitance as a function of the liquid level, in the case of the Cote-Shield system both the resistance and the capacitance variation are used by the electronics for level measurement.

The DRUCK electromanometer DPI 140 model, which is an improved pneumatic instrument, is a precision digital pressure indicator utilizing a vibrating cylinder pressure sensor to provide absolute pressure readout (single port) with an operating pressure range between 0 and 3.5 bar absolute.

The pneumatic system included eight bubbler probes (four in each tank leg) installed at different heights, according to the multiple probe technique proposed in (2). Regional tank temperatures are determined by eight platinum thermoresistors. Such a multiple probe system, connected to the automated RUSKA electromanometer, allows for timely measurement of density, liquid-column

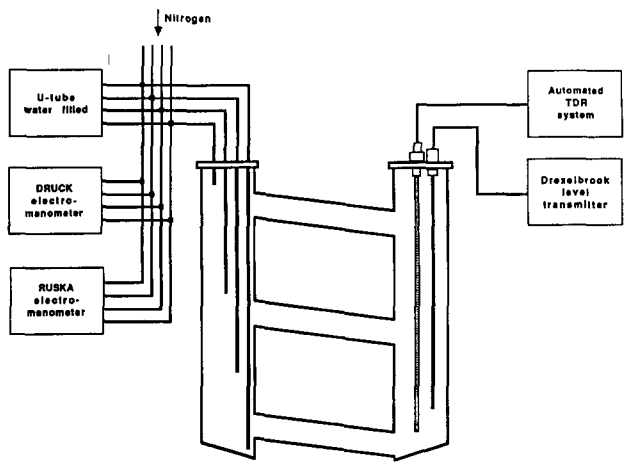


Figure 1. Input Accountancy Tank with a View of Volume Measurement Instruments

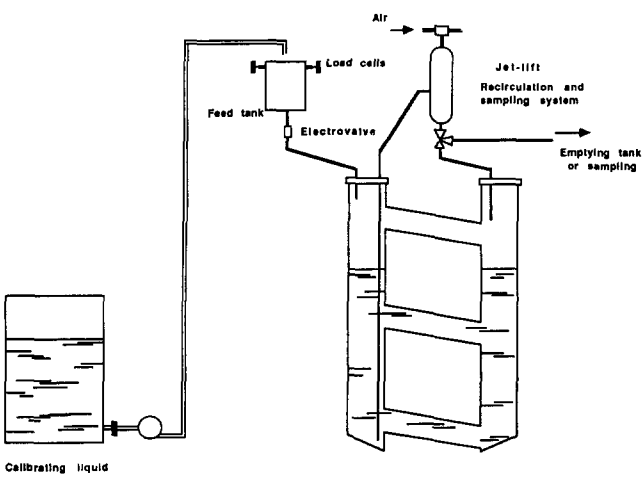


Figure 2. Scheme of Liquid Increment Weighing and Homogenization Systems

weight and temperature gradients over the full range of the tank. These redundant measurements can be used to verify the homogeneity of the tank solution before samples are drawn.

During calibration runs, the accurancy of density measurement carried out by the electromanometer was verified by sampling of the calibration liquids and successive vibrating tube densitometer (Anton Paar DMA 46) analysis. The whole experimental setup, including feed tank for liquid increment weighing and homogenization system, is shown in Figure 2. The feed tank mounting is suspended on three tension strain gauge load cells (BLH Bofors). Homogenization and sampling is performed by a jet-lift recirculation system.

In order to describe the geometry of the tank a mathematical model of the tank was developed on the basis of mechanical construction data.

EXPERIMENTAL TESTS

A series of tests has been designed and conducted aimed at evaluating the performance of the instrumental systems and at investigating the influence of physical and chemical parameters affecting calibration procedures and operational volume determinations. A brief description of the tests conducted is presented.

1) Tank Profile

During this test the tank was filled at a constant flow rate and level measurement were taken by both the RUSKA and TDR systems. The targets of the test were to obtain a picture of the tank shape, to determine the tank reference points and, finally, to check out the integrity of the hardware and pneumatic systems.

2) Multiple Probe Standardization

With the tank filled with a liquid of perfectly known density (demineralized water), a series of measurements were carried out by the RUSKA system in order to determine the probe separation values which allow, while in operation, the evaluation of density and consequently the actual level.

Figure 3 shows a typical Ruska printout for level measurement.

ENEA Prototype Tank

07:10:08 STATUS DISPLAY - NUMERICAL DATA 16:38:51

Ruska 0 (mm) 1.71 +/- .02 Vapor Head (mm) 2.56 +/- .02

Probe	Pressure (mmH2O)	Heigth (mm)
Right 1	232.8 +/- 1.13	233.4 +/- 1.13
Left 1	331.5 +/- 1.68	332.3 +/- 1.68
Right 2	711.5 +/- 1.12	713.2 +/- 1.12
Left 2	784.0 +/- 1.20	786.0 +/- 1.21
Right Major	1021.2 +/- 1.40	1023.6 +/- 1.41
Left Major	1045.6 +/- 2.33	1048.2 +/- 2.33

Temperature, (Deg C) 22.56: 22.66: 22.66: 23.11: 80.19: 22.68

Left Column	a	b	c
Probe Sep (mm)	453.6	262.1	715.8
Dens-Tab, (g/cm^3)	.99763	.99761	.99763
Dens-Meas,(g/cm^3)	.99771	.99813	.99780

Right Column	d	e	f
Probe Sep (mm)	479.9	318.4	798.3
Dens-Tab, (g/cm^3)	.99751	.99761	.99756
Dens-Meas,(g/cm^3)	.99666	.99711	.99621

Figure 3. Ruska System Level Measurement Printout

3) Calibration Runs

On the basis of the vessel configuration graphic function Volume-Level, several calibration runs were planned and performed in order to determine, for each installed measurement system, the experimental calibration functions of the tank.

Eight calibration runs were conducted respectively six by using demineralized water and two by using two different nitric acid solutions of Aluminum Nitrate (ρ_1 = 1.186 g/cm^3, ρ_2 = 1.75 g/cm^3 at 22°C) as calibrating liquids. The scheduled liquid increment weights added in the calibration runs ranged from 350 to 2700 grams.

4) Homogenization Tests

Two conditions which can be encountered in plant operations have been reproduced during the homogenization tests. In the first step a lighter liquid was introduced into the tank already filled with a heavier liquid phase. After a steady physical equilibrium was reached the recirculation system started and measurements were recorded until complete homogenization occured. In the second step the procedure was repeated with the heavier liquid phase introduced into the tank already filled with the lighter liquid phase.

5) Influence of Bubble Formation

The test was aimed at investigating the effects of different bubbler cut shapes on bubble formation and pressure measurement. Three different probe cuts were compared. Figures 4a, 4b, and 4c show the three types of cuts with the corresponding bubbles formation behaviors as obtained by the RUSKA system and a specific software evaluation program.

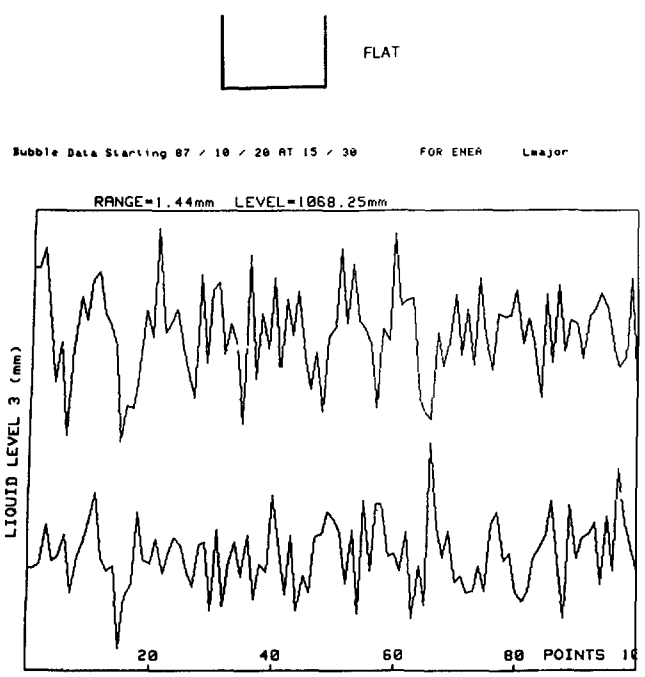


Figure 4a. Liquid level behavior, as measured by the Ruska System for a Flat Cut Dip-Tube

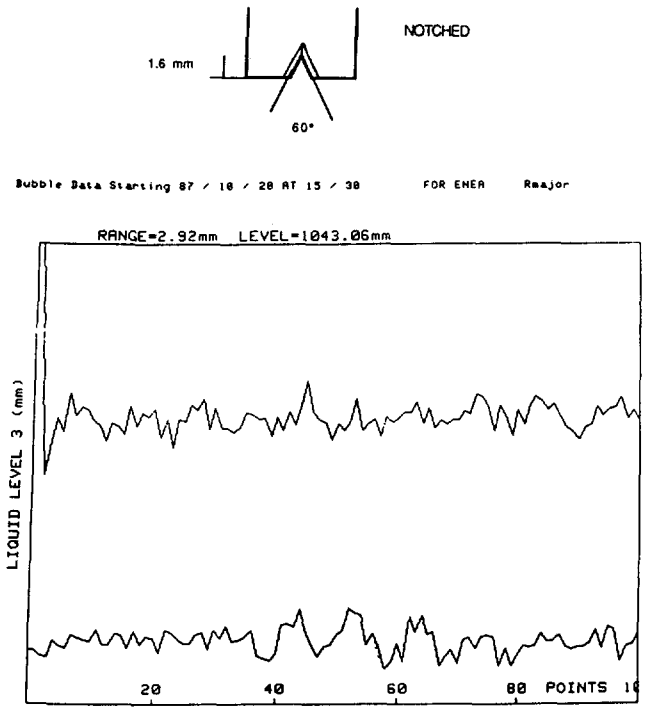


Figure 4b. Liquid level behavior for Notched Dip-Tube

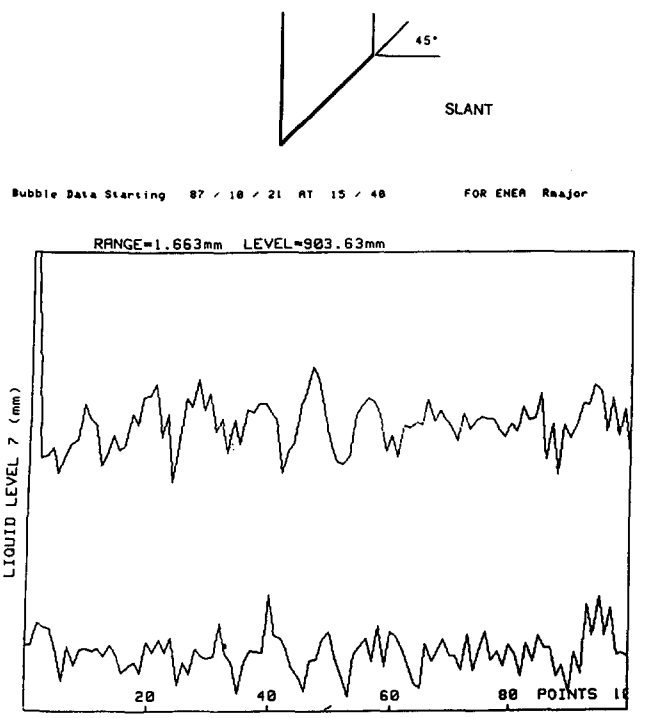


Figure 4c. Liquid level behavior for Slant Cut Dip-Tube

6) Temperature Effects

Temperature effects on volume measurement were studied during the cooling phase of 55°C heated solution added to the tank. The bubbler pressures were continuously recorded by the Ruska system during the cooling down to the room temperature (from 50°C to 23°C). The test was aimed at evaluating the probe and tank expansion characteristics as a function of liquid temperature changes.

PRELIMINARY CONCLUSIONS

The objectives of the test plan were met. The following is a summary of findings:

- a) Calculated volume equations of the tank, based on a dimensional model prepared during the test design, were verified by the profile test. Tank profile height of piping and changes in the cross-sectional area of the tank were identified by liquid height tracing while the tank was being filled at a constant rate.
- b) U-tube measurements can be very accurate under carefully monitored conditions. It was demonstrated that use of liquid column manometer data in IAEA inspections can be an effective cross-check on other liquid level measurement systems. However, U-tube measurements are time consuming and are generally associated with high data reading and recording error rates unless the data can be compared, on the spot, with corresponding digital or analog outputs.
- c) The results obtained with the new TDR system approach are excellent and demonstrate the higher reliability reached when associated to the present version of the data acquisition system. An overall improvement in both sensitivity and precision can be noted, making TDR system more suitable for reprocessing plant Safeguards controls.
- d) Probe separation and density calibrations with accuracy to 0.02-0.03% were obtained during periods of constant controlled air flow.
- e) Whether the liquid added on top is heavier or lighter than the base liquid makes a difference in mixing rates. Homogenization took longer and required more mixing when lighter liquid was added on top of a heavier one than when a heavier liquid was added to a lighter one.
- f) Notched and slant cut bubbler probes have very similar bubble patterns. Their bubble flows are smaller and more uniform than those generated by the flat cuts (Refer to Figures 4a, 4b and 4c). Variations observed in the pressure signal are the result of two separate bubble effects. One is caused by the bubble breaking through the surface of the liquid and the other is caused by the bubble breaking off from the tip of the bubbler probe. The dominant effect on the variation in the pressure reading seems to be the turbulence at the liquid surface.
- g) Temperature test results indicate that each probe has its own temperature response pattern which is a function of the probe tip height above the bottom of the tank and that temperature correction equations as commonly expressed in tank measurement algorithms apply only to probes near the bottom of the tank (i.e., with a relatively small heel).

CURRENT AND FUTURE WORK

Raw test data are now being processed by ENEA for distribution to participating personnel for detailed analysis. A working session on data analysis and documentation of test results is to be held at Brookhaven National Laboratory in January 1988.

Follow-on activities planned under the Joint ITA-USA-IAEA program involve field testing of the RUSKA electromanometer system and the Tracer Technique in the EUREX reprocessing plant, Saluggia, Italy, late 1988 or early 1989. The following are test design activities for the reprocessing input measurement exercise (RIMEX):

- 1) Volume instrumentation tests:
  Ruska-EUREX plant instrumentation comparisions.
  Tank profile, probe calibration and density standardization.
- 2) Input tank calibration (2 or 3 runs).
- 3) Tracer Technique determination of SNM mass in the input tank:
  Liquid tracer addition to UNH solution.
  Solution homogenization and sampling.
  Inspector samples sent to SAL and participating laboratories.
- 4) Conventional volume and concentration determination of SNM mass based on Ruska measurement data and sampling and chemical assay techniques.
- 5) Temperature expansion test with UNH and water solutions:
  Mass measurements using Ruska systems.
  Mass determination using tracer technique with inspector samples sent to SAL and participating laboratories.

REFERENCES

1. M. Aparo, G. Bardone, M. Dionisi, and C. Vicini, "An improved Time Domain Reflectometry (TDR) System for Liquid Level Measurement". To be published.
2. S. Suda, and F. Franssen, "A Safeguards Verification Technique for Solution Homogeneity and Volume Measurements in Process Tank", Nuclear Material Management, XVI, 760-763 (1987).

Max Aparo received his Degree in Nuclear Engineering from the University of Rome in 1980. He obtained an ENEA postgraduate fellowship in the field of research and development on Non Destructive Techniques for the essay of Special Nuclear Material.

In 1983 he joined the ENEA Fuel Cycle Department where he became involved in reprocessing plant Safeguards. Mr. Aparo took a leave of absence from ENEA for 9 months to join, as visiting scientist, the Non Destructive Techniques group of the Los Alamos National Laboratory. Mr. Aparo is the Italian representative in the ESARDA NDA Working Group.

Mario Dionisi received his Degree in Nuclear Engineering from the University of Rome in 1983.

From 1983 to 1986 he was involved in reprocessing plant Safeguards studying, on a fellowship of University of Rome and in cooperation with JRC ISPRA, the input measurement system in a reprocessing plant. In 1986 he joined the ENEA Fuel Cycle Department where he works in the Instrumentation and Automatization Laboratory. Mr. Dionisi is the Italian representative in the ESARDA RIV (Reprocessing Input Verification) Working Group.

Sylvester Suda received Degrees in Mathematics form the University of North Dakota in 1958 and from North Dakota State University in 1962.

Mr. Suda has been involved in volume calibration and reprocessing plant safeguards since 1965 during plant start-up at the Nuclear Fuel Services reprocessing plant, West Valley, N.Y., where he was the nuclear material accountability officer. Since joining the Technical Support Organization of the Department of Nuclear Energy at Brookhaven in 1968, he has participated in numerous domestic and international safeguards exercises. Mr. Suda developed the Ruska electromanometer system under the joint USA-JAPAN-FRANCE-IAEA TASTEX program conducted at the Tokai reprocessing plant form 1979 to 1981. From 1982 through 1985, Mr. Suda served in the Data Evaluation Section, Division of Evaluation of the International Atomic Energy Agency where he was instrumental in establishing the IAEA Bulk Calibration Laboratory. Mr. Suda was chairman of ANSI Standards Committee INMM 8.2 on Volume Calibration Techniques from 1972 to 1982.

Material Accountancy in the Triple Tank Systems of the Wackersdorf Reprocessing Plant

R. Avenhaus
German Armed Forces University
Federal Republic of Germany
M.J. Canty
Kernforschungsanlage Juelich GmbH, Juelich
Federal Republic of Germany
E. Leitner, R. Weh, H.-J. Hein
Deutsche Gesellschaft fuer Wiederaufarbeitung von Kernbrennstoffen mbH
Hannover, Federal Republic of Germany

ABSTRACT

A characteristic of the process flow sheet of the Wackersdorf plant is the serial arrangement of (usually) three tanks for the decoupling of major process stages. The contents of the middle tank are measured, while the content of the other two must be inferred. The operations, measurements, and extrapolations are described and analyzed for ideal and more realistic operating conditions. The analysis shows that reasonable values for the in-process inventory should be obtained in either case.

1. THE TRIPLE TANK CONCEPT IN THE WACKERSDORF REPROCESSING PLANT

A characteristic of the process flowsheet for the Wackersdorf reprocessing plant is the serial arrangement of (usually) three tanks for the decoupling of important process stages. This so-called "triple tank concept"[1] is of particular relevance to the establishment of the running Pu inventory in the process material balance area, and hence to the implementation of near real time material accountancy (NRTMA).

A typical example of a triple tank arrangement is shown schematically in Figure 1. The output (1BP stream) from the first extraction cycle leaves the 1BS scrub column, passes through a kerosine wash in the 1BK mixer-settler, from thence via the 1BKP throughput tank to the ROXI cell where the reduced Pu(III) is reoxidized to Pu(IV) preparatory to the next purification stage. The continuous output of the ROXI cell is then taken up by the first member of the 1BP triple tank system (labelled "catch"). This tank serves as a batcher, passing the liquor bath-wise to the second tank ("analysis") where a sample is taken for radiochemical analysis. After sampling, the analysis tank content is transferred batch-wise to the third tank in the system (labelled "feed") which acts as a de-batcher, providing continuous input to the next stage of purification (represented in the figure by the 2A pulse column).

Since these tanks also act as buffers between main processing stages, their inventory is considerable. The 1BP system, for example, has an average holdup of about 25 kg Pu. For the establishment of the material balance statistics needed for NRTMA, in-process inventories will have to be determined at regular intervals (e.g. once every 13 days[2]). Since the triple tank systems will account for a major portion of this inventory, it is worthwhile to examine in some detail their implications for material accountancy, and in particular for the implementation of near real time accounting in the plant.

The main difficulty is associated with the fact that an exact concentration measurement is only possible in the analysis tank, the other tanks not being equipped for homogenization, sampling and analysis. This, coupled with the possibility of variations in the plutonium concentration entering the triple tank system, may contribute to a degree of uncertainty in the total holdup in the process which would be detrimental to loss/diversion detection sensitivity.

We begin, in the next section, with a statistical analysis of the problem under the assumption of idealized operating conditions and demonstrate that the triple tank systems impose no restrictions in principle to the application of near real time accountancy.

The effect of departures from ideal operation are investigated in section 3 with the aid of a dynamic simulation of the process. It is shown that errors in holdup determinations introduced by concentration fluctuations in normal plant operation are small and probably negligible.

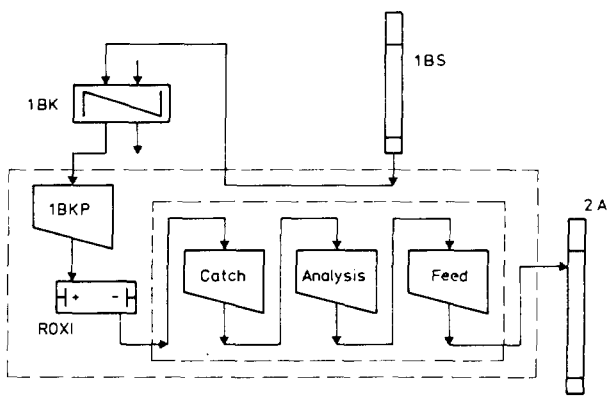


Figure 1. The 1BP Triple Tank System

2. ANALYSIS UNDER IDEAL OPERATING CONDITIONS

The flow of Pu-containing liquor through the triple tank system is shown schematically in Figure 2, where the contents of the three tanks as a function of time are represented. The catch tank is fed continuously and at a constant rate. During the time intervals $[(t-1)_b, (t-1)]$, $[t_b, t]$ etc., the content of the catch tank is transferred to the analysis tank, also at a constant rate as determined by an airlift. We assume that the catch tank is allowed to drain completely, although still accepting continuous input, so that at times $t-1, t, t+1, \ldots$ it is empty.

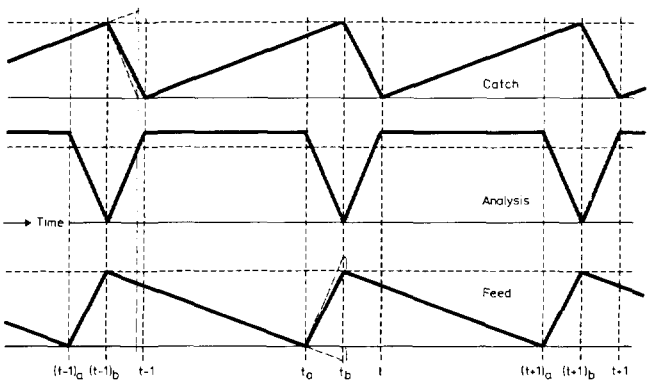


Figure 2. Inventories of the three tanks of the triple tank system as given in Figure 1, as a function of time. Explanation of dashed lines see text.

The third (feed) tank is also emptied continuously and during the intervals $[t-1)_a, (t-1)_b]$, $[t_a, t_b]$ ... receives transfers from the analysis tank.

The analysis tank content is constant over the intervals $[t-1, t_a]$, t, $[t+1]_a]$, ... during which time samples may be drawn and volume determination made.

Clearly under these operating assumptions, the total volume of the triple tank system over time is constant. Moreover the most reasonable times at which to establish the inventory of the three tanks are $t-1, t, t+1, \ldots$. At these times the catch tank is empty, the Pu content of the analysis tank is measured directly, and the Pu content of the feed tank is the product of its instantaneous volume and the concentration measured in the analysis tank prior to the last transfer. Thus, neither changes in Pu concentration nor continuous input/output to and from the triple tank system matter.

For the sake of simplicity, we consider a material balance area (MBA) which consists only of the triple tank system of Figure 1. Furthermore we consider NRTMA inventory periods synchronized with the batching period of the system, inventories being taken at $t-1, t, t+1$, etc. Let I_t^i denote the inventory of tank i, $i=1,2,3$ at time t, and let E_t^k and A_t^k represent the inputs and outputs for the MBA over the period $[t-k, t]$ $k=1,2, \ldots$ measured independently of the inventories. (In reality the measurements may take place far away from the triple tank system or are inventory measurements of previous or subsequent tank-systems, but this complication is ignored here for convenience.)

According to the measurement procedure described above we have

$$I_t^3 = (1-f)I_{t-1}^2 \qquad (2\text{-}1)$$

for any t, where $0<f<1$ is known. In the following we consider inventory periods of variable length, starting with the shortest possible one.

Let us consider first the sequence of shortest possible inventory periods $[t-1, t]$, $[t, t+1]$ etc. The material balance statistics defined in the usual way are

$$L_t^1 := I_{t-1}^2 + I_{t-1}^3 + E_t^1 - A_t^1 - I_t^2 - I_t^3 \qquad (2\text{-}2)$$

for any t, or with (2-1),

$$L_t^1 = (1-f)I_{t-2}^2 + fI_{t-1}^2 + E_t^1 - A_t^1 - I_t^2. \qquad (2\text{-}3)$$

This means that the balance statistic L_t^1 for the interval $[t-1, t]$ not only includes the inventories at the beginning and end of the interval, but also that of the previous interval (P_{t-2}). In addition we have

$$L_{t+1}^1 := (1-f)I_{t-1}^2 + fI_t^2 + E_{t+1}^1 - A_{t+1}^1 - I_{t+1}^2 \qquad (2\text{-}4)$$

$$L_{t+2}^1 := (1-f)I_t^2 + fI_{t+1}^2 + E_{t+2}^1 - A_{t+2}^1 - I_{t+2}^2 \qquad (2\text{-}5)$$

and so on. Therefore we can write

$$cov(L_t^1, L_{t+1}^1) = f(1-f)\,var(I_{t-1}^2) - f\,var(I_t^2). \qquad (2\text{-}6)$$

With our assumption of a stationary state,

$$var(I_t^2) = var(I^2) \qquad (2\text{-}7)$$

for any t, we obtain the following covariance matrix of the material balance statistics

$$cov(L_t^1, L_{t+k}^1) = \begin{cases} var(L_t^1) & \text{for } k = 0 \\ f^2 var(I^2) & \text{for } k = 1 \\ -(1-f)\,var(I^2) & \text{for } k = 2 \\ 0 & \text{for } k = 3,4\ldots \end{cases} \qquad (2\text{-}8)$$

We now consider the next shortest inventory periods $[t-2, t]$, $[t, t+2]$ etc. The corresponding material balance statistics are

$$L_t^2 := I_{t-2}^2 + I_{t-2}^3 + E_t^2 - A_t^2 - I_t^2 - I_t^3 \qquad (2\text{-}9)$$

or, again with (2-1)

$$L_t^2 := (1-f)I_{t-3}^2 + I_{t-2}^2 + E_t^2 - A_t^2 - I_t^2 - (1-f)I_{t-1}^2. \qquad (2\text{-}10)$$

Also, we have

$$L_{t+2}^2 = I_t^2 + (1-f)I_{t-1}^2 + E_{t+2}^2 - A_{t+2}^2 - I_{t+2}^2 - (1-f)I_{t-1}^2$$

$$L_{t+4}^2 = I_{t+2}^2 + (1-f)I_{t+1}^2 + E_{t+4}^2 - A_{t+4}^2 - I_{t+4}^2 - (1-f)I_{t+3}^2. \qquad (2\text{-}11)$$

Therefore, because of the stationary condition (2-7), we get the covariance matrix

$$cov(L_t^2,\ L_{t+2k}^2) = \begin{cases} var(L_t^2) & \text{for } k = 0 \\ -(1+(1-f^2))var(I^2) & \text{for } k = 1 \\ 0 & \text{for } k = 2,3\ldots \end{cases} \quad (2\text{-}12)$$

The same covariance structure pertains for all longer inventory periods.

Having thus determined the covariance matrix for a sequence of inventory periods of well-defined length, we can apply all statistical procedures for the evaluation of NRTMA data which have been discussed in the past. In particular, the independence transformation to obtain the MUF residuals can be performed[3] and tests made to detect loss/diversion from the triple tank system.

3. SIMULATION OF REAL OPERATING CONDITIONS

At present it is unclear whether or not the ideal operation of the triple tank system assumed above will be met in the running plant. In general it may be the case that, at any given time, and in particular at those times where an in-process inventory for NRTMA purposes is required across the entire process MBA, all three tanks will have significant holdups. With reference to Figure 1, consider the following situation:

At time t the analysis tank is full and a sample is taken. Since its input and output are closed, the catch tank is filling and the feed tank is emptying. Assume both these tanks to have no-negligible holdups. We are interested in the total inventory at t.

The (constant) volume in the analysis tank can be determined, as well as the instantaneous volumes in the other two tanks. However the concentrations in the catch and feed tanks are unknown. The concentration in the feed tank is only approximately that measured in the analysis tank at $t-1$ if it has a considerable heel (i.e. is not allowed to drain below a certain level). Similarly, the concentration to be measured in the analysis tank at $t+1$ is not that of the catch tank at t, since, before the next transfer takes place, the catch tank must first complete filling, and mixing will again occur.

The degree of uncertainty introduced by mixing is dependent upon the magnitude and rapidity of fluctuations in the Pu concentration in the 1BP stream as well as the size of the heels of the catch and feed tanks. Since an analytical treatment of this general case seemed to be impossible, it was decided to investigate the problem by means of process simulation.

In order to simulate mixing effects in the process tanks it is sufficient to assume a linear time dependence of the flow rates F and Pu concentrations C over the simulation time increment Δt.[4] For example, if the concentration in a material stream S has the value C at time t and is changing at the rate ΔC per unit time, then, over the interval $t \le t' \le t + \Delta t$, we assume

$$C(t') = C + (t' - t)\Delta C. \quad (3\text{-}1)$$

Similarly, for flow rates,

$$F(t') = F + (t' - t)\Delta F. \quad (3\text{-}2)$$

Let H be the holdup (inventory) at time t in a tank filling from stream S Then, after one time increment, the holdup is

$$H(t+\Delta t) = H + \int_{\Delta t} C(t')F(t')\,dt' =$$

$$H + CF\Delta t + \frac{\Delta t^2(C\Delta F + F\Delta C)}{2} + \frac{\Delta t^3 \Delta C \Delta F}{3}.$$

Similarly, the volume is given by

$$V(t+\Delta t) = V + \int_{\Delta t} F(t')\,dt' = F + \Delta t F + \frac{\Delta t^2 F}{2}.$$

The new tank concentration is then

$$(t+\Delta t) = \frac{H(t+\Delta t)}{V(t+\Delta t)} \quad (3\text{-}3)$$

assuming complete mixing.

A simulation program for the process area of the Wackersdorf plant, including the triple tank systems, already exists for the IBM mainframe computer at the KFA Juelich.[5] It is written in the SIMULA computer language.

For convenience of demonstration and graphics capability, it was decided to port the SIMULA routines for triple tank simulation to a personal computer running under the operating system MS-DOS. Since the language SIMULA is not available for MS-DOS, an emulation routine was written in Pascal which enabled the programming of concurrent processes (co-routining) in the style of SIMULA.[6,7] It was then relatively straightforward to carry over the simulation algorithms directly.

The program defines five parallel processes or co-routines:

- SOURCE: This co-routine simulates an external material stream with varying flow rate and concentration. The variations are modelled as a random walk centered about the corresponding flowsheet values. When the variations exceed a preset limit, the variable resets to the flowsheet value.
- A-TANK: A co-routine which simulates the sampling/analysis tank. The tank fills to capacity, pauses for sampling and empties completely (apart from a small heel).
- B-TANK: A co-routine which simulates batcher/debatcher and constant throughput tanks. This tank can run with either the input valve, the output valve or both valves open at all times.
- OPERATOR: A supervisory co-routine which is responsible for keeping the process running correctly.
- SINK: A co-routine to accept material leaving the process.

The outer dashed rectangle in Figure 1 indicates the process components included in the simulation program. Although the 1BKP throughput tank and the ROXI cell are not part of the triple tank system, they have a considerable holdup. Moreover, mixing in these components will tend to dampen any rapid concentration variations in the 1BP stream entering the system. They were, therefore, included in the simulation. The 1BKP tank and the ROXI cell are combined as an instance of a single B-TANK process. The catch and feed tanks are also instances of B-TANKs, while the analysis tank was instantiated as an A-TANK co-routine.

Procedures are included to accumulate statistics on tank concentrations and to calculate the standard deviation of the error in the estimated holdup caused by mixing in the throughput, catch and feed tanks.

The program is written in Turbo-Pascal (distributed by Borland International) and runs on an IBM PC/AT or compatible with Enhanced Graphics Adaptor and floating-point co-processor.

All flow rates were regulated in the simulation to ± 1%. The Pu concentration in the 1BP stream was allowed to vary within ± 20% of the flowsheet value of 5.07 g/l. These limits were based on an analysis of 1BP concentration data from experiments performed with a full scale mock-up of the first extraction cycle at the Karlsruhe Nuclear Research Center (unpublished data).

The result of a typical run is shown graphically in Figure 3 for a simulation time of 400 hours. At the top of the figure, the variation in the 1BP concentration about the flowsheet value is shown. The holdups in the four tanks as a function of time are shown in the lower half of the figure. From top to bottom:

1. 1BKP throughput tank (and ROXI cell), offset 45 kg.
2. 1BP catch tank, offset 30 kg.
3. 1BP analysis tank, offset 15 kg.
4. 2AF feed tank, offset 0 kg.

The system reaches equilibrium (periodicity) after the first few cycles. At the end of each sample period (flat top on the analysis tank curve) the true instantaneous inventory of all four tanks is recorded. With the above numbering of the four tanks, this is just

$$H_{true} = V_1 C_1 + V_2 C_2 + V_3 C_3 + V_4 C_4$$

At the same time, the estimated inventory is recorded. Two methods for the inventory estimation are assumed:
Method 1: The current concentration in the analysis tank is taken as a sufficient approximation for all four tanks:

$$H_{est} = (V_1 + V_2 + V_3 + V_4) C_3$$

Method 2: The concentration in the feed tank is taken to be that measured in the analysis tank on the previous batch (C_3^-). Similarly, the concentration in the catch tank (and, arbitrarily, in the 1BKP throughput tank and ROXI cell) is the concentration measured in the subsequent batch (C_3^+):

$$H_{est} = (V_1 + V_2) C_3^+ + V_3 C_3 + V_4 C_3 \ .$$

This estimate would be exact if at appropriate times of transfer both catch and feed tanks were emptied completely (see Fig. 2). The standard deviation, σ_{Hest}, of the estimated inventory from the true inventory is calculated after n samples according to

$$\sigma^2_{H_{est}} = \frac{1}{n-1} \sum_{i=1}^{n} (H^i_{est} - H^i_{true})^2 \qquad (3\text{-}4)$$

Table 1 shows the results for a simulation run of 2000 hours, corresponding to 210 analysis tank batches. Comparison is made to current estimates of the standard deviation of the inventory measurement error (analytic error only).

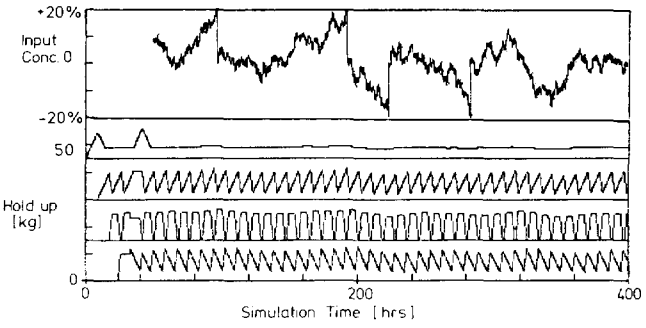


Figure 3. A typical simulation run. See text for details.

Table 1. Simulation Results

No. of samples: 210
Total inventory: 25 kg
Standard dev. (method 1): 0.29 kg
Standard dev. (method 2): 0.14 kg
Measurement error standard dev.: 1.1 kg

It may be concluded from the table that mixing effects in the triple tank inventory determination can be neglected provided the concentration variations in the input stream are of the order of or smaller than ± 20%

4. CONCLUDING REMARKS

Even if we assume the ideal situation of section 2 it is not to be expected that all of the triple tank system in the material balance area (MBA) will be in phase. However, this does not represent a problem in principle for the closing of the material balance area in the MBA.

In the event that, for operational reasons, the assumptions of section 2 are not valid, the simulation results of section 3 show that mixing effects in the triple tank inventory determination can be neglected provided the concentration variations in the input stream are of the order of or smaller than 20%.

5. REFERENCES

1. R. Weh, H.-H. Schmidt and M.J. Canty, "A realistic data basis for in-process inventory taking", Proc. 7th ESARDA Symp., Liege, 1985, p 65.
2. E. Leitner, R. Weh, R. Avenhaus and M.J. Canty, "Near real time material accountancy in an industrial scale reprocessing plant", Nuclear Safeguards Technology 1986, Vol. 1, IAEA, Vienna, 1987, p 365.
3. R. Avenhaus, "On the effect of systematic errors in near real time material accountancy", Proceedings of the 28th Annual INMM Meeting, Newport Beach, July, 1987, p 505.
4. E.A. Hakkila et al., "Coordinated safeguards for materials management in a fuel reprocessing plant, II Appendix", LA-6881, Vol II, 1977, p G-1.

5. M.J. Canty, "The influence of contractor and evaporator holdups on detection sensitivity", JINMM, Jan, 1987, p 17.
6. H. Rohlfing, "SIMULA Eine Einfuehrung", B.I. Mannheim, 1973.
7. M.S. Krishnamoorthy and S. Agnarsson, "Concurrent Programming in Turbo Pascal", BYTE, Vol. 12 No. 4, April, 1987, p 127.

Rudolf Avenhaus is Professor of Statistics and Operations Research at the German Armed Forces University, Munich. Prior to his academic appointment in 1980, he was Research Assistant at Mathematics and Physics Institutes of the Universities of Karlsruhe and Geneva, and Research Scholar at the Nuclear Research Center Karlsruhe. From 1973 to 1975 and again in 1980 he worked at the International Institute for Applied Systems Analysis (IIASA), Laxenburg near Vienna. He is the author of numerous papers in physics, statistics, game theory and its applications to nuclear problems, especially nuclear material safeguards; he is author of the books "Material Accountability" (Wiley 1977) and "Safeguards Systems Analysis" (Plenum 1986), and co-editor of the books "Mathematical and Statistical Methods in Nuclear Safeguards" (Harwood 1982) and Quantitive Assessment in Arms Control" (Plenum 1984). From 1976 to 1983 he was elected council member of the German Peace and Conflict Research Society.

Morton Canty received his Ph.D. in experimental nuclear physics from the University of Manitoba in 1969. He carried out research in low energy nuclear structure at the universities of Bonn, Groningen and Marburg. Since 1979 he has been working in the Program Group for Technology and Environment at the Nuclear Research Center in Jülich, in the field of safeguards systems development.

Rudolf Weh received his degree in chemical engineering from the Technical University of Munich, FRG, and afterwards spent more than seven years at the Institute for Radio-chemistry in Garching/Munich. He was mainly involved in research on extraction kinetics in Purex-like systems. He joined DWK in 1979 as a project engineer. Presently, he is head of the Safeguards Division and responsible for MC&A and international safeguards implementation for all DWK projects including reprocessing, intermediate storage and final disposal conditioning of spent fuel.

Erwin Leitner received his Dr. rer. nat. from the University of Heidelberg, FRG. He worked for several years in the field of high energy physics at Heidelberg and at the European Nuclear Research Centre (CERN) near Geneva, Switzerland. Since 1978 he has been with the DWK in Hannover, FRG. He is in charge of reprocessing plant safeguards, with particular involvement in system analytical studies, near real time accountancy, and NDA development.

Dr. H.-J. Hein received his Ph.D. in Inorganic Chemistry from the Technical University in Hannover, FRG, in 1955. Afterwards, he spent 5 years working for DEGUSSA. Following a period of training with the Mallinckrodt Nuclear Corporation, Plant Hermatite, he joined NUKEM, being responsible for chemical R & D work. From 1965 to 1983 he was responsible for MC&A with regard to the WAK in the GWK. Since 1983 Dr. Hein has been working as a consultant for DWK.

Monitoring of Field Data

R. Haas
CEC EURATOM Safeguards Directorate
Luxembourg
Y. Haurie and H.J. Metzdorf
CEC Joint Research Center
Ispra, Italy.
H. Reuters
PROCOM, Aachen, Federal Republic of Germany

ABSTRACT

EURATOM is developing presently a modular monitoring system in order to enhance containment and surveillance measures in nuclear plants. Since this monitoring system includes the authenticable transfer of measurement data it will be applicable also for the monitoring of NRTA field data.

In the paper the functional design of the modular monitoring system is described together with an application to a tank store.

INTRODUCTION

With the hope of improving the efficiency of today's safeguards and to cope with the evolution of the fuel cycle in the European Communities, EURATOM invests some effort to further develop containment and surveillance (C/S) methods (ref. 1). These efforts include also the further development of the technical means. It had been proposed that the integration of monitoring, or data logging into C/S significantly improves the assurance which is obtained from the application of C/S measures.

We are in the process of completing the development of a monitoring system which we consider suited for a large range of applications. The collection of NRTA field data should be another useful application for this monitoring system.

2. REQUIREMENTS FOR A SAFEGUARDS MONITORING SYSTEM

Data from different measurement instruments, which will be called sensors, must be collected in a central station or in substations. The sensors may be distributed over large areas of the plant. The monitoring system which collects these data must fullfill the following requirements:

- reliability (data must not get lost or modified),
- tamper resistence, data authentication,
- functional reliability,
- possibility for adaptation to field requirements and for extension,
- user-friendliness,
- cost efficiency (use of standard components).

Except for the authentication problem, commercial monitoring systems exist in industrial plants (so called Building Automation Systems), for instance, for the collection and evaluation of infrastructure related data. This experience had been incorporated into the design of the VACOSS fiber optic seal (ref. 2) which started to enter safeguards use some five years ago.

3. STRUCTURE OF THE VACOSS MONITORING SYSTEM

A design proposal for a Safeguards Monitoring System was made in the early 1980s (ref. 3) and a demonstration prototype was built for the continual verification of VACOSS seals, named Local Verification System (LOVER). Maintaining the basic structure, the system was redesigned and has been extended to accept as sensor also any ON/OFF sensor (ref. 4). Presently also general measurement sensors are being included. Fig 1. shows the lay-out of the basic system with its 4 levels. The combination of several systems in a fifth level, central station, is of course possible but not the scope of this presentation.

The system operates in a strictly hierarchical way, i.e. each level has direct access to the next lower level only. Each level operates autonomously after initialisation, surveils the lower level, retrieves and stores any new information and keeps it available for the next higher level. Since each level is equipped with suitable memory capacities the failure of a higher level does not cause a system failure.

The sensor data is read by the Level 2 sensor control unit (SUE); both are integrated into one tamper-resistent housing. Upon request by level 3 the SUE sends the requested information on the party-line to the adapter box III (ADBIII) as clear text and encrypted text. By decryption and comparison the ADBIII authenticates the message, adds it to its own data set and in case the data set had been requested by the host computer the latter receives the message.

The VACOSS 3 and the improved VACOSS 4 seals are both fiber optic sensors combined with a SUE of limited capacity. The VACOSS 4 special is essentially the SUE which may surveil any ON/OFF sensor (motion detector,

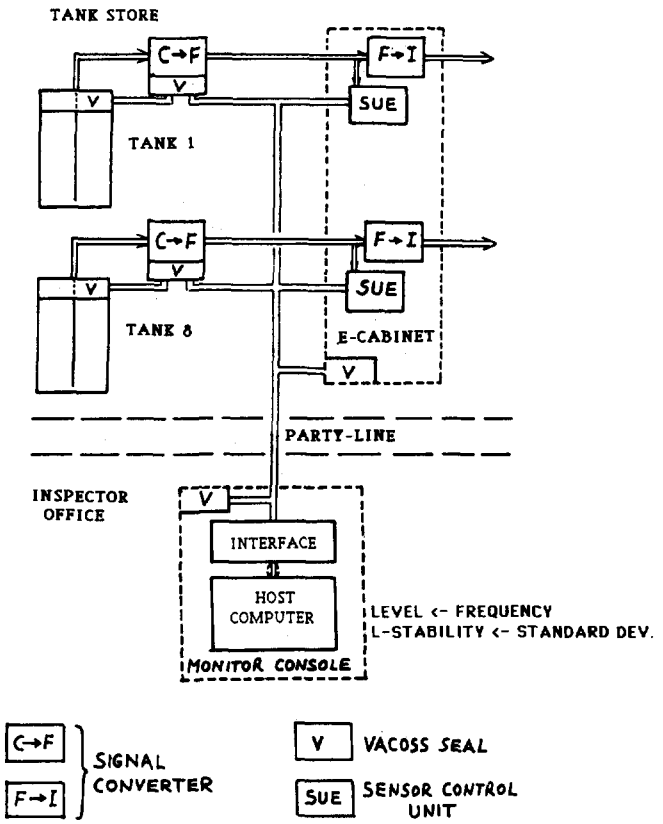


Figure 1. Modular Monitoring System

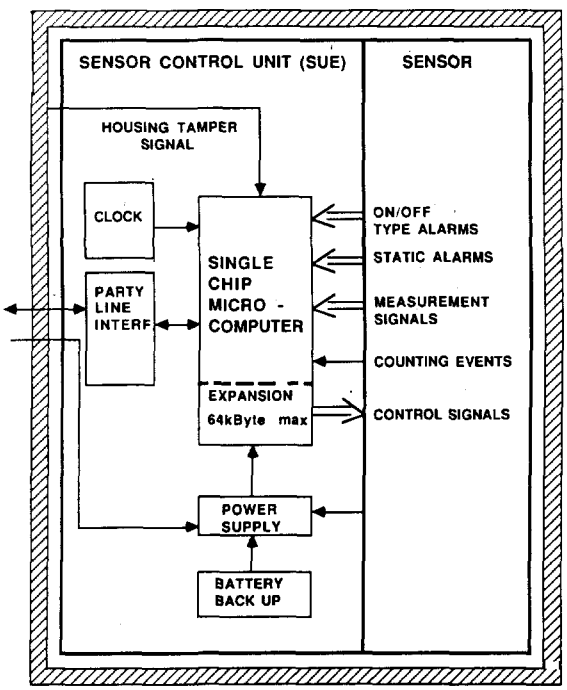


Figure 2. Schematic Diagram of Sensor Control Unit

threshold detector, etc.). This presentation is concerned with the general SUE.

4. DESCRIPTION OF THE MONITOR COMPONENTS

4.1 Sensor

Any device which produces an information signal (electric current, voltage, frequency, or digital signal) may be used as sensor. There may be several signals, representing measurement information and dynamic or static states of the sensor. Dynamic states may change repeatedly between ON and OFF (fiber loop, sensor power supply, etc.); a static variable can only change once after initialisation and it is normally used to indicate tamper conditions or component failure.

4.2 Sensor Control Unit (SUE)

Fig. 2. shows a symbolic diagramm of the SUE. The main component is a single chip microcomputer (8 k Byte memory). The SUE continuously surviels the state of the sensor, it keeps the time and a record of the last status changes with the time when they occurred. Upon request of level 3 the SUE may give control information to the sensor and read the measurement information.

The SUE number (the sensor address) and the identifier are fixed data; the encryption key and initialisation date and time are data which the SUE receives upon initialisation.

The SUE may be extended (64 k Byte maximum) which allows it to perform quite complex data collection and evaluation functions.

4.3 Adaptorbox III (ADBIII)

The originally developed adaptor boxes I and II were designed for manual interrogation of the VACOSS seals; the ADBIII has been developed for automated interrogation of VACOSS seals and the VACOSS compatible SUEs. The ADBIII is an interface unit, a single board microcomputer (FALCON from Digital Equipment Corporation), which executes all the routine work required for the interrogation of the SUEs. Its basic functions are as follows:

- management of the party-line communication,
- encryption/decryption and authentication,
- maintaining of the data required for addressing and communication with the SUEs,
- date and time keeping,
- cyclic surveillance of the SUEs for changes of status and updating of the alarm table (table of status changes obtained from SUEs and detected by the ADBIII),
- communication with SUEs upon specific request from the host computer,
- communication with the host computer via a RS-232 port.

The frequency of SUE interrogation, the encryption key, the identifier (encryption key for the first initialisation), and the configuration of the SUE status change table can be defined individually for each of the SUEs.

4.4 Host Computer

With the routine work being executed by the adaptor box the host computer can be selected in view of the:

- amount of data to be processed and the evaluation software,
- the required input/output facilities and periferals; one port (presently RS 232C) is required for the communication with the ADBIII.
- the environmental conditions.

Multiple I/O ports, multitasking or parallel processors will normally not be required for the monitoring task.

The application software of the host computer must satisfy the following functions:

a) Initialisation of all components (ADBIII and SUEs),
b) retrieval of status change information from the ADBIII, evaluation and storage,
c) retrieval of measurement information from the SUEs (through the ADBIII), evaluation and storage,
d) user-friendly inspector interface and preparation of output (hard copy, floppy disc, etc.)

We have used for a demonstration of the monitoring system with several VACOSS seals and a motion detector (VACOSS 4 special), satisfying functions a), b) and d) a HP41CX (ref. 4). For laboratory test and development an IBM compatible PC is used presently.

5. APPLICATION OF THE MONITORING SYSTEM

A first application of the monitoring system is presently developed for a Pu-nitrate store. The liquid arrives in small containers and is accumulated in 300 ltr. tanks. Sealing of the tanks for Safeguards purposes is not feasible technically.

In order to reduce the remeasurement effort the liquid volume will be monitored continuously using the operators level gauges (capacitance sensors). With the knowledge of:

- the present volume and
- the volume changes since the last verification measurement

the Pu content can be calculated if there were no volume additions in the mean time. Fig. 3 shows the system layout. The capacitance signal is converted to frequency and then converted into current to supply the operators control instrumentation. The output of the capacitance-frequency converter (sensor) is read by the SUE and transfered through the ADBIII to the host computer. The SUE will also monitor the status of the power supply of the converter. Since the frequency-current converter includes variable range adjustments it is better for safeguards purposes to pick-up the frequency signal. The electronic units and the positioning devices for the capacitive sensors will be protected by VACOSS seals.

The SUE in this application is equipped with an external memory expansion so that 2 types of measurement signals can be generated upon request of the host computer:

single frequency readings,
the average frequency and standard deviation of N readings at T/sec interval.

The host computer will obtain from the ADBIII the alarm information such as VACOSS seal events, power supply failures of converters, party-line continuity problems, etc. It will request through the ADBIII at regular intervals the results of the frequency measurement of the different SUEs.

The interpretation of the frequency values in volume is done by the host computer, using experimentally obtained calibration constants.

Calibration tests have shown that also temperature information is required for each tank in order to improve the volume calculation. This information is collected by different SUEs, which are not indicated in fig. 3.

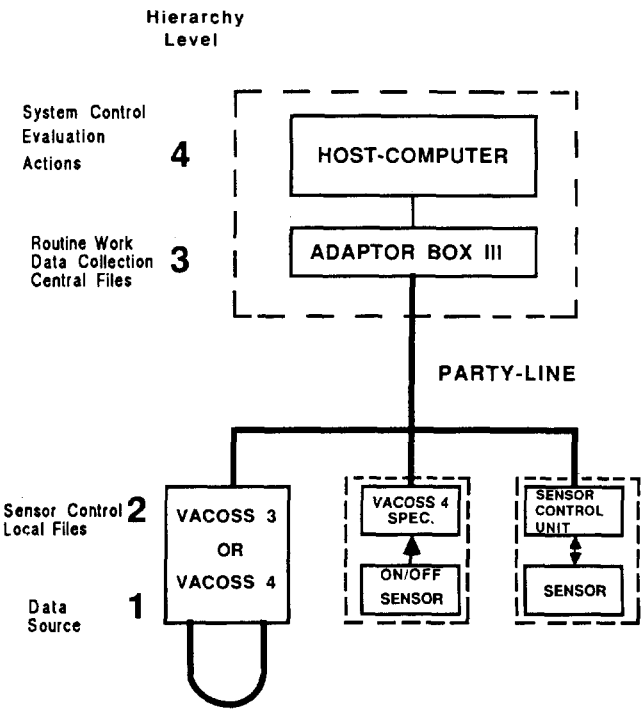


Figure 3. Liquid Level Monitor

With suitable algorithms the volumes, volume changes and the periods of stable volume are evaluated and stored.

Other software packages in support of the inspector are planned for the review, consolidation and documentation of the tank history. Together with inspection data from other sources the inspector will eventually be able to arrive at a complete safeguards analysis of the tank store. For this reason a multitasking micro-computer has been chosen as host computer.

In the present project 8 tanks will be read for level (frequency) and for temperature (current) and 5 VACOSS seals will be monitored, i.e. all together 21 sensors. In the long term the number of tanks will be increased. No basic prob-

lems are expected in that respect. Since the data communication will always use the same party-line, no modification of the installations will be required.

6. CONCLUSION

The above described modular monitoring system will permit to collect field data in authenticable way making use of operators sensors (and measurement equipment) and of standard components for data communication. Addressable sensor control units which are connected by a single party line and the encrypted data transfer simplify installation, operation and verification of the monitoring system. This system will be suited also for the monitoring of NRTA field data.

REFERENCES

1. M. Cuypers, R. Haas: Can Containment and Surveillance Play a more Important Role in Safeguards? Third ANS International Conference on the Process Operations-Safeguards Interface, San Diego, December 1987. to be Published.
2. F. Arning, H. Reuters, H. Bueker: Remote Verifiable Sealing System for Safeguards Application. ESARDA Bulletin Nr. 2, 1982.
3. H. Reuters, M. Wolf: Entwicklung eines Fernüberwachungssystems für Containment-und Serveillance-Instumentierung zum Zwecke der internationalen Spaltstoffflusskontrolle, Federal Republic of Germany, Forschungsbericht BMFT-EB (KWA 2040/3) 1981.
4. H.J. Metzdorf, R. Haas, H. Reuters, H. Bueker: Modular Monitoring System, 9th. ESARDA symposium on Safeguards and Nuclear Material Management, London, 1987.

Posts Vacant in the IAEA

The Department of State, the U.S. Arms Control and Disarmament Agency and the Department of Energy have initiated a program to improve recruitment of U.S. nationals for employment in the IAEA.

In an effort to support this program, *JNMM* will publish IAEA vacancies.

Deptartment of Nuclear Energy and Safety

Division: Scientific and Technical Information *Section:* INIS *Position:* Engineer *Grade:* P-3 *Vacancy* #88/037 *Opened:* 26 July 1988 *Closing:* 25 November 1988

Division: Nuclear Safety *Section:* Radiation Protection *Position:* Radiation Protection Officer *Grade:* P-4 *Vacancy* #88/032 *Opened:* 5 July 1988 *Closing:* 4 November 1988

Department of Research and Isotopes

Section: Industrial Applications & Chemistry *Position:* Industrial Tracer Specialist *Grade:* P-3 *Vacancy* #88/038 *Opened:* 26 July 1988 *Closing:* 25 November 1988

Division: Joint FAO/IAEA *Section:* Soil Fertility, Irrigation, and Crop Production *Position:* Soil Scientist/Plant Nutritionist *Grade:* P-3 *Vacancy* #88/034 *Opened:* 5 July 1988 *Closing:* 4 November 1988

Department of Safeguards

Division: Development and Technical Support *Section:* System Studies *Position:* Senior Safeguards Analyst *Grade:* P-5 *Vacancy* #88/036 *Opened:* 26 July 1988 *Closing:* 25 November 1988

Division: Operations *Section:* Nuclear Safeguards Inspector *Position:* P-4 (several positions) *Grade:* 87/SGO-4 *Vacancy* #9 June 1987 *Opened:* Continuous recruitment will be carried out until 31 December 1988

Division: Operations *Section:* Nuclear Safeguards Inspector *Position:* P-3 (several positions) *Grade:* 87/SGO-3 *Vacancy* #9 June 1987 *Opened:* Continuous recruitment will be carried out until 31 December 1988

Division: Operations *Position:* Nuclear Safeguards Inspector *Grade:* P-4 (several positions) *Vacancy* #88/SGO-4 *Closing:* Continuous recruitment will be carried out until 31 December 1988

Divisions: Operations *Position:* Nuclear Safeguards Inspector *Grade:* P-3 (several positions) *Vacancy* #88/SGO-3 *Opened:* 14 June 1988 *Closing:* Continuous recruitment will be carried out until 31 December 1988

How to Apply

Applications must include a vacancy notice number, and should be mailed to the United States Mission to the International Atomic Energy Agency, Kundmanngasse 21, 1030 Vienna, Austria (Attention Ronald Bartell). After U.S. Government endorsement is given, the Mission will forward the application to the Division of Personnel at the IAEA.

U.S. Candidates must also send a photocopy of the original application to: (for positions in the Department of Safeguards) P.O. Box 650, Brookhaven National Laboratory, Upton, N.Y. 11973, (for all other positions) IO/T/SCT, Rm. 5336, Department of State, Washington, D.C. 20520.

For more information contact Mr. W. Porter, Department of Energy, FTS 586-6175. Potential applicants should leave their name, address, and position in which they are interested. DOE will then forward a package of information on the IAEA and the position they wish to apply for.

TECHNICAL WORKING GROUPS

continued from page 5

Detecting Outsiders and Insiders by Integrating the Elements of Delay, Intrusion Detection, and Entry Control into Physical Security Systems

Workshops in this general topic area have been very interesting and well attended in the past. The most recent one was held in November 1987 in Kerrville, Texas. The next one is tentatively scheduled for the fall of 1989 in the mid-East Coast area. Douglas Kunze, (703) 934-4038, PSC, Inc., and James Hamilton, (614) 289-2331 ext 2204 or 2109, Martin Marietta Energy Systems, are the workshop co-Chairmen.

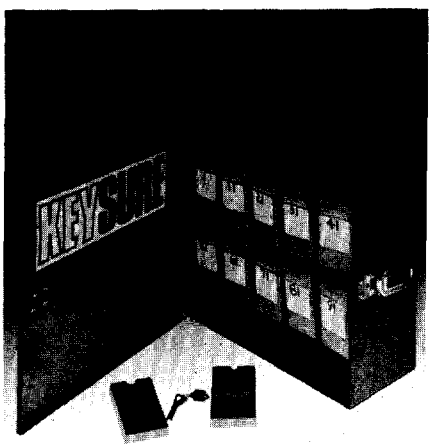
Security Personnel Training

This workshop was held at the Marriott Hotel in Albuquerque, N.M. on April 11-14, 1988. Many excellent sessions including a tour of the DOE's Central Training Academy were held. Fred Crane, Energy and Environmental Group, ERCI, and Dennis Wilson, DOE Central Training Academy were the Workshop Co-chairmen. The next workshop on this topic will probably be scheduled in the spring of 1990.

James D. Williams, Chairman
INMM Technical Working Group
on Physical Protection
Sandia National Laboratories
Albuquerque, New Mexico

New Keyless Control System

Individual "Keyless lockboxes" make up this new key control system. The individual lockboxes are actually a container in the form of a security seal. They are made of plastic and are designed to be broken to gain access to the key inside. These lockboxes are not reuseable after they are broken. The breaking indicates that the key has been used or tampered with. Authorizing signatures are required to validate each lockbox.



These lockboxes are a stand alone product and can be used independently of the storage cabinet. They can be carried and can also be surface mounted. KEYSURE is the only product that will give complete accountability for the use of a key or anything else that you might want to put inside, such as an access control card, PIN number, combination, access code or written document.

These "keyless lockboxes" are available in opaque blue and clear transparent plastic.

For more information contact: KEYSURE, P.O. Box 439, Prince Station, New York, N.Y. 10012-0008, phone 212/219-0015.

New Vehicle and Pedestrian Barriers

Hy-Security Gate Operators has developed a line of barriers that are effective against pedestrians as well as all types of vehicles, including bicycles and motorcycles.

The barriers are light weight and quickly deployed in any of four different methods. The barriers are designed to fit on a gate of any design and they close the entire opening to prevent passage of hostile elements.

The barriers are sized to fit the perceived threat and thus allow the user to select a barrier to fit his particular application.

For information contact Dave Lortz, 800/321-9947.

Radioactive Solutions and Standards

Isotope Products Laboratories manufactures a complete line of radioactive solutions and standards for use in research, instrument calibration and environmental applications. IPL provides alpha, beta and gamma standards, radioactive gas standards, large volume gamma standards and planchet style standards, all in various activities and configurations. Over fifty different standardized solutions are supplied in flame sealed ampoules or as nominal solutions. Bulk radioisotopes in solution are also available. Most standards are NBS traceable.

IPL has available for a forty page catalog which contains information about their complete product line. To order your catalog please call Isotope Products Laboratories at 818/843-7000.

October 30-November 4, 1988
International Conference of the American Nuclear Society, Washington, D.C. U.S.A. *Sponsors:* American Nuclear Society, European Nuclear Society *Contact:* Myron B. Kratzer, (301) 261-1501,1635 Orchard Dr., Annapolis, MD 21401

January 11-13, 1989
INMM Spent Fuel Management Seminar VI, Loew's L'Enfant Plaza, Washington, D.C. U.S.A. *Sponsor:* Institute of Nuclear Materials Management *Contact:* Beth Perry, (312) 480-9573, INMM, 60 Revere Dr., Suite 500, Northbrook, Ill. 60062

April 17-23, 1989
8th Symposium on the Training of Nuclear Facility Personnel, Gatlinburg, Tenn. *Sponsor:* Oak Ridge National Laboratory and Reactor Operations Division of the American Nuclear Society *Contact:* W.E. Eldridge, Co-chairman, 8th Symposium on the Training of Nuclear Facility Personnel, Oak Ridge National Laboratory, P.O. Box 2008, Bldg. 3042, Oak Ridge, TN 37831-6060.

May 1-June 1, 1989 (Call for Papers)
11th Symposium on Safeguards and Nuclear Material Management, Luxembourg *Sponsor:* European Safeguards Research and Development Association (ESARDA) *Contact:* L. Stanchi, CEC-JRC, 1-21020 Ispra (Verese) Italy.

June 1989 (Call for Papers)
30th Annual Meeting of the Institute of Nuclear Materials Management *Sponsor:* Institute of Nuclear Materials Management *Contact:* INMM Headquarters, 60 Revere Dr., Suite 500, Northbrook, IL 60062 312/480-9573.

June 11-16, 1989
9th International Symposium on the Packaging and Transportation of Radioactive Materials (PATRAM '89), Washington, D.C. U.S.A. *Sponsor:* U.S. Department of Energy and the International Atomic Energy Agency *Contact:* Judith Gale, (301) 986-4870, 7101 Wisconsin Ave., Suite 610, Bethesda, MD 20814

October 23-28, 1989
1989 Joint International Waste Management Conference, Kyoto, Japan *Sponsor:* ASME, JSME, AESJ *Contact:* To submit papers on high-level waste contact S.C. Slate, (509) 376-1867, Battelle, P.O. Box 999, Richland, WA 99352; to submit papers on low-level waste contact F. Fiezollahi, (415) 768-1234, Bethtel National, 50 Beale St., P.O. Box 3965, San Francisco, CA 94119

The events listed in this calendar were provided by Institute members or taken from widely available public listings. We urge INMM members, especially those from countries outside the United States, to send notices of other meetings, workshops or courses to INMM headquarters.

ADVERTISER INDEX