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ESARDA BULLETIN

News about ESARDA

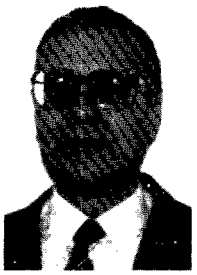
The ESARDA Bulletin welcomes two new convenors of ESARDA working groups appointed from January 1st, 1989 for a term of four years :

- **Mr. S. Guardini,** Commission of the European Communities, Joint Research Centre, Ispra, Italy, who is appointed as convenor of the ESARDA working party on Techniques and Standards for Non-Destructive Analysis (NDA).
- **Mr. R. Weh,** Deutsche Gesellschaft für Wiederaufarbeitung von Kernbrennstoffen mbH (DWK), Hannover, F.R. Germany, who is appointed as convenor of the ESARDA working group on Reprocessing Input Verification (RIV).

The ESARDA Bulletin is pleased to remind the main achievements of these working groups obtained under the guidance of the past convenors, Messrs. R.J.S. Harry, ECN Petten, Netherlands, for the NDA Working Group, and C. Foggi, CEC, JRC-Ispra, Italy, for the RIV Working Group.

S. Guardini, new convenor of the NDA WG

R. Weh, new convenor of the RIV WG



C. Foggi, past convenor of the RIV WG

R.J.S. Harry, past convenor of the NDA WG

ESARDA Working Group on Techniques and Standards for Non-Destructive Analysis (NDA)

Mr. R.J.S. Harry has been convenor since the second meeting of this working group on 8-9 July 1975, when he succeeded Mr. D.R. Terrey, until the 1st January 1989.

The NDA Working Group has been involved since the beginning in the following main areas of nondestructive assay : gamma-ray measurements, neutron (active and passive determinations), calorimetry, k-edge densitometry and study and production of Reference Materials.

Amongst the main activities of the NDA Working Group under the convenorship of Mr. Harry we can recall :

- At the beginning of the working group life, an inventory was taken of the different kinds of NDA-reference materials available and the various NDA techniques in use at that time. The results of these actions have been published in reports of the ESARDA Association.
- The gamma-spectrometric determination of the plutonium isotopic composition has been a regular subject on the agenda during all the years.
- An important initiative of the working group was the international project to establish a set of primary reference standards with different enrichments for the accurate gamma-spectrometric determination of the enrichment of uranium. The Certified Reference Materials (CRMs) for Gamma Spectrometry and Safeguards EC CNRM 171 NBS SRM 969 have been produced and certified in a co-operation with the CBNM (CEC, JRC-Geel, Central Bureau for Nuclear Measurements) and the NBS (National Bureau of Standards, U.S.A.). The measurement technique has been described thoroughly in a users manual.
- Three intercomparison studies have been performed : the Pu isotopic composition determination on NBS reference materials, the interlaboratory measurements on U_3O_8 CRMs and PIDIE (Plutonium Isotopic Determination Intercomparison Exercise), which is nearing completion soon.
- The working group has organized several special sessions on neutron coincidence counting in which also additional specialists participated.
- The experience gained with rod scanners was the subject of a special session in which also the plant operators participated.

ESARDA Working Group on Reprocessing Input Verification

Mr. Foggi has been the Convenor of the ESARDA Working Group for Reprocessing Input Verification (RIV) since the foundation of the group.

Earlier, from 1975 to 1983, he had been the Convenor of a former ESARDA Working Group dealing with a particular aspect of reprocessing input verification : Isotopic Correlation Techniques (ICT). In 1982, the Steering Committee changed the terms of reference and the name of this group which, from that time. covered the various aspects of the reprocessing input verification under the name of RIV.

Among the many achievements of the ICT and RIV Groups in the 1985-88 period, we would like to remind three types of activities :

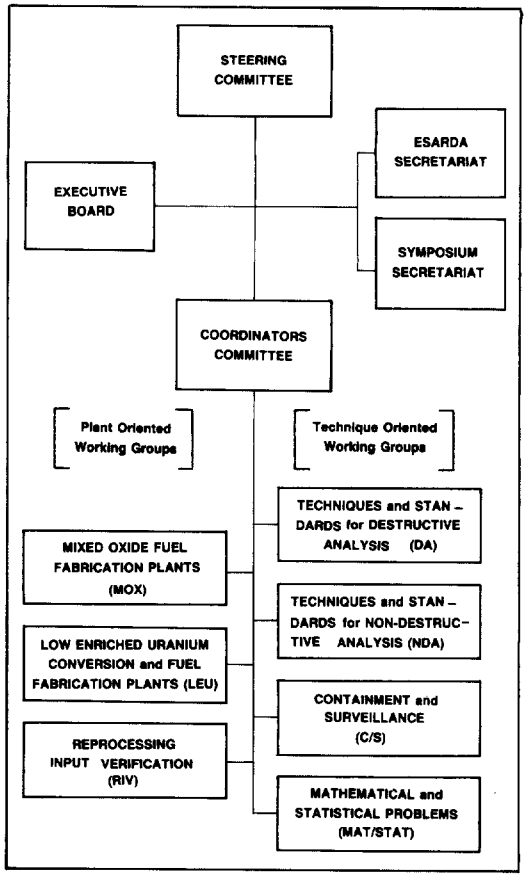
1) - the preparation of data bases for the isotopic composition of irradiated fuels
   - the creation of models for isotopic data correlation in irradiated nuclear fuels
   - the creation of statistical models for data evaluation, which were then utilized by research laboratories and inspectorates
2) - the Isotopic Correlation Experiment (ICE) (carried out at the WAK Reprocessing Plant)
   - the Benchmark Exercise on Isotopic Correlations (carried out on real data obtained at the COGEMA Reprocessing Plant)
3) - the Symposium on Isotopic Correlation Techniques (held in Stresa in 1978)
   - the Seminar on Tracer Techniques (held at Ispra in 1983).

In October 1988 Mr. Foggi was appointed Secretary of our Association.

ESARDA is an association of European organizations formed to advance and harmonize research and development of safeguards. It also provides a forum for the exchange of information and ideas between nuclear facility operators and safeguarding authorities.

Its partners as of 1st June 1989 were:

- The European Atomic Energy Community
- The Kernforschungszentrum Karlsruhe (KfK) - Fed. Rep. of Germany
- The Centre d'Etude de l'Energie Nucléaire - Studiecentrum voor Kernenergie (CEN/SCK) - Belgium
- The Comitato Nazionale per la Ricerca e per lo Sviluppo dell'Energia Nucleare e delle Energie Alternative (ENEA) - Italy
- The Stichting Energie Onderzoek Centrum Nederland (ECN) - Netherlands
- The United Kingdom Atomic Energy Authority (UKAEA) - United Kingdom
- The Energistyrelsen (ENS) - Denmark
- The Comissariat à l'Energie Atomique (CEA) - France
- British Nuclear Fuels plc (BNFL) - United Kingdom
- Kernforschung Anlage Jülich (KFA) - Fed. Rep. of Germany
- Centro de Investigaciones Energéticas Medio Ambientales y Tecnológicas (CIEMAT) - Spain



The Association is pleased to thank Messrs. Foggi and Harry for having contributed to the success of ESARDA with their leadership of their Working Groups and to acknowledge the valuable work carried out under their guidance.

Their persevering dedication over fourteen years has resulted in a harmonic development of their working groups with brilliant scientific and technical achievements in various projects and cooperative activities as described in the editorial.

Messrs. Foggi and Harry are continuing their collaboration with ESARDA in other positions.

C. Fizzotti
Chairman of ESARDA

Who's Who in ESARDA ?

(as of 1st June 1989)

Chairman 1989 *C. Fizzotti,* ENEA Casaccia, Italy
Appointed chairman 1990
A.M. Versteegh, ECN, Petten, Netherlands
Secretary *C. Foggi,* CEC, JRC-Ispra, Italy
Permanent Symposium
Scientific Secretary *L. Stanchi,* CEC, JRC-Ispra, Italy

ESARDA Steering Committee

C. Beets, Ministry of Foreign Affairs, Belgium
F. Brown, Dept. of Energy, U.K.
M.J.C. Charrault, CEC Brussels, Belgium
M. Cuypers, CEC, JRC-Ispra, Italy
A. Demildt, CEN/SCK Mol, Belgium
S. Finzi, CEC Brussels, Belgium
C. Fizzotti, ENEA Casaccia, Italy
P. Frederiksen, Risoe, Denmark
R. Gerstler, BMFT, F.R. Germany
A. Gloaguen, EDF, France
W. Gmelin, CEC, Safeguards Directorate, Luxembourg
B.W. Hooton, UKAEA, Harwell, U.K.
K.L. Huppert, WAK, Eggenstein-Leopoldshafen, F.R. Germany
R. Kroebel, KfK, Karlsruhe, F.R. Germany
J.M. Leblanc, Belgonucléaire, Belgium
G. Le Goff, CEA Paris, France
B. Lerouge, CEA Fontenay-aux-Roses, France
R.D. Marsh, BNFL Risley, U.K.
T.T. Nielsen, Ministry of Energy, Denmark
A. Petit, COGEMA, France
F. Pozzi, ENEA Saluggia, Italy
J. Sánchez, CIEMAT, Spain
G. Stein, KFA Jülich, F.R. Germany
P. Vanni, ENEA DISP, Italy
A.M. Versteegh, ECN Petten, Netherlands
H.J. Zakrocki, VDEW-RWE, F.R. Germany (Permanent observer)

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A. Demildt, CEN/SCK Mol, Belgium
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C. Fizzotti, ENEA Casaccia, Italy
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B. Lerouge, CEA Fontenay-aux-Roses, France
T.T. Nielsen, Ministry of Energy, Denmark
J. Sánchez, CIEMAT, Spain
G. Stein, KFA Jülich, F.R. Germany
A.M. Versteegh, ECN Petten, Netherlands
W. Stanners, CEC, Safeguards Directorate, Luxembourg

ESARDA Coordinators

M. Aparo, ENEA Casaccia, Italy
W.G. Bahm, KfK, Karlsruhe, F.R. Germany
R. Carchon, CEN/SCK Mol, Belgium
M. Cuypers, CEC, JRC-Ispra, Italy
P. Frederiksen, Risoe, Denmark
R.J.S. Harry, ECN Petten, Netherlands
Miss M. Neuilly, CEA Cadarache, France
B. Patrick, UKAEA Harwell, U.K.
G. Vandenput, CEC, SAfeguards Directorate, Luxembourg
A. Velilla, CIEMAT, Spain

Working Group Convenors

Techniques and Standards for Non-Destructive Analysis (NDA)
S. Guardini, CEC, JRC-Ispra, Italy

Techniques and Standards for Destructive Analysis (DA)
P. De Bièvre, CEC, JRC-Geel, Belgium

Reprocessing Input Verification (RIV)
R. Weh, DWK, F.R. Germany

Containment and Surveillance (C/S)
F.J. Walford, UKAEA Harwell, U.K.

Low-Enriched Uranium Conversion/Fabrication Plants (LEU)
P.P.A. Boermans, FBFC, Belgium

Mathematical and Statistical Problems (MAT/STAT)
to be appointed

MOX Fuel Fabrication Plants (MOX)
G. Le Goff, CEA Paris, France

ESARDA Bulletin Editor

L. Stanchi, CEC, JRC-Ispra, Italy

DWK Workshop on Tank Calibration and the CALDEX Exercise

R. Weh
DWK, Hannover, F.R. Germany

Introduction

The accuracy of the material balance in reprocessing plants is decisively influenced by the quality of the input measurement of the fuel solution. If the volumetric method is used here, knowledge of the analytical error as well as knowledge of the volume determination play an important part. DKW has, therefore, set up a test facility in the TEKO test establishment to gather information likely to come to bear on the optimization of the design of the Wackersdorf Reprocessing Plant with regard to the nuclear material accountancy and safeguards. The heart of the set up is an annular tank whose size and equipment correspond essentially to those of the input accountancy tank in Wackersdorf.

Within the framework of an extensive experiment entitled CALDEX (CALibration Demonstration EXercise) the accuracy achievable and the main limiting factors on the volumetric determination of the tank contents will be investigated as well as suitable calibration methods developed.

The organizers of the exercise thought it useful to hold a workshop to make sure that existing knowledge would be appropriately taken into consideration in the complex and extensive CALDEX tests. The idea was to give international experts the opportunity to present test results of and talk about experience with all the areas related to the volume and weight determination of the contents of tanks.

The Workshop of Tank Calibration

The workshop took place from 4 to 6 April 1989 at the Karlsruhe Nuclear Research Centre. It was organized by the Deutsche Gesellschaft für Wiederaufarbeitung von Kernbrennstoffen mbH (DWK) and prepared in cooperation with the WAK Operating Company, which also operates the CALDEX set up on behalf of DWK. Fourty one representatives from 6 countries as well as Euratom and the IAEA accepted DKW's invitation.

In the opening address by the organizers (co-chairmen R. Weh, H. Dratschmidt, DWK) the emphasis was put on the fact that the volumetric determination of tank contents has been paid considerably less attention than, for example, input analysis.

The future operators of the Wackersdorf Reprocessing Plant have set themselves the target of installing state-of-the-art measurement equipment for the input accountancy.

During the workshop existing knowledge was to be compiled and current experience discussed. Prior to the technical session of the workshop a comprehensive description of the CALDEX experiment and the test set up in the TEKO were given by Mr. Dratschmidt (DWK). In this context instruments were introduced which had been very kindly provided for the duration of the experiment by UKAEA Harwell (Mr. Haine: Sonic Ranger), ENEA (Mr. Aparo: Time Domain Reflectometer) and Siemens BW (Mr. Goenrich: Capacitive Probe).

The second day of the workshop was mainly spent discussing questions of volumetric determination of tank contents as well as tank weighing. First Mr. J. Lausch (WAK) reported on calibration tests on a test tank of the WAK. Mr. Schegk (WAK) supplemented the presentation with results of the determination of the heel as a function of the velocity in emptying the tank. Mr. Kerry of BNFL illustrated details and results of calibration tests on a so-called harp tank, the unusual design of which causes calibration problems of its own. Mr. Pradel (COGEMA) reported on the recently carried out calibration of the UP3 accountancy tank. Miss Neuilly (CEA) demonstrated an interesting variation of the dip tube technique using extremely low air flow rate. The method has been successfully tested in three cases (CAMEL, TOR, UP3) and yields amazingly positive results.

Mr. T.L. Jones (UKAEA Dounreay) presented a summary of the extensive research and development work carried out in the fields of tank weighing, tracer application and pneumercators. Mr. Schenkel (Euratom) illustrated calibration problems from the point of view of an inspector and pointed out areas which require further investigation. Mr. Dragnev (IAEA) reported on the IAEA calibration laboratory, questions of organisation and inspector training. He stressed the necessity for increased cooperation and, in that context, mentioned the PERLA laboratory in Ispra and other programmes such as RITCEX and CALDEX. Mr. Suda (BNL) referred to his long experience in the field of tank calibration. He went especially into the impact of mechanical distortion and temperature change in tests carried out with ENEA. Mr. Hirano (PNC) explained the operational procedure for the input accountancy vessel calibration at the Tokai Reprocessing Plant. Mr. Buyers of BNFL spoke about the high accuracy achieved and extensive experience gathered in the area of tank weighing. Essential preparatory work has been undertaken by Mr. T.L. Jones (UKAEA Dounreay) for a lutetium tracer experiment to be carried out during the CALDEX exercise. Mr. Cauchetier (CEA) reported on extensive tracer tests carried out in France. He compared various tracers such as Mg, U and Lu and explained the decision on Lu by way of test results gathered in TOR and UP3. Mr. Kerry illustrated the knowledge gathered by BNFL in using gadolinium, erbium and lutetium as tracers. At Sellafield, tracers are not only used for purposes of calibration, but they also present a fundamental accountancy tool. Mr. Koch (JRC Karlsruhe) raised the question of how a measurement precision of 0.04 % is expected despite the absence of certified standards and although in the case of plutonium even a value of 0.5% has been doubted.

The third day of the workshop was reserved for the treatment and evaluation of data gathered during calibration. Mr. Peter of KfK opened the session with a contribution on the so-called V-Mask technique. At KfK, it is used for the evaluation of calibration data from a hybrid instrument (K-edge densitometer combined with RFA). It remains to be seen whether this method could be modified for tank calibration. Mr. Goldman (IAEA) explained during a comprehensive description the entire problem of the mathematical and statistical treatment of data to attain the best calibration function. His presentation was supplemented with remarks by Mr. Suda (BNL). Mr. Foggi (JRC Ispra) concluded the session by pointing out the benefits of simulation as a part substitution for measurements. He introduced the simulation program SPRIT, developed at Ispra, and offered its use for CALDEX.

Considering the general mood on the conclusion of the workshop it was well received. The participants agreed that an exchange of information in such a way would be a welcome feature of the future.

CALDEX

As already mentioned in the introduction, CALDEX consists of extensive tests on the accuracy of the volume determination of the contents of tanks in near real conditions. Apart from establishing the influence of limiting quantities, various techniques such as dip tubes, tank weighing and tracer application will be compared. Different methods of measurements (differential pressure, TDR, acoustic and capacitive methods) and instruments (Ruska electromanometer, Crouzet electromanometer, Diptron 3 and Hartmann & Braun pressure transmitter) will be investigated.

Impacts to be looked at will be the form of the dip tube ends, the air flow rate, differences in vessel off-gas pressure, temperature changes, etc. In addition, calibration by feeding well-defined increments of calibration liquid will be compared to calibration by continuous feed. The heart of the experiment is a 12,500 l annular slab tank which corresponds in design to the one to be used in Wackersdorf. As the test set up as well as the actual test and the evaluation of the results will be described elsewhere (in a future edition of the ESARDA Bulletin), this shortened version should do for the time being. The experiment has already started and measurements will be carried out in the course of all of 1989.

Closing Remarks

It should be noted that the workshop as well as the actual CALDEX experiment have taken place and will take place with international participation. The tank calibration test is run within the framework of, among others,

- the Joint Programme on Technical Development and Further Improvement of IAEA Safeguards between the Government of the Federal Republic of Germany and the International Atomic Energy Agency,
- the ESARDA Working Group on Reprocessing Input Verification,
- the BMFT/US-DOE cooperation agreement in the field of safeguards,

and, of course, on the numerous excellent contacts with colleagues of domestic and foreign companies and institutions.

The organizer would like to take the opportunity at this point to thank all participants to the workshop, but especially those who have contributed actively to the equipment in the test facility and the preparation of the experiment. These are, first of all, the colleagues of the WAK as well as Mr. Aparo, Mr. Goenrich, Mr. Haine, Mr. T.L. Jones and Mr. Suda, to name but a few.

The participants in the DWK Workshop on Tank Calibration

List of participants in the
DWK Workshop on Tank Calibration
Karlsruhe, 4-6 April 1989

Messrs. Aparo, Dionisi (ENEA), Buyers, Howsley, Kerry (BNF plc), Cauchetier, Miss Neuilly, Platzer (CEA), Dragnev, Gharwal, Goldman (IAEA), Dratschmidt, Eggers, Weh (DWK), Ernstberger, Salacz, Schenkel (Euratom), Foggi (JC Ispra), Gauthier, Lausch, Schegk (WAK), Goenrich, Stau (Siemens BW), Golly, Peter, Seifert (KfK), Haine (UKAEA Harwell), Hirano (PNC, Japan), Hammon (EWW NUKEM), T.L. Jones (UKAEA Dounreay), Kobe (JNFS, Japan), Koch (JRC Karlsruhe), Huel, Pradel (COGEMA), Rathje (LURGI), Rodies (EWW Uhde), Someya (MMC, Japan), Suda (BNL, USA), Sugikawa (JAERI, Japan), Weinmann (Siemens KWU), Wenzel (KFA).

PERLA : Latest Achievements and Future Planning

M. Cuypers, H. Dworschak, S. Guardini
CEC, JRC-Ispra, Italy

1. Introduction

PERLA (PERformance LAboratory) is a complex of laboratories of the Institute for Safety Technology of the Joint Research Centre (JRC), set up in the framework of the Safeguards and Fissile Material Management Programme of the JRC. The basic aim of PERLA, right from the beginning, was to bridge the gap from laboratory development to application of safeguards instruments and techniques in an industrial environment. The laboratory is oriented specifically to non-destructive assay (NDA) techniques. The main obectives of the facility are :

- assessment of the performance of safeguards instruments and methods in near-field conditions,
- periodic calibration under well-defined conditions of instruments routinely used by safeguards inspectors and operators in industrial facilities,
- training of inspectors and operators,
- development and adaptation of methods according to emerging new needs.

In the past, several papers /1,2,3/ have been presented on the objectives of PERLA and the role it is expected to play in safeguards, as well as on the preparation of NDA standards. In particular, in the ESARDA Bulletin of May 1988 /4/, a progress report was presented together with details on the characterization of fissile material standards.

The aim of this paper is twofold : to report on the achievements of PERLA in 1988, and to outline the short-term future activities of the facility. Mainly three aspects are treated here :

1) the set-up of the laboratories and their structures in the ESSOR complex,
2) giving out a progress report on training (section 2.5),
3) the procurement and characterization of PERLA standards.

2. Set-Up of the Laboratories

PERLA (Fig. 1) uses different laboratories : PRE-PERLA, the Non Destructive Assay (NDA) laboratory, the spent fuel storage pool, and the NDA field facility (also called PERLA).

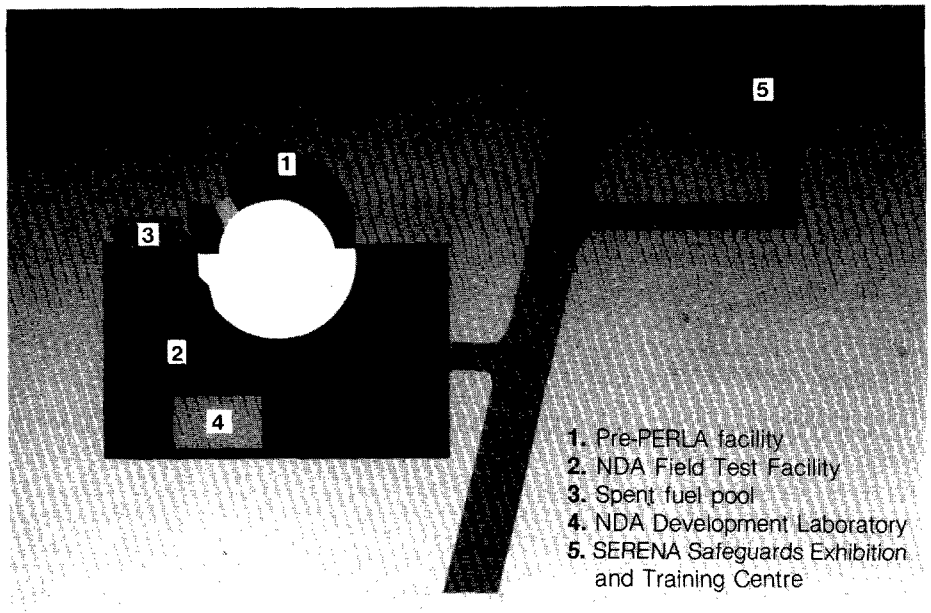

Fig. 1: - The PERLA Complex of Laboratories

2.1 PRE-PERLA facility

Awaiting the completion of the structures of the final facility, the PRE-PERLA laboratory (Fig. 2) has been set up inside the ESSOR reactor containment building. It is capable to perform all the operations foreseen for the final facility. It has been equipped to measure bulk quantities of fissile materials (U and Pu) in sealed samples. Four laboratories, storage rooms and a nuclear material handling room are available. PRE-PERLA became operative at the beginning of 1987.

During 1988, the following major activities have been carried on :

- receipt and characterization of Pu samples by NDA;
- calibration of Euratom instrumentation for uranium and plutonium bulk measurements. Four active well coincidence counters were intercalibrated by Euratom staff on high-enriched uranium (HEU) powders, as well as on MTRs and HEU metals with different enrichments of the PERLA inventory;
- calibration of Euratom high resolution gamma spectrometry instruments for plutonium isotopic ratio determination. Different hardware and software (LLNL "Blue Box", MGA and ISPRA PUIC) were compared;
- calibration of equivalent IAEA instrumentation - HLNCC for bulk Pu measurements, and MGA + VARRO (SILENA) - were tested;
- training (see section 2.6 for details).

2.2 PRE-PERLA planning

An intense working programme is scheduled in PRE-PERLA in the field of training, calibration and performance evaluation. The training planning is detailed in section 2.6.

The calibration activity on PERLA U and Pu standards has, in the meantime, become a routine activity. PRE-PERLA is designed and structured to give a continuous support to Euratom and IAEA inspectors such that, whenever they have to calibrate an instrument or to check a new technique, they can make extensive tests on PERLA samples.

Concerning performance evaluation, several tests are planned to assess the performance of instruments and techniques in :

- calorimetry, comparing performance of water and air-driven calorimeters,

Fig. 2: Pre-PERLA facility during a calibration exercise in July 1987

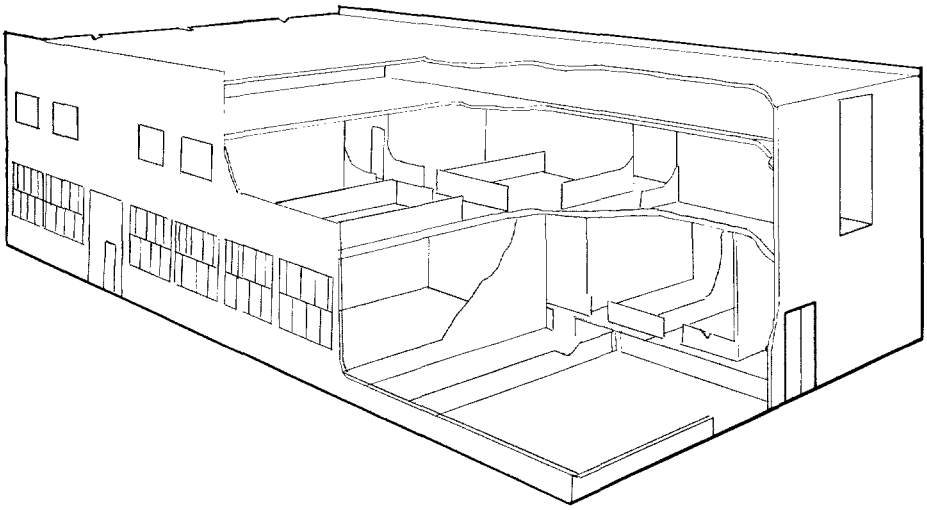

Fig. 3: A cut-away view of the NDA development laboratory

- neutron counting, both by active and passive mode.

It is worthwhile to mention a few more details on the exercise of INTERCOMPARISON of the different software packages for interpreting the plutonium gamma spectra to determine Pu isotopic ratios : five different codes currently used in the field and in the laboratory, coming from LLNL, LANL and Mound (DOE-USA), from ENEA-Italy and from JRC-Ispra, will be compared using standard spectra derived from Pu PERLA samples; PuO_2 of three different burn-ups and MOX of five different reactors (fast and thermal) will be employed in creating the standard spectra library. A computer management system, which generates similar records from the different codes, allows the transmission, storage, retrieval and statistical comparison of the results. The exercise will be carried out in July 1989.

2.3 NDA laboratory

The NDA laboratory occupies an area of 300 m^3 divided into 7 individual rooms (Fig. 3) where small quantities of fissile material can be handled. It operates since 1986 and is dedicated to research and development of NDA techniques. At present, the activities going on in this laboratory are :

- development of new instruments and techniques for passive neutron coincidence counting, in shift register mode and in higher neutron multiplicity mode for the monitoring of bulk Pu samples;
- development of active neutron devices for uranium sample measurements. PHONID /5/, DUCA /6/ and SIGMA /7/ are examples of such devices which were developed in the past and are now being used by the Euratom Safeguards Directorate.
  a. PHONID (Photo Neutron Interrogation Device) is an instrument for the accurate monitoring of bulk U and Pu samples.
  b. DUCA was developed to monitor small U samples.
  c. SIGMA is a delayed neutron counting device (like DUCA) for the monitoring of THTR fuel pebbles.
  Three items of PHONID 3bis are now being constructed with the assistance of external firms on the request of the Safeguards Directorate. These instruments are to be delivered by mid 1990;
- development of gamma spectrometry techniques and instruments both for uranium and plutonium assays;
- one gamma scanner for MTR monitoring which is under construction. This instrument is based on the measurement

of the gamma emission and transmission for the determination of the ^{235}U content in MTR fuel elements;
- Pu meters for Pu isotopic composition determination which were delivered last year to Euratom Safeguards for field measurements and are now being calibrated.

2.4 The spent fuel storage pool

Some spent MTR fuel elements from the ESSOR reactor were discharged in the pond in 1986.

In the future, some additional LWR spent fuels will be supplied and stored.

Training and development of NDA techniques for spent fuels will take place in the pond. The ESSOR spent fuel pool is shown in Fig. 4.

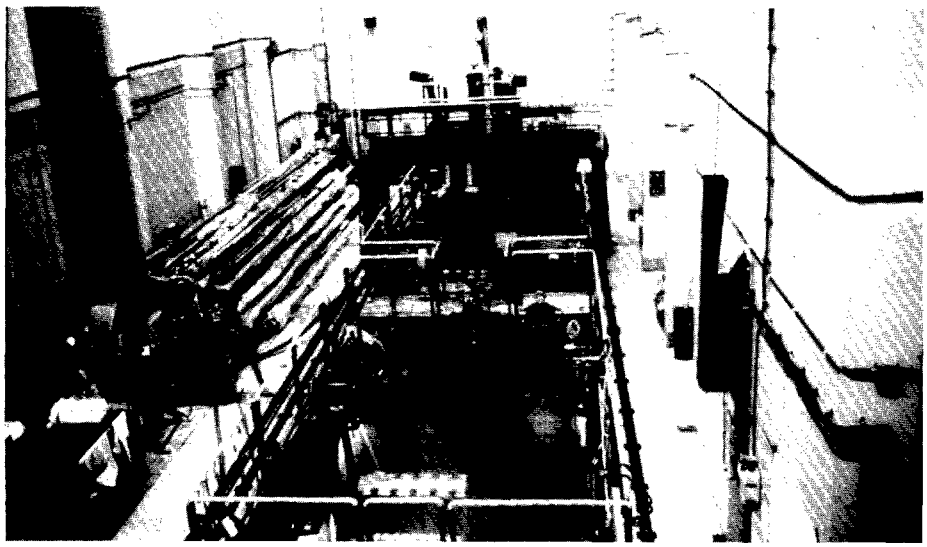

Fig. 4: A general view of the spent fuel storage pool

2.5 NDA field facility (PERLA)

The NDA field facility (sometimes itself called PERLA) will be set up while modifying a large existing laboratory (400 m^2). It will have the same characteristics as PRE-PERLA, i.e. it will be adapted to the measurement of bulk quantities of U and Pu.

In Fig. 5 the planimetry of the future laboratory is given. It consists of several "working areas" of different size, a personnel lock entrance, and a handling area equipped with some glove boxes for fuel sample receipt and control. The status of the facility is the following :

- gross civil works are almost completed;
- health physics instrumentation has been ordered and is to be delivered soon;
- the ventilation and air pressure control system is designed and will be contracted out during this year;
- the nuclear material management control software is under design and will cover the following functions :
  - a normal declaration from Euratom and IAEA according to the Euratom and the Non-Proliferation Treaty agreements,
  - internal nuclear material movements,
  - management of the certified data for establishing standards.

  The latter item will give the possibility to present the characteristics of the certified samples to the user, to help the user in choosing suitable samples, to know the preparation and characterization history of the standards, and to trace back the samples to the primary standards.

2.6 Training

Safeguards training has been traditionally an important activity in the JRC. In 1988, the following training courses were given in PRE-PERLA :

- three courses (of one week each) on **gamma spectrometry of Pu and U** isotopic measurements using instruments developed in industry and in-house;
- three courses on **passive neutron of Pu** bulk measurements using a HLNCC instrument, developed by LANL, and devices developed in-house;
- one **physical inventory verification** (PIV) exercise for HEU fuel fabrication plants, given to Euratom Directorate inspectors.

In the coming 12 months the following courses are scheduled :

- two courses on **neutron determination of Pu** bulk measurements. They consist in a general description of the neutron coincidence counting technique and,

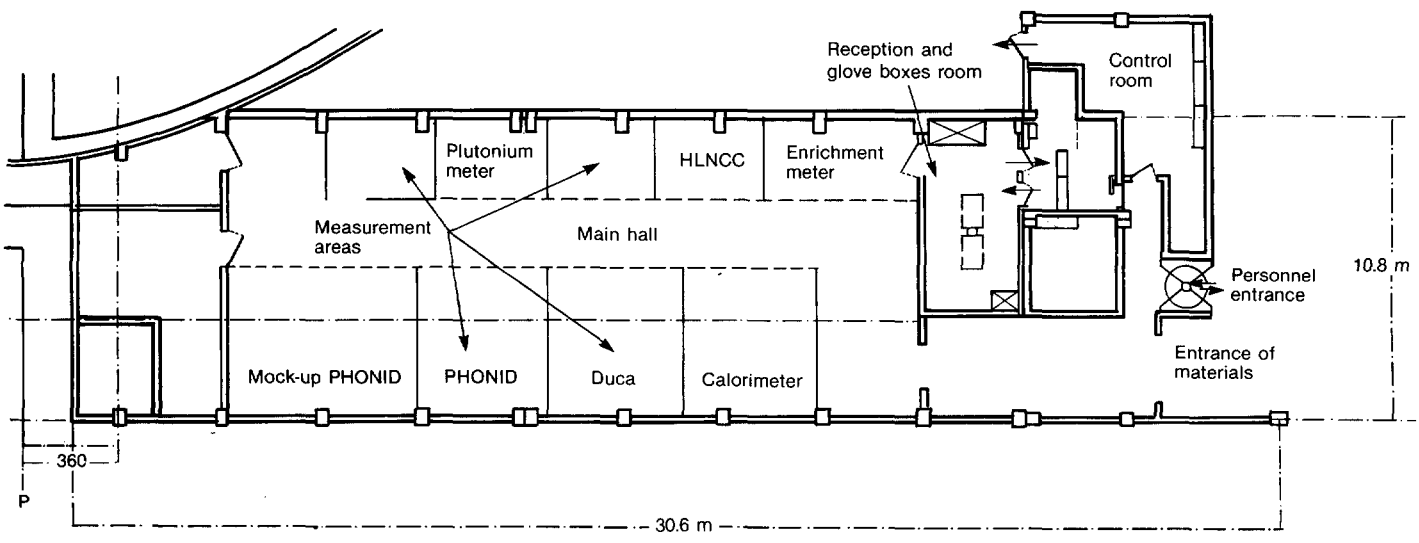

Fig. 5: A Schematic view of the new NDA field laboratory (new PERLA)

then, gaining practical experience on instruments and bulk samples of the PERLA inventory;

- two courses on **gamma spectrometry of Pu** for the determination of isotopic ratios, including theory, measurements and statistical data analysis;
- two courses on **gamma spectrometry of uranium** with the same characteristics as the courses on Pu isotopics;
- two courses on HEU PIVs, one for Euratom and one for Agency inspectors. The PIV oriented traning courses integrate sampling verification and data evaluation so as to provide inspectors with complete information on how to conduct a physical inventory verification in a facility.
- One **PIV for a Pu fabrication plant** is planned for February 1990.
- Finally, a training programme in **Statistics applied to safeguards** will be held consisting of ad hoc seminars and specific traning courses.

3. Standard Fuel Sample Inventory

3.1 The PERLA inventory

In Table I the total inventory envisaged for PERLA is summarized. At present, only HEU and Pu-bearing samples are in the inventory. The supply of LEU is under study and its scheme of procurement and certification is under preparation. It is expected to be received in the course of 1990. The characterization criteria of the PERLA standard samples has already been given in /4/. In Table I, together with their nature, the levels of characterization of the standard samples are given; PERLA, in fact, has an inventory of certified reference standards (like the U_3O_8 NBS/CBMN/ ESARDA samples) /8/ as well as standards characterized by different laboratories specified and coordinated by PERLA staff.

Table I - Nuclear Materials for PERLA

Material type			Certification level*
HEU	MTR platelets, plates	3 enrichments	4
	MTR assemblies (18)		4
	UO_2 powders, pellets (g.kg)	6 enrichments	3
	THTR particles, pebbles		3
	Metal buttons (kg)		4
LEU	UO_2 powders, pellets (g.kg)	not yet	
	UO_2 pins	procured	
	short assemblies		
	U_3O_8 CBNM/NBS	5 enrichments	1
PuO_2	Small cans (g)	3 burnups	2
	Large cans (kg)	3 burnups	2
	CBNM	5 samples	1
	PIDIE	7 samples	1
MOX	Pins	fast thermal	2
	Pellets	recycle	2
	Powders		4

*) The certification levels are as follows:
1: International reference material of many labs
2: PERLA certificate (3 labs)
3: PERLA certificate (2 labs)
4: PERLA certificate (1 lab)

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Comparison between Lutetium and Erbium Used as Tracers in the Determination of the Mass of U Present in a Tank of the ITREC Reprocessing Plant

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Abstract

After the ITITEX I and II experiments already performed in the ENEA ITREC plant at Rotondella, further experiments were carried out on the tracer technique with a new and special experiment to determine the mass of fissile material present in a tank which initially did not have a sampling system.

Special features of the experiment described were the type of tank (with double leg), the way in which the tracer was used and, finally, the comparison between the two tracers used : lutetium and erbium.

The results were first of all compared with those obtained with conventional plant methods and a significant agreement was found (0.5%). Then, after the two tracers had been compared, the economies of their use were evaluated.

Introduction

The ENEA-ITREC plant at Rotondella was designed and constructed as a pilot plant for the reprocessing of U-Th cycle fuel with "Elk River" elements.

In the past, many input tank calibration tests were performed in the technological hall of this plant using the tracer technique in a specially set up tank D-80. Tests were performed using lutetium as tracer and taking the samples at different volume levels, to check both the total volume of liquid present and the mass of fissile material contained in it /1,2/. It was arranged that the solutions used exactly simulated the chemical composition of the plant input accountancy tank D30.

About 10 years ago and during the "Nuclear Test Campaign" which dealt with the reprocessing of 20 Elk River elements, the solution obtained, which contains U-Th, was stored in the W-120 tank which is located in the waste park of the ITREC plant. Recently the Commission of the European Communities asked for a new characterisation of the solution in accordance with its safeguards obligations resulting from the NPT (Non Proliferation Treaty).

At the same time, and due to favourable circumstances, an experiment was carried out to confirm the applicability of lutetium as a tracer in the direct measurement of the total quantity of U contained in the accountability tank after the transfer of the solution from the W-120 tank. In parallel, erbium was also used as a tracer. Analytical characterisation tests using mass spectrometry had already been carried out on erbium /3/.

The entire experiment was the result of collaboration between the JRC-Ispra and ENEA-ITREC.

The results obtained with the tracer technique are in good agreement (0.5%) with those available at the plant. They confirm the applicability of the tracer technique as an alternative to traditional techniques in the particular conditions indicated.

Experimental Procedure

Plant procedure

The W-120 tank containing the dissolution products of about 20 Elk River elements (U-Th) is not equipped with homogenisation systems or, with more reason, sampling systems. To be able to use this solution, or at least a significant part of it, it was decided to transfer it, by air-lift, and following the reverse of the usual path, to the D30 input tank. The tracer technique was then applied and the necessary isotopic characterisation measurements were obtained.

The input tank (D30) has a typical two-leg shape (Fig. 1) which is suitable for preventing problems of critical mass which could be posed by solutions where, as in our case, there are high concentrations of fissile elements (^{235}U and ^{232}Th).

The sampling took place as laid down in the ITREC plant Operation Manual, first of all by measuring the density and volume with the associated instrumentation and then by checking their acceptability by the nuclear accounting section especially for the volumetric measurement on the two legs of the tank.

Considering that we worked by air lift to give a dilution 1:20, Table I shows the characterisation of the solution by measurements obtained with the instrumentation associated with the plant or performed in the adjacent laboratories.

Table I. Chemical and physical parameters of the solution transferred into the input accountancy tank

Acidity	0.01 M
Density	1.032
Thorium	13.7 g/l
Uranium	0.558 g/l
Total activity	3.5×10^{-2} c/l

All the experiments previously carried out on the ITREC plant at Rotondella (ITITEX I and II) and already mentioned, used a cyclindrical tank (D80) which was not yet inserted into the plant. For this reason the homogenisation problems never seemed difficult to solve and neither was the introduction of the tracer which, especially in plants constructed some time ago and not designed for this aim, could pose considerable difficulties.

Introduction of the tracer

In the existing operating conditions the sampling line is the only access to the tank. Unlike the normal use of this line which transfers the solution from the tank to a typically small sampling vessel, in this circumstance we decided to introduce the tracer working in such a way that a solution of it was sucked out of the vessel and put into the tank following the reverse route.

After a careful series of washings with water and to ensure the complete transfer of the tracer we proceeded in such a way that all the solution contained in the tank circulated continuously between the sampling station and the tank itself, thus facilitating the homogenisation of the tracer.

Chemical procedure

The tracer introduced was a mixture of Lu + Er : 2.16432 g Lu_2O_3 and 2.15355 g Er_2O_3 which, using the stoichiometric factors equal to 0.87938 and 0.87452, give

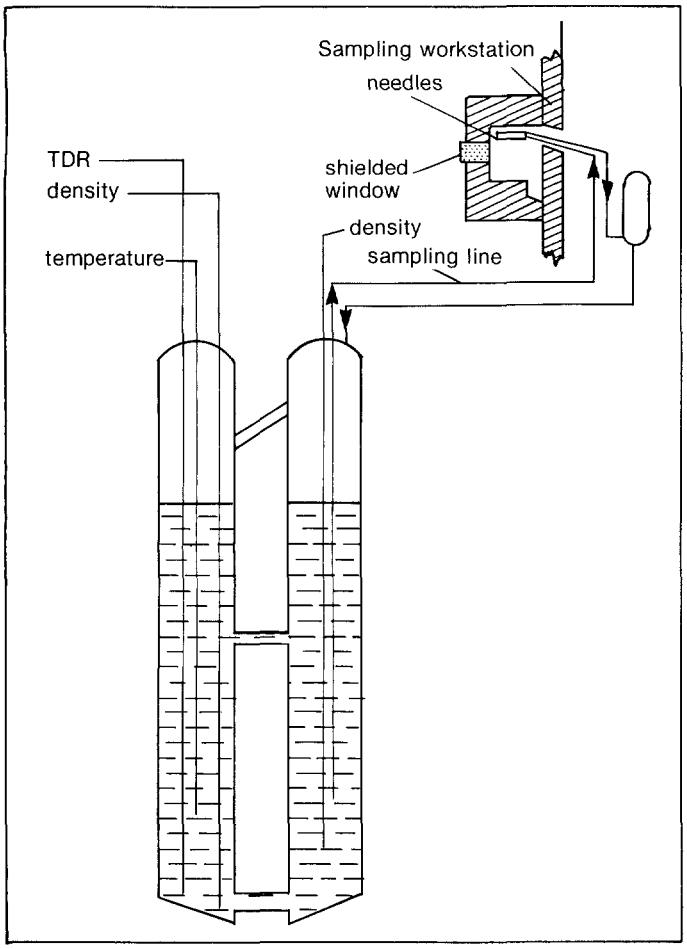

Fig. 1: ITREC plant: input accountancy tank

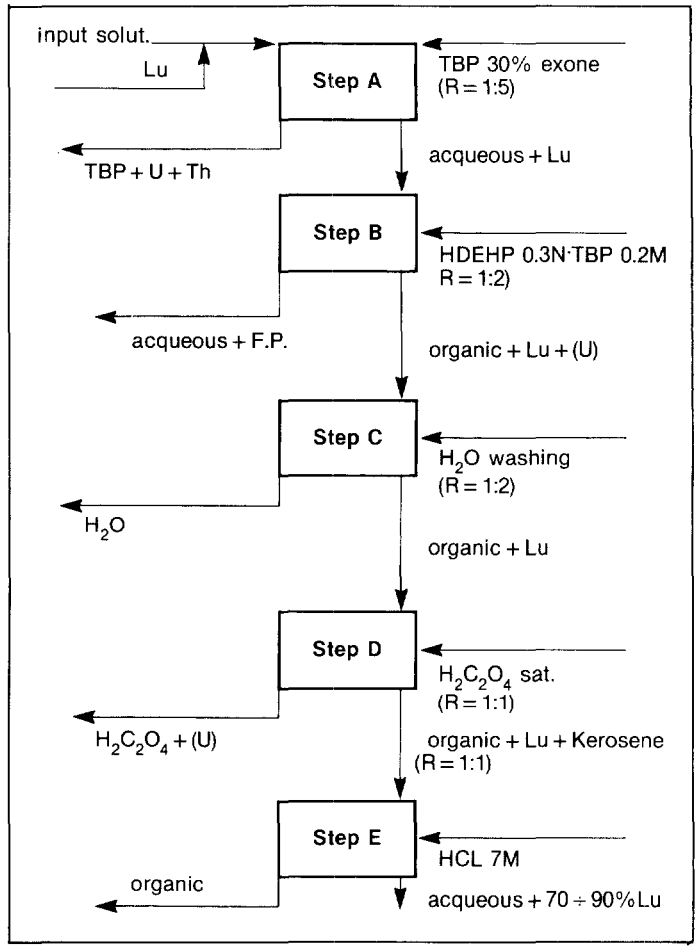

Fig. 2: Lutetium purification

1.90327 g of lutetium and 1.88332 g of erbium, respectively. After the homogenisation with recycle described and for a whole day two series of six samples each were taken. The first series was spiked with Lu (mass number 176 = 52%) and two of them were spiked with Er (mass number 162 = 26%). The second series was spiked with natural U.

The procedure for separation and purification of the uranium with TBP (TriButylPhosphate) at 30% in methyl-iso-butyl-cheton and successive reextraction in slightly acid water solution for HNO_3 is well known /4/.

The procedure used to decontaminate the sample and separate the rare earths used as spikes is well known /5/ but for completeness of information we reproduce the flow-sheet in Fig. 2.

All the operations were carried out in a hot cell until the reextraction and final washing for which a glove bow was used.

The samples thus treated were transported to the JRC of the CEC, Ispra, Italy where all the mass spectrometry measurements were performed.

All the aspects concerning the spectrometric determinations have been fully described /5 ib./ with the only variation from past experiments being that a spectrometer with a variable multicollector system (Finnigan Mat 261 VMC, Bremen, FRG) was used.

Results

The results obtained confirmed the validity of the test showing the suitability of the chemical procedure adopted even in difficult conditions, such as the handling of highly radioactive solutions derived from irradiated nuclear fuel elements.

Table II gives the concentrations (in mg/g) obtained by IDMS of the elements needed for the final calculation and present in the various mixtures.

Table II

Mix	[Lu] mg/g	[Er] mg/g	[U] mg/g
1A	20.12×10^{-3}	not present	0.546
2A	20.08×10^{-3}	not present	0.546
4A	20.10×10^{-3}	not present	0.545
5A	20.05×10^{-3}	19.74×10^{-3}	0.542
6A	not meas.	19.90×10^{-3}	0.545
Σ	20.09×10^{-3}	19.82×10^{-3}	0.545
σ	± 0.03	± 0.11	± 0.002

Remembering that one may obtain the total g of fissile material present in the solution contained in the tank by means of the formula :

mass of fissile material =
mass of tracer added x (fissile conc./tracer conc.)

Table III illustrates the g of U calculated with the different mixtures and tracers.

Finally, remembering that the quantity of U calculated by the plant with its own instrumentation was equal to 51.335 g, one can see some comparisons in Table IV.

Cost Evaluation

This is an important aspect which has been little considered up to now. The need to check the method's reliability has often overshadowed the question of tracer cost.

It may immediately be said that the conclusions which we will draw take account of an average application situation, i.e. the need for the tracer technique to be usable by any laboratory (mass spectrometry) for any equipped nuclear plant.

For this reason, we will discard a priori those solutions, which can only be proposed at a very high analytical level, which envisage the standardisation of materials

(especially tracers) made in-house. One therefore needs a tracer of very high quality and high purity (99.99%), which ensures an accurate result after simple handling operations (possibly dehumidification).

Identical observations may be made for the spike whose isotopic enrichment, certified by the producer, is controlled for the necessary agreement while the absolute quantity (or concentration), is controlled if possible with several analytical methods (weight, IDMS).

It is also clear that each of the uncertainties found in each passage will form the whole of the uncertainty of the final measurement evaluated with the statistical criteria of error theory.

Having said this and having analysed most of the procedures on the market, one can make reasonable predictions of the costs, depending on the tracer. Tables V and VI show these estimates.

Table III

Mix	Tracer Lu (g U)	Tracer Er (g U)	Plant conventional (g U)
1A	51.649	–	–
2A	51.752	–	–
4A	51.606	–	–
5A	51.449	51.702	–
6A	–	51.591	–
–			51.335
Σ	51.569 ±	51.647 ±	51.335
σ	0.086	0.078	

Table IV

Δ g U tracer Lu/plant	= 0.54%
Δ g U tracer Er/plant	= 0.61%
Δ g U tracer Lu/tracer Er	= 0.15%

Table V. Average cost of the possible tracers

Tracer (purity)	Quantity required (mg/l)	Cost/g (U.S.$)	Cost/10^3l of solution (U.S.$)
Lu 99.99%	10 - 20	73	1095
Er 99.99%	10 - 20	7	140

Table VI. Average cost per spiked sample

Spike mass number	% enrichm.	Cost/mg (U.S.$)	Spiking cost per sample (U.S.$)	Isotopic ratio enrich. nat.
Lu 176	52	118	6	20 : 1
Er 162	26	27	1	186 : 1
Er 167	96	1	.	4 : 1

Conclusions

One can immediately see that the experiment, performed on samples of hot solution from the reprocessing of the Elk River fuel elements, has allowed a check of all the tracer chemical separation phases in real operating conditions.

In reference to the total quantity of uranium present in the tank and calculated with two different methods, the plant method and the tracer method, one can easily say that :

a) the difference between the two final results is around 0.5%;
b) this difference lies within the upper limit of the error which was expected in calculating the nuclear balance;
c) the good test recorded should be better considered if one remembers that the tank involved is a two-leg tank in which homogenisation is not simple;
d) the favourable homogenisation conditions achieved (more than 24 h), allowed us to reach point c), but its study is critically imposed as a *conditio sine qua non* in future tanks, although more favourable tank shapes and tracer introduction conditions greatly reduce the operation time, which may be estimated as between 30 minutes and 3 hours.

Some observations may be made in reference to the economic aspects of the tracer technique :

- today, the application of lutetium as tracer costs globally about 1000 U.S.$ every 1000 litres of solution in the tank and while for pilot or semi-industrial plants such as ITREC, EUREX (I) and WAK (FRG), this does not have a great effect on the possible use of the technique, for large and new plants like UP3 La Hague (F), DWK (FRG) and THORP (U.K.) its use would result in costs of the order to 5-10,000 U.S.$ each time.
- as partial solution a new tracer, erbium, which has been studied and tested, would drastically reduce the costs by a factor 10.
- some suppliers (ESPI, California, U.S.A.) can supply erbium (Er_2O_3, 99.9%) at a price lower by another factor 3. This would reduce the price to about 35 U.S.$ per 1000 litres of solution to be measured. (Typically equal to about 880 U.S.$ for a THORP batch.)

The distinction reported in Table VI between the two types of enrichment of the erbium spike is to be considered as dependent on whether interfering masses of dysprosium are present or not. Whenever one intends to use the tracer technique in its full true potential (direct measurement of the fissile mass), it is possible and recommended to plan joint actions between users to produce, acquire and possibly characterise large quantities of tracers which benefit from the financial advantage of the economies of scale.

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Near Real Time Materials Accountancy Using SITMUF and a Joint Page's Test: Improvement of the Test

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Abstract

Development of the rules for choosing the two (H,K) pairs has led to an improved joint Page's test on SITMUF. This test has a higher probability of responding to abrupt loss, and provides better materials control by virtue of more timely response to protracted loss.

Software has been written to provide automated test generation for any plant. This software has facilitated characterization of the joint test and determination of the effect of balance frequency on its response.

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).

Introduction

The joint Page's test on SITMUF was introduced /1/ to meet the need for a versatile testing procedure which would respond to both abrupt and protracted losses. Subsequent work has shown that the joint test is superior to conventional accountancy /2/, and how the performance of the joint test depends on the frequency of balance taking /3/. In a recent report /4/, the joint test was compared with the MUF and CUMUF tests, and a joint Page's test on MUF. It was recommended that the joint Page's test on SITMUF should be adopted and developed for practical use in the control of materials loss.

This paper describes how the performance of the joint test has been improved by the use of new rules for choosing the two (H,K) pairs used in this joint test. The performance of the improved test is judged on the basis of sensitivity and timeliness for abrupt loss, and on average loss per campaign for protracted loss.

Description of Plant Characteristics

Previous work /2,3,4/ has chosen a campaign length of 240 days, divided into 40 balance periods of 6 days. The standard deviation of the throughput measurement error per balance period, **T**, set at 1 kg gives a standard deviation of the campaign throughput measurement error of 6.325 kg. This, and the standard deviation of the inventory measurement error, **I**, of 2 kg, is consistent with predictions for the THORP materials accountancy and control system /5/. The above values for **I** and **T** will be used as reference values in this paper.

Performance of Conventional Accountancy

Conventional accountancy for this plant configuration has been defined, and its application described in the previous edition of the ESARDA Bulletin /4/. Whilst it is not the main concern of this paper, the performance of conventional accountancy will be used as a yardstick for the assessment of the joint Page's tests on SITMUF. Interpreting the MUF value consists of checking whether, when divided by its standard deviation, it has reached a significance threshold (z) chosen such that the false alarm probability (FAP) is controlled at some nominal value, α . In other words,

$$z = U_{(1-\alpha)}$$

where **U** is the inverse standard normal distribution function.

The significance threshold, in order to give a 5% FAP is set at 1.6449 standard deviations, or 10.403 kg. An expected detection probability of 50% is achieved for a loss of 10.403 kg. Loss of twice this amount, 20.807 kg, raises the expected detection probability to 95%. The complete sigmoid power curve is shown in Figure 1. It is particularly important to note that, once the significance threshold has been set in accordance with the required FAP, the response of conventional accountancy to a loss depends only on the total size of the loss and **not**, in any way, on its form.

Specification of the Joint Test

The joint test procedure is made up of two components, each of which is a Page's test.

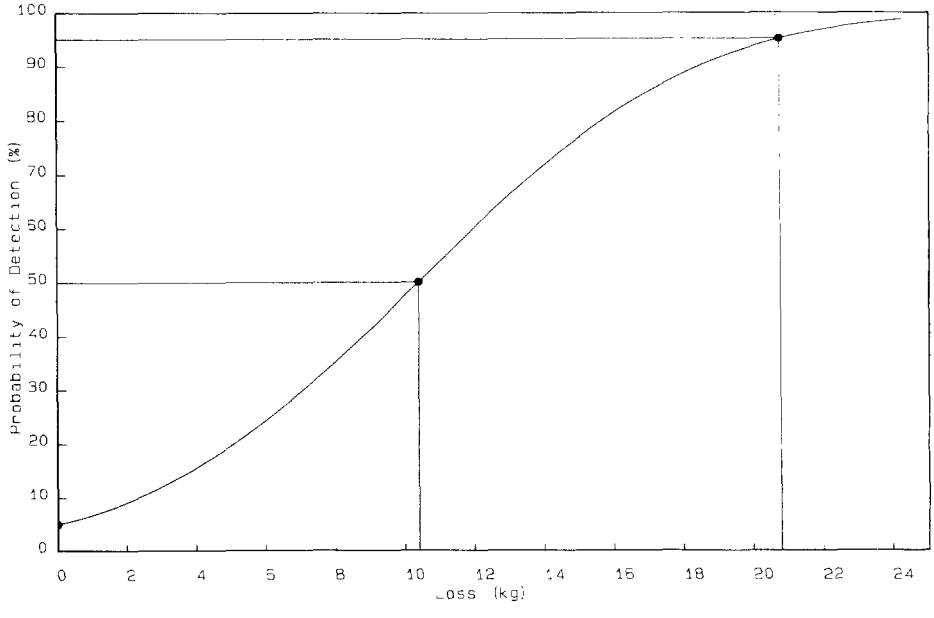

Fig. 1: Detection of Loss Using Conventional Accountancy

For these components, the two test statistics S1 and S2 are defined by

$S1_0 = 0$
$S2_0 = 0$
$S1_i = \max(0, S1_{i-1} + Y_i - K1) \qquad i > 0$
$S2_i = \max(0, S2_{i-1} + Y_i - K2) \qquad i > 0$

where $Y_1, Y_2, .., Y_i$ is the series of SITMUF /6/ values generated from MUF_1, MUF_2, ..., MUF_i. The test procedure is such that an alarm is given if $S1_i = H_1$, or $S2_i = H2$.

It can be seen that two (H,K) pairs, (H1,K1) and (H2,K2), have to be chosen before applying the joint test procedure. There is an infinite choice for the two (H,K) pairs corresponding to a given FAP and a fixed campaign length. The choice of these parameters controls the characteristics of the joint test. The first component of the joint test is designed to respond to abrupt losses quickly. To achieve this H1 is set to zero /7/. The second component of the joint test is designed to respond to a steady protracted loss lasting for the whole campaign. In this case K2 is set to zero. The complete procedure for setting up the joint test is described elsewhere /3/.

Ultimate Detection of Protected Loss

If "most difficult to detect" means that the loss scenario results in the lowest probability of ultimate detection, then the most difficult loss scenario to detect by near real time materials accountancy (NRTMA) is a regular protracted loss lasting for the whole campaign. The probability of ultimate detection of a protracted loss of 20.807 kg spread evenly over 10, 20, 30 and 40 periods is shown in Table I.

It can be seen that, using the above definition, the loss over periods 1 to 40 is hardest to detect whilst the same total loss over periods 1 to 10 is easiest. However, for the practical purpose of **materials control**, the probability of **ultimate detection** has limited relevance /3/; what matters is that loss of material should be minimized. The way in which this has been quantified before /3/ is to calculate the average loss per campaign for each scenario. The expected (ie average) loss, E(L), per campaign is calculated by

$$E(L) = \sum_{i=1}^{n} (L_i.(p_i - p_{i-1})) + L_n.(1 - p_n)$$

where L_i is the cumulative loss, and p_i the cumulative detection probability, by period i.

Table II shows the average losses for the same scenarios which were presented in Table I. There is no clear relationship between the probability of ultimate detection and the average loss. Indeed, the scenario most easily detected is the one which allows loss of the most material. This suggests that there may be scope for improving materials control by modifying the parameters of the joint Page's test. The effect on the probability of ultimate detection of changing the second component of the joint test is shown in Table III; the probability of ultimate detection reduces as H2 decreases. However, using two tests as examples, Figure 2 shows that, for most of the time, detection is more likely when H2 has the lower value. The nominal FAP (5%), and the allocation of 4% to the protracted component and 1% to the abrupt component, is maintained throughout.

Timely Detection of Protracted Loss

As illustrated in Figure 1, a loss of 20.807 kg would be detected by conventional accountancy with a probability of 95%.

Comparison of Tests

The testing procedure should respond to a systematic error, bias or protracted loss which lasts for only part of the campaign, and may occur at any time during the campaign. Therefore, the following criteria are proposed.

Any testing procedure aimed at detecting **protracted loss** should:

- quickly detect losses occurring at a slow rate;
- have a response which is relatively insensitive to the rate, time, and duration of the loss, and
- have an ultimate response which is comparable with conventional accountancy.

The choice of the parameters of the joint Page's test will influence its ability to meet these criteria. Tables II and IV to IX show how the average loss per campaign depends on the choice of the (H,K) pairs. When comparing tests, the aim should be to select the test which minimizes the maximum average loss per campaign for a range of scenarios (in this case the starting and ending points of the protracted loss).

Some of these results are displayed in Figures 3 to 5. Careful examination of these Figures reveals that the plots show certain similarities. For each loss scenario, there is a value of H2 for which the average loss is

Table I: Response to a Protracted Loss of 20.807 kg
Probability of Ultimate Detection (%)
H1 = 0 K1 = 3.4772 H2 = 13.5 K2 = 0.00254

Starting Period	Ending Period			
	10	20	30	40
1	99.8	98.6	96.4	91.7
11	—	99.7	98.6	95.0
21	—	—	99.7	97.3
31	—	—	—	99.1

Table II: Response to a Potential Protracted Loss of 20.807 kg
Average Loss per Campaign (kg)
H1 = 0 K1 = 3.4772 H2 = 13.5 K2 = 0.00254

Starting Period	Ending Period			
	10	20	30	40
1	14.792	14.562	14.006	13.559
11	—	14.682	13.503	12.821
21	—	—	13.788	12.546
31	—	—	—	13.012

Table III: Response to a Protracted Loss of 20.807 kg
Probability of Ultimate Detection for Various Joint Tests

H1	K1	H2	K2	Probability of Ultimate Detection (%)
0	3.4772	13.5	0.00254	91.7
0	3.4769	12.0	0.05457	91.1
0	3.4766	10.5	0.11226	90.0
0	3.4762	9.0	0.17920	88.3
0	3.4757	7.5	0.26233	85.2
0	3.4752	6.0	0.37563	79.4

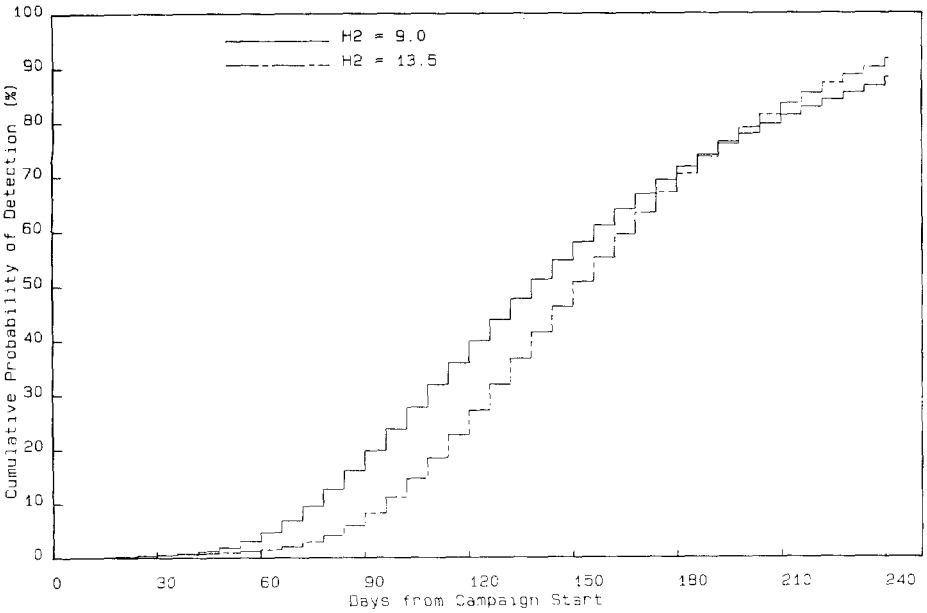

Fig. 2: Detection of a Protracted Loss of 20.807 kg

Table IV: Response to a Potential Protracted Loss of 20.807 kg
Average Loss per Campaign (kg)
H1 = 0 K1 = 3.4769 H2 = 12.0 K2 = 0.05457

Starting Period	Ending Period			
	10	20	30	40
1	14.077	13.824	13.487	13.248
11	—	14.010	12.918	12.445
21	—	—	13.257	12.134
31	—	—	—	12.649

Table V: Response to a Potential Protracted Loss of 20.807 kg
Average Loss per Campaign (kg)
H1 = 0 K1 = 3.4766 H2 = 10.5 K2 = 0.11226

Starting Period	Ending Period			
	10	20	30	40
1	13.275	13.046	12.957	12.953
11	—	13.270	12.310	12.072
21	—	—	12.666	11.695
31	—	—	—	12.213

Table VI: Response to a Potential Protracted Loss of 20.807 kg
Average Loss per Campaign (kg)
H1 = 0 K1 = 3.4762 H2 = 9.0 K2 = 0.17920

Starting Period	Ending Period			
	10	20	30	40
1	12.402	12.251	12.450	12.720
11	—	12.481	11.704	11.741
21	—	—	12.024	11.249
31	—	—	—	11.701

a minimum. The minimum value of the average loss increases, and is obtained for a larger H2, as the duration of the protracted loss increases. This means that the maximum, over all scenarios, of the minimum average loss will always occur for the most protracted scenario. The Tables show that reducing the value of H2 results in quicker detection of losses occurring at a slow rate, with a corresponding reduction in the average loss.

Some general observations can be made about Tables II and IV to IX but rigorous assessment is difficult since a different choice of loss scenarios would give different data.

1 Reduction of H2 brings about a general improvement in the average loss.

2 Reduction of H2 to about 9 seems to bring an improvement in robustness (as evidenced by the range of average loss). This range increases again when H2 is reduced further.

3 The minimum value for the average loss in the worst case (the 1 to 40 scenario) is achieved for a value of H2 near 7.5. By interpolation, this H2 value is found to be 7.75.

These observations are collected in Table X. The precision, when selecting H2, is limited, by current software, to 0.1. Using a value of H2 = 7.8, the joint test which minimizes the worst average loss is as follows:

H1 = 0 K1 = 3.4758
H2 = 7.8 K2 = 0.24389

The response of the improved test to a potential protracted loss of 20.807 kg has been evaluated for the same range of loss scenarios used earlier. Table XI shows the probabilities of ultimate detection, whilst Table XII shows the corresponding average losses. Comparing Tables XI and XII, it can be seen that lower probability of ultimate detection relates to higher average loss, and vice versa. In other words, regardless of whether ultimate probability of detection or average loss is used as the yardstick, regular protracted loss of material over the whole campaign is the most difficult to detect and control. Appropriate values from Table XI are incorporated in the foot of Table X.

Table XII shows the response of the same test to an abrupt loss of 10.403 kg.

Timely Detection of Abrupt Loss

Consider an abrupt loss of 10.403 kg. As illustrated in Figure 1, such a loss would be detected by conventional accountancy with a probability of 50%.

Table VII: Response to a Potential Protracted Loss of 20.807 kg
Average Loss per Campaign (kg)
H1 = 0 K1 = 3.4757 H2 = 7.5 K2 = 0.26233

Starting Period	Ending Period			
	10	20	30	40
1	11.475	11.483	12.043	12.644
11	—	11.669	11.155	11.535
21	—	—	11.349	10.841
31	—	—	—	11.123

Table VIII: Response to a Potential Protracted Loss of 20.807 kg
Average Loss per Campaign (kg)
H1 = 0 K1 = 3.4752 H2 = 6.0 K2 = 0.37563

Starting Period	Ending Period			
	10	20	30	40
1	10.530	10.852	11.911	12.915
11	—	10.888	10.781	11.635
21	—	—	10.677	10.573
31	—	—	—	10.507

Table IX: Response to a Potential Protracted Loss of 20.807 kg
Average Loss per Campaign (kg)
H1 = 0 K1 = 3.47475 H2 = 4.5 K2 = 0.54946

Starting Period	Ending Period			
	10	20	30	40
1	9.648	10.631	12.429	13.838
11	—	10.240	10.854	12.391
21	—	—	10.089	10.695
31	—	—	—	9.946

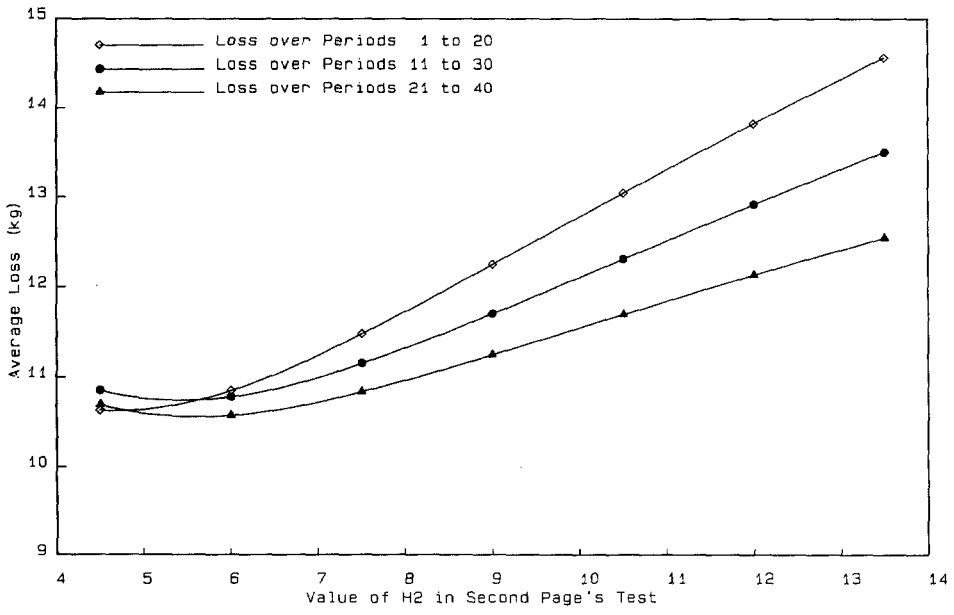

Fig. 3: Protracted Loss of 20.807 kg over 20 Periods

Comparison of Tests

Any testing procedure aimed at detecting abrupt loss should:

- detect abrupt losses quickly;
- have a good response to a loss occurring in any period, and
- have an ultimate response at least as good as conventional accountancy.

The concept of a timeliness period, 30 days here, was used to make sure that response within a stipulated time was considered. It has been shown above that there is a gain in the control of protracted loss if the previous test (H1 = 0 K1 = 3.4772 H2 = 13.5 K2 = 0.00254) is replaced by the improved test (H1 = 0 K1 = 3.4758 H2 = 7.8 K2 = 0.24389). This improved test is also expected to perform better for detection of abrupt loss because:

1 The abrupt component has a lower value for K1;
2 The protracted component uses an (H,K) pair more suited to detection of abrupt loss.

When comparing tests, the aim should be to select the test which maximizes the minimum probability of detection for a range of scenarios (in this case the period of the abrupt loss). The responses of the previous and the improved tests to a loss of 10.403 kg are shown in Figure 6. The traces in Figure 6 are similar in profile. A high response is achieved if the loss occurs in the first or last balance periods because the SITMUF variance is lower than in other periods on account of the zero beginning and ending inventories. Furthermore, the response is at its lowest if the loss occurs a few periods from the beginning of the campaign. For a campaign of 40 periods and a timeliness period of 30 days, the minimum probability of detection is lifted from 78.4% to 88.7% by adoption of the improved test.

Automated Test Generation

Expertise, gained in examining the factors on which the performance of the joint Page's test on SITMUF depends, has been engineered into a software package so that a joint test can be designed and characterized for any plant design and choice of operating conditions. Two sets of information are needed. Firstly, basic information about the campaign measurement characteristics, campaign length, and timeliness period is required. Secondly, key parameters must be specified for the NRTMA testing conditions.

The standard deviation of the throughput measurement error per **campaign,** T_C (kg), the standard deviation of the inventory measurement error, I (kg), the campaign length, P_C (days), and the timeliness period, P_T (days), are the required plant parameters.

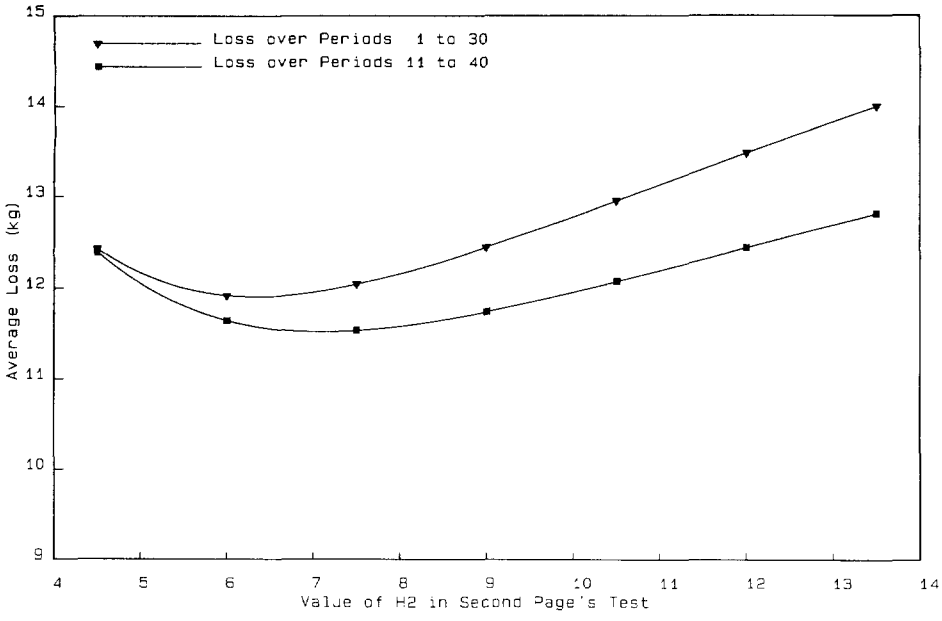

Fig. 4: Protracted Loss of 20.807 kg over 30 Periods

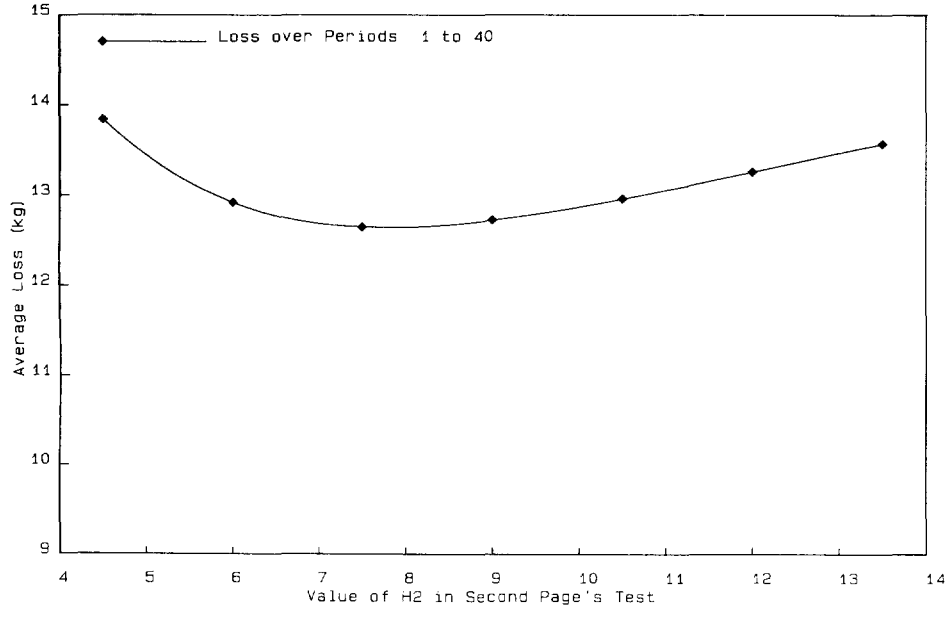

Fig. 5: Protracted Loss of 20.807 kg over 40 Periods

Table X: Dependence of Average Loss on Choice of Joint Test

	Average Loss (kg)				
				Loss Scenario	
H2	Lowest	Highest	Range	1 - 10	1 - 40
13.5	12.546	14.792	2.246	14.792	13.559
12.0	12.134	14.077	1.943	14.077	13.248
10.5	11.695	13.275	1.580	13.275	12.953
9.0	11.249	12.720	1.471	12.402	12.720
7.5	10.841	12.644	1.803	11.475	12.644
6.0	10.507	12.915	2.408	10.530	12.915
4.5	9.648	13.838	4.190	9.648	13.838
7.8	10.916	12.640	1.724	11.664	12.640

The campaign false alarm probability, **FAP** (%), the weighting of the joint test in favour of the protracted component, **W** (%), the balance period, P_B (days), and the timeliness period, P_T (days), are the required parameters associated with the testing procedure. Alternatively, the number of balances, N_T, to be taken in the timeliness period can be specified instead of P_B.

The following values for the reference model will be used for a worked example of the test generation procedure:

T_C = 6.325 kg
I = 2.000 kg
P_C = 240 days
P_T = 30 days
FAP = 5%
W = 80%
N_T = 5
P_B = 6 days
N_C = 40

The performance of conventional accountancy using the MUF test is first evaluated. The significance threshold, z, is calculated by:

$$z = U_{(1 - 0.05)} = 1.6449$$

The decision point, **DP**, for the MUF test is set so that:

$$DP = z \times T_C = 1.6449 \times 6.325 \text{ kg} = 10.403 \text{ kg}$$

Loss of this amount, call it L_A, will have a 50% probability of detection by conventional accountancy. Loss of twice this amount, call it L_P, will have a 95% probability of detection by conventional accountancy. These two losses will be used to evaluate the response of the joint test to abrupt and protracted loss respectively. Next two (H,K) pairs (H1,K1) and (H2,K2) have to be chosen. There will be an infinite choice of these pairs consistent with the specified FAP. The criterion for choosing the two (H,K) pairs is the proportions of the overall **FAP** which are allocated to the two components. Define FAP_A as the false alarm probability for the abrupt component and FAP_P as the false alarm probability for the protracted component.

$$FAP_P = FAP \times W \quad FAP_A = FAP \times (1 - W)$$

$$N_C = \frac{P_C}{P_B} \text{ or } N_C = \frac{P_C}{P_T} \times N_T$$

The optimal joint Page's test is chosen by selecting H2 to minimize the average loss for the most protracted loss scenario.

The Effect of Balance Frequency on the Response of the Improved Test

The effect of balance frequency on the response of the earlier version of the joint test has already been examined /3/. It was found that the control of protracted loss was enhanced, and the response to abrupt loss was lifted, by an increase in balance frequency. The improved test has been checked to see whether these characteristics have been retained.

Table XI: Response to a Protracted Loss of 20.807 kg
Probability of Ultimate Detection (%)
H1 = 0 K1 = 3.4758 H2 = 7.8 K2 = 0.24389

Starting Period	Ending Period			
	10	20	30	40
1	99.9	98.8	94.4	86.0
11	—	99.9	98.7	93.0
21	—	—	99.9	98.0
31	—	—	—	99.9

Table XII: Response to a Potential Protracted Loss of 20.807 kg
Average Loss per Campaign (kg)
H1 = 0 K1 = 3.4758 H2 = 7.8 K2 = 0.24389

Starting Period	Ending Period			
	10	20	30	40
1	11.664	11.631	12.110	12.640
11	—	11.831	11.256	11.560
21	—	—	11.485	10.916
31	—	—	—	11.243

Table XIII: Response to a Potential Protracted Loss of 20.807 kg
Average Loss per Campaign for Various Balance Frequencies
Improved Joint Tests

Balance Frequency (Days)	Balances per Campaign	Loss per Period (kg)	Average Loss per Campaign (kg)	Ultimate Prob. of Detection (%)
5	48	0.433	12.614	86.0
6	40	0.520	12.640	86.0
7.5	32	0.650	12.677	86.2
10	24	0.867	12.734	86.4
15	16	1.300	12.842	86.7
30	8	2.601	13.138	87.5
60	4	5.202	13.805	88.7
240	1	20.807	20.807	95.0

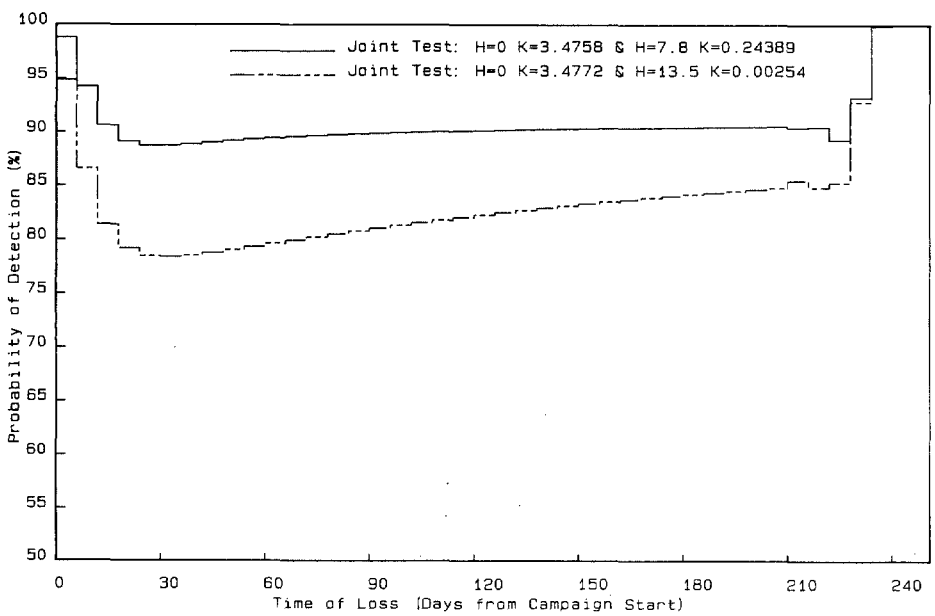

Fig. 6: Detection of Abrupt Loss of 10.403 kg within 30 Days

The response of the improved test to a protracted loss of 20.807 kg was examined. Table XIII shows how the average loss and the ultimate detection probability depend on the balance frequency. Figure 7 shows these values for the average loss, and allows comparison with the corresponding values for the previous test. The traces are similar in that the average loss with each version of the joint test seems to fall to a limiting value but which, for the improved test, is lower.

Table XIV shows, for a range of balance frequencies, the lowest response of the appropriate joint test to an abrupt loss of 10.403 kg. Figure 8 shows these values for the lowest responses related to the number of balances taken during the campaign, and allows comparison with the corresponding values for the previous test. The traces are similar but the improved test has a markedly better response for all balance frequencies. It has, therefore, been confirmed that NRTMA can achieve timely detection at any time the loss occurs provided that the balance frequency is chosen such that several balances are taken during the timeliness period.

Concluding Remarks

The (H,K) pairs in the original joint Page's test were chosen with the constraint that K2 should be close to zero, in order to maximize the probability of ultimate detection of a protracted loss lasting for the entire campaign. However, it has been stressed that, for the practical purposes of materials control, the probability of **ultimate** detection has limited relevance; what matters is that loss of material should be minimized. For a range of protracted loss scenarios, the average losses have been compared with the corresponding probabilities of ultimate detection. Paradoxically the scenario most easily detected was the one which allowed loss of the most material.

It has been found that if H2 is reduced, and the other parameters of the joint test adjusted accordingly to maintain the overall false alarm probability, then the average loss per campaign is reduced and materials control consequently improved. For the reference values used in this paper, it can be seen that lower probability of ultimate detection now relates to higher average loss, and vice versa. In other words, regardless of whether ultimate probability of detection or average loss is used as the yardstick, regular protracted loss of material over the whole campaign is the most difficult to detect and control.

Compared with the previous version of the joint test, the improved version has been shown to have a higher response to abrupt loss. This higher response occurs because the abrupt component has a lower value for K1, and the protracted component uses an

Table XIV: Response within 30 Days to an Abrupt Loss of 10.403 kg for Various Balance Frequencies
Improved Joint Tests

Balance Frequency (Days)	Balances per Campaign	Balances per 30 Days	Lowest Detection (%)	Lowest Detection	
				Period	Time (Days)
5	48	6	90.5	6	25-30
6	40	5	88.7	5	24-30
7.5	32	4	85.7	5	30-37.5
10	24	3	81.4	4	30-40
15	16	2	73.9	3	30-45
30	8	1	56.8	2	30-60

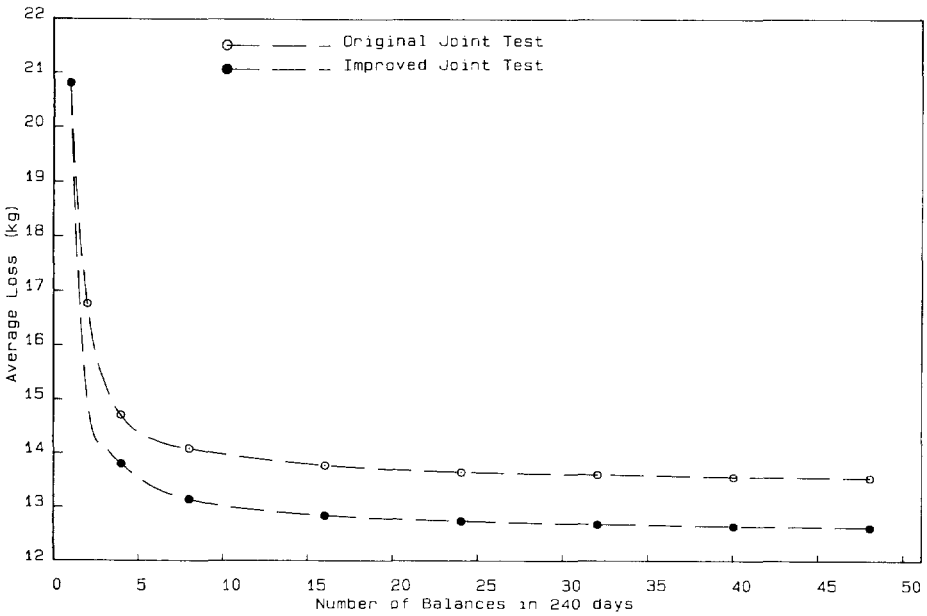

Fig. 7: Detection of Protracted Loss of 20.807 kg

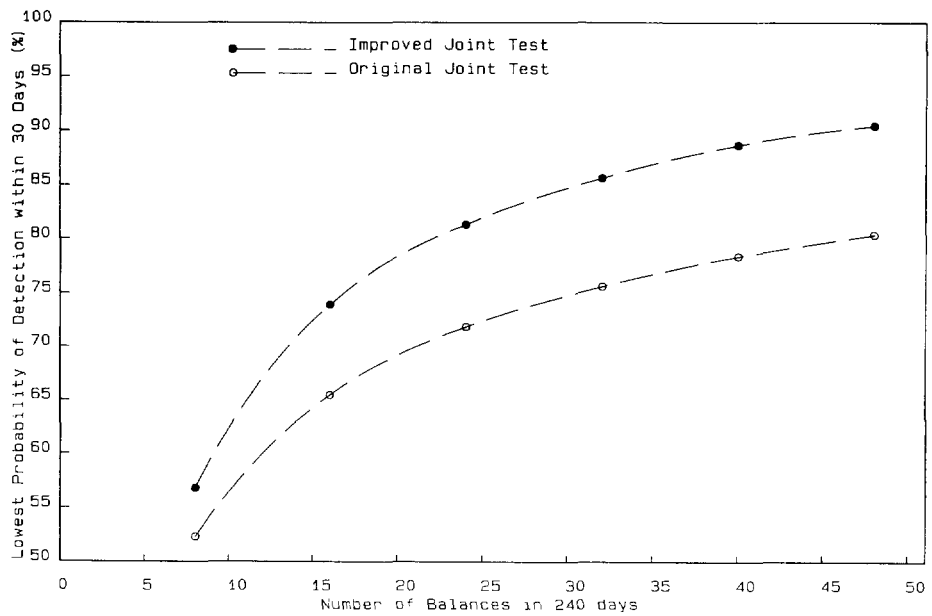

Fig. 8: Detection of Abrupt Loss of 10.403 kg within 30 Days

(H,K) pair more suited to detection of abrupt loss.

A software package has been engineered so that a joint test can be designed and characterized for any plant design and choice of operating conditions.

When the joint test is used to control protracted loss, increasing the balance frequency reduces the average loss per campaign and, with the improved version, the limiting value of the average loss is lower.

When the joint test is used to detect abrupt loss, increasing the balance frequency enhances the response and, with the improved version, the response is higher under corresponding conditions.

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ESARDA News

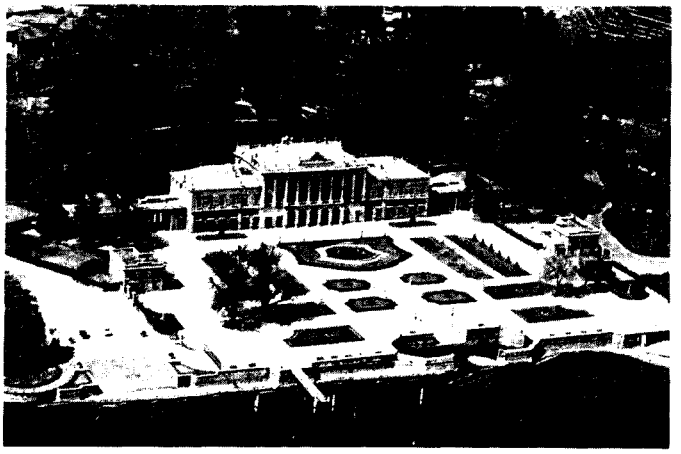
12th ANNUAL ESARDA MEETING (Restricted participation)

Como (Italy), 15 - 17 May 1990

The twelfth Annual Meeting will be held at the Centro di Cultura Scientifica "Alessandro Volta", Villa Olmo, Como, Italy.
The attendance will be limited to the ESARDA Steering Committee members, coordinators, working group members and observers.

Villa Olmo

Villa Olmo is a beautiful neo-classic building of the 18th century, designed by the famous architect Simone Cantoni who also planned its pavements and furnishings.
Villa Olmo represents the height of the neo-classic architecture historically corresponding with a period of grand revival due to the economic rebirth of the 18th and 19th centuries.
The neo-classic style of Villa Olmo is also applied to its interior.
The entrance hall, rising to the height of three floors with its gold stucco and decorations, is a worthy preface to the various rooms: the ballroom, containing a balcony with a gilded wrought iron railing, statues and reliefs by Carabelli and frescoes by Domenico Pozzi (end of the 18th century); the hall of mirrors; the wedding room most interesting for its elliptical architecture and decoration (allegorical fresco of the ceiling alluding to the union of Napoleon and the Cisalpina Republic); the square hall of Diana, (the myth of Diana and Actaeon is illustrated in the lunette over the door and in the ceiling fresco); the Garibaldi room, where the General was guest; the Bacchus room, once dining-room; the small theatre, a real jewel (1883) seating 92 people, frescoed by Fontana; the Odescalchi chapel, and the music-room. The great staircase (on the ceiling a fresco: Apollo on a chariot surrounded by gods and preceded by the Dawn) leads to the first floor where the Olympus room and the richly decorated Visconti di Modrone hall are now visible.
Behind the Villa lies a most inviting and relaxing park with its secular old trees (the elm tree which gave its name to the Villa no longer exists), and at the front, towards the lake almost as to accentuate the façade pure style, we find the geometric italian style garden, with many pagan God statues.



Villa Olmo

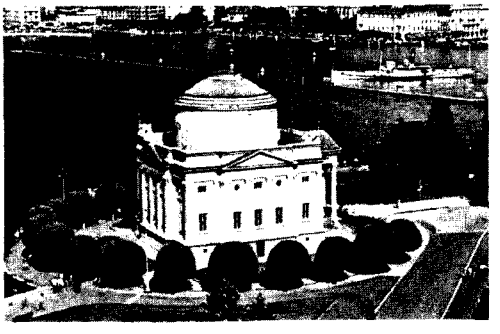
Como

Como was established as an urban town during the Roman era. Traces of its former civilization (Bronze and Iron Ages) can be found at the archaeological and art museum (Palazzo Giovio) and at the escavations of the so-called "Ca' Morta" (House of Death). Como, during the Roman era, was the birthplace of many illustrious figures such as naturalists Pliny the Elder and Pliny the Younger. In spite of remains of a Roman fortress, Como has the features and appearance of a medieval City; remains of this period are: the Baradello tower overlooking the entrance to the City, the fortress walls and 3 towers surrounding, to this very day, the inner city with its closely built houses, its narrow streets and stone-paved "piazzas", its elegant buildings kept in their original splendor (Palazzo Odescalchi, Palazzo Vescovile), the "Broletto" rebuilt and restored to allow the construction of the Cathedral and its tower. The construction of this church began in 1452 by the "Magistri Cumacini" and its structure mirrors the artistic life of the City dating from Middle Ages to modern times. The Romanesque stage in the history of the city holds a place of its own with its churches San Fedele and Sant'Abbondio which are of great architectural interest. Many monuments of recent times are worth visiting, such as "Tempio Voltiano", where the instruments invented and used by A. Volta are kept; the War Memorial and "Palazzo Novocomum", both erected by G. Terragni, an architect of rationalistic tendencies.

Bellagio from Villa Carlotta

Cathedral

Tempio Voltiano



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