JRC 85585

ISSN 1977-5296

ESARDA

Bulletin

NUMBER 21
DECEMBER 1992

The 15th ESARDA Symposium

11-13 May 1993, Augustinianum Institute, Vatican City, Rome, Italy

The ESARDA Symposium will return to Italy in 1993 after nine years. The preceding one was held in Venice in 1984 and many ESARDA members still have good memories of that successful Symposium. The 15th ESARDA Symposium will be held in Rome, in the heart of the Vatican City, close to St. Peter's church.

It is not necessary to give a long description of the city of Rome here. The monuments and the history of the Roman Empire are so well known that any description is superfluous. We think that it will be worthwhile to take the occasion of the symposium for a cultural journey that will certainly leave you with for lifelong memories.

During the symposium some interesting visits will be organized and an attractive spouse programme will be set up. But the suggestion is to stay a few more days in Rome to enjoy the magnificent city, its climate, its way of life and, last but not least, to come to know better, through its monuments, the history of the ancient "Caput Mundi".

The symposium will be held in the Patristic Institute "Augustinianum" situated in via Paolo VI (ex via Sant'Uffizio) 25, just by the side of the colonnade of St. Peter's square. This institute was created to promote theological studies and the thought of the Fathers of the Church, in particular St. Augustine.

The institute constitutes the continuation of the "Studium Generale Romanum" built in the XIV century at the St. Augustine convent. In 1882 the General Council of the Augustinianum Order moved to the present seat in the Renaissance "Villa Cesi" near St. Peter.This coincided with the resumption of the studies on the sacred sciences.

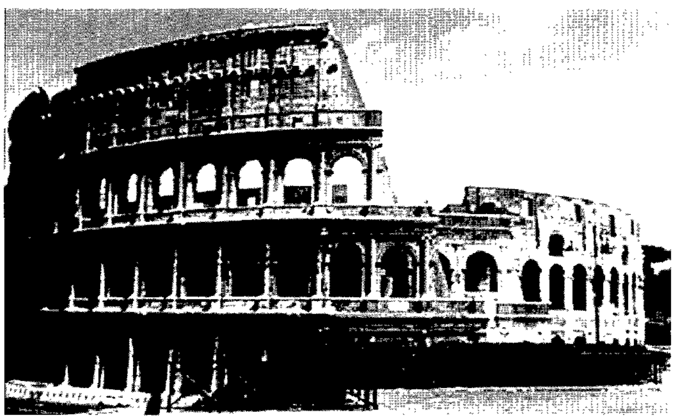
At the Patristic Institute Augustinianum the "Studio Teologico Agostiniano" was founded in 1965. At present it provides academic teaching at university level for Theological and Patristic Sciences.

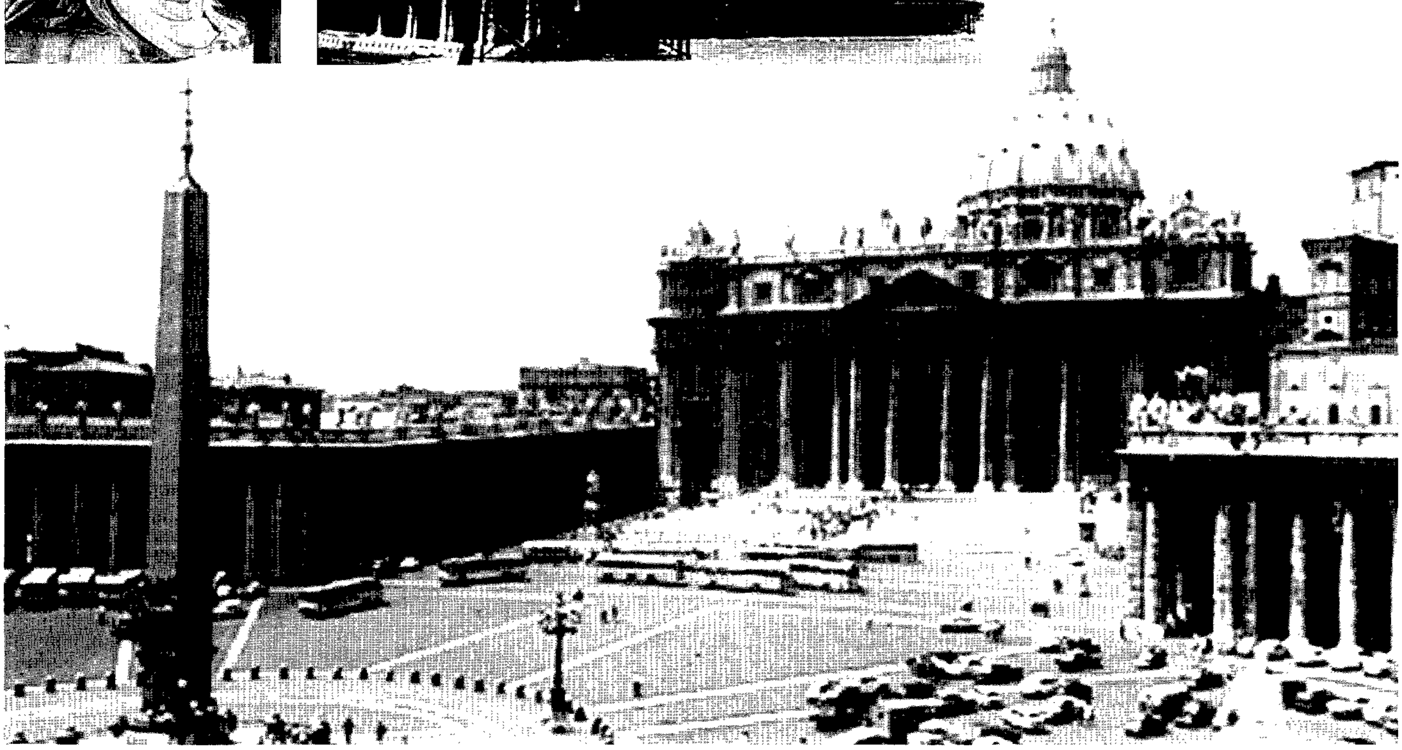
The Patristic Institute Augustinianum is included, as a result of agreements between the Holy See and the Italian Republic, among the official institutes for higher studies. It is also recognized by the Interuniversitary Centre of Athens as equivalent to the faculty of Theology of the Greek Universities.

The Auditorium of the Augustinianum is well equipped for congresses and hosts both religious and lay symposia.

The 15th ESARDA Symposium is being organized, as is customary, by the Commission of the European Communities, Joint Research Centre of Ispra. The Italian Nuclear and Alternativ Energy Agency, ENEA, will be taking care of all the details concerning the organization on the spot.

The organizing committee





A Data Base for Technical and Scientific Activities within ESARDA

C. Foggi
Joint Research Centre, Ispra

Introduction

One of the main objectives of the Association is the coordination of R&D activities. It is worthwhile to recall the exact terms of Article 2 of the ESARDA Agreement in this context:

"The purpose of the Agreement is to facilitate collaboration on research and development in the field of safeguards and on the application of such research and development to the safeguarding of source and special fissile material.

The research, development or application programmes of the Parties brought up to date annually shall be submitted to the Steering Committee, which will examine them in the light of identified safeguards topics which require investigation and recommend a basis for collaboration.

Collaboration shall be effected as appropriate by coordination of the research, development or application work, by the exchange of information and assistance on the personnel and technical levels and by the joint execution of these programmes or parts thereof."

The Steering Committee in its November 1990 meeting in Jülich has given recommendations to the Coordinators to put more effort in satisfying the main ESARDA objective. In this framework the Coordinators initiated two actions namely:

- preparation of an R&D data base
- analysis of ongoing R&D activities in different areas

The main features of the R&D data base are presented.

ESTABANK

ESTABANK (**ES**arda **TA**sks BANK) is a data base designed to record essential information *about the R&D and technical support activities* carried out by the ESARDA Parties in the field of safeguards and nuclear materials management.

ESTABANK was set up with a view to facilitiate handling, processing and use of the information provided by the Coordinators to the ESARDA Steering Committee, and to help them analyze and compare the R&D programmes of the ESARDA Parties. At present, the information contained in the data base are used by the ESARDA Parties and by the ESARDA Working Groups only.

The data base has been created and is operated by the Joint Research Center of the Commission of the European Communities. It is implemented on a PC-type computer under the management of the dBASE-III DBMS, and is physically located at Ispra. It is the responsibility of each Coordinator to make available periodically the input data to the data base. The JRC introduces the data and distributes regularly the updated versions as internal ESARDA working documents.

The basic unit of information stored in the data base is the "task", which is a well defined activity reported by one of the ESARDA Coordinators. The task is identified by means of its title and of the following additional information:

- name of the organization responsible for carrying out (or co-ordinating) the task;
- names of the organizations collaborating to the task;
- reference number used by the organization responsible for the task and, when applicable, those used by the IAEA and by the EURATOM Safeguards Directorate
- the "status" (in progress, frozen, terminated, completed).

To make the information stored in the data base selectively retrievable, each task has been preliminarily classified according to three different criteria and this classification has been recorded in the data base as a complementary information.

The three criteria are:

- The framework in which the task is carried out, which can be selected among the following:
  i) support to the EURATOM Safeguards Directorate,
  ii) support to the IAEA,
  iii) support to the plant operators,
  iv) R&D
- The scientific/technical discipline involved: this can be selected from a pre-established list of 6 major areas, which are further subdivided into more specific sub-areas, each sub-area being eventually subdivided into sub-sub-areas. As an example, "Measurement" is a major area, of which "NDA techniques" is a sub-area, of which "Neutron Measurement Techniques" is a sub-sub-area.
- The intended applications of the result. "Application" is the specification of the plant type to which the results of the activity are addressed. 11 possible major applications area have been identified; each of them is subdivided into several sub-areas, and each sub-area may be further subdivided into sub-sub-areas. As an example, "Fuel Fabrication Plants" is a major application area, of which "Low Enriched Uranium Plants" is a sub-area, of which "Products" is a sub-sub-area. As many applications as desired can be recorded for a given task.

The contents of the data base can be printed in a special compact format to allow easy comparison of the activities. An example is shown in Table 1.

As at present, 256 tasks are listed in ESTABANK.

Since the beginning of 1991, ESTABANK is used at each meeting of the-Coordinators to analyse different areas of the R&D programmes.

The following areas have been considered up to now:

- Containment and Surveillance
- Non-Destructive Techniques
- Destructive Analytical Techniques
- Techniques for Reprocessing Plants
- Techniques for Fabrication Plants

The results of the analysis performed by the Coordinators will be published in the ESARDA Bulletin as they become available.

Table 1: List of Tasks for Demonstration of the ESARDA Bulletin

Task Identification				Status	Task	Framework				Discipline			Application(s)			Participants	
d-Base	Original	IAEA	EURATOM			R&D	IAEA	EUR	OPER	1	2	3	1	2	3	Leader	Partners
JR 025		EUR E 00178			Image Processing System for Film and Videotape Rev iew (e.g. Polyline)		Y			CS	SURV		ALL			JRC	
JR 026		EUR E 00179		F	Feasibility Study of a PWR Fuel Assembly Sealing System		Y			CS	SEAL		REAC	LWR		JRC	SNL
JR 027		EUR E 00183	C/S 4		Development of a General Purpose Ultrasonic Seal (TITUS)		Y	Y		CS	SEAL		FABR ENR STO	ALL ALL ALL		JRC	CEA INDUST
JR 028		EUR E 00184	C/S 10		Industrialization of Bolt Seals for Spent Fuel Transport and Storage Cask Identification (underwater MEB) - Delivery of Large Number of Seals		Y	Y		CS	SEAL		STO	IRR		JRC	BNFL COGEMA
JR 040	FW 93 C/S				Study of Basic Techniques for Tagging Various Strategic and Valuable Items	Y				CS	SEAL		NOTSP			JRC	
JR 041			C/S 1.2		Testing of Video Components			Y		CS	SURV		ALL			JRC	
JR 043		JNT E 00481		F	Spent Fuel Transport Cask Identification		Y			CS	SEAL		TRANS			JRC	CEA COGEMA
JR 044			C/S 7.1		Automatic Verification of E-metal Seals			Y		CS	SEAL	DATA	ALL			JRC	

Analysis of R&D Activities in the Field of Containment and Surveillance

prepared by M. Cuypers
on behalf of ESARDA Coordinators

According to the recommendations of the Steering Committee, the Coordinators have analysed the R/D and technical support activities in the field of Containment and Surveillance (C/S), as declared by ESARDA partners.

The analysis was performed during the March and October 1991 meetings, using the ESTA-BAN K.

A summary of the analysis is presented below.

The field of C/S has been subdivided in two parts:
- Sealing Techniques
- Surveillance Techniques

Sealing Techniques

The data base lists 20 different activities under the heading "Sealing Techniques".

These activities are related mainly to:
a) Ultrasonic Seals
b) Electronic Seals
c) Fiber Optic Seals
d) E Metal Seals
e) Surface Topography Technique
f) Adhesive Surface Seals

a) Ultrasonic Seals

Two organisations are involved in the development and evaluation of ultrasonic sealing techniques. The studies of a general nature performed by JRC and UKAEA are concentrating on ultrasonic signature evaluation methods (correlation techniques) and development of reading devices.

Furthermore general studies on transducer reproducibility (polymer and ceramic transducers) and the investigation of new application areas are also pursued.

Four specific applications of ultrasonic sealing systems are being studied by the JRC in cooperation with different partners. They are for PWR fuel assemblies (feasibility study), for Multielement Bottles with BNFL (final field test), for tagging spent fuel casks with CEA and COGEMA (terminated because of licensing problems) and for general purpose applications (field test and large industrial production) with the EURATOM Safeguards Directorate (ESD) and CEA. These applications are performed in the framework of support programmes to the EURATOM and IAEA Inspectorates.

After a long development work, technological and operational difficulties have been overcome and for certain applications, the ultrasonic technique is now ready for implementation.

b) Electronic Seals

One organisation and one industrial firm are involved in electronic seal development and test.

The VACOSS seal (KFA + Industry) has reached the implementation phase and the main effort presently is concentrated on the industrial production of these seals and their interface with surveillance systems, also in cooperation with ESD and IAEA.

c) Fiber Optic Seals

Three organisations are involved in the development and tests of fiber optic seals. One seal is being developed by CEA with Industry. JRC, ESD and UKAEA are essentially performing environmental and tamper resistance tests on the three different types of fiber optic seals now existing (CLTO, COBRA, BROOKS).

One of the points which is not yet optimised is the on site reading device and signature comparison method.

The COBRA type seal is now largely implemented by inspectors.

d) E Metal Seals

The JRC has developed a system for the automatic storage, retrieval and analysis of E metal seal signatures which is now used by ESD.

e) Surface Topography Seal

Surface topography as a unique identification technique for items, structures or tags, is a research topic for the JRC. Only feasibility studies are being performed at present.

f) Adhesive Surface Seal

KFA is investigating, for the IAEA, the commercial availability of rapid short time sealing systems based on adhesive seals. This type of seal is already applied by inspectors but an improvement is still required.

Conclusions for Sealing Techniques

Table 1 summarizes the data and statements made above:
- Laboratories in EC are involved in the study/test of all existing seals available for safeguards.
- Under the heading "Application", most activities are categorised in the data base as of multiple use in different parts of the fuel cycle. Most of them are developed or used for sealing items or containers of non irradiated material. Some seals (ultrasonic, in particular) are made for sealing irradiated material underwater, but fiber optic, E metal and electronic seals are also applicable in dry conditions on containers for irradiated material.
- It is interesting that most of the activities on seals are now related to field tests or implementation problems and much less to laboratory developments.
- One of the major problems encountered for all types of seal categories is their industrial production and the passage of laboratory know-how to industry and developing the interest of industry for this limited market.

Table 1: C/S - Sealing Techniques

	Number of Tasks	Organisations Involved	Status			
			R&D	Field Test	Industrial Production	Implement.
a) Ultrasonic						
- general	4	JRC, UKAEA	X	X		
- applications	6	JRC, ESD, BNFL, CEA, COGEMA, Industry		X	X	
b) Electronic	4	KFA, Industry			X	X IAEA
c) Fiber Optic						
- development	1	CEA, Industry				
- tests	2	ESD, JRC UKAEA		X	X	X IAEA
d) E Metal	1	JRC, ESD			X	X
e) Surface Topography	1	JRC	X			
f) Adhesive	1	KFA, Industry			X	X IAEA

- Two laboratories and the ESD are involved in systematic field and tampering tests of seals. It is considered important to maintain such capabilities within EC countries. The recently established LaSCo laboratory at the JRC, Ispra is concentrating its efforts on performance assessment and training of C/S techniques and it is expected that the C/S Working Group will be providing some input for defining priorities for evaluation tests.
- Studies for the optimum use of sealing systems and characterisation of their performances are also being conducted by the UKAEA. In addition the C/S Working Group of ESARDA has discussed an application oriented study (Long Term Storage of Irradiated Fuel) at the topical meeting at Salamanca in May 1992.

Surveillance Techniques

The data base lists 16 activities under the heading "Surveillance Techniques". Four activities may be considered as completed. The activities are mainly related to:

a) Development of surveillance hardware and of software for the technical and safeguards evaluation/review of images
b) Development of multicamera/sensor systems
c) Tests of components and systems
d) Radiation monitoring

a) Development of Surveillance Hardware and Software

Two organisations (JRC, KFA) are involved in the development of components and/or systems for optical surveillance. KFA is addressing with the Industry the problem of the data link between image generation and image processing. Furthermore, a seal-surveillance system is being developed with potential applications in several areas where unattended safeguards is to be applied.

JRC has concentrated its effort on two general areas. One is the development of data treatment and computer aided review of surveillance pictures from single and multicamera systems, both for front and back end analysis. The second area is the development of a specific laser surveillance system, intended in particular for safeguarding storage areas.

Some of the experience obtained in the first area is now being applied by the EURATOM Safeguards Directorate (ESD).

KFA and an industrial company cooperate in developing a station for technical and safeguards review of video tapes from the Multi-Camera Optical Surveillance (MOS) System.

Enhanced review is possible with a user-friendly state-of-the-art menu-driven user-platform.

The laser surveillance system, was unfortunately developed without an adequate preliminary systems analysis for its potential use. The R&D and field tests have been completed and a new demonstration phase is needed to illustrate its potential benefit as an-independent and possibly complementary measure in an overall C/S system.

A further development based on a laser range finder is underway and aims to display a 3D picture of the environment. Another activity on remote verification using "mobile surveillance" has started at the JRC.

b) Development of Multicamera/Sensor Systems

Three organisations (CEA, JRC, KFA) are involved in this area. CEA and KFA are developing multisensor systems in cooperation with Industry.

KFA and an industrial company cooperate in implementing modules for the MOS System which are universally applicable. For instance, the Tamper Resistant TV-Link and Intermediate Video Storage Device have been successfully field-tested in connection with the Canadian MUX System in an industrial nuclearfacility.

The MOS System has many of the features of an Integrated Surveillance Package, discussions of which have been recently initialized in a topical meeting by the International Atomic Energy Agency. The MOS System was successfully field-tested in a commercial plant. KFA and the industrial company are presently integrating the electronic VACOSS-S seal system into the MOS System. For front-end data reduction other triggering sensors (e.g. video motion detectors) can be integrated into each camera channel. This will be demonstrated and field-tested.

Five integrated multisensor systems exist worldwide or are being developed for safeguards, from which three within EC, namely MOS, CAVIS, CONSULHA.

Most effort is concentrated on the selection of adequate sensors and cameras, transmission of data, data processing and the complex technical review and an efficient inspector interface.

The three systems, mentioned above, are being tested extensively in nuclear facilities and improvements of the systems are being introduced periodically.

Little or no standardisation exists in the development of components and the C/S Working Group should pay some attention to this important parameter.

The activities in this area are supported by both the EURATOM and IAEA Inspectorates.

c) Test of Components and Systems

Systematic tests of surveillance components and systems are being performed. They include performance, reliability and radiation resistant tests of cameras and electronics, evaluation of capabilities of reviewing aid systems.

Many surveillance and multisensor systems are being field tested as mentioned above and, while development work continues actively, it is not easy to dissociate some of the activities mentioned under a, b and c.

d) Radiation Monitoring

Only CEA is actively involved in radiation monitoring development, test and evaluation for safeguards.

In particular, the utilisation of fluxmetry for Pu storage surveillance. A second area is the incorporation of neutron and gamma detectors in the CONSULHA system.

These activities are mainly oriented now to extensive field tests.

Conclusions for Surveillance Techniques

Table 2 summarizes the data and statements made above.

- Laboratories in EC (in R&D organisations and Industry) are strongly involved in development and test of all aspects related to surveillance systems used for safeguards purposes.
- Much effort is dedicated presently to multicamera/sensor systems for safeguarding industrial fuel fabrication, reprocessing and storage facilities.
- Most projects are in the field test stage or are being implemented and need some further engineering support.
- Standardisation in the use of components or tapes is practically non existent.
- The C/S Working Group has made a very useful survey on optical surveillance data reduction technique in 1990 and has contributed to a clear formulation of the problems involved. It has anticipated the intensive discussions being held at IAEA on this subject.

Table 2: C/S - Surveillance Techniques

	Number of Tasks	Organisations Involved	Status		
			R&D	Field Test	Implement.
a) Development of Hard/Software	7	JRC, ESD, KFA, Industry	X	X	X
b) Development of Multisensor systems	3	CEA, ESD, JRC, KFA, Industry	X	X	
c) Test of Components and Systems	5	JRC, ESD, KFA		X	
d) Radiation Monitoring	1	CEA			X

Analysis of R&D Activities in the Field of NDA

prepared by R.J.S. Harry
ECN, Petten, Netherlands
on behalf of ESARDA Co-ordinators

According to the recommendation of the Steering Committee of ESARDA the project co-ordinators have continued the analysis of the Research and Development as declared by the ESARDA partners. This article deals with the analysis of the field of Non-Destructive Analysis.

The data of ESTABANK of tasks on NDA

The ESTABANK started with information on the 1990-1991 programmes of the ESARDA partners, and is updated regularly. This analysis is based on the hard copy of 21 February 1992 on the NDA tasks of the ESTABANK. Also included are the tasks of the ESARDA Working Group on Techniques and Standards for Non-Destructive Analysis (NDA Working Group). The number of tasks has to be considered with a certain caution, because the amount of work and budget involved varies considerably from task to task. First discussion by the project co-ordinators of these tasks took place at a meeting in Copenhagen on 26 February 1992 together with the convener of the NDA Working Group. The input to ESTABANK on the NDA R&D activities of the ESARDA partners was updated by oral statements during that meeting. This report on the analysis has been discussed, reviewed and approved by the project co-ordinators meeting in Ispra on 29 September 1992. In principle this analysis reflects the information status of 26 February. No effort has been undertaken to distinguish between tasks that are still active and tasks that have been completed or the few that have been discontinued.

In total 76 tasks on NDA are reported in the database. Sometimes measurement techniques involving sample-taking have been categorized as destructive analysis; likewise a non-radiometric technique like weighing had been handled separately from NDA. In ESTABANK tasks of such a "border-line" character have been included in this NDA-section. That means tasks dealing with:

- K-edge densitometry and X-ray fluorescence,
- intercomparison between NDA and weighing,
- and tasks labelled earlier as "mixed" measurement technique.

26 Tasks were reported to be completed and 3 tasks were in abeyance for different reasons.

In the following listings some tasks may appear two or more times because they address several aspects, or they are not counted in the specific subheading because they escape that category. For example some tasks that address more general aspects like operation of PERLA, organising workshops, establishing performance data etc. are not counted under disciplines.

Disciplines

30 Tasks are related to neutron measurement techniques.
29 Tasks are related to gamma-spectrometric techniques.
7 Tasks are related to K-edge densitometry and X-ray fluorescence techniques.
1 Task is related to calorimetry.
1 Task is related to in-line voltametry, hence classified as non-destructive.

The discipline oriented classification is impossible for a number of tasks. This applies in particular to the tasks that are of a more general nature. The listing according to objectives puts the tasks in another perspective. This subdivision is not directly recognized in the database.

Objectives

8 Tasks are addressing the establishment of performance data.
4 Tasks are addressing the establishment of reference materials.
5 Tasks are addressing the design and construction of new equipment.
5 Tasks are addressing the in-field testing and installation of equipment.
5 Tasks are addressing PERLA, training, and workshops
11 Tasks are addressing the measurement procedures, electronic equipment, software for data treatment, and error modelling (correct evaluation of the propagation of measurement uncertainties into the measurement results).

Framework

9 Tasks are carried out in a research and development framework only,
43 Tasks are carried out as part of "support programmes" to the IAEA,
28 Tasks are carried out for the EURATOM Safeguards Directorate (13 out of the 18 JRC tasks), and
15 Tasks are carried out for an operator.

Applications

Some tasks have a very plant or nuclear material specific application. Other tasks show a multitude of plants as application possibilities, while there are also tasks of which the application is not directly related to a specific part of the fuel cycle.

8 Tasks are related to enrichment facilities.
38 Tasks are related to fuel fabrication plants, of which:
  7 tasks are related to all kinds of fabrication plants,
  19 tasks are related to MOX fabrication plants,
  6 tasks are related to LEU fabrication plants,
  1 task is related to HEU fuel fabrication, and
  1 task is related to conversion plants.
9 Tasks are related to reactors.
38 Tasks are related to reprocessing, of which:
  4 tasks are related to the input accountability tank,
  4 tasks are related to nuclear material in the process,
  21 tasks are related to the output,
  5 tasks are related to nuclear material in waste from reprocessing plants.
  3 Tasks are related to nuclear material in waste in general.

Discussion on the technical aspects of the tasks in NDA

The detailed summaries and analyses in this chapter are based on the descriptions of the tasks and the additional oral information from the discussions in the first Project Co-ordinators meeting on this analysis. In the second discussion this report has been reviewed.

Disciplines

Neutron measurements

There is a wide range of applications found for neutron measurements. Much effort goes into the determination of plutonium with coincidence techniques. For well defined objects like fresh fuel elements the technique is maturing. There are a number of task in that area of the application, directed to inspector training and implementation. Remaining problems are related to more complex measurement problems such as plutonium oxide with an unknown moisture content, and not easy to characterize waste. The neutron measurement techniques are getting continuous attention in the co-ordinated research programme. More straightforward applications are found in the passive measurements and the combination with a gross gamma-measurement like the application of the ION-fork to light water reactor fuel under water.

Neutron coincidence counting and calorimetry

Neutron coincidence measurements on PuO_2 are sensitive to the moisture content. Both the Belgian and the Italian work on this subject is in co-operation with the Los Alamos National Laboratory. The opportunity to do experiments is dependent on the availability of material with a well known moisture. Operators are normally trying to minimize the moisture content. A suggestion was made to search for realistic samples for these measurements. This will be investigated by the project co-ordinators.

The neutron coincidence collar is in wide use. One task addresses the training of inspectors in its use for fresh fuel (SCK). A review of the instrumentation procedures addressed the HLNCC measurement of fast reactor assemblies (UKAEA), and it has been applied to the measurement of the SNR-300 fuel (INB). Investigations of its behaviour (UKAEA), the establishment of the uncertainty components in the measurement results (SCK), as well as work on a new time correlation analyzer (UKAEA), and the supply of software for the treatment of data from the neutron correlation measurements (JRC), illustrate the breadth of the related research. ESARDA is organizing a workshop on neutron coincidence counting at PERLA in the beginning of 1993, which will allow an overview of recent achievements in this field.

One fundamental problem is still not solved, the measurements as they have been performed up until recently do not give enough information to determine all the relevant parameters. A related task is the fission multiplicity study (CEA). A study is also being made of the interpretation model of neutron measurements (JRC). In case of an appreciable but unknown moisture contribution to the neutron measurement, calorimetry offers the best measurement solution; a problem is the fragility of the instrument, and its relatively long measurement times. These are seen as serious drawbacks for its wider implementation. The co-ordinators considered that only one task on calorimetry in the database reflects that it does not get enough attention at this moment.

Other active and passive neutron measurements

One task on active and passive neutron measurements is directed to the measurement of the quantity of nuclear material in solutions as well as in solid waste (CEA). For irradiated fuel monitoring an active and passive type of the ION-fork is being investigated (CEA).

Tasks on active neutron techniques are directed to the measurement of:

- ^{239}Pu in waste (SCK), fissile material in waste drums measured by a combination of differential die-away and delayed neutron modes (UKAEA), a lead slowing down spectrometer (UKAEA), a pulsed neutron source (UKAEA), delayed neutron measurements with a Cf-shuffler (UKAEA), and matrix effects, including discontinuities, in the differential die-away counter (UKAEA).
- UF_6 enrichment in large cylinders in storage (CEA),
- Three tasks are related to the PHONID device. One aims at producing operating instructions for the PHONID III-bis, one at the set-up of a PHONID Mock-Up at PERLA, and one on the design of a lighter version the PHONID-4 for measurement of MOX, U and Pu (JRC).

Tasks on passive neutron techniques are directed to the measurement of:

- PuO_2 and MOX in glove boxes to avoid sampling (SCK)
- plutonium inventory of evaporators at Dounreay (UKAEA)
- determination of the amount of UF_6 in feed stations of an enrichment facility (ECN).

The ION-fork detector is being investigated for the measurement of fresh MOX-LWR fuel under water (SCK) as well as the burn-up and cooling time of irradiated fuel under water (SCK).

Gamma measurements

Gamma measurements of plutonium

Gamma measurements to determine the isotopic composition of plutonium get a large fraction of the attention in the programme. The development goes in the direction of demonstration and in-field implementation by the inspectorates. The evaluation programmes running on a PC, which became available recently have strongly supported this progress. Study of the more fundamental aspects of the gamma-spectrometry of plutonium such as the nuclear data and uncertainty propagation models support further improvements. The joint work of the ESARDA NDA Working Group and the work of the CBNM towards procedural and material standards form another support to further improvements of this type of measurements.

- Three tasks address the need for equipment that can work with high counting rates for Pu-isotopic composition determination (UKAEA,ENEA), while another seven tasks are related with improvement of the software, installation of a work station and training on the evaluation of the Pu-isotopic composition data from the measured spectra and a statistical package for evaluation of the measurement results at a later stage, e.g. at inspectors head-quarters (ENEA,JRC).
- Absolute photon emission probabilities will be determined by use of well characterized reference material (PERLA - standards) (CEA).

Other applications are the tasks on

- improvement of gamma measurements for PuO_2 and MOX in glove boxes, which can avoid sampling (SCK),
- gamma measurement to determine nuclear material in solution from the attenuation (CEA), and the
- verification of the plutonium content of small, low activity waste containers (ENEA).

Gamma measurements of uranium

Gamma measurements of the enrichment of depleted, natural and low enriched uranium are applied already for many years. In the programme are a number of tasks which reflect new developments or adaptation of the technique aiming at the detection of high enrichment material. The four tasks related directly to NDA in the cascade area of centrifuge enrichment facilities are:

- field test of measurement of the UF_6-gas enrichment (GE),
- development of equipment for measurements on low pressure pipes (UKAEA), and
- improvement of measurement time (ECN), and
- a system for continuous monitoring (UKAEA).

Another task aims at the

- improvement of hardware and software of the MTR fuel bundle scanner at a fuel fabrication plant (JRC).

K-edge densitometry and X-ray fluorescence measurements

The successful application of the hybrid instrument to reprocessing input solutions is followed by further tasks on field evaluation and the supply of an instrument to SAL (KfK), the on line application in the residues recovery plant and on a pulsed column rig (UKAEA), the support to design, purchase, installation, calibration and use of the K-edge densitometer in nuclear plants (JRC), and the slightly different but similar dual energy system for the assay of mixed solutions and the combined passive and active technique for Pu solutions (ENEA).

Objectives

The number of tasks in this class shows clearly how they are centred around the real problems of application in safeguards practice. The selected objectives imply the technology transfer from laboratory to field use. The data illustrate the inspectors demand for support in this area. The category framework illustrates the relations with the EURATOM Safeguards Directorate and the IAEA.

Good data on the uncertainties of the measurements are needed for the proper evaluation of NDA inspection measurements for safeguards. The establishment of the performance values demands the combined effort of several experienced users of the NDA technique together with good calibration sources or preferably certified reference materials.

The ESARDA Working Group on techniques and standards for non-destructive analysis is the forum to combine all efforts in this area and to establish a consensus on the broad basis of the experienced participants in that group. For new techniques, the performance of intercomparison studies helps to establish the "state of the art" which might be used to set a goal to be reached as a future performance value, reflecting the more realistic values for the "state of practice".

The tasks of the NDA WG are related to the performance evaluation of NDA and the establishment of performance values. For plutonium isotopic composition determination by gamma spectrometry, the WG has successfully concluded the intercomparison study PIDIE, which will be followed by a further evaluation (Post-PIDIE) and definition of needs for reference materials. Specific workshops on the measurement of nuclear material in waste (Salamanca 1992) and neutron coincidence counting (PERLA 1993) are planned,

Our European Community Joint Research Centre has established the PERLA laboratory, which offers unique possibilities to work on the establishment of the performance values through comparison measurements and studies. It also serves as an experimental test bed and a training ground for the inspectorates.

Two tasks are related to PERLA operation and the characterization of the reference materials in PERLA (JRC). Also a task on the error modelling for NDA measurement data can be related to this central issue (JRC).

One task is directed to the determination of the performance of the neutron coincidence counter (SCK). One tasks specifies the participation in comparison projects PIDIE, Post PIDIE and PERLA evaluation (ECN).

Framework

The number of tasks related to IAEA "Support Programmes" (43) is relatively high compared to that number for the EURATOM Safeguards Directorate (28). There are a number of large and important tasks executed on a direct bilateral basis between EURATOM and the research institute or company that have not yet been incorporated in the database of ESTABANK.

Application

The data shows a good distribution over the fuel cycle with emphasis on the plants that handle (or could produce) materials with a high strategic value, i.e. enrichment, reprocessing and MOX fuel fabrication.

For the enrichment facilities the NDA tasks are related to the measurement of the enrichment of UF_6 in cylinders in storage (CEA), the improvement of the "enrichment meter" (JRC), the neutron measurement of UF_6 in feed stations (ECN), and to the NDA in the cascade area (UKAEA, KFA, ECN). The workshop on the measurement of nuclear material in waste (Salamanca 1992) of the NDA WG has been related also to enrichment (for the sake of completeness, it addresses all types of facilities in the fuel cycle).

The 38 tasks related to fuel fabrication are mainly related to the use of neutron coincidence counting by the collar for fuel bundles, the neutron coincidence counting of plutonium and the isotopic composition measurement by gamma spectrometry. It is quite evident that the largest number of tasks addresses MOX fabrication. But also all other types of fuel fabrication are present in the list. The measurement techniques have been reviewed already in quite detail under the heading disciplines.

It is not surprising that the same techniques that apply to fresh fuel at the fabrication plant are also applicable at the reactor site. For irradiated fuel the ION-fork techniques have been specially developed.

The high attention to applications at reprocessing partly coincides with the attention for the hybrid K-edge absorption and X-ray fluorescence measurements (mainly input and process), and partly with plutonium measurements by neutron coincidence and gamma spectrometry for the product. 5 Tasks are related specifically to the waste at the reprocessing facility. Two tasks which did not fit in properly with the discipline section are:

- An intercomparison between NDA, weighing, and DA for hull monitoring (ENEA), and
- the application of in-line voltametry (UKAEA).

Also three tasks are specifically related to waste. The distribution of tasks over the fuel cycle looks quite acceptable for safeguards purposes. Beyond safeguards however the way in which the law develops can result in nearly impossible measurement requirements, such as the need for very detailed characterization of waste before it can be buried. For instance the law could require the measurement of small residual amounts of fissile material in vitrified fission product blocks.

Conclusions

Many NDA measurement techniques are being implemented, and the tasks reflect the process of technology transfer to the inspectorates. There is a growing number of tasks related to the installation of equipment in the field, calibration, the training of inspectors, making adaptations of existing equipment to specific situations, the development of computer programmes to interpret the measurement data, and to the development of quality control e.g. represented here by the establishment of performance values.

There is a clear need for an improvement in the understanding of the measurement process. This supports computer modelling of the measurements which results in the possibility to make prediction models that will generate better calibration curves and evaluate measurement uncertainties, and will assist in the computer modelling for calculating the optimal design of new equipment.

Research is now concentrating on the more difficult problems. Several tasks on measurement techniques are aiming at e.g. glove boxes, evaporators, or conditioned waste. Also combinations of measurement techniques are being applied, e.g. the combination of a gross gamma and a neutron measurement in the ION-fork for measuring irradiated fuel, or the gamma-spectrum measurement and neutron coincidence counting or calorimetry on plutonium.

An advanced example of a combinations of techniques is found in the CONSULHA project at La Hague. The radiation monitoring function is combined with containment and surveillance measures. In the future more of these integrations of techniques will be investigated, and more often such a development will involve different ESARDA Working Groups at the same time.

It is expected that improvements of neutron coincidence counting are possible by use of a multiplicity counter.

The hybrid K-edge density X-ray fluorescence instrument has the potential to be applied to MOX powders or to co-precipitated solutions at the MOX fuel fabrication plants.

For the Workshop on measurements of nuclear material in waste (Salamanca 1992) it is expected that well developed equipment from the waste management area, like e.g. segmented gamma tomography will be presented. These more modern techniques can also help to solve safeguards measurement problems in this area.

From 5 to 8 May 1992, the "ESARDA workshop on non destructive assay techniques applicable to safeguarding nuclear material in wastes" has been held in Salamanca, Spain. The NDA information of ESTABANK from 21 February 1992, as analysed for this article can not contain the new tasks based on the conclusions of that workshop. Undoubtly that will be the case in a future analysis.

The workshop conclusions can be summarized as:

- There are no particular problem areas in the field of NDA on waste for safeguards.
- The NDA Working Group should continue its work on performance values (detection limits, accuracies).
- There is a great difference between the objectives of waste management and safeguards measurements.
- It is strongly recommended to perform a detailed search in the field of NDA for waste management to find also for safeguards applicable and pertinent NDA techniques.
- The frequent safeguards use of operators NDA equipment for waste management purposes, demands for proper authentication of the measurements with that equipment.

The discussions in the group of project co-ordinators have dealt with the technical features of the research tasks as well as other aspects. Other opportunities for further co-operation in ESARDA are emerging. The NDA Working Group initiative to have special meetings on particular topics like the workshop on measurements of nuclear material in waste and on coincidence counting contributes to the international exchange of information and establishment of co-operation. The trend to combine different safeguards techniques is also noted. It would be advisable to establish more contact between the ESARDA working groups to cope with this new trend.

The Integration of Optical Surveillance and Electronic Sealing

B. Richter and G. Neumann
KFA Jülich
Federal Republic of Germany

Introduction

A great deal of safeguards activities involve optical surveillance as a supporting measure to nuclear material accounting. The transition from film camera surveillance to video systems, in particular the implementation of high-capacity multi-plexed video systems, results in a large amount of recorded scenes. Consequently, there is a substantial increase in the person power requirements for review. Moreover, modern microprocessor controlled equipment facilitates integration of several originally independent systems into one system with new capabilities and the collection of additional data associated with each video scene. Both the scene and the annotated information have to be evaluated by the inspector.

Under the BMFT/IAEA Joint Programme the Multi-camera Optical Surveillance (MOS) System has been developed which aims at optimizing the capabilities of a multi-channel video system including the reviewing technique, also with regard to significantly reducing the person power requirements without loss of reliability. This concept was described in detail in a previous paper /1/. One feature of the MOS System is the capability to communicate with the VACOSS-S electronic seal which was also developed under the German Support Programme /2/. The background for the VACOSS-S/MOS coupling is to enable a facility operator to carry out safeguards relevant activities in the absence of an inspector without loss of continuity of knowledge. Such activities could be the shipment or receipt of nuclear material casks.

The VACOSS-S/MOS operating mode has not been described and is the subject of this paper. For reasons of better understanding the MOS System will be briefly described before entering into details on the communication of the MOS System with the VACOSS-S electronic seal. Finally, some applications of the integration of electronic sealing and video surveillance are discussed.

The Mos System

The Multi-camera Optical Surveillance (MOS) System, excluding the cameras, is designed to be installed in a safeguards control room of a nuclear facility with access restricted to inspectors. MOS provides long term unattended video surveillance. The standard MOS has 8 camera channels but can be expanded to 16. The basic features are as follows:

- Authentication of video signals of each camera channel using the Tamper Resistant TV-Link /3/
- Individual timing of recording of each camera channel
- External triggering e.g. using video motion detection
- Immediate storage of a detected i.e. externally triggered scene or of a programmable sequence of scenes at a different timing interval
- Interfacing of the VACOSS-S electronic safeguards seal /2/
- User definable text insertion for externally triggered scenes
- Electronic notebook for relevant inspection-period data
- Testing capability for a video motion detector
- Enhanced review station.

MOS has a modular design which enables flexibility in configuration and maintenance and allows for introduction of improved technology as it appears on the market. MOS complies with the European monochrome TV-standard CCIR and is adaptable to the US monochrome TV-standard EIA. The mechanical standard for the console meets the international 19" rack-mount requirements. Electrical and safety standards are met according to the requirements of the Federal Republic of Germany. As an example, Fig. 1 shows a four-channel MOS System with two video monitors and VCRs in a cabinet.

The basic components of MOS are the Tamper Resistant TV-Link (TRTL), a digital buffer memory for video scenes, a recording unit (remotely controllable Super-VHS video recorder), and a review station. MOS has a System Application Architecture software platform.

An alternative recording unit could be a time lapse recorder in the back-up recording channel. For immediate checking of the MOS performance the built-in recording unit can be used at the expense of loss of surveillance during review. Therefore, for inspection purposes a separate review station is necessary.

The video information recorded with MOS is credible because it is authenticated. The reliability of MOS is enhanced by the use of the digital video memory as a buffer before the VCR. MOS uses commercial video recorders. Front end data reduction can be implemented by the use of external triggering, e.g. video motion detection. The proper functioning of the video motion detector is checked by a built-in self-testing device. MOS can communicate with VACOSS-S. MOS has a number of self-diagnostic features the results of which are retrievable for evaluation. Video signals are coded in the invisible part of the frame. The code has binary format and precedes the video information. The channel number is assigned to each frame at the highest level of reliability. The coding also facilitates image processing. The review station is PC-controlled (self-instructive interactive display operation) and capable of channel sorting as well as detection of missing scenes. MOS complies with the relevant technical standards.

The Integration of VACOSS-S and MOS

Purpose

The integration of VACOSS-S and MOS into one functional concept of VACOSS-S/MOS operation serves the purpose to save inspection person days at the facility and therefore reduces inspection costs. There is no need for the inspector and facility operator to make any appointments regarding transport of nuclear material. VACOSS-S/MOS operation allows a facility operator to install before shipment or remove after receipt the VACOSS-S seal in the field of view of the video camera for verification at a later date

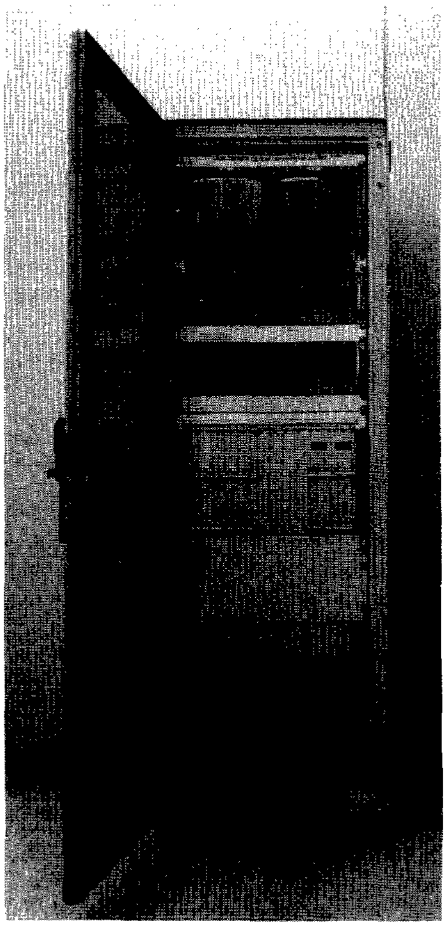


Fig.1: Four-channel MOS System with two video monitors and VCRs in a cabinet

by a safeguards inspector. Data stored in the seal and recorded on video tape are consistent with each other and cannot be manipulated by the facility operator.

Technical Concept

The basis is MOS as a standard multi-channel video surveillance system with video authentication. It is possible to use all MOS features including the self-testing device for video motion detectors and external event triggering mode. The concept is described using Fig. 2.

One camera channel of MOS is used for the VACOSS-S/MOS operation. An additional VCR for realtime recording of the seal operations and the Intelligent Terminal IT90 are connected to MOS. The MOS System including the additional VCR is contained in a sealed cabinet or safeguards control room, whereas the facility operator has access to the Intelligent Terminal IT90 and VACOSS-S seals. All this equipment constitutes the standard configuration of a MOS with the option to handle VACOSS-S seals under video surveillance.

The IT90 is permanently connected to the MOS System via a four-wire cable (RS485). In case of long distance transmission or strong interferences such as EMI, it is possible to install an optical transmission link between the MOS cabinet and IT90.

The functions of the IT90 are to instruct the user (facility operator) during attachment or removal of the VACOSS-S seal, to maintain communication with the MOS Network Controller, and to interrogate the seal. The option exists to extend the standard configuration in order to provide the facility operator with his own video camera, video monitor, VCR, CGA colour monitor, and printer. This additional equipment enables the facility operator to record and archive his own activities. However, this is an option only and no necessity, since it is up to the facility operator whether he wants to do his own recording.

Fig. 2 shows that the VACOSS-S/MOS coupling has been designed in a way to strictly distinguish between the responsibilities as well as equipment of the facility operator on the one hand and the safeguards inspector on the other. The Intelligent Terminal IT90 and the corresponding peripheral devices are installed, used and maintained by the facility operator only.

Intelligent Terminal IT90

The IT90 consists of a microcontroller with several interfaces and a 40 by 8 character LCD. The whole system is mounted in a 1/2 19" rack/box. Under the LCD there are 4 softkeys to enable all operations even under impeded conditions, e.g. with gloves.

The device has a built-in emergency power supply (accumulator) for a three-hour operation. The normal power supply is the facility mains. All user instructions can be displayed either in German or English. There is capacity for additional languages.

Pressing any of the four keys will turn the IT90 on and give the user the options of performing seal operations or changing the setup of the device. The possible settings of the IT90 are

printer output:	YES/NO
printer transmission rate:	9600 bps ....
PIN protection:	YES/NO
video standard:	CCIR/EIA
language:	GERMAN/ENGLISH

Once selected, settings will be permanently stored in the device.

Features and Procedures of the VACOSS-S/MOS operation

The features and operational procedure of the VACOSS-S/MOS mode are:

1) When switched on, the IT90 checks whether it is powered by battery or mains. In case of battery power, it checks whether there is still enough battery charge for one complete seal operation; if not, IT90 switches itself off. In case of mains power, battery operation will be automatically implemented upon blackout.
2) After selecting a seal operation, IT90 communicates with MOS to get an OK. A seal operation will be inhibited, if there is not enough memory capacity left for the storage of VACOSS-S seal data in the MOS electronic notebook, or if there is not enough capacity left on video tape, or if communication with MOS is impossible, or if there is a total failure of MOS, or if the camera video signal is not present.
3) The SEAL INSTALLATION procedure is only possible, if the seal shows NORMAL battery charge, no SEAL BOX OPEN event, and the correct status of the fibre optic cable, i.e. CLOSED before it is supposed to be opened for installation on a cask.
4) There are corresponding conditions for the SEAL REMOVAL procedure.
5) The seal data are interrogated three times and recorded on video tape by MOS, while only the third data set is recorded in the MOS notebook.
6) IT90 will inform MOS on each step of the VACOSS-S procedure. MOS will interrupt

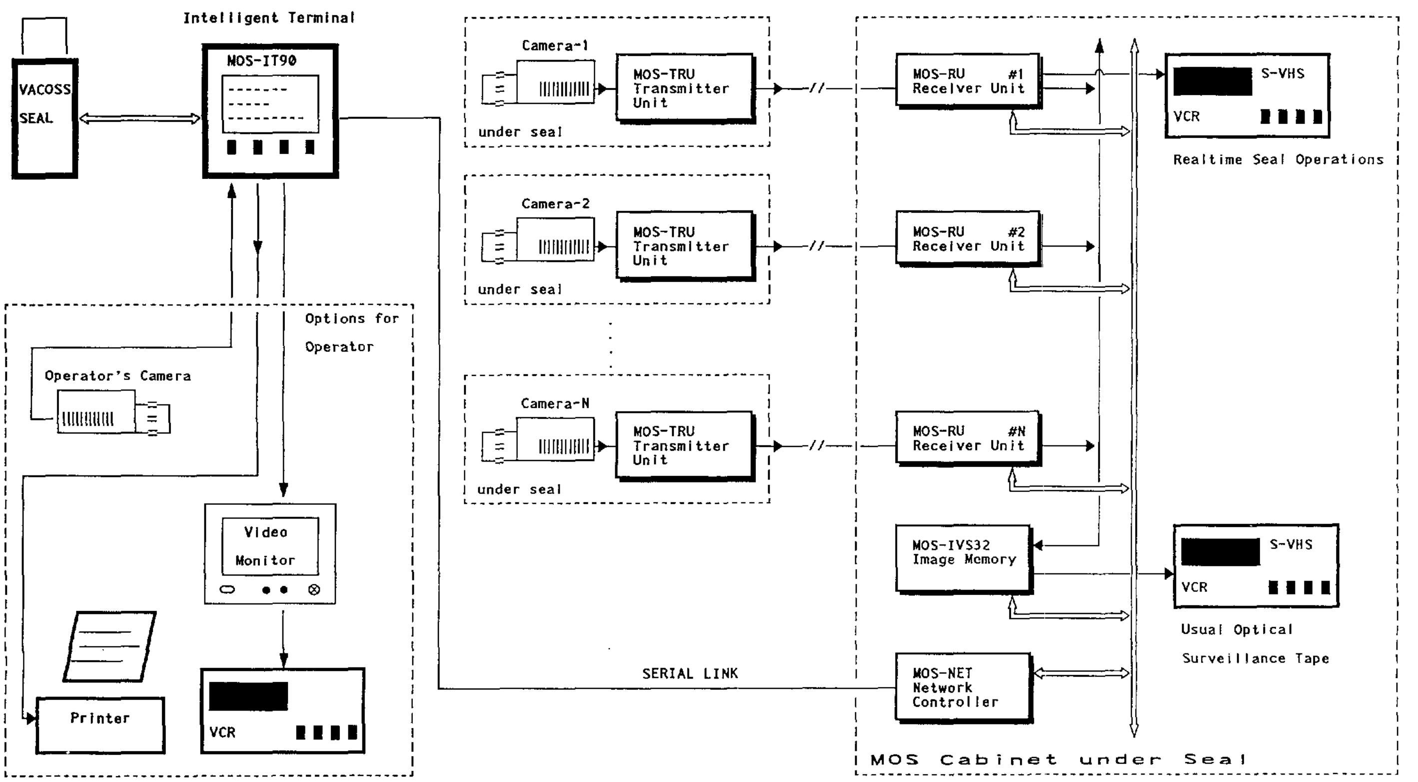


Fig. 2: Three-channel MOS System with VACOSS-S/MOS coupling

the seal operation, if the plant operator does not follow the instructions.

7) All instructions appear on the IT90 LCD, and, if desired, on the CGA monitor, and on the TV monitor, the latter showing also the video scene.
8) There are several options such as the choice of language, printout via serial interface, interfacing with an operator's PC and/or video system.

Inspector's Tool

The inspector when visiting the facility is interested in performing his agreed verification activities including video tape review and interrogation of VACOSS-S seals. A PC is the only necessary tool for the inspector who is able to retrieve the inspection period data from the electronic notebook of the MOS Network Controller including the seal data gathered during seal operations. Since the data are inserted in plain text into the camera channel dedicated to seal operations, the inspector has the data also available upon review of the tape which shows the VACOSS-S seal operations in realtime (see Fig. 2, camera channel no. 1). On the other hand, the inspector can use his PC to talk with the VACOSS-S seal directly while exploiting all resources provided by the PC, e.g. storage of seal data on diskette, printout of data, etc. The original communication unit for the seal which was the adapter box, has become obsolete. The PC can even be replaced by a palmtop computer, e.g. HP 95LX.

Applications

Sealing of items on the one hand and optical surveillance of containments on the other have been standard measures of international safeguards. The availability of microprocessor-controlled equipment offers the possibility to integrate an electronic sealing system and a video surveillance system into a containment and surveillance system of new capabilities.

A transport cask with spent nuclear fuel could be sealed with a VACOSS-S seal and the sealing operation could be performed under camera surveillance by the facility operator in the absence of the safeguards inspector. This possibility had been previously discussed with the operator of a nuclear power plant in anticipation of spent fuel shipments to a long term intermediate storage facility. A one-channel system was operated solely by the plant operator's personnel /4/. The results demonstrated an excellent proof of concept and led to the development of the VACOSS-S/MIVS Interface System /5/.

The operator of a storage facility could remove the VACOSS-S seal under camera surveillance when receiving transport casks with spent fuel designed for long term storage. Such an application will be tested using the MOS System as described above.

Similar applications of the VACOSS-S/MOS coupling are conceivable wherever inventories of nuclear material can be secured on a temporary basis by sealing and video surveillance, giving sufficient assurance in the absence of an inspector.

References

/1/ B. Richter, G. Neumann, K.J. Gärtner, G. Laszlo, P. Otto, H. Wagner; The Multi-camera Optical Surveillance System (MOS), Design and Reliability, ESARDA 24, 1991, p. 509.

/2/ B. Richter, G. Stein, R. Günzel, K.J. Gärtner, E. Yellin; The Design and Quality Assurance of the VACOSS Series Production Model, J. of the INMM, Vol. XVII, 1988, p. 666.

/3/ B. Richter, G. Stein, G. Neumann, K.J. Gärtner, J.V. Whichello; Design and Evaluation of the Tamper Resistant TV-Link, J. of the INMM, Vol. XVIII, 1989, p. 1040.

/4/ R.L. Martinez, S.L. Schneider, B. Richter, R. Guenzel, K.J. Gärtner, A. Terrasi; The New Design of the VACOSS-S/MIVS Interface System, J. of the INMM, Vol. XX, 1991, p. 637.

/5/ B. Richter, G. Stein, R.L. Martinez, S.L. Schneider, M. Heske, H. Stratmann, K.J. Gärtner, P. Ammann, J. Janssens, A. Terrasi; Installation and Operation of the VACOSS/MIVS Interface System at the THTR Facility, J. of the INMM, Vol. XIX, 1990, p. 829.

The PC Program MEMO - A Useful Tool to Calculate the Statistical Measurement Model for NRTA Test Procedures

R. Seifert, W. Golly, U. Bicking, W. Bahm
KfK, Kernforschungszentrum Karlsruhe GmbH
Federal Republic of Germany

Abstract

In the framework of the German support programme for the IAEA, PC computer programs have been developed for the routine use in the field. First, the package PROSA has been developed for the test of sequential material balances on statistical significance. Part of the input to this program consists of a statistical measurement model based on real nuclear material balance data. For this purpose the program MEMO has been developed which is capable of calculating a measurement model to the necessary level of detail. For easy handling in field applications a menu-guided user-shell has been integrated. The underlying statistical method as well as the program itself are described in this paper.

Introduction

The primary goal of IAEA safeguards is the timely detection of a diversion of significant quantities of nuclear material and deterrence by the risk of early detection.

Nuclear material balances related to material balance areas play the key role in safeguards application in bulk handling plants such as fuel fabrication and reprocessing facilities. In those cases where direct-use material is handled, the relevant safeguards criteria include short time detection goals requiring the application of advanced accountancy measures e.g. the so-called near real time accountancy (NRTA).

For more than a decade, various statistical approaches for NRTA have been developed in several countries. However, in many cases they remained on a theoretical level and have not been brought to a status of practical application. Therefore the benefit of such approaches for the solution of material balance problems in the field was often questioned.

Some 10 years ago, the development of NRTA methods was intensified by the Nuclear Research Centre Karlsruhe in particular in view of the Wackersdorf reprocessing project. After the theoretical development of the statistical methodology and its adaptation to nuclear material accountancy purposes much effort was spent to transpose the mathematical tools to a PC software which can be almost handled as easily as other application programs such as word processing. As a first result the PROSA package was released being capable of testing a sequence of nuclear material balances on statistical significance. It has undergone a series of field tests and further developments in order to improve user-friendliness and it has been already successfully applied by the IAEA to routine inspections.

The next step is the release of the package MEMO which can serve for the calculation of measurement models of real sequential balance data. "Real" in this connection means that a measurement model is calculated based on actual data on throughput and inventory of nuclear material and on related measurement errors. MEMO has been passed on recently to the IAEA for test purposes.

Sequential Balancing

The "classical" material balance approach assumes that the plant is shut down and cleaned out and all nuclear material is directly accessible for the purpose of verification. In this case the material balance closing can be described by the well kown equation:

$$MUF = I_B + T - I_E, \qquad (1)$$

where I_B and I_E stand for the inventory at the beginning or at the end of the reference time, T denotes the net transfers during the reference time and MUF means material unaccounted for. This so-called "classical" approach is capable of detecting a possible diversion with high probability.

But it is evident that this approach is not capable of meeting the timely detection goal due to the fact that the balance is closed only at the end of the reference time which is usually in the order of half a year to one year.

In order to meet the criteria of timely detection requires the application of NRTA-methods.

The basic idea is to subdivide the total reference time into N balance periods and to close the balance after each period. This procedure generates a sequence of material balance results MUF(i), i=1,..,N with:

$$MUF(i) = I(i-1) + T(i) - I(i), \qquad (2)$$

where I(i) is the ending inventory of period i as well as the beginning inventory of period (i+1), and T(i) is the net transfer in period i.

Using this approach at the end of the i-th balance period a decision can be taken on whether or not there is an anomaly, based on all i balance results MUF(1),...,MUF(i). Thus, trends can be recognized early and losses may be detected timely related to their occurrence.

But now a further problem arises. At first sight, one tends to assume that each MUF value in Formula (2) should be zero if no loss of material has occurred, or, viceversa, if there are MUF values greater than zero, nuclear material is missing. However, as the terms in the materials balance equation are the results of several measurements - each of them connected to characteristic measurement uncertainties - the MUF values generally do not amount to zero even in the case of no loss of material.

That means, at the end of each balance period i, a decision has to be taken whether or not the deviations of the sequence of MUF values MUF(1),...,MUF(i) from the expectation values zero can be explained by (known) measurement uncertainties.

To evaluate the series of MUF values in an objective and convenient manner the computer program PROSA /1,2/ was developed. Input of PROSA are the sequence of material balance results MUF(1),...,MUF(i) and the measurement model of the facility considered. Using sequential statistical test procedures PROSA evaluates the series of MUF values based on the measurement model. That means the output of PROSA is a decision on whether or not the series of materials balance results can be explained by the assumed measurement uncertainties. If not, further investigations are necessary in order to solve the discrepancy. If this is not possible, a diversion of nuclear material cannot be excluded.

In this connection the determination of the measurement model is an essential step in data evaluation. This measurement model contains all individual measurement uncertainties with random and systematic components, including the appropriate propagation of variances. From the statistical point of view, the measurement model is described by a matrix which can be regarded as the variance/covariance matrix or dispersion matrix of the MUF series.

In the last several years a lot of R&D effort was spent for theoretical considerations on measurement models /3,4/, for establishing detailed measurement models based on real process data /5,6/ and for developing related computerized tools /7/. In the following, theoretical and fundamental aspects are discussed and the PC program MEMO for computerized establishing of measurement models is introduced.

Some Remarks to the Measurement Model

In order to determine the measurement model, first of all it is necessary to define the facility model. This includes the number of inventory components in which nuclear material to be verified is contained and the number of input and output batches tranferred during the balance period. That means, for each balance period the facility model consists of a triple of integer values **ni,nr,no** where **ni** refers to the number of inventory components, **nr** to the number of input batches, and **no** to the number of output batches.

Next the error model has to be established. This model includes all measurement uncertainties of volume measurements as well as of concentration measurements.

Each single measurement - volume as well as concentration - is described by the relative standard deviation (rsd) of the

- multiplicative component of the systematic measurement uncertainty,
- multiplicative component of the random measurement uncertainty

and the standard deviation (sd) of the

- additive component of the systematic measurement uncertainty, and
- additive component of the random measurement uncertainty.

The facility model as well as the error model are constant as long as the facility design is not changed. The facility design could be changed either if a new component is added (change of facility model) or a new measurement procedure is introduced (change of error model).

The measurement model itself is affected by the measurement data through the relative error model. That means it is a function of the (long-term constant) facility model, of the (long-term constant) error model and of the (variable) measurement values, and, therefore, is not constant at all.

Assumptions on the Measurement Uncertainties

We assume that the considered amount of material in each inventory component and in each transfer batch can be determined as the mathematical product of a volume determination and a concentration determination:

$$\text{amount} = \text{vol} * \text{con}. \qquad (3)$$

Further we assume that each single determination (volume and concentration as well) can be conceived as a "measurement" with a systematic and a random error component.

Both, systematic and random error components, are assumed to be part of the relative error model; that means they have a multiplicative and an additive error component.

For example,

$$\text{con} = E(\text{con}) + E(\text{con}) * (\text{msc} + \text{mrc}) + \text{asc} + \text{arc}, \qquad (4)$$

with E(con): the true (but unknown) concentration value

msc: the multiplicative component of the systematic error of the concentration determination

asc: the additive component of the systematic error of the concentration determination

mrc: the multiplicative component of the random error of the concentration determination

arc: the additive component of the random error of the concentration determination.

The next assumption is that all error components are normally distributed with known standard deviation and mean zero. Mean zero means that all measurements are unbiased.

Volume measurements and concentration measurements are assumed to be mutually uncorrelated and the same applies to systematic and random error components as well. Correlations may occur when the same measurement method is used several times (propagation of variances for the systematic error component) or when the same measurement is used to determine the content of material in two or more components (propagation of variances for the random error component). This may occur in a case when the concentration is measured in a vessel and the same measurement value also *relates to the concentration of nuclear material* contained in the connected pipe.

Another assumption is that the systematic error is constant during the reference time; that means, no recalibration of measurement methods and instruments takes place.

Determination of the Measurement Model

In the facility considered, each amount of nuclear material contained in each process component and in each transfer batch is calculated by the mathematical product of a volume measurement (vol) and of a concentration measurement (con).

Using truncated Taylor series expansion in the mean values E(vol) and E(con) leads to

$$\text{vol} * \text{con} = E(\text{vol}) * E(\text{con}) + (\text{con} - E(\text{con})) * E(\text{vol}) + (\text{vol} - E(\text{vol})) * E(\text{con}), \qquad (5)$$

which results in the reasonable equation

$$E(\text{amount}) = E(\text{vol}) * E(\text{con}) \qquad (6)$$

With regard to the variances, the following expression holds:

$$\text{var}(\text{amount}) = (E(\text{vol}))^2 * \text{var}(\text{con}) + (E(\text{con}))^2 * \text{var}(\text{vol}) \qquad (7)$$

On the right hand of Formula (7) the terms E(vol) and E(con) appear which represent the true but unknown values of volume and concentration measurements.

These unknown values can be substituted by the measurement values themselves, because each measurement is an unbiased estimate of the true value. With this procedure, the variance of each batch of material can be calculated. Furthermore, the variances can be split into random and systematic components.

With flow-sheet information from the plant all variance and covariance calculations can be summarized into the so-called dispersion matrix of the MUF series. For example, the (i,j)-th element of the matrix describes the covariance between MUF(i) and MUF(j). The dispersion matrix is the condensed form of the measurement model and provides the necessary information to evaluate the sequential MUF series.

The Computer Program MEMO

The determination of the dispersion matrix can be easily facilitated by computerized procedures. Some ten years ago at the Kernforschungszentrum Karlsruhe a host version of a computer program to determine the measurement model was developed.

But for routine field use a PC version of such a computer program is necessary. Therefore, the host version was transposed into a PC version /7/. But some difficulties needed to be mastered. The greatest problem was the huge amount of memory needed by the old host version. The next problem was a run-time problem. The old program, fast on the host, was very slow on the PC. The third problem was that the old program was not able - neither on host nor on PC - to cover all correlations which may occur in practice.

Due to these reasons a completely new version was elaborated called MEMO 2.0 (**Me**asurement **Mo**del). The computer program MEMO 2.0 runs on Personal Computers which need at minimum the following configuration of hardware system:

- AT compatible computer system
- mathematical co-processor
- at least 256 kbyte memory
- hard-disk drive
- operating system DOS version 3.0 or higher.

To make MEMO user-friendly for routine field application, the MEMO program modules are covered in a menu-guided user-shell. The entry to MEMO application is shown in Fig. 1 which displays the main menu.

There is almost no risk of handling MEMO in an incorrect manner, because the user is menu-guided. Examples of incorrect use of MEMO may be the missing of initial data sets. In these cases, the program system generates self-explanatory messages which give the user advice how to proceed correctly.

MEMO-Version 2.0

MEMO Program:
Enter the Number of Your Choice

1 = Browse/Read/Edit/Print Input Data
2 = Run MEMO
3 = Browse Results
4 = Data Transfer to PROSA
Q = Quit the session

Fig. 1: The Main Menu of MEMO

As already explained, the measurement model is a function of the facility model, of the error model and of the actual measurement data. These input *information can be imported to the MEMO program* via two input data files. The first input data file, usually called "design.dat", contains all measurement methods (volume and concentration measurements) with their specific multiplicative/ additive, and systematic/random error components.

The second input data file, usually called "measure.dat", contains the facility model in the first line and the actual values of volume and concentration measurements in the following lines. These are complemented by key parameters in order to link the various measurement data with the associated measurement errors. Output of MEMO is the sequential MUF series which is computed from the individual measurements. A further output is the dispersion matrix of the MUF series. Both output components of MEMO, MUF series as well as dispersion matrix, are essential input components of the evaluation program PROSA.

In the current version 2.0, MEMO is able to determine the sequential measurement model of up to 50 balance periods as long as the sum of inventory components, input batches per period and output batches per period does not exceed a number of 100 items.

A further very comfortable feature of MEMO 2.O is the possibility to built up the measurement model from period to period. That means that only the last line of the dispersion matrix has actually to be calculated which then is added to the former matrix. This leads to a considerable reduction of the run-time.

Conclusions

The advanced PC program MEMO 2.O is the connecting piece between material accounting and data evaluation and therefore an important tool for international safeguards applications. On the basis of design information and actual measurement data MEMO 2.O is able to compute the sequential material balance results (MUF) and the related statistical measurement model of facility campaigns. Establishing the measurement model can be performed as detailed as necessary in order to describe the measurement situation as realistic as possible. MUF series as well as the measurement model are essential input data for evaluation programs like PROSA. The menu-guided user-shell of MEMO makes the application of MEMO user-friendly. Therefore, MEMO is very suitable in routine field use. A comprehensive manual is in preparation and will be made available before long.

References

/1/ Bicking U., Golly W., Seifert R.: "PROSA, an Advanced Computer Package for Sequential Evaluation of Nuclear Materials Balance Data", Proceedings of the 31st Annual Meeting of the INMM, Los Angeles, California, USA, July 15-18, 1990, p. 606-609

/2/ Bicking U., Golly W., Peter N., Seifert R.: "PROSA VERSION 4.0 Manual", KfK 4866, 1991

/3/ Beedgen R., Golly W., Seifert R.: "Problems in Establishing a Measurement Model for Reprocessing Facilities and Its Use in Applying Sequential Statistical Tests", Proceedings of the RECOD '87, Paris, August 23-27, 1987, p. 939-944

/4/ Beedgen R., Seifert R.: "Statistical Methods for Verification of Measurement Models", ESARDA Bulletin, No. 15, November 1988

/5/ Bicking U., Golly W., Seifert R.: "Establishing of a Detailed Measurement Model for NRTA Procedures", Proceedings of the 11th ESARDA Symposium on Safeguards and Nuclear Material Management, Luxembourg, 30 May - 1 June, 1989, p. 315-318

/6/ Bicking U., Golly W., Seifert R.: "Evaluation of Real Balance Data Using a Detailed Realistic Measurement Model", Proceedings of the 30th Annual Meeting of the INMM, Orlando, Florida, USA, July 9-12, 1989, p. 161-165

/7/ Bicking U., Golly W., Seifert R.: "The Computer Program MEMO - a Tool to Establish Detailed Measurement Models for NRTA Test Procedures", Proceedings of the 13th ESARDA Symposium on Safeguards and Nuclear Material Management, Avignon, France, 14-16 May 1991, p. 677-680

Practical Results in Establishing Statistical Measurement Models of Real Sequential Balance Data

R. Seifert, W. Golly, W. Bahm
KfK, *Kernforschungszentrum* Karlsruhe GmbH
Federal Republic of Germany

J. Lausch, D. Schmidt
WAK, Wiederaufarbeitungsanlage Karlsruhe Betriebsgesellschaft mbH
Federal Republic of Germany

Abstract

In order to demonstrate the applicability of NRTA measures for reprocessing plants the German Federal Ministry for Research and Technology has sponsored a research program for computerized inventory taking of nuclear materials at the Wiederaufarbeitungsanlage Karlsruhe. The iterative process of establishing the statistical measurement model based on real process data using the PC programs MEMO and PROSA is described in detail. Simulations by hypothetical loss-patterns demonstrate the applicability and good performance of the method.

Introduction

IAEA safeguards in large scale reprocessing plants require inspection schemes capable to timely detect a diversion of significant quantities of direct-use material. The generally agreed method in order to achieve this goal is the application of NRTA methods. For routine field use two program packages have been developed by the *Kernforschungszentrum Karlsruhe:* PROSA being capable to evaluate sequences of nuclear material balances, and MEMO which calculates measurement models based on actual plant data on inventory and throughput of nuclear material and related measurement errors. A detailed description of PROSA has been presented in /1/ and a report on field test performance is provided in /2/.

This publication describes test applications of MEMO in the WAK pilot reprocessing plant at Karlsruhe (Wiederaufarbeitungsanlage Karlsruhe) in the framework of a research program sponsored by the Federal Ministry for Research and Technology, which was aimed to demonstrate the applicability of NRTA measures in reprocessing plants.

Data on previous campaigns primarily generated for process control purposes were collected and used to establish sequential short time nuclear material balances. Sequential tests were applied to these data in order to decide on whether or not the observed differences between book inventories and measured inventories can be assigned to measurement errors.

The evaluation of material balance results, the so-called MUF values, is based on the measurement model of the facility considered. Therefore, the determination of the measurement model is an essential step in the application of NRTA measures. It includes all relevant measurement uncertainties and the related propagation of variances and is a function of the facility model, of the error model of applied measurement methods, and of the actual measurement data. This measurement model is represented by a matrix, which, from the statistical point of view, is the variance/covariance matrix or dispersion matrix of the MUF series.

This report describes the iterative process of establishing a detailed measurement model for NRTA measures of a WAK campaign using real process data.

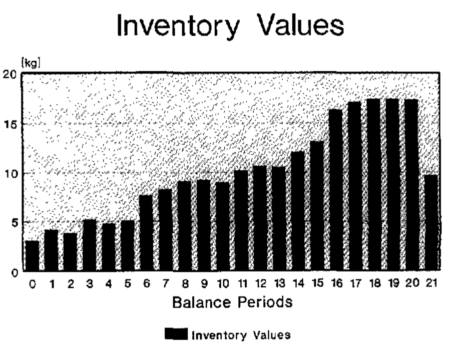


Fig. 1: *Pu-Inventory of the Campaign.*

Description of the Plant/Campaign

The Wiederaufarbeitungsanlage Karlsruhe served as a test bed in order to gain experience with establishing real measurement models. The Plutonium quantities to be verified are spread over some 70 process components and is calculated from some 100 individual measurements, namely from about 70 volume measurements and from about 30 concentration measurements. In order to determine the variance of inventory and transfer measurements, operational information as well as target values were used for estimation of measurement uncertainties.

The evaluation method was applied to data from the reprocessing campaign 2/83 of the WAK plant. Fig. 1 shows an increasing Pu-inventory over the time as a result of more than 100 single measurements in some 70 process components. From Fig. 1 it is obvious that the data do not represent at all a steady-state facility operation. Furthermore, the transfers differed considerably from period to period.

With the help of the PC program MEMO /3/, the MUF series, see Fig. 2, and the related measurement model were established. For that purpose a data handling program was necessary to transpose the process data generated for process control purposes into a proper input format for MEMO. In a next step, the sequential material balance data were evaluated by the PC program PROSA /1,2/ based on the dispersion matrix in order to investigate whether or not the data can be explained by the measurement model. In PROSA three sequential test procedures are included, namely Page's test /4/, GEMUF test /5/ and CUMUF test /6/. These three test procedures are the result of several years of research. At the moment they are supposed to be the most promising ones with respect to the detection probability of losses of material and to the timeliness of such a diversion as well /7/.

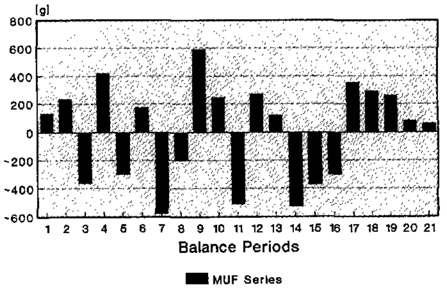


Fig. 2: MUF Series of the Campaign.

Practical Results of the Investigation

A first approach for the determination of a measurement model was performed using a so-called "One-block-model". That means the total inventory of the facility is assumed to be contained in one single component. However, evaluations with real process data revealed that the balance data were not in accordance with this measurement model. This was due to the fact that the distribution of the inventory among the various plant components could not be taken into account at all.

In a next step, a more detailed measurement model was established. But in this approach some inventory components with only small amounts of Plutonium like pipes were not included. Again the evaluation with PROSA caused an alarm. The reason was as follows:

At the beginning of the campaign all plant components including pipes were almost empty. With increasing inventories, in our model, more and more material unaccounted for "disappeared" in the pipes causing positive MUF values and consistently an alarm.

A further approach took all Plutonium-containing components into account. Thereby, each balance term was calculated via the mathematical product of the appropriate volume and concentration measurements. The results of test procedures contained in PROSA are shown in Fig. 3. The upper part of Fig. 3 shows the two-sided Page's test. The crosses in the upper and in the lower part of this diagram denote the test thresholds, and the squares denote the test statistics. The upper test statistics are tested against the upper thresholds, and the lower test statistics are tested against the lower thresholds. An alarm would be indicated, as soon as one of the statistics crosses their test thresholds. In the upper part of Fig. 3 this is not the case.

The middle and lower parts of Fig. 3 show the results of GEMUF test and of CUMUF test, respectively. These tests have only one test statistic each. The test statistics (squares) are tested against the thresholds (crosses). Here the GEMUF test in the middle part of Fig. 3 gives an alarm, whereas the CUMUF test in the lower part of Fig. 3 does not alarm.

The test statistics and the test thresholds are calculated due to the series of MUF values using PROSA based on the dispersion matrix established by MEMO. In general holds that an anomaly becomes true, as soon as one of the test procedures implemented in PROSA indicates an alarm.

But what was the reason for this alarm? All materials were accounted for. Therefore, missing material could not have caused the alarm. The fault which have been found by further investigations was, that the facility design has not been modelled properly enough.

At first it was recognized that the reading errors of various volume measurements were modelled as multiplicative errors rather than as additive errors. Furthermore, the strong correlation between some concentration measurements were not taken into account. For example, the concentration value measured in a vessel was assigned to the adjacent pipe. In this case the two concentration values are not only correlated through the systematic error component (same measurement method) but also correlated through the random error component (identical measurement).

By incorporation of these findings into the measurement model, the application of PROSA no longer gave any alarm. That means that the balance data were in accordance with the underlying measurement model. Figs. 4a to 4c show the results of the NRTA tests as described above but now based on a mixed multiplicative/additive measurement model, and in addition taken into account the various correlations between measurements. As can be seen in the middle part of Fig. 4, now also the GEMUF statistics do not yet cross the appropriate thresholds.

Now the question arose, whether the NRTA measures included in PROSA could detect a loss of material based on this detailed measurement model. In order to investigate this question, a loss of 0.125 kg Plutonium each from period 1 to period 4 was overlaid to the original balance data. The modified MUF data, see Fig. 5, were also evaluated with PROSA, again based on the same detailed measurement model as used in Fig. 4. Now Fig. 6 illustrates the results of NRTA tests applied to those MUF series shown in Fig. 5. The CUMUF test alarms in the second period (lower part of Fig. 6), and the GEMUF test in the fourth one (middle part of Fig. 6), whereas the Page's test does not alarm at all (upper part of Fig. 6).

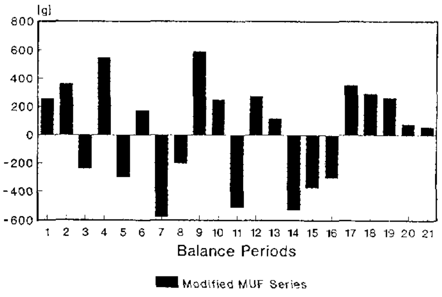


Fig. 5: Modified MUF Series.

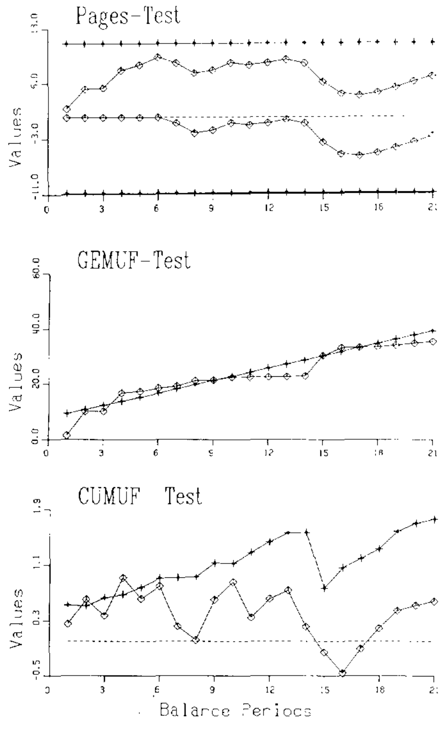


Fig. 6: Results of the NRTA Tests with the Modified MUF Series.

These evaluation results demonstrate that the established detailed measurement model is very close to the real situation: The original balance data can be explained by the measurement model, but the modified MUF series - the original MUF series was overlaid by the hypothetical loss pattern as mentioned above - is indicated to be not in accordance with the underlying measurement model.

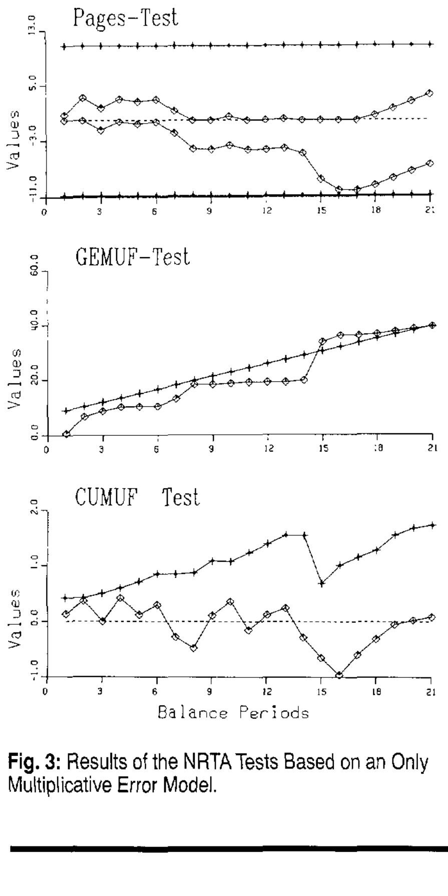


Fig. 3: Results of the NRTA Tests Based on an Only Multiplicative Error Model.

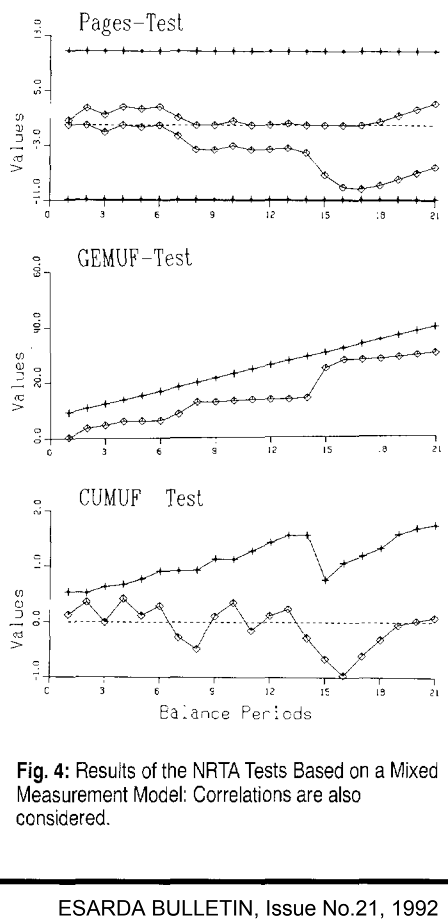


Fig. 4: Results of the NRTA Tests Based on a Mixed Measurement Model: Correlations are also considered.

Conclusion

The described investigations demonstrate that the determination of the statistical measurement model based on real balance data must be as detailed as possible. Furthermore the proper error structure of the applied measurement methods and the proper structure of their mutual correlations must be modelled correctly. Then the described method of establishing detailed measurement models for real process data using the computer program MEMO leads to very realistic results. The evaluation of the original balance data with the NRTA measures included in PROSA indicates that these data are in accordance with the established detailed measurement model. On the other hand, the NRTA measures give an alarm when a loss pattern is overlaid to the MUF values. This demonstrates the capability of NRTA measures, based on the described approach of establishing the detailed measurement model, to detect nuclear material losses.

References

/1/ Bicking U., Golly W., Peter N., Seifert R.: "PROSA VERSION 4.0 Manual", KfK 4866, 1991

/2/ Bicking U., Golly W., Seifert R.: "PROSA, an Advanced Computer Package for Sequential Evaluation of Nuclear Materials Balance Data", Proceedings of the 31st Annual Meeting of the INMM, Los Angeles, California, USA, July 15-18, 1990, p. 606-609

/3/ Bicking U., Golly W., Seifert R.: "MEMO - a PC Program to Establish Measurement Models for NRTA Evaluation Procedures", 3rd NRTA Workshop, Los Alamos, September 24-29, 1991

/4/ Pages E.S.: "Continuous Inspection Schemes", Biometrica 41, 1954, p. 100-115

/5/ Seifert R.: "The GEMUF Test - a New Sequential Test Procedure for Detecting a Loss of Material in a Sequence of Accounting Periods", Nuclear Safeguards Technology 1986, Vol. 1, IAEA, Vienna, 1987, p. 377-384

/6/ Beedgen R.: "Truncated Test Procedure Using the CUMUF Statistic for Timely Detection of Diversion", Nuclear Safeguards Technology 1982, Vol. 2, IAEA, Vienna 1983, p. 377-384

/7/ Seifert R.: "The GEMUF Test and Issues to the Near-Real Time-Accountancy", KfK report 4326, Karlsruhe Nuclear Research Center, November 1987

LB-AB-92-021-EN-N