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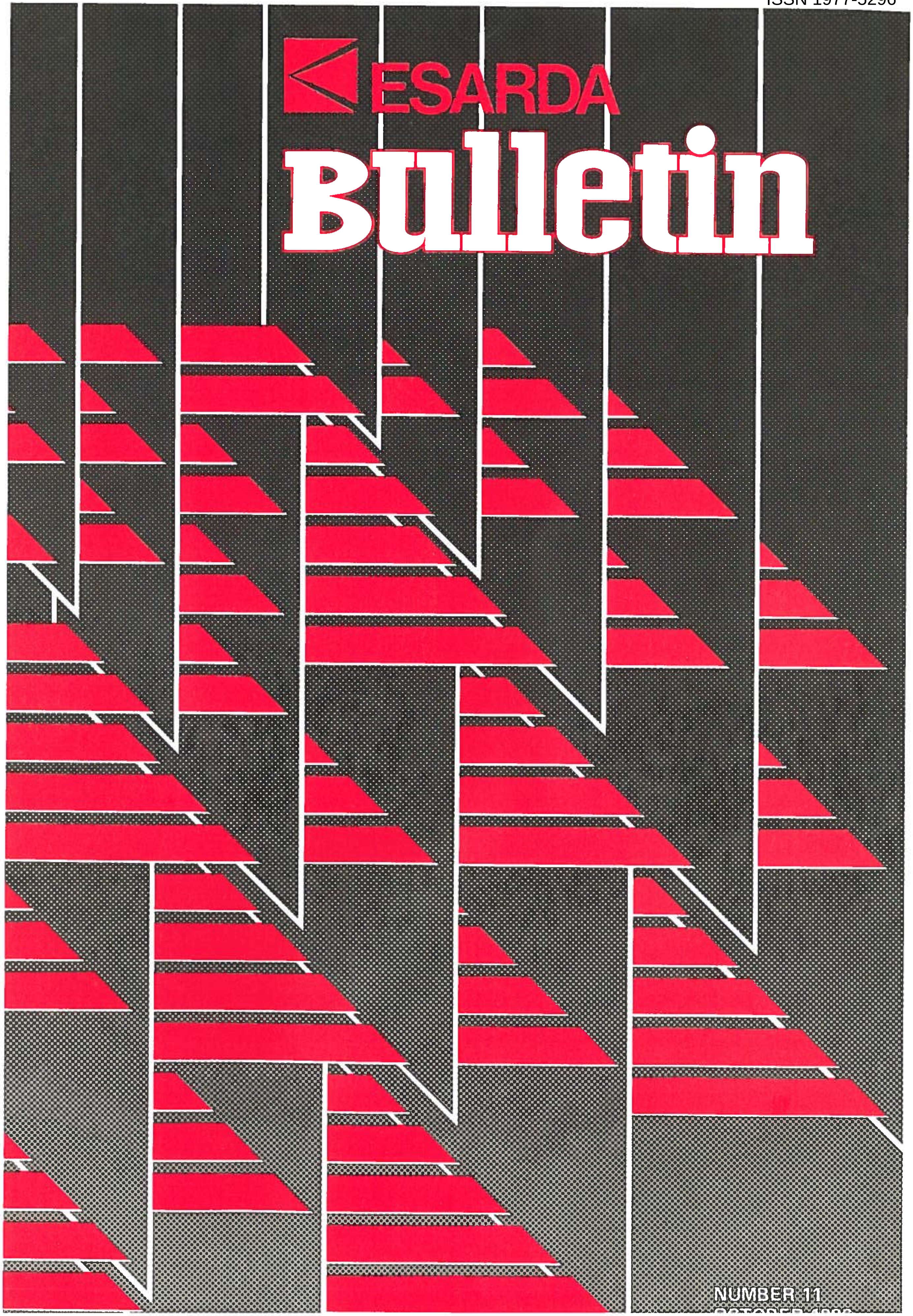

NUMBER 11

Capabilities and Objectives of the Use of NDA, DA and C/S Measures in Safeguards : Theme of the 1986 ESARDA Meeting

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Introduction*

For many years the seven ESARDA working groups, and in particular the technique oriented ones (DA, NDA and C/S), have concentrated their attention mainly on the development of methods and instruments and on the analysis of results obtained in laboratories and of experimental tests in field conditions. Many of these methods and instruments are now being used routinely both by operators and safeguards authorities. In the light of several years experience, both groups of users have suggested that ESARDA should pay more attention to the systematic evaluation of the performances and objectives of the measures presently used.

A first initiative in this direction was taken by organizing on 13-15 May 1986 an ESARDA meeting at Copenhagen with the objective to discuss on the theme "Capabilities and Objectives of the Use of NDA, DA and C/S Measures in Safeguards".

During the discussions in preparation of the Copenhagen meeting, several points were emphasized:

a) the general criteria for the assessment of capabilities or "performance values" should be derived from actual plant and inspection conditions rather than from simulated or laboratory conditions;
b) the term "performance values" is not only intended to cover **quantifiable features** but also those that can only be **formulated in a statement** as will be seen later in section 2;
c) during the assessment, one has to consider the fact that there are mainly three categories of people, directly concerned with nuclear materials measurements, namely the
   - operators
   - Safeguards Inspectorate
   - specialized laboratories.

*) This paper corresponds to a large extent to a presentation made by S. Finzi, 1986 Chairman of ESARDA, at the 27th Annual Meeting of INMM at New Orleans.

The start of the meeting. From left to right : J. Ley, secretary of ESARDA, S. Finzi, chairman of ESARDA, N.E. Busch, director general of Risö National Laboratory, and P. Frederiksen, ESARDA coordinator of Denmark

Specialized laboratories assist both the operators and the Safeguards Inspectorate by preparing and characterizing reference materials and by analysing process and final product materials. The three groups of people are, of course, all interested in the performances of measurements but sometimes with quite different objectives. Besides these groups, government authorities are involved in all questions regarding safeguards activities, because finally they have to take care that safeguards performance in the State is consistent with the relevant agreements, as far as their responsibilities are concerned.

2. Terms of Reference and Methodology

In order to assure that at the Copenhagen meeting the seven different working groups applied similar criteria in the analysis of their activities in the field of performance assessment, a working document was prepared by the ESARDA Coordinators and distributed to the participants several months before the meeting.

The point of reference for the discussions, or basic question to be answered, was the following:

With what uncertainty is it possible and needed to determine for one batch, the characteristics related to the amount of nuclear material and to what extent can continuity of knowledge of these characteristics be maintained ?

The answer to this question may be different for the three categories of people mentioned above, namely the operators, the inspectors and the specialized laboratories, because their measurement objectives may be very different.

Whereas the knowledge of the overall uncertainty and error sources associated with measurement systems was the basic question, other important parameters had to be considered in evaluating performance.

These **parameters** are, for example :

- reliability
- ease of implementation
- representativeness and authenticity
- intrusiveness to plant operation
- time to obtain a result
- cost.

The relative importance of these parameters may also be different for each category of users. As an example for specialised laboratories the characteristic and representativeness of a sample are of fundamental importance. For safeguards inspectors, intrusiveness to plant operation and authenticity are to be considered, at each time a new measurement system is introduced.

Point A and B, here below, illustrate briefly the meaning and significance of the **characteristics** and the **parameters.**

In general, when people consider performance values for measurement systems, they refer to only one of the characteristics or parameters mentioned above and overall statements are made very rarely. It is, in fact, not always easy to formulate a performance statement on **all parameters** applicable to **a whole batch** of nuclear materials. However, an attempt was made by the working groups to contribute to this overall performance statement. Some of the performance values were expressed numerically while others required a statement.

In order to assist the working groups in their evaluation, the Coordinators working document proposes a coherent terminology and explains in some details the meaning to be given to the characteristics and additional parameters, mentioned earlier, and by which general methodology they may be established.

The main points are summerized here:

A. Characteristics of a batch of nuclear materials

The objectives of measurements in nuclear material accountancy are to determine for a batch the mass, the elemental and isotopic composition of the nuclear materials. In order to determine these characteristics one has to determine :

1. the mass, or density and volume
2. the concentration for each constituent
3. the chemical composition for each constituent
4. the isotopic composition for each constituent.

Each of these material characteristics is determined with an uncertainty, the significance of which depends on the type of material and on the user.

The various sources of error, which contribute to the total uncertainty for a batch, are the errors linked diretly to the different measurements, to the uncertainty associated with the computational or interpretation model of the calibration curve and to the method of estimate of the final uncertainty.

Some views of the meeting room

B. Additional Parameters

The other parameters, mentioned earlier, are more linked to the actual use of a measurement technique in plant conditions.
Some of these parameters such as reliability, time to obtain results and cost may be quantified. The analysis of the other parameters, however, such as ease of implementation, representative nature of the sample and authentication of the measurement, and intrusiveness to plant operations may result in performance statements, which are very dependent of the final users.

Whereas for the NDA and DA, the above scheme for analysing the activities of the working groups was acceptable, for C/S the evaluation criteria had to be modified. For example the characteristics mentioned in 2.A are not directly applicable to containment and surveillance measures. Key judgement points are sensitivity (ability to detect and possibly quantify the movement or state of an item), tamper resistance and reliability, because C/S systems operate mostly in an unattended manner.

3. How to Establish Performance Values

Once a technique has been adequately developed in a laboratory the most usual way to establish its performance values is to participate in interlaboratory exercises. These exercises provide the **state of the art**, when a technique is specified for assaying a particular material. When, however, the routine technique is applied by each participating laboratory, the overall results provide the **state of the practice**.

The above considerations are very often applied for DA methods (applied in general in laboratories) and to a limited extent to NDA. For the latter one, in field tests are of fundamental importance, because they correspond to the day to day industrial and inspection reality. Also the in field tests are able to provide very useful information to make performance statements on the additional parameters, mentioned in 2.B.

For C/S the approach is certainly different to the previous scheme, and a well structured methodology on how to establish performance values was discussed but not completely defined.

4. Use of Performance Values

As mentioned in the introduction, operators, safeguards inspectors and specialised laboratories are the people directly interested in the performances of safeguards measures.

The operators need to maintain a nuclear material accountancy system for plant management requirements, process control and safeguards purposes. This nuclear material accountancy is based on measurements and/or estimates of both the flow and the inventory of nuclear materials. Therefore, there is a need not only to have a good knowledge of the performance of the measurement systems but also to be capable of maintaining them with time.

The criteria for the selection and use of measurement methods are mainly determined by requirements of economic and safe plant operation and by specifications of the final product.

The Safeguards Authority has to verify the declarations of the operators. For this purpose it must be able first to assess the operators measurement systems and secondly plan the optimum use of their own independent measurement system of verification. Finally the inspection results are to be avaluated, taking into account both operator's and inspector's measurement errors.

The evaluation of inspection results and comparison of these results with preestablished performance data should be understood as internal evaluation by safeguards authorities and should serve purposes such as, for example, decisions on resource allocation, initiation of R&D activities in order to improve verification activities, considerations on inspection goals using certain techniques, etc. However, performance data should not be transformed into a formal yardstick for inspection goal attainment.

For specialised laboratories, a regular comparison of their performances with those of other laboratories is needed to ensure that the current capability of the technique is achieved. The knowledge of actual performance values is also required to decide initiating further R&D, if new requirements are formulated by operators or Safeguards Inspectorates.

5. Questions to the ESARDA Working Groups

From sections 2, 3 and 4 it becomes clear that ESARDA focussed during the Copenhagen meeting its attention to the following points, which are formulated in the form of questions to the working groups.

a) Identify the main topics which have been treated in the area of evaluation of the performance of safeguards measures (NDA, DA, C/S) by the working group and the "user" to which each has been principally addressed — the safeguards authorites, the operator or a specialized laboratory.

b) Among the main characteristics, namely error sources and the other parameters (reliability, ease of implementation, representative nature and authenticity of samples, intrusiveness to plant operation, time and cost (see sections 2.A and 2.B)), which, in priority order, were of major concern for each topic identified in a).

c) Present a summary of not more than one page for each topic identified in a), giving the important results and the conclusions of the discussions on the main characteristics covered in b).

d) Give your assessment of whether, to what extent and how the above results were used by the "users" to whom they were principally addressed.

e) From your working group's viewpoint, what are the requirements of safeguards authorities and operators for further work on the performance of existing NDA, DA and C/S systems in routine use and under development ?

f) As a result of the above review, what are your proposals for further R&D work in the area of performance of safeguards measures in NDA, DA and C/S ?

6. Preliminary results

Each of the seven working groups provided at the end of the Copenhagen meeting a document addressing the questions mentioned under 5. The results of their internal discussions were presented in a plenary session, with the participation of the members of all the other working groups and of the ESARDA Steering Committee. This plenary session provided also an excellent forum for mutual information on the respective working groups activities.

It is premature to draw any final conclusion on the results obtained in this general ESARDA meeting.

In fact, the managerial levels of ESARDA are now analysing, in detail, the large documentation provided by the working groups (in September by coordinators and working group convenors, in October by Board, in November by Steering Committee).

The following general remarks may be made, however, for each of the different working groups in respect to their type of activities related to performance assessment. The results themselves are summarized in each of the working group reports provided at the end of the Copenhagen meeting.

A. Destructive Analysis (DA)

a. This working group has been primarily concerned with the evaluation of :
   - the error sources in sample treatment and measurements and their reliability
   - reliability of sampling and improved rapidity of verification measurements

   Measurements and techniques considered recently are :
   - UF_6 interlaboratory evaluation programme
   - U and Pu determination in irradiated fuel solutions (IDA 80 interlaboratory

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programme)
- volume measurements by tracer techniques (RITCEX)
- use of quadrupole mass spectrometer in field
- resin bead techniques.

The DA working group has also produced so-called "target values" for the uncertainty components in destructive analytical methods. These values are intended to provide estimates of the capability which can reasonably be expected from analytical laboratories under routine conditions and may represent the state of the practice for the most current methods.

b. The results of this working group have been primarily used by specialised laboratories as defined in section 1 and analytical laboratories of operators. Safeguards Inspectorates are now using some results for allocation of inspection effort and internal evaluation on the inspection results.

B. Non Destructive Assay (NDA)

a) The NDA working group has been mainly concerned with the error sources in measurements, measurement reliability and ease of implementation. In some cases, discussions on authentication have taken place.
Techniques considered for performance assessment in recent years have been :
- U-enrichment by gamma spectrometry, including preparation and characterisation of a primary reference material (U_3O_8) and preparation of a detailed users manual.
- Pu isotopic composition determination by gamma-spectrometry, including intercomparison exercises in laboratory and field conditions.
- Pu determination in bulk quantities by neutron coincidence counting and other techniques, such as calorimetry, in field conditions.
- U and Pu determination in solution by k-edge densitometry.

The NDA working group has also been discussing regularly the general approach of systematic performance assessment in realistic conditions, for example, in connection with the PERLA initiative of JRC-Ispra.
Furthermore, the methodology for NDA data processing and evaluation is also much being debated in relation to the error modelling of measurement methods, and data transmission between field and headquarter and operator-instrument interface. This last point may influence in a decisive manner the ease of implementation of several NDA techniques and instruments.
In general, the additional parameters mentioned in section 2 have received recently increased attention by the working group, even if no systematic work has been made yet.

b) The today results of the NDA working group are mainly oriented to the Safeguards Inspectorates, which implies that the safeguards approach plays not only a role in the requirements of performances for NDA techniques but also in their real achievements.

C. Containment and Surveillance (C/S)

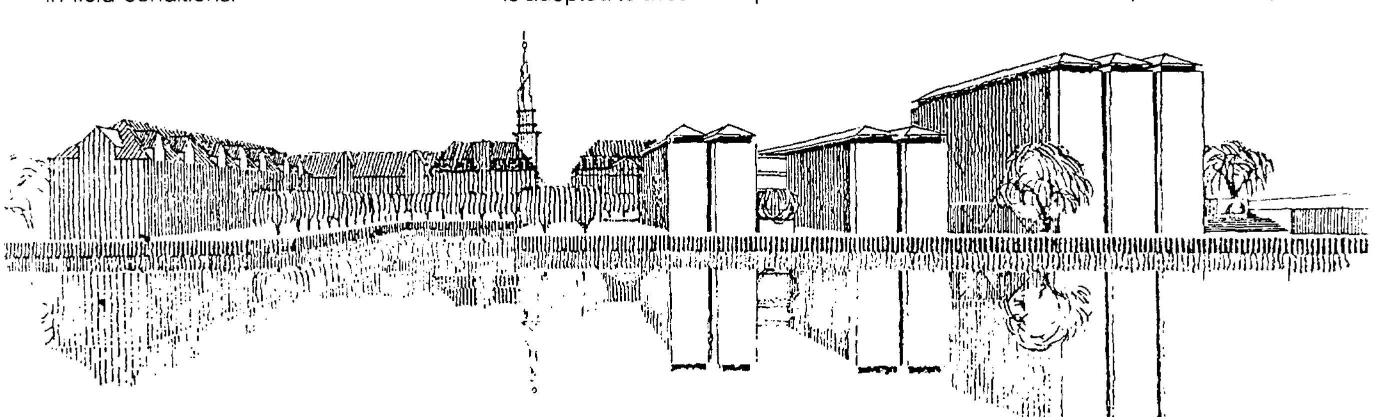
a) The C/S working group had difficulties at Copenhagen to treat the theme of "Performance Assessment" in the framework of the scheme proposed by the ESARDA coordinators.
The working group has focused its discussions over the years in field applications of devices and developments in laboratories. Much work has also been done in a better appreciation of the requirements of C/S in terms of functional and design specifications of devices for safeguards.
Since most of the criteria for C/S cannot be easily quantified, the method which is adopted to assess the performance of a new development or a device is to compare it with the performance of existing devices serving a similar purpose. From the Inspectorate's point of view the primary criterion will be whether a device performs a useful function, reliable, at reasonable cost. From the operator's point of view, it must do so safely, with minimum intrusion into operational procedures.
The working group is attempting to encourage now the development of systematic assessment procedures.

The techniques considered in the above framework are for example :
- fiber optic and electronic sealing systems for general purposes and type E seal
- ultrasonic sealing systems for LWR fuel bundles, spent fuel casks and general purpose seals
- optical surveillance systems (film camera, CCTV)
- portal monitors.

b) The results from the C/S working group are intended primarily for Safeguards Inspectorates but also for domestic security authorities. An exception is the use of CCTV by plant operators for process monitoring.

D. LEU Conversion/Fabrication Plant

a) This plant oriented working group, with representatives of all fabrication plants in the European Community (EC), has concentrated its interest on the assessment of the performances of a number of DA and NDA measurement techniques, applied by operators for management and safeguards purposes. For a number of these techniques, the error sources in routine plant application were of major interest. This was the case for the gravimetric method for the determination of U factor, the potentiometric titration of U, both applied on specially prepared standard UO_2 pellets for in plant use.



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Furthermore, an intercomparison exercise for calibrating weighing scales (up to 90 kg) was conducted in order to evaluate capabilities but, in particular, to reach a harmonisation in measurement control procedures and a standard methodology for the analysis of random and systematic errors.
The evaluation of sampling errors for UO_2 in powder barrels was also performed in several LEU fabrication plants.
Concerning existing or potential safeguards **verification** techniques, the working group has discussed in several meetings their error sources but, especially, their ease of implementation and intrusiveness to normal plant operation. This was the case for the neutron collar, the Phonid (active interrogation device for bulk U-assay) and the rod scanner, when used by inspectors.

b) The results of this working group are primarily used by plant operators but the evaluation of some verification techniques is also of great interest to Safeguards Inspectorates. Measurement errors estimates at batch level on main categories of LEU materials, which were discussed several years ago, are now being used for material balance evaluation experiments.

E. Mixed Oxide (MOX) Fuel Fabrication Plant

a) This working group has dedicated an important effort to review and discuss, for each of the different MOX fuel fabrication facilities in the European Community, the state of the practice of the operators measurement systems at batch level for the most important nuclear materials encountered in MOX facilities.
The clear definition of sampling errors was largely discussed, and in particular in connection with sampling and analyses procedures for reducing possible shipper-receiver (S-R) differences of PuO_2. The ease of implementation of different procedures was compared.
Finally, the assay of Pu nitrate and level monitoring was treated from the point of view of ease of implementation and authentication, when the same technique has to be used both by the operator and safeguards inspectors.

b) The results of the MOX working group are of direct interest to European Communities' plant operators, for gaining assurance that their performances are in line with practical capabilities.
The Safeguards Inspectorate is using the indicative measurement errors mentioned under a) for trial runs for evaluation of material balance data.

F. Reprocessing Input Verification (RIV)

a) The RIV working group is mainly interested in the verification of the input of nuclear materials into reprocessing plants. As a consequence, also the determination of such input is subject of investigation. Both the volumetric and gravimetric methods are being studied.
Several integral experiments performed in real plant conditions, with the participation of several measurement laboratories, led to results reflecting the overall uncertainty with which input material may be evaluated at the level of a batch or even a campaign.
For example : the Mol-IV experiment (EUROCHEMIC) to assess the performances of ICT, the ICE experiment (WAK) to assess the performances of both the conventional data evaluation and verification, and the ICT, the integral experiment (WAK) to quantify the head-end losses, the RITCEX experiment (EUROCHEMIC) to assess the precision and accuracy of input volume measurement and of the tracers technique, the Benchmark exercise (COGEMA) to assess the performances of ICT.
Some of these experiments were carried out in plants operating under normal working conditions and subject to routine safeguards procedures. The various activities were carried out with the active participation of operators (who provided data and access to their facilities), the Euratom and IAEA Inspectorates, numerous other organizations also including US-DOE and JAERI.
Whereas error sources for different techniques have been the main concern within this working group, reliability of measurement was often considered. In respect of the use of isotopic correlation techniques, intrusiveness has been a parameter which regularly is debated within the group, together with the data evaluation methodology.

b) The various results obtained within the working group are of interest in practice to all people concerned with measurements, namely operators, Safeguards Inspectorates and specialised laboratories.

G. Mathematical-Statistical Problems (MAT-STAT)

a) This working group has been involved essentially in discussions on methodologies for the error modelling of (see section 2A) different measurement techniques. Examples are process tank calibration, weighing scales, reprocessing plant input measurements including ICT and various NDA techniques. More specifically for NDA, the working group has organised at the JRC-Ispra in 1984 an ESARDA/INMM joint specialist meeting on NDA statistical problems.
In practice this working group has acted in several cases as an expert support to other working group activities, and during the Copenhagen meeting it was suggested that a direct participation of the MAT-STAT working group members to the other working groups was to be promoted.

b) The results of the working group are generally rather specific, and often of direct interest to the Safeguards Inspectorate, specialised laboratories and operators. They have provided R&D people involved in methods development with very useful information on the design of error models to be implemented in instrumentation.

7. Conclusions

The Copenhagen meeting provided good opportunity to the managerial levels of the ESARDA Association to make an assessment of the work performed in various fields through the information given by the working groups.

Each of the seven working groups addressed in much detail the subject "Capabilities and Objectives of the Use of NDA, DA and C/S Measures in Safeguards". They analysed their past activities in the area of the performance assessment of measurement techniques and evaluated which use has been made by plant operators, Safeguards Inspectorates and specialised analytical laboratories of the results obtained.

The meeting resulted in the production of detailed documentation from the working groups and the ESARDA bodies are now in process of evaluating them for preparing new guidelines or confirming existing ones for the future activities of the working groups.

The Copenhagen meeting also provided an excellent forum to promote the exchange of technical information of all those who are working in the Association framework and to confront the opinions between researchers, operators and inspectors to tackle safeguards problems in real life situations.

It was the first time that the producers of technical results in the working groups were openly and in a large forum confronted with the users of those results.

It is also expected that the detailed flow of information from working groups to users will result now in a detailed feedback from users to the working groups on measurement requirements and their performances.

Comments on Inspection Goal Criteria for Material Accountancy

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1. Introduction

The IAEA has established diversion detection goals which are based on significant quantities of nuclear material, e.g. 8 kg of Pu. In the application of safeguards to large scale bulk handling facilities the measurement uncertainty associated with closing the material balance and calculating MUF considerably exceeds the detection goal. The introduction of so-called facility inspection goals, and in particular the "accountancy verification goal" (AVG), represented a pragmatic attempt on the part of the Agency to extricate itself from this dilemma. More recently the Euratom inspectorate has introduced similar facility-specific inspection goals for the application of material accountancy. Unfortunately the algorithms used by both inspectorates, taken together with current IAEA conception of adequate assurance, imply unreasonably high verification efforts on the part of the inspectors and, by implication, an unreasonable degree of intrusiveness into plant operations. The reason for this is related to the current IAEA-internal goal of 95% detection probability for diversion of one goal quantity.

2. The MUF-D Test

In order to assess the inspectorates' quantity goals for material accountancy verification, it is useful to have a simple quantitative model for reference. This will be derived here.

For bulk handling facilities, the Agency will use the material balance test statistic MUF-D for one inventory period. The full theory of the hypothesis test based on this statistic is by no means trivial /1/, but with some simplifying assumptions, closed formulae can be written down. Assume the following /1/ :

the operator can divert into MUF, falsify data, or do a mixture of both;

if he falsifies data for items in a stratum, he falsifies them all by the same amount.

The guaranteed detection probability under these assumptions is /1/

$$1-\beta = \Phi(M/(\sigma_D^2 - \sigma_{MUF}^2)^{1/2} - U_{1-\alpha}) \qquad (1)$$

In this equation M is the amount of material diverted, σ_D and σ_{MUF} are the standard deviations of the D and MUF statistics, respectively, Φ is the normal distribution function and U is its inverse. As usual, α and β are the false alarm and non-detection probabilities.

If we assume further a static inventory of N identical batches (i.e. no material flows over an inventory period), then a simple expression exists for σ_D,

$$\sigma_D^2 = \Sigma_i(N^2/n_i)\,[\sigma_{Or}^2 + \sigma_{Ir}^2 + n_i(\sigma_{Os}^2 + \sigma_{Is}^2)]$$

The sum is over the two strata i = 1,2 consisting of beginning and ending inventory. n_i is the inspector's sample for the i-th stratum, σ_{Or} the standard deviation of the operator's random measurement error for one batch and σ_{Ir} is the standard deviation of the inspector's random measurement error for one batch. σ_{Os} and σ_{Is} are the corresponding systematic error standard deviations.

For simplicity, assume that the sample sizes are the same for both strata and that the single batch systematic error is the same fraction θ of the single batch random error for both operator and inspector, i.e.,

$$n_1 = n_2 = n$$
$$\sigma_{Os}^2 = \theta\sigma_{Or}^2 = \theta\sigma_O^2$$
$$\sigma_{Is}^2 = \theta\sigma_{Ir}^2 = \theta\sigma_I^2$$

If we now define $\gamma = \sigma_I^2 / \sigma_O^2$ we obtain

$$\sigma_D^2 = 2(N^2/n)\sigma_O^2(1+\gamma)(1+n\theta)$$

and for σ_{MUF}, recalling that there are only two strata, namely beginning and ending inventory,

$$\sigma_{MUF}^2 = 2(N\sigma_{Or}^2 + N^2\sigma_{Os}^2) = 2N\sigma_O^2(1+N\theta)$$

Using equation (1) and solving for M we have, with $\alpha = \beta = 0.05$,

$$M = 3.29\sigma_{MUF}[(N/n)(1+\gamma)(1+n\theta) / (1+N\theta) - 1]^{1/2} \qquad (2)$$

M is the amount of material which, if diverted over the inventory period, would lead to an alarm (i.e. detection) with probability 95%.

3. The IAEA Algorithm

The IAEA procedure for determining the accountancy verification goal (AVG) for bulk handling facilities is as follows /2/ :

a) Compute the quantity M using the expected accuracy δ_s for closing a material balance taken from an IAEA tabulation /2/ :

   $M = 3.29\delta_s A$

   where A is the plant inventory or throughput for one balance period, whichever is greater.

b) If M is equal to or larger than one SQ (significant quantity), set the verification goal quantity (AVG) equal to M.

c) If M is smaller than one SQ, set AVG equal to M + 1.

The quantity δ_s is defined in the IAEA tabulation as "expected operator measurement accuracy (standard deviation) associated with closing a material balance expressed as a percentage of the larger of inventory or throughput". The tabulated values are "international standards of accountancy which are considered achievable in practice at bulk nuclear facilities of each identified type". We thus conclude that, for a typical plant meeting international standards :

$$\delta_s A = \sigma_{MUF}$$

and we have for large scale bulk handling facilities,

$$AVG = M = 3.29\sigma_{MUF} \qquad (3)$$

If this goal is to be attained in the idealized situation of Section 2, then (2) and (3) can be compared to give

$$(N/n)(1+\gamma)(1+n\theta) / (1+N\theta) - 1 = 1$$

or, solving for n,

$$n = N(1+\gamma)/(2+N\theta(1-\gamma)) \qquad (4)$$

This function illustrates the stringency of the AVG. For if the inspector's measurement accuracy is comparable with that of the operator (i.e. $\sigma_I \simeq \sigma_O$), then $\gamma \simeq 1$ and $n \simeq N$. The inspector thus cannot apply random sampling, but must remeasure all of the inventory batches. Worse still, if $\gamma > 1$ then $n > N$ and the inspector must also make multiple measurements on some batches (drawing with replacement). Finally, if $\gamma \geq 1 + 2/N\theta$, $n \rightarrow \infty$ and no amount of inspection effort will attain the accountancy verification goal to the required assurance. (Note that, for N = 100 batches and θ = 0.25, $1 + 2/N\theta = 1.08$.)

4. The Euratom Algorithm

The algorithm adopted by Euratom /3/ explicitly recognizes the presence of an inspector measurement uncertainty. It is similar to the IAEA approach, except that sealed inventory is excluded from the determination of A (this is no doubt tacitly understood in the IAEA algorithm), δ_s is replaced by a weighted average uncertainty (denoted here by Δ). 100% inspector sampling is assumed from the outset (!) and the numerical factor 3.29 is replaced by 1.65. Thus

$$M = 1.65\Delta A \qquad (5)$$

with $\Delta = \Sigma_i \delta_i S_i / \Sigma_i S_i$.

Here S_i is the amount of material in the i-th stratum and δ_i is the combined relative measurement uncertainty for operator and inspector.

Returning to the simple model of Section 2, we can write

$S_1 = S_2 = A$ (since the inventory is static)
$\delta_1 = \delta_2 = \delta$ (since the measurement procedures are the same for both strata).

Thus

$$\Delta^2 = \delta^2 = \delta_O^2 + \delta_I^2$$

where δ_O^2 is the operator's relative measurement variance for one stratum, and δ_I^2 is the inspector's relative measurement variance for one stratum, assuming 100% sampling.

In other words,

$$(\delta_O A)^2 = N\sigma_O^2(1 + N\theta)$$
$$(\delta_I A)^2 = N\sigma_I^2(1 + N\theta)$$

Hence

$$(\Delta A)^2 = (\delta_O A)^2 + (\delta_I A)^2 = N(1 + N\theta)\sigma_O^2(1 + \gamma)$$

$$= \sigma_{MUF}^2(1 + \gamma)/2$$

using the expression for σ_{MUF} of Section 2. The Euratom goal quantity is then

$$M = 1.65\sigma_{MUF}[(1 + \gamma)/2)]^{1/2} \qquad (6)$$

Again, comparing with (2) with $n = N$ and solving for γ

$$\gamma = 1/7$$

Even with the requirement of 100% inspector sampling, the Euratom goal can only be attained if the inspector's measurement error variance is almost an order of magnitude better than that of the operator. The goal is thus even more stringent than the IAEA version.

5. Suggestions

For the more realistic situations (i.e. more complicated data falsification strategies, many flow and inventory strata, attributes/variables verification, etc.) the simple model of Section 2 of course does not apply. Indeed it may then be impossible to write down a guaranteed detection probability for accountancy verification for a fixed overall false alarm rate. If that is the case, then of course quantified goals of any kind are irrelevant since attainment or non-attainment cannot be established quantitatively. Nevertheless, the overall implication remains :

In order to achieve their accountancy verification goals to the currently required 95% confidence level, the inspectorates will have to invest ***at least*** the same measurement effort with the same accuracy as did the operator in establishing his material balance.

In this sense the goals are utopian from the inspectorates' standpoint and burdensome from the standpoint of the operator.

In practice, 100% sampling of inventory and flow batches will not be possible. The number of verification measurements will be dictated by available manpower resources, material accessibility, plant safety regulations, national licensing restrictions, available measuring devices, etc. On the basis of in-field experience, achievable sample sizes and measurement accuracies should be determined and used thereafter as a pragmatic and realistic basis for verification.

The AVG could still be maintained as a component of the Agency's effectiveness criteria. In the event that a detection probability can be validly deduced from the measurement data it would be stated as part of the safeguards conclusion for the plant in question, i.e. 1-β for one AVG at plant X was P%. The interpretation of P is, in the context of deterrence, a matter of political judgment and must be recognized as such /4/. There is certainly no reason why P must be at least 95% in order to conclude that safeguards are effective.

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Italian Support Programme for Safeguards Implementation to the Atomic Energy Agency

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Introduction

The Italian Support Programme for Safeguards Implementation was offered to the International Atomic Energy Agency by the Italian Government on the occasion of the IAEA Board of Governors Meeting held on June 1985.

The IAEA officially accepted the offer with a letter on September 1985 from the General Director, H. Blix.

After some technical meetings between IAEA and ENEA specialists in order to focus on and to define the detailed items of the tasks of common interest, to implement in the R & D Support Programme for the IAEA Safeguards, the formal commencement date for this Support Programme has been fixed on January 1986, although some preliminary work took place in 1985.

In the new Five Years Plan 1985-1989 of ENEA, the Italian Nuclear and Alternative Energy Commission, a considerable R & D effort is foreseen in the field of fuel cycle, taking advantage of the existing facilities such as the two reprocessing pilot plants, EUREX and ITREC, the plutonium fuel fabrication, hot cells and research laboratories at Casaccia.

As a consequence, the ENEA R & D programme on Safeguards Implementation, as well as the Support Programme itself, will concern mainly the field of the fuel cycle, with particular emphasis on the backend activities.

Scope of the Italian Support Programme

The general long-term objective of the Italian Programme is the optimization of safeguards measures aimed at improving process control through the realization of a near real time accountancy in its own fuel cycle pilot facilities.

The proposed programme, covering, in this first stage, the years 1986-1988, is mainly devoted to R & D activities concerning measurements technology for nuclear material accountancy, in order to minimize the impact of controls in the nuclear industry, while improving both efficiency and effectiveness of domestic and international safeguards.

Taking into account the capabilities and experience so far gained, the R & D activities will be carried out in cooperation with some well qualified national research organizations and industries, as well as with the European Atomic Energy Community (JRC-Ispra), in the frame of an existing Cooperation Agreement Euratom-ENEA.

The main operators at present involved in the implementation of the Support Programme are shown in Table 1.

Table 2 shows the financial and personnel resources at present devoted to the implementation of the Progamme.

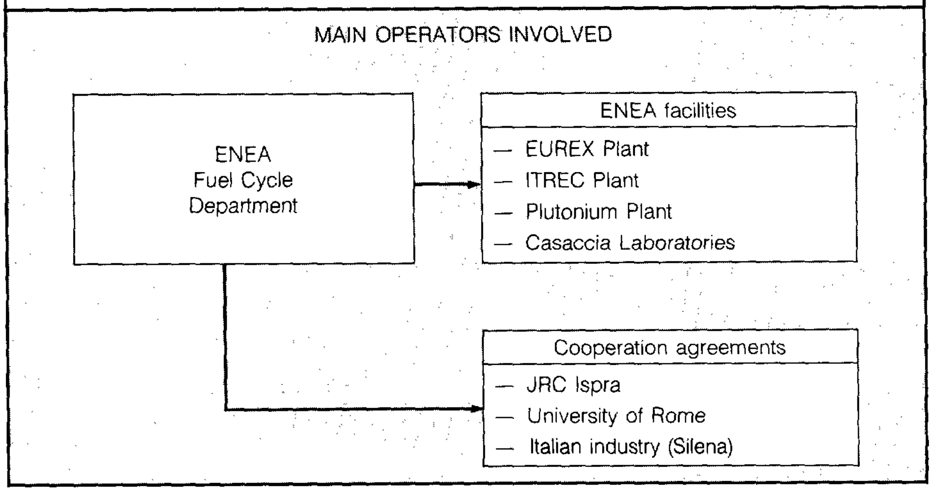
According to further developments of the Programme, both operators and resources can be increased.

Survey of contents of the Italian Support Programme

The joint programme is subdivided into five major task areas, identified among the existing ENEA plans and IAEA needs. The subject matter treated in each area under the individual tasks is summarized in Table 3.

Since the formal commencement date for the Support Programme has been fixed on January 1986, this paper will briefly report

Tab. 1 - ITALIAN SUPPORT PROGRAMME TO THE IAEA FOR SAFEGUARDS IMPLEMENTATION



Tab. 2 - ITALIAN SUPPORT PROGRAMME TO THE IAEA FOR SAFEGUARDS IMPLEMENTATION

FINANCIAL RESOURCES (Running and investment costs, excluding personnel)	dollars/year
• FOR ENEA R&D ACTIVITIES (INCLUDING EXTERNAL CONTRACTS)	500.000
• FOR SPECIAL CONTRIBUTION TOWARDS IAEA SAFEGUARDS PROGRAMME	100.000

PERSONNEL RESOURCES	men/year
• ENEA Staff	20
• External Operators	7-10

only the contents of the individual tasks, although some preliminary work took place in 1985, especially in the area A.

Measurement methods and techniques

The first two tasks of this area are concerned with the development and testing of absorptiometer systems able to determine simultaneously the concentration of two actinides (U-Pu, U-Th) in product solutions as an alternative to the existing systems.

Both the techniques rely on the transmission of photons of different energies in the range of L-edge (DEXA technique) or K-edge region (TEGA technique).

The ongoing R & D activities are mainly devoted to improve the performance of the systems which have already been tested for process control purposes.

Design modifications are foreseen in order to realize systems both for in-line installation and for utilization as compact, portable off-line instruments.

The expected relative precision for DEXA technique /1/ is about 1% in the range 35 ÷ 70 g/l of total heavy elements content, while preliminary tests show the possibility to obtain a relative precision below 1% for TEGA technique in the range 50 ÷ 300 g/l, with an average measuring time on the order of 10-15 minutes /2,3/.

For the further implementation of these activities, the help of the IAEA will be necessary, in order to better finalize our work towards the real needs of the Agency inspectors.

The second goal in the area A is to develop and test an advanced gamma spectrometric system for Pu isotopic ratio measurements at high count rate.

The development work will be mainly carried out in two directions in order to reduce the overall analytical time. For these purposes an improvement of an existing plutonium isotopic analysis software program is foreseen as well as the design and construction of a prototype pulse processor system able to handle high count rate (60,000-100,000 cps).

The design and the construction of the prototype will be carried out in co-operation with the Italian firm SILENA, which will also make use of existing high performance nuclear electronics of its production.

As far as the implementation of an upgraded software program is concerned, studies are carried out to optimize the Pu isotopic analysis for different sample situations as well as to reduce significantly the analysis time.

The program implementation will be studied both on the MCA currently in use at the Agency, the SILENA "Cicero" MCA, and on a newly designed SILENA microprocessor based MCA, the so-called "Livius" system.

The last task in area A concerns the development and testing of an automated instrument for the assay of plutonium content in 20 l low activity waste containers by gamma spectrometry.

These wastes are produced both by plutonium fuel fabrication pilot plants and pilot reprocessing plants.

Generally, wastes generated from reprocessing are not of primary importance for safeguards. Nevertheless, they are used to calculate the MUF of the respective MBA area. It is thus important that plutonium in wastes be measured to avoid questions on unusual MUF values observed.

ENEA intends make available to the IAEA the experience gained on a prototype instrument currently is use at its fuel cycle pilot plant for Pu content verification in waste containers.

Detection limit of Pu is 0.7 ppm or 0.07 g/m^3 of waste material /4/.

Optimization for safeguards purposes of process control instrumentation, methods and techniques

For the implementation of international safeguards in the large bulk handling nuclear facilities (i.e. reprocessing plant) it is proposed that conventional materials accountancy techniques, which are part of the detection process, should be enhanced by the use of near real time materials accountancy. Implementing NRTA requires a determination of in-process inventories in process equipment.

Methods for such a determination are based on volume measurements, concentration measurements by both off-line conventional analytical methods and on-line NDA instruments, and flow measurements.

The main task of this area is concerned with the development and demonstration of an automated nuclear material accounting system for near real time estimation of process inventory and material balance in a selected section of a reprocessing facility.

The goal is to demonstrate the overall system operability, cost-effectiveness, sensitivity and timeliness, through :

1. the design of a control plant by a mathematical model;
2. the selection of process monitoring techniques and instruments to be applied for plant tests;
3. the design and development of computerized data acquisition and treatment.

The activities carried out in the frame of the other tasks of the same area are related with the study of the methods and the techniques applied during the determination of in-process inventories, namely hull monitoring, tracers technique and level measurements.

As far as hull monitoring is concerned, two NDA techniques have been applied during the reprocessing campaign at the EUREX plant, namely weight technique and gamma spectrometry. Samples of hulls from all dissolution batches have been taken and analysed now by DA technique. Results are in course of evaluation in order to validate data obtained by both NDA techniques.

Tracer technique for the determination of volume and/or mass in accountancy vessel of reprocessing plants is an activity in which ENEA has been engaged for many years.

The tracers tested were mainly lutetium, neodinium and lead. Following a specific Agency request both technical and economic evaluations of the technique will be performed after further test in real plant hot operating campaign.

Tab. 3 - ITALIAN SUPPORT PROGRAMME TO THE IAEA FOR SAFEGUARDS IMPLEMENTATION

- NDA MEASUREMENTS METHODS AND TECHNIQUES
  - Dual Energy X-Ray Absorptiometer (DEXA) system for the assay of mixed SNM in solution;
  - Combined passive and active gamma technique for characterization of Pu solutions;
  - Pu isotopic ratio measurements by NDA (software development);
  - Pu isotopic measurements by NDA (hardware development);
  - Pu content verification in low activity waste containers.
- OPTIMIZATION FOR SAFEGUARDS PURPOSES OF PROCESS CONTROL INSTRUMENTATION, METHODS AND TECHNIQUES
  - Development and demostration of "Near Real Time Accountancy" (NRTA) for nuclear material control;
  - Volume and/or mass determination accountancy vessels by tracer technique;
  - Intercomparison between NDA and DA techniques for hull monitoring;
  - Field test of advanced instrumentation for level and density measurements in accountability vessel.
- FIELD TESTING OF NDA INSTRUMENTS
- INSTRUMENT AUTOMATION
- TRAINING OF IAEA STAFF

The activities on the level measurements will be carried out testing an electromanometer system (Ruska system) and comparing to alternative upgraded instrumentation systems (Time Domain Reflectometry, Capacitance probe).

The performance of the different instruments will be determined by a series of cold calibrations using different statistical techniques of data fitting and error evaluation.

The final goal is to test the level measurement systems during hot campaign at EUREX reprocessing pilot plant.

Field testing of IAEA NDA instruments

ENEA offers the Agency the possibility of testing NDA as well as surveillance instruments in some Italian facilities (EUREX and/or ITREC plant), also making available different nuclear materials.

Installation and future testing of the laser surveillance system in the pond of the ITREC plant is at present under investigation.

Training of IAEA staff on DA and NDA techniques and instrumentation and development of software and/or hardware dedicated microprocessor for data acquisition and evaluation

As far as these two areas are concerned, the activities will be defined case by case after selection of goals, following specific IAEA needs.

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On a Concept of the Application of Image Processing to the Identification of Metal-Cap Seals

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1. Introduction

Metal-cap seals of the types E & X are by far the most frequently used seals in safeguards. At present, the IAEA has 12,000 seals in use, and about half of them have to be exchanged every year. On the whole, the number of seals is expected to further increase in the years ahead.

Some marking (e.g. traces of soldering or scratches) on the inner surfaces of the metal-cap seals clearly distinguish them from each other. Before a seal is attached, this marking is photographed and the photo kept. As soon as the seal is removed and returned it is photographed again. Then, in a relatively time-consuming process, both photos are compared with one another to state their identity.

New methods and equipment are now available enabling an automatic analysis of images which will be discussed below in connection with the identification of metal-cap seals. A general survey of the application of image processing to safeguarding nuclear material has already been given in ref. /1/.

The application of pattern recognition using similar processes is now extensively investigated for the in-situ verification of COBRA seals under the Japanese support programme to IAEA safeguards /2/.

2. Description of the problem

In searching for new methods of seal identification the application of seals should be considered in its entirety. Besides the process of image analysis, also the taking of images, the storage of images and the storage of information about seals should be taken into account. As the large number of seals is still on the increase, the importance of

- high reliability in the identification of seals,
- rationalization of the analysing process (temporal and personnel expenditure),
- utilization of new storage media for seal images and the keeping of a central seal file

is continuously growing.

The use of an image processing system can more effectively contribute to meeting these requirements than any visual method, because it ensures a more rational and reliable analysis. As the functioning of such a system is based on digitized information, it can be coupled to various digital storage media.

3. Scanning of seals

A comparison of two images (i.e. original and comparison image) with high accuracy is only possible if the camera unit enables reproducible scanning. For this purpose the camera, seals adaptor and lighting have to be mounted in a pre-determined position and have to be adjustable by means of a control device in case they deviate from this standard position. To bring out distinctly the surface structures, the use of filtered light in special spectral ranges should be taken into account. The seals adaptor should allow to fix the seal in the camera's field of view in nearly the same position and orientation by means of positioning pins. To check the position of the seal, it is of advantage to fix to additional circular positioning marks on the side of the seal facing the camera outside the test area. They enable a fine positioning for the image processing.

For scanning the seals a camera is required which exactly assigns the pixels*, e.g. a CCD matrix camera having about 500 x 500 pixels with 4-bit grey-value information. The scanned image is stored in the computer of the processing unit. The camera unit is also equipped with a screen display to visualize the scanned image.

4. External image storage

Via an interface, the processing unit is connected to a large image store to keep the original images. For this purpose an optical disk store for digital storage can be used, which gives access by means of a specific computer. For 15,000 seals the capacity of this store has to be 4,000 M bytes.

*) pixel = picture element

5. Algorithmic possibilities of image comparison

Below the essential possibilities of image comparison are discussed.

The scanned digitized original image (512 x 512 x 4 bit) is in the store of the processing computer. After manual prepositioning of the seal by means of positioning pins, two positioning marks enable the fine positioning of the image by the computer. These marks are located inside the scanned image area but outside the test area. They are circular spots clearly contrasting with the ambient field (see Fig. 1).

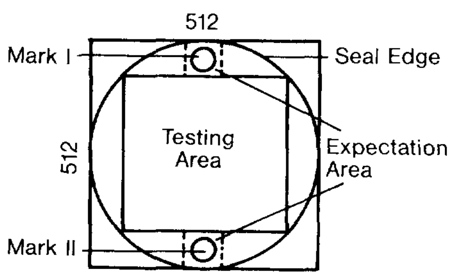

Figure 1

Due to the prepositioning before scanning the position of the marks to be expected is known to the computer. Within the expectation areas the image is converted with a fixed threshold into a binary information and the centres of the marks are computed. From the difference of the centres between the original image and comparison image correcting factors are calculated by means of which the coordinate systems of the comparison image is fine-positioned. To obtain a high speed in image processing, one should restrict oneself to translations which, at accordingly accurate prepositioning, are sufficient.

For the comparison, the entire test area is divided into squares (about 8 x 8 to 32 x 32 pixels per square). Inside the squares characteristics are computed, the difference of which allows identification. At first the following characteristics appear to be reasonable:

- number of extrema in grey-value course at line-by-line scanning (extreme value operator).

- number of extrema in the course of the density gradient after preceding gradient computation,
- position of intersections of clear edges (scratches, contours of tin spots) with square limits after preceding gradient computation and binarization by means of a threshold value operator,
- characteristics from the co-occurrence matrix describing the frequency distribution of grey-value pairs.

The extreme value operator is invariant to grey-value shifts due to corrosion and similar phenomena.

A final decision on suitable characteristics is possible only by using a set of test data. To increase confidence, several characteristics are computed for every square. Then the squares are identified by a permissible difference in the characteristics between the corresponding squares in the original and comparison image. This permissible difference in the characteristics should be determined by means of a sample.

The *non-identification* of a square is sufficient for the non-identification of the entire image.

The set of characteristics of the original images can be computed and stored as early as after scanning, which accelerates the process of comparison.

6. Technical equipment

The technical equipment can be an image taking and processing system, the modules of which are shown in Fig. 2. The processing unit is connected via a serial interface V 24 having a data transmission rate of 9.6 KBaud to the optical disk store.

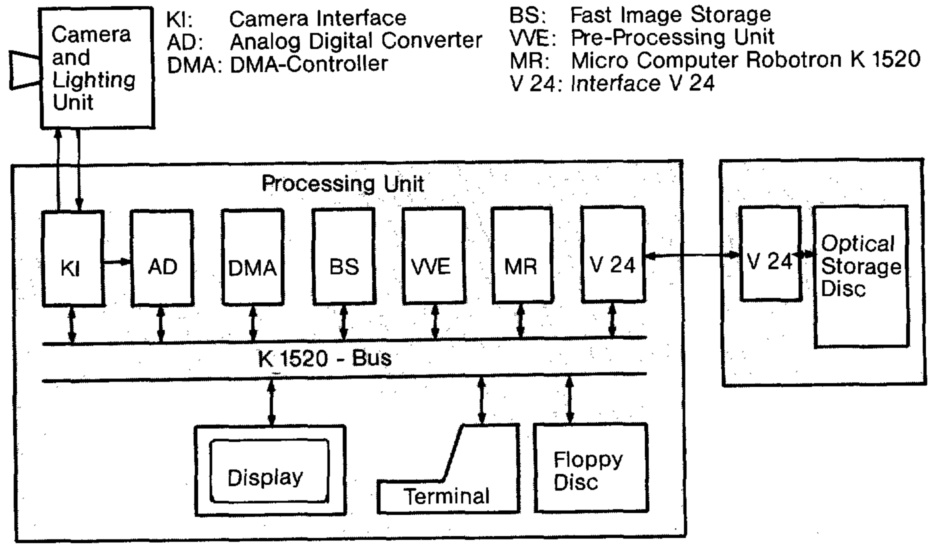

Figure 2

The image taking unit including camera, lighting and seals adaptor has been described in section 3. Via a camera interface, AD-converter and DMA-controller the image information with 16 grey tones is fed into the quick image store (pixel frequency 10 MHz).

The preprocessing unit contains 2 special processors for grey-value preprocessing having a 3 x 3 window (image smoothing, gradient operator, image restoration, etc.) and for computing the co-occurrence matrix in image sectors of up to 4096 pixels. The processing speeds are 800 ns or 1.2μs/pixel. Image taking and image processing are controlled by an 8-bit microcomputer ROBOTRON K1520 which can take over the necessary processing programs from a floppy-disk unit. Image processing (extraction of characteristics and comparison) is performed by software, using the special processors.

The processing time for the comparison of a scanned image with its original, including reading the set of characteristics from the optical disk store, lies at about 130 s/image. The transmission time of a scanned image from or to the optical store disk via the serial interface V 24 is 200 s. It is possible to use a quicker, internationally usual interface having a transmission time smaller by one order of magnitude.

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/2/ IAEA-STR-179, section IV, January 1985, pp. 110-111

Activities of the ESARDA Working Groups

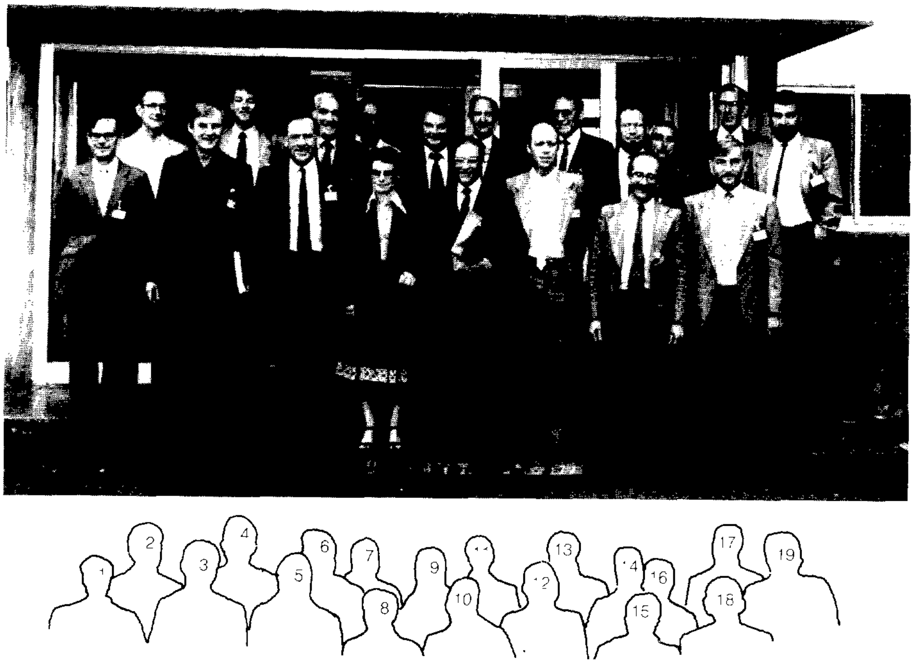
Destructive Analysis

WG Standpoint

The WG expresses its opinion that certain authorities, by their very nature and task, have the responsibility to decide **what** should be measured, e.g. fissionable isotope and/or fissionable element content of a given material, and possibly to what accuracy.

However, the Group also expresses its unanimous opinion that the full responsibility to decide **how** such measurements can best be made, must remain with measurement laboratories and that such a responsibility automatically includes the freedom of the choice of appropriate measurement methods. The latter entails the responsibility of the laboratories to demonstrate the quality of the measurements.

The Group stresses that the quality of a result should be the criterion on which to judge measurements, and not the choice of any given particular method or procedure. Such "quality" or "level of performance" or "state-of-the-practice" (as opposed to "state-of-the-art") can be derived from internal measurement control programmes combined with well conducted interlaboratory measurement evaluation programmes.



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The ESARDA Working Group on Techniques and Standards for Destructive Analysis (WGDA) held its 1985 annual meeting at the ENEA EUREX plant in Saluggia (Italy) on 1-2 October.

After discussion it formally approved a standpoint which is reproduced aside reprinted from Bulletin No. 10, page 12. This standpoint was deemed necessary in order to safeguard the freedom of analytical responsibles to carry out their task appropriately.

In its usual session "Focus on Measurement Techniques", the meeting reviewed the RITCEX experiment in Mol on input tank calibration.

The meeting also devoted attention to the preparation of "Target Values for sampling nuclear materials" aimed at establishing realistic figures for the uncertainties associated with this process.

The main topic of the meeting, however, was the setting up of a Regular European Interlaboratory Measurement Evaluation Programme (REIMEP) for nuclear materials.

The same Group at work under the chairmanship of P. De Bièvre, CBNM Geel

The objective of the programme was to obtain regular state-of-the-practice pictures for the assay of a given fissile isotope or element in nuclear materials. It would have not "educational" or "training" intentions, nor would it aim to evaluate particular methods or state-of-the-art. It was agreed that CBNM Geel would organize the programme, watch rigidly the coding of the participants and publish the results annually in the form of evaluation graphs. Help from several sides was offered such as the CEA and the IAEA. A redaction committee to draft a programme document was established.

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