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Plutonium Isotopic Determination by Gamma Spectrometry: Recommendations for the ^{242}Pu Content Evaluation using a new Algorithm

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On behalf of the ESARDA NDA Working Group

1. Introduction

Plutonium isotopic determination by gamma spectrometry is an important NDA method widely used by laboratories, operators and Safeguards directorates.

Significant improvements have been made during the last few years on plutonium gamma-ray analysis which have led to measurements accuracies lower than 0.5% for the detectable isotopes. This leads to the fact that one important source of error is now the ^{242}Pu content evaluation from correlations with the other isotopes /1/. Actually the ^{242}Pu is not detectable by gamma spectrometry and can only be determined by empirical isotope correlations. The difficulty in finding a "simple" law for the ^{242}Pu estimate in view of the complexity of the evolution chains for the build up of Pu isotopes has been realized for long time.

This problem has been largely discussed in the frame of the ESARDA NDA Working Group and much work has been carried out by the different authors (CEA, LLNL, TUI, BNFL), with the support of COGEMA for the supply of comprehensive destructive analysis data, in order to define a new algorithm.

After a brief review of today's state of the practice, this new correlation is described, including underlying theoretical approach, its experimental qualification with a large set of destructive analysis values, and last recommendations for the ^{242}Pu content evaluation.

2. State of Practice

As indicated above, the ^{242}Pu content evaluation is now becoming one of the major problems for the plutonium assay by NDA. This fact is particularly true today, because the new energy policy of a lot of Nuclear Power Plants tends to increase the initial enrichment in ^{235}U of the fuels (order of magnitude 4%) in order to reach higher burn-up (typically 50 GWd/tU).

In such a case, as indicated in figure 1, the ^{242}Pu content on the total Pu is not negligible (it can reach 10 %) for typical burn-up, and its evaluation with a good accuracy is of particular importance. This also means that a lack of knowledge on the ^{242}Pu content evaluation will generate a significant error on the total plutonium mass evaluation (using a classical combination of neutron coincidence counting and gamma spectrometry) /2/.

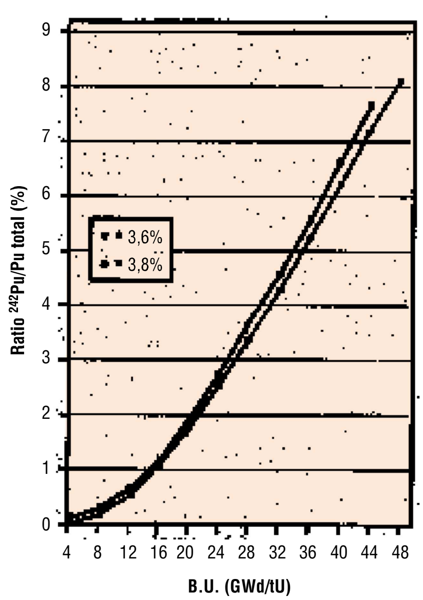

Figure 1: Ratio ^{242}Pu/Pu-total versus burn-up for different initial enrichments in ^{235}U [UOX fuels]

The correlation used by many codes (like MGA) until recently is as follows /3/:

$$^{242}\mathrm{Pu} = C\,\frac{^{240}\mathrm{Pu}}{^{239}\mathrm{Pu}}\;\frac{^{241}\mathrm{Pu}}{^{239}\mathrm{Pu}}$$

The ^{242}Pu estimate from this correlation may be in error by up to about 20-25 % for high burn-up /4/, which is not satisfactory at all.

In fact, such an error for ^{242}Pu content evaluation can bias the total plutonium mass determination by about 2 or 3%, in a neutron coincidence measurement.

3. Definition of the new Correlation

Considering the problem explained above, the authors have investigated a new correlation which, firstly, uses ratio of plutonium isotope abundances and not absolute data and which, secondly, does not include the ^{241}PU isotope (this isotope may introduce ambiguities in any correlation because of its short half-life and the equilibrium with ^{241}Am). This new correlation is of the following form /5/:

$$\frac{^{242}\mathrm{Pu}}{^{239}\mathrm{Pu}} = C_0\left(\frac{^{238}\mathrm{Pu}}{^{239}\mathrm{Pu}}\right)^{C_1}\left(\frac{^{240}\mathrm{Pu}}{^{239}\mathrm{Pu}}\right)^{C_2} \qquad (1)$$

Testing and qualification of this type of correlation have been done using both a theoretical and an experimental approach.

3.1. Theoretical Approach

This approach was necessary in order, firstly, to check the good "behaviour" of the coefficients C_0, C_1 and C_2, secondly, to obtain the best average values of these coefficients (giving way to perform experimental qualification) and finally, to link them to a physical explanation.

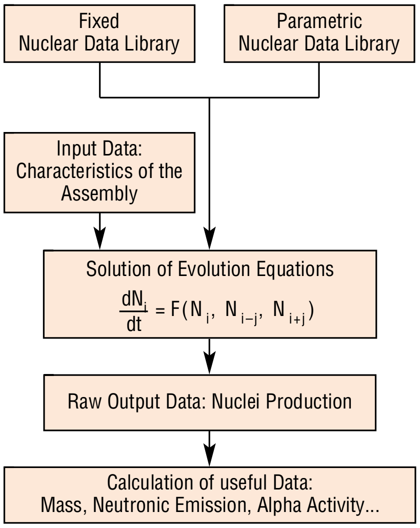

Figure 2: General scheme of the Burn-up Evolution Code

This approach has been performed in two steps:

• The first one, which is presented in detail in /6/, made use of a burn-up evolution code (see figure 2), covering a large range of nuclear characteristics of irradiated fuels.

Actually, the bum-up evolution code can calculate the three ratios of formula (1)

$$\left[\frac{^{238}Pu}{^{239}Pu}, \frac{^{240}Pu}{^{239}Pu}, \frac{^{242}Pu}{^{239}Pu}\right]$$

in a large panel of fuels (in terms of geometry of assemblies, initial enrichment in ^{235}U, burn-up and cooling time) - see figures 3a, 3b and 3c - and it is possible to evaluate a first set of the "best" values for the coefficients C_0, C_1 and C_2 from the formula (1) /6/. This approach also provided a first estimate for the average error which could be expected for the ^{242}Pu content evaluation, and it has shown us the way to perform the experimental approach.

Remark: This step has indicated clearly the relationship between the coefficient C_1 and C_2 versus the initial enrichment in ^{235}U /6/.

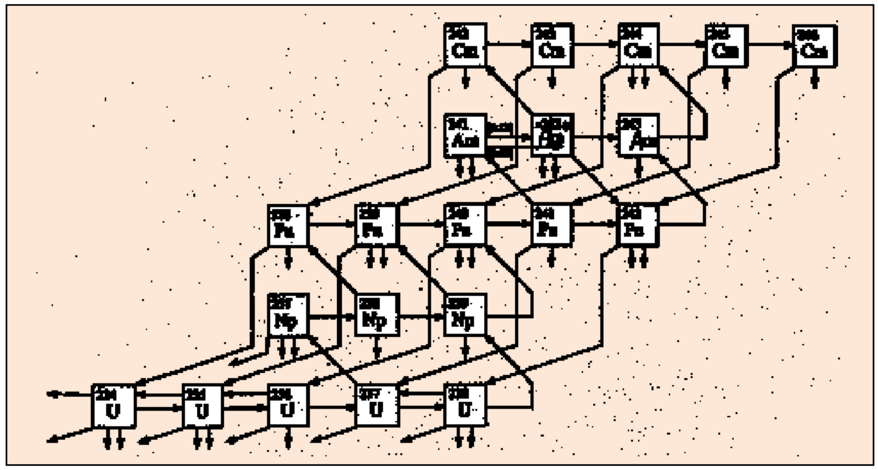

Figure 4a: Complete Evolution Chain

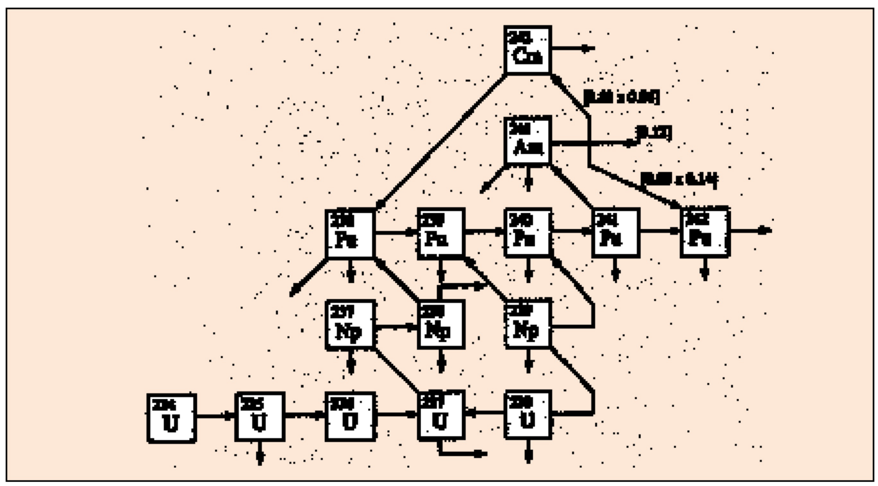

Figure 4b: Simplified Evolution Chain

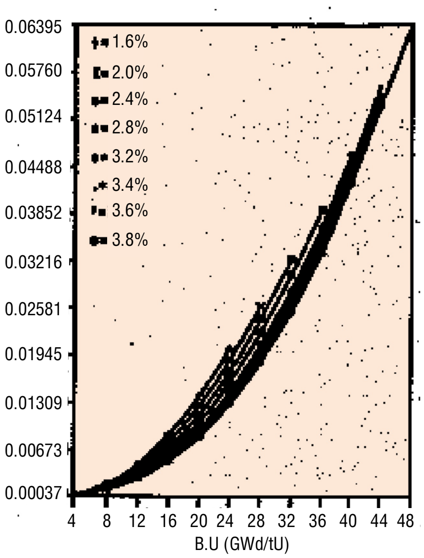

Figure 3a: Ratio $^{238}Pu/^{239}Pu$ for different intial enrichment (UOX PWR)

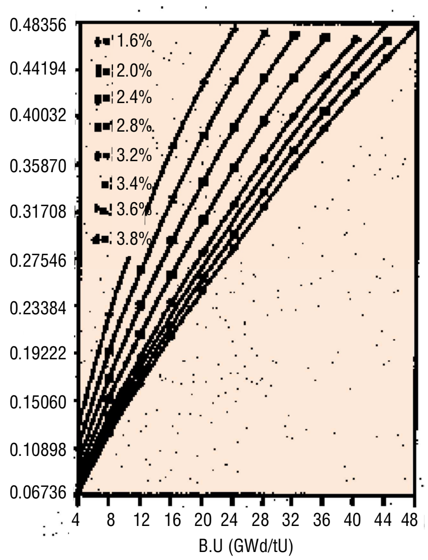

Figure 3b: Ratio $^{240}Pu/^{239}Pu$ for different intial enrichment (UOX PWR)

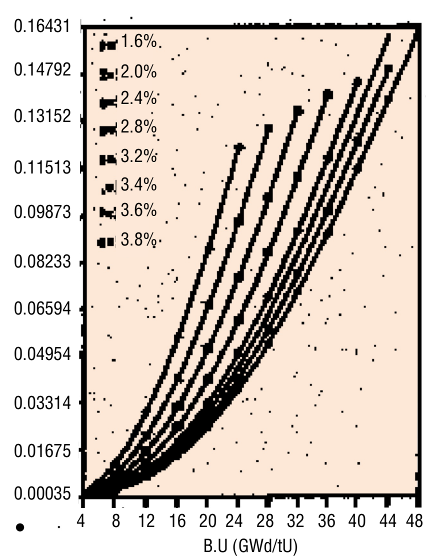

Figure 3c: Ratio $^{242}Pu/^{239}Pu$ for different intial enrichment (UOX PWR)

The second step has consisted of the precise analysis of the evolution equations in order to find a physical explanation for formula (1) and to learn about the physical tendency of the different coefficients [C_0, C_1, C_2]. This task was first completed by building a simplified evolution chain in order to be able to integrate theroretically the evolution equations (see figures 4a and 4b, previous page). Moreover, for simplification purpose, this study has been performed for one fuel irradiation cycle (300 days at nominal power of the reactor). The general formula for the evolution of a nuclide is as follows (differential equation):

This formula is a balance between the production (positive terms) and the disappearance (negative terms) of the nuclide N.

The resolution of such an equation in a simplified case (one cycle irradiation, hypothesis of constant cross-sections and neutron flux) allows us to obtain formal expression of the three isotope ratios in formula (1)

$$\left(\frac{^{238}Pu}{^{239}Pu}, \frac{^{240}Pu}{^{239}Pu}, \frac{^{242}Pu}{^{239}Pu}\right)$$

as follows:

$$rpu_{ij} = \frac{^{i}Pu}{^{j}Pu} = \frac{\sum_n \alpha_n e^{-k_n t}}{\sum_m \beta_m e^{-k_m t}} \qquad (2)$$

where α_n and β_m are constants (negative or positive) depending on various cross-sections and decay constants.

Due to the fact that there is no possible simplification on the number of exponentials in formula (2) (see box below), the expression of the plutonium isotope ratios has been simplified using a least-squares fitting with the following relations:

$$rpu_{i,j} = A_i t^{Bi}$$

that is to say:

$$\begin{bmatrix} rpu_{2,9} = {}^{242}Pu/{}^{239}Pu = A_2 t^{B_2} \\ rpu_{8,9} = {}^{238}Pu/{}^{239}Pu = A_8 t^{B_8} \\ rpu_{0,9} = {}^{240}Pu/{}^{239}Pu = A_0 t^{B_0} \end{bmatrix}$$

With this simplification it is possible to rewrite the formula (1) as follows:

$$A_2 t^{B_2} = C_0 (A_8 t^{B_8})^{C_1} (A_0 t^{B_0})^{C_2}$$

or

$$A_2 t^{B_2} = C_0 A_8^{C_1} A_0^{C_2}\, t^{(B_8 C_1 + B_0 C_2)} \qquad (3)$$

so, with identification of the two members of this expression:

$$\begin{cases} A_2 = C_0\, A_8^{C_1}\, A_0^{C_2} \\ B_2 = B_8\, C_1 + B_0\, C_2 \end{cases}$$

$$\begin{cases} \ln(A_2) = \ln(C_0) + C_1 \ln(A_2) + C_2 \ln(A_8) \\ B_2 = B_8\, C_1 + B_0\, C_2 \end{cases}$$

Considering the fact that C_0 is like a calibration constant in formula (1), it is possible to obtain C_1 and C_2 from the relations:

$$C_1 = \frac{B_0 \ln(A_2) - B_2 \ln(A_0) - B_0 \ln(C_0)}{B_0 \ln(A_8) - B_8 \ln(A_0)}$$

$$C_2 = \frac{B_2 \ln(A_8) - B_8 \ln(A_2) - B_8 \ln(C_0)}{B_0 \ln(A_8) - B_8 \ln(A_0)}$$

From these two steps of the theoretical approach we draw the following conclusions:

- There is good "behaviour" (from a numerical analysis point of view - stability, reproductibility) of the coefficients C_0, C_1 and C_2.
- Although C_0 varies according to the kind of reactor (initial enrichment, range of burn-up, see the recommendation in sect 4), it can be said that the best values of C_1 and C_2 are in the following range:

$$0 < C_1 < 0.5$$
$$C_2 > 1.5$$

$$\frac{dN(t)}{dt}[A,Z] = [\Phi\, \sigma_c\, N(t)]_{[A-1,Z]} + [\Phi\, \sigma_{n,2n}\, N(t)]_{[A+1,Z]} + [\lambda_{\beta^+}\, N(t)]_{[A,Z+1]} + [\lambda_{\beta^-}\, N(t)]_{[A,Z-1]} + [\lambda_\alpha\, N(t)]_{[A+4,Z+2]} + [\lambda_{TI}\, N(t)]_{[Ametastable,\, Z]} - \Phi\left[(\sigma_c + \sigma_f + \sigma_{n,2n})\, N(t)\right]_{[A,Z]} - \left[(\lambda_{\beta^+} + \lambda_{\beta^-} + \lambda_\alpha + \lambda_{TI} + \lambda_{Spontaneous\ Fission})\, N(t)\right]_{[A,Z]}$$

with:

Φ : neutron flux

σ_i : cross-section of reaction i, which could be:
- radiative capture: σ_c
- (n,2n) reaction: $\sigma_{n,2n}$
- fission reaction: σ_f

λ_j : decay constant type j, which could be:
- β^-, β^+, α or Spontaneuous Fission decay
- TI, isomeric transition, in case of metastable isotopes

N(t): Number of atoms of nuclide N as a function of time.

Formula 2

3.2. Experimental Approach

This approach represents the qualification of the new algorithm, making use of a large number of destructive analysis data obtained by mass spectrometry coming from the dissolution tanks of COGEMA-La Hague reprocessing plants /7/.

Actually, due to the wide reprocessing ability of the La Hague plant, this data is representative of a large range of irradiated fuel assemblies and therefore of plutonium production.

In a second step, as explained later, this approach has been tested with other DA data coming from TUI and BNFL.

<u>Range of qualification</u>:

4647 dissolution analysis data has been used for this qualification in the following ranges.

<u>Kind of fuel</u>: UOX-LWR

<u>Geometry of assemblies</u>:

PWR 17 x 17
16 x 16
15 x 15
14 x 14
BWR 8 x 8
7 x 7

<u>Initial enrichment in ^{235}U</u>: [1.1 – 4.36] %

<u>Burn-up</u>: [3341 - 44524] MWd/tU

<u>Cooling time</u>: [635 - 6511] days

The distribution of the dissolution analysis data versus the geometry of assemblies is as follows:

Geometry of assembly		Number of dissolution analysis data
PWR	17 x 17	2855
	16 x 16	273
	15 x 15*	673
	14 x 14*	213
BWR	8 x 8	313
	7 x 7	320
TOTAL		**4 647**

** For these two geometries, the data are separated according to two fuel fabricators: KWU and WESTINGHOUSE, because of different metallurgy of the assemblies (so different neutron spectrum and different plutonium production).*

<u>Methodology</u>:

Using the following notations:

$$^{8}R = \frac{^{238}Pu}{^{239}Pu},\ ^{0}R = \frac{^{240}Pu}{^{239}Pu},\ ^{2}R = \frac{^{242}Pu}{^{239}Pu}$$

the formula we want to qualify is as follows:

$$^{2}R \approx C_0\,[^{8}R]^{C_1}\,[^{0}R]^{C_2}$$

The use of the destructive analysis values for ^{8}R, ^{0}R, ^{2}R allows us to calculate the ratio:

$$R_c \approx C_0\,[^{8}R]^{C_1}\,[^{0}R]^{C_2}$$

and the absolute and relative quadratic errors:

$$\varepsilon_a^2 = \left[R_c - {}^{2}R\right]^2$$

$$\varepsilon_r^2 = \left[\frac{R_c}{^{2}R} - 1\right]^2$$

In order to define the "best values" of the coefficients C_0, C_1 and C_2, the average quadratic errors (ε_a^2 and/or ε_r^2) have to be minimized using the corresponding sets of n value $\{^{8}R_i,\ ^{0}R_i,\ ^{2}R_i;\ i = 1, n\}$ and $\{RC_i,\ \varepsilon_{ai},\ \varepsilon_{ri};\ i = 1, n\}$.

Different treatments have been applied according to the number of coefficients to be adjusted:

Treatment 1: C_1 and C_2 known, C_0 adjusted

Treatment 2: C_2 known, C_0 and C_1 adjusted

Treatment 3: C_1 known, C_0 and C_2 adjusted

Treatment 4: C_0, C_1 and C_2 adjusted.

As an example, the precise methodology for treatment 4 is as follows. Using the notations:

$$Y_i = \ln\left({}^{2}R_i\right);\ X_i = \ln\left({}^{8}R_i\right);\ Z_i = \ln\left({}^{0}R_i\right)$$

the coefficients C_0, C_1 and C_2 are obtained by solving the following linear equations:

- adjustment with ε_a:

$$\begin{pmatrix} n & \sum_i X_i & \sum_i Z_i \\ \sum_i X_i & \sum_i X_i^2 & \sum_i Z_i X_i \\ \sum_i Z_i & \sum_i X_i Z_i & \sum_i Z_i^2 \end{pmatrix} \begin{pmatrix} \ln C_0 \\ C_1 \\ C_2 \end{pmatrix} = \begin{pmatrix} \sum_i Y_i \\ \sum_i Y_i X_i \\ \sum_i Y_i Z_i \end{pmatrix}$$

- adjustment with ε_r:

$$\begin{pmatrix} \sum_i 1/Y_i^2 & \sum_i X_i/Y_i^2 & \sum_i Z_i/Y_i^2 \\ \sum_i X_i/Y_i^2 & \sum_i X_i^2/Y_i^2 & \sum_i Z_i X_i/Y_i^2 \\ \sum_i Z_i/Y_i^2 & \sum_i X_i Z_i/Y_i^2 & \sum_i X_i^2/Y_i^2 \end{pmatrix} \begin{pmatrix} \ln C_0 \\ C_1 \\ C_2 \end{pmatrix} = \begin{pmatrix} \sum_i 1/Y_i \\ \sum_i X_i/Y_i \\ \sum_i Z_i/Y_i \end{pmatrix}$$

Qualification of results:

The results of the fitting algorithm are as follows:

Case of PWR fuels (4014 sets of D.A. data)

As indicated in the tables below, treatment 4 appears to be the most interesting one:

- adjustment with ε_a:

Number of treatment	Average quadratic error (%)	C_0	C_1	C_2
1	10.26	2.07	0.5	1.5
2	3.44	1.30	0.37	1.5
3	6.66	1.59	0.5	1.18
4	2.95	1.33	0.33	1.70

- adjustment with ε_r:

Number of treatment	Average quadratic error (%)	C_0	C_1	C_2
1	8.8	2.14	0.5	1.5
2	3.44	1.29	0.37	1.5
3	6.72	1.43	0.5	1.05
4	2.96	1.32	0.33	1.70

The above results suggest that, with the set of coefficients $\{C_0 = 1.33;\ C_1 = 0.33;\ C_2 = 1.70\}$, the evaluation of the ^{242}Pu content with this new correlation will be performed with an average error of about 3% (in the range of plutonium production defined above).

Case of BWR fuels (633 sets of data)

The methodology described before has been applied using all the data coming from BWR dissolution analysis as well. As in the case of PWR, treatment 4 (C_0, C_1 and C_2 adjusted) appears to be the most interesting one yielding an average error for the ^{242}Pu content evaluation of about 6%.

The fact that this error is greater (about two times) than in the case of plutonium produced in PWR's is due to the more complex nuclear reactions in BWR's (axial variation of the moderation ratio, non-homogenous initial enrichment in ^{235}U, strong spectrum effect, ...). Moreover, the level of confidence of the evolution equations used in a burn-up evolution code (see figure 2) is not as good as in the case of PWR fuels, which further impairs the precision of the new correlation for BWR fuels.

The new correlation has been also tested at TUI and BNFL.

In the work at TUI the new correlation has been applied both to PWR and MAGNOX type of plutonium /2,4,8/. For higher burn-up PWR plutonium, again a precision of about 3% was observed for the ^{242}Pu estimate. One of the aims of the TUI work was to categorize and to group the isotopic data through plots of the ratios ^{8}R vs. ^{0}R as shown in Fig. 5, and to optimize the coefficients in formula 1 for different data groups in this representation. The figure illustrates, for example, that LWR and MAGNOX plutonium can be clearly discerned in this representation. For MAGNOX plutonium the new correlation requires different values for the coefficients C_0, C_1 and C_2. Those were determined from a least-squares fit to the available experimental data to 0.213, 0.075 and 2.071, respectively. With these coefficients the standard deviation for the ^{242}Pu estimate from MAGNOX plutonium was about 2.5% /8/.

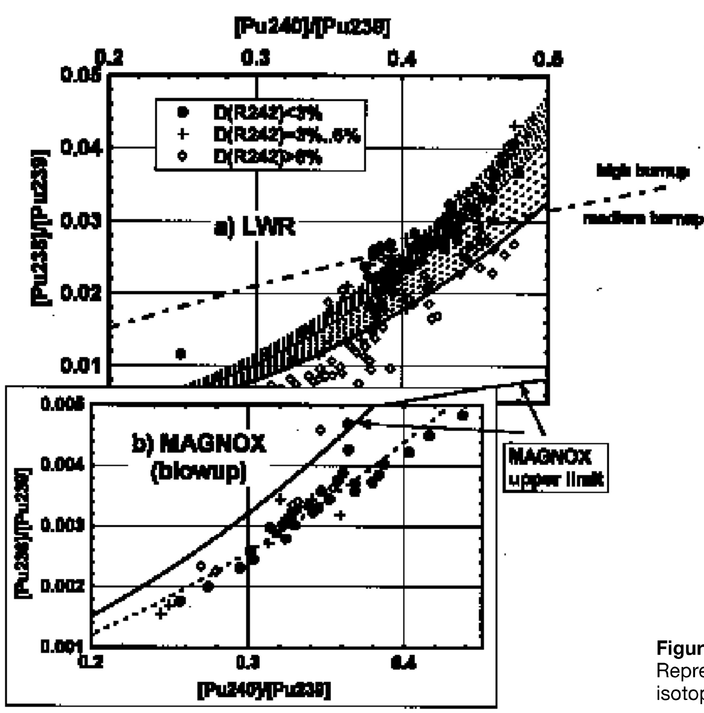

Figure 5: Representation of isotopic data used at TUI

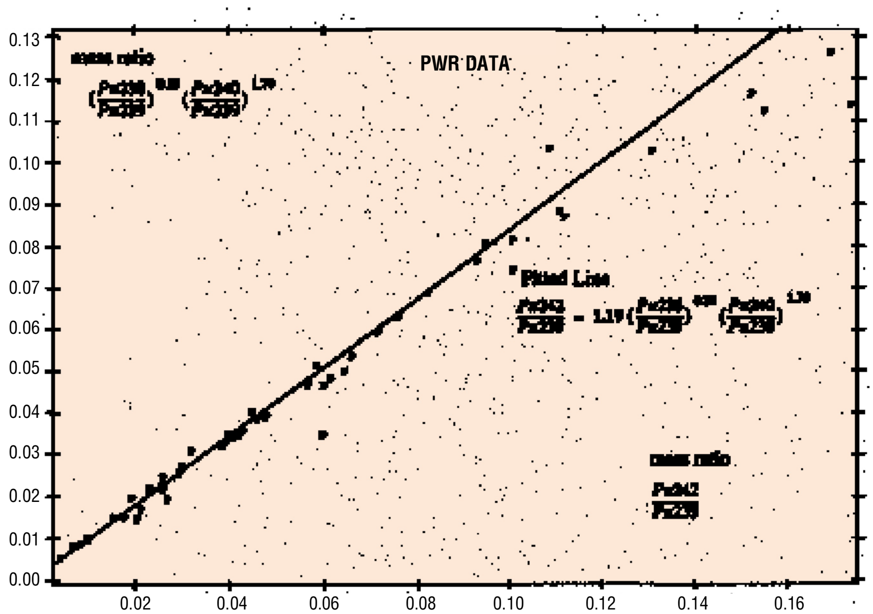

Figure 6: BNFL result of the new algorithm

The BNFL work consisted in testing this new algorithm with DA data from OBRIGHEIM and TRINO Reactors and it confirmed its good behaviour for PWR data as indicated Figure 6 /9/ (although the standard deviation is about 10% compared to the 3-6% obtained with La Hague data. This fact should be explained by the small number of DA data available in the case of BNFL work).

4. Recommendations

Considering the results from the experimental qualification for both the PWR and BWR data, the "best" adjustment [in terms of numerical stability and of minimization of the quadratic error] is obtained using treatment 4 with the coefficients $C_1 = 0.33$ and $C_2 = 1.70$ (the choice of the coefficient C_0 depends on the knowledge of the origin of the plutonium). This experimental approach, with the use of a large number of dissolution analysis data in a wide range of characteristics of irradiated fuels, leads us to recommend the following formula:

$$\frac{^{242}Pu}{^{239}Pu} = C_0\left(\frac{^{238}Pu}{^{239}Pu}\right)^{0,33}\left(\frac{^{240}Pu}{^{239}Pu}\right)^{1,7}$$

Choice of C_0:

Rather than using a constant value for C_0, a "data base" can be provided according to different families of plutonium production (in terms of range of initial enrichment, range of burn up ...).

The mean value of Co is 1.313 for PWR and 1.117 for BWR. It leads to an average error on ^{242}Pu evaluation of about 3% for PWR and about 7% for BWR.

A specific analysis of the dissolution data has been performed in order to provide such a data base, which will decrease the average quadratic errors. This data base is given in TABLE 1.

Table I: DataBase for the new correlation

Family	$^{238}Pu/^{239}Pu$	$^{240}Pu/^{239}Pu$	$^{242}Pu/^{239}Pu$	Range of initial enrichment in ^{235}U (%)	Average Burn – Up (MWD / t)	Number of D.A. data	Correlation $C_1 = 0.33$ $C_2 = 1.70$ Value of C_0	Average error on ^{242}Pu evaluation
PWR 17x17	$0.7851\ 10^{-2}$	0.3317	$0.4141\ 10^{-1}$	< 2.00	14318	765	1.325	2.47%
	$0.2100\ 10^{-1}$	0.4049	$0.8131\ 10^{-1}$	2.00 → 2.90	25183	1255	1.342	2.37%
	$0.3171\ 10^{-1}$	0.4281	0.1026	> 2.90	33568	835	1.351	1.76%
PWR 16x16	$0.2158\ 10^{-1}$	0.4291	$0.8859\ 10^{-1}$	≤ 2.90	24964	144	1.319	2.48%
	$0.3572\ 10^{-1}$	0.4586	0.1152	> 2.90	34388	129	1.292	2.31%
PWR 15x15 (WES)	$0.9957\ 10^{-2}$	0.3318	$0.4398\ 10^{-1}$	< 2.35	16388	78	1.299	2.77%
	$0.2286\ 10^{-1}$	0.3989	$0.8136\ 10^{-1}$	2.35 → 3.35	26994	270	1.340	2.19%
	$0.1790\ 10^{-1}$	0.2688	$0.3874\ 10^{-1}$	> 3.35	26799	203	1.360	2.77%
PWR 15x15 (KWU)	$0.1316\ 10^{-1}$	0.3535	$0.5442\ 10^{-1}$	≤ 2.80	18438	20	1.296	2.24%
	$0.2952\ 10^{-1}$	0.4242	$0.9547\ 10^{-1}$	> 2.80	31854	253	1.297	2.51%
PWR 14x14 (WES)	$0.1973\ 10^{-1}$	0.3696	$0.6644\ 10^{-1}$	≥ 3	25085	55	1.302	3.83%
	$0.2620\ 10^{-1}$	0.3825	$0.7879\ 10^{-1}$	> 3	30543	87	1.321	2.92%
PWR 14x14 (KWU)	$0.2273\ 10^{-1}$	0.4098	$0.8035\ 10^{-1}$	≤ 2.90	25547	11	1.276	1.43%
	$0.2709\ 10^{-1}$	0.4066	$0.8305\ 10^{-1}$	> 2.90	29657	60	1.260	2.53%
BWR 8x8 (GE)	$0.1328\ 10^{-1}$	0.3894	$0.5917\ 10^{-1}$	< 2	18137	170	1.175	6.27%
	$0.1626\ 10^{-1}$	0.3929	$0.6363\ 10^{-1}$	2.00 → 2.50	21093	85	1.204	2.75%
	$0.2551\ 10^{-1}$	0.4526	$0.8786\ 10^{-1}$	> 2.50	25929	58	1.111	6.08%
BWR 7x7	$0.8607\ 10^{-2}$	0.3281	$0.3323\ 10^{-1}$	< 2	11155	83	1.019	7.95%
	$0.117\ 10^{-1}$	0.4036	$06229\ 10^{-1}$	2.00 → 2.50	19851	117	1.089	7.31%
	$0.2538\ 10^{-1}$	0.4318	$0.7973\ 10^{-1}$	> 2.50	24668	120	1.107	5.10%

5. Conclusions

The studies described in this paper lead to the following conclusions:

- from a theoretical point of view, it is interesting and physically consistent to use the three plutonium isotopic ratio of the new correlation:

$$\frac{^{238}Pu}{^{239}Pu};\quad \frac{^{240}Pu}{^{239}Pu};\quad \frac{^{242}Pu}{^{239}Pu}.$$

- From an experimental point of view, the results presented in this document indicate that the new correlation has been qualified in a large range of characteristics of irradiated fuels using about 4700 destructive dissolution analysis data coming from the reprocessing plants of COGEMA-LA HAGUE and confirmed by investigations performed by TUI and BNFL works.
- The coefficients of this new correlation, given in our recommendations, allow an evaluation of the ^{242}Pu content with an average error within ± 3% (for plutonium coming from PWR) and ± 6% (for plutonium coming from BWR).

This means that the use of this new correlation leads to a significant improvement of the ^{242}Pu content evaluation compared to the algorithms used before (yielding average errors up to 20 - 25%). That is to say that this new correlation is recommended for any plutonium isotopic composition determination by gamma spectrometry either for laboratories, operators and Safeguards inspectors.

References

/1/ M. BICKEL, S. ABOUSAHL, A. RODRIGUEZ R. GUNNINK, "The International MGA User's Workshop, 1994", Proceedings of the 17th ESARDA Symposium, Aachen (May 1995).

/2/ A. SCHUBERT, H. OTTMAR, "Empirical determination of ^{242}Pu in Non-Destructive Assay. Where are the limits?", Proceedings of the 17th ESARDA Symposium, Aachen (May 1995).

/3/ R. GUNNINK, "A New one detector analysis method for rapid high precision plutonium isotopic measurements", Proceedings of the 9th ESARDA Symposium, London (May 1987).

/4/ H. OTTMAR et al, "MGA in K-edge gamma and neutron-gamma counters", Proceedings of the MGA User's Workshop, Geel (October 1994).

/5/ W. RUTHER et al, "MGA and passive neutron measurements", Proceedings of the ESARDA Workshop on Passive Coincidence Counting, Ispra (April 1993).

/6/ G. BIGNAN et al, "New algorithm for ^{242}Pu content evaluation", Proceeding of the MGA User's Workshop, Geel (October 1994).

/7/ G. BIGNAN, H. RECROIX, B. MITTERAND, W. RUHTER, "Recommendations for the ^{242}Pu content evaluation using a new algorithm", Proceedings of the 5th ANS International Conference on Facility Operations-Safeguards Interface, Jackson-Hole (September 1995).

/8/ H. OTTMAR, A. SCHUBERT, O. CROMBOOM, H. EBERLE "Non-Destructive Assay of small PUO_2 samples by Neutron-Gamma Counting - Expectations and Achievements". Proceedings of the 5th ANS International Conference on Facility Operations-Safeguards Interface, Jackson-Hole (September 1995).

/9/ Minutes of the ESARDA NDA Working Group Meeting, Paris (October 1995).

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Aspects of Remote Data Transmission in Safeguards

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1. Introduction

The present paper deals with the relevant questions encountered with remote data transmission, reflects discussions of the ESARDA Working Group on Containment and Surveillance, and draws some conclusions.

The workload of the Euratom Safeguards Directorate (Euratom) and of the International Atomic Energy (IAEA) has grown during the 1990's, as both the number of nuclear facilities under safeguards and their complexity have increased. In addition, the IAEA will be charged to detect undeclared nuclear activities. In the face of budgetary constraints both inspectorates have to reduce their inspection efforts by increasing the efficiency of routine safeguards without loss of safeguards effectiveness.

The New Partnership Approach agreed upon between Euratom and IAEA is an approach towards minimizing the IAEA's inspection efforts in the European Union. Both inspectorates anticipate reductions of inspection efforts to result from the implementation of remote data transmission.

During the last years a number of states has carried out field trials and studied the impacts of remote data transmission on safeguards.

2. Remote Data Transmission Activities

Euratom in cooperation with several member states is testing the remote transmission of state-of-health data from facilities to Luxemburg. For the time being, Euratom is mainly interested in monitoring the uninterrupted operation of unattended safeguards systems to ensure the continuity-of-knowledge. For instance, the presence of mains power is monitored and an according status signal is transmitted. No safeguards data (such as video images) are remotely retrieved.

The IAEA with support of a number of member states and in the frame of its Program '93+2 is developing strategies to reduce its inspection effort in declared facilities without loss of safeguards effectiveness. Among others the Program '93+2 foresees the implementation of remote data transmission.

The IAEA's field test investigations concentrate on combining remote data transmission with containment and surveillance measures, in order to determine where remote monitoring systems show potential cost benefits compared to existing safeguards. The IAEA's major interest lies with the implementation of remote surveillance systems, i.e. the retrieval of optical safeguards data.

The US Government sponsors the International Remote Monitoring Project (IRMP) which brings together the IAEA and a number of states under the project leadership of Sandia National Laboratories. The IRMP goal is to carry out field trials in the states to the end of there implementing remote monitoring systems. The following states are participating: Argentina, Australia, Finland, Germany, Japan, South Korea, Sweden, and USA. Sandia also has a cooperation with the Joint Research Centre at Ispra.

As an example, the Australian field trial yielded the major result that the public switched telephone network (PSTN) was not an appropriate transmission medium. In principle, Australia would agree to implementing remote monitoring in her facilities.

Sweden has also drawn positive conclusions from her field trials and would agree to remote data transmission.

Germany is very carefully addressing the remote transmission of video data in a field trial involving the German nuclear industry and Sandia but, for the time being, not the safeguards inspectorates.

3. Problem Definition

It shall be understood that remote data transmission involves the data retrieval out of facilities and possibly, but not necessarily, across national borders.

Its acceptability will depend on the solution of a number of technical and non-technical issues.

The inspectorates are interested in the acquisition of authentic data. Therefore, authentication is an important requirement when designing remote data transmission systems.

The states/operators are interested in the confidentiality of the gathered information. Therefore, encryption is another important requirement.

Of all safeguards data digital optical data pose the highest technical requirements regarding processing and storage. A single image consists of a huge amount of pixel data to be compiled in a file. Prior to transmitting an image it has to be digitized, compressed, authenticated, encrypted, and stored.

The failure of the transmission medium will result in the loss of the data.
Therefore, remote data transmission requires a reliable backup data storage in the facility.

The release of video data for transmission out of a facility and across borders will depend on viable solutions reached between the inspectorates, governments, facility operators and trade unions.

4. Evaluation Criteria

The following criteria are used to evaluate remote data transmission field tests:

- System performance including the transmission medium
- data authenticity
- data confidentiality
- completeness of transmitted data
- quality of received data
- time required for the data transmission
- restart after power failure
- maintenance requirements
- data storage capacity requirements on site and at headquarters
- operator's effort in a remote monitoring concept
- reduction of inspection effort
- impact on the inspectorates' infrastructures

5. Discussion

It is possible to configure and operate remote monitoring systems consisting of customized sensors including digital sensor electronics and commercially available PC hardware, software and modems. The transmission media could be PSTN, ISDN, satellite links or the Internet. The remote transmission could be restricted to state-of-health data only or also comprise safeguards data.

The following discussion highlights the

principal issues and concerns related to the anticipated implementation of remote data transmission for safeguards.

5.1 State-of-Health Data

Both inspectors and facility operators are interested in maintaining the continuity-of-knowledge. Regarding the realtime transmission of state-of-health data both parties would, above all, benefit, if a loss of continuity-of-knowledge and thus follow-up actions such as the remeasurement of nuclear material inventory could be avoided.

The safeguards authorities are primarily concerned of power outages. A live status signal indicating the uninterrupted presence of mains power supplying the safeguards equipment could be transmitted to the inspectorates' headquarters. In case of a power failure, the responsible facility inspector would immediately contact the facility operator and ask for the provision of power.

In order to avoid a loss of continuity-of-knowledge, safeguards systems are normally equipped with backup batteries for the supply of uninterrupted power. The power capacity should be capable of bridging the vast majority of power outages experienced in the country under consideration.

A loss of continuity-of-knowledge may result in a remeasurement of the nuclear material inventory which requires great effort also on the plant operator's side and possibly results in an increased safety risk (handling of spent fuel should be avoided as far as possible).

However, power outage is only one possible failure mode and, for the time being, may be the only one which lies in the operator's influence. Other failure modes of the remote monitoring system could be defective PC's and modems, outage of the transmission medium (PSTN, ISDN, satellite link, Internet), or an interruption between the sensors and the modem. Currently, these failure modes are handled by the inspectorates themselves except for outages of the transmission medium.

On the other hand, status monitoring may have the potential of indicating the gradual degradation of safeguards equipment. In this case, the inspectors will be able to respond by establishing appropriate service, maintenance, repair, and replacement schemes, in order to avoid equipment failures.

Another aspect is, that outages of the safeguards system may become known to the facility operator, contrary to Euratom's current policy.

In remotely acquiring state-of-health data, the inspectorates have to be able to determine, whether a state-of-health alarm is false or true. A country may create such alarms as part of its diversion strategy.

The timeliness criterion would not be affected by the realtime transmission of state-of-health data. The inspector would continue to visit the facility according to current inspection schemes.

Finally, the plant operator may request assurance from the inspector that exclusively state-of-health data are being transmitted and not also, for instance, video images. It may be very difficult to prove this.

5.2 Safeguards Data

Governments request that the safeguards authorities manage the safeguards data confidentially. Therefore, remote data transmission requires encryption to be agreed upon between the safeguards authorities on the one hand and the individual governments on the other.

Experience has shown that the security level of the encryption is ruled by the length of the encryption key. As governments may want to be able to control all the data flowing in their countries, they may agree to a restricted length of the encryption keys to be applied. Consequently, governments would be able to know, if and when a safeguards system would be down.

The release of surveillance images is a particularly crucial issue. Trade unions may have problems, if facility staff can be identified on the video images. In this case, solutions could be to limit the resolution of the images, or to set the field of view so that no persons will appear on the images. However, in many countries the safeguards authorities are allowed to carry away surveillance data showing persons.

The plant management may have reservations regarding the realtime transmission of surveillance images. There could be a safety relevant incident within the field of view, which might be published by a third party in spite of the encryption, prior to the plant operator being able to take remedial actions. A solution is to use a delayed transmission scheme for images. This may require active participation on the plant operator's side.

The inspectorates' timeliness goals do not require to implement live transmission. On the other hand, there are countries that do want live transmissions for the inspectors to observe their plants remotely.

5.3 Key Management and Encryption Algorithms

The key management for the encryption of images is to be agreed upon between the inspectorates on the one hand and individual governments on the other.

It is in the inspectors' interest not to be prone to theft and blackmail. They would benefit from the remote transmission of video images, which could not be stolen from their cars or hotel rooms. Currently, in states which allow the retrieval of video tapes, the images are not encrypted and thus readable by everyone.

The key management should be standardized, in order to minimize the inspectorates' efforts.

As far as the encryption algorithms affect the inspectorates' efforts, their number selected for safeguards should be as small as possible.

5.4 Authentication

In a remote monitoring scheme it has to be ensured that authentic data arrive at the review station which will be located at the inspectorates' headquarters or regional offices. At present, this authenticity requirement is restricted to the in-plant recording station. The key management for the authentication algorithm will be exclusively the inspectorates' responsibility.

5.5 Unambiguity of Data

In order to ensure the unambiguity of data generated in unattended integrated safeguards systems, the equipment components need to be synchronized; i.e. NDA and surveillance components must use the same time stamps, in order to enable the unambiguous correlation of different sensor data. This can be done using an internal reference time signal or by receiving an external one. In Germany, the DCF77 radio-frequency time signal could be used.

5.6 Handling of Large Data Volumes

The longterm stability of electronic storage media and the transmission of large amounts of data are unresolved issues for the inspectorates. To the end of limiting the data flow and storage requirements the consequent application of data reduction methods including both front end triggering and data compression algorithms will be necessary.

The inspectorates' infrastructures have to be adapted to the new data management requirements. The incoming data must be receivable in a data collection system necessarily connected to the outside world. For data processing and archiving the inspectorates need an internal data network which is inaccessible, i.e. completely disconnected from the outside world.

5.7 Independence of Euratom and IAEA

Under the New Partnership Approach Euratom and IAEA will not need their own independent transmission channels, if authenticated data are transmitted.

5.8 False Alarms

For each application of remote monitoring the types and consequences of false alarms have to be clarified between the inspectorates and the operator. Implementation tests have to precede actual implementation. In principle, the number of false alarms should approach zero.

5.9 Plant Safety

The operator must be able to convince himself, that no safety relevant incidents will be effected by the safeguards equipment. A precondition for implementation will be that all components show the according certificates necessary for licensing in the respective member state.

5.10 Transmission Media

The PSTN is the least reliable transmission medium compared to ISDN and satellite links. Among others this is due to the network quality varying from state to state as well as to signal attenuation and build-up of noise on long distances. In addition, the transmission rate is small compared to ISDN and satellite links.

ISDN is being implemented in an increasing number of states. It is assumed that within the European Union it could be used for remote monitoring, as the technical standards are widely harmonized. Also the transmission rate is acceptable.

Satellite communication is globally applicable. It is superior to the PSTN. However, it is vulnerable to weather-induced outages. The transmission rate is comparable to that of ISDN.

The banks apply very strong security criteria when effecting financial transfers. Nevertheless, they do use the Internet. Therefore, the Internet should not be excluded from being considered for use in safeguards.

In principle, every transmission medium can fail for one reason or another. This has an impact on the design of remote monitoring concepts, if timeliness is taken into account. Also the capacity of backup powering (uninterrupted power supply) as well as front end data storage are ruled by this aspect.

5.11 Cost Benefits

In a remote monitoring scheme the inspectors would save on travelling, as the data would be transmitted to headquarters or regional offices. This would give the inspectors more office hours. Safeguards would become more cost efficient.

The facility operators would save on escorting. In addition, they would have more flexibility in running their plants because of the reduced inspection schedules.

6. Conclusions

The remote transmission of state-of-health data only does not yield all the perceivable advantages and benefits compared to the remote transmission of both state-of-health and safeguards data.

The benefits both for the inspector and the operator become apparent, once the inspector is able to drastically reduce his/her on-site inspection effort. For instance, in some types of facilities it may be possible to reduce the number of inspections per annum to the one for Physical Inventory Taking. This will also result in a reduction of escorting requirements on the operator's side and more flexibility in plant operation. Some countries discuss with the IAEA the implementation of remote transmission of safeguards data in connection with a Short Notice Random Inspection (SNRI) scheme.

A novel issue to be solved by the inspectorates and the governments will be the management of encryption keys.

Although plant management and trade unions may not really trust the security of the encryption applied to remotely transmitted images, they should be aware of the fact that this approach is far superior to the current safeguards practice. Encrypted data will make the inspectors less prone to theft and blackmail both when carried away (provided the key is not left with the data) and even more so when transmitted remotely.

The remote transmission of surveillance images may be acceptable in many states, if flexible schemes for the timing of the transmission can be agreed upon such as delayed transmission schemes. Safeguards systems are conceivable, where there is a delayed transmission of surveillance data and a live transmission of all other data including NDA and state-of-health data. In delayed transmission schemes the plant operator may have to play an active role.

Only safeguards equipment showing the certificates (in particular regarding electromagnetic compatibility) necessary for licensing in the respective member state should be considered for implementation.

On the Optimization of Interim Inspections

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Abstract

One considers the situation in which between two fixed inspections, a few interim inspections can be performed, the latter being chosen among several possible periods. The study of this problem is based on the reasoning of two adversaries: an inspector and an inspectee. The information each adversary possesses, as well as their skill to manage it, appears to play a fundamental role.

1. Introduction

Inspection problems arise when an inspector has to verify whether an inspectee has behaved legally, according to an agreement. If the inspectee chooses to behave illegally, he will try to conceal this illegal action as long as possible. For instance, if he diverts nuclear materials, he will attempt to maximize the detection time, which is the time elapsed between the diversion and the subsequent inspection. On the other hand, the inspector will try to minimize this detection time.

The reduction of the number of inspections, while maintaining a high detection efficiency is an important problem of the safeguards implementation. In this paper, the following idealised model is studied:

A reference time period is subdivided into T distinct periods of equal length. At the end of each of them, an inspection can take place. A perfect inventory always takes place at the end of the reference period, so at the end of the T^{th} period. During the game; the inspector performs k inspections (k < T) over and above the final perfect inventory verification. The inspectee is allowed exactly one diversion at the beginning of one of the T periods.

If there is no interim inspection (k = 0), the problem is quite clear: the inspectee has an interest in deciding to divert at the beginning of the game, and then the detection time is t_d = T. In order to reduce the value of t_d, the inspector will perform some interim inspections. If the number and periods of those interim inspections are previously known by the inspectee, he will divert just after an inspection and the optimized (for the inspector) distribution of the inspections is the equal distribution which corresponds to t_d=T/(k+1) At this stage, the problem of the inspector is to try to improve the efficiency of the inspection dispositions, i.e. to reduce t_d for a fixed inspection effort (corresponding to an imposed k value). We shall see in the following of this paper that this will be possible only if the inspectee is not informed at the beginning of the game (at t = 0) of the number of inspections to be performed.

2. On the information

In order to try to reduce the value of t_d, still maintaining a constant inspection effort k (or at least an average value <k> of constant inspection effort), the inspector proceeds such that the inspectee receives imprecision or uncertainty on the knowledge of the future inspections.

One way is to carry out randomized inspections: the inspector selects a number k_a of possible inspection periods (equally spaced) at which he inspects with an equal probability p determined randomly. The average inspection effort <k> is then:

$$\langle k\rangle = k_a\, p \qquad (1)$$

In this case, the inspectee has an interest in diverting at the beginning and the average value of the detection time is:

$$\langle t_d\rangle = \frac{T}{k_a+1}\left\{\sum_{n=1}^{k_a-1} np(1-p)^{n-1} + k_a(1-p)^{k_a}\right\} \qquad (2)$$

An advantage of randomized inspections appears to be their simplicity to be implemented. However, one may also consider instead the situation in which the inspection probability is no longer constant but depends on the period of inspection i, and is denoted p_i. In that case, the inspector will minimize the detection time t_d optimizing the p_i values, while the inspectee will choose the diversion period in order to maximize t_d. When the problem is formulated in this fashion, one is naturally led to a zero-sum game [AC, GW].

The behaviour of each of both players must be considered following three parameters:

1. Before the beginning of the game, we regard the knowledge possessed by the players concerning the number of actions that will be performed by the adversary. If this number is known, the information is said to be *complete*, otherwise it is *incomplete*.
2. During the game, if each player remembers at each period what he has done and what he knew before, then the game is of *perfect recall.*
3. During the game as well, if each player knows at each period the actions yet performed by its adversary, then his information is *perfect,* otherwise, it is called *imperfect.*

We will consider in the following that the game is of *perfect recall,* since in the world of nuclear materials, both inspector and inspectee are usually conscious persons. We shall also suppose, for the sake of *perfect recall,* that the game is either played by the same players throughout, or if one of the players is replaced, then the former informs him of everything that happened during the previous periods.

Considering the inspector's information, at the beginning of the game he knows he will have to face a single diversion. His infommation is *complete.* Meanwhile, he discovers the diversion at the following inspection period, signifying his information is delayed and hence *imperfect.*

The inspectee's is, in a way, more complex. We consider different situations:

1. If he is informed after each period of the inspector's move, then he knows whether there was an inspection, and his information is *perfect* (this situation can be relevant for intemational safeguards, when the inspectee is the operator of the concemed facility). On the opposite, if the inspectee has occasionally access to the nuclear materials, he is not informed about the past inspections and the information he possesses is *imperfect* (this situation is relevant for national safeguards, when the inspectee is an employee with limited responsibilities or authorization inside the facility).
2. The other aspect of the inspectee's information depends on whether he knows exactly how many inspections will be performed during the game.

Indeed, either the number of inspections to perforn is known by both players, or a probability distribution over different numbers of possible inspections is announced. In the former case the inspectee has a *complete* information on the game, and in latter, his information is *incomplete* [Z].

3. The impact of the information on the average detection time

The inspection game played on T periods with one diversion and k inspections has been studied in these different contexts of information by Avenhaus and Canty [AC], and Goutal and Werkoff [GW, G].

It is clear that when the inspectee has a *complete* information on the number of inspections to be performed, he has an advantage in programming the diversion right after the last inspection seen, as mentioned in [AC]. It is not the case if he only has a probability on the number of inspections to be done, since he generally doesn't know if an inspection is indeed the last one to be performed. As well, if the inspectee has a *perfect* information on the actions of the inspector, he can plan his diversion according to the periods at which there was an inspection instead of blindly programming it. This means that the best detection times, from an inspector point of view, are obtained when the game is of *imperfect* and *incomplete* information. However, regarding the "perfectness" of the information, one should consider the assumptions that have to be taken in each particular situation: national or international safeguards. Anyway, for each case, *incomplete* information gives the lowest detection times. This is shown on Figure 1. It exhibits the average detection times obtained for games played over six periods during which the inspector may perform one or two inspections (the values are given versus p_2, the probability of having two inspections).

The setting of *incomplete* information requires some efforts, and the size of the games gets very large with T increasing [G] (Table 1). Fortunately, Figure 1 shows also that for some probability values, the detection times obtained for a *perfect-incomplete* information game are close to the ones obtained for an *imperfect-complete* information game, easier to solve.

Nonetheless, we found it necessary to estimate the improvement that *incomplete* information can bring to the detection time (in the case of *perfect* information). To do so, we have considered situations in which the average inspection effort is kept constant. We give the example of a game played over eight periods with none, one or two inspections, and during which the constant inspection effort is of one inspection. Hence, if p_0 p_1 and p_2 are the respective probabilities of having zero, one or two inspections done during the eight periods, then they verify

$$p_0 = p_2 \quad \text{and} \quad p_1 = 1 - 2\,p_0 \qquad (3)$$

The average inspection effort is kept equal to one since

$$0.p_0 + p_1 + 2\,p_2 = 1. \qquad (4)$$

In fact, the value $p_0 = 0$ corresponds to the *complete* information game (and of *perfect* information) with exactly one inspection announced. We found out that there is a benefit produced by *incomplete* information, as seen on Figure 2. Table 2 gives the value of the relative maximum benefit defined as the ration of the difference between the value of the *complete* information game and the minimum value of the *incomplete* information game, divided by the value of the *complete* information game. We can appreciate the fact that this produced benefit increases with the number of periods.

Table 1: Number of non-dominated inspectee's strategies with respect to the maximum number of possible inspections (kmax)

Number of periods	kmax=1	kmax=2	kmax=3
T=4	3	5	5
T=5	4	16	26
T=6	5	65	417
T=7	6	326	27106
T=8	7	1957	8836557
T=9	8	13700	17293142050
T=10	9	91457	$2369160461\ 10^{5}$
T=11	10	936410	$2166763083\ 10^{10}$
T=12	11	9864101	$2137316772\ 10^{16}$
T=13	12	108505112	$2108270851\ 10^{23}$

Table 2: Improvement in the detection time brought by incomplete information compared to the detection time of a game of complete information with one inspection

T	4	5	6	7	8
Improvement	0	2.55%	4.08%	4.68%	4.88%

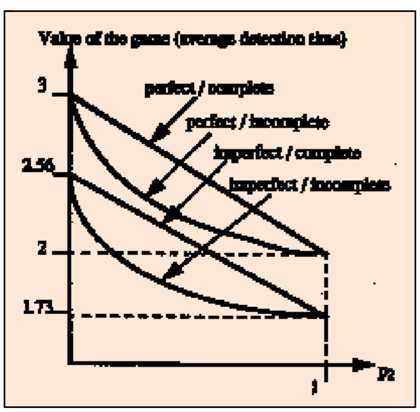

Figure 1: Impact of the information on the detection time

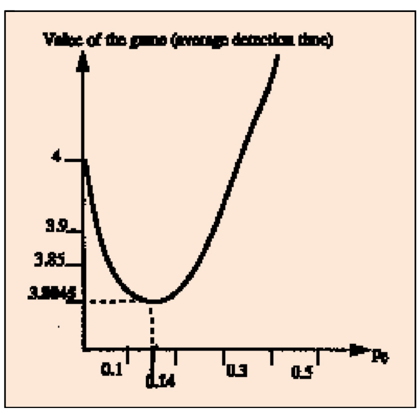

Figure 2: Benefit produced by incomplete information , T=8

4. Conclusion

This study leads us to the following principal conclusion. The inspectee is considerably favoured if he knows all the past actions of the inspector, and if he knows how many times the latter will inspect. Moreover, the advantage conferred by *perfect* information is reduced when the game is of *incomplete* information. However the non negligible improvement brought by *incomplete* information is stained by the fact that the size of the linear problem to be solved to obtain the detection time of the diversion increases with the number of periods of play.

References

[AC] AVENHAUS R., CANTY M., *Optimal Randomized strategies for timely verification,* Proceedings of the 13th Annual Symposium on Safeguards and Nuclear Material Management, pp. 39-45, Avignon 14-16 may 1991.

[GW] GOUTAL P., WERKOFF F., *On an inspection game with incomplete information,* Proceedings of the 17th Annual Symposium on Safeguards and Nuclear Material Management, pp. 607-703, Aachen 9-11 May 1995.

[Z] ZAMIR S., *Repeated games with incomplete information,* Handbook of Game Theory, edited by R. Aumann and S. Hart, 1, Elsevier, 1992.

[G] GOUTAL P., *Game theory applied to non-proliferation,* Proceedings of the Workshop INMM-ESARDA on Nuclear Safeguards, pp. 191-202, Arona, 28-31 October 1996.

Role of Containment and Surveillance Strategies in the U.S. National Safeguards Program

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1. Introduction

This paper examines the policy and operational aspects of implementing approaches of containments and surveillance (C/S) strategies for fissile material storage. This examination is important to the Department of Energy utilizing to its full extent C/S systems to provide critical safeguards controls over static stores of excess plutonium (Pu) and highly-enriched uranium (HEU) while addressing ever increasing safety and cost issues. There is an increased emphasis in the use of technologies and non-intrusive measures to provide knowledge of these fissile inventories while satisfying personnel radiation and dose rate minimization requirements and reducing cost of operations.

Nuclear material operations in the Department of Energy up to the early l990's were primarily processing and production. Due to the greater reliance on accountability and process monitoring associated with these operations, C/S was not widely used. The Department is now moving toward more static long-term storage in the post-Cold War era. As a result of downsizing and weapons dismantlement activities, the U.S. now has an increased opportunity to utilize C/S systems over its own fissile materials. Most of the work performed in the U.S. in the area of C/S development was primarily directed toward supporting the IAEA. The U.S. can now benefit from the experience obtained from the IAEA which has applied these U.S.-developed systems at a variety of nuclear facilities worldwide. Before the U.S. embarks on a large-scale program of implementing C/S systems over its fissile materials inventories, defining performance criteria and identifying specific locations and situations where C/S can be practically implemented must be developed. Finally, specific benefits from the use of C/S must be weighed against costs and impacts on operations.

The Department of Energy has been in the forefront in developing C/S technologies for not only domestic but international safeguards application. This development has been sponsored by the technology based development program, funded by the Office of Safeguards and Security as well as by the Office of Arms Control and Nonproliferation. Also, the U.S. program for technical assistance to the IAEA has been an important mechanism for moving these Department of Energydeveloped C/S systems into the international safeguards arena. These systems include active seals, advanced surveillance systems such as image processing and item monitoring devices. As a result of Programme "93+2" and the impetus behind expanded use of nontraditional safeguards to support an expanded nuclear nonproliferation regime, remote monitoring systems incorporating C/S features have been demonstrated by the U.S. and are being considered for widespread use by the IAEA in maintaining knowledge over static inventories. Finally, authenticating domestic safeguards systems can allow for the IAEA to utilize existing or in-place facility C/S technologies. The possibility of authentication is being incorporated into C/S applications to promote more efficient and effective safeguards.

2. U.S. Fissile Material Inventories: Status and Implications on C/S

Developing comprehensive protection strategies and budgetary planning is necessary to the process of selecting technical measures such as C/S for keeping fissile material inventories secure. A major factor in these efforts is the size of the inventories at issue. Total fissile inventories in the U.S. remain classified as well as exact rates associated with weapons dismantlement activities. What is available are fissile material inventory quantities declared excess to defense needs and the percentage and quantities of those inventories under international inspection. The fact is that these excess inventories exist in large quantities (over 200 tons) in many locations across the U.S. Although many of these materials will be eventually processed for either use in MOX fuel or for stabilization for long-term or interim storage, there will likely be opportunities to use C/S as an option for safeguarding these materials prior to and after processing.

Increased fissile materials monitoring and surveillance activities will be occurring at major U.S. storage facilities such as the Y-12 Plant in Oak Ridge, Tennessee, and Pantex in Amarillo, Texas. The cost of these activities is being closely factored into program and operational planning since cost is generally an infrastructure resource requirement in terms of personnel, systems, maintenance and safety. So, the opportunity to implement C/S and the apparent benefits of C/S to reduce program and operational costs at these and other facilities makes examining C/S strategies today both timely and important.

An aspect of nuclear weapons dismantlement and production cut-off that supports bilateral inspections and nuclear nonproliferation treaty commitments is transparency. C/S is a means to ensure that current and expanding fissile material inventories are remaining secure and not being reintroduced into facilities where weapons production operations are taking place. Improving security while addressing other program needs (e.g., safety) and demonstrating irreversibility in weapons dismantlement are imperatives to managing U.S. fissile inventories. These improvements and demonstrations can be supported by C/S.

3. The Role of C/S in Safeguards

The use of C/S has long been recognized as a complementary measure to traditional accountability elements of safeguards that include measurements and measurement control. In describing aspects of a fundamental safeguards program, no discussion is complete without a discussion of continuity-of-knowledge. No measurement is meaningful unless it can be both traceable to basic physical units (i.e., moles or atoms representing an amount of substance) and to the inventory or material under investigation. C/S does not assist in assuring what the material is but, instead, relates the significance of an activity (such as personnel access to a storage location) to confidence in the material inventory's integrity. This is where the use of C/S in a static storage of nonprocessing environment can be fully exploited. The integrity of U.S. fissile materials is not changing due to processing or chemical transformation for a large portion of material in storage. Additionally, since long-term storage of fissile material does not include - human access or exposure to materials, changes or potential for changes in inventories are greatly reduced. This means that the emphasis on continuity-of-knowledge through C/S can provide more assurance as to the status of material inventories while not reducing significantly the effectiveness of the safeguards program. This is not to infer that measurements are not important (they serve as a verification and quality check as to the performance and effectiveness of C/S and other measures); C/S can reduce the frequency and level of verification associated with measurements. C/S can also provide real time capabilities for detecting diversion while measurements provide delayed detection through periodic material attribute tests.

Domestic safeguards policies are explicit in terms of recognizing C/S as an integral part of a comprehensive complete safeguards system. Requirements for materials control, particularly surveillance and containment mechanisms, which include tags and seals, as well as assessment can be satisfied through the use of C/S. In addition to C/S playing a significant role in terms of cost-effective and practical implementation of extended physical inventory policies, the use of C/S can reduce sampling plan requirements by reducing numbers of measurements. The selection and use of C/S to implement these policies must be based on maintaining high levels of confidence of inventory integrity. DOE has identified types of C/S and performance criteria related to their use which provide such requisite levels of confidence. These include item monitoring systems, fiber optic seals and image processing. Other policies in the environment, safety and health arena will require facilities to achieve a greater balance between reduced access to radioactive materials and protection controls to reduce personnel radiation exposure while providing safeguards assurance and confidence over fissile material inventories. C/S is a means to achieve and maintain this balance.

4. C/S Performance

Decisions regarding the use of C/S should consider the degree to which containment and detection is required to maintain confidence in inventories between verification (or measurements) periods. It is also necessary to ensure that the environment and operating conditions can maintain the C/S systems' functionality over a long period of time. So various features of C/S need to be evaluated to determine if desired performance and functionality are achieved.

Defining"successful" C/S requires the establishment of specific criteria which can serve as performance and functionality characteristics to which decisions related to selection, use and evaluation can be based. The success of C/S is also a function of the type of threat that is deemed credible for the storage or processing location and the risk associated with the loss of the inventory or a portion thereof. The Department of Energy looks at security threats in terms of outsiders (e.g., terrorists) as well as insiders (e.g., facility personnel with authorized access to material stores). The risks to fissile inventories associated with these threat types include primarily diversion and theft and, to a lesser extent, sabotage. So features that characterize successful C/S include functional specifications of C/S systems, location, risks and threat.

The following table summarizes what the Department of Energy defines as successful C/S. Performance standards for specific locations or fissile material stores must be defined on a facility- or inventory-specific basis according to other protection or assurance features in place and the dependence the facility's safeguards system places on C/S. The features and criteria which are contained in the table below and constitute successful C/S can be useful in for planning, implementing and evaluating C/S strategies.

C/S Features	Criteria
Reliability	Redundant and independent
Ability to detect tampering	Ability to detect falsification or manipulation of data or containers
Easily maintained	Resistant to harsh radiation and environmental conditions
Acceptable to facility operator	Non-intrusive to operations and safety

5. Dual and Independent C/S

One important topic related to C/S performance is the concept of dual and independent C/S. This concept can increase confidence in remote and unattended monitoring and can ensure continuity-of-knowledge over inventories. Advanced technologies being developed and applied at the Department of Energy and by the IAEA are directed toward dual and independent C/S by eliminating common-mode failure possibilities and addressing a wider spectrum of diversion possibilities. Greater capabilities for maintaining C/S can permit U.S. facilities to extend physical inventory verification intervals and, in some cases, reduce sampling and measurement requirements during physical inventories. The IAEA has considered the concept of dual and independent C/S in its long-term criteria which can similarly reduce IAEA verification requirements while still achieving its safeguards verification goals in order to make positive conclusions about the fissile material inventories. In addition to improved detection, assessment of anomalous activities (e.g., diversion) in terms of all potential diversion paths can be enhanced through the use of dual and independent C/S.

As the U.S. implements the recently announced[1] excess plutonium disposition options which include the immobilization of plutonium in borosilicate glass and geologic emplacement, the IAEA may choose to monitor these fissile stores as part of the U. S. voluntary offer. Since underground emplacement of plutonium precludes the implementation of measurements and periodic physical inventories, dual and independent C/S can serve to provide assurance that undeclared removal of plutonium (e.g., through tunneling) will be detected while reducing inspector presence and improving allocation of resources within the IAEA.

6. C/S Technologies at U.S. Facilities

The U. S . has developed a remote monitoring system that is being field tested at the Y- 12 Plant for both domestic and international safeguards use. This advanced C/S system also is equipped with sensors that can measure radiation emissions and enrichment levels that can confirm the presence of HEU. The C/S features include cameras and image processing for materials surveillance and fiber optic sensors and item motion detectors to monitor material access, containment and movement. The camera will be "sensor event" triggered and events recorded for review and assessment. The remote monitoring system is primarily being installed at a Y-12 Plant vault under IAEA inspection to reduce inspection requirements. From a domestic safeguards standpoint, the remote monitoring can extend physical inventory periods by several years, depending on the number and redundancy of its components. The IAEA use of the system will require sensor and image data to be stored locally on a

[1] Secretary of Energy Press Conference, December 9, 1996.

small computer for remote transfer on demand by IAEA Headquarters via satellite or telephone.

Dual containment features are in place over excess plutonium at the Rocky Flats Environmental Technology Site currently under IAEA inspection. These include the use of fiber optic seals on individual containers as well as the door to the vault-type room housing the plutonium. The IAEA is currently field testing 'Gemini' camera systems for remote monitoring use that will serve to reduce inspector presence between physical inventory verification periods. Lastly, Pantex is evaluating the use of item monitoring systems as part of an integrated safeguards package for containers of plutonium components in long-term storage there. If successful, this C/S system will be incorporated in a pallet that will be used for container storage.

7. Conclusion

As a result of increased fissile material storage operations in the U.S., non-intrusive and remote capabilities characteristic of C/S are becoming an increasingly attractive safeguards tool for use at Department of Energy nuclear facilities. The U. S. is evaluating and will be applying C/S as a major element of its national-level safeguards program. Increased long-term storage of Pu and HEU resulting from post-Cold War reduction in weapons manufacturing and increased weapons dismantlement provides an opportunity to implement C/S on a broader scale. C/S can also address significant radiation exposure issues arising from highdensity storage configurations. C/S can also improve the efficiency of safeguards by allowing physical inventory and measurement verification requirements to be reduced. Performance of C/S systems must be assessed against fundamental reliability and redundancy criteria to ensure that high confidence in safeguards effectiveness is achieved through their use. Although the U.S. has been a major developer of C/S for international safeguards use, it can benefit from current field trials of these systems and experience associated with their use by the IAEA.

We hope that this paper can serve as a basis for further discussions on the increased role of C/S in terms of new technologies, specific applications and lessons-learned. Such discussions can undoubtedly benefit all parties and further improvements in the uses of C/S for both safeguards and treaty verification and arms control purposes.

References

/1/ Department of Energy Order 5633.3B.

/2/ IAEA, Safeguards Criteria for the Period 1991-1995.

/3/ IAEA, Remote Monitoring Evaluation Phase 2: Y-12 HEU Storage Vault Field Trial Work Plan, January 25, 1996.

/4/ IAEA, Safeguards Policy Series, Number 11 (1989).

/5/ IAEA, "Report of the IAEA Advisory Group Meetings on the Use of Containment and Surveillance and In Situ Verifiable Seals," STR-247, Vienna (1988).

/6/ CRAWFORD, D., MANGAN, D., "Containment and Surveillance Strategies for Safeguarding Spent Fuel and Waste Destined for Final Disposal," 1990.

Computerised Methods for Time Correlation in Passive Neutron Counting for Fissile Material Determination

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1. Introduction

Passive counting of spontaneous fission neutrons for the determination of plutonium mass present in bulk samples is routinely carried out, as a well established procedure, by measurement instruments designed to implement coincidence counting techniques developed from the Rossi-α method /1/. Such instruments, for instance the Shift Register for the Neutron Coincidence Counting (NCC) technique /2/ or the Time Correlation Analyser for the Neutron Multiplicity Counting (NMC) technique /3/, perform real time analyses of detected neutron pulse trains through proper electronic coincidence circuits. As well known, this allows to discriminate real coincidences originated by the neutrons emitted from the same event, such as one spontaneous or induced fission, from accidental coincidences following single neutron events, such as (α, n) reactions. Such discrimination gives the basis for the determination of the fissile mass within the sample. It is worth to remark that in all these instrumental methods the neutron pulse sequence is regarded only as a trigger for permitting counting in proper gates.

With the aim to exploit information from the neutron pulse train as a whole, the present work follows a different approach: for a given measuring time, the neutron pulse train is stored by proper hardware and then it is analysed via software. This procedure permits to assay the same neutron pulse train by different time correlation methods.

In the following, a description of the hardware for neutron pulse trains collection is given along with the analysis software; experimental results obtained with PuO_2 in the mass range 10÷2500 g are also presented.

2. Neutron pulse train collection

The recording of the whole neutron pulse train is performed by means of an electronic board plugged in an IBM-compatible PC. As described in figure 1, the board, interfaced directly to a conventional detection head, is able to associate to each logic pulse (or to the interval between two successive pulses) its arrival date (or the time length of the interval). This time information is recorded by a RAM buffer memory and then delivered to the PC hard disk, where the whole pulse train is stored under form of an ASCII file.

In particular, for the present work, two different types of boards have been utilized: the Pulse Dating System (PDS) /5/, developed by University of Rome "La Sapienza" and ANPA/DISP, and the Pulse Interval Analyser (PIA) /6/, developed at the Ispra site of the JRC. As suggested by respective names, PDS collects a pulse train as a sequence of time of arrivals while PIA records a sequence of intervals between two successive pulses.

3. Neutron pulse train analysis

A special computer code, "Neutron Pulse Train Analysis" (NPTA), has been developed by University of Rome "La Sapienza" and ANPA/DISP for the

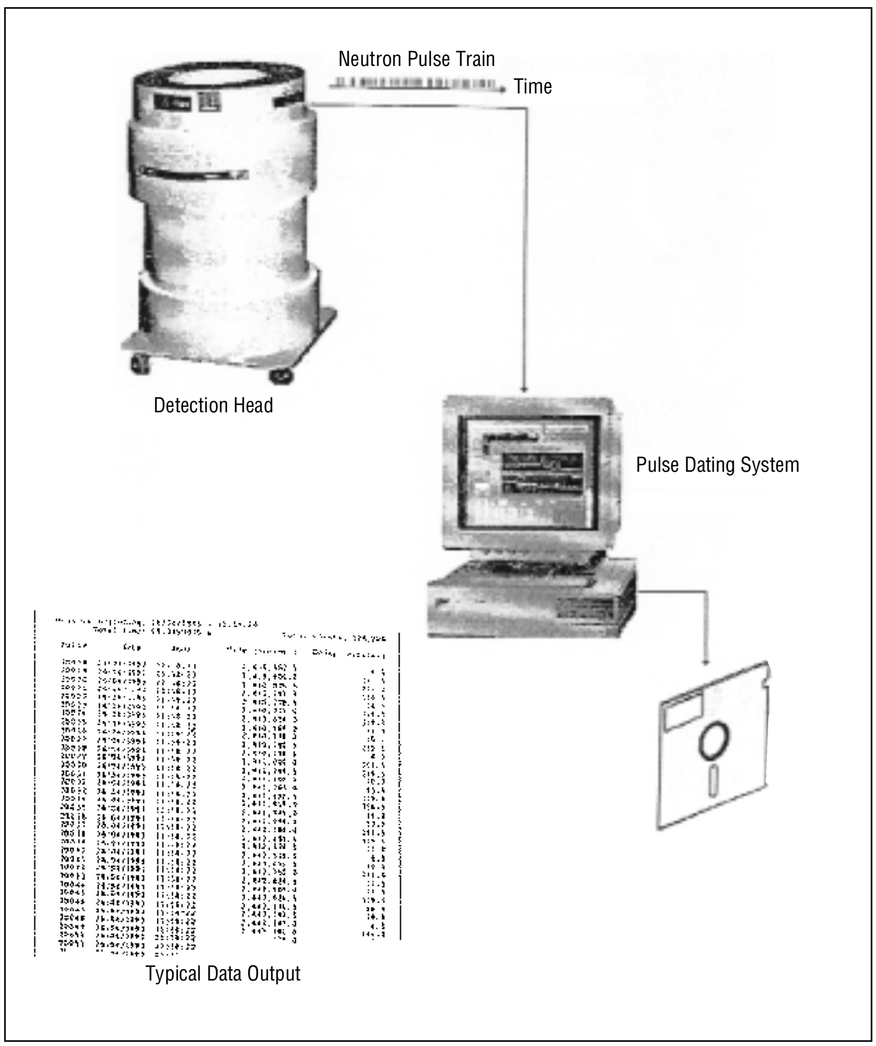


Figure 1: ASCII file recording of a neutron pulse train

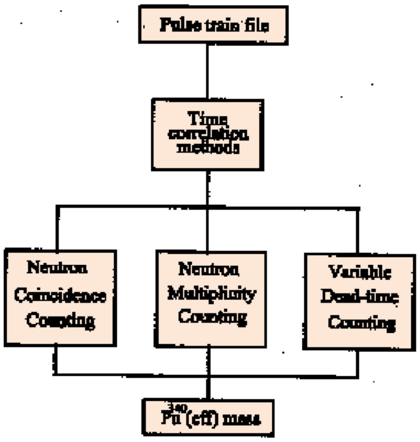


Figure 2: Structure on NPTA code

analysis of neutron pulse train. Such software, written in C++ language, is able to treat both sequences of times of arrival (pulse trains from PDS) or interval time lengths (pulse trains from PIA).

NPTA code (fig.2), once the neutron pulse train is recorded on an ASCII file, allows the user to run the following time correlation methods:

Variable Dead-time Counting (VDC) /6/;
Neutron Coincidence Counting (NCC) /2/;
Neutron Multiplicity Counting (NMC) /3/.

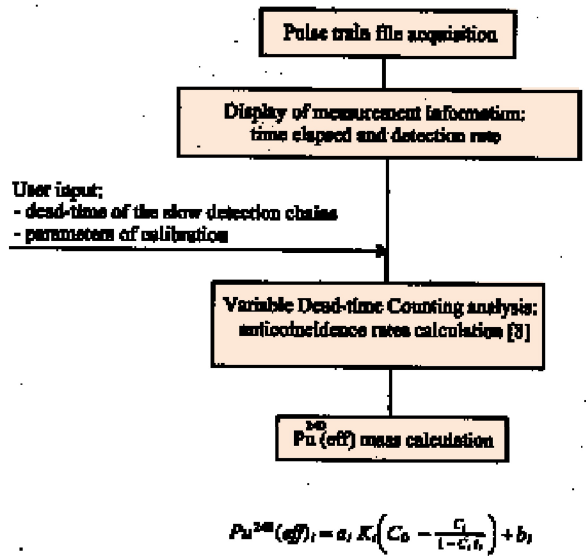
For each method, the output of the analysis is given in terms of the effective mass of plutonium-240.

Software implementation of these methods has been realized by defining algorithms reproducing the sequence of operations carried out electronically by the corresponding instrument, i.e. the Variable Dead-time Counter for VDC, the Shift Register for NCC and the Time Correlation Analyser for NMC. In other words, the operational logic scheme of each instrument has been translated into a software algorithm.

A synthetic description of the software is given in figures 3, 4 and 5.

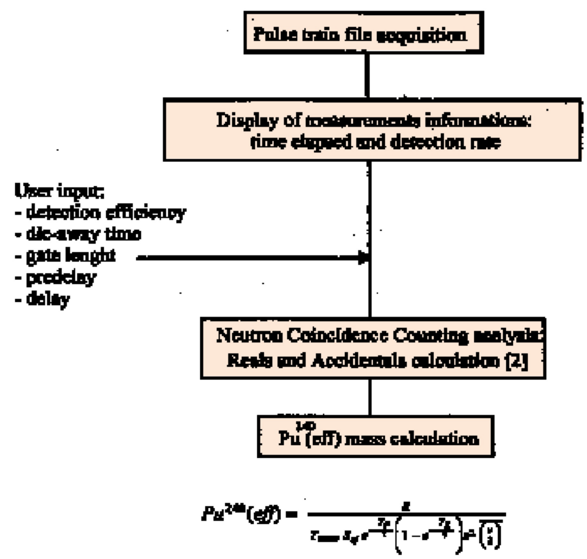
4. Measurement results

A series of experimental measurements of PuO_2 reference standards has been carried out at the PERLA facility at the Ispra site of the JRC. As may be seen in table 1, next page, the plutonium mass of the PuO_2 reference standards covered the range 8 g ÷ 2390 g. They all, except PERLA 104, derived from high burn-up plutonium, thus constituting well mixed sources of correlated and uncorrelated neutrons. In particular, the expected value of the ratio between neutron emission due to (α, n) reactions and due to spontaneous fissions was about 0.9 for all the standards; only PERLA 104, due to its lower burn-up, was characterised by a ratio of about 0.5.



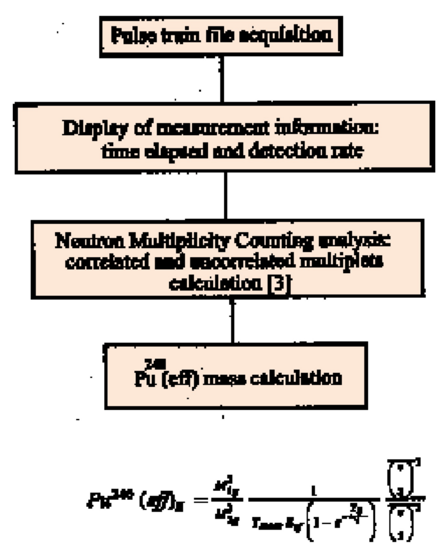
K_i calibration constants obtained with an (α, n) reaction source;
t_i dead time of the i^{th} slow chain;
C_i anticoincidence rate of the i^{th} slow chain;
a_i, b_i calibration constants obtained with two different Pu reference standards.

Figure 3: VDC method as implemented in NPTA code



R coincidence rate
T_{meas} measurement time;
ε detection efficiency;
S_{sf} Pu^{240} spontaneous fission yield ($s^{-1}g^{-1}$);
τ die-away time;
T_p predelay;
T_g gate lenght;
ν spontaneous fission neutron multiplicity.

Figure 4: NCC method as implemented in NPTA code



M_{1g} first-order moment for gate lenght g;
M_{2g} second-order moment for gate lenght g;
T_{meas} measurement time;
S_{sf} Pu^{240} spontaneous fission yield ($s^{-1}g^{-1}$);
τ die-away time;
T_g gate lenght;
ν spontaneous fission neutron multiplicity.

Figure 5: NMC method as implemented in NPTA code.

Table 1: PERLA reference standards

	Plutonium dioxide Reference standards							
	PERLA 7	**PERLA 103**	**PERLA 104**	**PERLA 105**	**PERLA 106**	**PERLA 110**	**PERLA 113**	**PERLA 120**
Pu mass (g)	7.805	48.324	97.242	101.501	97.882	487.249	972.639	2390.86
Isotopic mass fraction (%)								
Pu238	1.685	1.685	0.195	1.461	1.685	1.685	1.685	1.685
Pu239	59.614	59.614	72.808	62.579	59.614	59.614	59.614	59.614
Pu240	25.403	25.403	25.213	24.040	25.403	25.403	25.403	25.403
Pu241	7.505	7.505	2.526	7.102	7.505	7.505	7.505	7.505
Pu242	5.793	5.793	1.001	4.959	5.793	5.793	5.793	5.793
Am241	3.957	3.957	1.850	3.756	3.957	3.957	3.957	3.957
Pu240(eff) (g)	3.074	19.031	26.631	36.595	38.547	191.884	383.036	941.546
calculated neutron emission from spontaneous fissions (1/s)	3141	19448	27178	37394	39393	196094	391440	962205
calculated ratio between emissions from (alpha, n) reactions and spontaneous fissions	0.971	0.971	0.498	0.963	0.971	0.971	0.971	0.971

Values at measurement date. Certified data have been updated according to [7-Ch.21].
Isotopic mass fraction of Am^{241} is relative to total plutonium mass.
Pu^{240} (eff)=2.52 Pu^{238}+Pu^{240}+1.68 Pu^{242}
Calculations of neutron emission have been carried out according to [7- Tab. 11/1, 11/3].

Neutron pulses have been derived from a Jomar Canberra Model JCC-31 detection head (fig. 6), endowed with 18 ^{3}He tubes for a recommended overall detection efficiency of 18% and a die-away time of 50 ms. Pulse collection has been operated by a PIA board with 30 ns time resolution and 3 10^5 s^{-1} maximum pulse rate. Each neutron pulse train has been analysed by the NPTA code. To allow a comprehensive evaluation of data, each measurement has been replicated also with a conventional shift register (JSR 12).

For each reference standard a series of three measurements has been carried out. Every measurement consisted in the collection, by the PIA board, of the corresponding neutron pulse train. The time length of measurements has been optimized to have about 1 10^6 pulses for each pulse train. The PIA board was plugged in an IBM compatible 486 personal computer. Each pulse train has been recorded as one ASCII file on the hard disk of the same computer; later, these files have been analysed by the NPTA code, giving a measured value of ^{240}Pu(eff) mass for each one of the options implemented (NCC, VDC, NMC and IDA). The same measurements have been carried out also by means of a conventional shift register Jomar Canberra JSR12, which was the unique "hardware correlator" available in that moment. Data from the JRS 12 have been utilized as a benchmark for the computerised NCC method, results are shown in figure 7, next page.

Figure 8 next page reports the results from the analysis of the same neutron pulse trains of figure 10 with all the options of the menu "Time Correlation Methods" of the code NPTA.

5. Conclusions

A system based on the collection of the whole neutron pulse train and its subsequent software analysis may constitute a useful tool for R/D activities. For instance, the possibility to work directly on the neutron pulse train may constitute an easy platform to investigate validity of correction algorithms, such as those ones for neutron self-multiplication and dead-time.

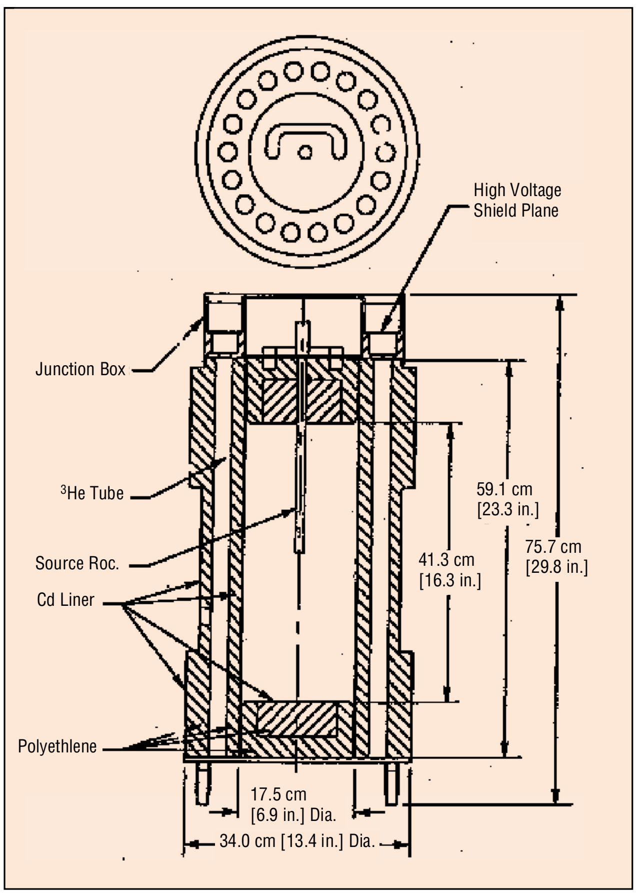


Figure 6: Model JCC-31 High Level Neutron Coincidence Counter (from Canberra Nuclear).

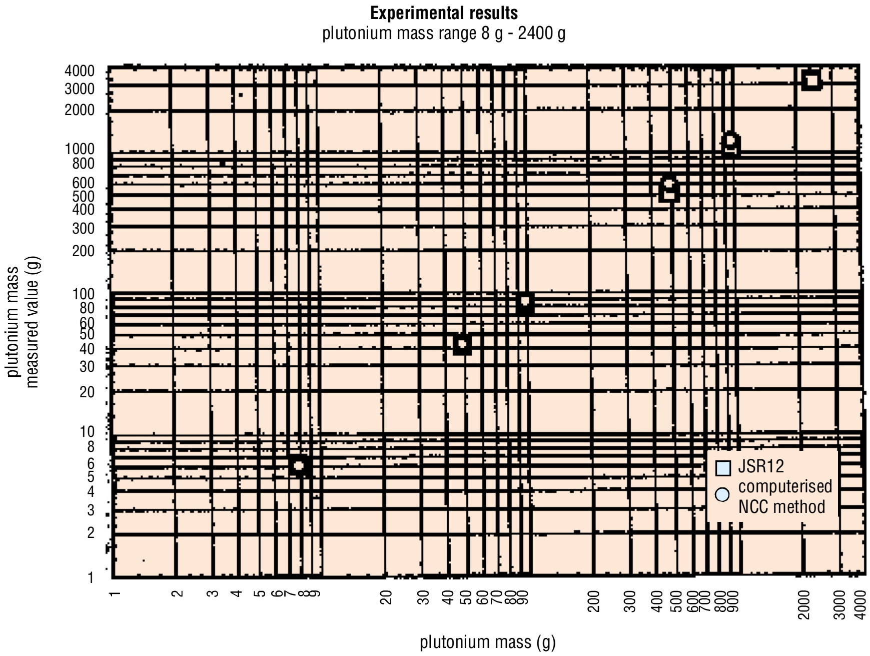


Figure 7: Neutron Coincidence Counting method: comparison between software analysis of the pulse trains and data from a “hardware correlator” JSR-12 (no correction for multiplication).
The count rate (> $3x10^5$ s^{-1}) from the 2390 g Pu standard is out of the maximum rate accepted by PIA

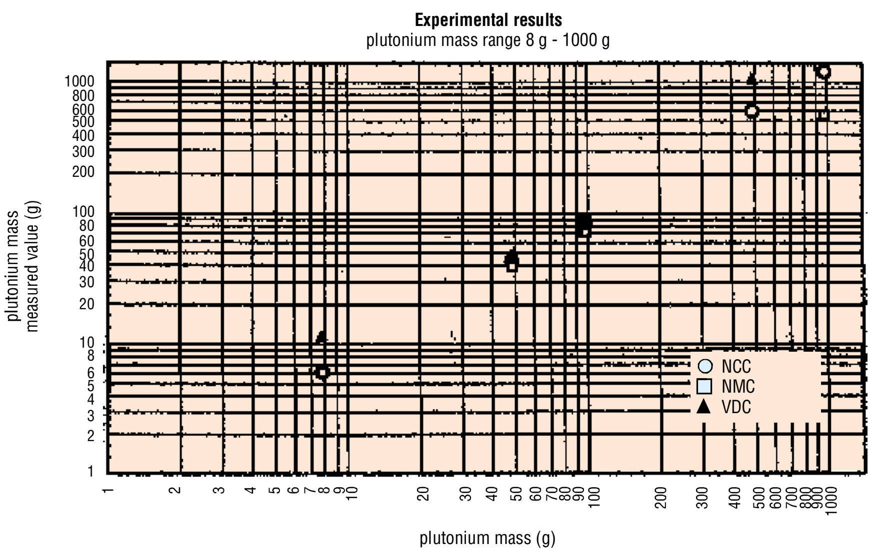


Figure 8: An example of analysis with NPTA code: comparison among different time correlation methods applied to the same neutron pulse trains (no correction for multiplication).
For the 487 g Pu standard NMC algorithm gave solutions without physical meaning.
For the 973 g Pu standard VDC algorithm gave a result greater than 2000 g

Bibliography

/1/ N. PACILIO, “Reactor Noise Analysis in the time domain” - U.S. Atomic Energy Commission/ Division of Technical Information.

/2/ N. ENSSLIN, M.L. EVANS, H.O. MENLOVE, J.E. SWANSEN, “Neutron Coincidence Counters for Plutonium Measurements” - Nuclear Materials Management, VII, 43 (1978).

/3/ R. DIERCKX, W. HAGE, “Neutron Signal Multiplet Analysis for the Mass Determination of Spontaneous Fission Isotopes” - Nuclear Science and Engineering, 85, 325-338 (1983).

/4/ A. DODARO, F. V. FRAZZOLI, R. REMETTI, P. ZEPPA, “Pulse Correlation Study: Development of a Special Dating System” - Proceedings of the 15th Annual ESARDA Meeting, “Augustinianum”, Roma, 1993.

/5/ V. VOCINO, L. BECKER, N. FARESE, L. LEZZOLI, B. PEDERSEN, P. SCHILLEBEECKX, U. WENG, “Passive and Active Neutron Interrogation Techniques at the Joint Research Centre Ispra” - Proceedings of the IAEA Symposium on International Safeguards, Vienna, 14-18 March 1994.

/6/ E.W. LEES, F.J.G. ROGERS, “Experimental and theoretical observations on the use of the EURATOM Variable Dead-time Counter for the passive assay of Plutonium” - Proceedings of the International Symposium on Nuclear Material Safeguards, Vienna, 2-6 October 1978.

/7/ “Passive Non Destructive Assay of Nuclear Materials” - NUREG / CR - 5550, LA-UR-90-732.

Statistical Analysis of Experimental Data from Different Analytical Techniques

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1. Abstract

The determination of the true chemical composition of a given material is a very difficult task. Usually, the most probable value obtained by means of an already established analytical technique is accepted as the true value. However, in many routine situations in laboratories, or during material certification procedures, it is necessary to compare results obtained by means of different analytical techniques, an operation that may lead to wrong conclusions. This work will exhibit the results of a material certification exercise performed at the Instituto de Pesquisas Energéticas e Nucleares (IPEN) in cooperation with the Instituto de Matemática e Estatística da Universidade de São Paulo (IME - USP). Samples of U_3O_8 (Uranium Oxide) were analysed by different analytical techniques. A statistical analysis using ANOVA, as well as some robust and weighted methods, will be discussed.

2. Introduction

A chemical analysis of a given material is one of the oldest activities in science, however, in spite of the development of sofisticated analytical techniques, the determination of the true value of a chemical component is still an open question.

In a routine laboratory operation, the analyst needs to control many factors related with instruments and procedures that can affect in a significant way the quality of the results obtained, since every analytical technique has limitations. Many statistical methodologies are developed in order to assure the quality of the results, to provide an evaluation of the behavior of an analytical procedure and to establish a comparison pattern with the results obtained in other laboratories. The majority of these methods operates relative to standards, and makes use of highly pure and certified chemical materials.

In the choice of a material to be certified, several factors must be considered, among which: the future applications of the material, the methodologies used to obtain it, and the statistical methods used to investigate the numerical values. Taking all this into account, the program's protocols are prepared, the number and the quality of the essays to characterize the chemical and physical properties of the chosen material are defined, as well as the procedures for the statistical analysis of the data.

The aim of this work is to discuss different statistical approaches to analyse data from material certification programs.

3. Previous research exercises

With the purpose of developing a suitable statistical model, 15 analysis were carried out at the IPEN (Instituto de Pesquisas Energéticas e Nucleares) by 15 different analysts, allowing in this way to simulate two intercomparison exercises between 15 different laboratories employing the same analytical technique. The material used was U_3O_8 (Uranium Oxide) of nuclear grade produced at the IPEN.

Two statistical methodologies were used to analyse the data. In the first exercise, classical statistical techniques like ANOVA (Analysis of Variance) /1/ were used preceded by outlier detection tests to ensure that the data set fulfills the necessary conditions, such as variance equality and data with Normal distribution.

Data elimination may introduce tendency in the results, because the discarded values can be due to material variability, and not from measurement errors. In this sense, robust methods were used (Dod Estimators-Distribution of differences) keeping all values in the variability estimation of a data set derived from a Normal distribution. These estimators can be very useful because, to the contrary of classical methods, they are rather unsensitive in presence of outliers. Details about these methods can be found in Beyrich et al. /2/.

The results of the first exercise, found in Cordani and Yamamoto /3/, demonstrated that within the uncertainty of the same analytical technique, graphical methods of data analysis (Dotplot, Boxplot and Youden), as well as classical techniques with result eliminations can be used with the same efficiency when compared with robust methods.

In the second exercise (Cordani and Fukunaga /4/), time was included as perturbation factor, and an increase in the variability of the results was observed. In this case, the use of classical methods of analysis may distort the final results, and therefore the use of robust methods was more adequate.

4. The balanced method

In order to further develop the same research line, we investigated the case of an intercomparison of data from different laboratories, when obtained by different analytical techniques.

With this purpose the Balanced Method was employed, a robust statistical technique described in Analytical Methods Committee /5/. This technique consists in proposing estimators for the mean and for the standard deviation that are not sensitive to the presence of outliers.

Assuming the participation of L laboratories, each one with r measurements, a particular measurement from a given laboratory may be defined as in equation (1):

$$x_{ki} = \mu + \alpha_k + \varepsilon_{ki}, \qquad (1)$$

where:

x_{ki} : i-th measurement of the k-th laboratory

α_k: k-th laboratory error.

ε_{ki}: associated error.

$VAR(\alpha_k)=\sigma_L^2 \quad k=1,\ldots,L$

$VAR(\varepsilon_{ki})=\sigma_e^2 \quad k=1,\ldots,r.$

In the same way, the mean from a given laboratory may be written as in equation (2):

$$\mu_k = \mu + \alpha_k \qquad (2)$$

At first, the internal variability σ_e^2 of each laboratory shall be estimated, as well as its respective mean value μ_k. Secondly, the estimation of σ_L^2 shall be determined, representing the inter-laboratory variability.

Because all laboratories are equally treated by the method, the description below corresponds to an iterative calculation procedure applied to each laboratory.

It is here proposed that the estimation shall be done through a weighted mean of the observations x_{ki} of each laboratory, where to each measurement will be given a weight w_{ki}, obtained according equation (3):

$$w_{ki} = \begin{cases} 1 & \text{if } \left|x_{ki} - \mu_k\right| \le c\sigma_e \\ \dfrac{c\sigma_e}{\left|x_{ki} - \mu_k\right|} & \text{otherwise} \end{cases} \qquad (3)$$

where σ_e is a robust standard deviation and c is a suitable constant previously determined by the user, with values between 1 and 2. In this work the more recommended value c = 1.5 will be used. Hence, according to equation (3), if a particular observation is dislocated from its laboratory mean more than $c\sigma_e$, its value will be "diminished" receiving a weight smaller than 1, that decreased with the increase of the distance between this observation and the mean intralaboratory value.

The estimation of σ_e shall be made simultaneously with the estimation of μ_k at each step of this iterative process. Thus, a weighted observation may be defined by equation (4):

$$x_{ki}' = w_{ki} \cdot x_{ki} \qquad (4)$$

The procedure to estimate σ_e is similar to the one previously described, where in each step:

$$\sigma_e = \sqrt{\frac{\Sigma\left(x_{ki'} - \mu_k\right)^2}{n\beta}} \qquad (5)$$

where n is the number of measurements of each laboratory and ß is a constant chosen in order to obtain a consistent answer with normally distributed data. The values of ß are tabled in Analytical Methods Committee /5/.

The initial value for μ_k can be taken as the mean or median of the original data set, whereas the suggestion given in Analytical Methods Committee /5/ to the initial value of σ_e is:

$$\text{median } \frac{\left(\left|x_{ki} - \mu_k\right|\right)}{0.6745} \qquad (6)$$

The end of the process only occurs when the difference between two iterations would be smaller than a fixed value. In this exercise, 10^{-2} will be used as a stopping condition.

Next step corresponds to analyse the estimated means according to what was described to estimate the certified value μ and the material's variability σ_1^2 where:

$$\sigma_1^2 = \sigma_L^2 + \frac{\sigma_e^2}{r} \qquad (7)$$

Once σ_e^2 is already estimated, only σ_L^2 remains to be estimated, according to equation (7). This estimation is done in analogy to the process described earlier, considering the L means estimated from all laboratories like observations from the same laboratory.

To compare this method with the others used in the previous exercises, purity percentages of U_3O_8 were measured in 6 IPEN's laboratories employing the following analytical techniques: Voltametry, Isotope Dilution Mass Spectrometry, Davies & Gray, High Performance Liquid Chromatography and Inductively Coupled Plasma Atomic Emission Spectrometry. In each laboratory 8 measurements were carried out, resulting in 48 observations presented in Table 1.

The values higher than 100% are a consequence of contamination in the measurements. Therefore, despite such results are not theorically expected, in practice they can occur. The data were analysed by ANOVA, Dod and by the balanced method.

5. Results

5.1. Analysis by ANOVA

At first a graphical analysis is presented of the data, through a Dotplot, by laboratory (Figure 1).

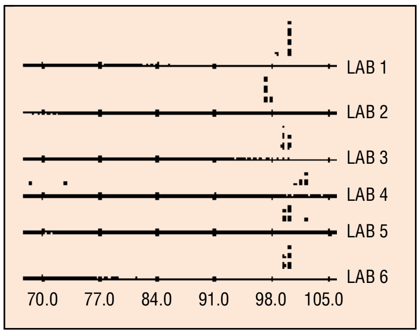

Figure 1: Dotplot of purity percentages of U_3O_8

It can be noted that, generally, data's dispersion is low. However, Laboratory 4 exhibits two observations located very distant from the others that may be considered outliers:

In Table 2, sample means and standard deviations by laboratory are presented.

From Table 2, the variability of Laboratory 4 resulted very large, because of the presence of extreme values affecting mean and standard deviation.

Table 2: Sample means and standard deviations

Laboratory	Mean	Std. Deviation
1	99.70%	0.45%
2	97.58%	0.15%
3	99.66%	0.10%
4	93.88%	**14.28%**
5	100.19%	0.92%
6	99.74%	0.18%

Dixon's outliers detection test /6/ and Cochran's variance equality test /7/ were used in this classical approach with significance level of 5%. After the application of these tests, the two aberrant observations from Laboratory 4, as well as another one from Laboratory 1 and another from Laboratory 5 were eliminated. The two last ones present a relatively small displacement in the graph; moreover, if they originated for instance in Laboratory 4, they probably would not have been eliminated. The discarded observations are very visible in Table 1. All laboratories were kept by Cochran's test.

The new values for mean and standard deviation, after discarding the mentioned outliers, are presented in Table 3.

Table 3: Means and standard deviations after the elimination of the outliers

Laboratory	Mean	Std. Deviation
1	99.85%	0.10%
2	97.58%	0.15%
3	99.66%	0.10%
4	101.57%	**0.56%**
5	99.89%	0.38%
6	99.74%	0.18%

A quick comparison of Tables 2 and 3 demonstrates the improvement, especially in the variability of Laboratory 4, resulting from the elimination of the extreme values.

Table 1: Purity percentages of U_3O_8

Lab 1	Lab 2	Lab 3	Lab 4	Lab 5	Lab 6
98.60%	97.52%	99.65%	**68.65%**	100.20%	99.87%
99.80%	97.73%	99.76%	**73.02%**	99.60%	99.49%
99.80%	97.83%	99.65%	101.88%	100.20%	99.84%
100.00%	97.36%	99.76%	101.66%	99.50%	99.89%
99.80%	97.62%	99.53%	100.50%	100.40%	99.62%
99.80%	97.46%	99.76%	101.46%	99.50%	99.79%
99.80%	97.62%	99.53%	101.97%	**102.30%**	99.94%
100.00%	97.46%	99.65%	101.93%	99.80%	99.49%

Finally, after the application of ANOVA for the 44 remaining values, the following estimatives were obtained:

- Average purity percentage: 99.63%
- StandardDeviation: 0.51%

5.2. Analysis by Dod

Using the original data set, the Dod robust technique was applied. This method do not eliminate observations and estimates only the variability of the measurements.

With the help of a computational program developed in Pascal language, the following variability estimative was obtained through the DodM estimator:

- Standard Deviation: 0.23%

5.3. Analysis by balanced method

In order to apply this technique, a computational program developed in Fortran language will be used (Analytical Methods Committee /5/). Table 4 presents means and standard deviations of the 6 laboratories obtained by the iterative process of balanced method. The estimatives of the mean and standard deviation for the whole data set are also presented.

- Average purity percentage: 99.69%
- Standard deviation: 0.18%

The results of Table 4 are very similar to the ones presented in Table 3, indicating that even such methods that do not eliminate observations can be good alternatives of analysis.

Table 4: Means and standard deviations of the final iteration of the balanced method

Laboratory	Mean	Std. Deviation
1	99.77%	026%
2	97.58%	0.15%
3	99.61%	0.10%
4	101.41%	0.53%
5	99.97%	0.43%
6	99.74%	0.18%

6. Discussion

For the purity average value, results of ANOVA and balanced method were very close, suggesting that robust methods allow similar conclusions to the classical, without eliminating data.

Purity's variability presented larger differences, specially when robust methods are used. It is important to remark that even when all observations are kept, the variability estimated by these methods was smaller than that one obtained by ANOVA. The reason is that robust estimators reduce the influence of data very far from the mean, introducing a significant effect in the standard deviation's estimative.

Another important point is that the balanced method assigned, in its final iteration, weights lower than 1 to 5 observations. Four among them are the same excluded by the outliers detection test, indicating that there is some coherence in this approach to detect suspicious observations.

It must be also noted that the variability estimated by ANOVA is acceptable, in view of the errors of the laboratorial techniques utilized. Moreover, the results of robust methods' variability were much smaller than the classical, due to the fact that the values measured by all laboratories, excepting some outliers, are very similar.

7. Conclusions

From all exercises carried out in the past 3 years, it can be concluded that methods that do not eliminate data are good alternative of analysis and that outliers must be considered as real circunstancial values, included within the material and technical variabilities.

It was also noticed that the balanced method reduces the influence of outliers in variability's estimation and that elimination of data may introduce tendency in the results. Moreover, discarding observations is nothing more than loosing information, diminishing the strength of the conclusions.

It became clear that the notion of outlier depends on a context, because a value can be considered outlier in a laboratory, but it may not be in another.

Therefore, alternative methods to the classical ones shall be more and more employed, in the future, with the aim of determining their advantages and limitations. We consider that what has been done so far is only a beginning for the exploration of alternative statistical methods. Moreover, a better quality control of the analytical performance of laboratories is needed, in order to improve every step of the materials certification processes.

8. References

/1/ NETER, J., WASSERMAN, W., KUTNER, M.H. (1990). Applied linear statistical models: regression, analysis of variance and experimental design. 3 ed. Homewood: Richard D. Irwin. 1181p.

/2/ BEYRICH, W., GOLLY, W. (1989). Evaluation of IDA-80 data by the Dod method. Relatório técnico KfK 4157, EUR 10533EN-PWA 64/89, Karlsruhe, Germany. 20p.

/3/ CORDANI, L.K., YAMAMOTO, W.H. (1992). Programa de certificação de materiais estratégicos. São Paulo, IME-USP, 42p. RAE-CEA-9215.

/4/ CORDANI, L. K., FUKUNAGA, E.T. (1993). Análise estatística de dados provenientes de programa de certificaçào química de compostos de uranio. São Paulo, IME-USP, 42p. RAE-CEA-9316.

/5/ Analytical Methods Committee (1989). Robust statistics - How not to reject outliers. Part 1 - Basic concepts. Part 2 - Intercomparative trials. Analyst, 114, 1693-1702.

/6/ DIXON, W.J. (1953). Processing data for outliers. Biometrics, 9, 74-89.

/7/ WINER, B.J. (1971). Statistical principles in experimental design. 2ed. New York: McGraw-Hill. 907p.

Activity Report of the Esarda Working Group on Techniques and Standards for Non-Destructive Analysis

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1. Introduction

The main tasks of the ESARDA Working Group on TECHNIQUES AND STANDARDS FOR NON-DESTRUCTIVE ANALYSIS, as described by its terms of reference, are the following:

- Facilitate circulation of information and technology transfer.
- Define needs for procedural standards and reference materials.
- Design and sometimes produce reference materials
- Assess and contribute to improving the performances of NDA techniques
- Assist operators and Safeguards Authorities in their duty of Safeguards implementation
- Set up and maintain a list of NDA instruments and methods currently used for Safeguards purposes

The group is presently composed of members from EU member countries and observers from Japan (PNC), USA (LLNL, LANL, BNL), Hungary (Technical University Budapest) and IAEA Vienna. Very recently the application of the Brazilian Nuclear Energy board has been accepted.

Members are appointed by UK (AEA, BNFL, 2 members), France (CEA: 4 members), Germany (WAK), The Netherlands (ECN), Belgium (SCK/CEN), Spain (ENUSA), Italy (ANPA) and Finland (STUK). The European Commission provides 4 members: one from the Euratom Safeguards Directorate (ESD) and three from each JRC laboratory, at IRMM-Geel, TUI-Karlsruhe and ISIS-Ispra.

Members and observers represent plant operators, the nuclear industry, R&D laboratories, NDA instrument developers and both safeguards control authorities.

The participation of major European plant operators and of the EURATOM Safeguards Directorate and IAEA has always been assured and contributes to the good outcome of the WG activities. Meetings take place twice per year. Special topical meetings are held frequently on items of specific interest, like NDA on nuclear waste materials or passive neutron assay.

2. Activities of the NDA Working Group

Following the main tasks of the Group, as described in the previous section, a number of activities were and are being carried out and concluded by the group. They are described here.

But before describing the areas mentioned, it is worth mentioning that the working method of the group, is essentially based on the analysis of the “client” requests or of its identified needs. As examples the analysis of the sampling variability of batches (Sampling error in NDA), has been strongly supported by operators and then conducted by different laboratories and two important LEU plant operators: BNFL-Sellafield and FBFC-Dessel. Safeguards Authorities were of course interested, as reflected by the Euratom list of Safeguards needs, therefore the project was started, with the full collaboration of operators and inspectorates, as well as of R&D laboratories. There are other examples indicating that the working group tackles R&D needs which are of primary interest for safeguards and NM accountancy, sometimes even before formal needs appear, because the “need” was in any case raised beforehand in the group discussions. Some examples are:

- Monte Carlo performance intercomparisons
- ^{242}Pu uncertainty
- NDA Sampling errors
- General NDA performance evaluations

2.1 Standards and reference materials

This is the area that the NDA working group has always considered of primary importance, since some of the characteristics that reference materials (RMs) must have are such that they can frequently be satisfied only in a forum like ESARDA. RMs in fact must:

- be representative of production batches of the fuel cycle
- be characterised following internationally agreed procedures and certified by internationally accredited authorities.

The best forum to achieve the above requirements is ESARDA, which includes representatives of R&D laboratories from all over the world, control Authorities and central reference laboratories (like JRC-IRMM) are sitting. Moreover a permanent concern of the group is to identify the requirements for and the needs of reference materials, both for R&D applications and for field monitoring and process control.

One of the first and best examples of reference material projects identified, designed and managed by the ESARDA WG was the U308 CBNM/NBS/ESARDA reference material EC-NRM-171/NBS SRM-969 /1/ proposed and specified by the NDA WG, then jointly produced and characterized by US-NBS and JRC-CBNM (now IRMM). KFK-Karlsruhe and JRC-Ispra contributed at various stages of the project with essential activities.

A new project which has been specified in the last 12-18 months and has just been launched, having finally received funding by the European Commission, concerns the realisation of standard drums for calibrating waste assay.

Nuclear waste assay is becoming one of the most important issues in the fields of safeguards and waste management and disposal. Nuclear waste management is constantly in the public eye. From a technical point of view it is one of the most challenging issues for R&D laboratories. Waste drums can only be assayed by NDA techniques prior to being disposed of, or accounted for by Safeguards Authorities. Measurement problems are linked with the low Special Nuclear Materials (SNMs) content to be assayed and to the absence of well characterised, highly certified reference materials, representative of the waste population currently produced in the EU. Some working standards are presently used in different facilities, but they do not have the level of primary certification, and therefore of international acceptance, that national and European authorities require for waste management and safeguards purposes.

Therefore, stimulated by the request of important EU plant operators and by control authorities, the NDA working group decided to design a project for constructing Pu-bearing reference waste drums, which will be used for calibrating, assessing and improving NDA techniques currently used to assay the Pu content of waste drums.

The objective of the project is to design, produce and certify waste drum standards, with variable Pu mass contents, constructed in such a way that different mass and geometric configurations of the Pu sources can be prepared. The problem has been solved by deciding to procure and certify about 100 sealed Pu sources, with Pu content from 5mg to 10g, welded in 35 pins that can be rearranged in different positions inside the drum (see figure 1).

Pu sources will be characterised by JRC-IRMM and welded into pins by CEA-Cadarache. The drums and drum matrices will be provided and characterized by BNFL-Sellafield.

The drums will then be used for a blind round robin to assess performances of waste assay, but the drums will then be kept as international reference materials for any further purpose.

In table 1 the main drum and source parameters.

2.2 Performance Evaluation

The NDA working group has for some years been engaged in setting up, maintaining and updating an extensive list of performances regarding NDA techniques applied to the most common material types of the fuel cycle, including waste materials, that are becoming more and more important for safeguards as well. The outcome of this work has been a set of documents and papers on behalf of the working group presented on various occasions to meetings and Symposia /2/ and the contribution given to the International Target Values list /3/.

The activity of the working group in the area of performance evaluation has however always had a more direct component as well: international intercomparisons and round robin exercises have been regularly conducted to obtain clear knowledge of the performances of the methods and techniques.

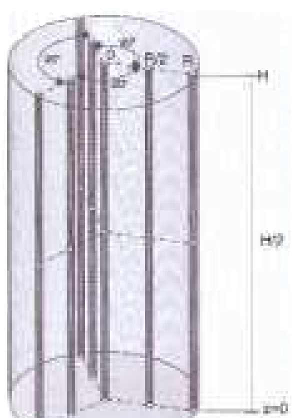

Figure 1: ESARDA Standard drum, with the source channels

a. - Uranium Enrichment Measurement Exercise

The latest example of an international round robin under way is the intercomparison of gamma spectrometry techniques for the determination of U^{235} abundance in low and highly enriched uranium samples. The exercise decided and specified by the working group,is managed by CEA-Saclay and JRC-IRMM and conducted at the IRMM establishment of Geel (B). Different NDA gamma spectrometric methods are applied to different Uranium samples.

The participants applied one or more of the currently used gamma spectrometry methods, employing the traditional infinite thickness approach, or the more recent approaches that do not require external calibrations.

- The samples employed were:
- 6 LEU pellet samples
- 3 LEU powder samples and
- 6 LEU, freshly converted, powder samples
- 1 HEU metal plate Al canned

- The participants were:
- CEA, Grenoble (France)
- Canberra (Belgium)
- LLNL (USA)
- LANL (USA)
- SCK/CEN, Mol (Belgium)
- CEA, Fontenay-aux-Roses (France)
- ABACC
- CNEN (Brazil)
- Academy of Science, Budapest (Hungary)
- CEA, Saclay (France)
- UKAEA, Harwell (United Kingdom)
- JRC, TUI, Karlsruhe (Germany)
- GreenStar, Moscow, (Russian Federation)
- STUK, Helsinki (Finland)
- JRC, IRMM, (Belgium)

Preliminary results of the exercise have been presented at the 1997 ESARDA Symposium, at Montpellier.

Pu sources	accuracy	pins	drums	matrix
#105	.5% on Pu cont .1% on Pu^{239} .2% on Am^{241}	#35	8x100 1 8x200 1	.15 g/cm^3 .15 g/cm^3 +pvc .4 g/cm^3

Table 1: Details of the ESARDA Standards Drums

b. - ^{242}Pu uncertainty

It is well known /4/ that the impossibility of determining the ^{242}Pu abundance by HRGS (High Resolution Gamma Spectrometry) gives rise to significant uncertainty in the knowledge of its isotopic abundance, with a relevant impact on the uncertainty of the ^{240}Pu-equivalent

$$^{240}Pu_{eq.} = 2.431\ ^{238}Pu + {}^{240}Pu + 1.667\ ^{242}Pu$$

and therefore on the uncertainty of Pu mass assay by neutron coincidence counting.

The situation with ^{242}Pu evaluated by traditional isotopic correlations, is represented in Figure 2, page 24: the contribution from ^{242}Pu uncertainty to the overall $^{240}Pu_{equ}$ uncertainty may be significant: with high burnup Pu, an uncertainty on ^{242}Pu of the order of 10% (not unusual: even higher errors are frequently quoted!), can be higher that the neutron assay uncertainty, so frustrating efforts to reduce neutron assay uncertainty.

Aware of this problem, the working group decided to launch an international collaboration programme aimed at developing a new approach, or more reliable isotopic correlations, so as to reduce the ^{242}Pu contribution to Pu assay by NDA. Again the experience of different laboratories and institutions was decisive for the good outcome of the project, since the analysis had to cover different Pu batches, from different reactors, fuel cycles, burn-ups etc.

Several laboratories participated (from EU and US) with the result that a new isotopic correlation has been proposed, which can be used for different Pu types (BWR and PWR) and different burnups. The evaluated uncertainty is 3-6%.

A paper showing the results of the research is reported in this Bulletin /5/, presented by CEA, JRC-TUI, BNFL and LLNL.

c. - Monte Carlo intercomparisons

One of the activities that has been frequently claimed to be promising in the past, but which has not received sufficient attention, is the use of theoretical codes, like Monte Carlo, to evaluate results and reduce the number of required reference material standards. Now, under the stimulation of the EURATOM Safeguards Directorate, which has listed this issue in their needs list, the NDA working group has decided to initiate an action to evaluate the potential of theoretical methodologies and in particular of Monte Carlo packages (e.g. MCNP).

The first action decided was an assessment of the actual capabilities of theoretical methods in evaluating results from NCC (neutron coincidence counting) methods.

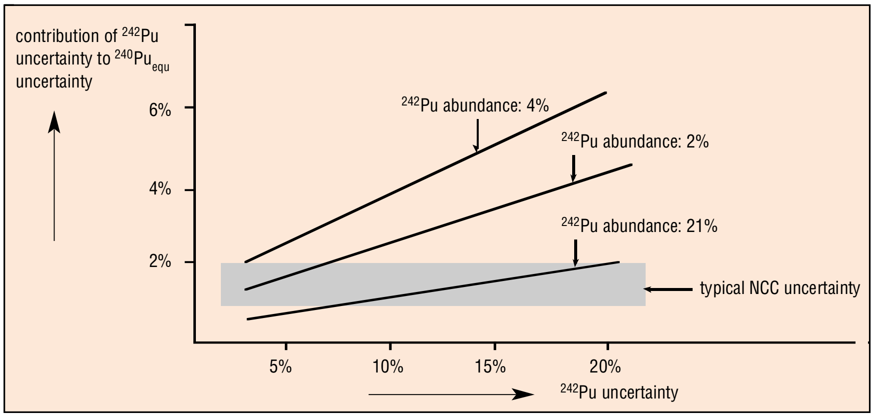

Figure 2: ^{242}Pu Uncertainty Behaviour

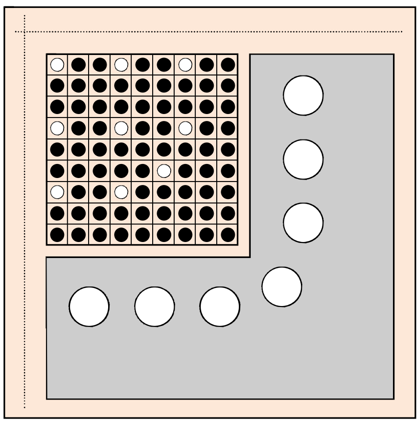

Figure 3: Geometry of NCC with the fuel bundle for "real" evaluations

For that purpose the LEU reference PERLA fuel bundle /6/ was chosen: participant laboratories were provided a MCNP input file and will evaluate the "reals" rate, as recorded by a standard shift register (fig. 3). The shift register record will be determined in reference conditions by PERLA laboratory. Preliminary results have been produced and reported to the Montpellier Symposium.

Participants come from CEA (F), AEA Harwell (UK), SCK/CEN (B), ANPA/ Università La Sapienza Rome (I), EC EURATOM Safeguards Directorate and JRC. Participation of US laboratories is sought as well.

The second part of the exercise will require participants to use Monte Carlo packages to evaluate counting rates produced by total and coincidence neutron counting from a simple geometry, consisting of an He^3 detector tube, exposed to a neutron flux from a AmLi source, after crossing a polyethylene slab. Participants will be required to model the experimental configuration with their code(s), e.g. MCNP, and to evaluate total and coincidence counting rates.

The final purpose of the exercise is to enable laboratories to set up a computational system capable of field prediction of instrument answers, as well as to limit the number of calibration curves required, therefore also limiting the number of required reference material standards.

d. - Sampling in NDA

Assay by NDA is frequently assumed to be free from sampling errors, contrary to DA assay where the representativeness of the sample is frequently a significant component of the total uncertainty. Nevertheless when NDA is applied to batches composed of many items and the batch value is derived from a few (a sample of) items, the representativeness of the sampled items is a significant aspect in NDA assay as well.

Work has been started by the NDA working group, also involving DA and LEU ESARDA working groups, to study the influence of 'sampling' on NDA performances. The study has been supported by experimental results derived by comparing destructive and non-destructive determinations on LEU powders in two important LEU fabrication facilities: FBFC-Dessel (B) and BNFL-Springfields (UK).

Results have been presented at Montpellier /7/.

3. Future

The NDA WG intends to continue the 'statutory' activities that have been outlined in the previous sections, in the framework of circulation of information, technology transfer and Performance Evaluation.

Here are some specific areas which will be followed with particular attention.

List of NDA instruments

As outlined in the introduction, one of the main items of the group's terms of reference is keeping a list of NDA instruments.

The group has recently started to discuss and specify this project, deciding to set up not just a list of items, but to "frame" the instruments into facility safeguards schemes. The decision was made to start with a prototype data base which will consider the back/back end of the fuel cycle, the final disposal of spent fuel. The project is in the starting phase and it is being performed by STUK (F). After the first prototype, other facilities will be considered, like fabrication, reprocessing etc. Scheduling the project is not easy at present (the outcome of the first phase is important to decide the overall size of the project); the prototype will work by June '98, with steps of 12 months. Other facilities will follow.

Unattended/integrated systems

The evolution of the fuel cycle towards large automated facilities and a more cost/effective use of human resources, requires new technical approaches, such as the development of newly designed instruments, more automated and remote controlled.

This topic has recently received quite considerable attention in the safeguards field. It is in fact one of the most important directions for future technical developments of field systems. The NDA WG has therefore proposed, among other actions, common meetings with the C/S and plant oriented working groups to develop technical and managerial guidelines for the future. The discussion and exchange of information will continue, as well as the contacts with other groups, in particular with the LEU group, to fully exploit new instrumental achievements in the field of integrated/automated systems /8/.

Performance Evaluation

Some milestones have recently been or will soon be reached in the area of NDA performance evaluation:

- The ^{242}Pu uncertainty improvement project is coming to an end with the issuing of a new correlation. Some follow-up activities are planned, but the research phase is terminated.
- The NCC "reals" evaluation and the Monte Carlo "simple case" round robin are continuing and will be terminated by spring 1998 (see planning in Figure 4, next page)
- The Uranium Enrichment Measurement Exercise will see preliminary results in May at Montpellier; final evaluation by end 1997
- The waste drum standards are being characterised and constructed: they will be available by spring 1998. The round robin amongst laboratories will then start: summer 1998.
- As a consequence of some of the above actions and of R&D programmes in laboratories around the world, the NDA technique performances are being improved: this suggests that the "compilation" of performance values

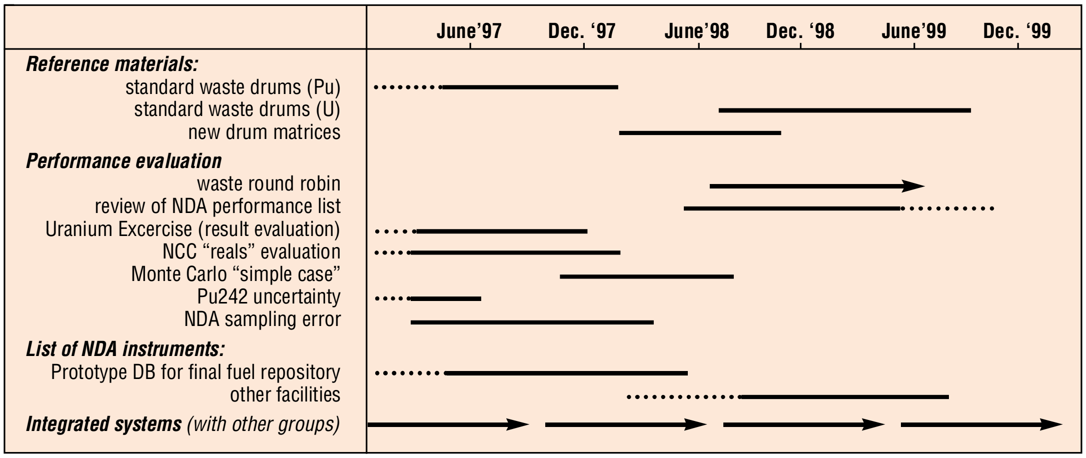

Figure 4: Planning of Activities of the ESARDA NDA WG

issued by the working group in 1993 /2/ should be reviewed. The NDA sampling error project result so far collected and new results which will be produced, will also serve as an input to the reviewing of performances. The review will start in May 1998.

Technical aspects deriving from new safeguards regimes

The evolution of the fuel cycles and the new world political framework impose new technical challenges to international safeguards and non-proliferation. We have already mentioned some technical challenges represented by the fuel cycle demands in new areas like integrated/unattended systems and remote monitoring, or final spent fuel repository. But international safeguards is also undergoing substantial changes as a consequence of recent events (e.g. Iraqi issue) and even more challenging problems will be represented by nuclear weapon arsenal dismantling, strengthening controls against nuclear material smuggling as well as by the controls required by a possible cut off convention. All these facts are having and will have an extraordinary high impact on the technologies to be developed for use in the controls required by the new regimes. Again one example already showing that laboratories must now start to develop new technologies, is environmental monitoring, which is giving promising results for "new" regimes (93+2, II part) as well as for the traditional regime.

Following these needs the group will start to discuss the technical impacts that the above issues will have on the development and application of NDA techniques under the new requirements. Preliminary discussions are planned for the two meetings of 1997.

4. Concluding Remarks

The activities illustrated above and the achievements shown, demonstrate once again the importance of a tool like ESARDA working groups. It is generally recognised that this kind of international "forum" is important in enhancing information exchange, which is of course true; but the direct R&D role these groups have, is not shown sufficiently.

Areas like performance assessment, essential for safeguards implementation, or like development of internationally guaranteed reference materials can only be covered in an international R&D framework.

But also topics like ^{242}Pu abundance determination, that could certainly be afforded by a single, well experienced laboratory, find a better solution in an international collaboration framework, where experiences and data can be shared, wrong or inappropriate R&D directions can be avoided, and appropriate technical and scientific competences can be found and shared.

In a world which is looking more and more to an effective and efficient use of R&D resources, R&D management groups like ESARDA wgs represent a powerful tool for good resource management, in order to avoiding duplications and dead-end research lines and finally achieving a cost/effective utilisation of resources.

One last remark on the role of the client. As mentioned above, one of the important features of the ESARDA wgs is the fact that the "client", whether plant operator or safeguards directorate or R&D laboratory, has a voice in the planning of the group Agenda. The client must not lose the opportunity to present its needs, to guide the group towards the fulfilling of its requests: mostly its demands will be fulfilled by the group itself or by one of the member laboratories, or a consortium of laboratories. The recent example of the safeguards R&D needs proposed by ESD is eloquent: some of the needs of the Euratom list have been fulfilled even before the appearance of the list, because they were proposed to the group by the ESD members. Others are being tackled now. The same is true for requests from IAEA, plant operators and R&D laboratories. Esarda wgs are powerful tools, if properly used.

6. References

/1/ P. DE BIEVRE et al., "235-Uranium Isotope Abundance Certified Reference Material for Gamma Spectrometry", EC - Nuclear Reference Materials 171 Certification Report, 1985, COM4153

/2/ G. BIGNAN, R.S.J. HARRY, S. GUARDINI, E. LEITNER, H. OTTMAR, "Performance Values of Non-Destructive Assay Techniques Applied to Safeguards: the 1993 Evaluation by the ESARDA NDA Working Group", Proceedings of the 15th ESARDA Annual Symposium, Rome (Italy) 11-13 May 1993

/3/ S. DERON et al., "1993 International Target Values for Uncertainty Components in Fissile Isotopes and Element Accountancy for the Effective Safeguarding of Nuclear Materials", IAEA-STR 294, October 1993.

/4/ S. GUARDINI et al., "Performance Evaluation of Non-Destructive Assay Techniques and Characterization of Standards for NDA in Safeguards", ESARDA Bulletin No. 17, Dec. 1989

/5/ G. BIGNAN, W. RUHTER, H. OTTMAR, C. ZIMMERMAN, "Plutonium Isotopic Determination by Gamma Spectrometry: Recommendations for the ^{242}Pu Content Evaluation Using a New Algorithm", this Bulletin

/6/ H. AIGNER et al., "Procurement and Characterization of LEU Special Nuclear Material Standards for PERLA", 36th Annual INMM Meeting, Palm Desert (Ca, USA), 9-12 July 1995

/7/ P. BOERMANS et al., "An Investigation of Sampling Error at LEU facilities"; 19th ESARDA Annual Symposium, Montpellier (France), 13-15 May, 1997

/8/ M. FRANKLIN, M. SWINHOE et al., "Testing of unattended Measurement Station for Fresh Fuel Assemblies", 19th ESARDA Annual Symposium, Montpellier, (France), 13-15 May, 1997

ESARDA Working Group on Containment & Surveillance

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The previous convenor's report was published in October 1994 /1/. Until the end of 1996 the Working Group held five more meetings. Its main activities were related to presentations and discussions on

- unattended integrated safeguards systems
- the use of optical surveillance for design information verification
- software tools for the evaluation of commercial satellite images, and
- remote data transmission.

The Working Group also issued its terms of reference harmonized with those of the other ESARDA Working Groups. Another activity was related to a compendium of C/S products which was first distributed in early 1995 and, upon request of the ESARDA Coordinators and Scientific Board, will be updated on a regular basis. In order to obtain information on issues of practical safeguards implementation in large complex facilities, the Working Group visited the plants at Cap de la Hague in France and Sellafield in the United Kingdom.

In a joint meeting with the ESARDA Working Groups on Techniques and Standards for Non-destructive Assay (NDA), Low Enriched Uranium Conversion and Fuel Fabrication Plants (LEU), and Mixed Oxide Fuel Fabrication Plants (MOX) the topic of unattended integrated safeguards systems was dealt with. The convenors of the four Working Groups published the results of that meeting in March 1996 /2/.

A method of using optical surveillance for design information verification was presented by a Working Group member from the JRC Ispra. It was on purpose that the Working Group addressed the topic in connection with its visit to the Sellafield plant, as the method was attributed a potential for safeguards application in complex plants; and Sellafield is one of the largest complex commercial nuclear plants in the European Union. At the initial verification stage images are taken and archived. Upon subsequent inspections theses images would be used to check for plant modifications. Suitable references are also required to ensure that the camera can be positioned in the same place and at similar angles to allow comparison of pictures taken at different times. Data about camera orientation and settings are to be held with the images.

In discussing the method the Working Group identified some crucial but not insurmountable issues that would have to be solved with regard to a practical implementation. Among those were impacts due to changing old plant components for new ones where components were similar but their surface finish and hence reflectance was different. Changes in lighting levels might also affect the interpretation of the images. Moving images in the background would cause some problems but could be blacked out. The Working Group agreed that the method had the potential of becoming a useful tool recognizing, however, that the development work was still in its relatively early stage and use in positions which are difficult to access had not yet been considered.

To the end of familiarizing itself with the issue of satellite-based imaging the Working Group invited a developer from the Juelich Research Centre to give a presentation on software tools for the evaluation of commercial satellite images. The topic has to be seen in connection with the IAEA Programme 93+2, the implementation of which will require the International Atomic Energy Agency (IAEA) to detect undeclared nuclear activities in states. The presentation focused on the evaluation of multi-spectral images which, in spite of their comparably poor spatial resolution (>20 m per pixel), offer a sufficiently large potential for the detection of changes, discrimination, and semi-automatic land-use determination. The acquired data reduction method was the principal component analysis. The visualization of the image contents was achieved by false color composites, edge enhancement, and unsupervised classification. In addition, pattern recognition was applied. Classical statistical methods and feed-forward neural networks were used for supervised land-use classification. The ultimate goal of evaluating satellite images is to detect and monitor facilities and associated activities as well as changes in the natural environment caused by these nuclear activities.

In the discussion it was stated that satellite images only would normally be incapable of proving undeclared nuclear activities. However, they had the potential to detect anomalies and thus to trigger e.g. special inspections. In addition, it was considered that when examining very large areas, some selection was needed to reduce the options being examined. A feasible practical application in the European Union was seen in the future surveillance of closed geological repository sites for spent nuclear fuel.

The Working Group concentrated its most recent attention on the issue of remote data transmission which has gained great importance in the light of the IAEA Programme 93+2. The safeguards authorities anticipate that the implementation of remote data transmission will significantly contribute to the increase of safeguards efficiency and enhancing of safeguards effectiveness. Four invited presentations given by representatives from the Euratom Safeguards Directorate, the Swedish Nuclear Power Inspectorate (SKI), the IAEA, and the Juelich Research Centre stimulated lively discussions of the Working Group.

Euratom focused on the issue of continuity-of-knowledge of safeguards relevant information. To this end the reliability of unattended in-field instrumentation had to be ensured. The concept of remote transmission of state-of-health (SOH) data was considered to support the quality assurance of instrumentation operating unattendedly in the field by triggering early repair in case of system failure. The use of the Public Switched Telephone Network (PSTN) could be adequate for the transmission of SOH data from the plants to the Euratom Headquarters in Luxemburg.

SKI started testing the transmission of accountancy data from nuclear facilities to its Stockholm-based headquarters and from Stockholm to the Agency in Vienna. However, SKI's main interest lay with optical surveillance. Therefore, another field test performed in the reactor hall of a nuclear power reactor and completed early in 1996 involved a video camera and microwave sensors for front end triggering. Data including video images were retrieved from Stockholm. The potential for data reduction appeared to be significant when using a front end triggering system compared to time triggered image acquisition, because only relevant video scenes were recorded and transmitted. In conclusion, SKI acquired a positive attitude towards implementing remote data transmission. However, the implementation procedure as well as technical matters had to be carefully analysed and evaluated beforehand.

The IAEA reported on a field test using a remote monitoring system installed in a Swiss facility and comprising two digital video cameras and two remotely readable seals of the VACOSS-S type. The cameras featured digitization, front end scene change detection, data compression, authentication, encryption, and storage. Images and data were transmitted to Vienna via satellite for review and archiving. Image and data transmission and storage were all digital. There was uninterruptible power to all system components. The network concept allowed expansion of the remote system to more facilities and review stations. The Agency considered it possible to implement the system for safeguards.

The Juelich Research Centre together with industrial partners had performed a field test in a commercial facility for the dry storage of spent nuclear fuel in casks. The remote monitoring system comprised a digital video camera of the same type as used in the Agency's field test and two PC's. One of the PC's functioned as the data collection system recording the digital video data on a removable data carrier. The second PC was connected to an ISDN transmission line accessible from outside the facility. Once per week, the facility operator exchanged the data carriers between the two PC's. Thus it was in the facility operator's power to decide upon the timing of releasing the image data, and the scheme of delayed image release being totally transparent to the facility operator. Images were retrieved from Juelich and Pulheim for review and archiving. Data transmission and storage were all digital. The following conclusions had been derived from this field test:

- ISDN was a reliable transmission medium.
- The digital camera module functioned reliably.
- The commercial communication software was not adequate.
- The technique of the removable data carrier was totally unreliable.
- Synchronization of the field test equipment was not possible using the DCF77 radio-frequency receiver/timer. Obviously, the radio signal was too much attenuated at the location where the equipment was installed. The synchronization of the camera module and PC's was necessary for reasons of unambiguity of the processed data.

In the discussions the Working Group came to the following conclusions:

- The concept of transmission of SOH data does not affect the timeliness of detection of a diversion, as the inspection period is not reduced; i.e. the review period of the safeguards relevant data is not altered. Therefore, in case of unattended system failure the transmission of SOH data will not avoid reverification of inventory, e.g. by measurements. However, the possibility of rapid inspectorate response to a system failure would, in fact, have a deterrent effect by limiting the time available to complete a diversion.
- With the SOH data being remotely transmitted, there is a potential for divertors to know when safeguards devices have failed. Therefore, the question arises, whether the safeguards authorities should use their own encryption scheme for the remote transmission of SOH data.
- Strategies for archiving and review of remotely transmitted data are still in a conceptual stage. The long-term reliability of electronic media for archiving has to be proven. With regard to a future remote data transmission approach including both safeguards and SOH data, front end data reduction methods (i.e. front end triggering and data compression algorithms) will be necessary to limit the time required for transmission but also the effort for review and archiving.
- It is not yet conceivable, how many data channels would be required for Euratom and the Agency when implementing remote data transmission concepts.
- The unattended safeguards system must have sufficient and reliable data storage capacity in order to avoid loss of information, because the transmission channels as well as the data collection system at headquarters may break down.
- Both authentication and encryption will be required to ensure authenticity and confidentiality of the transmitted data.
- There are states which will not allow remote data transmission at all. States allowing remote data transmission may accept different approaches, e.g. SOH data retrieval only or video data retrieval according to a delayed image release concept.
- Every instrumentation for remote data transmission will have to be licensed and approved by the relevant national authorities for use in the facilities.
- The main benefit from remote data transmission schemes is expected to be a reduction of on-site inspection effort. Therefore, the occurrence of false alarms will be a crucial issue ruling the implementation of remote data transmission.
- At present, power reactors are the main focus for implementation of remote data transmission.

The ESARDA Working Group on Containment and Surveillance has not completed its discussions on remote data transmission. In the forthcoming meeting it will allocate further time to this important issue. Therefore, the above conclusions must be considered preliminary and non-exhaustive.

6. References

/1/ B. RICHTER, "Report of the ESARDA Working Group on Containment and Surveillance", ESARDA Bulletin No. 24, 1994, pp. 17-18.

/2/ P. BOERMANS, S. GUARDINI, R. INGELS, B. RICHTER, "Report on the Joint Meeting of ESARDA Working Groups (LEU, MOX, C/S, NDA) on Unattended/Integrated Safeguards Systems", ESARDA Bulletin No. 26, 1996, pp. 7-8.

One year of ESARDA activities

The past year has been a very active one for ESARDA which was engaged, in addition to its ordinary work within the various Working Groups, in 4 major events.

Workshop on "Science and Modern Technology for Safeguards"

Arona, Italy • 28-31 October, 1996

The Joint Workshop on "Science and Modern Technology for Safeguards" was jointly organized by ESARDA and INMM. It was hosted by the Joint Research Centre of the European Commission (Ispra Centre) and was held in Arona, Italy, October 28-31, 1996.

It was attended by 120 participants, consisting principally of scientists from various disciplines and safeguards experts from the inspectorates. The Workshop provided a full discussion on several near and long term scientific technologies that may be applied to safeguards. In addition, there were extended discussions on the social and political aspects surrounding the areas of Nonproliferation, International Safeguards, and Regional Safeguards

The purpose of the workshop was:

- to inform the safeguards community about selected sciences and advanced technologies that are currently available, or that will be available in the next few years, that could be used to support needed advances in international safeguards;
- to inform the practitioners of these sciences and technologies of the needs of the safeguards community for the implementation of technology;
- to stimulate a continuing interchange between experts in various technologies and safeguards practitioners.

The workshop was structured in a plenary session and 4 Working Groups, respectively dealing with: i) Physics and Chemistry Data generation, ii) Computing Technology, Data Collection and Organization, iii) Mathematics, Statistics and Decision Support and iv) Socio-Political Aspects of Safeguards. It provided a forum for the presentation and discussion of selected fields of science and modern technology that have not, as yet, been considered or have not been fully exploited by safeguards institutions. Priority was not given to providing a comprehensive representation of scientific possibilities; instead the agenda was limited to those areas that the technical organizing committee determined would offer realistic possibilities for application to safeguards. The Workshop helped to determine the extent to which this and the other selected technologies might be used to improve safeguards in the future.

The general opinion was that the Workshop met and exceeded its goals, setting the stage for future workshops of this type. One of the outstanding characteristics of this Workshop was the ample amount of time allowed for full discussion of each presentation, both for technical issues and social/political issues. The workshop was not expected to produce immediate products for safeguards application but rather to identify areas into which research may be directed for future applications. In this regard, the Workshop should be understood as the starting point for a further series of similar events that will be devoted to specific and limited fields identified from the initial workshop as being fruitful for safeguards applications.

It is also important to recognize that, in international safeguards, virtually nothing is purely technical. In almost all cases, implementation of modifications and advancements is part technically based and part politically or policy based.

Proceedings were published. They can be obtained from the ESARDA Secretariat at the price of 50 ECU.

The organizers of the Workshop. From left:
G. Stein (FZJ, Germany, Overall Co-Chairman);
C. Foggi (EC, JRC, Ispra, Scientific Secretary);
C. Sonnier (US-DOE Consultant, Albuquerque, USA, Overall Co-Chairman)

Workshop on "The Status of Measurement Techniques for the Identification of Nuclear Signatures"

Geel, Belgium • 25-27 February, 1997

The Workshop was organized by ESARDA and was hosted by the Institute for Reference Materials and Measurements of the Joint Reseach Centre of the European Commission, in Geel, Belgium.

Safeguards applications of information obtained from environmental analysis can yield additional knowledge on the handling of nuclear material in a country or area, and have been gaining in importance since the recent demonstration of the usefulness of this methods in detecting undeclared activities. The importance of nuclear signatures is also reflected in the IAEA programme "93+2".

ESARDA has therefore decided to organize this workshop to establish the status of measurement techniques for the identification of nuclear signatures, in general and in Europe in particular. The Workshop has concentrated exclusively on the scientific aspects of the measurement techniques. It has addressed sample preparation for measurements, but not sampling as such.

The number of participants was limited (53 attended) to keep the Workshop to a manageable size, in order to help person-to-person contact and discussion. Thirty seven presentations were made, subdivided into 5 main oral sessions and one poster session. The oral sessions related to the following topics: Radiometric Techniques, Particle and Total Sample Analysis, Mass-spectrometry Techniques, and Reliability of Measurement Techniques.

The Chairman of the Seminar, Mr. P. De Bièvre, summarized the discussions as follows.

Conclusions from "Round Table" discussions at the Workshop

Compiled by P. De Bièvre from display boards in the meeting room, where the comments "crystallised" in full view of the participants.

1. On the reliability of the results

- there exists a lack of understanding of expressing uncertainties
- there is a need for Safeguards Authorities, calling for the services of measurement laboratories, to specify required uncertainty ('target values' for uncertainty)
- use of internal control charts in measurement laboratories necessary
- measurement laboratories should register performance as function of time
- results without proper uncertainty budget (ISO/BIPM) should be disregarded
- uncertainty of chemical preparation should be included in the uncertainty budget
- uncertainty of sampling (separately) should be included in the uncertainty budget
- method and instruments should be validated by means of matrix Reference Materials
- trackability of samples/kit must be clearly spelled out

2. Requirements for the members of laboratory networks for environmental Safeguards

- have documented procedures
- have documented validation of method
- have an intemal QA/QC system
- participate in regular external QC programmes with published performance pictures
- use SI-traceable Reference Materials
- have a comprehensive reporting system
- have proof of result-orientated quality evaluation
- have proof of scientific qualification
- present full uncertainty budget
- prescribe consistency in uncertainty reporting
- look for true expertise if and as required, also meeting 'geographical distribution' criteria
- have a scientific advisory committee
- have peer review on behalf of IAEA, including external QC with certified test samples (CTS) (no coding of participants)

3. Operation of networks

- Safeguard Authorities to put out list of requirements to members
- evaluation of laboratory is important instead of testing
- use scientific qualifications only

4. Useful measurement techniques

- accelerator MS
- NAA (fluorine determination in combination with U/Pu)
- SIMS for particle analysis
- TIMS for isotope ratios
- Phil Krey's list

5. Bulk and particle analysis techniques are complementary

	bulk	particle
• expensive	less	more
• vegetation	yes	yes
• sediments	yes (softer)	no
• air-filters	yes	yes
• water	yes	no - particulates in water - yes
• time specific	less	more

- sample collection is better performed inside plants than outside
- use of SIMS as 'filter' for bulk is an alternative approach
- particle analysis is not applicable for wide area surveys
- clear formulation of objectives by Safeguards Authorities is needed
- Pu in U hot-cell: bulk analysis is the way to go
- intelligent sample processing is required
- intelligent sample analysis is required
- better knowledge of dynamics of formation of particles on surfaces is required
- strategy should be developed for each type of facility
- find the right particle!

6. Final remarks

- All human activities leave traces in the environment
- The traces go down various drains-some stay longer; few last
- Identifying specific ones can lead us upstream to their causes
- Quality means proof by participation in result-orientated international and "external" Quality Assurance/ Quality Control programmes
- Reliability of conclusions is related to the reliability of the work
- Human observation and interpretation are a most essential part of the process. This requires:
  - – isotopic knowledge
  - – isotope chemistry
  - – keen detection skills
  - – trained observation power
  - – appropriate measurement equipment
  - – suitable scientifical/technical training
  - – correct setting of objectives.

It has to be noted that the Workshop initiated the discussion on the reliability of the results derived from environmental indicators for nuclear activities; this reliability is an essential element whenever the implemented capabilities have to be assessed and the strategy has to be defined in an international safeguards framework.

Proceedings were published. They can be obtained from the ESARDA Secretariat at the price of 50 ECU.

IAEA Symposium on International Safeguards

Vienna, Austria • 13-17 October, 1997

ESARDA assisted the IAEA in organizing its Symposium on International Safeguards, which was held in Vienna, Austria, from 13 to 17 October, 1997. During the opening session, the ESARDA Chairman, Mr. R.J. Page, gave an address to the participants, which is summarised here below.

Summary of the opening address by Dr R.J. Page to the IAEA Symposium on International Safeguards

- On behalf of ESARDA I would like to congratulate the IAEA on its 40th anniversary
- I am very pleased that ESARDA has been able to assist in organising this 7th Safeguards Symposium.
- The excellent programme will foster a broad exchange of experience, concepts and technologies.
- This Symposium provides the opportunity for discussion of important issues which will set the stage for safeguards verification into the new Millennium.
- I strongly believe that the outlook for the future must be to take a more holistic and embracing attitude to non-proliferation and in this regard I personally congratulate the Board of Governors for the adoption of the full package of safeguards strengthening measures in May this year.
- It is by learning from history in this way and adapting the lessons learnt that we are not condemned to repeat it.
- Nuclear power is the only currently available and sustainable form of energy which, if properly engineered and managed, offers safe and environmentally friendly power into the distant future. It is not, however, far from public or political concerns.
- Public acceptability of nuclear power relies in a large part on the reliability of the International regimes to control proliferation and to demonstrate to all the peaceful use of all fuel cycles, whether once through or closed cycles.
- Maximum safeguards visibility goes hand in hand with the minimisation of proliferation risk.
- Safeguards visibility is the challenge to States, the inspectorates and to the operators alike.
- The emphasis must be on co-operation, integration and continuous improvement of safeguards technologies and approaches and to embrace and make maximum use of both qualitative and quantitative information.
- The safeguards community is no longer alone in this challenge and there is much scope for interchange with the emerging verification regimes of the Chemical Weapons Convention and the Comprehensive Test Ban Treaty.
- ESARDA, the European Safeguards Research and Development Association, will continue to play a key rôle in the exchange of research and development information within the safeguards field, and sees an increasing rôle in the cross-fertilisation of ideas between safeguards R&D and other related fields. Collaboration leads not only to greater efficiency and effectiveness but also enhances the goal of openness and visibility.

Symposium on Safeguards and Nuclear Material Management

Montpellier, France • 13-15 May, 1997

Every two years, ESARDA organizes a Symposium on “Safeguards and Nuclear Material Management”, which is hosted, in rotation, by one of the ESARDA Parties. This time the host was the French CEA-IPSN and the meeting was held in South France, at Montpellier. 226 participants attended and 112 papers were presented.

Proceedings were published. They can be obtained from the ESARDA Secretariat at the price of 50 ECU.

ESARDA news

Two new Partners to the ESARDA Agreement

As of October 10, 1996, the Finnish STUK (Säteilyturvakeskus or “Radiation and Nuclear Safety Authority”) is a Party to the ESARDA Agreement.

As of January 1st, 1998, the Italian ANPA (Agenzia Nazionale per la Protezione dell’Ambiente) is a Party to the ESARDA Agreement.

ENEA retires from the ESARDA Agreement

As of April 12, 1997, ENEA has retired from the ESARDA Agreement.

Changes in ESARDA

Chairman

The Chairman of ESARDA for 1997 was Mr. R.J. Page, of BNFL. The Chairman for 1998 is Mr. D. Flory, of the French CEA-IPSN.

Steering Committee

Mr. P.P. De Regge has retired from the ESARDA Steering Committee, where he has been representing the Belgian CEN/SCK since 1990. He was the ESARDA Chairman for 1996. Mr. De Regge has now taken a post at the IAEA. Mr. G. Collard has been appointed his successor.

Mr. J. Fuger has retired from the ESARDA Steering Committee, where he has been representing the Joint Research Centre of the European Commission. Mr. R. Schenkel (of the JRC, Karlsruhe Centre) has been appointed his successor.

Mr. R.J. Page of BNFL is a new Member of the Steering Committee, representing the BNFL. He has been the ESARDA Chairman for 1997.

Mr. M. Tarvainen is a new Member of the Steering Committee, representing a new ESARDA Party, the Finnish STUK.

Scientific Council and Co-ordination Board

Mr. M. Cuypers, of the Joint Research Centre of the European Commission has left his assignement as ESARDA Co-ordinator for the JRC. Mr. S. Guardini has been appointed his successor.

Mr. R.J.S. Harry, of the Dutch ECN has left his assignement as ESARDA Co-ordinator for the Netherlands. Mr. Th. van der Kaa has been appointed his successor.

Mr. H. Lefèvre, of the French CEA-IPSN has left his assignement as ESARDA Co-ordinator for France. Mr. J.C. Niel has been appointed his successor.

Mr. M. Tarvainen of the Finnish STUK is the new Co-ordinator for Finland.

Convenors of the ESARDA Working Groups

Mr. P. De Bièvre, of the JRC-Geel, has retired from his post of Convenor of the ESARDA Working Group on Techniques and Standards for Destructive Analysis (DA-WG).

Mr. R.F. Ingels, of Belgonucléaire, has retired from his post of Convenor of the ESARDA Working Group on Mixed Oxide Fuel Fabrication Plants (MOX-WG).

Mr. K. Mayer, of the JRC-Karlsruhe has been appointed Convenor of the ESARDA DA-WG.

Mr. E. Haas, of Siemens. Hanau, Germany, has been appointed Convenor of the ESARDA MOX-WG.

ESARDA thanks all departing people for their contribution to the activities of the Association, in particular the Convenors of the Working Groups for their continuous commitment and dedication, which have contributed so much to the success of the Association.

ESARDA Symposia Proceedings

Every two years ESARDA organizes a Symposium on “Safeguards and Nuclear Material Management”. The Proceedings of these Symposia are distributed free of charge to the participants. Copies can be obtained by non participants at the price of 50 ECU per copy. For orders, please contact the ESARDA Symposium Secretariat, c/o Joint Research Centre, I-21020 ISPRA, Italy.

ESARDA also organizes, every two years, an “Internal Meeting” of the Association. Proceedings may be published or not, according to a case to case decision. The distribution of these Proceedings is in principle limited to ESARDA Partners and Working Groups Members only.

A new honorary member of ESARDA


Mr. R.J.S. Harry

The ESARDA Steering Committee has appointed Mr. R.J.S. Harry Honorary Member of ESARDA, in recognition of his outstanding contributions to the activities of the Association.

Mr. R.J.S. Harry has been ESARDA Co-ordinator for the Netherlands from 1971 and Convenor of the ESARDA Working Group on Techniques and Standards for Non-Destructive Analysis from 1975 to 1989. He was also member of the ESARDA Working Group on Low Enriched Uranium Fabrication Plants and of the ESARDA Working Group on Containment and Surveillance.

The Association greatly benefited from Mr. Harry's wide technical expertise and from his experience in matters of international safeguards and policy. It is appropriate to remember that he has been, inter alia, Project Co-ordinator of safeguards research at the Reactor Centrum Netherland (RCN, later Energy Research Foundation, ECN), Co-ordinator of the Dutch programme for assistance to IAEA safeguards, advisor to the Dutch Government on safeguards matters, adviser to the Joint Research Centre of the European Commission on its safeguards programme, deputy Chairman of the Convention on Physical Protection of Nuclear Materials and Chairman of the NDA Working Group of the Hexapartite Safeguards Project. He has also been Member or Chairman in many IAEA Advisory Groups.

Mr. Harry retired from ECN on July 1st, 1996, but is still active as an advisor.

Who's Who in ESARDA?

(as of 1st January 1998)

Chairman 1998: *D. Flory*, CEA, IPSN, Fontenay-aux-Roses, France
Secretary: *C. Foggi*, EC, JRC, Ispra, Italy

Steering Committee

G. Andrews, DTI, London , United Kingdom
C. Beets, Ministry of Foreign Affairs, Liège, Belgium
C.P. Behrens, Kernkraftwerk Philippsburg, Germany
J.C. Charrault, EC, Brussels, Belgium
G. Collard, CEN/SCK, Mol, Belgium
M. Cuypers, EC, JRC, Ispra, Italy
F. De Cormis (Mrs), EDF, Paris, France
D. Flory, CEA, IPSN, Fontenay-aux-Roses, France
F. Garcìa González (Mrs), CIEMAT, Madrid, Spain
W. Gmelin, EC, ESD, Luxembourg
R. Howsley, BNFL, Risley, UK
R.F. Ingels, Belgonucléaire, Dessel, Belgium
G. Le Goff, CEA, Paris, France
R.J. Page, BNFL, Springfields, United Kingdom
B.H. Patrick, UKAEA, Harwell, United Kingdom
J. Régnier, COGEMA, Velizy-Villacoûblay, France
H. Remagen, BMBF, Bonn, Germany
R. Schenkel, EC, JRC, Karlsruhe, Germany
G. Stein, Forschungszentrum Jülich, Germany
M. Tarvainen, STUK, Helsinki, Finland
A.M. Versteegh, ECN, Petten, Netherlands
R. Weh, WKK, Bonn, Germany

Executive Committee

D. Flory, CEA, IPSN, Fontenay-aux-Roses, France
C. Foggi, EC, JRC, Ispra, Italy
F. Garcìa González (Mrs.), CIEMAT, Madrid, Spain
W. Klöckner, EC, ESD, Luxembourg
R.J. Page, BNFL, Springfields, United Kingdom
M. Tarvainen, STUK, Helsinki, Finland
One ANPA representative, Italy

Coordinators

R. Carchon, CEN/SCK, Mol, Belgium
F. Garcìa González (Mrs.), CIEMAT, Madrid, Spain
S. Guardini, EC, JRC, Ispra, Italy
W.D. Lauppe, Forschungszentrum, Jülich, Germany
H. Nackaerts, EC, ESD, Luxembourg
J.C. Niel, CEA, Fontenay-aux-Roses, France
M. Tarvainen, STUK, Helsinki, Finland
Th. van der Kaa, ECN, Petten, The Nederlands
M.D. Ward, UKAEA, Risley, United Kingdom
One ANPA representative, Italy

Working Group Convenors

Working group on Techniques and Standards for Non-Destructive Analysis (NDA)
S. Guardini, EC, JRC, Ispra, Italy
Working group on Techniques and Standards for Destructive Analysis (DA)
K. Mayer, EC, JRC, Karlsruhe, Germany
Working group on Containment and Surveillance (C/S)
B. Richter, Forschungzentrum Jülich, Germany
Working group on Low-Enriched Uranium Conversion and Fuel Fabrication Plants (LEU)
F. Mousty, EC, JRC, Ispra, Italy
Working group on Mixed Oxide Fuel Fabrication Plants (MOX)
E. Haas, SIEMENS, Hanau, Germany
Working group on the Back-End of the Fuel Cycle (BFC)
M. Dionisi, ANPA, Rome, Italy

ESARDA Bulletin Editors

C. Foggi, F. Genoni (Mrs), EC, JRC, Ispra, Italy

In Memoriam

On 20th March 1997, Dr. Dipak Gupta died at the age of 69, after a short illness, at his home in Unna, Germany.

Dipak Gupta had been one of the promoters of ESARDA, Member of its Steering Committee and Chairman in 1980. His enthusiasm and his vision greatly contributed to shape the Association.

For all people involved in Safeguards, Dipak Gupta represented a clear point of reference, especially in the European Community. From the beginning he offered an understanding of safeguards issues which, although not disconnected from German questions, was clear, logic and systematic. He was a sincere voice, and he gained the esteem and the appreciation of all the people who met him.

R. Avenhaus and D. Sellinschegg, interpreting the feelings of all who knew Dipak Gupta, wrote the following recollection.

Dipak Gupta was head of the German safeguards project (Spaltstoffflusskontrolle, SPFK) from 1973 to 1986. His life was devoted to the passionate promotion of a world-wide objective safeguards system which, in his mind, was a necessary complementary measure for the peaceful uses of nuclear energy. This dedication is reflected in the high esteem in which he was held by his peers throughout the world.

Born in India in 1928, he studied chemistry at the University Calcutta and finished his theses at the University Aachen in 1954. From 1955 to 1962 he was head of the chemical engineering research laboratory at the Atomic Energy Establishment, Trombay, Bombay. In 1963, he was recruited by the Nuclear Research Centre Karlsruhe (KFK) where he joined the chemical engineering department to undertake work on uranium enrichment by nozzle separation. In 1966, a section for the fast breeder fuel cycle was set up in the KFK within the applied physics department headed by Dr. W. Haefele, and Dipak Gupta was appointed as section head.

In 1967, the project SPFK was initiated in the KFK, on behalf of the German government, to assist the negotiations on the Non-Proliferation Treaty (NPT) and to develop a novel regime of routine world-wide controls conducted by the International Atomic Energy Agency (IAEA) in Vienna. The designated leader of the project, Dr. W. Haefele delegated the coordination of the project to Dipak Gupta.

The project SPFK required the cooperation of research and industry to a very great degree: Research in several areas including radiochemistry, neutron-physics, statistical analysis etc. was successfully conducted in KFK as well as in the Nuclear Research Centre Juelich (KFA). The cooperation of the Nuclear Industry was needed in order to determine the practical implications of applying the developed safeguards measures and techniques to process operation. Eventually international cooperation essential to the implementation of a world-wide safeguards system was achieved. Research institutes all over the world were involved in various studies that originated from the SPFK project. Some of the widely known projects were JEX 70 which was designed to compute material balances, or IDA 72 which estimated the measurement error levels of well established measurement techniques.

The coordination and organization of the SPFK project which made this ambitious project successful was mainly the accomplishment of Dipak Gupta. He never lacked enthusiasm and patience and his dedication to this project was well known to those who worked with him. He had the outstanding ability of being able to focus discussions, workshops or conferences on the goals of the project.

His enthusiasm at work carried over into social activities. We can still remember one of the annual Christmas parties, which always included a show organized, prepared and presented by members of a section selected from the department, where he entered the room on a flying carpet playing the flute as a snake-charmer.

After the resignation of Dr. W. Haefele in1973, Dipak Gupta was named the new leader of the SPFK project, in recognition of his accomplishments. At this time, the NPT had been agreed and the difficult task of implementing the new system at the IAEA began. Dipak Gupta attended and chaired numerous Safeguards meetings in the Agency on behalf of the German government. He was also, for many years, the German representative at the Standing Advisory Group for Safeguards Implementation (SAGSI), and was one of the founding members of the European Safeguards Research and Development Association (ESARDA). In addition he organized two ESARDA symposia in Karlsruhe.

In 1974, the SPFK project was extended to include also R&D activities for physical protection measures in nuclear facilities. On behalf of the German government, Dipak Gupta successfully negotiated a cooperation agreement on physical protection measures, with the United States Department of Energy.

In 1986, the project SPFK was terminated by the management of KFK and Dipak Gupta was recruited by the IAEA as a senior advisor on nuclear safety and physical protection of nuclear materials. In this function he prepared the ground for an international early warning system of nuclear accidents and trafficking of nuclear materials which is in place now at the IAEA.

In 1991, he retired because of health problems and returned to Germany. We had not heard from him since his retirement and assumed he was enjoying retirement and were shocked to hear about his ultimate death.

Dipak Gupta was actively and widely involved in the development of nuclear materials safeguards for more than 20 years and his efforts received international recognition including that of Dr. Eklund, who found his thorough knowledge and clear articulation invaluable.

We will always remember with respect his wealth of international experience and expert knowledge, but also, with deep gratitude and heartfelt warmth, his open-mindedness, his charismatic nature and his positive, optimistic outlook on all things.

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