



## SAFEGUARDS AND NON-DESTRUCTIVE ASSAY

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### Objectives

- ☒ To contribute to the non-proliferation of nuclear materials by maintaining an up-to-date expertise in the field of safeguards and by providing consultancy, guidance and scientific and technical support to the Belgian Authorities and nuclear industries
- ☒ To keep an up-to-date knowledge and expertise in the field of Non-Destructive Assay (NDA) in general and of the assay of special nuclear material in particular in order to fulfil SCK•CEN's statutory missions and to contribute to safeguards technologies in the field of NDA.
- ☒ To develop new NDA technology according to current and future needs.

### Programme

- ☒ To assure nuclear materials accountability of SCK•CEN;
- ☒ To contribute to the implementation of Integrated Safeguards measures in Belgium and to assist the IAEA through the Belgian Support Programme;
- ☒ To render services to internal and external customers in the field of safeguards;
- ☒ To improve passive neutron coincidence counting techniques for waste assay and safeguards verification measurements by R&D on correlation algorithms implemented via software or dedicated hardware;
- ☒ To improve gamma assay techniques for waste assay by implementing advanced scanning techniques and different correction algorithms;
- ☒ To develop numerical calibration techniques.

### Achievements

#### Nuclear Materials Accountability

SCK•CEN installations are subject to routine inspections and to physical inventory verifications within the regular verification activities of Euratom and the IAEA (International Atomic Energy Agency). Nuclear materials accountability (NMA) was assured for the different material balance areas to comply with the non-proliferation commitment.

We developed a new NMA software that can be used by different users and is available on the internal network. Depending on the users, we made more or less functionality available. The database of the new program is based on SQL Server 7.0. This SQL Server offers a reliable, secure and optimal management of

information toward the authorised users. The software itself is based on Visual Basic 6.0, whereas the reporting function is written in Crystal Report 8.0. These reports integrate perfectly in the Visual Basic environment. The Visual SourceSafe manages version control and access to the source code.

#### Integrated Safeguards

A task was initiated with the IAEA within the framework of the Belgian Support Programme to the IAEA to explore and identify how the current safeguards applied to the Belgian installations can be strengthened and made more cost-effective by integrating the current measures with those requested by the additional protocol.

We formed a working group with operators and authorities to study IAEA proposals and to make own proposals on the implementation of integrated safeguards in our installations.

#### Spent Fuel Measurements

The task takes place within the framework of the Belgian Support Programme to the IAEA, in collaboration with support programmes from Finland and Sweden and aims at improving the performance of spent fuel assembly measurement devices and methods. An analysis of historical data on PWR fuel was made to account for the <sup>137</sup>Cs contribution to the gamma output of the assembly and to check the validity of the method for a wide range of burnup values and cooling times.

#### Development of Linguistic Evaluation Model for Strengthened Safeguards Information

Assurance of non-diversion of nuclear materials in a state is the ultimate goal of safeguards verification. Since the detection of undeclared nuclear activities in Iraq in 1990, the safeguards community enlarged its mandate, in the sense that not only declared activities had to be verified, but that also an additional effort would be undertaken to detect undeclared nuclear activities and facilities.

This strengthened safeguards regime (INF-CIRC/540) is essentially based on additional information, that can originate from the state, from inspections made by the IAEA and from open sources (such as media, studies, etc.). It is obvious

that the amount of data is enormous and that not all information contributes to a better knowledge of the situation in a particular state. The aim is to establish a mathematical framework for synthesis and evaluation analysis of multidimensional safeguards information, especially to deal with information that may be unquantifiable due to its nature and that may be imprecise, too complex, ill-defined, etc for which the traditional quantitative approach (e.g., statistical approach) does not give an adequate answer. Accordingly, a flexible and realistic approach is followed by the use of linguistic assessment based on fuzzy sets theory. Fuzzy logic provides a systematic way to handle fuzziness and represent qualitative aspects as linguistic labels by means of linguistic variables. So it can be viewed as complementary to traditional methods and can be a powerful tool to deal with imprecise information, especially linguistic information.

The project aims at modelling the processes of the aggregation of weighted linguistic information in the fusion and evaluation of nuclear safeguards relevant information.

A mathematical algorithm on modelling the processes of the aggregation of weighted linguistic information was developed. Common aggregation operators of weighted linguistic information are investigated, which are very useful for modelling those processes in which there are various information sources and the information is linguistic in nature and is not equally important. Computer software based on this new algorithm is being developed in the fusion and evaluation of nuclear safeguards information.

### Non-destructive assay

We contributed to the definition of a test programme for the high level waste (HLW) glass canisters resulting from the reprocessing of the fuel of the Belgian nuclear power plants. Measurement systems for gamma spectroscopy and passive neutron counting on these canisters were defined.

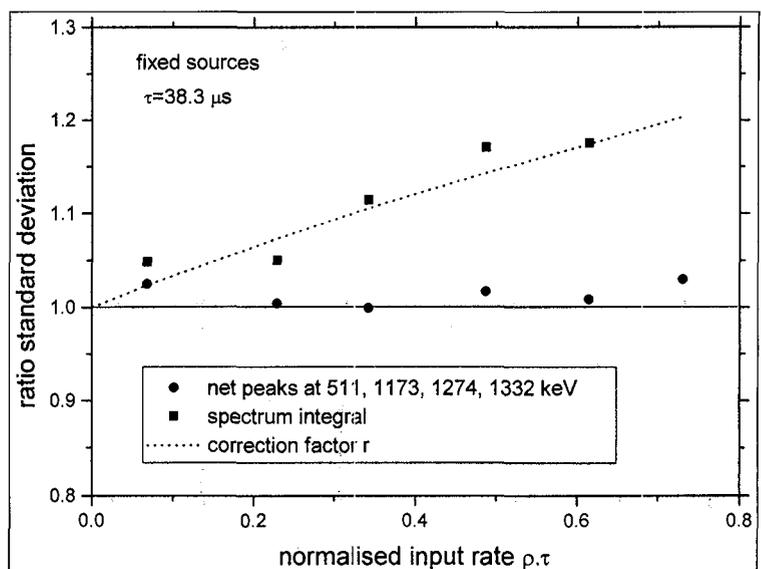
We developed the Time Interval Correlation Spectroscopy (TICS) Analyser hardware, based on Programmable Logic Devices (PLD) aiming at making neutron multiplicity measurements at high count-rates. The TICS Analyser records Rossi-alpha distributions, which are auto-correlation functions of the time distribution between the pulses of detected neutron multiplets. The communication between the TICS hardware and a PC was realised. We tested the hardware and used it in the VENUS reactor where

Rossi-alpha distributions were recorded to determine  $\beta$ -effective and other dynamic reactor parameters. The TICS Analyser also has been supplemented with firmware to record impulse responses, allowing the recording of the time evolution of a neutron population after external triggering. This operating mode of TICS is applicable where dynamical parameters in pulsed neutron experiments have to be determined (e.g. in pulsed neutron assay systems).

The NeuTICS software, which we developed to implement Computed Neutron Coincidence Counting, is being upgraded. The new version of the software is now database oriented (based on SQL Server) and supports multi-user network functionality. Acquisition and analysis routines have been optimised for minimum execution time. A C++ class was developed for uncertainty propagation calculations associated with the different modules of the NeuTICS software. We made neutron multiplicity measurements on a MOX sample containing 50% U and 50% Pu. The multiplicity measurements allow to account for the neutron multiplication in the U and to make a correct Pu assay in presence of this effect.

We studied the dependency between atmospheric pressure and neutron background, which is important for low count rates; the figure gives the results for single neutrons.

We made different MCNP simulation studies and studied a new design of a passive neutron counter for 200 l drums. In the new design, detector tubes were arranged in a way that they optimally cover the waste



Relation between atmospheric pressure and neutron background for single neutrons.

drum. Compared to the pilot system, the new design has an increased detection efficiency (4% improvement) while the total detector volume ( $^3\text{He}$  detector tubes) is equal for both configurations. We investigated a set-up to be installed in a hot cell at SCK•CEN, for measuring the neutron emission rates of an irradiated fuel pin. We used the simulations to investigate the effects of neutron scattering in the 2 m long lead collimator and to determine the fuel pin volume contributing to the neutron signal in a small array of  $^3\text{He}$  tubes.

We participated in ESARDA's Pu-2000 exercise, an inter-laboratory test organised at IRMM Geel. The test consists in the determination of the plutonium isotopic composition of various plutonium samples. We used different Ge-detectors and Multi Group Analysis (MGA) U/Pu software for the determination of the Pu isotopics.

We developed software to compute tomographs from transmission data. Tomography might be used in the future for the assay of nuclear waste packages (200 and 400 l waste drums). The tomography data will be collected with the 3Ax gamma scanner. The tomography software was developed in the framework of an engineer's thesis. To test the software, we simulated tomography data with Solidang, which allows to simulate the response of a gamma detector as a function of various measurement configurations.

## Perspectives

- The new NMA software will be tested and used;
- Based on the current research results of fuzzy logic application to safeguards, a further validation of the computer programme will be provided with various case studies;
- Start with the design of a scanner system to perform NDA (gamma and neutron) on HLW glass canisters;
- Finalise TICS (hardware and software).

## Scientific Output

### Publications

D. Ruan, J. Liu, and R. Carchon, "A lattice-valued linguistic decision model for safeguards application", Proc. of the 8th Zittau Fuzzy Colloquium (East-West Fuzzy Colloquium 2000), September, 2000, Zittau, Germany, pp. 284-292.

P. Baeten, M. Bruggeman, R. Carchon, "Validation aspects of Multiplicity Counting: a new Approach by Time Interval Analysis", Proceedings of the International Workshop on

Quality Requirements of NDA Measurements, C. Foggi, E. Petraglia eds., Ispra, Italy, 2000, pp. 83

M. Bruggeman, R. Carchon, "Solidang, a computer code for the computation of the effective solid angle and correction factors for gamma spectroscopy-based waste assay", Appl. Rad. Isot. 52 (2000) pp.771-776

### Presentations

R. Carchon, D. Ruan, J. Liu, M. Bruggeman, "Application of Logical Computing Methods", The Annual ESARDA Symposium on Safeguards and Nuclear Material Management, Dresden, Germany, May, 2000.

M. Bruggeman, "What progress is to be expected in Passive Neutron Assay for Quality Checking of Nuclear Waste after one decade of research and experience?", Workshop on "Past, Present and Future of NDA QA/QC", Petten, 19-20 June 2000.

M. Bruggeman, P. Baeten, R. Carchon, T. Bücherl and Ch. Lierse, C. Vicini, G. Grossi and D. Lisi, G. Caspary, P. Filß and J. Kühne, S. Guldbakke, E. Dietz, H. Klein, D. Schlegel, A. Lyoussi, A. Mariani and J. P. Coulon, F. V. Frazzoli, R. Remetti, N. Cherubini, "Improvement of Passive and Active Neutron Assay Techniques for the Characterisation of Radioactive Waste Packages", Workshop on "Past, Present and Future of NDA QA/QC", Petten, 19-20 June 2000.