SYNOPSIS OF NEUTRON ASSAY SYSTEMS

Comparison of Neutron Determining Systems and Measuring Procedures for Radioactive Waste Packages

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# Table of Contents

1 INTRODUCTION ........................................................................................................... 5

2 PRINCIPLE OF NEUTRON MEASUREMENTS ........................................................... 6
  2.1 General ....................................................................................................................... 6
  2.2 Neutron Counting System ......................................................................................... 6
  2.3 Moderator .................................................................................................................. 7
  2.4 Background Shielding ............................................................................................... 7
  2.5 Manipulator ............................................................................................................... 7
  2.6 Control Unit .............................................................................................................. 8
  2.7 Data Evaluation Unit ............................................................................................... 8
  2.8 Additional Equipment ............................................................................................. 8

3 MEASUREMENT MODES ............................................................................................. 8
  3.1 General ..................................................................................................................... 8
  3.2 Total Neutron Counting ........................................................................................... 8
  3.3 Segmented Neutron Counting ................................................................................ 8
  3.4 Time Correlation Methods ...................................................................................... 9
  3.5 Selection of Scan Modes .......................................................................................... 9

4 DATA PROCESSING AND EVALUATION ............................................................... 9
  4.1 General ..................................................................................................................... 9
  4.2 Basic Relations ........................................................................................................ 9
  4.3 Experimentally Determined Correlation Factor ...................................................... 9
  4.4 Calculated Correlation Factor ................................................................................. 10
  4.5 Remarks .................................................................................................................. 10

5 VALIDATION .............................................................................................................. 10

6 REFERENCES .............................................................................................................. 10

TECHNICAL TERMS ...................................................................................................... APPENDIX A

COMPARISON OF TECHNICAL DATA OF PASSIVE NEUTRON ASSAY SYSTEMS ...... APPENDIX B

DESCRIPTION OF THE INDIVIDUAL PASSIVE NEUTRON ASSAY SYSTEMS .......... APPENDIX C

LIST OF CONTACT PERSONS ....................................................................................... APPENDIX D
Preface

At the second meeting of the Working Group 4 of the 'European Network of Testing Facilities for the Quality Checking of Radioactive Waste Packages' held in Arnhem, The Netherlands, 15. November 1995, it was decided by all members to create a synopsis of existing systems for the neutron measurement of radioactive waste packages, comparable to those for gamma scanning systems [BUC98]. A questionnaire on the set-up and on the operation modes of neutron assay systems was compiled and distributed to the members of the Working Group. The summary of the answers and general information on neutron assay are presented within this synopsis. Its intention is to help people interested in setting up or in upgrading an existing assay system in their decision for an appropriate system for their specific requirements. A list of institutions and contact persons working in this field of application is added to enable the user of this synopsis to get quick access to further information and to exchange experiences.

Garching, September 2001

The authors
1 Introduction

Radioactive waste can originate from different producers such as nuclear power plants, research institutes, nuclear medicine and others. It has to meet certain specifications and acceptance criteria defined by regulatory and management authorities. These criteria differ depending on the form and type of radioactive waste and on the individual country regulations.

Appropriate control procedures to ensure the compliance with these restrictions and limitations are necessary for quality control. They can take place either at the origin of the radioactive waste generation, during the conditioning or at the final conditioned waste package. Preferably non-destructive testing methods are used in order to minimise the radiation dose to the personnel, to avoid secondary radioactive waste and to minimise costs. Furthermore, with destructive testing there will always be the essential question of taking a representative sample.

In recent years several non-destructive methods for quality checking of radioactive waste packages have been developed and tested. They can be distinguished by the measured quantity, mainly gamma radiation and/or neutrons, and due to their operation mode, i.e. passive or active measuring modes. A summary of conventional assay is given in Table 1.

This synopsis focuses on the passive neutron assay used for the characterisation of radioactive waste packages, i.e. the detection of neutrons emitted by spontaneous fission (sf) or by (α,n)-reactions in a waste package. No external neutron or gamma interrogation source is applied.

The synopsis aims in summarising the basic principles of operation, the required equipment and the layout of a system. Information on technical terms, existing systems and contact persons or institutions for further information is given in the annexes.

<table>
<thead>
<tr>
<th>Table 1: Measuring modes conventionally used in quality control of radioactive waste packages.</th>
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<td>interrogation techniques</td>
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2 Principle of Neutron Measurements

2.1 General

The main objective of passive neutron assay is to prove the presence of neutron emitters within a waste package and to quantify them in terms of a $^{240}\text{Pu}_{\text{equiv}}$ mass. An isotope specific identification and quantification is not possible since the neutron emission spectra of different isotopes measured outside a waste package do not show characteristic differences like e.g. gamma spectra. But using time correlation methods (TCM) a general distinction and quantification between spontaneous (sf) and $(\alpha,n)$-reaction neutron sources is possible.

A suitable neutron assay system consists typically of

- a number of neutron detector systems,
- a moderator,
- a background shielding,
- a manipulator,
- a control unit,
- a data evaluation unit and
- optional additional equipment (e.g. turntable, transmission source, time correlation method systems, etc.).

The design of a passive neutron assay system and the choice of the most appropriate additional equipment must be adapted to type and to size of the waste packages to be characterised and to the measurement modes to be applied.

2.2 Neutron Counting System

Neutrons cannot be detected directly like charged particles or gamma radiation. Therefore nuclear reactions are used to convert neutrons in energetic charged particles like protons, $\alpha$-particles, etc. These secondary particles then can be detected using conventional radiation detectors like proportional counters, scintillation detectors, etc. [KNO89]. The cross section for the interactions of neutrons with the target material strongly depends on neutron energy for most materials, resulting in different techniques and designs for neutron detectors. For the neutron assay of waste packages conventionally thermal neutron detectors are used, although fast or epi-thermal neutron detectors may also be applied. This synopsis only focuses on the use of thermal neutron detectors, as these are the most frequently used ones.

Neutron detectors can be simple counting tubes or one- or two-dimensional position sensitive detectors, typically using $^3\text{He}$ as conversion material. The use of the first will give mainly integral information on the neutron emitters while position sensitive detectors offer the possibility of segmented neutron counting.

A block diagram of a typical neutron detection system is shown in Figure 1.

The detector may be a $^3\text{He}$-counting tube, a BF$_3$-counting tube, a Gd- or B-loaded scintillation detector, a fission chamber, etc. [KNO89]. In most current operating systems $^3\text{He}$-counting tubes are used.

The high voltage power supply is required for the operation of the detector and is conventionally called detector bias supply.

The output of the detector is a small burst of charge that cannot be dealt with in the subsequent electronic components without an amplification step. This is performed by the preamplifier. It is located as close as possible to the detector.

---

**Figure 1:** Block diagram of a typical neutron detection system.
Synopsis of Neutron Assay Systems

The linear amplifier that is connected to the preamplifier provides two elements in the pulse processing chain: pulse shaping and amplitude gain. The amplification factor or gain is conventionally adjustable over a wide range and must be adjusted carefully since it influences the signal-to-noise ratio.

The discriminator filters out signals not originated by neutrons but by other effects, e.g. by gamma-ray background, etc. The discriminator level must be set carefully not to cancel out neutron signals but to account for gamma background, etc.

After discrimination the analogous signal is triggering a logical pulse that is used for further processing (e.g. counting, registration of arrival time etc.) by a computer.

Several additional components in the detection chain (Figure 1) are available and sometimes in use (e.g. pulse generators for calibration purposes).

A calibration of the discriminator settings has to be performed after each shut down of the system and of individual detector chains, respectively. Furthermore, the discriminator settings have to be checked periodically for quality control and if any doubts on the correctness of the actual calibration may occur (e.g. strong fluctuations of the count-rates of neighbouring detectors).

To achieve a high detection efficiency the complete waste package should be surrounded by neutron detectors, i.e. the neutron detectors should be arranged as close as possible to a $4\pi$-geometry.

2.3 Moderator

The energy range of the neutrons emitted by sf or $(\alpha,n)$-reactions generally is about 1 MeV to 10 MeV. For an effective detection using thermal neutron detectors these fast neutrons must be slowed down to energies of less than 1 eV, i.e. the emitted neutrons must be moderated to thermal energies. This is performed by surrounding the neutron detectors with moderating (i.e. thermalising) material, e.g. polyethylene. The thickness of this material must be adapted to the moderation properties of the waste packages to be characterised and is typically about 1 cm to 3 cm of polyethylene.

Conventionally several detectors are grouped together within a moderator block.

The moderator blocks may be lined with cadmium foils to limit matrix effects and induced fission multiplication effects for time correlation system-measurements. Additional shielding (e.g. lead) might be necessary for protecting the neutron counters against gamma radiation that may influence the measured count-rates but may increase the background signal due to spallation processes.

2.4 Background Shielding

The detectors record the number of neutrons emitted by the waste package and some background signals that can originate from

- natural radioactivity in the surrounding,
- neutrons created by spallation effects,
- neutron emitting facilities (e.g. reactors) or sources (radioactive sources),
- other radioactive waste packages.

Because the magnitude of the background ultimately determines the minimum detectable signal a shielding of the detectors is preferred. Shielding materials commonly used are polyethylene, cadmium, etc. for neutron shielding and lead, tungsten, etc. for gamma radiation shielding.

For shielding purposes some passive neutron assay systems are housed within a polyethylene cube with wall thickness of up to 20 cm.

An appropriate choice of the place of operation of the passive neutron assay system may significantly influence the minimum detectable signal and may reduce the required shielding dimensions.

2.5 Manipulator

In general the neutron emitters are not distributed homogeneously within the waste package. Therefore, an integral determination of the neutron count-rate, i.e. the sum of the count-rates of all individual detectors, will not give representative information on the content of the waste package. Evaluation of the individual detector count-rates will improve the information, but depending on the detector arrangement, additional manipulation of the waste package may be necessary to gather further information, e.g. performing segmented neutron counting. This will result in a much more reliable and representative characterisation of the waste package than by simple integral counting.

Conventionally the manipulator system is limited to a single turntable for rotating the waste package.
2.6 Control Unit

The control unit, usually a computer, controls both the movements of the manipulator system and the measuring process. Conventionally these tasks are synchronised. The measured data, i.e. the count-rates of the individual detector chains and/or the neutron arrival times, is stored on appropriate media (e. g. hard disk of the computer) together with additional information (e. g. measuring date and time, position of the waste package, etc.) necessary for data evaluation and for the final documentation.

2.7 Data Evaluation Unit

Using the measured and stored data the quantification of the neutron emitting material present in the waste package is performed by appropriate software programs. This data evaluation can be performed on an additional computer system or is included within the control unit.

2.8 Additional Equipment

Most recently set-up passive neutron assay systems are equipped with time correlation method (TCM) systems. These systems distinguish between neutrons originating from sf and from (α,n)-reactions.

A correction of the attenuation properties of the matrix is based on the use of an external neutron source (e. g. 244Cm, 252Cf, etc.). This matrix interrogation is conventionally performed as a simple transmission measurement.

3 Measurement Modes

3.1 General

In passive neutron assay of (large volume) waste packages the measured data does not contain nuclide specific information for identifying the neutron emitter like in gamma scanning [BUC98]. Without additional a priori information only general information in terms of a reference material (e. g. 240Pu-quvis) can be given.

Nevertheless, different measurement modes are known differing in the number of resulting data and in the application of additional equipment.

Integral and segmented measurements both aim in determining the total (i.e. the combined sf- and (α,n)-reaction) neutron count-rates on the surface of the waste package being investigated.

A further distinction between neutrons emitted by sf- and (α,n)-reactions can be performed when applying additional equipment like time correlation systems.

3.2 Total Neutron Counting

Total neutron counting is an integral measurement. It is the simplest measuring mode in passive neutron assay simply summing up the signals of all individual detectors.

During the measurement the waste package may be rotated which is recommended when only a small fraction of the waste package surface is "seen" by the neutron detectors, levelling out small inhomogeneities of the neutron emission-rate distribution on the surface of the waste package.

The evaluation of that data is only representative and reliable for a nearly homogeneous distribution of the neutron emitters within the waste package and a nearly homogeneous matrix.

3.3 Segmented Neutron Counting

In segmented neutron scanning (SNS) the distribution of the neutron emission-rates on the surface of the waste package is determined.

For this purpose the waste package surface is subdivided into M (equidistant) segments and each segment is subdivided into N sectors. Additionally, bottom and top of the waste package are subdivided into N_o and N_T sectors, respectively. For each sector the neutron emission-rate has to be determined. This requires either (2-dimensional) position sensitive detectors surrounding the waste package or, alternatively, a special arrangement of vertically and horizontally arranged neutron detector tubes in combination with an appropriate manipulation (i.e. rotation) of the waste package. Next a deconvolution of the measured data is performed resulting in a set of (N·M + N_o + N_T) data giving information on the distribution of the neutron emission rate on the waste package surface [BUC99].
Based on these data a verification of the assumptions of homogeneity required for applying the total neutron counting evaluation procedure can be performed and hot spots can be detected.

3.4 Time Correlation Methods

Application of time correlation methods aims in separating the neutron emission-rates on the surface of a waste package originating from sf- and (α, n)-reactions, respectively.

The signals of all individual detectors are summed up and fed into a special time correlation method system.

During the measurement the waste package may be rotated which is recommended when only a small fraction of the waste package surface is “seen” by the neutron detectors, levelling out small inhomogeneities of the neutron emission-rate distribution on the surface of the waste package.

3.5 Selection of Scan Modes

Depending on the available and reliable a-priori information given on the waste package and by the specific task description the most appropriate method must be chosen.

If information on the amount of sf- and (α, n)-reaction neutrons is required an appropriate time correlation method must be applied. For this purpose different methods are known like e.g. the shift register method, the neutron coincidence counting (NCC) and the neutron multiplicity counting (NMC). The shift-register method has proven to give acceptable results for waste packages containing low density materials but often fails for dense matrices. NCC, which needs information on the matrix properties, and NMC have shown their applicability not only for light matrices but also for metallic matrices [BUC99]. NMC is self-calibrating, i.e. no information on the matrix properties must be known, and is to some extent insensitive to the actual source distribution, but its application is limited to $^{240}\text{Pu}_{\text{equiv}}$-masses of at least 100 mg. Furthermore, it is strongly sensitive to background effects.

4 Data Processing and Evaluation

4.1 General

The results of passive neutron measurements are count-rates. The quantification is conventionally based on the total net count-rate, assuming a homogeneous distribution of the neutron emitters and of the matrix. The distribution of neutron emitters, measured with the segmented neutron counting mode, give information on the correctness of that assumption. Improved evaluation procedures are known (e.g. [BUC99]) but usually not applied in practice due to the increased requirements for the operator’s skills and for the time needed for measurement and data evaluation.

The conventionally applied evaluation procedures calculate the $^{240}\text{Pu}_{\text{equiv}}$-mass usually in a conservative way, i.e. for an inhomogeneous distribution of neutron emitters the $^{240}\text{Pu}_{\text{equiv}}$-mass will be lower than calculated.

4.2 Basic Relations

The method of calculating the $^{240}\text{Pu}_{\text{equiv}}$-mass $M$ from the total net count-rate $Z$ is given by the basic relation

$$M = \frac{Z}{k}$$  \hspace{1cm} (1)

with $M$: $^{240}\text{Pu}_{\text{equiv}}$-mass [g], $Z$: net count-rate [s⁻¹], $k$: transfer or correlation factor [s·g⁻¹]

The transfer or correlation factor $k$ can either be determined experimentally or by mathematical calculations.

4.3 Experimentally Determined Correlation Factor

This method is based on a set of calibration measurements. Well defined standards being representative for the types of waste packages to be investigated are measured and the correlation factors between the well known neutron emission-rates and the measured count-rates as a function of matrix and source distribution are determined (using equation 1) and stored in a look-up table.

European Network of Testing Facilities for the Quality Checking of Radioactive Waste Packages

Knowing the matrix and source distribution of a waste package either from a-priori information or from additional matrix interrogation and segmented neutron counting measurements the corresponding correlation factor can be selected from the look-up table for data evaluation.

Very often the properties of the investigated waste package do not completely fit to the properties of a calibration standard. Then the correlation factor has to be determined by an appropriate combination (e.g. averaging) of existing correlation factors being representative for similar matrices and distributions of the neutron emitters.

The disadvantage of this calibration method is the necessity of a large number of calibration drums, depending on the number of different types of waste packages and matrices to be investigated.

4.4 Calculated Correlation Factor

The calculation of the correlation factor is mostly based on the use of Monte-Carlo methods. This modelling requires at first a detailed and complete description of the measuring device (i.e. detector system, shielding, moderator, etc.). Using a set of modelled standards, a look-up table can be calculated.

If the properties of the investigated waste package do not completely fit with the properties of a standard, the corresponding correlation factor can either be determined by an appropriate combination of correlation factors for similar matrices and distributions of neutron emitters, or the correlation factor is determined by a new Monte-Carlo calculation using the specific properties of that waste package.

Nevertheless, some calibration drums are still recommended to validate the correctness of the calculated correlation factors.

The disadvantage of this calibration method is the large calculation time for determining one correlation factor and the necessity of an expert to perform these calculations.

4.5 Remarks

The accuracy of the results obtained from both methods strongly depends on the knowledge about the composition of the matrix and of the distribution of the neutron emitters. If no or only a little information is available an improvement can be achieved experimentally by using the results of additional matrix interrogation measurements and of segmented neutron counting, respectively.

In general, the neutron emitters are not homogeneously distributed over the complete volume of the waste package. If the waste package is not completely surrounded by neutron detectors and/or the arrangement of the neutron detectors is not the same for each position (e.g. when using horizontal and vertical detector tubes) then an averaging is achieved by rotating the waste package. This enables a quantification assuming a homogeneous activity distribution.

5 Validation

The passive neutron assay system must be verified to ensure the accuracy of the results. The verification must be performed after each restart of the system, when a new calibration is performed and in regular intervals during routine operation. Therefore, dummy waste packages with well defined compositions and activity contents similar to those, which have to be characterised in practice, are measured and evaluated. These waste packages must not be the same as used for any calibration procedure in order to avoid the abolishment of systematic errors.

If the results of the validation measurements deviate from the declared values of the dummy waste packages, the system has to be checked, repaired and new calibrated. All waste packages characterised since the last verification shall be characterised once again. Alternatively, if the reason for and the date of the first deviation can be determined precisely corrections of the results may be performed.

6 References


Technical Terms

To avoid misunderstandings in discussion of neutron measurement of waste packages, the most relevant technical terms as used within the Working Groups of the “Network” are given below. They are in accordance with ISO\textsuperscript{1} [ISO99].

\begin{itemize}
  \item \((\alpha,n)\)-reaction: reaction which induces neutron emission via an alpha-particle
  \item background shielding: shielding of the measurement chamber against neutrons from the surrounding, i.e. not emitted from the investigated package
  \item container: package envelope
  \item control unit: system for controlling the manipulator system and the data acquisition process
  \item data evaluation unit: system for evaluation of the measurement data
  \item detector: device providing an electrical signal proportional to the neutron flux irradiating it; the signal depends on the neutron energy
  \item passive neutron assay: system for measurement of the neutrons emitted from a package without the use of any external neutron interrogation source
  \item \(^{240}\text{Pu}\) eff-mass: mass \([\text{g}]\) of pure \(^{240}\text{Pu}\) that would produce a signal identical to the one recorded by the measurement device
  \item reference package: mock-up representative of a package with precisely known characteristics; the radioactive characteristics are determined with respect to a reference material
  \item matrix: inactive material contained in the package
  \item neutron counting system: system for measurement of neutrons
  \item package: object to be characterised, comprising the leak tight envelope
  \item PSD: position sensitive detector
  \item segmented neutron counting: performing subsequent neutron measurements at different height positions
  \item sf: abbr.: spontaneous fission
  \item time correlation method: measurement of the time dependence of the neutron detection within a passive neutron assay
  \item transmission source: external neutron source for determining the matrix properties by transmission measurements
  \item waste package: package containing waste
\end{itemize}

Comparison of Technical Data of Neutron Assay Systems

Appendix B offers a fast abbreviation on all relevant technical data of the individual passive neutron assay systems. Which are described in general in the subsequent Appendix C. The association between the columns of the technical terms and the owners of the systems is made by the abbreviations listed below.

RCM: Institut für Radiochemie, Technische Universität München, Walther-Meißner-Str. 3, D-85748 Garching, Germany

ENEA: ENEA, CR CASACCIA – Via Anguillarese, 301 – 00060 S. Maria di Galeria (Rome), Italy

JRC: Joint Research Centre, I-21020 Ispra (VA), Italy

SCK: SCK-CEN, Boeretang 200, B-2400 Mol, Belgium

CEA1: French Atomic Energy Commission, Cadarache Centre, DED/SCCD/LDMN, 13108 Saint Paul lez Durance cedex, France

CEA2: Commissariat à l’Energie Atomique, Centre d’Etude de Cadarache, SCCD/LDMN Bât. 326, 13108 Saint Paul Lez Durance, France
## Synopsis of Neutron Assay Systems

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### Labour

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### Detector System

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<td>10 vertical modules forming a decagon, 3 modules on top, 3 modules on bottom</td>
<td>36 in a hexagonal arrangement + 12 top + 12 bottom</td>
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<td>decagonal arrangement of 40 detectors + 12 top detectors and 12 bottom detectors</td>
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</tr>
</thead>
<tbody>
<tr>
<td>routine [%]</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>research [%]</td>
<td></td>
<td></td>
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### Mechanical Specifications

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>movement of</td>
<td></td>
<td></td>
</tr>
<tr>
<td>waste package</td>
<td>rotation</td>
<td>rotation</td>
</tr>
<tr>
<td>detector(s)</td>
<td>no</td>
<td></td>
</tr>
<tr>
<td>others</td>
<td>semi-automatic drum loading</td>
<td></td>
</tr>
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</table>

### Waste Package

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>max. drum size [l]</td>
<td>118</td>
<td>220</td>
</tr>
<tr>
<td>max. weight [kg]</td>
<td>50/150(with/without rotation)</td>
<td>500</td>
</tr>
</tbody>
</table>

### Detector System

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>type</td>
<td>30NH15, 410NH1C/5, 300NH1C/5, 205NH50/5</td>
<td>He counting tube</td>
</tr>
<tr>
<td>company</td>
<td>Eurisys Mesures</td>
<td>Eurisys Mesures/Dextray, France</td>
</tr>
<tr>
<td>number</td>
<td>1/30/28/30</td>
<td>99/1</td>
</tr>
<tr>
<td>length [cm]</td>
<td>15/100/100/50</td>
<td>50/15</td>
</tr>
<tr>
<td>diameter [cm]</td>
<td>1/2/2/2</td>
<td>5/2.5</td>
</tr>
<tr>
<td>gas</td>
<td>He</td>
<td>He</td>
</tr>
<tr>
<td>pressure [bar]</td>
<td>6/4/2/4</td>
<td>4/2</td>
</tr>
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</table>

### Detector Arrangement

<p>| | | |</p>
<table>
<thead>
<tr>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>external/lateral face/lateral face/door</td>
<td>3 x 33 horizontal arrangement with 2 layers</td>
<td></td>
</tr>
</tbody>
</table>

### Moderation System

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>graphite</td>
<td></td>
<td>graphite carbone</td>
</tr>
</tbody>
</table>

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European Network of Testing Facilities for the Quality Checking of Radioactive Waste Packages

### Synopsis of Neutron Assay Systems

#### Appendix B-3

<table>
<thead>
<tr>
<th><strong>Background Shielding</strong></th>
<th><strong>RCM</strong></th>
<th><strong>ENEA</strong></th>
<th><strong>JRC</strong></th>
<th><strong>SCK</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>general</td>
<td>measuring system is placed in a cube having PE-walls of 20 cm thickness</td>
<td>outer stainless steel liner (1 mm)</td>
<td>22 cm of HD-PE, 1 mm Cd</td>
<td>Paraffin castle with PE roof and doors</td>
</tr>
<tr>
<td>background count-rate</td>
<td>ca. 3 s⁻¹</td>
<td>ca. 3 s⁻¹</td>
<td>2.4 s⁻¹</td>
<td>Singles : 1.85 s⁻¹ Doubles: 0.052 s⁻¹ Triples : 0.007 s⁻¹</td>
</tr>
</tbody>
</table>

#### Electronics

| **preamplifier** | 142IH (EG&G Ortec) | home-made | AMPTEK 111A |
| **amplifier** | RCM module | home-made | AMPTEK 111A |
| **ADC** | RCM module | home-made | AMPTEK 111A |
| **discriminator** | RCM module | home-made | AMPTEK 111A |
| **multichannel scaler** | | | |
| **multiplicity recorder** | | Geotest TIA board + software | |
| **counter/timer card** | CIO-CTR10 plug-in card (Computer Boards Inc.) | | Geotest TIA board |
| **HV power supply** | 556 (EG&G Ortec) | home-made | Model 3125 (Canberra) |
| **Power supply** | 4002P (EG&G Ortec) | home-made | Nim Bin power supply |
| **TCA** | Model 1001 Neutron Time Correlation Analyser (Antech A. N. Technology Ltd.) | Model 1001 Neutron Time Correlation Analyser (Antech A. N. Technology Ltd.) | see TIA |
| **NCC** | JSR-12 (Canberra) | | see TIA |
| **TIA** | GT657-TIA (Geotest) | | GT657-TIA (Geotest) |
### Synopsis of Neutron Assay Systems

#### Appendix B-3a

<table>
<thead>
<tr>
<th><strong>Background Shielding</strong></th>
<th>CEA1</th>
<th>CEA2</th>
</tr>
</thead>
<tbody>
<tr>
<td>general</td>
<td>10 cm CH₂ on external faces</td>
<td>external PE walls (10 cm), inner Cd (2 mm) and Pb walls (5 cm)</td>
</tr>
<tr>
<td>background count-rate</td>
<td>total: 1.3 s⁻¹ coinc.: 0.12 s⁻¹</td>
<td>total: 8 s⁻¹ coinc.: 1.3 s⁻¹</td>
</tr>
<tr>
<td></td>
<td>total counting (activ): 30 s⁻¹ coinc. counting (act.iv): 0.1 s⁻¹</td>
<td>prompt neutrons: 5000 s⁻¹ delayed neutrons: 54 s⁻¹</td>
</tr>
</tbody>
</table>

#### Electronics

<table>
<thead>
<tr>
<th></th>
<th>CEA1</th>
<th>CEA2</th>
</tr>
</thead>
<tbody>
<tr>
<td>preamplifier</td>
<td>ACHNA98 (Eurisys Mesures)</td>
<td>ACHNA98 (Eurisys Mesures)</td>
</tr>
<tr>
<td>amplifier</td>
<td>ACHNA98 (Eurisys Mesures)</td>
<td>ACHNA98 (Eurisys Mesures)</td>
</tr>
<tr>
<td>ADC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>discriminator</td>
<td></td>
<td></td>
</tr>
<tr>
<td>multichannel scaler</td>
<td>Novelec</td>
<td></td>
</tr>
<tr>
<td>multiplicity recorder</td>
<td>Histoc (CEA patent)</td>
<td></td>
</tr>
<tr>
<td>counter/timer card</td>
<td></td>
<td>Medas plug in card (Cesigma)</td>
</tr>
</tbody>
</table>

| HV power supply  | Model 7181 (Eurisys Mesures) | Model 7181 (Eurisys Mesures) |
| Power supply     | NIM BIN power supply 7000H (Eurisys Mesures) | NIM BIN power supply 7000H (Eurisys Mesures) |

| TCA              |                             |                             |
| NCC              |                             |                             |
| TIA              |                             |                             |
## Synopsis of Neutron Assay Systems

### Computer System

<table>
<thead>
<tr>
<th></th>
<th>RCM</th>
<th>ENEA</th>
<th>JRC</th>
<th>SCK</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC-system</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PC-system, microprocessor system</td>
<td>PC-system</td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

### Software

<table>
<thead>
<tr>
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<th>RCM</th>
<th>ENEA</th>
<th>JRC</th>
<th>SCK</th>
</tr>
</thead>
<tbody>
<tr>
<td>control of</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>system</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>manipulator</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>data acquisition</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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### Measurement Modes

<table>
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<tr>
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<th>JRC</th>
<th>SCK</th>
</tr>
</thead>
<tbody>
<tr>
<td>total neutron counting</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>segmented neutron counting</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>coincidence counting</td>
<td>TCA</td>
<td>NMC, NCC, TCA</td>
<td>X</td>
<td>X</td>
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### Calibration

<table>
<thead>
<tr>
<th></th>
<th>RCM</th>
<th>ENEA</th>
<th>JRC</th>
<th>SCK</th>
</tr>
</thead>
<tbody>
<tr>
<td>general</td>
<td>no</td>
<td></td>
<td>X</td>
<td>no</td>
</tr>
<tr>
<td>waste dependent</td>
<td>mock-up drums</td>
<td>Monte Carlo modelling</td>
<td>-</td>
<td>mock-up drums + Monte Carlo modelling</td>
</tr>
<tr>
<td>sources</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$^{252}$Cf</td>
<td>5E+6 n/s</td>
<td>certified standards</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$^{244}$Cm</td>
<td>3E+5 n/s</td>
<td>some</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$^{241}$Am</td>
<td>4.3E+2 n/s, 9.6E+2 n/s</td>
<td>Am/Li certified standards</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Am/Be</td>
<td></td>
<td>certified standards</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pu, PuO$_2$</td>
<td>1.5E+2 n/s (PuO$_2$)</td>
<td>5E+0 n/s to 3E+2 n/s</td>
<td>certified standards</td>
<td></td>
</tr>
<tr>
<td>U, UO$_2$, ThO$_2$</td>
<td></td>
<td>set of well characterised sources</td>
<td></td>
<td></td>
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</tbody>
</table>

### Passive Detection Limit

<table>
<thead>
<tr>
<th>radioactive isotope</th>
<th>total counting</th>
<th>coincidence counting</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{240}$Pu</td>
<td>10 mg</td>
<td>1-2 mg</td>
</tr>
<tr>
<td>$^{240}$Pu</td>
<td>10-20 mg</td>
<td>10 mg</td>
</tr>
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</table>

### Active Detection Limit

<table>
<thead>
<tr>
<th>radioactive isotope</th>
<th>Pu</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{239}$Pu</td>
<td></td>
</tr>
<tr>
<td>$^{239}$Pu</td>
<td></td>
</tr>
</tbody>
</table>
## Synopsis of Neutron Assay Systems

### Computer System
<table>
<thead>
<tr>
<th></th>
<th>CEA1</th>
<th>CEA2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>PC - system</td>
</tr>
</tbody>
</table>

### Software
- **control of system**
  - manipulator: X (turntable) X (turntable)
  - data acquisition: X X
- **analysis of**
  - total counting: X X
  - time correlation analysis: X X
  - signal frequency distribution of n pulse trains: X X
  - coincidence counting: X X
  - multiplicity counting: X X

### Measurement Modes
- **total neutron counting**: X (passive and active modes) X (passive and active modes)
- **segmented neutron counting**: X (angular) X (angular)
- **coincidence counting**: X (passive and active modes) NMC, NCC, TCA (passive and active modes)

### Calibration
- **general**: no
- **waste dependent**
  - mock-up drums + Monte Carlo modelling
  - mock-up drums + Monte Carlo modelling

### Sources
- **$^{252}$Cf**
  - certified standards
- **$^{244}$Cm**
- **$^{241}$Am**
- **Am/Be**
  - X
- **Pu, PuO$_2$**
  - X (active mode)
  - set of well characterised sources
- **U, UO$_2$, ThO$_2$**
  - X (active mode)
  - set of well characterised sources

### Passive Detection Limit
- **$^{240}$Pu (total counting)**: 1 mg 2 mg
- **$^{240}$Pu (coincidence counting)**: 2.4 mg 10 mg

### Active Detection Limit
- **$^{239}$Pu**: 0.03 mg (total) 0.36 mg (prompt)
- **$^{239}$Pu**: 0.045 mg (coinc.) 25 mg (delayed)
## Synopsis of Neutron Assay Systems

<table>
<thead>
<tr>
<th>Absorption Correction</th>
<th>RCM</th>
<th>ENEA</th>
<th>JRC</th>
<th>SCK</th>
</tr>
</thead>
<tbody>
<tr>
<td>no absorption correction</td>
<td>in routine operation</td>
<td>in routine operation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>absorption correction</td>
<td>by matrix interrogation and modelling</td>
<td>by MCNP modelling</td>
<td>by analysis</td>
<td>by add-a-source technique + modelling for interpolation</td>
</tr>
</tbody>
</table>

### Additional Equipment

<table>
<thead>
<tr>
<th>Matrix Interrogation</th>
<th>Model 1001 Neutron Time Correlation Analyser (Antech A. N. Technology Ltd.)</th>
<th>Model 1001 Neutron Time Correlation Analyser (Antech A. N. Technology Ltd.)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>TCA</td>
<td>JSR-12 (Canberra)</td>
<td>JSR-12, JSR-14, AMSR</td>
<td></td>
</tr>
<tr>
<td>NCC</td>
<td>GT657-TIA (Geotest)</td>
<td>GT657-TIA (Geotest)</td>
<td></td>
</tr>
<tr>
<td>NMC</td>
<td>MGA-equipment X</td>
<td>Gamma Scanner + MGA</td>
<td></td>
</tr>
<tr>
<td>HP-Ge detector</td>
<td></td>
<td>Gamma Scanner</td>
<td></td>
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</tbody>
</table>

### References


---

European Network of Testing Facilities for the Quality Checking of Radioactive Waste Packages
## Synopsis of Neutron Assay Systems

### Absorption Correction

<table>
<thead>
<tr>
<th></th>
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<th>CEA2</th>
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</thead>
<tbody>
<tr>
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<td></td>
<td>X</td>
</tr>
<tr>
<td>absorption correction</td>
<td></td>
<td></td>
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</tbody>
</table>

### Additional Equipment

<table>
<thead>
<tr>
<th></th>
<th>CEA1</th>
<th>CEA2</th>
</tr>
</thead>
<tbody>
<tr>
<td>matrix interrogation</td>
<td>in progress</td>
<td></td>
</tr>
<tr>
<td>TCA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NCC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TIA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NMC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MGA-equipment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HP-Ge detector</td>
<td></td>
<td>Gamma radiography + gamma spectrometry</td>
</tr>
</tbody>
</table>

### References

<table>
<thead>
<tr>
<th></th>
<th>CEA1</th>
<th>CEA2</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENDF/BVI JEF-PC</td>
<td></td>
<td>ENDF/BVI JEF-PC</td>
</tr>
</tbody>
</table>
Description of the Individual Passive Neutron Assay Systems

In Appendix C general descriptions of the passive neutron assay systems are given. For each system the abbreviation as defined in Appendix B, the address of the owner and its main features are listed together with a photograph of the system. A short general information summarizes the applications and features followed by the principle of operation. A short summary of the system components and a list with the main specifications completes the general overview. For more detailed information refer to Appendix B with the technical data table or to Appendix D with the list of contact persons.
Synopsis of Neutron Assay Systems

SANDRA (RCM)
Special Arrangement for Neutron Detection in Radioactive Waste

Address

Institut für Radiochemie
Technische Universität München
Walther-Meissner-Str. 3
D-85748 Garching
Germany
Tel.: ++49-89-289-1 22 02
Fax: ++49-89-3 26 11 15

Features

- Mobile system
- Segmented neutron scanner
- Object dimensions up to 1.0 m diameter, 1.0 m height and 2000 kg weight
- 36 $^3$He-counting tubes
- Typical detection efficiencies: 3% to 15%
- Detection limit for $^{240}$Pu$_{eff}$: 10 mg minimum
- Software control of data acquisition and analysis
- Time Correlation Analyser
- Matrix interrogation technique

General

The mobile neutron assay SANDRA is designed for the non-destructive characterisation of transuranic material in radioactive waste packages by their neutron emission due to spontaneous fission (sf) or $(\alpha, n)$-reactions. The system is integrated in a 19" container for transportation by a lorry with a transportation bed.

System Description

The passive neutron assay SANDRA measures the emitted neutrons by scanning the surface of the container using 36 $^3$He-counting tubes, all embedded in 7 polyethylene benches. Six of them set-up a hexagonal array surrounding the waste package. Each is equipped with 5 vertical counting tubes of 1.0 m active length, except one bench equipped with 6 horizontal counting tubes of 0.45 m active length. The remaining detector bench is placed on the top of the waste package containing 5 counting tubes of 1.0 m active length.

Principle of Operation

In a typical inspection measurement a sequence of 6 independent measurements is performed with a rotation of 60° in between, therefore scanning the complete surface of the waste package with the horizontal and vertical detectors. Then a two-dimensional surface distribution of the count-rates is determined by combining the results of the measuring sequence. Matrix interrogation measurements using a $^{240}$Cm-source with a neutron emission rate of 8E+4 n/s give information on the matrix properties by performing a number of subsequent transmission measurements at different height position covering the complete height of the waste package. During the measurement the waste package can be rotated by 360° to cancel out angular inhomogeneities of the matrix.

The count-rate distribution and the information of matrix properties are then merged to determine the $^{240}$Pu$_{eff}$ mass using appropriate models. The results of the Time Correlation Analyser (TCA) allows to distinguish between neutrons created by spontaneous fission and by $(\alpha, n)$-reactions.

Specifications

Container

- Separate loading area, measuring chamber and control room
- Outer dimensions: 6.0 m x 2.5 m x 2.85 m (L x W x H)
- Total weight: 15000 kg maximum
- Loading of waste package: Top loading by crane (hatchway) or side loading by fork lift at the rear door. Mechanical transfer of waste packages
from the loading position to
the measuring position and
back by a carriage
- Transportation: Lorry with
transportation bed
- Power requirements:
  3 x 230 V/50 Hz

Measuring Chamber
- Outer dimensions:
  2.0 m x 2.0 m x 2.4 m
  (L x W x H)
- Inner dimensions:
  1.6 m x 1.6 m x 1.7 m
  (L x W x H)
- Walls: 0.2 m polyethylene at
each side including top, bottom
and doors, supported by
steel frames
- Turntable:
  2000 kg maximum load
- Size of waste packages up to
  400 l drums

Detector system
- 25 vertical $^3$He-counting tubes
  (1.0 m length, 2.5 cm diameter,
  4 bar pressure) embedded in
  5 polyethylene (PE) moder­
ator blocks of 1.0 m height,
  0.6 m length and 0.1 m width.
  Thickness of PE-layer towards
  measuring object: 2.5 cm
- 1 PE bench of identical outer
dimensions equipped with 6
horizontal $^3$He-counting tubes
  (0.45 m length, 2.5 cm diamet­
er, 4 bar pressure)
- 1 PE bench on the top of the
  waste package equipped with
  5 $^3$He-counting tubes (1.0 m
  length, 2.5 cm diameter, 4 bar
  pressure)

Data Acquisition and Sig­
nal Processing
- Amplifier/discriminator: 36
  independent channels with
  preamplifiers (0.5 $\mu$s shaping
  time) and fast pulse discrimi­
nators
- Logical OR and analogue sum
  of the amplifier signals at
  positive or negative polarity
- Pulse counting: 4 software
  controlled plug-in modules
  for 40 channels (CIO-CTR10,
  Plug-In)
- Measurement time: 0.1 s to
  100000 s per interval, number
  of cycles arbitrary
- Controller: Time control, data
  acquisition, on-line indication
  of current measurement, me­
chanical movements and data
  analysis by a PC 486
- Background: Less than 0.1
cps/counter (depending on
environment)
- Gross counting efficiency: 3 %
to 15 % concerning 200 l
  drums (depends on matrix
  properties)
- Detection limit: 10 mg
  $^{239}$Pu equiv at minimum (1000 s
  time interval)

Hardware
- Control of mechanics, data
  acquisition and data evalu­
ation: PC 486/66
- Control of TCA: PC 486/66

Software
- Operating system:
  Windows 95
- Control, data acquisition and
  data evaluation: NESDAQ 1.0
  (RCM)

Additional Equipment
- Matrix interrogation unit:
  Source $^{241}$Am, $^{244}$Cm,
  8E+4 n/s,
  lifting range: from 0.0 m up to
  1.0 m height
- Time Correlation Analyser
  (TCA): Model 1001 Neutron
  Time Correlation Analyser
  Antech A. N. Technology Ltd.
**SMNP (ENEA)**
Sistema di Misura Neutronica Passiva

**Address**

ENEA-RAD-LAB  
C.R. Casaccia  
I-00060 S. Maria di Galeria (Rome)  
Italy  
Tel.: ++39-06 3048 6586  
Fax: ++39-06 3048 6590

**Features**

- Transportable system, fixed geometry
- Can accommodate drums up to 400 l, 1000 kg
- 64 $^3$He-counting tubes
- Typical detection efficiency: 20%
- Detection limit for $^{239}$Pu: 10 mg minimum
- Software controlled data acquisition and analysis
- Neutron Multiplicity Counting (JRC-Ispra)
- Neutron Coincidence Counting (LANL)

**General**

The SMNP (Sistema di Misura Neutronica Passiva) was designed for the assay of radioactive waste drums containing contaminated material. The instrument based on a original JRC-Ispra design measures the neutron emission from spontaneous fission and from $(\alpha,n)$-reaction.

**System Description**

The detection head is constituted by one vertical section decagon shaped with 4 detectors for 10 sectors and two horizontal sections (top and bottom of the sample cavity) with 4 detector for 3 sectors each.

An eight input channel digital mixer receives the analogue signals from the nuclear electronics, converts them into TTL standard signals which are then fed to the Time Correlation Analyser (TCA), Shift Register (SR) and Time Interval Analyser (TIA) modules allowing the simultaneous operation of the three systems of analyses.

The loading of the waste package is carried out through two mobile side walls (doors) of the decagon by a crane manually operated (hatch-way).

**Principle of Operation**

The measurement is performed with the waste package suspended in the middle of the cavity without rotating the drum. The simultaneous operation of the analyses system allows measurement of a waste package by the three different techniques implemented.

In a typical inspection measurement the sequence is:
- Single measurement of ten minutes to estimate the neutron count-rate.
- Series of “long-time” measurements (typ. 6 measurements).
- Series of “short-time” measurements (typ. 15).

For each measurement the results of TCA, SR and the pulse train collected by TIA are stored for subsequent analysis by software.

**Specifications**

**Capacities**

Size:
- Height: 1100 mm  
- Diameter: 700 mm  
- Weight: 1000 kg (max.)

**Measuring Chamber**

Outer dimensions:
- Length: 1463 mm  
- Width: 1540 mm  
- Height: 1890 mm

Inner dimensions:
- Diameter: 745 mm  
- Height: 1170 mm

**Background shielding**

- Walls: 220 mm polyethylene, 1 mm outer stainless steel liner
Synopsis of Neutron Assay Systems

and 1 mm inner cadmium liner at each side including top, bottom and doors.

Detector system

- 40 vertically mounted ³He-Ar counters (5 bar pressure), 1000 mm active length, 25.4 mm diameter, embedded in 10 polyethylene moderator blocks of 1040 mm height, 244 mm length and 102 mm width.
- 1.0 mm cadmium liner.
- Thickness of PE-layer towards measuring object 100 mm.
- 2 polyethylene benches of identical mechanical dimensions with 24 horizontally mounted ³He-Ar counters (4+1 bar pressure), 1000 mm length, 25.4 mm diameter on the top (12) and on the bottom (12) of the measuring chamber.

Physical

- Maximum burden: kN.
- Clearance size: 3200 x 2250 x 3055 mm.

Data Acquisition and Signal Processing

- 16 quadruple preamplifiers
- 16 linear amplifier/discriminators grouping 16 detectors
- 4 HV power supplies
- Time Correlation Analyser (TCA, JRC Ispra design)
- Neutron Coincidence Counter (NCC, JSR-11 Jomar, Canberra)
- Time Interval Analysis card, PC-AT bus compatible (ALL DATA mod GT657); 16 input channels, 2 MB RAM, time resolution and measurement rate up to 1E+7 s⁻¹, resolution 20 ns
- Controller: Time control, data acquisition on-line indication and data analysis by PC 286 (TCA), Shift Register JSR-11 (NCC), Pentium 75 (TIA)

- Simultaneous operation of the three counting systems assured by eight input channel digital mixer
- Background: 5 cps (depending on environment)
- Detection limit: 10 mg ²⁴²P₂equiv

Hardware

- Control of TCA: PC 386
- Control of TIA: Pentium 75
- NCC operated by Jomar-Canberra electronics JSR-11

Software

- Operating system: DOS, Windows 95
- TCA software for data acquisition and analysis (JRC-Ispra)
- TIA software ATEasy 2.0 (GEOTEST) for data acquisition
- Self-developed C++ software implementing NCC, NMC, bi- and three-dimensional Rossi-Alpha algorithms
JRC Drum Monitor (JRC)
Assay of Pu bearing intermediate and low level waste in 220 litre drums

Address
European Commission
Joint Research Centre
Institute for Systems, Informatics and Safety
I-21020 Ispra (VA)
Tel: +39-0332 789802
Fax: +39-0332 789072

Features
• Modular design for easy assembly on site
• Drum volume up to 220 litres and mass up to 1000 kg
• Detection efficiency of 19% with 64 He-3 detector tubes
• Detection limit for Pu-240eff: 1-2 mg (Totals counting)
• Semi-automatic drum loading/unloading
• Absolute Pu mass assay employing the triple neutron correlation analysis
• Mechanical design in compliance with requirements for CE certification

General
The JRC Drum Monitor is a comprehensive measurement system for the determination of plutonium mass in intermediate/low level waste in 220 litre drums. The operation of the instrument is based on passive neutron coincidence/multiplicity counting. The design is the result of 30 years experience in the Joint Research Centre in the field of passive neutron assay. The JRC Drum Monitor has characteristics which are optimised for the plutonium mass determination by the so called neutron correlation analysis.

System Description
The neutron detection system employs 64 He-3 tubes grouped in 16 rectangular polyethylene modules each with 4 tubes connected to a high voltage junction box containing the charge sensitive pre-amplifier/amplifier circuit and connections for high voltage, low voltage, and signal cables. The detector modules are fixed inside an outer shield of polyethylene of 220 mm thickness and covered in stainless steel. The internal and external module surfaces are covered in cadmium. The design is based on a modular concept to facilitate easy assembly and flexibility in operation mode. For example the inner cadmium can be removed to increase the detection probability to achieve very low level detection with total neutron counting, the moderator thickness can be varied for special applications, a lead shielding may be added between the modules and the drum for highly gamma active waste.

The current drum loading system consists of a manually operated crane and automatically operated doors. This system is easily modified into a semi-automatic drum loading/unloading operated via the host computer. The commercial version of the JRC Drum Monitor employs a conveyer belt instead of the crane for the drum manipulations.

Principle of Operation
Spontaneous fission neutrons emitted from the Pu bearing drum are detected in the detector modules. The signal pulse train, representing the time of detection of neutrons, is analysed with a signal frequency analyser. The frequency analyser currently used is the ANTECH 1000 Series multiplicity counter. The analysis of the frequency histograms is done according to either the pair correlation method or the triple correlation method. In the pair correlation method the measured Reals are used with a predetermined calibration curve to determine the Pu-240eff mass and hence the total Pu mass.
For a wide range of plutonium containing materials, however, the neutron multiplication may be considered unitary and the triple correlation method may be applied for the absolute determination of the plutonium mass. With this procedure the plutonium mass is determined without the use of a calibration function and the matrix characteristics are determined from the measured detection efficiency.

**Specifications**

**Capacity**
- 220 litre (55 gallon) drums (Max. diameter 70 cm, max. height 110 cm) 1000 kg weight

**Measuring Chamber**
- Diameter: 74.9 cm
- Height: 111.5 cm

**Background Shielding**
- 22 cm of polyethylene, 1 mm of cadmium

**Detector System**
- 64 $^3$He detectors (active length 100 cm)
- 64 pre-amplifiers/amplifiers
- Operating voltage 950 V
- Detector efficiency 20 %
- Die-away time 68 µs

**Physical**
- External dimensions: 320 cm x 176 cm x 215 cm (H x W x L)

**Hardware**
Sealed air-conditioned cabinet containing:
- Electronics for amplifier diagnostics and regulation,
- ANTECH 1000 Series multiplicity counter,
- Host computer with Windows NT and data storage,
- Un-interruptible Power Supply, printer.

**Software**
- Windows NT based software controls data acquisition and analysis algorithms. Option for computer controlled automated measurement cycle.

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European Network of Testing Facilities for the Quality Checking of Radioactive Waste Packages
Hexagon Passive Neutron Counter (SCK)

Address

SCK-CEN
Boeretang 200
B-2400 Mol
Belgium
Tel.: ++32-14 33 22 63
Fax: ++32-14 32 15 29

Features

- 60 \(^{3}\)He detectors
- 20 detector benches of 3 detectors
- 16 individual counting channels
- Cadmium lined sample chamber
- Matrix interrogation with external source
- Software control of data acquisition and analysis
- Neutron Counting with Time Interval analyser
- Computed Neutron Coincidence Counting (CNCC)
- Multiplicity Counting

General

The passive neutron assay system is built with 20 detector modules which are fixed to a modular frame. The frame is currently dimensioned to form a detector cavity for 220 l waste drums. The detector cavity has 12 detectors on top and 12 detectors at the bottom, the remaining 36 detectors are positioned vertically in a hexagonal configuration. The frame contains 2 hinged doors through which the drum is entered in the system. The neutron counter is installed in a paraffin castle for background suppression. The drum is manually entered in the system via two rails.

System Description

The detector assembly contains 60 \(^{3}\)He detector tubes of 1 m active length. The detector tubes are arranged in 20 equal detector blocks made of high density polyethylene. The detector blocks are fixed on a modular frame in a 4 \(\pi\) detection geometry. One side of the detector blocks is cadmium lined. The 4 detector blocks of respectively top and bottom of the cavity are connected 2 by 2 to an OR-gate to constitute 4 channels. In total 16 individual channels are available for neutron emission rate monitoring.

Data acquisition is made by a Time Interval Analyser (TIA) board plugged in to a PC. Software is used to implement coincidence and multiplicity counting. The TIA is applicable for waste assay with moderate neutron emission.

Principle of Operation

The \(^{3}\)He detectors detect neutrons emitted by the waste package. The neutron arrival time of each detected neutron is measured with a Time Interval Analyser board with a resolution of 20 ns. The arrival times are continuously processed by software modules, which compute the neutron coincidence information via Rossi-Alpha spectra. No pulse pile-up exists between pulses in different channels.

Software modules for totals counting, coincidence counting (Reals and Accidentals) and multiplicity counting (Singles, Doubles and Triples) are implemented. In the multiplicity mode the assay does generally not require an efficiency calibration and detection efficiency, \((\alpha,n)\) production rate and \(^{240}\)Pu mass are determined in the multiplicity analyses (Pu mass must exceed 100 mg). In doubles coincidence mode an efficiency calibration is necessary to relate plutonium mass and doubles rate. Matrix interrogation is used to identify the appropriate item specific calibration curve. Count rate distributions are
Synopsis of Neutron Assay Systems

used to determine the activity distribution in the drum from which correction factors for the source distribution can be computed.

Specifications

Cavity & Detectors

- $4\pi$ detection configuration
- 60 $^3\text{He}$ detectors, 4 bar, 1 bar Argon, 1.0 m length, 2.5 cm diameter
- 20 identical detector benches: 1.0 m length, 0.2 m width, 0.1 m depth, 1 mm cadmium lining, 2.5 cm thick PE moderator, 5 cm thick PE reflector
- max. detection efficiency 12% (point source in centre of cavity)
- 20 Amptek preamplifiers/discriminators (1 amplifier per 3 detectors)
- system dimensions (outer): 1.0 m length, 1.0 m width, 1.5 m height (220 l drum configuration)
- sample loading via two roller rails and 2 hinged doors of the cavity
- max. load: 1000 kg

Background shielding

- Paraffin castle with 40 cm thick walls and 2 sliding doors in PE houses the neutron counter
- An active background rejection filter is used in the multiplicity counting mode to reduce high multiplicity events due to spallation neutrons caused by cosmic rays
- Background levels: Singles: 1.85 c/s Doubles: 0.052 c/s Triples: 0.007 c/s

Electronics

- Amplifiers: Amptek 111A
- 16 channel TIA board

Data Acquisition and Signal Processing

- 16 channel TIA board (Geotest)
- 20 ns Pulse to Pulse resolution
- 10 Mpulses/s data acquisition
- 20 k pulses/s on-line data processing
- evaluation and acquisition: Pentium 200 MHz

Hardware

- Control of mechanics, data acquisition and data evaluation: PC Pentium (200 MHz)

Software

- Control and acquisition: SCK-CEN software based on LabVIEW interfacing with TIA board

Additional Equipment

- Matrix interrogation unit
**PROMETHEE**
(CEA1)

Alpha low level waste assay in 118 litre drums (passive and active measurements)

**Address**
French Atomic Energy Commission
Cadarache Centre
DED/SCCD/LDMN
13108 Saint Paul lez Durance cedex
France

Tel. ++33-442252847
Fax ++33-442252367

**Features**
- R&D prototype
- 118 litre drums, max weight 50 kg with rotation, 150 kg without a turntable (movement of rotation of the drum for angular measurements)
- 14 MeV pulsed neutron generator (Gin26 = 1.6E+6 s⁻¹, Genie36 = 2.4E+6 s⁻¹)
- main constituents: graphite for moderation, polyethylene covering external faces of graphite to reduce the background and to serve as a biological protection
- detection units in polyethylene, covered with cadmium and boron carbide and including a total of 88 ³He proportional counters (2 inch in diameter, active lengths of 100 cm and 50 cm)
- an external monitor (bare ³He proportional counter, 1 inch in diameter, active length of 15 cm)
- active and passive neutron measurements in both total and coincidence counting modes, plus multiplicity analysis

**General**
Interrogating neutrons are produced during 15 μs at a repetition rate of 125 Hz. These interrogating neutrons are thermalized within the graphite walls and induce fissions of the fissile contaminant of the waste (DDT method). Prompt fast neutrons resulting from fissions are discriminated from the interrogating neutrons through the cadmium and the boron carbide. They are detected in the ³He counters located in the door and in the two lateral faces of the cell. The fissile mass is deduced from an appropriate calibration curve with the help of Monte Carlo calculations. The measured objects are low gamma irradiating drums. Passive and active neutron measurements of the non-fissile (²³⁸Pu, ²³⁹Pu, ²⁴²Pu, ²⁴²Cm, ²⁴⁴Cm …) and the fissile (²³³U, ²³⁵U, ²³⁹Pu, ²⁴¹Pu…) isotopes, respectively, contained in 118 litre-«European» drums are the two methods set up in the PROMETHEE measurement cell.

**System Description**
The generator is settled within the graphite located in the opposite face of the door. Three detection units are placed in the two other lateral faces and in the door of the cell, at a distance of 100 mm from the measurement cavity (the floor and the roof contain no detector). Each detection unit is composed of polyethylene covered with cadmium on the side towards the cavity, and B₄C on the five other sides. The two lateral blocks each contain two layers of horizontal ³He-proportional counters, 2 inch in diameter, 100 active cm long and filled with ³He at a pressure of 4 bars (first layer, 15 detectors) and 2 bars (second layer, 14 detectors). The door block contains two layers of 8 and 7 vertical, superimposed ³He-proportional counters, 2 inch in diameter, 50 active cm long and filled with ³He at a pressure of 4 bars. The PROMETHEE cell contains a total of 88 ³He-proportional counters. An external bare counter, 15 active cm long and filled with ³He at a pressure of 6 bars, is also used to monitor the...
Synopsis of Neutron Assay Systems

generator neutron emission. The detector signals are amplified and shaped in 24 charge amplifiers (ACHNA98, Eurisys Mesures). These modules are placed close to the detector outputs, inside the irradiation hall. Each amplifier output is transmitted out of the irradiation hall through 50 Ω cables and fed to multichannel scalers (Novelec). The monitor signal is transmitted out of the irradiation hall through a shielded 50 Ω cable to an ADSF current amplifier module and then to a multichannel scaler. The detection of a signal is synchronized with the generator pulse and recorded between each sweep. The twenty-four measurement banks are connected to a passive and active coincidence or multiplicity counting card Histoc using twelve inputs (Novelec, CEA patent). Data are recorded in a dedicated PC. Finally, a second PC equipped with specific software developed at the laboratory is dedicated to the total neutron counting.

Principle of Operation

Both passive and active measurements are performed with the waste package hand-placed inside the cavity (angular rotations are possible). The total passive and the total prompt active signals are detected using all the 88 ³He counters connected to 21 MCS channels. The bare monitor is connected to its own MCs channel. The coincidence and multiplicity signals can be extracted from data delivered by the Histoc acquisition device. Both experimental and calculated calibration curves are used to deduce the non fissile (passive mode) and the fissile (active mode) material from the signals.

Specifications

General
- outer dimensions (L x W x H): 190 cm x 140 cm x 160 cm
- mainly composed of high purity graphite

Cavity &Detectors
- 118 litre drums
- dimensions of the cavity (L x W x H): 55 cm x 55 cm x 90 cm
- a turntable supporting 50 kg in rotation (150 kg without rotation movement)
- possibility of segmented neutron counting

Detectors
- three faces geometry
- all faces detectors embedded in polyethylene wrapped in cadmium and boron carbide
- lateral faces: 2 horizontal layers of (15 ³He proportional counters, 4 bars, 100 active cm long, 2 inch. in diameter + 14 ³He proportional counters, 2 bars, 100 active cm long, 2 inch. in diameter)
- door: 2 vertical layers of (8+7) superimposed ³He proportional counters, 4 bars, 50 active cm long, 2 inch. in diameter
- monitor: an external ³He proportional counter, 6 bars, 15 active cm long, 1 inch in diameter
- amplifier: 24 charge amplifiers (ACHNA98 (Eurisys Mesures)) for the face detectors, 1 current amplifier ADSF (Eurisys Mesures) for the monitor

Background shielding
- 10 cm CH₂ covering the external faces of the measurement cell

Data Acquisition and Signal Processing
- 22 MCS channels
- 12 Histoc channels
- evaluation and acquisition: PC 486 (MCS Novelec), Pentium 80 MHz (Histoc)

Hardware
- Turntable: PC 486 (Novelec)
- Neutron generator: Portable Pentium 120 MHz

Software
- Operating system: Windows 3.1 (Novelec), Windows 95 (Histoc + neutron generator)
- Self developed software for data analysis implementing MCS (Novelec), NCC, NMC, Ross Alpha (Histoc)
- Neutron generator software (Sodern)

Additional Equipment
- in progress: matrix correction method using the prompt gamma rays resulting from neutron capture
SYMERIC

(CEA2)

Système de Mesures - Tri de Colis

Address

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SCCD/LDMN Bât. 326
13108 Saint Paul Lez Durance
France

Tel.: +33-4-42-25-35-67
Fax.: +33-4-42-25-23-67

Features

- Drum volume up to 220 litres and mass up to 500 kg
- Detection efficiency of 23 % with 99 3 He detector tubes
- Genie 36, 14 MeV neutron generator (up to 2E+9 n·s⁻¹, pulsed mode, Soderm)
- Medas, counter/timer card, 32 channels, identification of each input channel (Cesigma)
- Typical detection efficiency: 5 % to 23 %
- Passive detection limit for ²⁴⁰Pu: 10 mg (coincidence counting, 600 s)
- Active detection limit for ²³⁹Pu: 0.36 mg (prompt neutron, 900 s, neutron generator emission 1E+9 n·s⁻¹)
- Semi-automatic drum loading/unloading
- Software control of data acquisition and analysis
- Neutron Multiplicity counting
- Neutron coincidence counting (passive and active mode)

General

The SYMETRIC (Système de Mesures - Tri de Colis) device is designed for the assay of radioactive intermediate level waste drums containing α and β contamination material (up to 3 Gy·h⁻¹). The device is dedicated to both passive (total and coincidence) and active (prompt and delayed) neutron measurements associated with gamma radiography and a gamma spectrometry systems.

System Description

The neutron cell design is a parallelepiped in which three among the four vertical walls are equipped with horizontal detectors. Each instrumented wall contains 33 ³ He tubes (0.5 m active length) distributed in two layers (inner layer: 17 detectors, outer layer: 16 detectors) in a polyethylene module wrapped with a 2 mm cadmium protection. The inner face of the wall is protected with a 5 cm lead shielding against drum potential gamma irradiation. The outer face is composed of graphite. The whole cavity is protected with an aluminium skin for decontamination purpose. The fourth wall, essentially made of graphite (opposite to the door), is dedicated to the neutron pulsed generator which is surrounded by lead. Top and bottom of the device are made of graphite. An external polyethylene shielding of the device ensures the radioprotection purpose. Each group of 3 or 4 tubes is connected to a high voltage junction box containing the charge sensitive pre-amplifier/amplifier circuit (less than 1 m long cable) and connections for high voltage, low voltage, and logical and analogical signals cables. The logical signals are fed to the counter/timer card that allows both passive (NMC, NCC, TCA) and active (DDT) treatment. The box is fixed outside the cell. The drum loading consists in manually or automatically operated system depending on the waste gamma activity and semi-automatically operated door. The cell is equipped with a turntable.

Principle of Operation

Both active and passive measurements are performed with the waste package rotating by 360° to cancel out angular inhomogeneities of the matrix. The counter/timer card Medas associated with specific software
Synopsis of Neutron Assay Systems

allows to extract the coincidence signal for the passive measurement and the prompt and delayed signals for the active one. Simulation models are then used to estimate $^{239}$Pu from the coincidence signal, and to quantify separately $^{239}$Pu and $^{235}$U from prompt and delayed signals. Gamma radiography and spectrometry are used to add more information for the active signals interpretation.

Specifications

Capacity

- 220 litre drums

Measuring Chamber

- Outer dimensions:
  length: 185/355 cm (closed/open)
  width: 196 cm
  height: 255 cm
- Inner dimensions:
  length: 74.8 cm
  width: 74.8 cm
  height: 121.5 cm
- turntable: 500 kg (max.) load, 1 to 10 min

Background shielding

- walls: 10 cm (vertical walls), 50 cm (roof of the cell) of polyethylene
- detection modules: 2 mm of cadmium

Detector system

- 99 $^3$He detectors (active length 50 cm, 5 cm diameter, 4 bar), 1 $^3$He detector outside the cell (active length 15 cm, 2.5 cm diameter, 2 bar)
- 31 pre-amplifiers/amplifiers

Data Acquisition and Signal Processing

- Medas, counter/timer card (PCI card): 32 input channels for measurement, 1 input channel for neutron generator trigger, identification of each channel, measurement rate up to $2 \times 10^7$ s$^{-1}$ per channel, resolution 25 ns
- 6 HV power supplies
- 3 double LV supplies

Hardware

- Control of Medas card: Pentium III, 500 MHz
- Control of neutron generator: Pentium Pro 200 MHz

Software

- Operating system: Windows NT 4.0
- Medas (Cesigma) software for data acquisition
- Self developed software for data analysis implementing NCC, NMC, DDT and Rossi-Alpha algorithm
- Neutron generator software (Sodern)
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Synopsis of Neutron Assay Systems

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