European Commission

SYNOPSIS OF NEUTRON ASSAY SYSTEMS

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

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

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**EUROPEAN NETWORK OF TESTING FACILITIES
FOR THE QUALITY CHECKING OF
RADIOACTIVE WASTE PACKAGES**

Working Group A

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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 1: *Measuring modes conventionally used in quality control of radioactive waste packages.*

	gamma radiation	neutrons
passive	dose rate measurements gamma counting segmented gamma scanning	total neutron counting segmented neutron counting time correlation methods
active	radiography tomography interrogation techniques	interrogation techniques

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 $^{240}Pu_{equiv}$ 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 (α,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, α-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 ^3He 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 ^3He-counting tube, a BF_3-counting tube, a Gd- or B-loaded scintillation detector, a fission chamber, etc. [KNO89]. In most current operating systems ^3He-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.

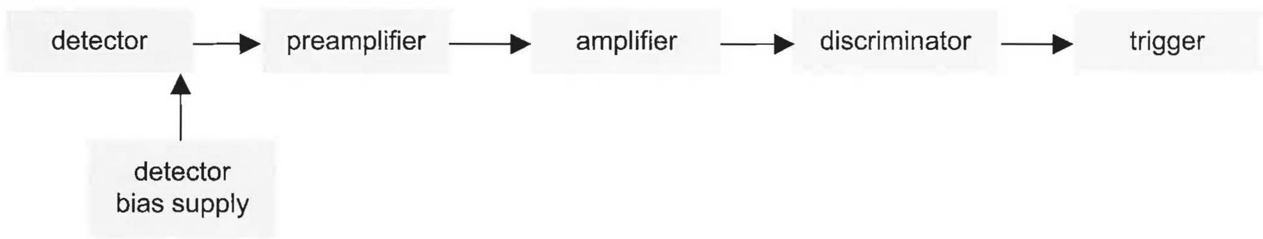


Figure 1: *Block diagram of a typical neutron detection system.*

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 4π-geometry.

2.3 Moderator

The energy range of the neutrons emitted by sf or (α,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 origin for example 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. ^{244}Cm, ^{252}Cf, 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. $^{240}Pu_{equiv}$) can be given.

Nethertheless, 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_B 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 ($N \cdot M + N_B + N_T$) 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 extend insensitive to the actual source distribution, but its application is limited to $^{240}Pu_{eff}$-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 $^{240}Pu_{equiv}$-mass usually in a conservative way, i.e. for an inhomogeneous distribution of neutron emitters the $^{240}Pu_{equiv}$-mass will be lower than calculated.

4.2 Basic Relations

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

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

with M: $^{240}Pu_{equiv}$-mass [g]
Z: net count-rate [s^{-1}]
k: transfer or correlation factor [$s \cdot g^{-1}$]

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.

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.

Nethertheless, 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 calibration 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

[BUC98] T. Bücherl, E. Kaciniel, Ch. Lierse, "Synopsis of Gamma Scanning Systems - Comparison of Gamma Determining Systems and Measuring Procedures for Radioactive Waste Packages", European Network of Testing Facilities for the Quality Checking of Radioactive Waste Packages, Report WG-A-01, September 1998.

[BUC99] Bücherl T., Vicini C., Filß P., Caspary G., Guldbakke S., Bruggeman M., Frazzoli F. V., Lyoussi A., "Improvement of passive and active neutron assay techniques for the characterisation of radioactive waste packages - Final Report", ISBN 92-828-7646-2, EUR 19121 EN (1999).

[KNO89] G. F. Knoll, Radiation detection and measurement, John Wiley & Sons, Inc. 1989.

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[1] [ISO99].

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

[1] ISO-standard "Radioactive characterisation of waste packages - Passive Neutron Counting" is under preparation. Actual number: ISO/TC85/SC5/WG5 N172, January 1999.

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

	RCM	ENEA	JRC	SCK
General				
commercial system	no	no	yes	no
company	-		Antech A. N. Technology Ltd.	
model	-		Drum Monitor Series 2200	
mobile	yes	yes	yes	yes
Labour				
routine [%]	40	80	50	
research [%]	60	20	50	100
Mechanical Specifications				
movement of				
waste package	rotation	no	no	no
detector(s)	no	no	no	no
others	interrogation source		semi-automatic drum loading	interrogation source
Waste Package				
max. drum size [l]	400	400	220	200
max. weight [kg]	2000	1000	1000	1000
Detector System				
type	^{3}He-counting tube	^{3}He-counting tube	^{3}He-counting tube	^{3}He-counting tube
company	Berthold, Germany	Xeram, France	Xeram, France	Eurysis Mesures/ Dextray, France
number	30/6	64	64	60
length [cm]	100/45	100	100	100
diameter [cm]	2.5	2.54	2.54	2.5
gas	^{3}He	^{3}He + Ar	^{3}He	^{3}He + Ar
pressure [bar]	4	4 + 1	4	4 + 1
Detector Arrangement				
	hexagonal arrangement of 31 detectors + 5 top detectors	decagonal arrangement of 40 detectors + 12 top detectors and 12 bottom detectors	10 vertical modules forming a decagon, 3 modules on top, 3 modules on bottom	36 in a hexagonal arrangement + 12 top + 12 bottom
Moderation System				
	PE	PE	HD-PE	PE

	CEA1	CEA2		
General				
commercial system	no	no		
company				
model	prototype			
mobile	no	no		
Labour				
routine [%]				
research [%]	100	100		
Mechanical Specifications				
movement of				
waste package	rotation	rotation		
detector(s)		no		
others		semi-automatic drum loading		
Waste Package				
max. drum size [l]	118	220		
max. weight [kg]	50/150 (with/ without rotation	500		
Detector System				
type	30NH15, 410NH1C/5, 300NH1C/5, 205NH50/5	^{3}He counting tube		
company	Eurisys Mesures	Eurisys Mesures/ Dextray, France		
number	1/30/28/30	99/1		
length [cm]	15/100/100/50	50/15		
diameter [cm]	1/2/2/2	5/2.5		
gas	^{3}He	^{3}He		
pressure [bar]	6/4/2/4	4/2		
Detector Arrangement				
	external/ lateral face/ lateral face/ door	3 x 33 horizontal arrangement with 2 layers		
Moderation System				
	graphite	graphite carbone		

	RCM	ENEA	JRC	SCK
Background Shielding				
general	measuring system is placed in a cube having PE-walls of 20 cm thickness	outer stainless steel liner (1 mm) inner cadmium liner (1 mm)	22 cm of HD-PE, 1 mm Cd	Paraffin castle with PE roof and doors
background count-rate	ca. 3 s^{-1}	ca. 3 s^{-1}	2.4 s^{-1}	Singles : 1.85 s^{-1} Doubles: 0.052 s^{-1} Triples : 0.007 s^{-1}
Electronics				
preamplifier	142IH (EG&G Ortec)		home-made	AMPTEK 111A
amplifier	RCM module		home-made	AMPTEK 111A
ADC	RCM module		home-made	
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)

	CEA1	CEA2		
Background Shielding				
general	10 cm CH_2 on external faces	external PE walls (10 cm), inner Cd (2 mm) and Pb walls (5 cm)		
background count-rate	total: 1.3 s^{-1} coinc.: 0.12 s^{-1} total counting (activ): 30 s^{-1} coinc. counting (act.iv): 0.1 s^{-1}	total: 8 s^{-1} coinc: 1.3 s^{-1} prompt neutrons: 5000 s^{-1} delayed neutrons: 54 s^{-1}		
Electronics				
preamplifier	ACHNA98 (Eurisys Mesures)	ACHNA98 (Eurisys Mesures)		
amplifier	ACHNA98 (Eurisys Mesures)	ACHNA98 (Eurisys Mesures)		
ADC				
discriminator				
multichannel scaler	Novelec			
multiplicity recorder	Histoc (CEA patent)			
counter/timer card		Medas plug in card (Cesigma)		
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				

	RCM	ENEA	JRC	SCK
Computer System				
	PC-system	PC-system, microprocessor system	PC-system	PC-system
Software				
control of				
system	X			X
manipulator	X			X
data acquisition	X	X	X	X
analysis of				
total counting	X	X	X	X
time correlation analysis	X	X		X
signal frequency distribution of n pulse trains		X	X	X
coincidence counting		X	X	X
multiplicity counting		X	X	X
Measurement Modes				
total neutron counting	X		X	X
segmented neutron counting	X			X (angular)
coincidence counting	TCA	NMC, NCC, TCA	X	X
Calibration				
general	no	X		no
waste dependent	mock-up drums	Monte Carlo modelling	-	mock-up drums + Monte Carlo modelling
sources				
^{252}Cf	5E+6 n/s		certified standards	
^{244}Cm	3E+5 n/s		some	
^{241}Am	4.3E+2 n/s 9.6E+2 n/s		Am/Li certified standards	
Am/Be			certified standards	
Pu, PuO_2	1.5E+2 n/s (PuO_2)	5E+0 n/s to 3E+2 n/s	certified standards	
U, UO_2, ThO_2				set of well characterised sources
Passive Detection Limit				
^{240}Pu (total counting)	10 mg		1-2 mg	1 mg
^{240}Pu (coincidence counting)			10-20 mg	10 mg
Active Detection Limit				
^{239}Pu				
^{239}Pu				

	CEA1	CEA2		
Computer System				
		PC - system		
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	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)		

	RCM	ENEA	JRC	SCK
Absorption Correction				
no absorption correction	in routine operation	in routine operation		
absorption correction	by matrix interrogation and modelling	by MCNP modelling	by analysis	by add-a-source technique + modelling for interpolation
Additional Equipment				
matrix interrogation	yes			yes
TCA	Model 1001 Neutron Time Correlation Analyser (Antech A. N. Technology Ltd.)		Model 1001 Neutron Time Correlation Analyser (Antech A. N. Technology Ltd.)	
NCC		JSR-12 (Canberra)	JSR-12, JSR-14, AMSR	
TIA		GT657-TIA (Geotest)		GT657-TIA (Geotest)
NMC				
MGA-equipment	X			Gamma Scanner + MGA
HP-Ge detector				Gamma Scanner
References				
	JEF-PC: A program for displaying data from Joint Evaluated File, O.E.C.D./NEA Data Bank (1995)	JEF-PC: A program for displaying data from Joint Evaluated File, O.E.C.D./NEA Data Bank (1995)		Compilation of fission yields and multiplicity data

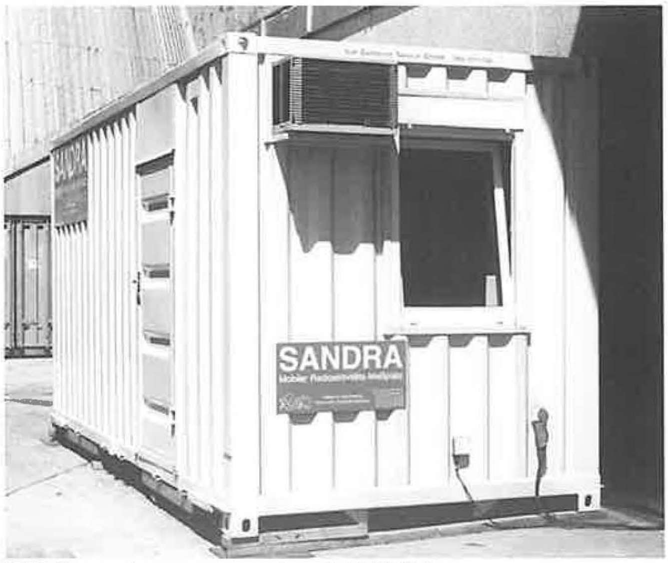
	CEA1	CEA2		
Absorption Correction				
no absorption correction		X		
absorption correction				
Additional Equipment				
matrix interrogation	in progress			
TCA				
NCC				
TIA				
NMC				
MGA-equipment				
HP-Ge detector		Gamma radiography + gamma spectrometry		
References				
	ENDF/BVI JEF-PC	ENDF/BVI JEF-PC		

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.

SANDRA (RCM)

Special Arrangement for Neutron Detection in RAdioactive Waste



Mobile neutron assay system SANDRA.

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 (α,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 $^{243/244}Cm$-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 (α,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) moderator 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 diameter, 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 Signal Processing

- Amplifier/discriminator: 36 independent channels with preamplifiers (0.5 µs shaping time) and fast pulse discriminators
- 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, mechanical 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 $^{240}Pu_{equiv}$ at minimum (1000 s time interval)

Hardware

- Control of mechanics, data acquisition and data evaluation: 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 $^{243/244}$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 Correaltion 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

View of the measuring head and the loading system.

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 $^{240}Pu_{eff}$: 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 α-contaminated material.
The instrument based on a original JRC-Ispra design measures the neutron emission from spontaneous fission and from (α,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 and 1 mm inner cadmium liner at each side including top, bottom and doors.

Detector system

- 40 vericaly mounted ^{3}He-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 ^{3}He-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 Intervall Analyser 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: 5cps (depending on environment)
- Detection limit:
  10 mg $^{240}Pu_{equiv}$

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 acquisiton 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

View of the measuring head.

Address

European Commission
Joint Research Centre
Institute for Systems, Informatics and Safety
I-21020 Ispra (VA)
Tel: +39-0332 789802
Fax: +39-0332 785072

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:

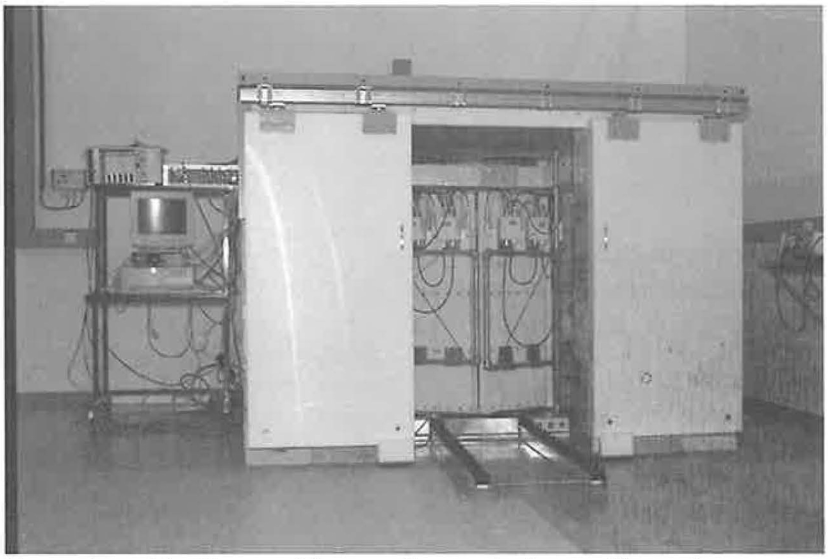
- Electronics for amplifier diagnostics and regulation,
- ANTECH 1000 Series multiplicity counter,
- Host computer with Windows NT and data storage,
- Un-interruptible Power Supply, printer.

Software

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

Hexagon Passive Neutron Counter (SCK)

Hexagon Passive Neutron Counter



Front view of the Hexagon Neutron Counter in the paraffin castle.

Address

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

Features

- 60 ^3He 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 ^3He 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 4π 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 far waste assay with moderate neutron emission.

Principle of Operation

The ^3He 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, (α,n) production rate and $^{240}Pu_{eff}$ 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

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

Specifications

Cavity &Detectors

- 4π detection configuration
- 60 ^3He 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: 1000kg

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 kpulses/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

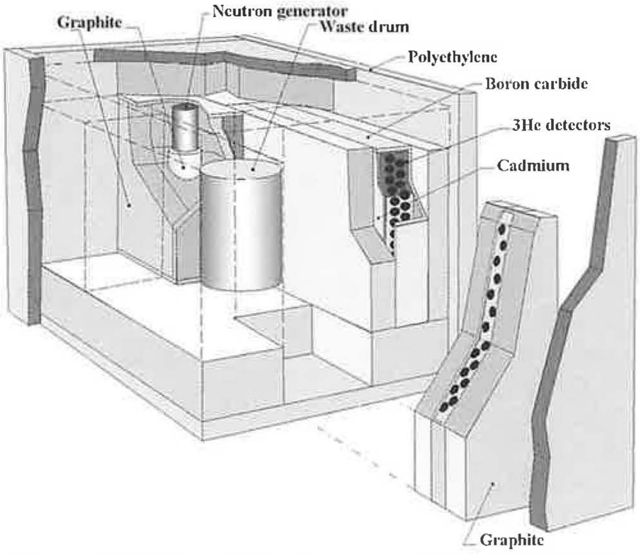
Additional Equipment

- Matrix interrogation unit

PROMETHEE

(CEA1)

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



Schematic view of the PROMETHEE waste assay system

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+ 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 ^{3}He 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 ^{3}He 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 (^{238}Pu, ^{240}Pu, ^{242}Pu, ^{242}Cm, ^{244}Cm ...) and the fissile (^{233}U, ^{235}U, ^{239}Pu, ^{241}Pu...) 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 B_4C on the five other sides. The two lateral blocks each contain two layers of horizontal ^{3}He-proportional counters, 2 inch in diameter, 100 active cm long and filled with ^{3}He 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 ^{3}He-proportional counters, 2 inch in diameter, 50 active cm long and filled with ^{3}He at a pressure of 4 bars. The PROMETHEE cell contains a total of 88 ^{3}He-proportional counters. An external bare counter, 15 active cm long and filled with ^{3}He at a pressure of 6 bars, is also used to monitor the 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 ^{3}He 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 × W × H): 190 cm × 140 cm × 160 cm
- mainly composed of high purity graphite

Cavity &Detectors

- 118 litre drums
- dimensions of the cavity (L × W × H): 55 cm × 55 cm × 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 ^{3}He proportional counters, 4 bars, 100 active cm long, 2 inch. in diameter + 14 ^{3}He proportional counters, 2 bars, 100 active cm long, 2 inch. in diameter)
- door: 2 vertical layers of (8+7) superimposed ^{3}He proportional counters, 4 bars, 50 active cm long, 2 inch. in diameter
- monitor: an external ^{3}He 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 CH_2 covering the external faces of the measurement cell
- background levels: total passive 1.3 s^{-1}, coincidence passive 0.12 s^{-1}, total active 30 s^{-1}, coincidence active 0.1 s^{-1}

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

SYMETRIC

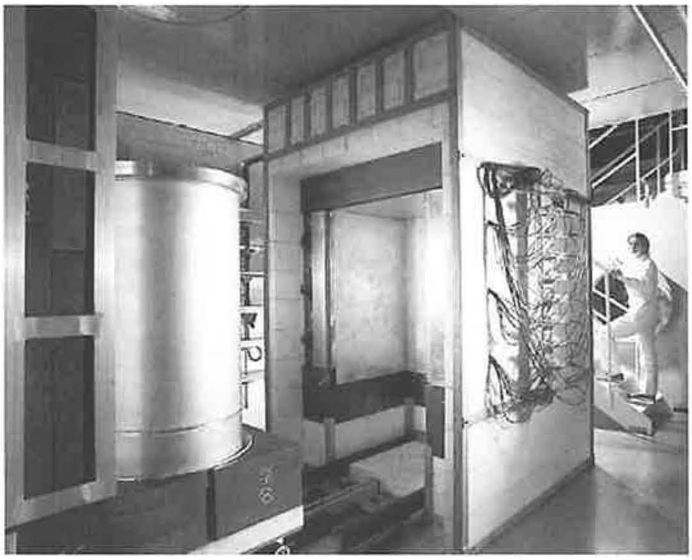
(CEA2)

Système de Mesures – Tri de Colis

Address

Commissariat à l'Energie Atomique
Centre d'Etude de Cadarache
SCCD/LDMN Bât. 326
13108 Saint Paul Lez Durance
France

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



View of the SYMETRIC neutron cell (open door)

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, Sodern)
- Medas, counter/timer card, 32 channels, identification of each input channel (Cesigma),
- Typical detection efficiency: 5 % to 23 %
- Passive detection limit for $^{240}Pu_{eff}$: 10 mg (coincidence counting, 600 s)
- Active detection limit for $^{239}Pu_{eff}$: 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 βγ contaminated 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 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 $^{240}Pu_{eff}$ 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^{-1}

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 E+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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