European Commission

SYNOPSIS OF GAMMA SCANNING SYSTEMS

Comparison of Gamma 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 third meeting of the Working Group 1 of the 'European Network of Testing Facilities for the Quality Checking of Radioactive Waste Packages' held in Saluggia, 13. December 1994, it was decided by all members to create a synopsis of existing systems for the gamma scanning of radioactive waste packages. A questionnaire on the setup and on the operation modes of gamma scanning systems was compiled and distributed to the members of the Working Group. The summary of the answers and a general information on gamma scanning 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. Furthermore, it was intended to establish a common wording.

Of course, such a synopsis would not have evolved without the encouragement and support of the members of the Working Group 1. In particular the authors wish to thank A. Lewis and H.-J. Sanden for reading the manuscript and giving valuable corrections.

Garching, September 1998

The authors

1 Introduction

Radioactive waste can originate from different producers such as nuclear power plants, reprocessing 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 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. A summary of conventional assay is given in Table 1.

One of the simplest but with limitations most powerful inspection technique is the segmented gamma scanning. It results in the identification of the gamma emitting isotopes present in the radioactive waste package via their characteristic gamma lines. Quantification of the gamma activity can be achieved by using appropriate interpretation models.

This synopsis focuses on the segmented gamma scanning assay used for the characterisation of radioactive waste packages. It summarises the basic principles of operation and the different scan modes and their main field of applicability. Furthermore, two interpretation models often used in practice for the evaluation of the measured data are presented and advice for the calibration and validation procedures of the assays is given. Information on technical terms, existing systems and contact persons or institutions for further information are given in the annexes.

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

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

2 Principle of Gamma Scanning

The main objective of non-destructive gamma scanning is to identify and quantify the gamma emitters present in the radioactive waste package by evaluation of gamma spectra measured outside a waste package.

A suitable gamma assay system consists of

- one (or more) gamma spectroscopy system(s)
- shielding and collimation of the detector(s)
- the mechanic, to manipulate the waste package and/or the detector system(s)
- a control unit
- a data evaluation unit and
- optional additional equipment (e. g. weighing unit, transmission source, etc.).

2.1 Gamma Spectroscopy System
The block diagram of a typical gamma spectroscopy system is shown in Figure 1.

A high purity germanium detector (HPGe) associated to a cooling cryogenic or cryolectric system is usually used, although in some (older) systems NaI- and Ge(Li) detectors are still in use. In practice germanium detectors are preferred for the analysis of complex gamma-ray spectra involving many peaks due to their high energy resolution.

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, which 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.

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

The amplified and shaped linear pulse is converted into a digital number by the analogue-to-digital converter (ADC) for further processing by a computer. The digital number is proportional to the amplitude of the analogue input pulse. At present the ADC is usually combined with the multichannel analyser (MCA).

The MCA stores the pulse height spectrum which is defined by the number of occurrences of the digital numbers created in the ADC. These numbers define the channel number of the MCA. At present most of the MCA's are plug-in boards for computer.

Several additional components in the detector chain (Figure 1) are available and sometimes in use (e. g. spectrum stabiliser, pulse generators for calibration purposes, pile-up rejectors and baseline restorers for high count rates, etc.).

In addition, shielding of the detector system against background and scattered radiation is required. An energy calibration of the gamma spectroscopy system must be performed after each shutdown of the complete system or of single components of the system and if the cooling of the detector was interrupted. Furthermore, the energy calibration must be performed in periodical intervals for quality control and if any doubts on the correctness of the actual calibration may occur (e. g. drift of peak position). The gamma lines of the calibration sources should cover the full energy range of application.

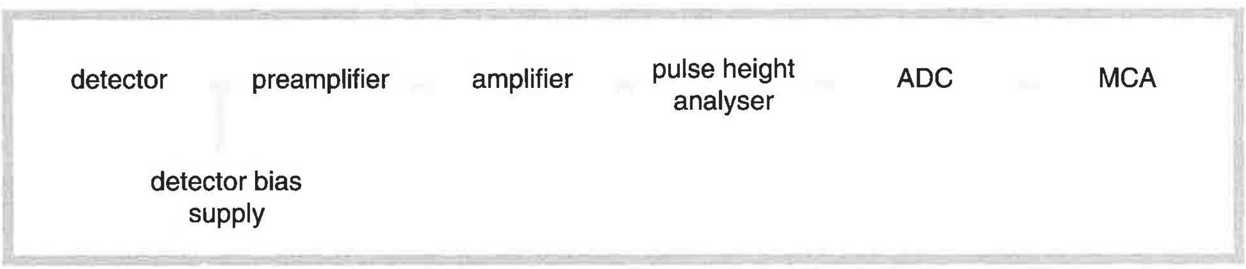


Figure 1: *Block diagram of a typical gamma spectroscopy system.*

2.2 Shielding and Collimation

The gamma detector records the gamma spectrum emitted by radionuclides in the waste package and some background signals which can originate from natural radioactivity in the enviroment, or other radioactive waste containers, radioactive sources, etc. Because the magnitude of the background ultimately determines the minimum detectable signal an external shielding of the detector is preferred. Shielding materials commonly used are lead (Pb) and tungsten (W).

For segmented gamma scanning, an appropriate collimator system is required. This system can consist of a lead or tungsten block with a rectangular or circular opening, enabling the detector to 'see' only a part of the waste package, i. e. only the radiation emitted in the volume 'seen' by the collimated detector is recorded. The size of that volume is defined by the aperture of the collimator and the distance between detector and waste package.

2.3 Manipulator

In general, the gamma emitting radioisotopes are not distributed homogeneously within the waste package. Therefore a gamma measurement at a single position will not give representative information on the content of the waste package. Using an appropriate manipulator system, measurements at different positions can be performed, resulting in a much more reliable and representative characterisation of the waste package. The procedure of performing subsequent measurements of gamma spectra at different positions is called scanning of the waste package. A basic manipulator system consists of a turntable and a lifting unit or the equivalent components as given in Table 2. The swivel and translational units are optional and are used for an improved characterisation of the radioactive waste package compared to conventional gamma scanning. An appropriate calibration of the manipulator system must be performed to ensure correct positioning and moving of all components.

Table 2: *Components of a manipulator system.*

component	movement	equivalent movement
turntable	rotation of waste package	rotation of detector around the waste package
lifting unit	lifting of the detector	lifting of the waste package
swivel unit	swivelling of the detector	-
translation unit	horizontal movement of the waste package	horizontal movement of the detector

2.4 Control Unit

The control unit, usually a computer, controls both the movements of the manipulator system and the measuring process. Conventionally these two tasks are synchronised. The measured data, i. e. the gamma spectra, is stored on appropriate media (e. g. hard-disk of computer) together with additional information (e. g. real, live and dead times, position of detector, etc.) necessary for data evaluation and for the final documentation.

2.5 Data Evaluation Unit

From the measured and stored spectra the identification and quantification of the gamma emitting nuclides 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.

2.6 Additional Equipment

Most of the recently setup gamma scanning systems are equipped with a weighing unit. The mass of the investigated waste package may be used for the calculation of correction values, e. g. considering the attenuation of gamma lines within the matrix of the waste package. A more precise determination of these correction values is based on the use of an additional external gamma source (e. g. ^{22}Na, ^{60}Co, ^{110m}Ag, ^{137}Cs, ^{152}Eu, etc). From transmission measurements the mean attenuation coefficients within the waste package can be determined. An appropriate calibration of the additional equipment must be performed to ensure correct working (e. g. calibration of weighing unit etc.).

3 Scan Modes

In segmented gamma scanning the measurement procedure can be subdivided into a number of submeasurements at different positions of the detector relative to the waste package.

The scanning of all measurement positions can be performed either by a discrete step or by a continuous movement of the relevant axis.

The measurement positions for one rotation are defined as sectors, the height positions as segments and the horizontal translational steps or swivels as steps. Each submeasurement results in of a complete gamma measurement, i. e. the gamma spectrum, the real and live times, etc.

Depending on the measurement conditions and requirements an appropriate scan mode must be selected. For example, an activity distribution within the waste package can be determined with a high resolution by using collimators with small apertures and the multiple rotational scan mode with a large number of segments and sectors.

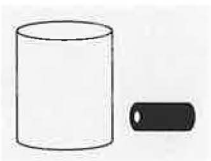
On the other hand, if low detection limits are desired, the rotational scan mode in open geometry (i. e. the detector always 'sees' the complete waste package) with only one sector and one segment is preferred. It is obvious that for a given measurement time both objectives exclude each other.

Therefore, before starting a measurement the user has to make a proper decision on its final aims and must select the optimum scan mode.

In the next paragraphs different commonly used scan modes are presented. The description of the movements is related to a system with a turntable for the waste package and a detector system which can be lifted, swivelled and horizontally translated.

Other arrangements can be easily transferred to this basic set-up like using more than one detector system (i. e. multiple detector system) which can decrease the overall measurement time. The fields of application given for each scan mode are only examples and do not exclude other applications!

3.1 Point Measurement



The detector and the waste package are at rest. Depending on the aperture of the selected collimator and the height position of the detector $h_{meas.}$ the detector „sees' for a given distance to the waste package the complete waste package (so called open geometry) or only a fraction of the waste package (collimated geometry).

This scan mode can be used for detailed studies (e. g. investigation of hot spots) or if the waste package is known to be fairly homogeneous.

segments: 1
sectors: 1
steps: 1
spectra: 1

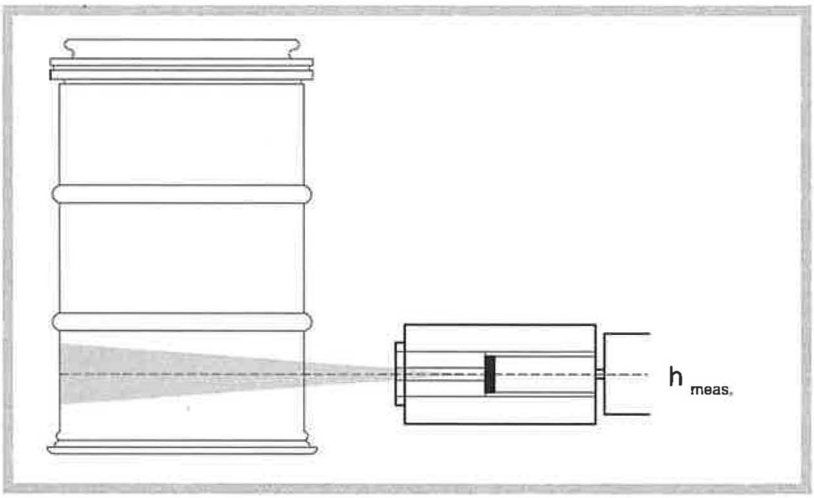
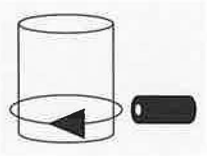


Figure 2: *Point measurement.*

3.2 Rotational Scan



The detector is at rest at a certain height position $h_{meas.}$ while the waste package is rotating by 360° or a multiple of it. Each complete rotation is subdivided into N sectors. For each sector the complete gamma spectrum is measured and stored. Depending on the aperture of the selected collimator and on the height position of the detector, the detector 'sees' for a given distance to the waste package the complete waste package or only a fraction of it within the rotations. This scan mode can be used for the characterisation of a homogeneous waste package and for detailed studies (e. g. investigation of hot spots). If the waste package is homogeneous within certain segments, it is possible to limit the investigations to these segments by use of an appropriate collimator and/or distance between the collimated detector and the waste package. Then, the rotation is performed to level out radial and angular inhomogeneities within a given height segment. By combination of the results of the evaluations of all segments quasi-homogeneous waste packages can be characterised.

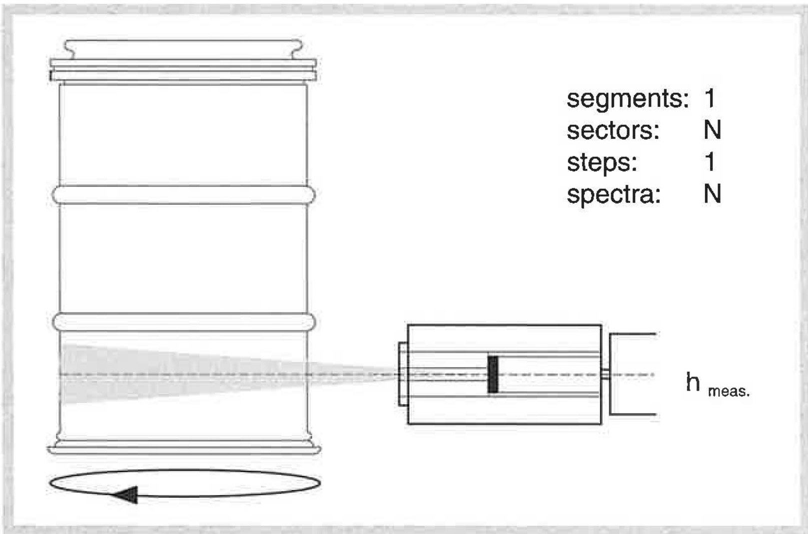
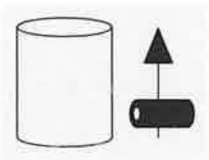


Figure 3: *Rotational scan.*

3.3 Vertical Translational Scan



The waste package is at rest, while the lifting of the detector starts at the height position h_{start} and stops at the height position h_{stop}. This lifting is subdivided into M segments. For each segment a complete gamma spectrum is measured and stored. Depending on the aperture of the selected collimator and due to the missing rotation, the detector may 'see' for a given distance to the waste package only a fraction of the complete waste package. This scan mode can be used for detail studies (e. g. detection of localited activity distributions) or if the waste package is previously known to be homogeneous within certain segments. The lifting of the detector levels out height inhomogeneities, but does not consider radial or angular inhomogeneities.

segments: M
sectors: 1
steps: 1
spectra: M

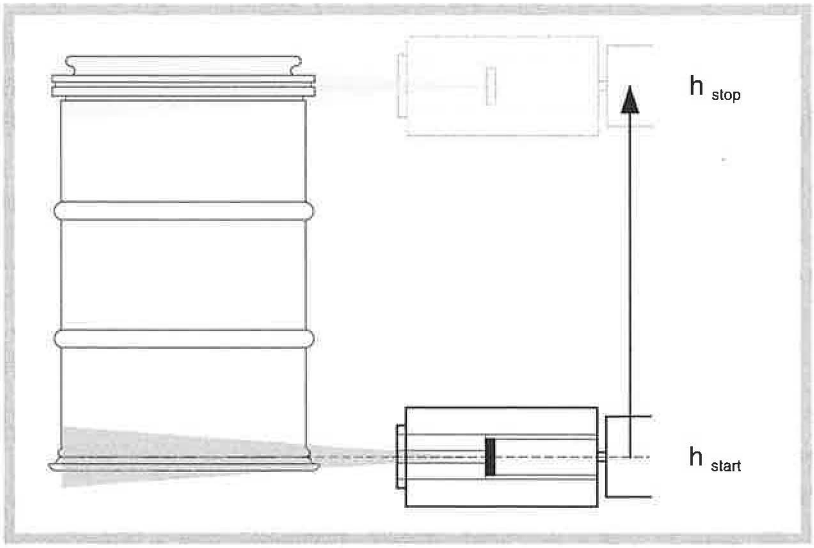
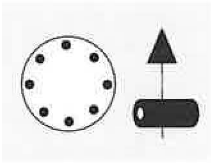


Figure 4: *Vertical translational scan.*

3.4 Horizontal Translational Scan



The detector is translated in a horizontal direction starting at position y_{start} and stopping at y_{stop} while the waste package is at rest. This horizontal movement is subdivided into K steps. For each step a complete gamma spectrum is measured and stored. Depending on the aperture of the selected collimator and due to the missing rotation of the waste package, the detector 'sees' for a given distance to the waste package only a fraction of the complete waste package.

This scan mode can be used for detailed studies (e. g. detection of localised activity distributions).

segments:	1
sectors:	1
steps:	K
spectra:	K

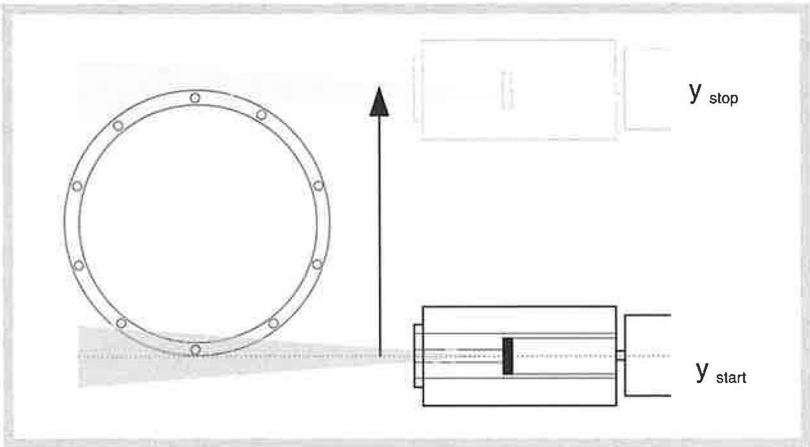
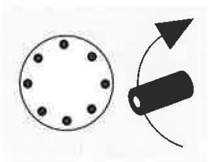


Figure 5: *Horizontal translational scan.*

3.5 Swivel Scan



The detector is swivelled in a horizontal plane starting at the angle F_{start} and stopping at the angle F_{stop} while the waste package is at rest. This swivelling is subdivided into K steps. For each step a complete gamma spectrum is measured and stored. Depending on the aperture of the selected collimator and due to the missing rotation of the waste package, the detector 'sees' only a fraction of the complete waste package.

This scan mode can be used for detailed studies (e. g. detection of localised activity distributions).

segments:	1
sectors:	1
steps:	K
spectra:	K

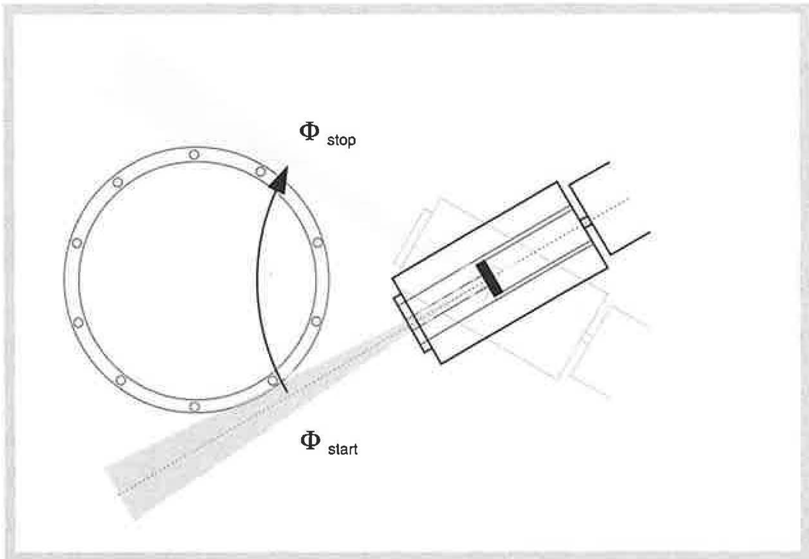
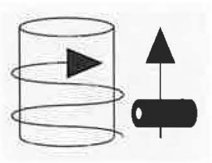


Figure 6: *Swivel scan.*

3.6 Spiral Scan



The detector is lifted starting at height position h_{start} and stopping at height position h_{stop} while the waste package is rotating. This lifting of the detector is subdivided into M segments, while the drum is rotated by 360° per segment. Each of these rotations is subdivided into N sectors. In total $M{\cdot}N$ complete gamma spectra are measured and stored. Using appropriate parameters (e. g. collimator aperture, speed of rotation and lifting, etc.), the detector 'sees' the complete waste package.

This scan mode can be used for the characterisation of a waste package. Currently, this scan mode is more and more replaced by the multiple rotational scan mode, although the resulting principle information is the same.

segments: M
sectors: N
steps: 1
spectra: M·N

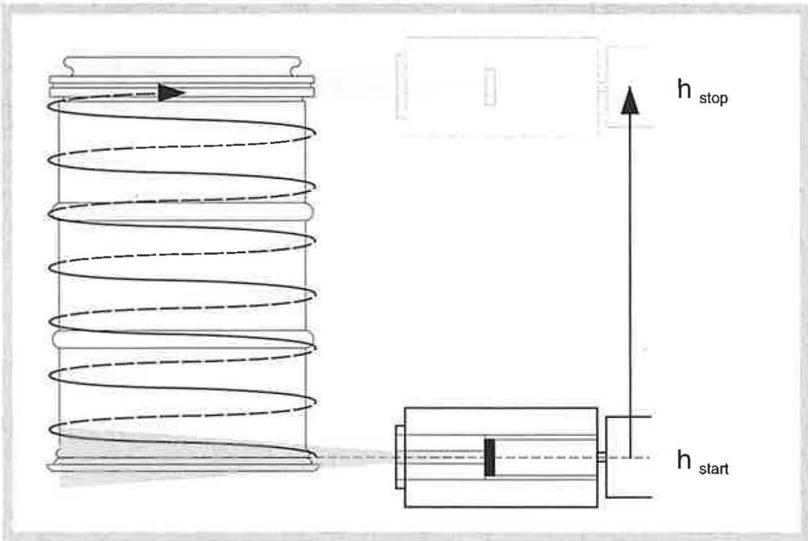
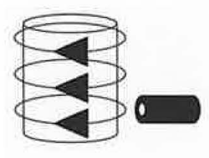


Figure 7: *Spiral scan.*

3.7 Multiple Rotational Scan

The waste package is subdivided into M equidistant segments. For each segment the drum is rotated by 360° or a multiple of 360°. After each rotation the detector is lifted for a given height increment starting at the first height position $h_1=h_{start}$ and stopping at the last height position $h_M=h_{stop}$. Each rotation is subdivided into N sectors, for which complete gamma spectra are measured and stored. Using appropriate parameters (e. g. collimator aperture, number of rotations and liftings, etc.), the detector 'sees' the complete waste package.



This scan mode can be used for the characterisation of a waste package. From the measured gamma spectra and the sum spectrum the gamma emitting radioisotopes present in the waste package can be identified and quantified using some assumptions (see e. g. chapter 4). Additionally, the nuclide distribution as a function of height and rotation angle can be investigated resulting in information on homogeneity and hot spots, respectively.

segments: M
sectors: N
steps: 1
spectra: M·N

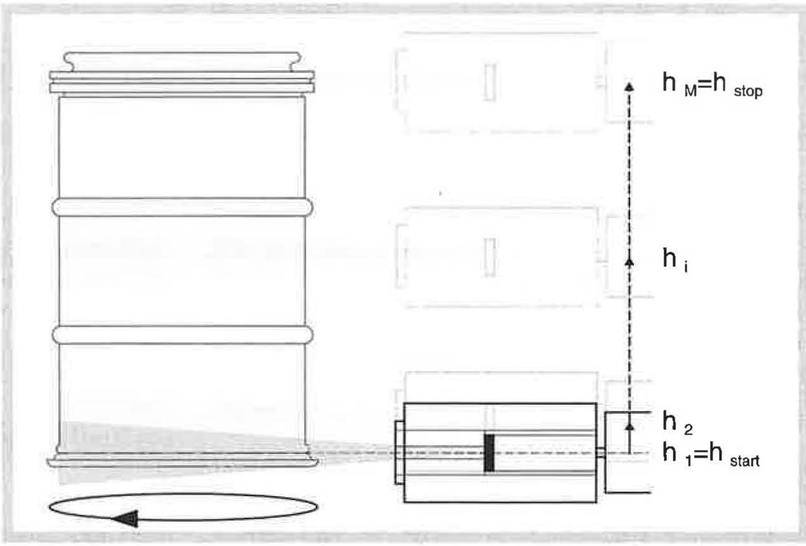


Figure 8: *Multiple rotational scan.*

tion with an axial symmetry (e. g. in an inner canister) is present, additional scan modes like the swivel scan or the horizontal translational scan may be applied. The density of the matrix is either determined by simple weighing of the drum and subtracting the net weight of the drum or by a transmission measurement using an external gamma source.

If axial inhomogeneities are detected, the waste package is subdivided into a number of axial regions with (quasi) homogeneous activity distributions. For each of these regions the evaluation is performed either by calculating sum spectra for each region using the data of the multiple rotational scan, or by performing rotational scans for each region. If the density is assumed to be constant for all regions, then simple weighing of the waste package is sufficient. This assumption may lead sometimes to great errors, therefore the use of transmission measurements for each region is recommended. Since axial deviations of measured count rates for a nuclide may also be caused by inhomogeneous density distributions in the presence of an homogeneous activity distribution, the latter method also corrects for this effect.

Radial inhomogeneities require more sophisticated methods for data evaluation when using segmented gamma scanning or the use of emission computerized tomography, which both are not considered in this synopsis.

All scan modes not considered in this chapter can be used for getting more detailed information. E. g. the vertical translational scan can give a more accurate subdivision in axial regions than the multiple rotational scan, since the distance between two succeeding segments can be selected much smaller for the first one considering the limited measuring times in practice.

Point measurements can be used to investigate single positions of the surface of the waste package in more detail, e. g. by increasing the measuring time.

3.10 Remarks

Further combinations of the movements of detector and waste package may be appropriate for some specific investigations, but will not be used in routine.

Repeated application of the horizontal translational scan mode and of the horizontal meander scan mode for different angular positions of the detector relative to the drum, enables a two- or three-dimensional tomographic reconstruction of the activity distribution (emission computerised tomography), although for the attenuation correction the density distributions within the waste package must be known from additional transmission measurements.

4 Data Processing and Evaluation

The results of segmented gamma scanning are the segment spectra and the sum spectrum. The latter is calculated by summing up all segment spectra. While all spectra are used for nuclide identification by their characteristic gamma lines, the quantification of the identified gamma emitting isotopes is conventionally based on the net peak count rates of the characteristic (undisturbed) gamma lines in the sum spectrum. Furthermore, an homogeneous distribution of the activity and the matrix is assumed. The isotope specific activity distributions resulting from the segment spectra (e. g. measured with the multiple rotational scan mode) give information on the correctness of that assumption. Improved evaluation procedures are known (e. g. [Mar89]), but usually not applied in practice due to the increased requirements on the operators skills and on the time needed for measuring and data evaluation. The conventionally applied evaluation procedures calculate the activities in a conservative way, i. e. for an inhomogeneous activity distribution the activity reality will be lower than calculated.

4.1 Basic Relations

Two methods of calculating the (specific) activity from the net peak count rate Z, determined from the sum spectrum, were established in the last years. They can be mainly distinguished by the correlation methods applied. The basic relation of both evaluation methods is given by

$$a = T \cdot Z \qquad (1)$$

with a: specific activity [$Bq \cdot g^{-1}$]
T: transfer or correlation function [g^{-1}]
Z: net peak count rate [s^{-1}]

The activity A of an isotope can be calculated by multiplying the specific activity a (equation 1) with the net mass M of the active matrix

$$A = M \cdot a \qquad (2)$$

As shown in equation 1 the measured quantity Z, the net peak count rate, is correlated in a certain way with the specific activity a to be determined.

The correlation function T can either be determined experimentally or by mathematical calculations. These two different approaches in setting-up the correlation functions T are presented in the next two paragraphs.

4.2 Experimentally Determined Correlation Function

This method is based on a calibration measurement, which can be performed using either a volume, disk or point source of well defined properties (e. g. activity, size, composition, etc.). The calibration factor HE, which depends only on the energy and on the size of the collimator, is defined by the relation

$$HE = \frac{A_0}{Z_0 \cdot \eta_0 \cdot F_0} \qquad (3)$$

with HE: calibration factor [cm^{-2}]
A_0: activity of the calibration (volume) source [Bq]
Z_0: net peak count rate of a gamma line [s^{-1}]
η_0: emission probability of calibration source
F_0: area of detector cone at the volume source [cm^2]

Therefore it is necessary to measure calibration factors for each type of collimator used and for each energy of interest. In practice the calibration measurement will be performed for all collimators only for a few energies covering the whole range of application (e. g. by using ^{152}Eu and ^{241}Am). From this data all other values are estimated by interpolation. The overall correlation function is defined by the relation

$$T = HE \cdot \frac{1}{\eta} \cdot \frac{\mu}{\rho} \cdot \frac{K_2 \cdot K_3}{K_1} \qquad (4)$$

with HE: energy and collimator dependent calibration factor [cm^{-2}]
η: emission probability
μ/ρ: mass attenuation coefficient of active matrix [$cm^2 \cdot g^{-1}$]
K_1: correction factor for attenuation within the active matrix
K_2: correction factor for attenuation in the inactive shielding
K_3: correction factor considering the part of the time, the detector does not see the complete active matrix.

The correction factors can be calculated on the basis of the information about the composition of the waste matrix. For large fairly homogeneous volume sources the results are independent of

the distance between the detector and the source as long as the source completely fills the detector cone,
the depth of the active matrix as long as $K_1 \cong 1$,
the density ρ of the active matrix,
the material properties of the active matrix.

A detailed derivation of equation 3 and 4 is given by Filß [Fil89]. In this publication the mass attenuation coefficient is considered within the calibration factor *H*. For harmonisation, this factor was eliminated and the new calibration factor was called HE (equation 3). The mass attenuation factor is now considered in the correlation function T.

4.3 Calculated Correlation Function

This method was developed to 'ensure harmonisation in terms of measuring geometry, type and activity of the package to be characterised' [Cha94] and is applied to all types of waste packages having cylindrical geometry.

The cylindrical volume source is approximated by a linear source with the same activity but placed behind a flat shield. The mass attenuation and the density of the shielding are the same as for the cylindrical matrix. The self-attenuation equivalent thickness of this shielding is calculated as a function of the mass attenuation coefficient and the radius of the waste package. Therefore the correlation function is given by the expression

$$T = \frac{1}{\varepsilon \cdot \eta} \cdot \frac{R_0}{2 \cdot (R+d)} \cdot \int_0^{\arctan \alpha} e^{-f(\Theta, b_2)} d\theta \qquad (5)$$

with
- ε: detection efficiency
- η: emission probability
- R_0: radius of cylinder
- R: distance detector-surface of cylinder
- d: self-absorption equivalent thickness of flat shield
- θ: opening angle

and with

$$\alpha = \frac{H_0}{2 \cdot (Z+R)} \qquad (6)$$

and

$$b_2 = \rho \cdot Z \cdot \sum_j m_j \mu_j + \sum_i \rho_i \mu_i t_i \qquad (7)$$

- Z: shield thickness equivalent of matrix self-attenuation
- H_0: height of waste package
- ρ: theoretical density of waste
- ρ_i: density of shielding material
- m_j: mass ratio of waste elements
- μ_i: mass attenuation coefficient
- t_i: thickness of shielding

A detailed derivation of equation 5 is given in reference [Cha94].

4.4 Remarks

The accuracy of the results obtained from both methods strongly depends on the knowledge about the composition of the matrix. If no or only a little information is available an improvement can be achieved experimentally by using the results of additional transmission measurements. The gamma transmission source should emit photons in the same energy range as covered by the emitting radionuclides present in the waste package.

In general, the specific activity is not homogeneously distributed over the complete volume of the waste package. By rotating the waste package and lifting the detector (e. g. using the multiple rotational scan mode or the spiral scan mode) an averaging is achieved and enables the quantification assuming an homogeneous activity distribution.

5 Validation

The gamma scanning 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 the 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

[Cha94] Chabalier B., "Non-Destructive Determination of Activity", Special Issue of Nuclear Technology, Article No. 7, 1994.

[Fil89] Filß P., "Specific activity of large-volume sources determined by a collimated external gamma detector", Kerntechnik 54 (1989) No. 3, 198-201.

[Mar89] Martens B.-R., Filß P., "Determination of the Radionuclide Inventory for Waste Packages using Gamma-Ray-Detectors of Low Beam Widths", Proc. of a topical meeting organised by the Commission of the European Communities, Directorate General, held in Cadarache, France, 20-22 November 1989, edited: Eid C., Bernard P.

Technical Terms

To avoid misunderstandings in discussion of gamma measurements of waste packages, the most relevant technical terms as used within the Working Groups of the "Network" are given below.

collimator:	system that collimates the radiation coming into the detector to a restricted area of the waste package
control unit:	system for controlling the manipulator system and the data acquisition process
data evaluation unit:	system for the evaluation of measurement data
detection unit:	system for the measurement of a gamma spectrum of a selected region of the waste package
energy calibration:	procedure to calibrate the correlation between channel number of the multichannel analyser und the corresponding energy
energy range:	range between a minimum and a maximum energy for which the detection process is performed
efficiency calibration:	procedure to calibrate the system response, which is a combination of the intrinsic photopeak efficiency and the geometrical efficiency
gamma emitters:	radioisotopes emitting gamma radiation
gamma spectroscopy system:	system for the measurement of gamma radiation
gamma spectrum:	energy distribution of measured gamma radiation
manipulator system:	system to move the waste package and /or the detector system
mechanical unit:	system for manipulating the waste package and / or the detector system
open geometry:	measurement using an uncollimated detector
positioning system:	system for positioning the waste package and / or the detector system
radioactive waste package:	container filled with radioactive waste
scan mode:	measurement procedure defining the way of performing subsequent measurements of gamma spectra at different positions
sector:	subdivision of a rotation
segment:	subdivision of a vertical movement
segmented gamma scanning:	performing subsequent gamma measurements at different height positions
step:	subdivision of a horizontal or swivelling movement
sum spectrum:	combination of a number of spectra by simple adding

shielding:	devices for shielding the detector against interfering radiation (e. g. background radiation)
turntable:	mechanical system for rotation of the waste package
transmission source:	external gamma source for determining the matrix properties by transmission measurements
weighing unit:	system for determining the weight of the waste package, often attached to the turntable

Comparison of Technical Data of Gammma Scanning Systems

Appendix B offers a fast abbreviations on all relvant technical data of the individual gamma scanning 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.

RCM1: Institut für Radiochemie, Technische Universität München, Walther-Meissner-Strasse 3, D-85748 Garching, Germany

RCM2: Institut für Radiochemie, Technische Universität München, Walther-Meissner-Strasse 3, D-85748 Garching, Germany

FZJ: Forschungszentrum Jülich GmbH, ISR-PKS, Postfach 19 13, D-52425 Jülich, Germany

NNC: Waste Quality Checking Laboratory, Winfrith Technology Centre, Dorchester, Dorset, DT28DH, Great Britain

LOVI: Imatran Voima Oy, Loviisa NPP, P. O. Box 23, FIN-07901 Loviisa, Finland

TVO: Teollisuuden Voima Oy, Olkiluoto NPP, FIN-27160 Olkiluoto, Finland

SCK1: SCK•CEN, Boeretang 200, B-2400 Mol, Belgium

SCK2: SCK•CEN, Boeretang 200, B-2400 Mol, Belgium

ITN: CIEMAT-DFN, Avda. Complutense 22, E-28040 Madrid, Spain

NUCL: Societa per l'Ecoingegneria Nucleare, Via Anguillarese 301, I-00060 S. Maria di Galeria (Roma), Italy

ENEA: ENEA-ERG-SAL-LAB, C. R. Casaccia, I-00060 S. Maria di Galeria (Roma), Italy

CEA1: CEA/ Cadarache, DCC/DESD/SCCD Bât. 326, F-13108 St.-Paul-lez-Durance, France

CEA2: CEA/ Cadarache, DCC/DESD/SCCD Bât. 326, F-13108 St.-Paul-lez-Durance, France

CEA3: CEA/ Cadarache, DCC/DESD/SCCD Bât. 326, F-13108 St.-Paul-lez-Durance, France

KEMA1: KEMA N. V., Utrechtseweg 310, Postbus 9035, NL-6800 ET Arnhem, Netherlands

KEMA2: KEMA N. V., Utrechtseweg 310, Postbus 9035, NL-6800 ET Arnhem, Netherlands

	RCM1	RCM2	FZJ	NNC	LOVI	TVO	SCK1	SCK2	ITN	NUCL	ENEA
	D	D	D	GB	FIN	FIN	B	B	E	I	I
Principle (type of measurement)											
segmented	x	x	x	x			x		x	x	x
unsegmented	x		x		x	x		x			
Mechanical Specifications											
movement of package											
rotation	x	x	x	x	x		x	x	x	x	x
translation		x									(x)
lifting					x		x		x	x	
movement of detector											
translation							x		x		(x)
lifting	x	x	x	x							x
swivelling	x		x								(x)
max. size of package											
diameter [mm]	800	1400	900	580		580	720	600	760	680	800
height [mm]	>1500	1400	1000	900		870	1068	890	n. def.	860	1200
max. weight of package [kg]	15000	15000	15000	800		200	600	450	2000	350	1500

	CEA1	CEA2	CEA3	KEMA1	KEMA2
	F	F	F	NL	NL
Principle (type of measurement)					
segmented		x	x		
unsegmented	x			x	x
Mechanical Specifications					
movement of package					
rotation	x	x	x	x	
translation		x			
lifting		x	x		
movement of detector					
translation					
lifting					
swivelling					
max. size of package					
diameter [mm]	1500	800	600		600
height [mm]	1500	1000	1000		900
max. weight of package [kg]	10000	20000	500	100	1000

	RCM1	RCM2	FZJ	NNC	LOVI	TVO	SCK1	SCK2	ITN	NUCL	ENEA
	D	D	D	GB	FIN	FIN	B	B	E	I	I
Detector System											
number of detectors	1	1	1	1	1	1	1	3	1	1	1
HPGe detector	x	x	x	x	x	x	x	x	x	x	x
rel. efficiency at 1332 keV [%]	31.6	77	20	30	17	15	10	20	15	64	40
crystal dimensions											
diameter [mm]	58.4	73.7	50	56.5		52.1	42.5	50	48.5	72	
height [mm]	56.7	69.5	53	52.5		40.5	44.5	50	55	66	
energy range used											
min. E [keV]	30	30	30	50	75	200	50	50	100	60	60
max. E [keV]	2800	2800	2700	2000	2000	1600	1500	1500	1500	1900	2800
peak/Compton ratio at 1332 keV	66:1	90:1	45:1	54:1	50:1	50:1	40:1	53:1	57:1	67.5:1	62:1
energy resolution at											
60 keV in keV			0.7								
122 keV in keV	0.8	0.9		1.2			0.83	1.1	0.87	1.04	0.7
433 keV in keV					1.8						
600 keV in keV											
1332 keV in keV	1.7	1.8	2.0	2.0		1.7	1.8	2.0	1.7	2.1	1.8
1800 keV in keV											
detector cooling											
liquid nitrogen	x	x	x	x	x	x	x	x		x	x
electro cooling									x		
cooling time [days]	4	10		4			7	2.5		10	10

	CEA1	CEA2	CEA3	KEMA1	KEMA2
	F	F	F	NL	NL
Detector System					
number of detectors	2	1	1	1	1
HPGe detector	x	x	x	x	x
rel. efficiency at 1332 keV [%]	15	15	15	10	24
crystal dimensions					
diameter [mm]	40/25	5	5		50
height [mm]					51.4
energy range used					
min. E [keV]	20	20	20	40	40
max. E [keV]	2000	2000	2000	2800	2800
peak/Compton ratio at 1332 keV	32:1	32:1	32:1		
energy resolution at					
60 keV in keV					
122 keV in keV	0.8	0.8	0.8	0.9	0.8
433 keV in keV					
600 keV in keV					
1332 keV in keV	1.8	1.8	1.8	1.9	1.8
1800 keV in keV					
detector cooling					
liquid nitrogen	x	x	x	x	x
electro cooling					
cooling time [days]	5	5	5	10	3

	RCM1	RCM2	FZJ	NNC	LOVI	TVO	SCK1	SCK2	ITN	NUCL	ENEA
	D	D	D	GB	FIN	FIN	B	B	E	I	I
Shielding and Collimation											
no shielding/collimation				x							
shielding material											
Pb	x		x	x	x				x	x	x
Pb/W		x									
low background steel								x			
Cu, Cd lining				x							
number of available collimators	5	4	3	1		1	1	0	4	1	5
collimator material											
Pb	x		x	x	x	x	x		x	x	
Pb with Cu lining								x			x
Pb/W											
W		x									
aperture (2ϕ) [°]											
collimator 1	1.4	2.0	2.9				18.8			26.6	
collimator 2	5.7	3.4	5.7								
collimator 3	11.3	13.2	11.3								
collimator 4	16.7	43.3	16.7								

	CEA1	CEA2	CEA3	KEMA1	KEMA2
	F	F	F	NL	NL
Shielding and Collimation					
no shielding/collimation				x	x
shielding material					
Pb	x	x	x		
Pb/W	x				
low background steel					
Cu, Cd lining	x	x	x		
number of available collimators	4	1	1		
collimator material					
Pb	x	x	x		
Pb with Cu lining	x				
Pb/W					
W	x				
aperture (2ϕ) [°]					
collimator 1	1.8	2.2	3.6		
collimator 2	3.6				
collimator 3	26.6				
collimator 4					

	RCM1 D	RCM2 D	FZJ D	NNC GB	LOVI FIN	TVO FIN	SCK1 B	SCK2 B	ITN E	NUCL I	ENEA I
Electronics											
preamplifier											
attached to detector, EG&G ORTEC	x	x	x								
2001, CANBERRA					x						
2002, CANBERRA							x		x	x	
2004, CANBERRA				x							
2008, CANBERRA								x			
RC-PSC 821 GeR, SILENA											x
compatible to 142A, EG&G ORTEC											
Resistif-Transistor reset, EURISYS											
amplifier											
92X, EG&G ORTEC	x					x					
472, EG&G ORTEC					x						
572, EG&G ORTEC											
672, EG&G ORTEC		x									
972, EG&G ORTEC			x								
2020, CANBERRA							x		x		
2024, CANBERRA				x						x	
2025, CANBERRA								x			
7201, EURISYS											
7244, EURISYS											
9308A, SILENA											x
Oxford/Tennelec 245											

	CEA1	CEA2	CEA3	KEMA1	KEMA2
	F	F	F	NL	NL
Electronics					
preamplifier					
attached to detector, EG&G ORTEC					
2001, CANBERRA	x	x	x		
2002, CANBERRA					
2004, CANBERRA				x	
2008, CANBERRA					
RC-PSC 821 GeR, SILENA					
compatible to 142A, EG&G ORTEC					
Resistif-Transistor reset, EURISYS	x	x	x		x
amplifier					
92X, EG&G ORTEC					
472,EG&G ORTEC					
572,EG&G ORTEC					
672,EG&G ORTEC					
972, EG&G ORTEC					
2020, CANBERRA	x	x	x		
2024, CANBERRA	x	x	x	x	
2025, CANBERRA					
7201, EURISYS	x	x			
7244, EURISYS	x	x	x		
9308A, SILENA					
Oxford/Tennelec 245					x

	RCM1	RCM2	FZJ	NNC	LOVI	TVO	SCK1	SCK2	ITN	NUCL	ENEA
	D	D	D	GB	FIN	FIN	B	B	E	I	I
ADC											
92X, EG&G ORTEC	x					x					
916 A, EG&G ORTEC											
918 or 919, EG&G ORTEC			x								
450 MHz Fast Wilkinson, CANBERRA				x							
ND-570, CANBERRA					x						
8706, CANBERRA		x									
8075, CANBERRA							x		x		
8077, CANBERRA										x	
AccuSpec A, CANBERRA								x			
7601, EURISYS											
7602, EURISYS											
9308A (Wilkinson 100 MHz), SILENA											x
7600 EURISYS suc. app. 750 ns											
multi channel analyzer											
92X EG&G ORTEC	x					x					
ADC with PC			x								
AIM 556, CANBERRA		x									
5100, CANBERRA				x			x				
ND-66, CANBERRA					x						
AccuSpec A, CANBERRA								x			
Series 35+, CANBERRA									x	x	
PCA 16 CIC, EURISYS											
9308A, SILENA + C89											x
PC-Card Interfast, EURISYS											

	CEA1	CEA2	CEA2	KEMA1	KEMA2
	F	F	F	NL	NL
ADC					
92X, EG&G ORTEC					
916 A, EG&G ORTEC					
918 or 919, EG&G ORTEC					
450 MHz Fast Wilkinson, CANBERRA					
ND-570, CANBERRA					
8706, CANBERRA					
8075, CANBERRA					
8077, CANBERRA	x	x	x		
AccuSpec A, CANBERRA					
7601, EURISYS	x	x	x		
7602, EURISYS	x	x	x		
9308A (Wilkinson 100 MHz), SILENA				x	
7600 EURISYS suc. app. 750 ns					x
multi channel analyzer					
92X EG&G ORTEC					
ADC with PC					
AIM 556, CANBERRA					
5100, CANBERRA					
ND-66, CANBERRA					
AccuSpec A, CANBERRA	x				
Series 35+, CANBERRA				x	
PCA 16 CIC, EURISYS	x	x	x		
9308A, SILENA + C89					
PC-Card Interfast, EURISYS					x

	RCM1	RCM2	FZJ	NNC	LOVI	TVO	SCK1	SCK2	ITN	NUCL	ENEA
	D	D	D	GB	FIN	FIN	B	B	E	I	I
Computer System											
computer type											
IBM or compatible	x		x	x		x	x	x	x	x	x
VAX 3400					x						
VAX 4000/90		x									
PDP 11/73		x									
operating system											
DOS			x	x		x		x	x	x	x
Windows	x		x				x				x
VMS 5.5		x			x						
equipment											
RAM [MByte]	8	40	8	16	20	8	4	4	2	2	16
HD [MByte]	1000	4000	450	1000	2 x 154	270	60		405	70	1200
local area network connection	x	x	(x)								(x)

	CEA1	CEA2	CEA3	KEMA1	KEMA2
	F	F	F	NL	NL
Computer System					
computer type					
IBM or compatible	x	x	x	x	x
VAX 3400					
VAX 4000/90					
PDP 11/73					
operating system					
DOS	x	x	x		x
Windows	x	x	x	x	x
VMS 5.5					
equipment					
RAM [MByte]	16	16	16	16	16
HD [MByte]	520	510	510	2000	1000
local area network connection		x		x	

Data Recording software	RCM1 D	RCM2 D	FZJ D	NNC GB	LOVI FIN	TVO FIN	SCK1 B	SCK2 B	ITN E	NUCL I	ENEA I
GimScan 1.3 (GIM)	x										
Maestro II and Gammavision, EG&G ORTEC			x								
Genie, CANBERRA + ITS-Software		x									
S100 +specific software, CANBERRA				x			x				
NDS 3.0, CANBERRA					x						
Spectran-AT 4.3 (4.0), CANBERRA										x	
AccuSpec+AQ2 1.2, CANBERRA								x			
DB Gamma 6.0, CANBERRA											
Maestro II, EG&G ORTEC						x					
Jessara 1.9, CIEMAT-ENRESA									x		
S.Q.A. , SILENA											x
Intergamma-Interwinner 5.42, EURISYS											

Data Recording	CEA1 F	CEA2 F	CEA3 F	KEMA1 NL	KEMA2 NL
software					
GimScan 1.3 (GIM)					
Maestro II and Gammavision, EG&G ORTEC					
Genie, CANBERRA + ITS-Software	x			x	
S100 +specific software, CANBERRA					
NDS 3.0, CANBERRA					
Spectran-AT 4.3 (4.0), CANBERRA				x	
AccuSpec+AQ2 1.2, CANBERRA					
DB Gamma 6.0, CANBERRA					
Maestro II, EG&G ORTEC					
Jessara 1.9, CIEMAT-ENRESA					
S.Q.A. , SILENA					
Intergamma-Interwinner 5.42, EURISYS	x	x	x		x

	RCM1 D	RCM2 D	FZJ D	NNC GB	LOVI FIN	TVO FIN	SCK1 B	SCK2 B	ITN E	NUCL I	ENEA I
Data Recording (contd.)											
information											
full energy spectrum (size in kByte)	8	8	8	17	4	x	8	4	10	18	18
preselected ROI's (max. ROI's)			8	12			x	x		inf.	x
dose rate data									x	x	x
showing real time spectrum	x	x	x	x	x	x	x	x		x	x
showing real time ROI data			x				x	x		x	x
showing real time dose rate data										x	
segment spectra (size in kByte)	8	8	8	17			8	4	10	18	18
realtime data evaluation			x	x			(x)	x			x

	CEA1	CEA2	CEA3	KEMA1	KEMA2
	F	F	F	NL	NL
Data Recording (contd.)					
information					
full energy spectrum (size in kByte)	17	17	17	18	17
preselected ROI's (max. ROI's)		10			
dose rate data					
showing real time spectrum	x	x	x	x	x
showing real time ROI data					
showing real time dose rate data					
segment spectra (size in kByte)	17	17	17		
realtime data evaluation	x	x	x		x

Data Analysis software	RCM1 D	RCM2 D	FZJ D	NNC GB	LOVI FIN	TVO FIN	SCK1 B	SCK2 B	ITN E	NUCL I	ENEA I
GimScan 1.3 (GIM)	x										
Genie, CANBERRA + ITS-Software		x									
KFA/EG&G ORTEC			x								
Fitzpeaks 2.9, J. Fitzgerald				x							
NDS 3.0, CANBERRA					x						
Omnigam, EG&G ORTEC						x					
Spectran-AT 4.3 (4.0), CANBERRA							x		x	x	
AQ2 LLW Assay SW 1.2, CANBERRA								x			
S.Q.A. and W.Q.A., SILENA											x
Same 7.1											
Intergamma-Interwinner, EURISYS	x										

Data Analysis software	CEA1 F	CEA2 F	CEA3 F	KEMA1 NL	KEMA2 NL
GimScan 1.3 (GIM)					
Genie, CANBERRA + ITS-Software		x			
KFA/EG&G ORTEC					
Fitzpeaks 2.9, J. Fitzgerald					
NDS 3.0, CANBERRA					
Omnigam, EG&G ORTEC					
Spectran-AT 4.3 (4.0), CANBERRA				x	
AQ2 LLW Assay SW 1.2, CANBERRA					
S.Q.A. and W.Q.A., SILENA					
Same 7.1					
Intergamma-Interwinner, EURISYS	x	x	x		x

	RCM1	RCM2	FZJ	NNC	LOVI	TVO	SCK1	SCK2	ITN	NUCL	ENEA
	D	D	D	GB	FIN	FIN	B	B	E	I	I
Data Analysis (contd.)											
information											
total count rate [cps]	x	x		x		x				x	x
net peak count rate [cps]	x	x	x		x	x			x	x	x
background count rate [cps]	x	x			x	x			x	x	x
live time	x		x	x	x	x	x		x	x	x
real time	x	x		x	x	x	x			x	x
dead time	x			x		x	x		x	x	x
net peak areas [cps]	x	x	x	x	x	x	x	x	x	x	x
background [cps]	x	x		x	x	x	x		x	x	x
nuclide detected	x	x	x	x	x	x	x	x	x	x	x
specific activity for each nuclide detected	x	x	x					x			
activity for each nuclide detected	x	x		x	x	x	x	x	x	x	x
overall activity	x	x	x	x				x		x	x
minimum detectable activity		x		x	x	x	x	x	x	x	x
half width of detected peaks	x	x	x	x	x	x	x		x	x	x
peak efficiency	x	x			x						
additional features											
peak search on segment spectra	x	x	x			x				x	x
nuclide library	x	x	x	x	x	x			x	x	x

	CEA1	CEA2	CEA3	KEMA1	KEMA2
	F	F	F	NL	NL
Data Analysis (contd.)					
information					
total count rate [cps]	x	x	x	x	x
net peak count rate [cps]	x	x	x	x	x
background count rate [cps]	x	x	x	x	x
live time	x	x	x	x	x
real time	x	x	x	x	x
dead time	x	x	x	x	x
net peak areas [cps]	x	x	x	x	x
background [cps]	x	x	x	x	x
nuclide detected	x	x	x	x	x
specific activity for each nuclide detected				x	x
activity for each nuclide detected	x	x	x	x	x
overall activity				x	x
minimum detectable activity	x		x	x	x
half width of detected peaks	x	x	x	x	x
peak efficiency	x	x	x	x	x
additional features					
peak search on segment spectra					
nuclide library	x	x	x	x	x

	RCM1 D	RCM2 D	FZJ D	NNC GB	LOVI FIN	TVO FIN	SCK1 B	SCK2 B	ITN E	NUCL I	ENEA I
Scan Mode (max./typ. # of segments)											
point measurement	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1
rotational scan	24/24	-/24	12/8	1/1					-/1		x
vertical translational scan	40/40	-/40		40/8			-/4		-/8	-/8	-/8-10
horizontal translational scan		-/40	10/10								
spiral scan	-/216	-/216	120/80		-/2						
multiple rotational scan	-/336	-/336	120/96								
swivel scan	60/30										
meander scan		-/>400									
Absorption Correction											
no correction											
matrix is known			x		x				x	x	
mean density correction (weighing)	x	x	x				x	x	x		x
differential absorption correction											(x)
additional transmission measurement	x	x	(x)	x						x	x
external source:											
Eu-152 GBq at 01.01.1996				0.3							
Co-60 GBq at 01.01.1996		12570									
Na-22 GBq at 01.07.1996										0.1	0.9

	CEA1	CEA2	CEA3	KEMA1	KEMA2
	F	F	F	NL	NL
Scan Mode (max./typ. # of segments)					
point measurement	1/1	1/1	1/1	1/1	1/1
rotational scan		-/9			
vertical translational scan	7/7	-/12	12/12		
horizontal translational scan		-/9			
spiral scan					
multiple rotational scan		-/12			
swivel scan					
horizontal meander scan					
Absorption Correction					
no correction					
matrix is known	x	x	x	x	x
mean density correction (weighing)					
differential absorption correction					
additional transmission measurement	x	x	x		
external source:					
Eu-152 GBq at 01.01.1996					
Co-60 GBq at 01.01.1996		300			
Na-22 GBq at 01.07.1996					

	RCM1 D	RCM2 D	FZJ D	NNC GB	LOVI FIN	TVO FIN	SCK1 B	SCK2 B	ITN E	NUCL I	ENEA I
Calibration											
waste dependent					x	x	x	x	x	x	x
number of waste packages					1	3	4	4	4	1	3
minimum density [g/cm^3]											0.4
maximum density [g/cm^3]											2
number of sources											
Eu-152 line source							x				
general calibration	x	x		x	x	x	x				
point sources											
Co-60	x	x	x		x						x
Y-88					x						
Ru-106											
Ba-133	x	x			x						x
Cs-134	x	x									
Cs-137	x	x	x		x						x
Eu-152	x	x	x				x			x	x
Eu-154	x	x									
Am-241	x	x	x								
line sources											
Eu-152								x			
disk sources											
Eu-152	x	x									
Eu-154	x	x									
Tl-208			x								

	CEA1	CEA2	CEA3	KEMA1	KEMA2
	F	F	F	NL	NL
Calibration					
waste dependent				x	x
number of waste packages					
minimum density [g/cm^3]					
maximum density [g/cm^3]		2.3			
number of sources					
Eu-152 line source					
general calibration	x	x	x	x	x
point sources					
Co-60	x	x	x	x	
Y-88	x	x	x	x	
Ru-106					
Ba-133	x	x	x	x	
Cs-134					
Cs-137	x	x	x	x	
Eu-152	x	x	x		
Eu-154					
Am-241	x	x	x	x	
line sources					
Eu-152		x			
disk sources					
Eu-152					
Eu-154					
Tl-208					

	RCM1	RCM2	FZJ	NNC	LOVI	TVO	SCK1	SCK2	ITN	NUCL	ENEA
	D	D	D	GB	FIN	FIN	B	B	E	I	I
Calibration											
volume sources											
Co-60			x	x		x					
Sr-85											
Y-88				x							
Cd-109				x							
Sn-113				x							
Sb-125				x							
Ba-133				x							
Cs-137			x	x		x					
Eu-152	x	x				x					
Eu-154	x	x									
Hg-203				x							
Ra-226											
Am-241	x	x		x							
Additional Equipment											
weighing unit	x		x	x		x	x	x		x	x
anticompton system											
dose rate measurement										x	x
dead time correction (Y-88)										x	x

	CEA1 F	CEA2 F	CEA3 F	KEMA1 NL	KEMA2 NL
Calibration					
volume sources					
Co-60					
Sr-85					
Y-88					
Cd-109					
Sn-113					
Sb-125					
Ba-133					
Cs-137					
Eu-152					
Eu-154					
Hg-203					
Ra-226					x
Am-241					
Additional Equipment					
weighing unit	x			x	
anticompton system					
dose rate measurement					
dead time correction (Y-88)					

	CEA1	CEA2	CEA3	KEMA1	KEMA2
	F	F	F	NL	NL
General					
routine inspection [%]	50			100	20
research purposes [%]		100	100		80
Waste Packages and Matrices					
waste packages					
100 L raw waste	x	x	x	x	
220 L packages (raw)	x	x	x		x
220 L packages (condit.)	x	x	x		x
400 L packages	x				x
500 L packages	x				
570 L packages	x				x
shielded containers		x	x		x
1 m^3 containers					
2 L specimen					
range of matrix densities					
min. [g/cm^3]	0.2	0.2		0.2	0.2
max. [g/cm^3]	6	2.3		1.0	4.0

	RCM1 D	RCM2 D	FZJ D	NNC GB	LOVI FIN	TVO FIN	SCK1 B	SCK2 B	ITN E	NUCL I	ENEA I
Libraries of Nuclides											
software											
InterLara (EURISYS)	x	x									
OMNIGAM nuclide library											
CANBERRA Spectran-F Analysis Package										x	
JEF PC nuclear data				x			x	x			
literature											
M. Lederer, V. Shirley, "Table of Isotopes", John Wiley & Sons, Inc., New York	x	x		x							
E. Brown, R. Firestone, "Table of Radioactive Isotopes", John Wiley & Sons, New York	x	x									
G. Erdtmann, W. Soyka, "The Gamma Rays of the Radio-nuclides", Verlag Chemie	x	x									x
D. N. Slater, "Gamma-rays of Radionuclides in Order of In-creasing Energy", Butter-worths, London	x	x									
Rad decay libraries							x	x			
W. Wahl, "α, β, γ - Table of Commonly Used Radionucli-des"	x	x									
Catalogue of gamma rays from radioactive decay - Atomic Data and Nuclear Data Tables, Vol. 29, No. 12, Sept. 1983									x		
ICRP 38											

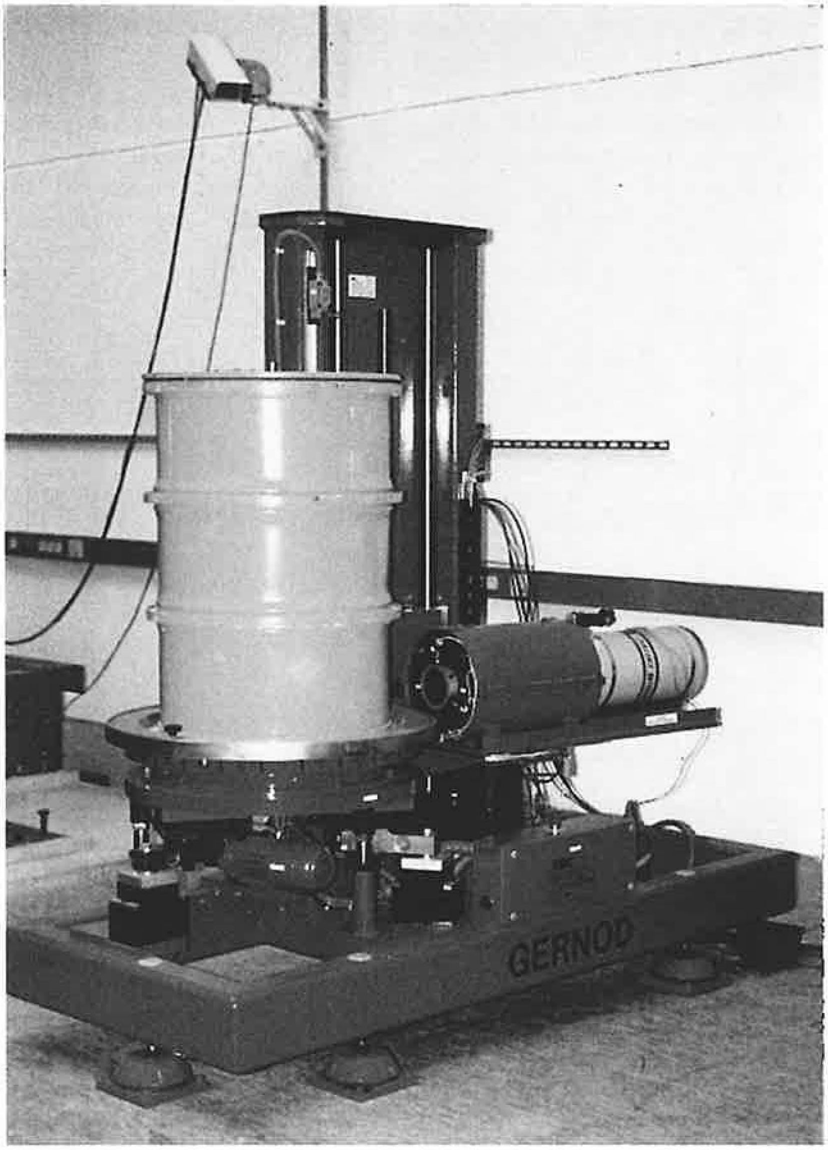
	CEA1	CEA2	CEA3	KEMA1	KEMA2
	F	F	F	NL	NL
Libraries of Nuclides					
software					
InterLara (EURISYS)	x	x	x	x	x
OMNIGAM nuclide library					
CANBERRA Spectran-F Analysis Package				x	x
JEF PC nuclear data					
literature					
M. Lederer, V. Shirley, "Table of Isotopes", John Wiley & Sons, Inc., New York				x	x
E. Brown, R. Firestone, "Table of Radioactive Isotopes", John Wiley & Sons, New York				x	x
G. Erdtmann, W. Soyka, "The Gamma Rays of the Radio-nuclides", Verlag Chemie					
D. N. Slater, "Gamma-rays of Radionuclides in Order of In-creasing Energy", Butter-worths, London					
Rad decay libraries					
W. Wahl, "α, β, γ - Table of Commonly Used Radionucli-des"					
Catalogue of gamma rays from radioactive decay - Atomic Data and Nuclear Data Tables, Vol. 29, No. 12, Sept. 1983					
ICRP 38				x	x

Description of the Individual Gamma Scanning Systems

In Appendix C general descriptions of the individual gamma scanning 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 description of 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 informations refer to Appendix B with the technial data tables or to Appendix D with the list of contact persons.

MGS (RCM1)

Mobile Gamma Scanner



Mobile Gamma Scanner (MGS).

Address

Institut für Radiochemie
Technische Universität München
Walther-Meissner-Strasse 3
D-85748 Garching
Germany
Tel.: ++49-89-289-12202
Fax: ++49-89-3261115

Features

Segmented gamma scanner
Mobile system
Designed for object dimensions up to 0.8 m diameter, 1.5 m height and 15000 kg weight
Different gamma scan modes
Software control of data acquisition and analysis
High purity germanium detector
Energy range: 30 to 2800 keV
Weighing unit
Optional: additional LOAX-detector in open geometry

General

The MGS is designed for the mobile non-destructive assay of radioactive waste packages in order to identify and quantify the gamma emitting inventory.

Principle of Operation

The MGS measures the emitted gamma radiation by scanning the surface of the container using a collimated high purity germanium detector (31.6 % relative efficiency). Depending on the scan mode selected (e. g. multiple rotational scan) the data recording is performed for a preselectable number of intervals (segments, sectors and/or steps). For each interval a complete gamma spectrum is measured and stored. By summing up these segment spectra the sum spectrum is calculated. From this, the gamma emitting nuclides are detected via their characteristic gamma lines. An additional peak search on the segment spectra can be performed to identify nuclides (hot spots) whose gamma lines may be covered by other nuclides and their Compton background in the sum spectrum. The corresponding net peak areas of all identified gamma lines are used for the determination of the nuclide specific activities.

Optionally an additional LOAX-detector can be used in the 'open geometry' mode to improve the detection limits in the low energy region, i. e. below 300 keV.

Information on the matrix necessary for absorption correction in calculating the gamma activities is based either on documentation or on weighing, determining the mean density of the matrix.

System Description

The gamma scanning system consists of four parts: the mechanics, the detector system, the mechanical control and the data acquisition and processing unit.

Mechanics
The mechanical system consists of a turntable for rotating the waste package and a lifting unit with an integrated swivelling unit for the detector system. Accuracy and reproducibility of the movement of these axis are less than 0.5 mm and 0.5 degree, respectively. Additionally, the distance between the detector and the turntable can be adjusted.

Detector System
A high purity germanium detector of 31.6 % relative efficiency, p-type, is mounted on the lifting unit so that the detector can scan the complete height of the object. The shielding against background radiation is assured by a lead cylinder of 300 mm diameter and 400 mm length. To adjust the measuring geometry to the activity of the object to be investigated collimators (lead) with different diameters are available. For cooling of the detector liquid nitrogen is used.

Mechanical Control
The mechanics are controlled by an IBM compatible PC. During measurements using any scan mode available, the mechanical control is combined with the control of the detector system and data acquisition, respectively

Data Acquisition and Processing
The data acquisition is performed by an integrated gamma spectroscopy system. During measurement the actual data is transferred to the control computer where it is summed up to the sum spectrum. This is visualized on-line on the monitor.

After the measurement, peak search routines are running on all segment spectra resulting in the corresponding specific net peak areas for all gamma lines detected. This data is transferred to a second computer via network or disk where the evaluation of nuclide activity is performed.

Specifications

Detector
High purity germanium detector, p-type, with 31.6 % relative efficiency and 1.7 keV energy resolution at 1.33 MeV, using liquid nitrogen for cooling
Optional: additional high purity, low energy detector (LOAX)

Shielding and Collimation
Shielding:
lead cylinder of 300 mm diameter and 400 mm length
Collimation:
5 cylindrical lead collimators with 5, 20, 40, 60 and 99 mm diameter and 200 mm length

Physical
Max. burden:
1.5 kN
Clearence size:
2.2 m x 0.9 m x 2.1 m
(H x W x D)

Mechanics
Ranges:
360° for rotation,
-30° to +30° for swivelling,
1.1 m for lifting (can be expanded to 1.6 m)

Electronics
Integrated gamma spectroscopy system:
92X, EG&G ORTEC

Container Capacities
Size:
diameter max. 0.8 m
height >1.8 m
Weight:
max. 15000 kg

Hardware
Control of mechanics and data acquisition:
PC 486/66 and plug-in cards
Data evaluation:
PC 586/133 compatible

Software
Operating systems:
Windows 3.11 and NT 4.0
Data acquisition:
GimScan 1.3 (GIM)
Gamma spectrometry:
InterGamma
EURISYS
Data evaluation:
RCM software

ITS (RCM2)

Integrated Tomography System

Address

Institut für Radiochemie
Technische Universität München
Walther-Meissner-Strasse 3
D-85748 Garching
Germany
Tel.: ++49-89-289-12202
Fax: ++49-89-3261115

Features

- Segmented gamma scanner
- Designed for object dimensions up to 1.4 m diameter, 1.8 m height and 15000 kg weight
- Different gamma scan modes
- Transmission source ^{60}Co, 9.8 · 10^{12} Bq (01.01.1998).
- Software control of data acquisition and analysis
- High purity germanium detector
- Additional measuring modes: Digital Radiography Transmission and Emission Computerised Tomography

Integrated Tomography System (ITS).

General

The ITS was originally designed and constructed by Sauerwein System-Technik GmbH (Haan/ Germany) for the investigation of large and heavy objects by transmission techniques: Digital Radiography (DR) and Transmission Computerised Tomography (TCT). An extension for segmented Gamma Scanning (GS) and Emission Computerised Tomography (ECT) was added later to assay radioactive medical, industrial, research or nuclear power plant waste.

The system enables measurements of objects with dimensions ranging on a large scale of size. On the one hand, there are small and light objects with dimensions of some centimetres, on the other hand, there are objects with dimensions of up to 1.4 m in diameter, 1.8 m in height and 15000 kg in weight. The basis for this flexibility is a very precise mechanical construction.

Principle of Operation

In the GS mode, the ITS measures the emitted gamma radiation by scanning the surface of the container using a collimated high purity germanium detector (ca. 77 % relative efficiency). Depending on the scan mode selected (e. g. multiple rotational scan) the data recording is performed for a preselectable number of intervals (segments). For each segment a complete gamma spectrum is measured and stored. By summing up these segment spectra the sum spectrum is calculated. From this, the gamma emitting nuclides are detected via their characteristic gamma lines. An additional peak search on the segment spectra can be performed to identify nuclides (hot spots) whose gamma lines may be covered by other nuclides and their Compton background in the sum spectrum. The corresponding net peak areas of all identified gamma lines are used for the determination of the nuclide specific activities.

Additionally, the external ^{60}Co transmission source can be used to measure the mean density of the matrix by Digital Radiography necessary for absorption correction in calculating the gamma activies for inhomogeneous matrices. In difficult cases Transmission

Computerised Tomography is used to get information on the real density distribution within the matrix.

System Description

The gamma scanning system consists of four parts: the mechanics, the detector system, the mechanical control and the data acquisition and processing unit.

Mechanics
The mechanical system consists of a combined translation and rotation unit for the waste container and two lifting units for the detector system and the transmission source, respectively.

Accuracy and reproducibility of the movement of these axes are less than 0.1 mm and 0.1 degree, respectively.

Detector System
A high purity germanium detector of ca. 77 % relative efficiency, p-type, is mounted on one lifting unit so that the detector can scan the complete height of the object. The shielding against background radiation is assured by a lead/tungsten cylinder of 92 mm diameter. To adjust the measuring geometry to the activity of the object to be investigated collimators (tungsten) with different diameters are available. For cooling of the detector liquid nitrogen is used.

Mechanical Control
The mechanics can be controlled either by hand using a steering gear or by computer.

The latter is performed by a DEC PDP 11/73. This computer is connected to a VAX 4000/90 master on which the control software is running.

During measurements using any scan mode available, the mechanical control is combined with the control of the detector system and data acquisition, respectively.

Data Acquisition and Processing
The electronic chain of the detector system consists of a preamplifier, an amplifier and an ADC.

After the digitalisation of the detector signal the data is transferred to a transputer, buffered in a second transputer and then transferred to the VAX 4000/90 where it is manipulated by a multichannel analyser emulation program.

When the measurement is finished peak search routines are running on all segment spectra resulting in the corresponding gamma line specific net peak areas. This data is transferred further to a personal computer for calculation of the corresponding activities.

If necessary the data of Digital Radiography or Transmission Computerised Tomography is taken into account as well.

Specifications

Detector
High purity germanium
detector with 77 % relative
efficiency and 1.81 keV
energy resolution at
1.33 MeV, using liquid
nitrogen for cooling

Shielding and Collimation
Shielding:
lead/tungsten cylinder
of 92 mm diameter
Collimation:
2 tungsten collimators with
2 mm and 20 mm diameter

Physical
Max. burden:
200 kN
Clearence size:
3.5 m x 4.4 m x 4.0 m
(H x W x D)

Mechanics
Ranges:
2.8 m for translation
1.8 m for lifting
Accuracy:
<0.1 mm for translation
<0.1 degree for rotation

Electronics
Amplifier:
EG&G ORTEC 672
ADC:
4720/G (SILENA)
Transputer:
Gammascan ECT
(Sauerwein)

Container Capacities
Size:
max. diameter 1.4 m
max. height 1.8 m
Weight:
max. 15000 kg

Hardware
Control of mechanics:
DEC PDP 11/73
Data acquisition:
DEC VAX 4000/90
Data evaluation:
PC 586/133 compatible

Software
Operating systems:
DEC VMS Windows 95
MCA emulation:
Genie (CANBERRA)
Gamma spectrometry:
Genie (CANBERRA)
Data evaluation:
RCM software

Gernod II (FZJ)

Segmented Gamma Scanner System

Address

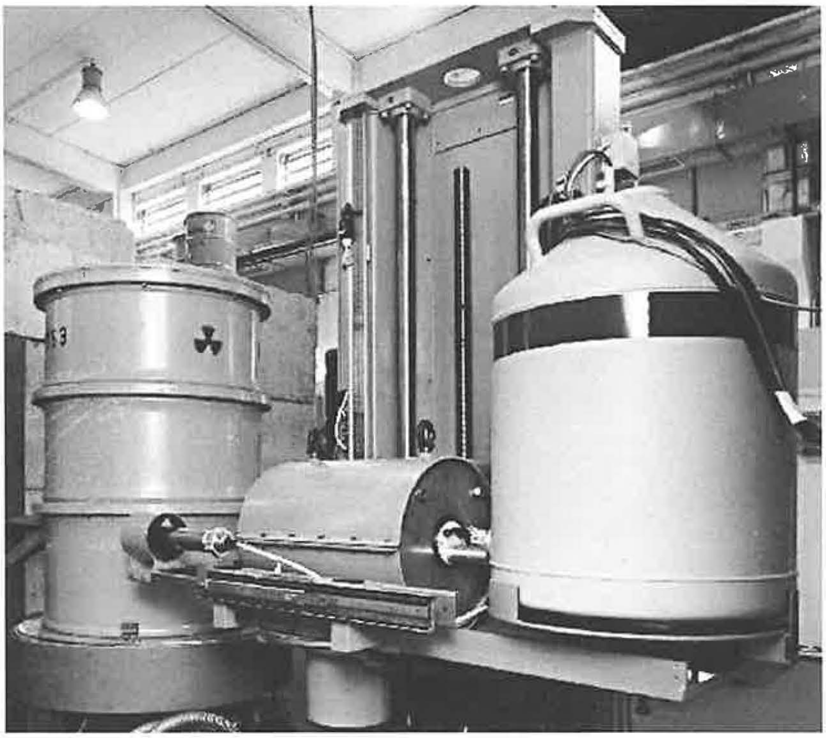
Forschungszentrum Jülich GmbH
Institut für Sicherheitsforschung und Reaktortechnik, ISR
D-52428 Jülich
Germany
Tel.: ++49-2461-61-5299
Fax: ++49-2461-61-2992

Features

Fast accurate assay of 200 L and 400 L waste drums with wide range of matrices and isotopic compositions
Segmented gamma scanner with drum rotation and vertical detector movement
High resolution germanium detector
Predefined and user selectable scan modes available
Max. weight of drum: 6000 kg
Collimation: adaptable to surface dose rate
Microsoft Windows based system software for measurement, control and automated data analysis
Additional features:
- passive neutron counting with ^{3}He tubes
- dose rate measurement
- advanced waste matrix correction techniques

General

The Segmented gamma scanner GERNOD II is a completely new designed version of the GERNOD I system developed by KFA in cooperation with industrial partners. It is built for the characterisation of radioactive waste contained in 200 L or 400 L drums.



Segmented Gamma Scanner System.

Principle of Operation

The radioactivity analysis is based on the measurement of the emitted gamma radiation at the surface of a drum by a standard HPGe detector. The detector may be used together with different collimation/shielding assemblies to account for different levels of count rate.

During a measurement the drum is normally rotated on a turntable and the detector is moved in the vertical direction focusing the centre of the drum. This enables the system to scan the complete surface of the object (without bottom and top).

There are different predefined scan modes available: spiral scan, multiple rotational scan with different vertical segments or grid scan, depending on the information desired. During a scan partial spectra are recorded within preselectable intervals (segments) thus making it possible to derive the count rate distribution of individual nuclides at the surface of the drum. This gives information about the degree of homogeneity of the activity distribution in the waste drum.

The sum of all spectra is used to calculate the mean activity of all detectable nuclides by standard gamma spectrometric methods. For overlapping peaks the net peak areas can be calculated by deconvolution. The basic formula used for the calculation of the specific activity is given by equation (1) and (4) on page 14.

The mean mass attenuation coefficient of the waste matrix is calculated from documented data or due to 'reasonable' assumptions. Additionally, correction factors are used to account for gamma attenuation in the matrix and the drum wall, inhomogeneities of the drum filling, internal shieldings, filling height etc.

The total activity of all nuclides in the waste is calculated by multiplying the specific activity with the net weight of the drum. For drums containing low level waste measurements can be done in the 'open geometry mode', e. g. with a wide-open conical collimator to achieve lower detection limits.

System Description

The gamma scanning system consists of the following parts:
1. mechanical system
2. control unit
3. detection systems
4. system unit and operator interface

Mechanical System
The mechanical system consists basically of a turntable to accommodate different waste drums and a platform for the vertical movement of the gamma detection and collimation unit. The driving units incorporate stepping motors with superior positioning capabilities.

Control Unit
The positioning of drum and detector is handled by a SPS control unit. This offers superior positioning capabilities together with highly reliable performance and control of the system status. Scanning programs are performed either continuously (fast measurements) or in a step-by-step mode (longtime measurements)

Detection Systems
The detection of gamma emitting nuclides is performed by a high resolution germanium detector. The detector can be used together with different collimators. The choice of the detector and collimation/shielding depends on the type of application. The HPGe detector is connected to standard NIM-modules for signal processing and data acquisition. A dosemeter is attached to the gamma detector to record the dose rate at the surface of the drum over the whole measuring period. For α-containing waste an additional neutron detection system based on ^{3}He counter tubes with shift register logic is incorporated. It has been designed to perform measurements simultaneously with the gamma scanning.

System Unit and Operator Interface
All routine operator interactions are carried out via a PC-based control system. The system software has been developed by KFA Jülich for ease of operation and reliable data handling and analysis. The system software runs completely under Windows 3.11 or Windows 95.

During a measurement a lifetime display of the acquired sum-spectrum is generated together with a second window showing count rate distributions for pre-selected regions-of-interest, dead-time of the ADC or dose rate at the drum surface.

The system has inbuilt standard routines to check the system's performance and integrity (QA/QC procedures). All data belonging to a certain measurement including calibration and general information about the scan are stored in one separate directory. Data analysis can be done after the measurement has been completed or can be repeated on any other PC system.

Specifications

Turntable with Weighing Unit
Accommodates 100 L, 200 L, 280 L and 400 L drums
Max. weight:
6000 kg
Drum speed:
0.1 to 4 rpm in the continuous mode

Detector/Preamplifier
HPGe, p- or n-type with typically 30 % relative efficiency
LN_2 cooling
Resistive feed-back or transistor reset preamplifier

Nuclear Electronics
Spectroscopy Amplifier:
EG&G ORTEC 672 or 973u
ADC/MCB:
EG&G ORTEC 918, 919 or 921

Shielding and Collimation
Collimators and shielding made of lead or tungsten
Cylindrical collimators with 200 mm length and different diameters: 10, 20, 40, 100 mm
'Open geometry': conical collimator with 84° opening angle

Dosemeter
3 dosemeters:
at 10 cm from the surface
at the bottom and
in 100 cm distance
Range:
0.1 to 10000 µSv/h

Control Unit
Control of mechanics and motors by SPS unit (Berger & Lahr)
Control of scanning programs and data acquisition by standard PC-hardware

Software
Operation System:
Windows 3.11 or
Windows 95 (Microsoft)
MCA-Software:
Gamma Vision (EG&G ORTEC)
Vers. 2.30
Operating and analysis software:
SCANNER
(KFA Jülich), Vers. 1.2

Physical
Clearance size:
2.0 m x 0.9 m x 2.4 m
Weight:
ca. 12 kN
Power supply:
380 V/AC

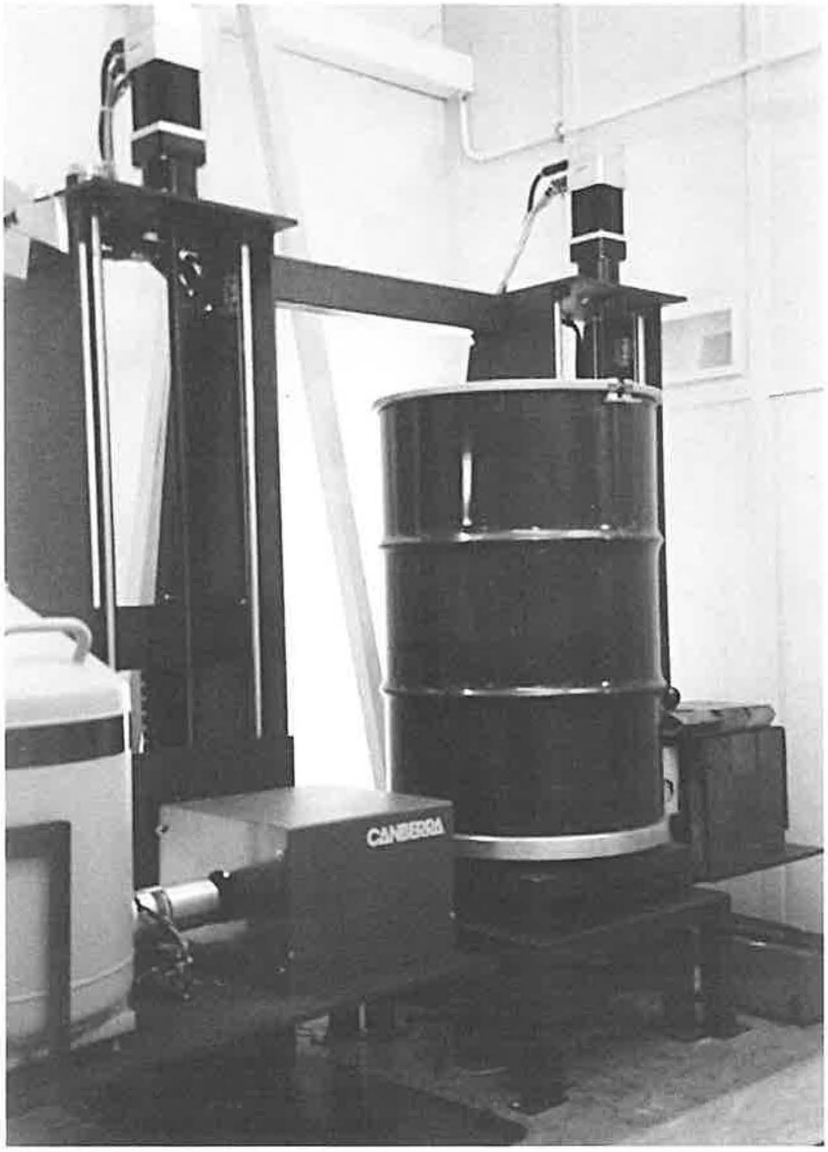
SGS (NNC)
Segmented Gamma Scanner

Address

Waste Quality Checking
Laboratory
Winfrith Technology Centre
Dorchester, Dorset, DT2 8DH
Great Britain
Tel.: ++44-1305-852-230
Fax: ++44-1305-853-858

Features

- Segmented gamma scanner
- Transmission source ^{152}Eu ($3.0 \cdot 10^8$ Bq)
- High purity germanium detector
- Designed for object dimensions 900 mm x 580 mm and 1000 kg weight



Segmented Gamma Scanner (SGS).

General

The Segmented gamma scanner (SGS) employed at the WQCL is a CANBERRA Packard system. The system is used to identify and quantify the gamma emitting radioisotopes present in drummed low level radioactive waste.

The system is designed to routinely measure 220 L drums of waste with the possibility of measuring 100 L drummed waste if required. The maximum loading capacity of the system is 1000 kg, and the maximum dimensions 900 mm x 580 mm.

Principle of Operation

The SGS assays the drummed waste in discrete vertical segments, routinely 8. The ^{152}Eu external transmission source determines the density correction factor which must be applied to all measurements in each particular segment. A gamma spectrum is measured for each segment and the gamma emitting radioisotopes are determined by identification of their characteristic gamma lines. The net peak area of each identified gamma ray is corrected for attenuation using the density correction factor determined for the appropriate segment and subsequently the respective radioisotope radioactivities are determined. The analysis software is able to distinguish between interfering gamma rays.

System Description

The SGS system consists of four main parts: the mechanics, the detector system, the mechanical control and the data acqusition and processing unit.

Mechanical System
Consists of two vertical drive assemblies which lift the detector and the ^{152}Eu external transmission source past the drum in segments. The turntable rotates during measurement at a speed of 10 rpm and has a maximum loading capacity of 1000 kg. Accuracy of lift-ing mechanism is <0.1 mm.

Detector System
A high purity germanium detector of 30 % relative efficiency, p-

type, is mounted on one of the vertical drive assemblies so that the drum can be assayed in a series of vertical segments. Shielding of the detector against background radiation is provided by a lead shield which acts as the collimator. It is also possible to insert a lead collimator into this lead shield, if high count rates are experienced. The detector is cooled using liquid nitrogen.

Mechanical Control
The mechanics are controlled via a VIGLEN P 150 computer on which the analysis software is also installed.

Data Acquisition and Processing
The detector system consists of a preamplifier, an amplifier and an ADC. After the ADC the data is fed into a CANBERRA Packard Series 100 multichannel analyser.

Once each segment is measured the analysis software analyses the spectra for that segment using a peak search program to identify any radioisotopes present from their characteristic gamma lines. The density correction factor for the segment is applied to the net peak area of the identified gamma ray to correct for attenuation by the waste matrix and this data is used to calculate the radioactivity of the particular radioisotopes in each segment.

Specifications

Detector
High purity germanium detector with 30 % relative efficiency and 2.0 keV FWHM at 1.33 MeV, using liquid nitrogen cooling

Shielding and Collimation
Shielding:
lead rectangular shield providing 10 cm rectangular opening
Collimation:
routinely provided by above shielding; option of inserting a collimator to provide 2 cm rectangular opening

Physical
Maximum turntable capacity:
1000 kg
Dimensions of drum:
900 mm x 580 mm

Mechanics
Ranges:
max. 1.0 m for lifting
Accuracy:
<0.1 mm for lifting

Electronics
Amplifier:
CANBERRA Packard 2024
ADC:
CANBERRA Packard 8706

Container Capacities
Weight:
max. 1000 kg
Dimensions:
max. 900 mm x 580 mm

Hardware
Control of mechanics and data evaluation via VIGLEN P 150 computer

Software
Series 100 MCA
CANBERRA Packard
Spectran Gamma Analysis
CANBERRA Packard
FITZPEAKS Data Evaluation
Jim Fitzgerald

IVO / Loviisa NPP

(LOVI)
Low Level Waste Drum Measurement System

Low Level Waste Drum Measurement System.

Address

Imatran Voima OY
Loviisa NPP
P. O. Box 23
FIN-07901 Loviisa
Finland
Tel.: ++358-19-550-1
Fax: ++358-19-550-4435

Features

Unsegmented gamma scanner for standard waste drum measurements
Liquid nitrogen cooled high purity germanium detector
Software control of data acquisition and analysis
Energy range 75 to 2000 keV

General

The system is used for routine waste package measurements at the Loviisa nuclear power plant (PWR). The waste drums produced at the plant are measured for gamma activity before disposal into the interim storage or final repository.

Principle of Operation

The system is based on a stationary collimated high purity HPGe detector, which is used in an unsegmented measurement mode. The waste drum is rotated and lifted during the measurement. The spectra are collected and analysed with computer based analysis software. Measurement results are recorded in the plant data base. Calibration is based on experimental methods.

Specifications

Detector
High purity germanium detector with 17 % relative efficiency using liquid nitrogen cooling

Shielding and Collimation
Lead shielding and collimator

Electronics
NIM - BIN:
CANBERRA 2100 - 2
HV:
CANBERRA ICB 9645 6 kV HV
Preamplifier:
CANBERRA 2001
Amplifier:
CANBERRA ICB 9615
ADC:
CANBERRA ICB 9635
MCA:
CANBERRA ICB 556 AIM
LFC- module:
CANBERRA 599
Interface:
CANBERRA ICB 554 RPI

Hardware
VAX 4090

Software
CANBERRA Genie-ESP

TVO/Olkiluoto NPP

(TVO)
Low Level Waste Drum Measurement System

Address

Teollisuuden Voima Oy (TVO)
Olkiluoto NPP
FIN-27160 Olkiluoto
Finland
Tel.: ++358-2-8381-5535
Fax: ++358-2-8381-5549

Features

- Unsegmented gamma scanner for standard waste drum measurements
- Liquid nitrogen cooled high purity germanium detector
- Software control of data acquisition and analysis
- Energy range 200 to 1600 keV

General

The system is used for routine waste package measurements at the Olkiluoto nuclear power plant (BWR). The waste drums produced at the plant are measured for gamma activity before disposal into the interim storage or final repository. The described drum measurement system is used for medium level waste drum measurements. Also low level drums are measured.

Principle of Operation

The system is based on a stationary collimated high purity HPGe detector, which is used in an unsegmented measurement mode. Long drum-detector distance (up to 8 meters) allows also for high activity measurements. The spectra are collected and analysed with computer based analysis software. Measurement results are recorded in the plant data base. Calibration is based on ^{152}Eu standard source (the standard solution is blended with the waste matrix).

Low Level Waste Drum Measurement System.

Specifications

Detector
High purity germanium detector with 15 % relative efficiency

Shielding and Collimation
Lead collimator combined with concrete wall shielding

Electronics
Preamplifier:
attached to the detector
EG&G ORTEC
Amplifier:
92X, EG&G ORTEC
ADC:
92X, EG&G ORTEC
MCA:
92X, EG&G ORTEC

Hardware
IBM compatible

Software
Maestro II, EG&G ORTEC
Omnigam, EG&G ORTEC

SGS (SCK1)
Segmented Gamma Scanner

Address

SCK•CEN
Boeretang 200
B-2400 Mol
Belgium
Tel.: ++32-14-33-2263
Fax: ++32-14-32-1529

Features

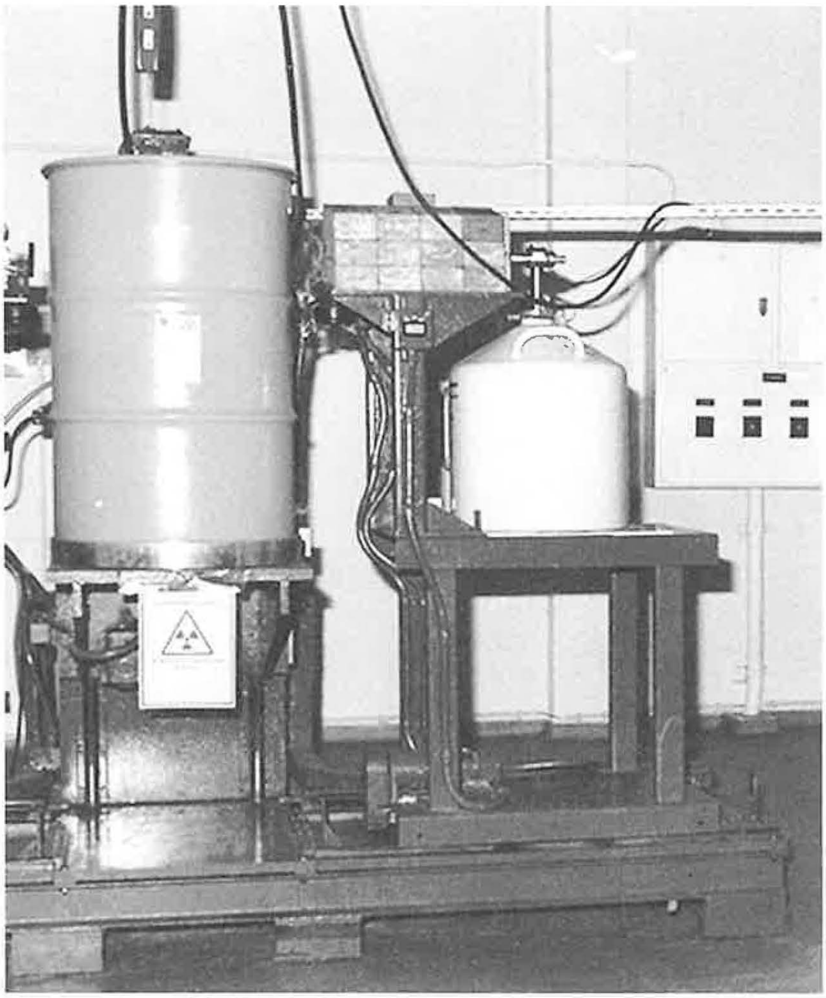
- Objects: 400 L and 220 L drums with a max. load of 1500 kg
- High purity germanium detector
- Multiple rotational scan
- Spiral scan

General

The SGS at SCK•CEN is originally a model 2220 BC scanner from CANBERRA built in the seventies. The system was recently upgraded by SCK•CEN. The turntable is in the middle of the system and can move up and down (for vertical scanning). The collimated detector is at a fixed height and is located on a trolley which can move vertically which allows to change the distance between detector and waste drum. An identical trolley at the left and opposite to the detector trolley can hold a transmission source.

Principle of Operation

A collimated detector is used to scan the drum positioned on the turntable. The spectrum acquisition and the turntable position are controlled by the main software and a user selectable number of segments can be defined. The SGS is equipped with a Ge-Reverse coaxial detector (Be window) with a relative detection efficiency of 10 %. The detector is fixed in a lead collimator which can hold collimator-inserts of different apertures.



The SGS (detail of the turntable and right trolley holding the detector and collimator).

The correction for gamma attenuation is based on the mean density of the waste and is calibrated with the aid of calibration drums with known matrix density and for a homogeneous source distribution.

System Description

The SGS consists of three parts: the mechanics, the detector system and the data acquisition and processing unit.

The Mechanical System

The mechanical system consists of an elevation unit for the turntable and two trolleys positioned respectively on the left and right hand side of the turntable opposite to one another. The left trolley holds the detector-collimator system. The right trolley can be equipped with a transmission source. Both trolleys can move horizontally towards and from the drum.

Detector System

A high purity germanium detector (Ge-Reverse coaxial detector with Be window) with a relative detection efficiency of 10 % is mounted on the right trolley of the SGS. The trolley also holds the lead collimator. The main collimator which also shields the detector can hold smaller insert collimators with different apertures.

Mechanical Control

The turntable elevation and trolley positions can be controlled manually from the control panel or automatically by computer. In routine measurements, the positioning is controlled by computer. The positioning systems use analog position sensors controlled by digital process indicators communicating with the computer via RS232.

Weighing of the drum is performed with an external dynamometer being a part of the pulley system used to lift the drum on the turntable.

Data Acquisition and Processing
The measurement chain contains a preamplifier, spectroscopy amplifier, ADC and the S100 MCA. Data acquisition is performed and controlled by the main program which communicates with the Genie-2000 acquisition module.

The spectra of all segments are first stored and are summed and analysed after the complete scanning of the drum.

Specifications

Detector
High purity germanium detector (coaxial RE, Be window) of 10 % relative efficiency and 1.8 keV (FWHM) resolution at 1332 keV, using liquid nitrogen for cooling

Collimation
A main lead collimator contains the detector, the collimator can hold different collimator-inserts with different apertures

Physical
Max. sample load 1500 kg
Dimensions:
4.0 m x 1.5 m x 1.9 m
(L x W x H)

Mechanics
Drum lifting range:
1.2 m, accuracy 0.5 mm
(driven by AC motor)
Trolley position range:
50 cm, accuracy 0.5 mm
(driven by AC motor)
Turntable: 10 rpm
(continuous rotation, driven by AC motor)

Electronics
Amplifier:
AFT Research amplifier Model 2025, CANBERRA
ADC Model 8075, CANBERRA
MCA S100 PC board, CANBERRA

Container Capacities
Max. 400 L drums
Max. load: 1500 kg

Hardware
Digital process indicators (Druck) for control of positioning via analog position sensors
386 PC

Software
Main program:
SCK•CEN software
Data acquisition, MCA:
Genie-2000 (CANBERRA)
Spectrum analysis:
Genie-2000 (CANBERRA)
Data evaluation and activity report:
SCK•CEN software
Reporter.XLS

Q^2 (SCK2)

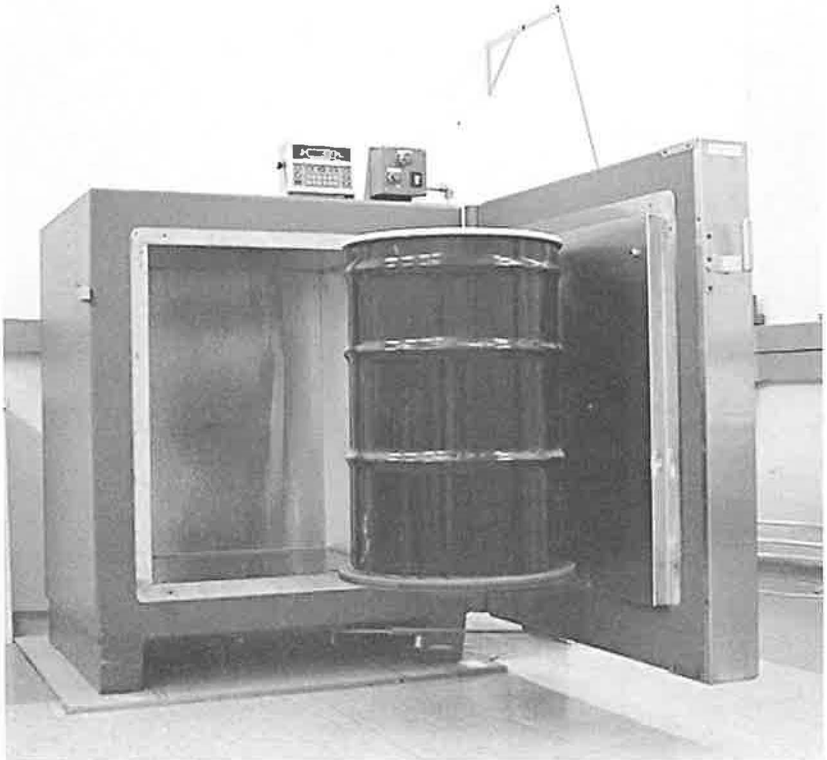
Low Level Waste Assay System Q^2

Address

SCK•CEN
Boeretang 200
B-2400 Mol
Belgium
Tel.: ++32-14-33-2263
Fax: ++32-14-32-1529

Features

- Three detector system
- Completely shielded measurement cavity for 220 L drums
- Detection limits of the order of a few hundred Bequerels with 10 min counting time
- Free release measurements



The Low Level Waste Assay System, with an open cavity showing a 220 L drum loaded on the turntable.

General

The Low Level Waste Assay System is a completely shielded gamma assay system. The shielding is 15 cm thick and made of low background steel.

The gamma spectrometry is performed with 3 uncollimated 20 % relative efficiency coaxial Ge detectors. The end caps of the detectors are only a few centimetres from the drum wall. This allows low detection limits for the detection of gamma emitters in 220 L waste drums (typical 370 Bq per drum with 10 min measuring time).

Principle of Operation

The waste drum rotates at 10 rpm while three Ge detectors are used simultaneously to scan the drum. The three resulting spectra are summed together prior to the analysis. A QA module is used to check regularly the energy and FWHM calibrations in order to match peaks at the same channels in the three spectra. The gamma attenuation correction is based on the average density of the content of the waste drum and is calculated from a set of detection efficiency calibrations with reference drums with homogeneous matrices and a homogeneous source distribution.

System Description

The Low Level Waste Assay System Q^2 consists of three main parts, the shielding cabinet and turntable, the detector system and the data acquisition, and the processing unit.

The Shielding and Turntable

The shielding cabinet (cavity) is made of a 15 cm thick low background steel and has a hinged door to access the interior of the shielding. The inside of the cavity is covered with an inox cladding for easy decontamination.

The door is equipped with a turntable for 220 L drums which have a maximum load of 450 kg. The turntable has a load cell which is connected to a weighing unit installed on top of the cabinet. The weighing unit is read out by the PC used for the data acquisition.

Detector System

Three high purity germanium detectors of ca. 20 % relative efficiency (coaxial p-type) are mounted through three holes in the right side wall of the shielding cabinet one above the other. The detectors view the 220 L drum from the side at respectively the top, the mid height and the bottom position.

Data Acquisition and Processing

Each detector has his own measurement chain with preamplifier, spectroscopy amplifier and ADC/MCA. The ADC/MCA is the ACCUSPEC PC board of CANBERRA. The main software starts the acquisition with the three detectors, calculates the sum spectrum and performs the spectrum analysis of this sum spectrum and calculates the gamma yield for each detected peak. This data is then transferred to another PC which identifies the isotopes and generates the final measurement report.

Specifications

Detector

3 high purity germanium detectors with 20 % relative efficiency each, and 1.9 keV (FWHM) resolution at 1408 keV (CANBERRA)
7 L liquid nitrogen dewars, requiring 2 fillings a week

Shielding

A 15 cm thick low background steel shielding cabinet, access is via a hinged door

Physical

Max. load:
450 kg
System dimensions:
1.52 m x 1.72 m x 1.22 m
System weight:
8000 kg

Electronics

Amplifiers:
3 AFT Research Amplifiers Model 2025, CANBERRA
ADC/MCA: 3 AccuSpec A boards, CANBERRA

Container Capacities

220 L drum and smaller containers, absolute filters
Max. weight:
450 kg

Hardware

Data acquisition:
386 PC
Data evaluation:
PC Pentium 75 MHz

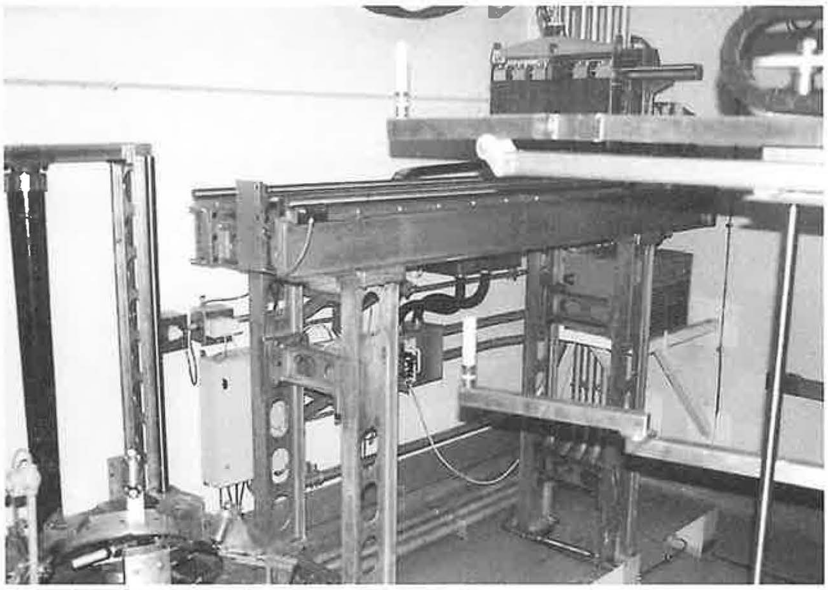
Software

AQ2 software, based on ABACOS-II (CANBERRA)
Nuclide identification and reporting is based on a SCK•CEN Visual Basic program for EXCEL

IRB (ITN)

Address

CIEMAT DFN
Avda. Complutense, 22
E-28040 Madrid
Spain
Tel.: ++34-(9)1-3466476
Fax: ++34-(9)1-3466576



IRB System in LVCR Enresa-El Cabril.

Features

- Segmented gamma scanner
- Dose rate measurements
- Designed for objects up to 1.2 m height, 0.76 m diameter and 1500 kg
- Automatic change of collimator diaphragm
- Detector-object distance automatically controlled
- Weighing unit with 1500 kg capability
- Software control of mechanical movements, data acquisition and data analysis
- HPGe detectors
- Geiger-Müller detectors
- Full scale calibration sources

General

The design of the IRB system is based on studies supported by CEC and ENRESA, CIEMAT-DFN on the development of a non-destructive method for the QC and QA of L&MLW packages for the El Cabril near surface repository in Spain.

The system enables measurements of objects of several sizes ranging from 100 mm diameter and 200 mm height drill specimens up to 480 L drums with 0.71 m diameter .

Measurement geometries available are:

- Liquid and solid homogeneous cemented radioactive waste in 220 L drums
- Contaminated primary coolant cartridge filters in special internal concrete reinforced 220 L drums
- Heterogeneous pre-compacted solid waste in both, pre-shielded and non-pre-shielded 220 L drums with concrete
- Metallic and heavy contaminated pieces in concrete matrix in 220 L drums
- Scrap metals from radioactive lighting rods decommissioning (^{241}Am determination) in 220 L drums
- Homogeneous 220 L drums reconditioned in concrete pre-shielded 480 L drums
- 2 L specimens from drilling of homogeneous 220 L drums
- Supercompacted 220 L pellets in 290 L drums (in development)
- Non-compactable heterogeneous waste (e. g. scrap metals and decommissioning waste) in 220 L drums with and without special lead and/or concrete shielding (in development)

Principle of Operation

The system performs the measurement of the packages using a multiple rotational gamma scan with typically 8 segments for 220 L drums, using a collimated Ge detector (7 % or 25 % relative efficiency), specific collimation diaphragm and an appropriate detector-drum distance, in order to assure overlapping of solid angles and avoid saturation effects of the detector as a function of the count rate.

The system acquires two spectra per segment, the PHA$^+$ spectrum for radionuclide identification and quantification and the MCS spectrum which represents total gamma counts per rotational degree and measurement time.

Analysis is performed on the sum of the individual segment spectra once corrected in function of attenuation, self-absorption and dead time.

As a result, the activity of the radionuclides identified by software and the distribution of these nuclides per segment is determined. Also a 2D plot of MCS spectra is performed.

System Description

The IRB gamma scanner is divided into three parts: the mechanical system, the detection system and the process control system.

Mechanical System
The mechanical system consists of a turntable with a lifting unit that can load and weigh objects up to 1500 kg. The maximum vertical displacement is 1.32 m and the maximum diameter of loaded objects is 0.76 m.

Detector, Collimator-Set and Shielding
The system is installed in a structure that allows its displacement from the turntable in a maximum range from 0.0 to 2.0 m. Each collimator set has 4 collimators and allows their automatic change. Two sets of diaphragms are available.

The angular speed of the turntable is 7 rpm and the vertical, the collimator change and the detector-drum movement speeds are in the range of 1.0m to 1.5 m/min.

The accuracy of the movement control is 1 degree in rotation and 0.1 mm in linear movements.

A remote controlled arm with Geiger-Müller detectors, which are used to take the segmented dose rate of the drum, is installed.

All movements are controlled automatically by an interface installed in the process control system and by a redundant manually control system.

Detection System
In the shielding-collimator support an electro-cooled HPGe detector of ca. 17 % relative efficiency is mounted.

The detector is shielded by a lead cylinder of 100 mm thickness. A set of 6 lead and copper platings is available.

A gamma spectrometry system (ADC, spectrometry amplifier, preamplifier, MCS module) prepared for high count rates and counter scales for Geiger-Müller detectors ise used.

Data Acquisition and Processing
Digital data coming from the electronics is transferred to an external MCA and then to a computer. The computer also controls the acquisition start/stop presets and is transferring commands for both gamma and dose rate measurements.

Movements and relative positions of drum, detector, collimators and 5 cm dose rate detector position are controlled in real time during the measurement process.

Individual segment spectra in ASCII format are corrected by specific algorithms for each geometry and analysis conditions. The sum spectrum is transformed in Spectran-AT file format in order to perform peak localisation and calculation using Spectran-AT (gamma spectrum analysis program).

Output results are prepared in customised form and saved in data base format, presented on screen and printed out.

The system is divided into 5 parts: calibrations, input data of sample, measurements, analysis and results, coordinated by sample name in a data base compatible MS Access.

Specifications

Detector
High purity germanium detector with 17 % relative efficiency and 0.87 keV resolution at 122 keV and 1.71 keV at 1332 keV. The detector is electro-cooled.

Shielding and Collimation
Shielding:
lead cylinder of 100 mm diameter
Collimation:
2 sets of lead/copper plating collimators with 5 mm to 50 mm diameter and set of non-circular sections collimators

Mechanics
Ranges:
2.0 m for detector translation
1.35 m for drum lifting
max. linear speed 1.5 m/min
max. angular speed 7 rpm
Accuracy:
1 mm for linear displacement
1 degree for angular displacement

Electronics
2002 CANBERRA Preamplifier
2020 CANBERRA Amplifier
8075 CANBERRA Amplifier
S35+ CANBERRA MCA

Container Capacities
Size:
max. diameter 0.7 m
max. height 1.5 m
Weight:
1500 kg

Hardware
PC 586/133
Printer LaserJet HP III

Software
Operating System:
MS Windows 3.1x
Gamma spectrometry:
Spectran-AT Vers. 4.3 (CANBERRA)
Data acquisition, mechanics control, data evaluation and output results, calibration procedure control:
Jessara 4.0 W

NWAS (NUCL)

Segmented Gamma Scanner
Nucleco Waste Assay System

Address

NUCLECO S. p. A.
Società per l´ Ecoingegneria
Nucleare
Via Anguillarese 301
I-00060 S. Maria di Galeria (Roma)
Italy
Tel.: ++39-6-30345-1
Fax: ++39-6-30483081

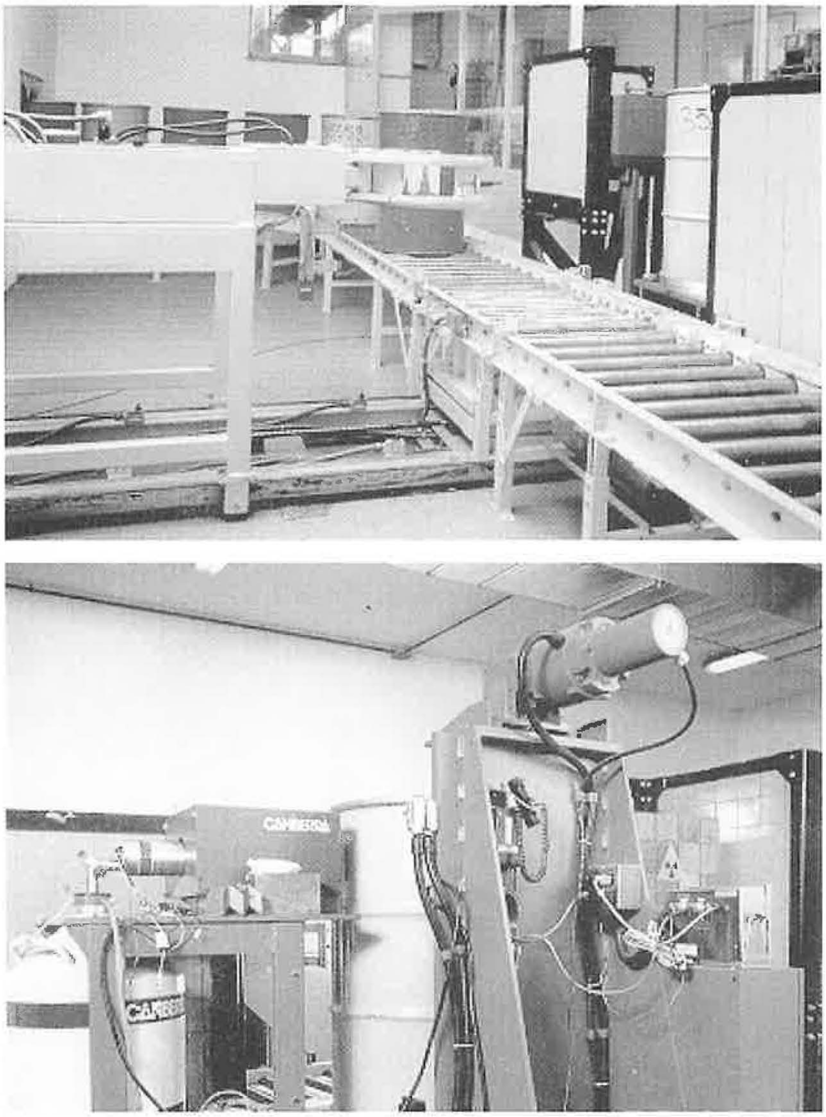
Features

- Segmented gamma scanner
- Automatic loading and unloading system for max. 200 L drums, 350 kg max. weight
- Automatic loading/ unloading conveyor
- Segmented assay with ^{22}Na transmission source
- Density correction by transmission correction factors
- Automatic barrel weighing system load cell based
- CANBERRA Spectran-AT analysis software
- Waste stream correction for non-gamma emitters
- Dose rate meter (ionisation chamber)
- Software for verification of compliance with domestic regulation

General

The automated waste assay system is a PC based system using the IBM PS2 60 computer for driving/ control and analysis.

The assay system is a standard barrel segmented gamma scanner with a transmission source module.



Segmented Gamma Scanner, Nucleco Waste Assay System.

The turntable is lifted while rotating by a mechanism driven by a stepper motor.

The turntable rotates the drum at 12 rpm and it accommodates drums up to 350 kg and 220 L capacity. Load cells are installed under the turntable for measuring the drum mass. A ^{22}Na transmission source is also provided. An automatic roller conveyor and an associated side fork lift system allow the automatic loading/unloading of the drums. Driving and control of the mechanism are performed by a Superior Electric Modulinx stepper motor and an I/O control system interfaced to an IBM computer by RS232.

The data acquisition unit is constituted by a high purity germanium detector interfaced to the MCA. A gate integrator amplifier and a fast ADC are used to manage high count rates.

Spectrum data is transferred to the IBM computer by a fast IBM interface.

Principle of Operation

The CANBERRA 2440 Waste Assay System uses a segmented scanning technique which calls for the summation of several individual segment assays performed on isolated cylindrical slices along the entire height of a container.

Each measurement is corrected to reflect the gamma ray intensity which would have been obtained from a non-attenuating cylindrical slice containing the same amount of radioactive material. The SGS CANBERRA 2440 is a part of the Radiological Characterisation Station and it is used to determine qualitatively and quantitatively the gamma emitting nuclides contained in waste drums. The system uses a high resolution HPGe coaxial detector, 60 % relative efficiency, liquid nitrogen cooled. The mass of the drum is determined by three load cells (350 kg max. weight, precision 1 % full scale) installed under the turntable. A ^{22}Na (10^9 Bq) transmission source is used for the matrix attenuation correction while a ^{88}Y source is used for the dead time correction.

The corrected measurements are summed together to represent a number which is directly proportional to the quantity of material of interest.

System Description

The Radiological Characterisation Station consists of five modules:

- Detector system
- Segmented gamma scanner mechanics
- Data acquisition and processing unit
- Automatic loading conveyor
- PLC multitask controller
- SGS Mechanics

It is constituted by:

- Carrying structure
- Detector assembly and dose rate meter
- Transmission source
- Turntable and weighing unit

Detector System
The system is equipped with a CANBERRA GC6021 HPGe detector, 60 % relative efficiency, mounted on a trolley support.

The detector to package surface distance can be varied by sliding back the trolley (1.0 m).

The collimation is obtained by a window in front of the detector shielding.

Loading / Unloading Mechanics
The loading/unloading automatic system consists of a roller motorised conveyor (10 drums for cycle) with a fork lift for loading/unloading the drum on the turntable.

Mechanical Control
Both mechanisms are supervised by a MITSUBISHI PLC associated to the PC IBM PS2 60. The system can be manually and automatically operated.

Data Acquisition and Processing
The electronics consists of:

CANBERRA 2002 preamplifier
CANBERRA 2024 amplifier
CANBERRA 35 plus MCA
CANBERRA Fast ADC 8077

The spectrum from the MCA is transferred to a PC IBM PS2. The CANBERRA Spectran-AT software provides the qualitative and quantitative analysis of the spectrum of the discrete segments (8 segments in the standard routine assay). The sum of the activity of each segment is reported in the final analysis data sheet.

Specifications

Detector
High purity germanium detector:
Energy range:
40 keV to 10 MeV
Relative efficiency:
60 %
Resolution:
2.1 keV at 1332 keV
Peak/Compton ratio:
71.0 at 1332 keV
Cooling:
liquid nitrogen

Shielding and Collimation
Lead parallel-epiped:
300 mm x 250 mm x 380 mm
Window:
200 mm x 100 mm
Copper liner thickness:
1 mm

Physical
SGS and loading/unloading conveyor clearance size 80 m^2

Mechanics
Ranges:
Lifting: 950 mm
Rotation: 12 rpm
Turntable diameter: 600 mm
Load cell: 350 kg ± 0.1 %

Electronics
Preamplifier:
CANBERRA 2002
Amplifier:
CANBERRA 2024
MCA:
CANBERRA 35 PLUS
ADC:
CANBERRA Fast ADC 8077

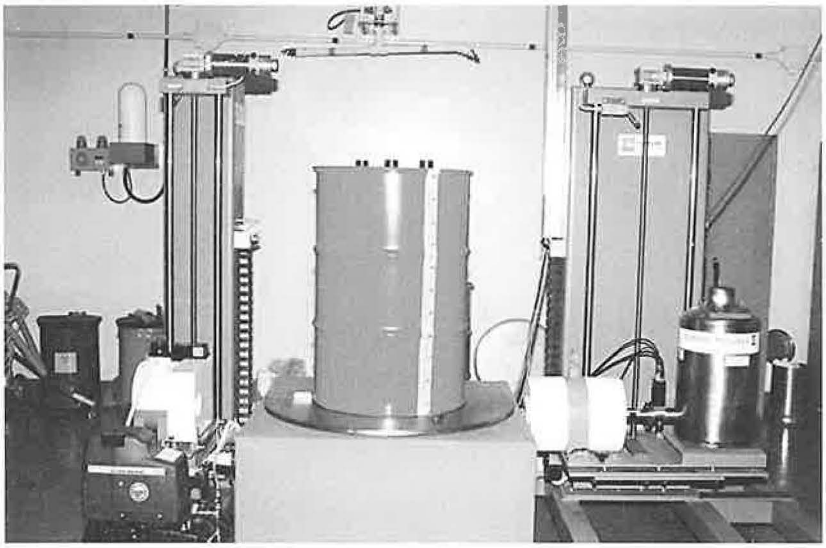
Container Capacities
Size: H 857 mm x Ø 600 mm
Max. weight: 350 kg

Hardware
Mechanism control:
PLC MITSUBISHI Melsec F_2-60 M with interface module Melsec F_2-232 M
Data evaluation:
PC IBM PS2 60

Software
Operating system: DOS 3.3
Administration software:
CANBERRA Nucleco Waste Assay System
Gamma spectrometry:
CANBERRA Spectran-AT

SRWGA (ENEA)

SEA Radioactive Waste Gamma Analyser



SEA Radioactive Waste Gamma Analyser (SRWGA).

Address

ENEA-ERG-SAL-LAB
C. R. Casaccia
I-00060 S. Maria di Galeria (Roma)
Italy
Tel.: ++39-6-3048-6662
Fax: ++39-6-3048-6590

Features

Segmented gamma scanner
scan modes:
- vertical scan
- rotational scan
- spiral scan
- multiple rotational scan

Can accommodate drums up to
0.8 m diameter,
1.3 m height and
1500 kg weight.

Transmission sources:
^{60}Co (10^9 Bq)
^{137}Cs (10^9 Bq)
^{110m}Ag ($5 \cdot 10^9$ Bq)

Laser controlled transmission source-detector alignment
HPGe detector
Bar-code reader
Load cells based weighing system
Computer controlled mechanical movements and electronic data acquisition
Designed to easily implement point measurements (open geometry), horizontal scan (low-resolution tomography), swivel scan

General

The SRWGA (SEA Radioactive Waste Gamma Analyser) was designed for the assay of radioactive waste drums containing gamma emitting nuclides.

It accommodates drums up to 1500 kg and 220 L, 400 L and 500 L capacity.

The system is an improved segmented gamma scanner using a high resolution HPGe coaxial detector, 40 % relative efficiency, liquid nitrogen cooled.

Three load cells are installed under the turntable for measuring the drum mass and three transmission sources are provided (^{60}Co, ^{137}Cs and ^{110m}Ag).

Two separate synchronised computer units control the mechanics, the data acquisition and analysis system.

The main characteristics of the design are:

Modularity, transportability, rugged construction, precise and reliable components for the moving units, easy implementation of different scan modes.

Principle of Operation

The system is based on the segmented gamma scanning technique. To minimise axial non-homogeneity errors, the measurements are performed on discrete segments along the vertical axis of the package to be investigated, while errors due to radial inhomogeneity are minimised by rotation.

The nuclides are identified from a spectrum of the gamma rays emitted, and their activity quantified. The spectrum of each segment of the waste container is analysed separately, and the results are reported for each segment and for the total drum activity.

The vertical scanning is carried out by moving simultaneously the detector and the transmission source; the alignment of the two units is laser controlled.

Matrix attenuation correction can be performed by a correction factor derived from:

The mean density of the matrix of the drum
Transmission measurement using external sources.

A HPGe detector with 40 % relative efficiency, nitrogen cooled, installed in a shielded and collimated cylinder, is used to measure the gamma rays from the package.

To record the dose rate during the scanning, a GM probe and associated signal conditioning electronics are also mounted on the detector unit.

A weighing unit constituted by three load cells installed under the turntable is also provided to supply the mass of the package.

System Description

The system is constituted by four main sections:

Mechanics
Electric/electronics
Driving/control
Data acquisition and analysis

Mechanics
It is constituted by:
Carrying structure and safety protection cabin
Detector assembly with the associated lifting system and dose rate meter
Transmission source with associated lifting system
Turntable and weighing unit

Detector System
A high purity Ge detector, low background configuration, is mounted into a cylindrical lead shielding. Collimators with different windows can be mounted. The distance detector to drum surface can be varied by sliding back the detector holding base (max. 0.5 m).

The detector cooling is provided by an automatic feeder of liquid nitrogen.

Cd and Cu liners are installed inside the detector shielding around the detector cap.

Mechanical Control
Manual and automatic actuation of the mechanical components are provided. The automatic control is performed by a microprocessor based multitask controller with PLC function included.

Transmission source to detector alignment is controlled by a He-Ne laser with its associated signal processing electronics: output is sent to PLC.

Data Acquisition and Processing
Besides the detector and its preamplifier, the nuclear electronics are constituted by a memory buffer card with the amplifier and the ADC, Wilkinson type, integrated. A software performs the MCA emulation (gamma acquisition and spectrum display), data reduction, analysis and reporting.

Specifications

Detector
HPGe
Energy range:
40 keV to 10 MeV
Relative efficiency:
40 %
Resolution:
0.9 keV at 122 keV
1.8 keV at 1332 keV
Peak/compton ratio:
65.8 at 1332 keV
Cryostat:
20 L, holding time 7 days

Shielding and Collimation
Shielding:
lead cylinder
diameter: 285 mm
length: 358 mm
thickness: 100 mm
Cu and Cd liner thickness:
1 mm
Collimators:
five lead cylinders
diameter: 100 mm
length: 200 mm
window: rectangular and circular shape of variable size.

Physical
Max. burden: 20 kN
Clearance size:
2.8 m x 1.2 m x 2.3 m

Mechanics
Ranges:
Lifting: 1.3 m ± 0.1 mm
Rotation: 0 to 6 rpm
Turntable diameter:
max. 0.9 m
Load cells system:
max. 1500 kg ± 15 g
overload capacity

Electronics
Preamplifier:
PSC 761 R, EURISYS
MCA/ADC/Amplifier Card
9308/A, SILENA
GM dose rate meter:
RV-12C, SEA mod.
Driving/control:
CNS801, MEPS

Container Capacities
Size:
Height: 1.3 m
Diameter: 0.9 m
Weight: 1500 kg

Hardware
Control of mechanism:
CNS801, MEPS
Data acquisition and evaluation: PC 586/33

Software
Operating system:
DOS and WINDOWS 95
MCA emulation:
Emcaplus, SILENA
Gamma spectrometry:
Gammaplus, SILENA
Data analysis and evaluation:
Gammaplus and custom software

MARCO-CARACO

(CEA1)
Mesure de l'Activitè des Radionuclèides des COlis de dèchets
Correction de l'Activitè des Radionuclèides des COlis de dèchets

MARCO-CARACO system for the activity determination of radionuclides.

Address

CEA/Cadarache
DCC/DESD/SCCD Bât. 326
F-13108 St. Paul-lez-Durance
France
Tel.: ++33-4-42-25-2590
Fax: ++33-4-42-25-7377

Features

- Mobile gamma scanner
- Designed for object dimensions up to 1.7 m diameter 1.7 m height and for cubic volumes up to 1.7 m x 1.7 m x 1.7 m, 10000 kg weight
- Global measurement
- High purity germanium detector
- Software controlled data acquisition and analysis
- Specific software for corrections

General

The MARCO system is a mobile equipment designed for measurements on different sites. Fixed systems have also been developed. There is also a version for inclusion in a PADIRAC unit (RD 15 type cask) which is directly attached to a hot cell.

The package to be measured is placed on a turntable opposite to a shielded detector.

Turntable characteristics: rotates at 1 rpm. Equipped with three weight sensors. Load capacity 10000 kg.

The unit is positioned with respect of height and azimuth and in relation to the package by a detector holder. The package-detector alignment is laser controlled.

Principle of Operation

To quantify the activity of beta/ gamma and alpha/gamma radionuclides, contained in either a waste package or in raw waste, a correction factor must applied to resolve the problems encountered in determining the activity of all types of waste having a cylindrical or cubic geometry . The spatial distribution of radionuclides in waste packages is supposed to be homogeneous.

The transfer function is computed using the following parameters, which are known more or less accurately:

- Object-detector distance and efficiency calibration distance
- Object geometry, diameter, height
- Nature of materials composing the waste and/or the matrix and the shielding
- Photon energy

The third parameter (nature of material composing the waste and/or matrix, nature and geometry of shielding) is given by the waste producer or the waste manager and is known with sufficient accuracy to compute a mathematical correction. To validate the parameters that are used to determine correction factor, CARACO includes an algorithm based on comparison between data activity of multi energy gamma emitting isotopes detected with MARCO and computed by CARACO.

When the matrix is known with too poor accuracy, the mass attenuation coefficient may be determined experimentally by taking into account the test results obtained using a transmission measuring system; the transfer function calculation can thus be improved and uncertainties on activity reduced.

Hence measurement by transmission must be made with a multi energetic source to determine the absorption coefficient over the whole range of application. The mass attenuation coefficient will be determined by tomodensitometric (TCT) and/or radiographic (DR) examinations, which provide respectively density maps within a slice and the average density axial profile, and by using known data concerning the type of waste (see Appendix C-26).

System Description

MARCO-CARACO system consists of the mechanics, the opened or collimated detector system, the mechanical control and data acquisition unit and a post-processing unit.

Mechanics
The 10000 kg self motoring support includes rotation of the drum.

Detector System and Electronic
A HPGe detector coupled with its preamplifier is used for all emission measurements and is placed in a lead background shielding. This cylindric shielding receives the different collimators and allows their alignment.

The associated electronics include the following modules:

Amplifier with filters, giving different time constants, and a 'pile up rejector/live time corrector' circuit for reducing errors due to count losses
Analogue-to-digital converter, which may be on either variable dead time or fixed time
Count losses corrections possible in real or active time

Data Acquisition and Processing
After digitalisation of detector signals through standard electronic components data is stored in a multichannel analyser. The PC/AT computer equipped with an arithmetic coprocessor includes the following:

Analyser for classifying coded data in a storage block
Spectra acquisition and processing software
The CARACO or MARCO software

Specifications

Detector
The high purity germanium detector may be:

either planar (low energy germanium) for better resolution at low energy levels (<400 keV):
energy resolution 0.23 keV at 5.9 keV
energy resolution 0.54 keV at 122 keV
or coaxial:
energy resolution 0.84 keV at 122 keV
energy resolution 1.8 keV at 1332 keV

Shielding and Collimation
Shielding:
lead or tungsten cylinder of 160 mm diameter and 280 mm length
Collimation:
lead or tungsten collimator of 80, 10, 5 mm for global measurements and
20 x 2 mm^2 for vertical scanning measurements

Physical
Overall dimensions:
1 m x 5 m x 2 m
(H x W x D)

Mechanics
Ranges: 1 rpm for rotation

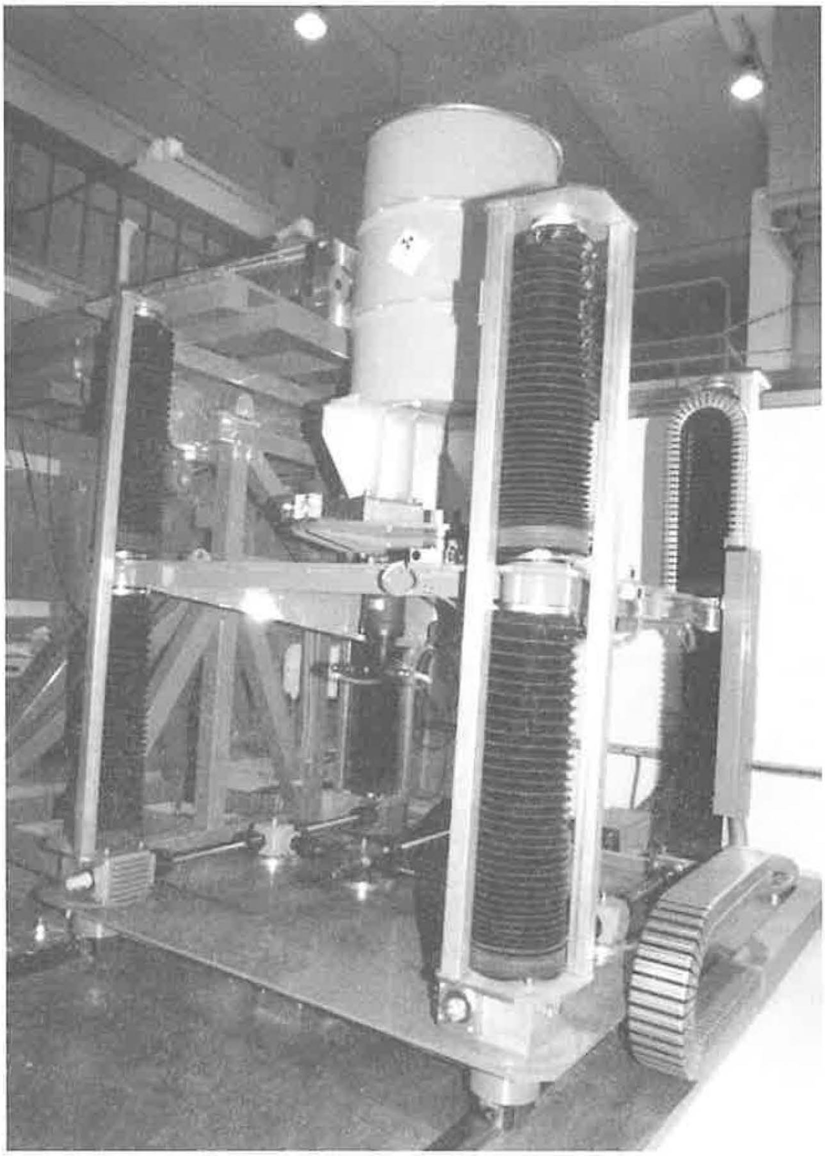
Electronics
Amplifier:
7244, EURISYS
ADC:
7600, EURISYS

Container Capacities
Size:
max. 1.7 m x 1.7 m x 1.7 m
Weight:
max. 10000 kg

Software
InterGamma Interwinner, (EURISYS)
Genie PC MGA (CANBERRA)
CARACO/Windows (CEA/EURISYS)

TEMISEC (CEA2)

Tomographe d'**EMIS**sion pour l'**E**xpertise des **C**olis



TEMISEC System for emission tomography.

Address

CEA/Cadarache
DCC/DESD/SCCD Bât. 326
F-13108 St. Paul-lez-Durance
France
Tel.: ++33-4-42-25-2590
Fax: ++33-4-42-25-7377

Features

- Passive segmented gamma scanner
- Designed for object dimensions up to 0.8 m diameter, 1.1 m height and 2000 kg weight
- Different gamma scan modes: global measurement, multiple rotational scan and emission computerised tomography
- High purity germanium detector
- Software controlled data acquisition and analysis
- Specific software for corrections and image reconstructions

General

TEMISEC is a three axes drum manipulator with two collimation-detection supports. The first support allows open geometry for global (point) measurements and collimated geometry for multiple rotational scanning measurements. The second support is designed for the horizontal translational scans needed to compute the 2D emission tomographic images of the activity distribution in each transversal slice. Several segmented acquisitions can be automatically chained.

Principle of Operation

The point measurement is typically an open geometry with a minimum distance between the cylindric drum and the detector of five times the drum radius. The drum is rotating during all the acquisition time and the detector 'sees' the complete waste package. A CARACO correction is applied on the sum spectrum and gives the activity of each identified gamma emitting isotope.

This correction assumes a physical matrix homogeneity. The absorption computation takes into account matrix composition, the container shielding and the mean density.

This sum spectrum (reference spectrum) is used to define some regions of interest for the next segmented measurements.

The vertical scanning measurements are carried out under the same geometric conditions as the point measurements but using a rectangular collimator. The detector 'sees' all the diameter of the cylindrical drum and the height of the aperture defines the number of vertical steps and the total number of acquisitions (spectra). After that, CARACO corrections are applied on each acquisition, the mean density used for absorption corrections can be issued from transversal measurements (digital radiography).

The horizontal scanning measurements are carried out with a square collimator designed to minimize the geometric blur. The aperture defines the number of segments for each projection (specific angular position). These measurements are repeated on several angular positions of the drum. After completion of acquisitions and the spectra processing for regions of interest (net peak areas) a specific software performs an iterative reconstruction to produce a 2D image for each emission energy. The reconstruction takes into account the acquisition geometry, the mean density if the object is assumed homogeneous or a spatially consistent transmission data set (transmission computerised tomography).

System Description

This multi gamma scanning system consists of the mechanics, the opened or collimated detector system, the mechanical control and data acquisition unit and a post-processing unit.

Mechanics
The 2000 kg self motoring support induces three motions on the drum with accuracy and repeatability compatible with spatial resolutions. The motors are coupled with synchro-resolvers on each axe.

Detector System
A high purity germanium detector coupled with its preamplifier is used for all emission measurements and placed in a lead background shielding. This cylindric shielding receives the different collimators and allows their alignment.

Mechanical Control
The mechanical control is performed by a three axes numerical command which communicates with the control unit through an opto-isolated RS422 asynchronous line and a specific protocol. This numerical command receives an electronic interface to convert the analog resolver signals and compute the current position.

Data Acquisition and Processing
After digitalisation of detector signals through standard electronic components data is stored in a multichannel analyser. After each segmented acquisition peak surface and corrections routines are running on interest regions defined on the reference spectrum. These data are associated with manipulator coordinates and transferred through local network on a post-processing workstation.

Post-Processing
The post-processing unit is used to compute, display and manipulate 2D images generated by different corrections and algorithm routines.

Specifications

Detector
Coaxial high purity germanium detector using liquid nitrogen for cooling
Energy resolution:
<1 keV at 122 keV and
<2 keV at 1332 keV

Shielding and Collimation
Shielding:
lead cylinder of 120 mm diameter and 300 mm or 600 mm length
Collimation:
lead collimator 20 mm x 2 mm for vertical scanning measurements, two lead collimators 30 mm x 30 mm for transversal scanning measurements

Physical
Overall dimensions:
2.2 m x 4.7 m x 3.2 m
(H x W x D)

Mechanics
Ranges:
2.8 m for translation and
1.1 m for lifting
Accuracy:
<1 mm for translation and lifting and
<1 degree for rotation

Electronics
Amplifier:
7244, EURISYS
ADC:
7600, EURISYS

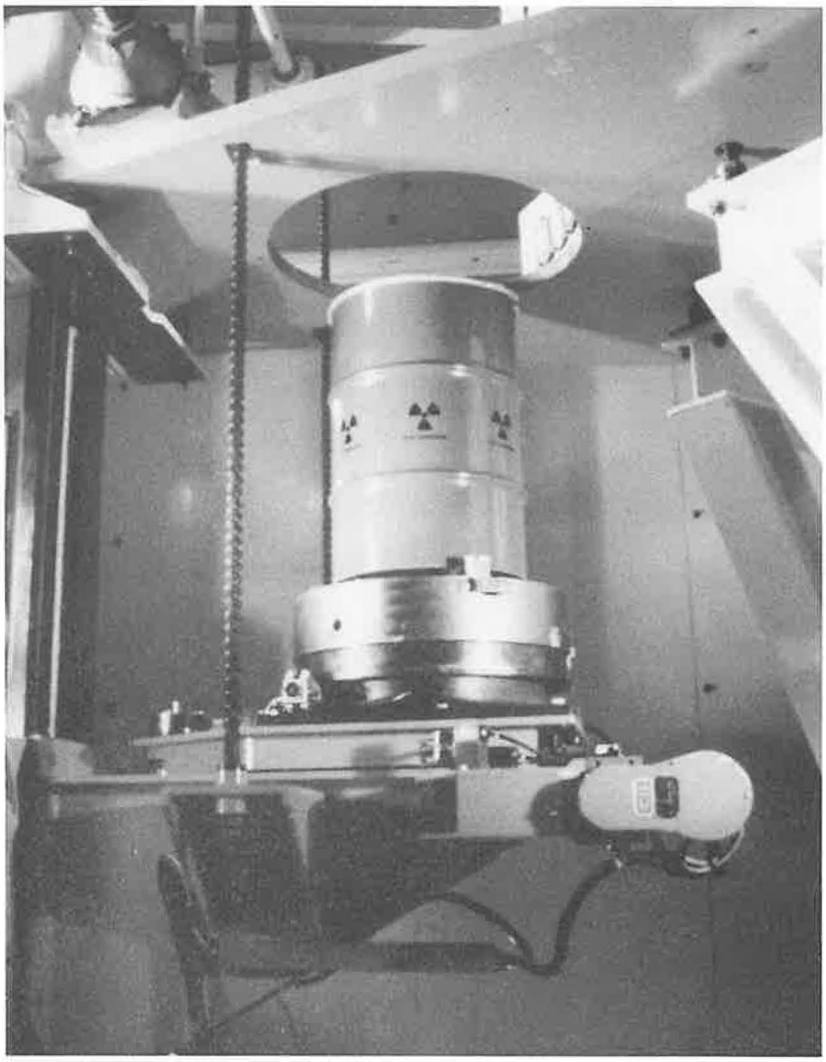
Container Capacities
Size:
max. diameter 0.8 m
max. height 1.1 m
Weight:
max. 2000 kg

Hardware
Mechanical control:
Cyber 4000 PARVEX
Data acquisition:
InterFast board (EURISYS) plugged in a PC 486
Data evaluation:
HP 9000/735

Software
Operating systems:
WFW 3.11 and HP-UX 9.05
InterGamma
(EURISYS)
Specific software and InterBatch routines
CARACO/Windows
(CEA/EURISYS)
Development Environment Software:
Turbo C++ (Borland) and HP-UX/C
Image Reconstruction:
specific software and Matlab (Scientific Software-Maths Works Inc.)

TOGTEC (CEA3)

Transmission measurements for MARCO-CARACO and TEMISEC



TOGTEC system.

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DCC/DESD/SCCD Bât. 326
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France
Tel.: ++33-4-42-25-2590
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Features

- Active segmented gamma scanner
- Designed for object dimensions up to 0.6 m diameter, 1.2 m height and 500 kg weight
- Different gamma scan modes: vertical translational scan coupled with swivel scan for digital radiography and rotational scan coupled with swivel scan for transmission computed tomography
- 10 NaI-PM detectors
- Software control data acquisition
- Specific software for 2D image reconstruction and analysis

General

TOGTEC is adapted to transmission measurements with a three axes drum manipulator and a fixed irradiation-detection system. A gamma ray source of ^{60}Co with a primary collimation shapes a fan beam adapted to the 0,6 m diameter, 2.1 mm height reconstruction field. A multipurpose detector contains ten modules located 1 m from the point source. Each module includes a secondary collimator, a NaI scintillating crystal and a photoelectron multiplier with preamplifier. The swivel scan is used to multiply the number of measurements for each projection by 25. A specific multi channel CAMAC electronic carries out amplification, threshold discrimination and counting on the detector signals. The ^{60}Co source is interesting because it emits 2 gamma rays on 1173 and 1332 keV with very good statistics. These high energies (>1 MeV) induce a linear relation between the linear attenuation and the density for nearly all materials.

Principle of Operation

The vertical translational scanning measurements are realized every 2 mm on the total drum height. The angular position of the drum is constant. Each attenuation measurement is corrected by the length of the theoretical straight path in the cylindric drum. Then a digital radiographic image is generated.

The rotational scanning measurements are realized every 2 degrees around the drum. The lifting position of the drum is constant. The total number of measurements is equal to 180 by 250 and its data set is compatible with a filtered-back-projection algorithm adapted to the fan geometry to compute a 2D tomographic image of the transversal slice.

If the ^{60}Co drum activity is important a substraction of emission projections is needed before reconstruction, so two acquisition cycles are necessary.

System Description

This multi gamma scanning system consists of the mechanics, an irradiation equipment, a multipurpose collimated detector system, a mechanical control and data acquisition unit and a post-processing unit.

Mechanics
The 500 kg self motoring support induces three motions on the drum with accuracy and repeatability compatible with spatial resolutions. The motors are associated with an electronic encoding unit on each axis.

Detector System
A NaI scintillating detector coupled with its photoelectron multiplier and preamplifier is used for attenuation measurements and placed in a lead background shielding. This shielding receives 10 detection modules and allows their angular and horizontal alignments.

Mechanical Control
The mechanical control is performed by a two stepping motors axes command for rotational and swivel motions. This command communicates with the control unit through an RS422 asynchronous line and a specific protocol. The control unit receives the position data from the encoding units on two RS422 asynchronous lines. On the lifting motion an asynchronous motor is directly commanded by binary states on control lines.

Data Acquisition and Processing
After amplification, a threshold discrimination of pulses removes the Compton signal and the gamma emission of the object below 1 MeV. A 10 channels counting scale stores the number of remaining pulses during the acquisition time. The fast reading operations of the counting scale are started by hardware interrupts on the data acquisition computer through a GPIB bus. These operations are repeated 25 times on each detection channel during the constant speed swivelling motion of the drum. Between each swivelling motion a lifting or rotational motion is applied on the drum respectively for a digital radiography and a tomography. When all acquisition segments are finished the projections are stored on an hard disk as ASCII files.

Post-Processing
The post-processing unit is used to compute, display and analyse 2D images generated by the RPF routine.

Specifications

Source
^{60}Co isotopic source of 303 GBq
Focal spot:
2.1 mm diameter
Adapted shielding manipulator:
GR 50 and TE 2000 (CGA-HBS)

Detector
NaI crystal:
44 mm diameter
51 mm thickness
15 % efficiency
Scintibloc detector NaI/PM CRISMATEC with integrated preamplifier

Shielding and Collimation
Shielding:
lead block
Collimation:
lead collimator:
2.1 mm x 4.2 mm x 200 mm (H x L x D)

Physical
Overall dimensions of steel radioprotection chamber:
4.0 m x 4.7 m x 4.0 m (H x W x D)

Mechanics
Ranges:
±3 degrees for swivelling and 1.2 m for lifting
Accuracy:
<1 mm for lifting,
<0.01 mm for swivelling and
<0.1 degree for rotation

Electronics
Amplifier, discriminator and counting scale:
NIM modules (Lecroy)
Synchronisation and shaping pulse:
NIM modules (CEA)
CAMAC/GPIB Interface (Lecroy)

Container Capacities
Size:
max. diameter 0.6 m
max. height 1.2 m
Weight:
max. 500 kg

Hardware
Mechanical control:
2 axes stepping motor unit Elstep (Hanssen), encoding units (Elesta)
Data acquisition:
HP 9000/330 with peripheral cards
Data evaluation:
HP 9000/735

Software
Operating systems:
HP-UX 7.0 and HP-UX 9.05
Specific software for acquisition and control
Development Environment Software:
HP-UX/C, X11, MOTIF, AGX/Toolmaster (AVS)
Image reconstruction and analysis:
specific software

KONGS (KEMA1)

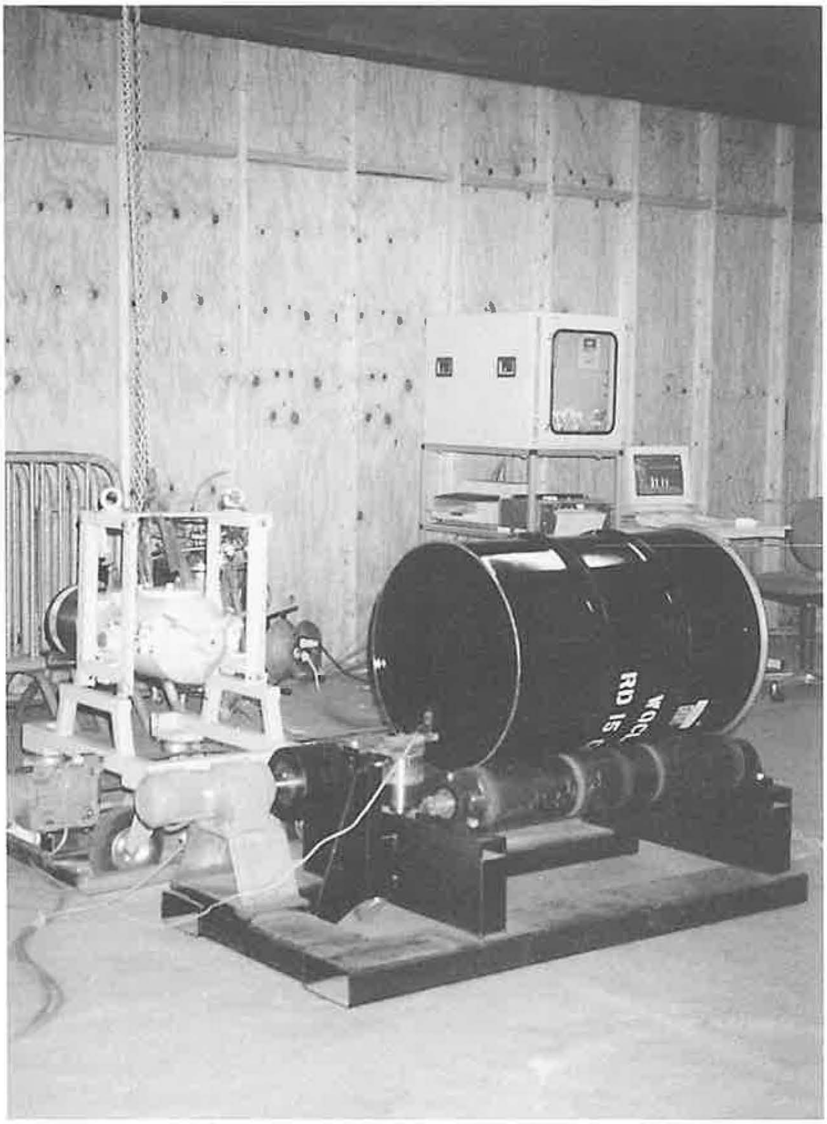
KEMA's Overall Nuclide Gamma Scanner

Address

KEMA N. V.
Utrechtseweg 310, Postbus 9035
NL-6800 ET Arnhem
Netherlands
Tel.: ++31-26-356-2593
Fax: ++31-26-442-3635

Features

- Horizontal spiral scanner
- Passive/non-destructive gamma spectroscopy
- High purity germanium detector
- Dynamic linear counting range, up to 360000 cps
- An energy range of 50 to 1800 keV
- Designed for waste packages of 50 to 400 L and with a weight of up to 1000 kg
- Fully adjustable and independent detector unit
- Fully adjustable and independent rotation unit
- Fast detection by software special applied for routine inspection
- Fully automatic or manual control of data acquisition and analysis



KEMA's Overall Nuclide Gamma Scanner.

General

Purpose of this gamma scanning system is to determine the specific nuclide activity, inhomogeneity and overall inhomogeneity.

The realisation and design is performed by KEMA Nuclear.

The concept is 100 % specialised for routine use.

The system is transportable and its components can be used independently. It is built to be used for measuring radioactive waste in relation with transport. It can handle packages of 50 L up to 400 L. If necessary, very large or small packages can be scanned with solely the detector unit.

A scan will produce a result regarding the overall activity and a mapping of the activity distribution (hot spots).

The software is reaching a high degree in being user friendly and is undergoing further refinement.

Principle of Operation

The scan peels the surface of the waste barrel. While the barrel rotates horizontally on its central axis, the detector moves along the long side. Depending on the activity, the movement unit with the detector can be placed at any distance to the surface.

System Description

The gamma scanning system consists of four parts: the mechanics, the detector system, the mechanical control and the data acquisition and processing unit.

Mechanics

The mechanical system consists of a rotation unit for the waste package and a translation unit for the shielded HPGe detector.

Accuracy and reproducibility of the movement of these axes are less then 1.0 mm.

Detector System
It is a unsegmented type of measurement making a continuous spiral scan.

The waste container is placed horizontally on a turntable, rotating around its central axis.

A high purity germanium detector of ca. 24 % relative efficiency, p-type, is mounted on one transverse movement unit, scanning the long side of the waste container from bottom to top.

Shielding against background radiation is assured by a special conical lead shielding, part of the movement unit for the detector.

Adjustments for containers with a different geometry can easily be performed.

The detector is cooled with a cryostat filled with liquid nitrogen.

Mechanical Control
The two movements units can be controlled either by hand using adjustable turn switches or automatically.

The automatic performance of the movements is done with special process electronics.

Data Acquisition and Processing
The electronic chain of the detector system consists of a high voltage unit, a preamplifier, an amplifier, an analogue and digital counter, an ADC, a real-time recorder and a printer device.

After the digitalisation of the signal, the data is transferred to a IBM compatible PC. All data is then processed by a gamma analysis program and during the measurement a recorder provides a plot of the incoming counts.

The gamma analysis program produces a full energy spectrum of 18 kBytes, showing the spectrum in real time.

A summary of the program´s features:

network connection, total count rate (cps), net peak count rate (cps), background count rate (cps), live time, dead time, net peak areas (cts), background (cts), nuclide detected, specific activity for each nuclide detected, overall activity, minimum detectable activity, half width of detected peaks, peak efficiency, nuclide library, library of known matrices, waste dependent calculations and general calibration.

Specifications

Detector
High purity germanium detector with 24 % relative efficiency and 6.0 keV energy resolution at 1.33 MeV, using liquid nitrogen for cooling

Shielding and Collimation
Shielding:
special conical lead shielding
Collimation:
5 conical lead collimators with 2 up to 10 mm in diameter

Physical
Max. burden:
10 kN
Clearance size:
2.00 m x 1.00 m x 0.23 m (H x W x D)

Mechanics
Ranges:
1.00 m for translation
Accuracy:
<1.0 mm for translation
<1.0 mm for rotation

Electronics
Preamplifier:
resistif-transistor reset EURISYS
Amplifier:
245 , Oxford/Tennelec
ADC:
Type 7600 succesive approximation 750 ns of EURISYS
MCA:
Interfast card of EURISYS

Container Capacities
Size:
standard 100 L to 400 L
Weight:
max. 10 kN

Hardware
IBM compatible,
P120 120 MHz, 16 MB/2 GB

Software
Operating systems:
Windows 3.11
Data recording and gamma analysis software:
Interwinner, EURISYS

KINGS (KEMA2)

KEMA's IN-homogeneity Gamma Spectroscopy System

KEMA's Inhomogeneity Gamma Spectroscopy System.

Address

KEMA N. V.
Utrechtseweg 310, Postbus 9035
NL-6800 ET Arnhem
Netherlands
Tel.: ++31-26-356-2593
Fax: ++31-26-442-3635

Features

- Non-destructive, passive gamma spectroscopy
- High purity germanium detector
- Dynamic linear counting range up to 36000 cps
- Energy range 50 to 1800 keV
- Fast detection by software special applied for routine inspection
- Fully automatic or manual control of data acquisition and analysis

General

Purpose of this gamma scanning system is to determine the nuclide specific activity and their inhomogeneity in all types of L/ILW waste packages. The realisation and design is performed by KEMA Nuclear.

The concept is first of all specialised for routine (80 %) and can be used for research (20 %).

The system is transportable and it can handle any packages of any size as the detector is placed at the side centre of the package and on top of the package.

Both scans will produce a result regarding the overall activity and homogeneity.

The software is reaching a high degree in being user friendly and is undergoing further refinement.

Principle of Operation

The waste container is placed standing up.

Measurement is performed by placing the detector on top of the package and at the side centre.

System Description

The gamma scanning system consists of three parts: the mechanics, the detector system and the data acquisition and processing unit.

Mechanics
The mechanical system consists of an adjustable stand for an unshielded detector. Accuracy and reproducibility of the movement of the height is less then 1.0 mm.

Detector System
It is an unsegmented type of measurement consisting of two measurements.

One measurement with a HPGe detector, p-type, is mounted on the top of the package in a stand, scanning it from the top.

The second measurement is performed by placing the detector along the side centre of the package, using the stand to adjust the height.

Shielding against background radiation is not needed, due to a high dynamic linear counting range of the system.

Adjustments in calculation for containers with a different geometry is easily performed by special software.

Data Acquisition and Processing
The electronic chain of the detector system consists of a high voltage unit, a preamplifier, an amplifier, an analogue and digital counter, an ADC, a real-time recorder and a printer device.

After the digitalisation of the signal, the data is transferred to a IBM compatible PC. All data is then processed by a gamma analysis program and during the measurement a recorder provides a plot of the incoming counts.

The gamma analysis program produces a full energy spectrum of 18 kBytes, showing the spectrum in real time.

A summary of the programs features:

network connection, total count rate (cps), net peak count rate (cps), background count rate (cps), live time, dead time, net peak areas (cts), background (cts), nuclide detected, specific activity for each nuclide detected, overall activity, minimum detectable activity, half width of detected peaks, peak efficiency, nuclide library, library of known matrices, waste dependent calculations and general calibration.

Specifications

Detector
High purity germanium detector with 24 % relative efficiency and 6.0 keV energy resolution at 1.33 MeV, using liquid nitrogen for cooling

Shielding and Collimation
None

Physical
In principle no restriction

Mechanics
Adjustable height:
0.0 to 1.0 m
Accuracy:
0.5 mm

Electronics
Preamplifier:
resistif-transistor reset, EURISYS
Amplifier:
245, Oxford/Tennelec
ADC:
Type 7600 successive approximation 750 ns of EURISYS
MCA:
Interfast card of EURISYS

Container Capacities
In principle no restriction

Hardware
IBM compatible,
P120 120 MHz, 16 MB/1 GB

Software
Operating systems:
Windows 95
Data recording & gamma analysis software:
Interwinner, EURISYS

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