ORTEC®

ELSE

AURAS-3000

Free Release Waste Assay Counter

AURAS-3000[1]

Free Release Waste Assay Counter for Large Boxes, Drums and Other Containers of Decommissioning Waste

- Free Release Assay of large waste containers up to 3 m^3: B25 ISO Box, smaller boxes, 220L Barrels.
- Container Weights up to 6000 kg, ±1 kg resolution.
- Full Quantitative Assay of all detectable gamma emitters, with non-gamma emitter estimates by correlated scaling factors.
- High sensitivity from four large area integrated HPGe detectors (85 mm diameter).
- Individual and averaged activity AND MDA reporting.
- Automated Scanning System, computer control of vertical and lateral detector positions.
- Extensive Safety Protection.
- Tested to EMC, Electrical and Safety standards.

[1]AURAS: Automated Release Assessment System.

AURAS-3000

Free Release Waste Assay Counter

Decommissioning of a nuclear facility is generally an immense engineering effort. The operations generate large quantities of low-activity waste. For economic disposal, it is necessary to certify waste as suitable for free release. Every container must be assayed to a sufficient degree of accuracy and sensitivity so that it may be certified as "free release." The more reliable the analysis, the lower the total cost of decommissioning because of the high cost of radioactive waste disposal. The ORTEC AURAS-3000 is designed to meet this need.

AURAS-3000 is a highly automated system for measuring a variety of sample sizes and forms (bags, boxes, barrels, and B25 containers), with densities approximately in the range 100 kg/m^3 to 2000 kg/m^3. The system uses four ORTEC "IDMs" (interchangeable detector modules) mechanically cooled HPGe spectrometers. The IDMs simplify the mechanical design and improve the serviceability. Analysis of spectra is performed with the ORTEC ISOTOPIC waste assay software operating under the control of a user interface developed with National Instruments LabVIEW. Detection limits better than 0.01Bq/g are generally achievable in a 40 minute count for low density materials.

AURAS-3000 System Overview

Reliability and Serviceability: Built In

AURAS-3000 is designed for heavy work and long life. The use of four ORTEC IDM "all in one" HPGe spectrometers transforms serviceability. Continuous operation is realistically achievable by keeping a limited number of IDM spares on site and available for immediate replacement in the system. A load capacity of 6000 kg is indicative of the overall rugged nature of the mechanical construction.

Safety

All circuits and precautionary devices are designed to achieve high levels of safety of the machinery. All of the following machinery safety and protection devices are provided:

Photoelectric safety barriers
Emergency stop switches
Circuit breaker protection devices
Anti-collision sensors and proximity switches

Principle of Operation

A sample container is first positioned by crane or forklift onto the heavy duty scanning platform. The operator starts the scan and chooses the container type to be scanned. This results in an adjustment of the detector position under computer control as required by the counting geometry. "Bookkeeping" data such as container description is entered at this stage.

The scan commences and the heavy duty conveyor moves the container through the center of the four detectors, stopping to count at predetermined positions for predetermined count times along the range of travel. The container is weighed automatically by the online weighing system to a resolution of 1 kg.

The spectra from each detector/position combination are saved and analyzed individually using the ORTEC ISOTOPIC waste assay software. An individual assay value for the container is calculated, based on each detector/position individually, and an averaged value is also calculated. If one or more values are in large disagreement with the averaged value, this is an indication of non-uniformity in the contents of the box. Individual and averaged MDA values are also calculated.

AURAS-3000 Hardware

The system hardware comprises the following major sub-systems:

- Spectroscopy Hardware: four ORTEC IDMs (interchangeable detector modules).
- Mechanical Hardware: container conveyor and detector support and positioning mechanism.
- Operator console and PLC.
- System control computer.

Spectroscopy Hardware: The Interchangeable Detector Module (IDM)

The spectroscopy system hardware is implemented using a fundamental gamma-ray detection "building block," the ORTEC Interchangeable Detector Module or "IDM." The IDM consists of an 85 mm x 30 mm HPGe Detector, Stirling cooler, Digital Signal Processing MCA, high voltage supply, and high speed USB communication. It uses standard, low-current mains power.

The large diameter detector gives good efficiency in the range of ~40 to ~3000 keV. Standardized detector crystal dimensions mean that all IDMs will perform in a consistent manner.

IDMs are rugged and designed for long, reliable service, and are interchangeable. An IDM can be swapped out for service quickly, resulting in high system availability and limiting down time to an absolute minimum. The hardened cryostat is designed for long operational life and can be temperature cycled at any time, even from partial warm-up, eliminating the problems associated with loss of electrical power. If the power is turned off, it will automatically restart when the power is turned on. The IDM is light enough to be installed by one person.

IDM[2] Feature Summary

HPGe Detector

- High low-energy efficiency
- Uniform detector size
- High cooling capacity with highly reliable Stirling cooler
- Integrated high voltage supply

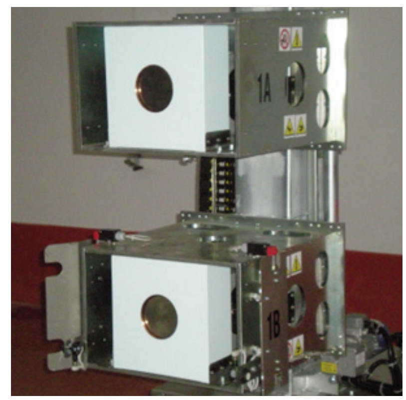
Digital MCA

- 16k channels
- Digital low frequency noise rejection

USB Connection

- High speed connection
- Mains powered

The IDM.



"Face view" of IDMs showing collimator detail.

Each IDM is provided with a 10 cm deep, rectangular lead shield which provides cylindrical collimation. The minimum lateral wall thickness is 10 cm. Each collimator is provided with a copper liner along the internal surface.The collimator depth is variable between 0.5 cm and 3 cm to vary the field of view for different containers.

Mechanical Hardware: Container Conveyor and Detector Support and Positioning Mechanism

The container conveyor is of very robust design. The sample platform can accommodate B-25 ISO containers (3 m^3), smaller boxes and standard drums, such as 220L sizes. The maximum container weight is 6000 kg. An automatic weigh scale with a resolution of ±1 kg is integrated within the conveyor.

Horizontal movement of the sample platform takes place through a computer-controlled automatic Cart-On-Track (Rail) conveyor. A semi-automated sequence moves the container into three different positions: loading area, weighing/measurement area and unloading area. Two "tower" detector assemblies are positioned on both sides of the container and the detector-to-container distance can be adjusted manually.

The vertical positioning of the detectors is also carried out under computer control with a resolution of ±1 mm to handle different container sizes. All machinery movements are implemented and controlled locally by a PLC and are managed remotely by a host Personal Computer which provides the system operator interface.

General view of sample platform showing the mounting of the two IDMs and collimators on either side of the measurement zone through which the container passes.

[2]http://www.ortec-online.com/download.asbx?AttributeField=44358d3a-9d73-4a4b-9937-f3a734173010.

Operator Console and Programmable Logic Controller

The electronic hardware, with the exception of the spectroscopy systems, is controlled by means of a Programmable Logic Controller (PLC). The PLC firmware supports a local MMI (Man Machine Interface) and an Ethernet interface allowing remote control of the system by means of a computer program. The MMI features a touch-screen LCD allowing any kind of system set-up and calibration (for example, test of the scale accuracy), plus manual positioning of the container platform and the detectors. The positioning functions — useful to perform radiometric calibrations and special test measurements — can be done both through visual feedback and set up of precise coordinates in the horizontal and vertical directions.

The local interface is locked when the PLC is executing remote procedures, to avoid conflicts between automatic and manual operations. The PLC firmware also manages all the system safety features (light barriers, anti-collision sensors, etc.), immediately stopping any running motor if a security input is triggered. Diagnostic messages are issued and archived by the PLC whenever anomaly conditions occur.

Operator Console.

AURAS-3000 Software

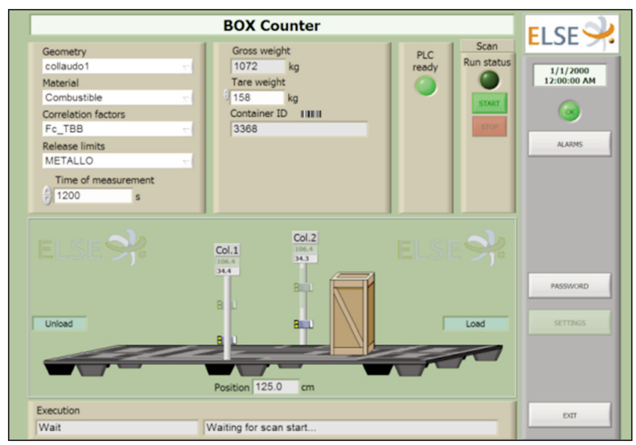
In routine operation, the system is controlled by the operator through the host PC.

Spectrum analysis is provided by the well known ORTEC ISOPLUS-32 (Isotopic)[3] analysis package. The LabVIEW user interface program provides hardware control, analysis set-up, and measurement process management.

Routine Measurement Process

Only five choices are required for an operator to start a routine scan:

- The measurement geometry (defines the container type and the measurement positions).
- The material in the container (chosen from a dropdown list of database materials).
- The correlation factor table (which may vary depending on the waste material type and origin).
- The concentration limit table (which may vary depending on the material type: metal, concrete, etc.).
- The preset time for the spectrometric measurement in each position.



Main Operator Screen.

The Operator Mode Program:

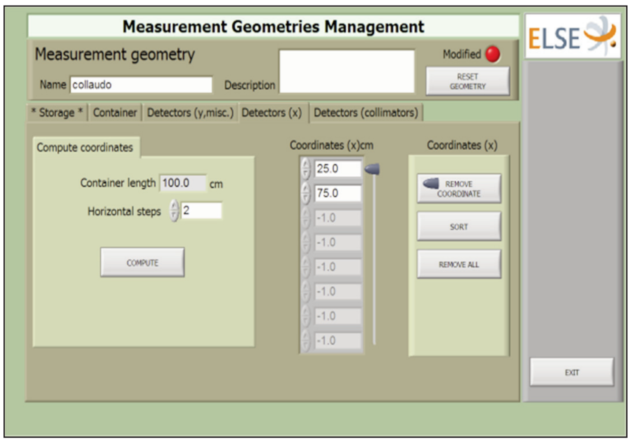
- Helps guide an operator through the procedure and records the container weight after loading.
- Moves the scanning platform and the detectors to the target positions and properly synchronizes the container positioning with the spectrometric data acquisition program. (No user intervention is required once the measurement sequence is started.)
- At the end of spectral acquisition and primary analysis, carries out a post-processing to produce a set of "release indexes" for each found nuclide and spectrum, based on a customizable isotope release concentration limit table. (Multiple limit tables can be edited and saved depending on waste material type.)
- Using a customizable correlation scaling factor table, adds to the spectrometric results low or non-gamma emitting nuclides that cannot be seen directly, but are known to be present. Scaling factors can be referred to a given date and properly recalculated to take into account the different decay of the vector isotope and its associated nuclide; multiple scaling factor tables can be edited and saved, depending on the type and origin of the waste material. It is also possible to specify a list of isotopes that are not correlated to anything else, but are known to be present in a given (fixed) concentration. These fixed concentrations are often estimates that give a "baseline" release index value contributing to the total value.
- Compares analysis results to a table of release limits, if desired. Release limits are often dependent on the type of the material to be released (for example, metal and concrete rubble); therefore multiple tables may be used.

[3] http://www.ortec-online.com/download.asbx?AttributeField=26cfc278-6608-4b4d-b0fc-27e316dc6b3d.

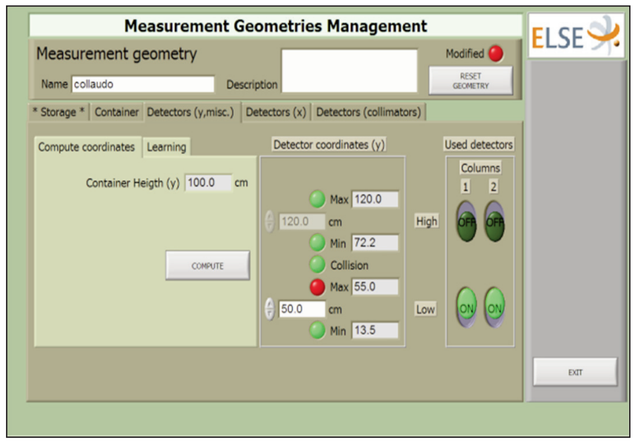
- Produces a final report where all relevant input data are listed, together with the results of the scan. Different sections of the sample are compared graphically in order to make non-homogeneities in the container evident and results may be expressed as a fraction of release limits. A final release index value is shown that marks the item as releasable or not depending on a user defined level. The report can be saved and printed.
- If the user accepts the report, all relevant data (settings, spectra files, post-processing tables, etc.) are saved to disk and can be later retrieved for re-analysis. Multiple scans of a single item are supported with no overwriting on disk.
- Based on the spectrum taken at each measurement position, multiple estimates for the activity in the container may be made. These may be averaged or examined individually. If one or more of the measurements of a container are not consistent with each other or with the container average, there is a suggestion of non-uniformity which may require further scrutiny.

Measurement Set-up Procedure

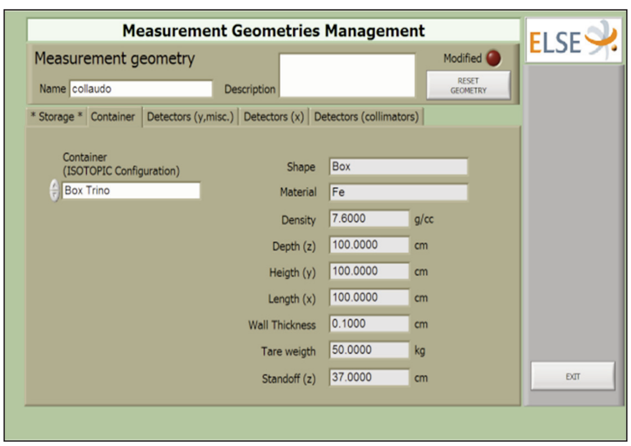
Set-up is carried out by a supervisory level user. In this process, the following are defined:



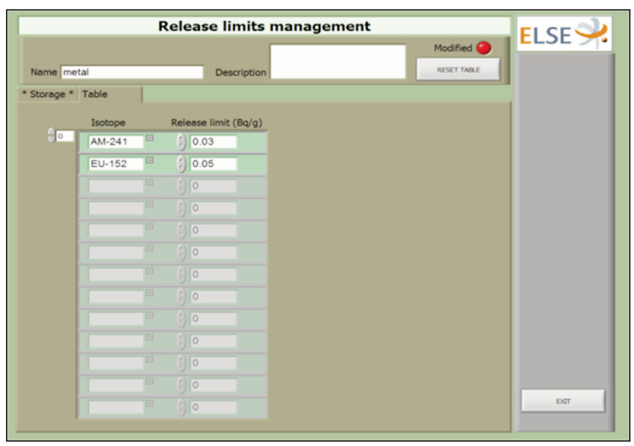
Horizontal Measurement Positions.



Vertical Measurement Positions.



Container Parameters: dimensions and materials.



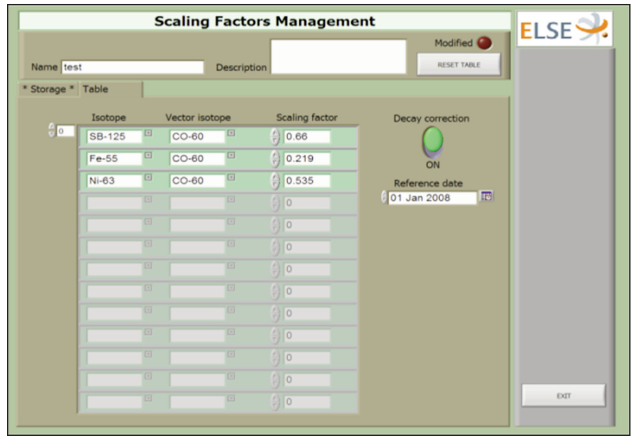
Nuclide Release Limits.

AURAS-3000

Free Release Waste Assay Counter

Horizontal measurement positions are calculated depending on the number of counting positions required. Every horizontal position generates up to four entries in the scan configuration, one for each detector (e.g., a three-step, four-detector scan would produce 12 entires). This automated process saves time and eliminates operator error. Vertical detector positions can be computed, set manually, or "learned" by moving the detector to the desired height using the operator console. The program warns the user if the computed detector coordinates are out of range or would lead to a detector collision.

Any subset of the available four detectors can be used for a measurement.



Nuclide Activity Scaling (correlation) Factors.

AURAS-3000 Typical Performance

The tables below present actual values measured or computed from real test data for uniform waste and matrices. In the case of the single detector MDA results, the MDA value presented is the highest (most conservative) value obtained according to the NUREG 4.16 methodology. Performance in other situations may vary due to variations in sample content or in environmental background. These data can, however, be considered to be "typical." No special measures were taken to enhance these values.

MDA on Single Spectrum (1 m³ container)

Radionuclide	Measured 0.4 g/cc 40 min	Measured 1.8 g/cc 4 hr	Clearance Limit Regulations Bq/g				
			RP 89 [a]	RP 113 [b]	RP 122 [c]	USNRC [d]	IAEA [e]
Mn-54	0.0030	0.0004	1.0	0.1	0.1	0.1	0.3
Co-60	0.0019	0.0003	1.0	0.1	0.1	0.4	0.3
Sb-125	0.0102	0.0013	10.0	1.0	1.0	0.2	
Cs-134	0.0032	0.0005	1.0	0.1	0.1	0.0	0.3
Cs-137	0.0037	0.0005	1.0	1.0	.0	0.0	0.3
Eu-152	0.0131	0.0019	1.0	0.1	0.1	0.1	0.3
Eu-154	0.0080	0.0013	1.0	0.1	0.1	0.1	
Am-241	0.0655	0.0066	1.0	0.1	0.1	0.1	0.3

MDA Averaged on Multiple Spectra (1 m³ container)

Radionuclide	Measured 0.4 g/cc 40 min	Measured 1.8 g/cc 4 hr	Clearance Limit Regulations Bq/g				
			RP 89 [a]	RP 113 [b]	RP 122 [c]	USNRC [d]	IAEA [e]
Mn-54	0.0011	0.0003	1.0	0.1	0.1	0.1	0.3
Co-60	0.0007	0.0002	1.0	0.1	0.1	0.4	0.3
Sb-125	0.0039	0.0009	10.0	1.0	1.0	0.2	
Cs-134	0.0013	0.0003	1.0	0.1	0.1	0.0	0.3
Cs-137	0.0014	0.0004	1.0	1.0	.0	0.0	0.3
Eu-152	0.0049	0.0013	1.0	0.1	0.1	0.1	0.3
Eu-154	0.0028	0.0007	1.0	0.1	0.1	0.1	
Am-241	0.0270	0.0037	1.0	0.1	0.1	0.1	0.3

Clearance Limit Regulation References

[a] Recommended radiological protection criteria for the recycling of metals from the dismantling of nuclear installations, Radiation Protection No. 89, 1998. European Commission, Directorate-General: Environment.

[b] Recommended radiological protection criteria for the clearance of buildings and building rubble from the dismantling of nuclear installations, Radiation Protection No. 113, 2000. European Commission, Directorate-General: Environment.

[c] Practical Use of the Concepts of Clearance and Exemption – Part 1: Guidance on General Clearance Levels for Practices, Radiation Protection No. 122. European Commission, Directorate-General: Environment.

[d] Nuclear Regulatory Commission, Radiological Assessments for Clearance of Equipment and Materials from Nuclear Facilities, Washington, D.C., Draft, NUREG-1640 (1998).

[e] International Atomic Energy Agency, Clearance Levels for Radionuclides in Solid Materials – Application of Exemption Principles, Vienna, IAEA-TECDOC-855 (1996).

Measurement Accuracy

Measurement accuracy depends on the nature of the waste, uniform or non-uniform, the density of the matrix, and the number of measurements used to compute the activities within the container. For uniform source and matrix distributions, an accuracy of a few percent (less than 10) is to be expected, whereas in less uniform distributions of source and matrix a few tens of percent might be expected.

Susceptibility to Vibration and Electrical Noise

AURAS-3000 is designed to minimize the electrical noise generated by the motors and the associated drivers through the study of the design, the use of shielded cables, ferrite, and EMC filters. Testing has shown a high level of noise immunity of the spectroscopy system performance to electrical and mechanical vibration associated with motion of the system components. The table below shows some actual test data demonstrating the high level of electrical noise immunity reached.

FWHM (keV) Measurements Using Eu-152 Reference Source

Reference Conditions	Real Time (s)	Live Time (s)	Dead Time (%)	FWHM @ 121.78 keV	FWHM @ 344.28 keV	FWHM @ 778.9 keV	FWHM @ 1112.11 keV	FWHM @ 1408 keV	Integral Total Counts
Static	300	206.18	31.27	1.12	1.28	1.58	1.79	1.95	2.18E+06
Convey in Motion	300	205.64	31.45	1.12	1.28	1.59	1.78	1.97	2.17E+06
Detector Housing in Motion	300	208.88	31.71	1.11	1.27	1.56	1.73	2.04	2.13E+06

AURAS-3000 Detailed Specifications

Automatic Cart-On-Track (Rail) Container Conveyor System

- Container platform dimensions: 3200 mm (l) x 1160 mm (w) x 410 mm (h).
- Closed loop steel chain with floating-tension pulley.
- Electric motor (3 PH – 0.55 kW/0.75HP) with torque limiter gear box.
- Automatic weighing system.
  - Maximum weight: 6000 kg.
  - Resolution: ±1 kg.
- End limit switches and position sensors.
- 3 each double rail segments. Dimensions: 1 each 2200 mm (l) x 1340 mm (w) and 2 each 2700 mm (l) x 1340 mm (w).
- Maximum speed: 40 mm/s, positioning resolution ±15 mm.

Tower Detector Assemblies (2 each)

Each assembly includes:

- 2 each elevator detector platforms.
- 2 each rectangular lead shield with cylindrical collimation and copper liner along the internal surface; dimensions: 314 mm (l) x 314 mm (h) x 122 mm (w).
- 2 each 600 mm linear actuator (0.09 kW, maximum force 600 kg).
- End limit switches and position sensors.
- Proximity and mechanical anti-collision sensors.
- 1 each double rail segment, length 2750 mm.
- Maximum speed: 6 mm/s, positioning resolution ±1.5 mm.

Operator Console

- Programmable Logic Controller (PLC) with firmware supporting a local MMI (Man Machine Interface).
- 10/100 Ethernet interface.
- 5.7 inch LCD operator touch panel.
- 5 each inverter motor controllers.
- Circuit breakers, over-current, and thermal protection devices.
- Emergency stop switch.
- 2 each photoelectric safety barriers, operative distance: 0.5 m up to 25 m.

PC Minimum Requirements

- Pentium Dual-Core Processor.
- 2 GB RAM.
- 250 GB Hard Drive.
- 10/100 Ethernet Interface.
- Windows XP Pro SP3 Operating System.
- 19" color LCD Monitor.
- Inkjet or Laser color printer.
- Mouse and keyboard.

Software Package

- El.Se. AURAS Graphical User Interface control and reporting Software.

Overall Electrical Requirements

- 400 V AC/ 50 Hz/15 A – (3P+PE).

Overall Dimensions and Weight

- 8820 mm (l) x 5600 (w) x 2450 (h).
- 5000 kg.

Environmental Conditions

- Temperature: 5°C up to 40°C.
- Humidity: 20% up to 80% (no condensation).

Compliance with Directives

The system meets the requirements of the regulations below. Testing has been conducted under collaboration with an accredited laboratory and supervised by qualified companies.

2006/42/CE – Machinery Directive

2006/95/CE – Low Voltage Directive

2004/108/EC – EMC Directive

89/106/CEE – Construction Product Directive

Harmonized

Electrical Machinery Equipment: (CEI 44-14, CEI EN 60439-1:1998, CEI 17-52:1997, CEI 17-43:2000, CEI EN 61131, EN 62061:2005, CEI EN 60204-1, EN ISO 13849-1:2008, UNI EN 981:2009, EN 61310-1:2008 ……….)

Mechanical Components, Electrical Safety and Machinery Safety : (EN ISO 12100-1:2004, EN ISO 12100-2:2004, UNI EN 349, UNI EN 953, EN 1005-4:2005, prEN 894-1, prEN 894-3, EN 842:1996 + A1:2008, UNI EN 10278: 02, EN287, EN 9606ed EN 1418, ………)

EMC (ESD, EM Field, Burst, Surge, Irradiated Emissions…): (CEI EN 61000-6-4, EN 61000-4-2:1995, EN 61000-4-3:2006, EN 61000-4-4:2004, EN 61000-4-5:1995, EN 61000-4-6:2006, EN 61000-4-8:2001, EN 61000-4-11:2004………..)

Risk Assessment: (EN ISO 14121:2004, ISO /TR 14121–2:2007)

Ordering Information

The AURAS-3000 is a development of the ORTEC Integrated Systems Group and EL. SE. s.r.l. It is available exclusively through the ORTEC distribution organization. Contact your local ORTEC representative for a quote.

Appendix: AURAS-3000 Analysis Methodology

The underlying activity calculations are performed by ORTEC ISOPlus-32 version 4.1 operating in “container mode.”

Each detector (IDM) is characterized by a single point-source measurement, and knowledge of detector crystal dimensions, dead-layer and end cap thickness.

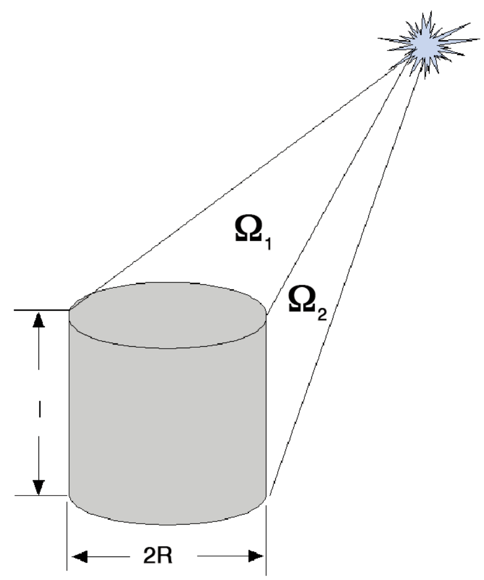
This primary calibration, which can be traceable in the event a traceable standard is used, is then extrapolated to match the physical situation of the sample; container geometry, material, and matrix composition. The entire measurement problem is broken down into multiple source/matrix voxels and their contributions to the composite spectrum are calculated and summed.

No special separate measurements are needed to characterize the detector other than one point-source calibration. The container or “item” is modelled, based on its physical dimensions, material and knowledge of the average density of the waste matrix. The method amounts to an “efficiency transfer” method in which an efficiency measured with a standard in one (calibration) geometry is transformed by calculation to the efficiency which would be measured in a second (sample) configuration.

Summary of Calculational Methods[4]

For a point-source placed off-axis with respect to the crystal, in the absence of any source matrix attenuation effects or any detector collimation, the activity is given by

$$Act_{ps} = \frac{CR \bullet 4\pi}{(\varepsilon_{if} \bullet C_1 \bullet C_2 \bullet \Omega_1 \bullet + \varepsilon_{is} \bullet C_3 \bullet C_4 \bullet \Omega_2) \bullet k}$$



where

Actps = reported activity (Bq)

CR = net peak count-rate

$\Omega 1$ = the solid angle subtended on the top surface of the detector (radians)

$\Omega 2$ = the solid angle subtended on the side surface of the detector (radians)

C1 = attenuation correction factor for the aluminum end cap

C2= attenuation correction factor for the dead layer of germanium

C3 = attenuation through the side of the end cap and cup holding the detector

C4 = attenuation through the side dead layer of Ge

ε_{if} = frontal full energy peak intrinsic efficiency

ε_{is} = side full-energy peak intrinsic efficiency

k = constant involving the yield (branching ratio), decay corrections, and unit conversion factors (γ emitted/Bq)

For an “item” which is not a point source, the activity of a voxel, Act_i is computed similarly to a point-source:

$$Act_i = \frac{CR \bullet V_i \bullet 4\pi}{(\varepsilon_{if} \bullet C_1 \bullet C_2 \bullet \Omega_1 \bullet + \varepsilon_{is} \bullet C_3 \bullet C_4 \bullet \Omega_2) \bullet V \bullet k}$$

The activity of the item is then given by the summation

$$Act_{item} = \frac{1}{\sum_{i=1}^{n} \frac{D_{1i} \bullet D_{2i} \bullet D_{3i}}{Act_i}}$$

[4]For more details see the ISOPlus-32 supervisor manual available on request from ORTEC.

where

Act_{item} = activity of item being measured (Bq)

V = volume of the item (cm[2])

V_i = volume of the i^{th} voxel (cm[2])

D_{1i} = matrix correction for the i^{th} voxel, calculated as $e^{-\mu_1 d_1 l_1}$, where μ_1 is the mass attenuation coefficient for the matrix, d_1 is the matrix density, and l_1 is the matrix thickness

D_{2i} = inner container correction factor for the i^{th} voxel, calculated as $e^{-\mu_2 d_2 l_2}$, where μ_2 is the mass attenuation coefficient for the inner container, d_2 is the inner container denisty, and l_2 is the inner container thickness

D_{3i} = outer container correction factor for the i^{th} voxel, calculated as $e^{-\mu_3 d_3 l_3}$, where μ_3 is the mass attenuation coefficient for the outer container, d_3 is the outer container denisty, and l_3 is the outer container thickness

n = number of voxels

Calculation of Averaged Detection Limits

Averaged MDAs are also available according to the NUREG 4.16 which can be extended, in the case of four similar detectors to:

$$MDA_{SUM} = \frac{2.71 + 4.66 \bullet \sqrt{\sigma_{B1}^2 + \sigma_{B2}^2 + \sigma_{B3}^2 + \sigma_{B4}^2}}{\gamma\,(LT_1 + LT_2 + LT_3 + LT_4) \bullet \bar{\epsilon}_\sigma}$$

where:

σ_i = the uncertainty in the background in peak area i

γ = the branching ratio or gamma-ray yield

LT_i = the live time of the spectrum from detector i

$\bar{\epsilon}_\sigma$ = the corrected efficiency (absorption and geometry)

If the background term $4.66 \bullet \sqrt{\sigma_{B1}^2 + \sigma_{B2}^2 + \sigma_{B3}^2 + \sigma_{B4}^2}$ is much larger than 2.71 then for identical detectors and backgrounds this reduces to:

$$MDA_{SUM} = \frac{MDA_1}{\sqrt{d}} = \frac{MDA_1}{2}$$

where MDA_1 is the MDA for a single detector.

Correlation: Scaling Factor Half-Life Correction

Scaling factors are generally dependent on the material type and origin and are determined for a given date by direct measurement and/or theoretical considerations.

The factors may be recomputed to the measurement date, taking into account the different half-life of the two nuclides involved: the vector nuclide, which is directly measured, and the correlated one. The scaling factor f_{ivm} of the i^{th} nuclide, correlated to the vector isotope v, at the measurement time D_m is given by the following formula:

$$f_{ivm} = f_{ivr} \frac{e^{-\left(\frac{ln\,2(D_m - D_r)}{T_{1/2i}}\right)}}{e^{-\left(\frac{ln\,2(D_m - D_r)}{T_{1/2v}}\right)}}$$

Where f_{ivr} is the table scaling factor valid for the reference date D_r, while $T_{1/2i}$ and $T_{1/2v}$ are the half-lives of the nuclides.

Specifications subject to change
081610

ORTEC®
www.ortec-online.com
Tel. (865) 482-4411 • Fax (865) 483-0396 • ortec.info@ametek.com
801 South Illinois Ave., Oak Ridge, TN 37831-0895 U.S.A.
For International Office Locations, Visit Our Website

AMETEK®
ADVANCED MEASUREMENT TECHNOLOGY