IAEA
International Atomic Energy Agency

LESSON 8:

GAMMA AND ALPHA SPECTROMETRY FOR WORKPLACE MONITORING

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- Introduction to alpha and gamma spectrometry
- Alpha Spectrometry system
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- Gamma spectrometry system
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  - Detectors and their applications to workplace monitoring

Need for Spectrometry Method

- Qualitative and quantitative determination of isotopes present in the workplace is sometimes necessary to decide on suitable protective measures.
  - Gross alpha and gamma activity does not provide energy information about isotopes.
- Radionuclide distribution can be identified.
- Natural activity may be eliminated by means of energy discrimination
- NORM and man made isotopes may be distinguished through pulse height discrimination

Examples of Application of Spectrometry

Samples from workplace containing mixture of radionuclides can be analysed using spectrometry.(e.g. filter papers and air/gas samples).

Assessment of contamination from surface spectrometric measurement.

Introduction to Gamma and Alpha Spectrometry

- Radionuclides emit alpha and gamma radiation with characteristic energy.
- Energy selective detectors (e.g. NaI(Tl), HPGe, PIPS,SiO_2) yield electronic pulses with amplitudes proportional to the emitted energy.
- Measurement system (spectrometer) arranges the pulses by amplitude and counts them.
- Plot of count rate vs energy is called as spectrum.
- Spectrum evaluation gives information on the radionuclide via energy and activity via counts.

Introduction to Gamma and Alpha Spectrometry

Characteristics of alpha and gamma spectra:

Alpha and gamma spectra can provide fingerprints of radionuclides.

Depending on the resolution of detector the isotopes with closed peak energies can be resolved.

Area under the peak is proportional to activity of the given sample.

GAMMA SPECTROMETRY

Alpha Spectrometry-Theory

Alpha energy is converted to electronic signal (pulse) via semiconductor detector.

- Passivated Implanted Planar Silicon (PIPS) Detector

Intensity of pulse height produced is proportional to the alpha energy.

- Mono-energetic alpha particles
- Energy Calibration vs. Pulse Height

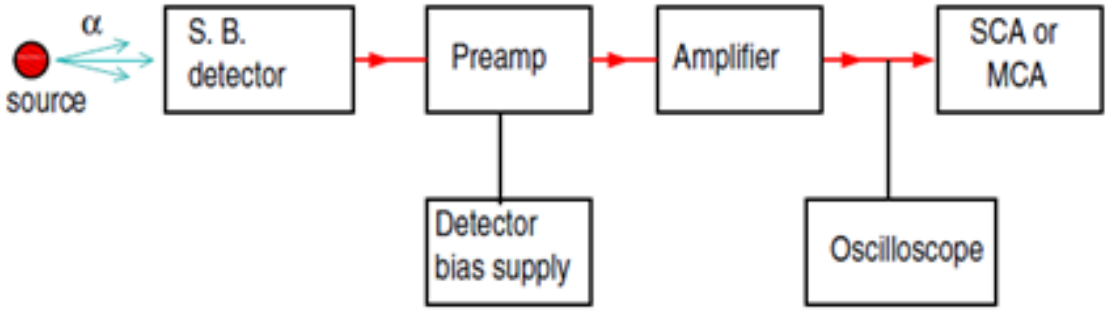
Number of pulses are proportional to the amount of isotope present.

- Efficiency Calibration

Alpha Spectrometry

- Alpha spectroscopy is a widely used technique for the identification and quantification of alpha-emitting radionuclides.
  - Naturally occurring alpha emitters
  - Transuranic elements, special nuclear materials
- It is characterized by high efficiency, low background and low detection limits.
- It can be applied for the assay of a variety of samples.

Typical Alpha Spectrometry Block Diagram



Alpha spectrometer with Multi Channel Analyser

Passivated Implanted Planar Silicon (PIPS) detector

There are three main parameters that define a silicon surface-barrier detector:

- active area,
- resolution,
- depletion depth.

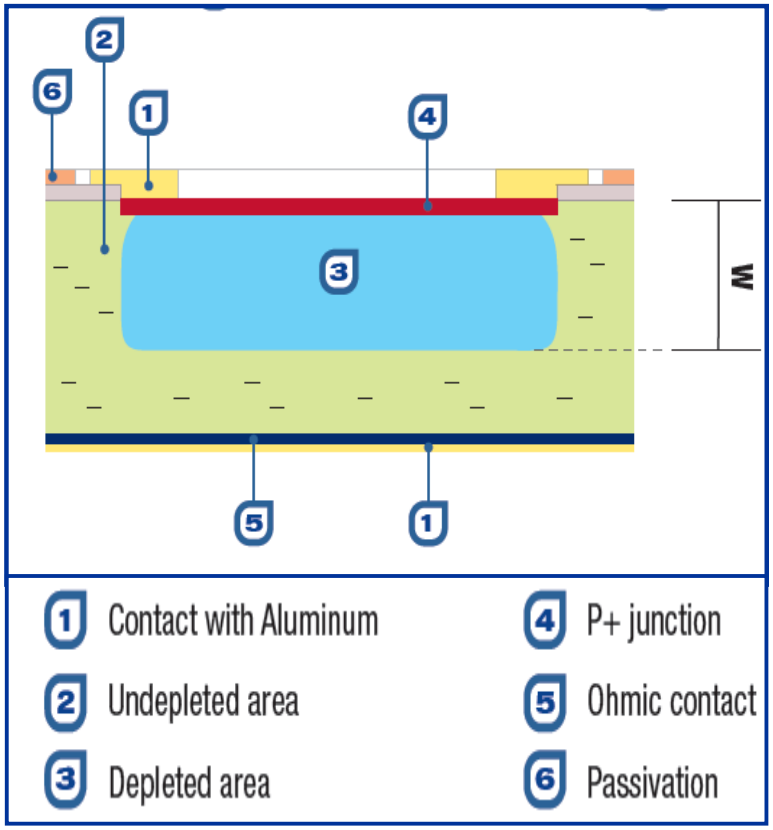
Detectors are optimized for Alpha Spectroscopy applications which require high resolution, high sensitivity and low background.

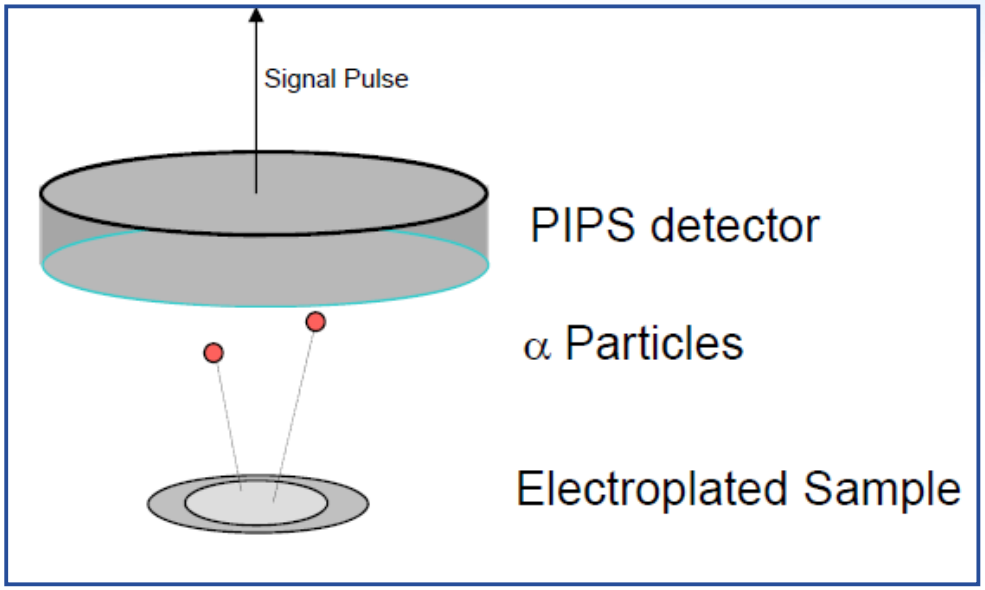
Passivated Implanted Planar Silicon (PIPS) detector

Operating Principle

- Alpha particles are stopped in the depletion region, forming electron-hole pairs.
- The number of electron-hole pairs ultimately formed is thus directly proportional to the energy of the particle.
- The electric field in the depletion region sweeps the electrons to one terminal and the holes to the other.
- The resultant charge pulse is integrated in a charge sensitive preamplifier to produce a voltage pulse.

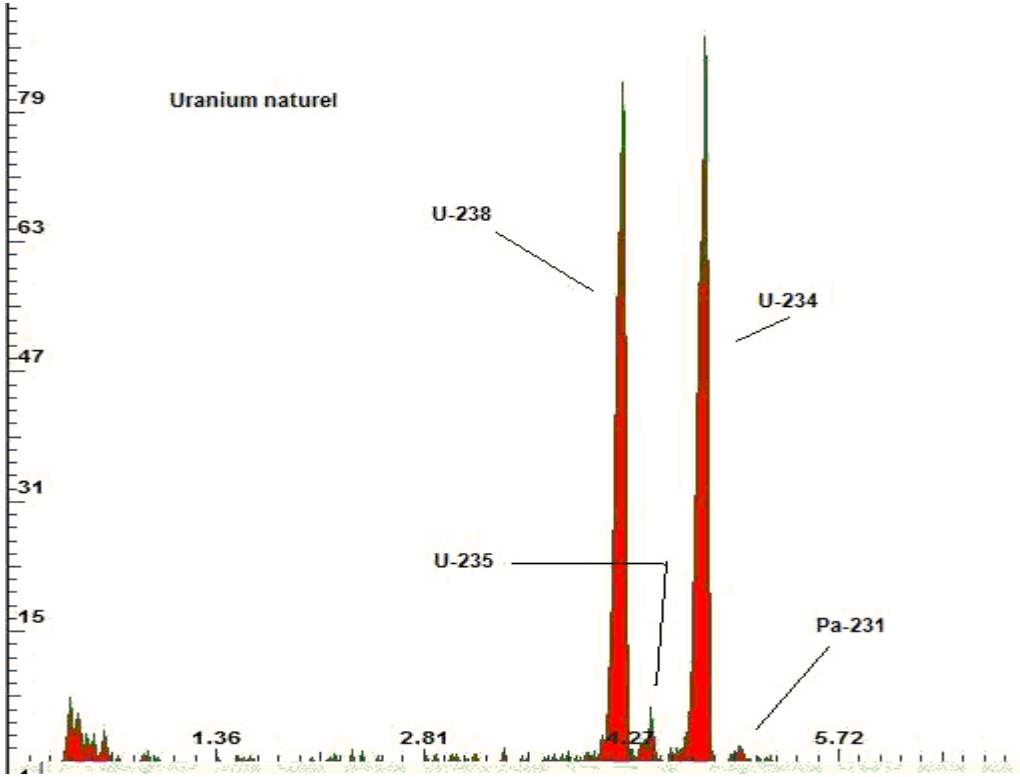
Depletion Layer in Surface Barrier





Courtesy: Canberra

Typical Alpha Spectrum of Natural Uranium



Alpha spectrum recorded using surface barrier detectors

Laboratory Alpha Spectrometry System

- Most widely used are silicon semiconductor detectors (e.g. PIPS, SSB)

Sample holder in spectrometer

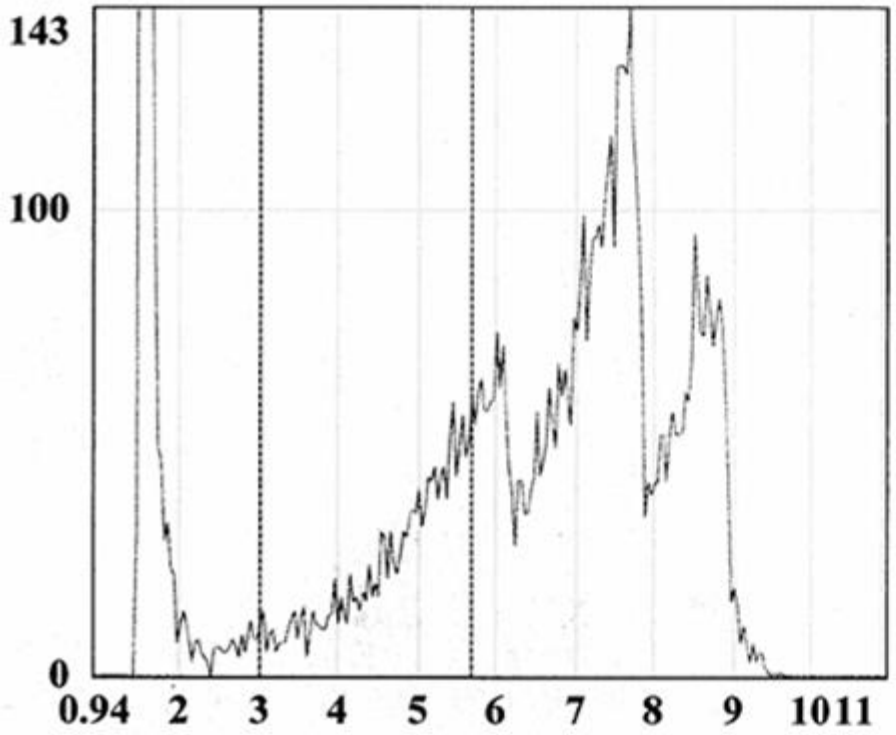
Application of Alpha Spectroscopy in CAM

CAM for alpha detection

Courtesy:Canberra

Typical PIPS detector

Example: Alpha Spectrum of Air Filter

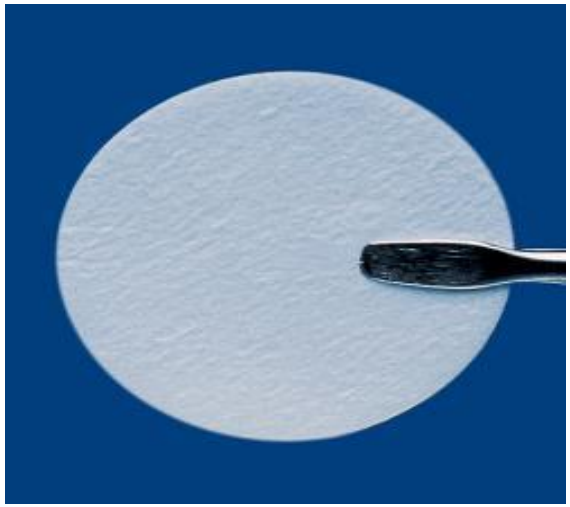


Air Volume:	**373260 l**
Air flow:	**41.153 l/min**
CPM:	**1.7455**
CPM Error:	**82.812 %**
Uncorr. CPM:	**27.75**
Unc. CPM Err:	**2.4507 %**
DAC Hours:	**0.80122 DAC h**
Concentration:	**-0.05797 Bq/m³**
Conc. Error:	**3525 %**
Critical level:	**1.0948 DAC h**
Filter time:	**142h**
Slope:	**0.039 MeV/Ch**

Alpha spectrum of a filter paper sample

Collection Media

- The collection media should be carefully chosen.
- Glass fiber filters being used in alpha spectrometers should have good “front surface” collection characteristics that will prevent burial of collected particles in the filter bed.



Glass fibre filter papers

Portable continuous Air Monitors

Portable planar silicon detectors for alpha spectrometry

GAMMA SPECTROMETRY

Gamma Ray Spectrometers- Theory

Gamma spectrometry is based on three fundamental interactions of radiation with matter.

- Photo electric effect
- Compton scattering
- Pair production

The probability of gamma ray interaction is depends on atomic number, density of materials and energy of gamma rays.

Gamma Ray Spectrometers- Theory

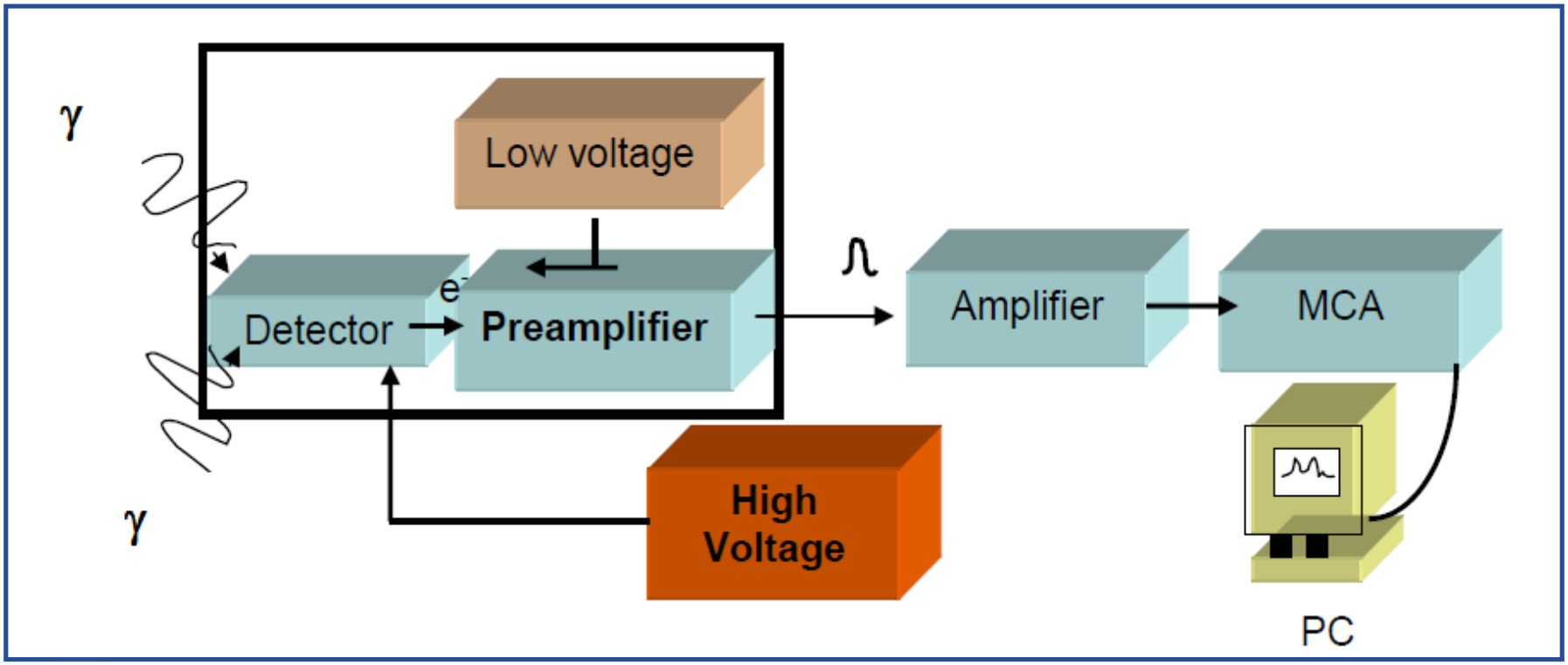
Conversion of ionizing radiation into visible light is called Scintillation.

Depending on the application many types of detectors are employed.

For high efficient detection of gamma one has to rely on NaI(Tl)

For high spectroscopic resolution, HPGe is preferred

Block Diagram of Gamma Ray Spectrometer



Block diagram of a basic gamma spectrometry system

Gamma Spectrometers Set Up

The spectrometer shall be first adjusted to your measurement task:

Set up the energy – channel number function by reference sources with known energies (~ energy calibration).

Set up the activity – counts function by reference sources with known energy and activity (~ efficiency calibration).

Reference sources (IEC recommended) should have the same geometry as your sample.

Types of Gamma Ray Spectrometers

NaI(Tl)
- High efficiency but poor resolution (7-8 %@662 keV)
- Operable at room temperature

HPGe
- High resolution (0.2 -1.2 %@662 keV)
- Need liquid nitrogen cooling or electrical cooling.

CdZnTe
- high efficient and very compact
- Moderate energy resolution (2 keV @ 662 keV)

$LaBr_3$
- Ce Low resolution (2.8-4 %@662 keV) but high efficiency

→ Detectors are chosen depending on the application

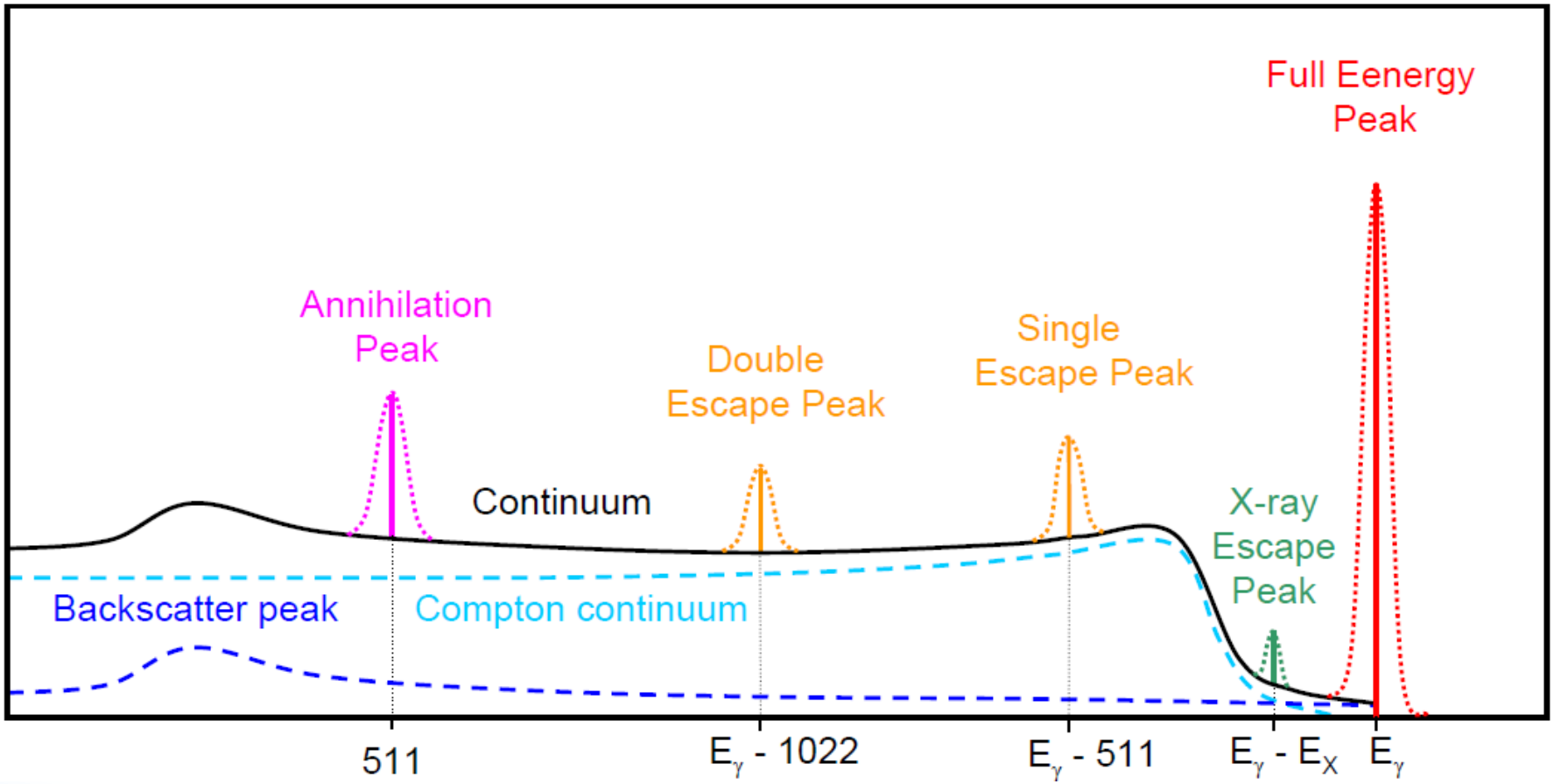
Gamma Ray Spectrometry as Analytical Tool

Allows the identification and quantification of gamma emitting isotopes in a variety of samples

The spectrum evaluation consists of:

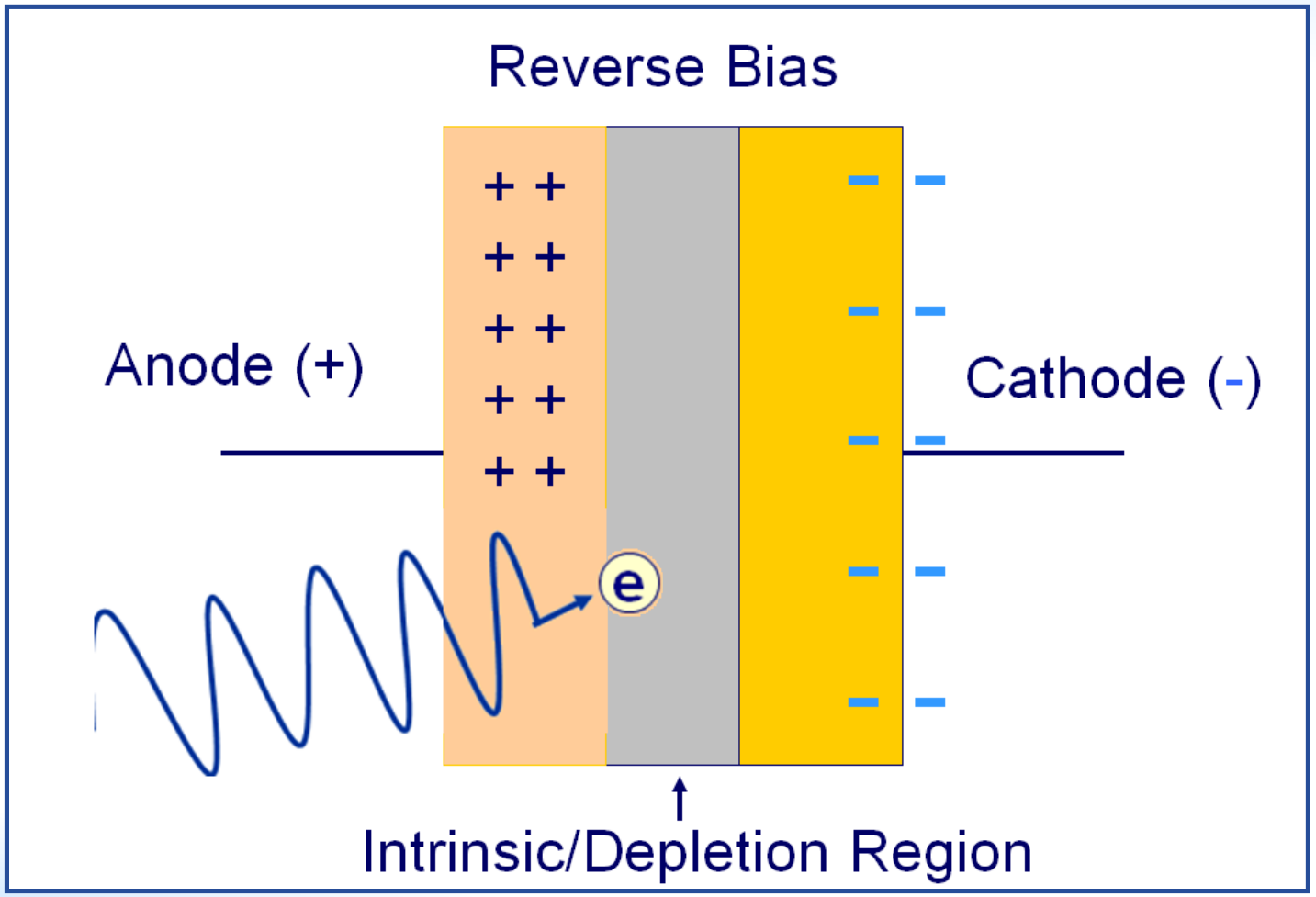
- Identification of peaks
- Determination of peak energies
- Identification of radionuclides
- Calculation of peak total areas, subtraction of background
- Determination of activities and uncertainties
- Use of a spectrometry software

Components of Gamma Spectrum



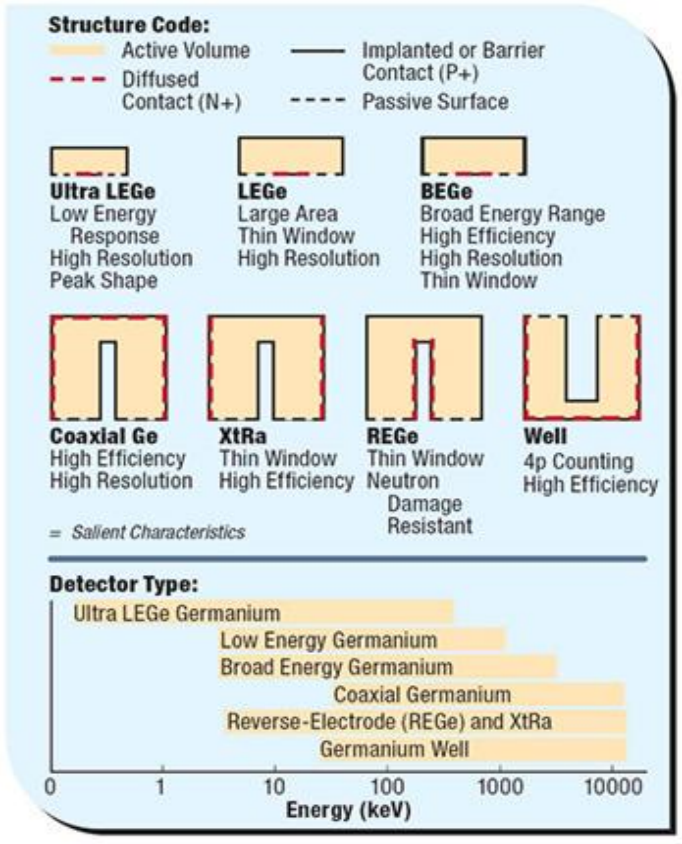
Theoretical spectrum of gamma ray

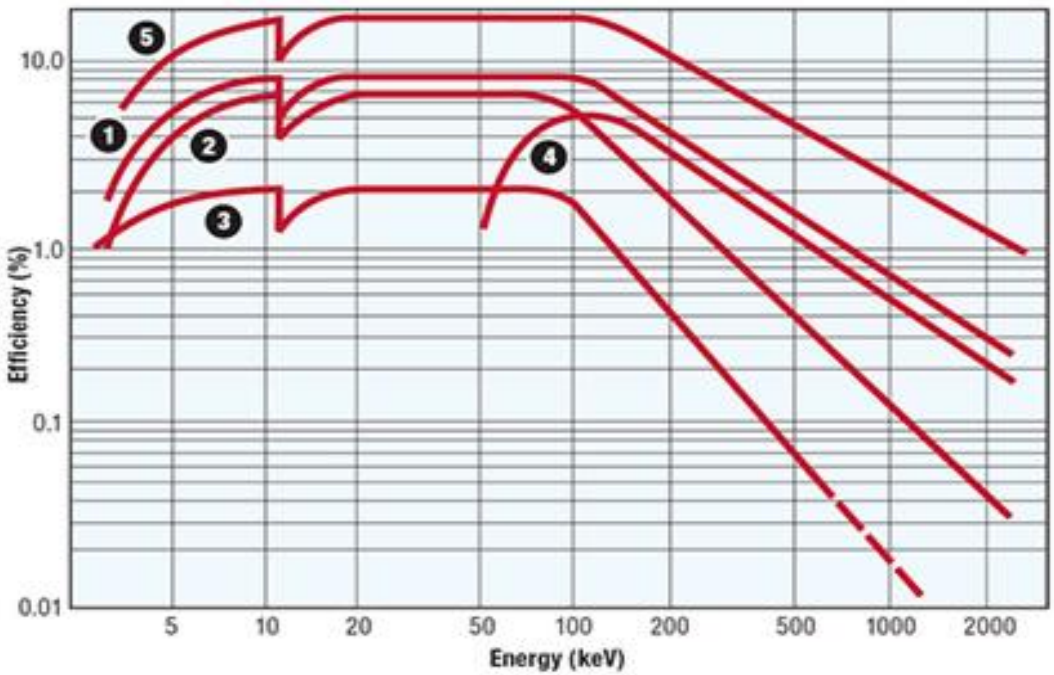
Semiconductor Detectors (1)



Semiconductor Detectors (2)

➢ HPGe detector types and efficiency curves





Typical absolute efficiency curves for various Ge detectors with 2.5 cm source to end-cap spacing

1. REGe, 15% Relative Efficiency XtRa, 15% Relative Efficiency
2. LEGe, 10 cm² x 15 mm thick
3. LEGe, 200 mm² x 10 mm thick
4. Coaxial Ge, 10% Relative Efficiency
5. BEGe, 5000 mm² x 30 mm thick

Courtesy: Canberra

Spectrometry Process

Constitution of a spectrometry chain

Detector - Pre-amplifier
Scintillator + Photomultiplier
Semiconductor

Detection

Production of a pulse whose amplitude is proportional to the energy deposited in the detector

Amplifier

Signal shaping

Analog-digital converter

Conversion of the analog signal into a digital value

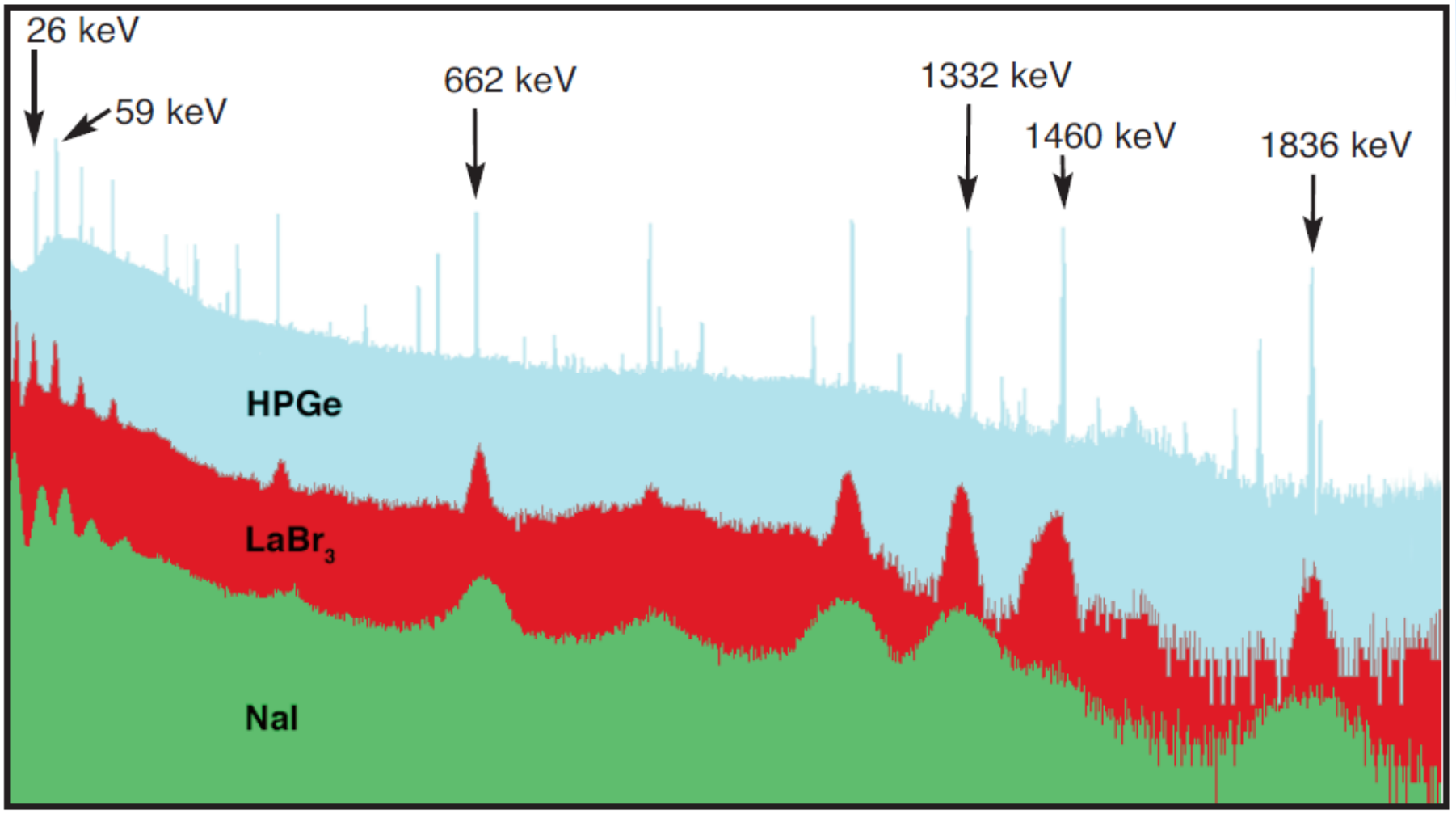
Multichannel analyzer

Recording of the events received in a memory.

Spectrometry software

Piloting of the spectrum acquisition, visualization and processing

Energy Resolution



APPLICATION OF GAMMA RAY SPECTROMETRY

Analysis of lab samples using HPGe spectrometry systems

HPGe system for radionuclide analysis

Application of portable HPGe in contamination monitoring

An example of one portable commercial system with an electric cooling system.

- Used mainly for qualitative analysis, i.e. identification of contamination and of radionuclides
- Used to check the surface contamination in workplace.

Application in identification unknown isotopes inside the container

Identification of unknown radioactive materials using HPGe

Different configurations of portable gamma spectrometric systems

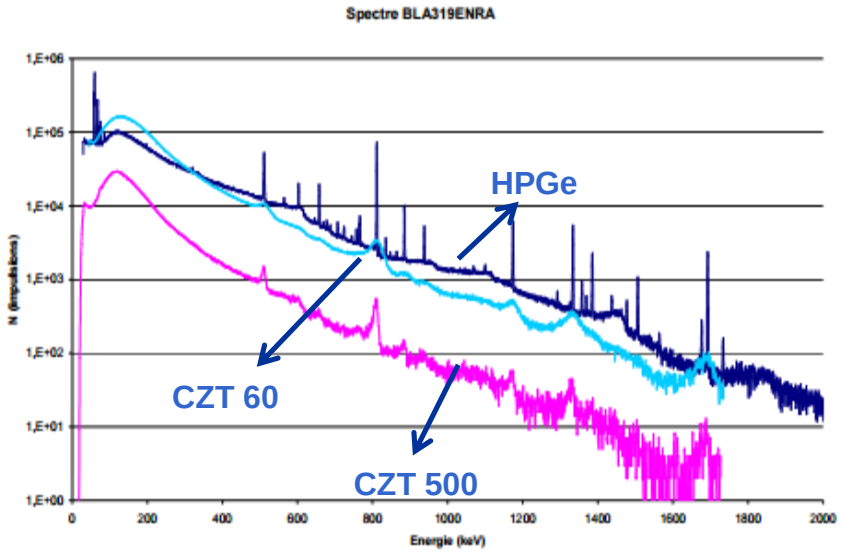
Hand held portable spectrometer with NaI(Tl)

CdZnTe probes

CdZnTe probes

- Used mainly for qualitative analysis, i.e. identification of contamination and of radionuclides.
- Suitable for a few radionuclides present with distinct energies, due to the poor energy resolution.
- Measures surface contamination in workplace.

Comparison of different systems for in-situ spectrometric monitoring



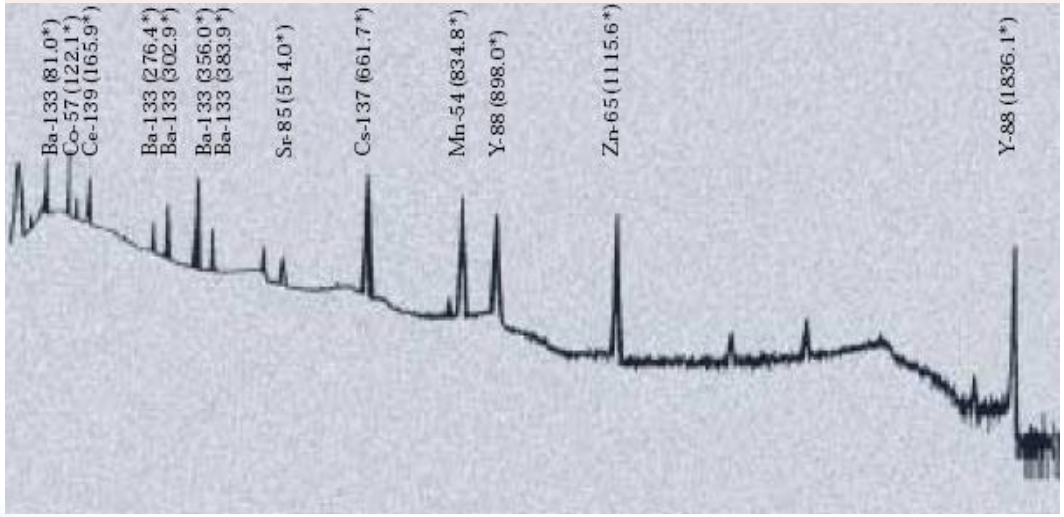
Gamma spectrum recorded using different configurations of spectrometer

	Ge (%)	± 2σ (%)	CZT 60 (%)	± 2σ (%)	CZT 500 (%)	± 2σ (%)
^{58}Co	**65,6**	1,1	**74,2**	6.6	**76,5**	6.8
^{60}Co	**11**	0,5	**9,4**	3.3	**10,7**	4,4
^{124}Sb	5,8	0,4	7,5	3	7,5	3,4
^{122}Sb	1,8	0,2				
^{110m}Ag	8,7	0,4	8,9	3.2	5,3	2,8
^{95}Zr						
^{54}Mn	1,7	0,2				
^{59}Fe	1	0,3				
^{51}Cr	4,6	0,7				

Gamma Spectrometry for Air Monitoring

Cartridge samples

Energy range	Radionuclide(s)	Nominal total activity [kBq]	Density [g/cm³]	Product code
80-1836keV	Mixture NG1: Ba-133, Co-57, Ce-139, Sr-85, Cs-137, Mn-54, Zn-65, Y-88	44	0.5-0.6	QCRB5968
60-1836keV	Mixture NG3: Am-241, Cd-109, Co-57, Ce-139, Hg-203, Sn-113, Sr-85, Cs-137, Co-60, Y-88	40	0.5-0.6	QCRB1127



Typical gamma spectrum of filter cartridge