

Semiconductor Detector

General

1. Introduction

A semiconductor detector is used for

- a. checking the radionuclidic purity of radiopharmaceuticals and calibration sources;
- b. the quantitative analysis of tracers in blood products, excreta, waste water and tissues of wipe tests.

The system is usually built up around a germanium crystal (it is therefore sometimes also called a germanium detector) and also comprises an amplifier and a multichannel analyser. This last component is often linked to a personal computer (PC), with which the measured spectrum can be automatically analysed and with which calibrations can be performed.

To minimise the contribution of the electron noise, the detector crystal is cooled with liquid nitrogen. In the case of the older type of germanium-lithium detector crystals, cooling failure leads to permanent damage; modern germanium crystals may be warmed up without any trouble to room temperature for maintenance purposes, provided they are made voltage-free. Follow the manufacturer's instructions.

The energy measurement range of semiconductor detectors is roughly from 50 keV to 2 MeV. The lower limit depends on the detector type and the thickness of the casing (the terminal window).

To maximally reduce background radiation - and especially variations thereof - the detector crystal is mounted in a lead castle.

2. Selection of tests and frequency

ANSI/IEEE standard 325 (1996) is an international guideline for the conduct of energy and sensitivity calibrations.

All tests should be performed on (re)acceptance. It is recommended that the sensitivity and energy calibration are checked after major maintenance and that these checks are integrated into a comprehensive maintenance programme that takes place roughly annually.

It is further recommended that a close eye is kept daily on the overall energy calibration based on the peaks of the radionuclides used clinically.

3. Requirements

Various radioactive sources are needed for checking the semiconductor detector. These are further specified under the individual part protocols. In addition, containers in various geometries (e.g. bottles having different volumes) are required for the liquid sources. The geometry of the calibration source must always be equal to that of the samples to be measured.

4. Archiving

The test results and calibration data, including data on the sources used, holders, adjustments and settings must be recorded in a spreadsheet.

5. Literature

- Adam F, Dams R. Applied gamma-ray spectrometry. Pergamon Press Inc. New York; 1979.
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- Hamilton JH, Manthuruthil JC. Radioactivity in Nuclear Spectroscopy. New York: Gordon & Breach; 1972.
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- L'Annunziata MF. Chapter 4: Solid State Detectors. In: Radionuclide tracers. Academic Press; 1987.
- Mann WB, Rytz A, Spornol A. Chapter 4: Detectors. In: Radioactivity measurements. Pergamon Press; 1988/1991.
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Energy calibration

1. Introduction

The display of the measured spectrum is determined to a great extent by the width of the individual channels in the multichannel analyser. For qualitatively good semiconductor detectors, the channel width in the energy range from 50 keV to 2 MeV will be practically independent of the energy, resulting in a linear relationship between the photon energy (y) and the channel number (x):

$$y = a + bx$$

in which:

a = the offset (keV),

b = the conversion factor (keV/channel).

The conversion factor depends on the number of available channels (preferably 4096 or 8192) and the set amplification factor. For a continuous range to below 50 keV, a quadratic function is required:

$$y = a + bx + cx^2$$

2. Frequency

The energy calibration must be verified on (re)acceptance and before and after major maintenance or major repairs. In addition, it is recommended that the checks are integrated into a comprehensive maintenance programme that takes place roughly annually.

It is further recommended that the peaks of the radionuclides used clinically are checked daily during routine usage.

3. Method

Record a spectrum with a minimum of two (linear relationship) or three (quadratic relationship) well-defined and very different photopeaks, roughly covering the energy range of the detector. Determine the linear or quadratic function through the measuring points. If a calibration must be checked for energies between 15 keV and 50 keV, the specific X-ray emissions of some radionuclides (e.g. ^{137}Cs) can be used.

4. Requirements

Source holder, tweezers and calibration sources from a standard set of calibration sources, e.g. ^{57}Co , ^{60}Co , ^{137}Cs , ^{133}Ba , ^{241}Am , ^{88}Y , ^{22}Na or a ^{152}Eu calibration source filled with ^{137}Cs or sources of radiopharmaceuticals made in-house (bottles or paper) with a low activity, e.g. ^{125}I , $^{99\text{m}}\text{Tc}$, ^{111}In , ^{67}Ga , ^{131}I .

5. Procedure

Adjust the amplification factor in such a way that the available number of channels corresponds to an energy range of about 2 MeV (such that, for example, the 1836 keV line from ^{88}Y is still only just visible). Most photopeaks from radionuclides used in nuclear medicine will occur in this energy range. It goes without saying that sometimes a smaller energy range up to, for example, 1 MeV, will be sufficient, especially if the number of available channels is limited.

Record the spectrum of one or more calibration sources, containing at least two well-defined and distinct photopeaks which span most of the available energy range. The count rate must be so low that the dead time is less than 10% (e.g. 1000 cps in the entire spectrum).

Collect enough counts (e.g. at least 3000 in the whole peak), such that the peaks can be accurately determined.

6. Analysis and interpretation

Collect the measurement points in a spreadsheet, draw a graph and fit a linear or quadratic trend.

7. Action thresholds and actions

Recalibration is necessary if the conversion factor deviates by more than 1% and/or the offset deviates by more than 1 keV from the previously determined values.

8. Pitfalls and remarks

If the conversion factor exceeds 0,5 keV/channel (energy range >1 MeV in 2048 channels, or >2 MeV in 4096 channels), the photopeak comprises only a few channels. The location of the peak can then no longer be accurately determined.

Because of sum peaks and/or multiplets, the exact locations of the individual peaks are difficult to determine. It is therefore better not to use these peaks for checking the energy calibration.

If an accurate check of the calibration of the low energy range is necessary, it is not sufficient to use one spectrum measurement only of a ^{152}Eu source. A further source with a photopeak or an X-ray emission in the low energy range is also needed to be used (e.g. ^{137}Cs) in that specific situation.

9. Literature

- Connelly AL, Black WW. Automatic location and area determination of photopeaks. Nucl Instrum Meth 1970;82:141-8.
- Hine CJ, Sorenson JA. Instrumentation in nuclear medicine. New York: Academic Press Inc.; 1974.
- International Commission on Radiological Protection. Radionuclide Transformations Energy and Intensity of Emissions, Publication 38. Oxford: Pergamon Press, Annals of the ICRP; 1983: Vol. 11-13.
- Table of Isotopes. New York: Lederer & Shirley John Wiley & sons Inc.; 1978.
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Energy resolution

1. Introduction

The energy resolution is a measure of the ability of the detector to distinguish photons of different energies from each other. The energy resolution is measured as full width at half maximum (FWHM) of the relevant photopeak and expressed in keV, for ^{57}Co (122 keV) and ^{60}Co (1332 keV). Representative values are 0,8 keV and 2,0 keV respectively.

2. Frequency

It is recommended that this check is performed on (re)acceptance.

3. Method

Measure the spectrum of a radionuclide in a 'scatter-free' measurement setup and determine the width of the photopeak at half height (FWHM). To measure the energy resolution, the conversion factor must be known. To make an accurate determination of the FWHM possible, at least 10 channels must fall within the FWHM of the photopeak. This is the case with a conversion factor of about 0,20 keV per channel, that is, approximately 8000 channels for an energy range up to 2 MeV. Possibly, the conversion factor may need to be modified with the help of amplification or tuning of the analogue-digital converter (gain, range and offset).

4. Requirements

Source holder for good reproducible geometry with a negligible scatter contribution. Calibration sources of ^{57}Co and ^{60}Co (possibly also ^{137}Cs if these data are given in the detector specifications). Source intensity up to 30 kBq (dead time less than 10%).

5. Procedure

Position the ^{57}Co source at a distance of approximately 10 cm centrally above the middle of the detector in or on the source holder in the lead castle and close this. Record a spectrum with at least 10.000 counts in the entire photopeak. Repeat the test with the other calibration source(s): ^{60}Co and possibly ^{137}Cs .

6. Analysis and interpretation

If the multichannel analyser is equipped with software to detect and analyse peaks in the spectrum (peak search), then the centre of the peak and the FWHM are given in channel number and number of channels respectively, or - if the energy calibration is implemented

- in keV. If such software is not available, the FWHM of the photopeak must be determined manually for both radionuclides.

Apart from the determination of the FWHM, determination of the full width at tenth maximum (FWTM) for ^{60}Co (1332 keV) is only useful if given in the detector specifications. Compare the results with the detector specifications on delivery and with the values found in previous measurements.

7. Action thresholds and actions

For a germanium detector with a high resolution, the broadening of the photopeak relative to the specifications must not amount to more than 20%. If there is a larger increase in the FWHM, the analysis of complex spectra, as well as simple spectra in the low energy range, is rendered more difficult. Such a broadening will most probably not be a source of errors in applications of a routine nature.

8. Pitfalls and remarks

A high count-rate can cause peak broadening due to 'pile up'.

Sensitivity

1. Introduction

To perform absolute measurements of the amount of activity in a specimen using a semiconductor detector, this measurement device must be calibrated with one or more calibration sources under exactly the same geometrical conditions: source volume, distance to the detector and the lead castle, and source absorption. Each geometry has a different sensitivity curve.

Apart from the absolute sensitivity of the detector, the manufacturer will often also specify a relative sensitivity of the measurement system. This will be expressed relative to the sensitivity of a 3"×3" NaI crystal at 1332 keV.

2. Frequency

The sensitivity must be checked on (re)acceptance and after major maintenance. Additionally, it is recommended that this check is integrated into a comprehensive maintenance programme that takes place annually.

3. Method

A spectrum is recorded from a source that emits photons of different energies (e.g. ^{152}Eu), with an accurately known source intensity. The geometry of the source and the position relative to the detector must be exactly the same as for the samples to be analysed.

To determine the relative sensitivity of the detector, a spectrum is recorded of a ^{60}Co point source with an accurately known strength in such a way that no self-absorption and/or scatter can occur. After correction for background radiation, the relative sensitivity can be calculated.

4. Requirements

Calibrated source which is liquid or cast in resin, e.g. ^{152}Eu or a mixture or combination of radionuclides with known intensity, such as ^{241}Am , ^{109}Cd , ^{57}Co , $^{123\text{m}}\text{Te}$, ^{51}Cr , ^{113}Sn , ^{85}Sr ,

^{137}Cs , ^{60}Co and ^{88}Y .

For the low energy range, a liquid ^{125}I calibration source and a solid ^{60}Co point source. By means of dilution, adjust the intensity of the liquid calibration sources to the activity of the samples to be measured.

5. Procedure

a. Absolute sensitivity

Record a spectrum of the multi-gamma source with enough counts (at least 1000 counts per photopeak) at low count rate (dead time below 10%).

b. Relative sensitivity

Position the ^{60}Co point source at a distance of 25 cm from the end window centrally in front of the detector. Collect a spectrum during 1000 seconds with a low count rate (<1000 counts per second (cps) in the entire spectrum).

6. Analysis and interpretation

a. Absolute sensitivity

Determine the 'background spectrum' at the location of a number of important photopeaks over the entire energy range by means of interpolation from the spectrum directly on either side of each photopeak. Determine the net count rate (above the 'background spectrum') in the photopeaks (cps). Using the source intensities and the percentage incidence of photons with the relevant energy, calculate the number of gammas per second (gps). Repeat this for each photopeak. From this, calculate the sensitivity: cps/gps. Print out the sensitivity curve, note the calibration parameters or collect the results in a spreadsheet and draw a graph with logarithmic axes.

b. Relative sensitivity

Determine the net number of counts in the photopeak at 1332 keV. The relative sensitivity (S_{eff}) is now given by

$$S_{\text{eff}} = \frac{\text{cps}}{\text{gps}} \times \frac{1}{1,2 \times 10^{-3}} \times 100 [\%]$$

in which:

cps = the count rate in the 1332 keV photopeak

gps = source intensity

the constant $1,2 \times 10^{-3}$ = sensitivity of a 3" x 3" NaI detector for a ^{60}Co source at a distance of 25 cm.

Compare the results with those of the previous measurements.

7. Action thresholds and actions

Upon acceptance, comparisons must be made with the specifications.

If the results differ by more than 5% from the previous measurements, the adjustments and settings of the electronic components must first be checked. If, after adjustment, the relative sensitivity appears to have been standardised, then absolute sensitivity calibrations may be omitted.

If the detector appears to be responsible for the decrease in sensitivity, a partial warming

may be the cause. A complete warm-up/cool-down cycle may result in improvement. If the relative sensitivity does not improve, the sensitivity for all geometries must be reassessed.

8. Pitfalls and remarks

- a. The count rate should be low enough that no deformation of the sensitivity curve occurs due to dead time (<10%). During the calibration, multiplets must be avoided.
- b. If the calibration sources themselves are made by dilution, one needs to be cautious for glass wall absorption and prevent contamination. The accuracy of the calibrations - and thus of the measurements on the samples - is adversely affected by this. A dose calibrator is not suitable for determining the intensity of calibration sources (insufficient accuracy).
- c. The relative sensitivity is measured in an easily reproducible set-up using a point source of ^{60}Co (1332 keV) with an accurately known intensity and it can therefore be quickly determined. However, the measurement is carried out at a photon energy that is much higher than the photon energies of radionuclides commonly used in nuclear medicine.
- d. The measurement must be carried out in such a way that only very little self-absorption and/or scatter will occur.
- e. Copper lining on the inside of the lead castle prevents the production of bremsstrahlung by β emitters.
- f. For highly sensitive measurements, the use of "old lead" may be considered (lower activity of its own).