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**Test procedures for germanium
gamma-ray detectors**

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Foreword

This translation has been made based on the original Japanese Industrial Standard established by the Minister of Economy, Trade and Industry through deliberations at the Japanese Industrial Standards Committee according to the proposal of establishing a Japanese Industrial Standard from Japan Electric Measuring Instruments Manufacturers' Association (JEMIMA)/Japanese Standards Association (JSA) with a draft of Industrial Standard based on the provision of Article 12 Clause 1 of the Industrial Standardization Law.

This Standard has been made based on **IEC 60973 : 1989** *Test procedures for germanium gamma-ray detectors* for the purposes of making it easier to compare this Standard with International Standard; to prepare Japanese Industrial Standard conforming with International Standard; and to propose a draft of an International Standard which is based on Japanese Industrial Standard.

Attention is drawn to the possibility that some parts of this Standard may conflict with a patent right, application for a patent after opening to the public, utility model right or application for registration of utility model after opening to the public which have technical properties. The relevant Minister and the Japanese Industrial Standards Committee are not responsible for identifying the patent right, application for a patent after opening to the public, utility model right or application for registration of utility model after opening to the public which have the said technical properties.

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In the event of any doubts arising as to the contents,
the original JIS is to be the final authority.

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Test procedures for germanium gamma-ray detectors

Introduction This Japanese Industrial Standard has been prepared based on the first edition of **IEC 60973** *Test procedures for germanium gamma-ray detectors* published in 1989.

The portions given dotted underlines are the matters in which the contents of the original International Standard have been modified. A list of modifications with the explanations is given in Annex (informative).

1 Scope This Standard specifies the test procedures for performance and characteristics of the germanium gamma-ray detectors, which are important to manufacturers and users. The test procedures for germanium gamma-ray detectors used for the high-resolution gamma-ray spectroscopy are mainly specified.

NOTE : The International Standard corresponding to this Standard is as follows.

In addition, the symbols which denote the degree of correspondence in the contents between **JIS** and the relevant International Standard are IDT (identical), MOD (modified) and NEQ (not equivalent) according to **ISO/IEC Guide 21**.

IEC 60973:1989 *Test procedures for germanium gamma-ray detectors*
(MOD)

2 Normative references The following standards contain provisions which, through reference in this text, constitute provisions of this Standard. If the indication of the year of publication is given to these referred standards, only the edition of the indicated year constitutes the provision of this Standard but the revision and amendment made thereafter do not apply. The normative references without the indication of the year of coming into effect apply only to the most recent editions (including amendments).

JIS Z 4001 *Glossary of terms used in nuclear energy*

JIS Z 8103 *Glossary of terms used in measurement*

IEC 60333:1993 *Nuclear instrumentation—Semiconductor charged-particle detectors—Test procedures*

IEC 60759:1983 *Standard test procedures for semiconductor X-ray energy spectrometers*

3 Terms and definitions For the purposes of this Standard, the definitions given in **JIS Z 4001** and **JIS Z 8103**, and the following definitions apply.

- a) **ion implantation** a process in which a beam of energetic ions incident upon the surface of crystal results in the implantation of those ions into crystal
- b) **full width at half maximum, FWHM** the full width of a distribution measured at half the maximum value of peak

For a normal distribution, it is equal to 2.35 times the standard deviation σ .

- c) **full width at 0.1 maximum, FW0.1M** the full width of a distribution measured at one tenth the maximum value of peak

Also called FW1/10M.

- d) **full width at 0.02 maximum, FW0.02M** the full width of a distribution measured at one fiftieth the maximum value of peak

Also called FW1/50M.

- e) **high-purity germanium gamma-ray detector, HPGe** a gamma-ray detector which uses a high-purity germanium single crystal (The concentration of impurities is usually $1 \times 10^{10} \text{ cm}^{-3}$ or under.)

It should be cooled only at the time of use.

- f) **germanium gamma-ray detector** a general term for a high-purity germanium gamma-ray detector, a lithium drift germanium gamma-ray detector, etc.

4 Structure

4.1 General The germanium gamma-ray detector element is a single crystal of germanium which will operate as a diode capable of withstanding high reverse bias voltage at cryogenic temperature (liquid nitrogen temperature range). When the reverse bias voltage is applied, the depletion region is formed in the bulk of the detector. Under these conditions, electrons and electron holes generated by the interaction of photons are swept to respective electrodes in the depletion region. The induced charge is integrated to produce an output pulse whose magnitude is proportional to the absorbed photon energy.

The germanium gamma-ray detector is usually mounted in a cryostat to permit cooling the detector and maintaining it at cryogenic temperature for the purpose of reducing leakage current and thermal noise. The cryostat also provides protection and appropriate environment for the detector.

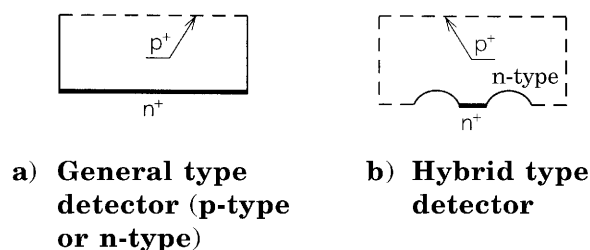
For the usual germanium gamma-ray detector, a germanium crystal, a preamplifier, a high voltage filter and a cryostat are combined in an integrated unit, and it is not practical to measure performance of the detector as a single unit which is isolated from the preamplifier.

4.2 Detector classification Germanium gamma-ray detector types are classified by material and geometry.

- a) **Classification by material** Materials used are p-type germanium and n-type germanium. A high-purity germanium gamma-ray detector which uses a high-purity germanium single crystal is usually used.

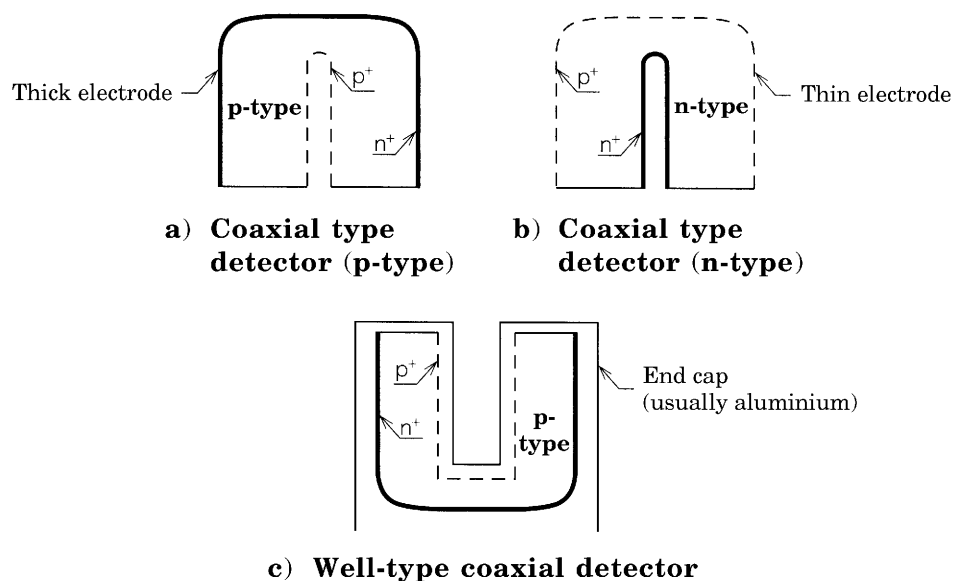
- 1) **p-type detector** The p-type detector is made with p-type germanium crystal [see figure 2 a)] with an n^+ outer electrode (usually lithium diffusion with a dead-layer of 0.5 mm to 0.8 mm in thickness). The p^+ inner electrode is made by ion implantation of boron and the like. High positive voltage is applied to the n^+ outer electrode to form depletion region.

- 2) **n-type detector** The n-type detector which is also called the reverse-electrode detector is made with n-type germanium crystal with a p^+ outer electrode. This outer electrode is made by ion implantation of boron and the like [see figure 2 b)]. The inner electrode is usually made by lithium diffusion. High negative voltage is applied to the p^+ outer electrode to form depletion region. Thin (approximately $0.3 \mu\text{m}$) outer electrode makes it possible to use this detector also for low energy X-ray detector. The n-type detector is more resistant to neutron damage than the p-type detector.
- b) **Classification by geometry** Geometries usually used are a planar type and a coaxial type. The difference depends on the structure of electrodes. The planar type is usually a disc shape with electrodes of parallel planes (see figure 1). The coaxial type has electrodes of the coaxial cylinder shape of which one end is closed (see figure 2).
- 1) **Planar type detector** The planar type geometry is useful for constructing small-diameter detectors and/or low capacitance detectors which make possible low noise, and has characteristics for obtaining high resolution especially for low energy X-rays. Some planar type detectors also have large front surface areas with high capacitance, and are capable of detecting even low-energy X-rays by making the outer electrode thin. Planar type detectors include the general type and the hybrid type. The general type is a simple flat-plates in parallel structure [see figure 1 a)]. The hybrid type structure is such that the one side electrode area is made small to achieve low capacitance [see figure 1 b)].
 - 2) **Coaxial type detector** The coaxial type geometry makes possible detectors with high capacitance to be able to obtain relatively high efficiency for detecting high energy gamma-rays.
 - 3) **Well-type coaxial detector** The well-type coaxial detector has a structure in such a way that the sample can be inserted in the inner electrode. The sample is essentially surrounded by the detector [see figure 2 c)].



NOTE : The dotted line indicates a thin p^+ electrode, and the thick solid line indicates a relatively thick n^+ electrode.

Figure 1 Planar type detector



NOTE : The dotted line indicates a thin p^+ electrode, and the thick solid line indicates a relatively thick n^+ electrode.

Figure 2 Coaxial type detector

5 General test conditions Although it is not necessary to perform all tests specified in this Standard, when tests concerned are performed, the procedures specified in this Standard shall be followed except when agreed between the parties concerned with delivery.

The general test conditions specified in this Standard shall be as follows.

- The maximum apply voltage, device ambient temperature and environment and other operational conditions specified by manufacturers should not exceed limits when testing since permanent changes of the detector performance may result.
- The high voltage power supply, amplifier, multichannel pulse-height analyzer, and other equipment used for the test shall not significantly influence the performance test for the detector because of their instability, nonlinearity or other performances.
- Changes in measurement system components or changes in system parameters (e.g. amplifier gain) shall not be made without complete system recalibration.
- The performance test results should be reproducible within the measurement precision range after any one or all tests are completed.

6 Energy spectroscopy measurement For the energy spectroscopy measurement, unless specially agreed between the parties concerned with delivery, a spectral peak shall be at least six channels at FWHM and the total counts within FWHM shall be at least 50 000. The radiation source shall be located on-axis of the detector and 25.0 cm from the end cap surface.

6.1 Recommended radiation source Radiation sources given in table 1 are recommended as radionuclide sources for the measurement of energy resolution of the detector and/or the spectroscopy system.

Table 1 Recommended radiation source

Radionuclide source	Half-life	Energy
^{55}Fe	2.7 years	5.9 keV
^{241}Am	433 years	59.5 keV, 26.36 keV. X-rays
^{109}Cd	453 days	22.1 keV (X-ray, doublet peak), 88.0 keV
^{57}Co	270 days	122.1 keV, 136.5 keV
^{137}Cs	30 years	661.6 keV
^{22}Na	2.60 years	1 274.5 keV
^{60}Co	5.24 years	1 173.2 keV, 1 332.5 keV ⁽¹⁾
^{208}Tl (nuclide series of ^{228}Th)	1.91 years	2 614.5 keV

Note (1) 1 332.5 keV of ^{60}Co is the gamma-ray preferred for the performance test of a coaxial detector.

For the multi-line gamma-ray sources, ^{56}Co (half-life 77 days) with energy range from 847 keV to 3 600 keV, and ^{152}Eu (half-life 13 years) with energy range from 122 keV to 1 769 keV may be used. In the energy resolution measurement, it is assumed that the measurement system is energy calibrated in units of eV, or keV per channel.

The energy calibration shall be performed by using plural gamma-rays which should be sufficiently close in energy to the peak under study to reduce problems arising from measurement system nonlinearities. For example, in the case of ^{60}Co , 1 173.2 keV and 1 332.5 keV gamma-rays are suitable for this purpose. In the case of the mono-energetic gamma-ray emitter ^{137}Cs , ^{207}Bi (569.7 keV) or ^{54}Mn (835 keV) should be combined.

6.2 Connection method of test equipment Connect the preamplifier, main amplifier, and multichannel pulse-height analyzer to the detector as shown in figure 3.

The detector and preamplifier are usually supplied as an integral unit. The main amplifier shaping is usually set to the conditions to obtain the optimum performance of the detector. The method and parameters of main amplifier shaping used shall be given with each energy resolution measurement results or specifications. A pulse generator (see **IEC 60333**) connected to the measurement system can be run simultaneously with the gamma-ray measurement, provided that it does not distort other peaks (e.g. by baseline undershoot) or cause significant errors in dead-time correction for the detection efficiency measurement.

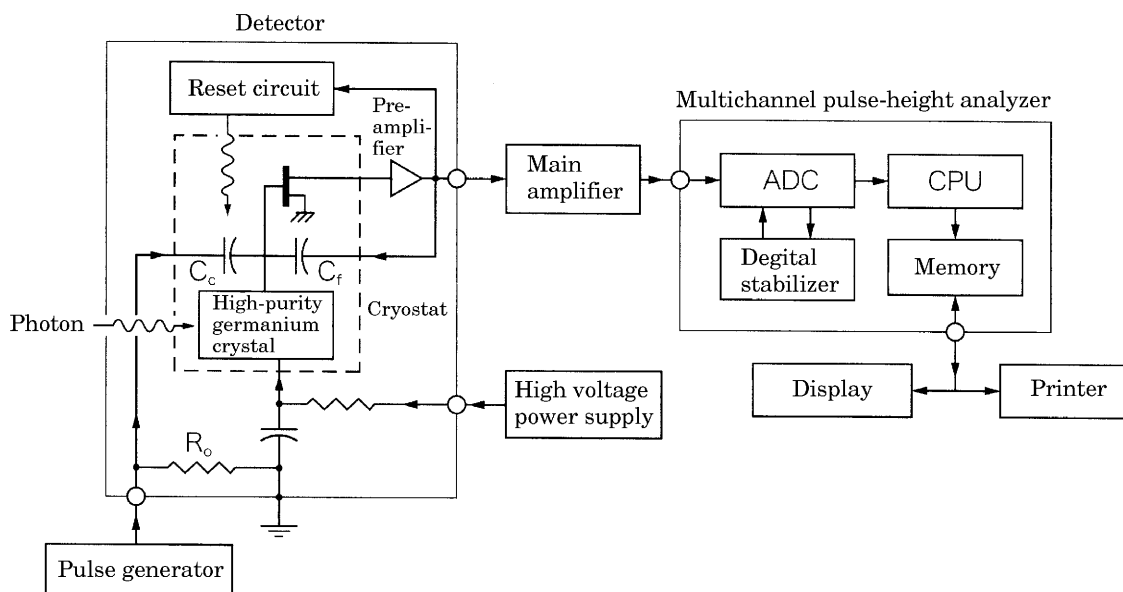


Figure 3 Block diagram of typical germanium gamma-ray spectroscopy system

6.3 Determination of peak area Although the method of peak area determination (net counts of peak) includes many methods such as a method of summing the counts per channel and a peak function fitting method, a peak-sum method shall be specified in this Standard so that the calculation result of peak area can be easily ensured. Even in the peak-sum method, although there are some methods for determination of a baseline area, here, the following two methods shall be specified. Either method may be used, however, the method by which the test is performed shall be clearly stated.

Information : For the method **a)**, in the case of a high-resolution germanium gamma-ray detector, accuracy becomes poor according to how to draw a straight baseline. Furthermore, since the method **a)** is complicated because it requires the determination of baseline counts per channel and so on, the method **b)** is usually used.

- a) For the method of calculating baseline area by summing baseline counts per channel, the procedure shall be as follows.
 - 1) As shown in figure 4, pulse-height distribution shall be plotted as the log of the number of counts N_x in channel X versus channel number X . On this semilog plot, the straight line a-d shall be fitted to represent an approximation of the baseline under the peak. The mean value of 10 data points above and below the peak may be used to fit the baseline.
 - 2) Draw a smooth curve through the peak data points, extending the curve on each side at the base of the peak to intersect the baseline (curve A-B and curve C-D).
 - 3) The area below the straight line (A-D) bounded by two points of intersection with the peak curve shall be taken as the baseline area.