A SIMPLE AND VERSATILE GAMMA-RAY SOURCE FOR THE CALIBRATION OF HIGH-ENERGY Ge(Li) SPECTRA

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A simple and inexpensive source of mono-energetic high-energy γ-rays of many different energies, suited for the energy-calibration of Ge(Li) spectra, is described.

A difficulty in the study of high-energy γ-rays ($E_\gamma \gtrsim 4$ MeV) with Ge(Li) detectors is the lack of adequate and convenient sources for the energy calibration.

In the energy range $E_\gamma \leq 2.75$ MeV, many radioactive sources are known [1]. The ^{56}Co source [2] enables calibration up to $E_\gamma = 3.5$ MeV; it has, however, the disadvantages of a short half-life (77 d) and a complex spectrum. Recently, a ^{239}Pu-^{10}B source, providing 3.85 MeV γ-rays, has been described [3]. Because of Doppler broadening the application of α-particle sources for the production of sharp high-energy γ-calibration lines is limited to long-lived levels. Highly excited states with a long lifetime are scarce.

Previously, calibration lines with $E_\gamma > 4$ MeV have mostly been produced at reactors or with beams of accelerated particles. This method is inconvenient and expensive; it also introduces inaccuracies when the desired simultaneous recording of spectrum and calibration lines is impossible.

This letter draws the attention to the possibility to use non-broadened neutron capture γ-lines of many different energies for calibration purposes.

Fast neutrons are readily available from a variety of α-emitter-Be sources. After thermalization the neutrons can be used to induce (n,γ) reactions. A selection of capturing materials with a sufficiently high thermal-neutron capture cross section and a simple decay scheme then provides useful sources of many different mono-energetic high-energy γ-rays.

A few simple experiments have been performed to demonstrate the feasability of this calibration procedure. A 2.6×10^6 n/s ^{241}Am-Be source ($\tau_{\frac{1}{2}} = 458$ y) was placed in a 22 cm diam. vessel of water for thermalization. The 45 cm^3

Nuclear Diodes Ge(Li) detector was shielded against low-energy γ-rays from the source by 8 cm of lead. The total source-detector distance was 30-35 cm. The most convenient location for the capturing material was found to be close to the detector. At other places more material is required to obtain comparable γ-ray intensities.

The optimal dimensions for a particular capturing material depend on the relative values of its thermal-neutron capture cross section and γ-ray absorption coefficient. Optimalization of the γ-ray yield has not been the purpose of the present introductory experiments. In most of the examples given below, we simply used pieces of capturing material that were available in the laboratory (see table 1).

Iron. The head of a gas cylinder, outer diam. 9 cm, wall-thickness 0.2 - 0.4 cm, was placed around the detector. The counting rate in the double-escape peak of the ^{57}Fe 7.63 - 7.64 MeV doublet, 270 h^{-1}, is comparable to that in a peak of a typical (p,γ) resonance spectrum. A 4 cm thick cylinder around the counter only increases the counting rate by a factor of four, mainly due to γ-ray absorption in the iron.

The 7.63 - 7.64 MeV doublet has often been used to test the performance of Ge(Li) spectrometers. The 9.30 MeV transition in ^{55}Fe is also interesting, but rather weak.

Copper. The simple spectrum is dominated by the 7.92 and 7.64 MeV γ-rays from ^{65}Cu.

Nickel. The spectrum has beautifully isolated high energy ^{60}Ni lines of e.g. 9.00, 8.53 and 6.84 MeV.

Chloride. Because of the high capturing cross section, chlorine is an attractive material. This is especially so since the capture γ-ray spectrum has relatively strong and well-isolated peaks over a broad energy range:

Table 1.
Survey of properties and yields of the capturing materials used

Material (natural)	Shape (cm)	σ_{nat}[4] (b)	Main branch [4] E_γ(MeV)	I_γ(%)	Counting rate a) in pair-peak(h^{-1})	Other γ-rays [4] (MeV;%)
Fe	cylinder-head	2.55	7.63 + 7.64	40	270	9.30(3), 7.28(5), 6.02(8), 5.92(8)
Fe	$15\phi\times 10^c$)				1100	
Cu	$15\phi\times 3^d$)	3.8	7.92	35	500	7.64(15), 7.31(8)
Ni	$19\times 9\times 0.9^d$)	4.6	9.00	30	400	8.53(12), 7.82(6), 6.84(9)
Cl^b)	$20\phi\times 9^c$)	33.2	6.11	25	1300	many: 8.58 – 0.52
Al	$24\phi\times 9^c$)	0.24	7.72	20	200	--

a) Measured with a 45 cm^3 Ge(Li) detector at 30-35 cm from the source.
b) NaCl was used.
c) Detector placed in central hole (8 cm $\phi\times$ 7.5 cm) in capturing material.
d) Placed in front of detector.

E_γ = 0.52 - 8.58 MeV. In this experiment the capturing material was NaCl; probably better would be CCl_4 or C_2Cl_6. In view of the high capturing cross section Cl can be used with relatively weak neutron sources.

Aluminium. To test the applicability of materials with lower thermal-neutron capture cross sections, capture in ^{27}Al(σ = 240 mb) was investigated. The counting rate in the pair-peak of the 7.72 MeV transition, 200 h^{-1}, is useful in many experiments.

Other elements. Several other elements have promisingly high thermal-neutron capture cross sections. A drawback in some cases is the com-

plexity of the decay spectrum. In practice, the choice of the capturing material will depend on the problem studied.

As an example of an application of the method described above, fig. 1 gives parts of a spectrum in which Fe capture γ-rays were measured simultaneously with those from the ^{26}Mg(p,γ)^{27}Al reaction at E_p = 454 keV. Since the energies of the iron capture γ-rays are known very precisely [5], a (p,γ) Q-value of Q_0 = 8 271.2 ± 0.8 keV could be deduced from this measurement. The 1964 mass table [6] gives Q_0 = 8 270.9 ± 2.3 keV.

A few final remarks:
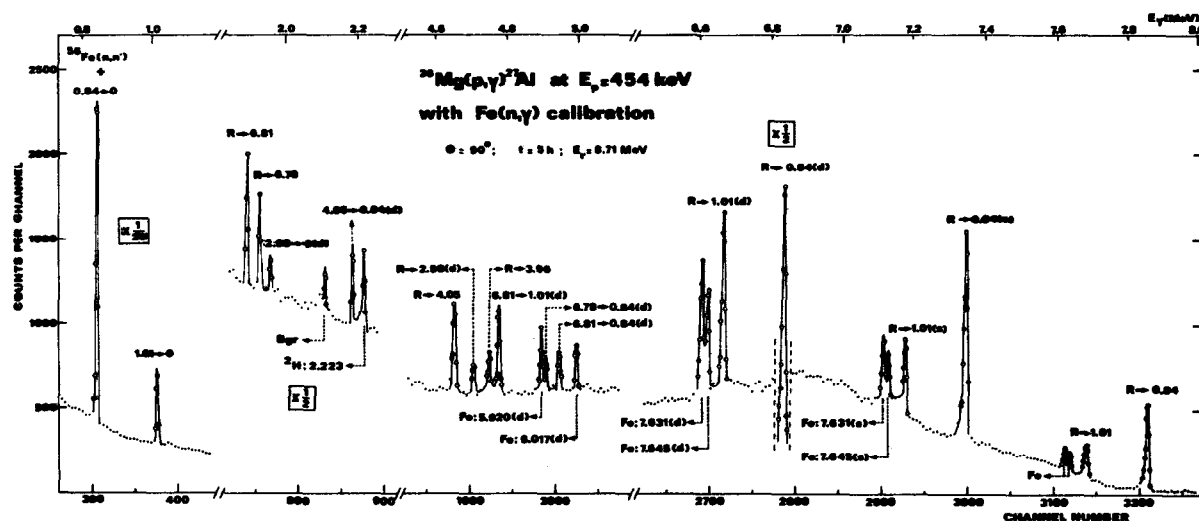a) Several of the γ-rays discussed above are

Fig. 1. Parts of the ^{26}Mg(p,γ)^{27}Al spectrum with simultaneously recorded Fe(n,γ) calibration lines. In flat areas between peaks, the data points (dots) represent averages over four channels. The high-energy part of the spectrum shows the ^{27}Al γ-rays and the ^{57}Fe calibration lines used in the Q-value measurement. The excitation energies of the lowest two ^{27}Al levels, E_x = 843.69 ± 0.10 and 1014.4 ± 0.2 keV, have been determined from a separate run with radioactive sources. The low-energy parts demonstrate that the neutron-capture spectrum does not spoil the spectrum under investigation.

not yet qualified as calibration lines since their energies have not been measured precisely. The method described above can be applied in reverse for precision measurements of high-energy neutron-capture γ-rays. Some (p,γ) resonances decay with both high-energy and low-energy cascade γ-rays. By summing the energies of the latter, which can be calibrated with accurately known lines from radioactive sources, one finds the precise energy of the high-energy γ-rays. Though these lines in themselves are very inconvenient for routine calibrations, they might be used once to provide precision energies for the readily available neutron-capture γ-rays.

b) If strong sources are used, or weaker sources for a long time, it might be advisable to protect the Ge detector against neutrons by a thin layer of B_4C or ^6LiF.

c) In some reaction studies, e.g. (α,γ) with the contaminant $^{13}C(\alpha,n)$ reaction, or (d,p) with competing (d,n), the background neutrons might be used to replace the neutron source. One then only has to place some capturing material around the detector to produce neutron-capture γ-rays.

d) A rather complete efficiency curve for a detector may be obtained from one measurement of e.g. the $^{35}Cl(n,\gamma)$ spectrum, if the relative intensities of the strong transitions in the spectrum are accurately known.

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