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ENERGY CALIBRATION OF NE-213 SCINTILLATION COUNTERS BY γ-RAYS

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ABSTRACT

An accurate energy calibration of organic scintillation counters by means of γ-rays is described. The position of the Compton edge has been precisely determined comparing measured with calculated spectra. The calculation includes wall and light pipe effects and the influence of channel dependent pulse height resolution. Relations are given for the position of the maximum and the half maximum of a Compton spectrum as a function of the incident photon energy and the resolution of the detector. Results are given with uncertainties smaller than 1 %.

INTRODUCTION

The application of organic scintillation counters for neutron spectroscopy, neutron time-of-flight measurements and neutron monitoring requires an accurate energy calibration of the detectors being used.

The relation between the recoil proton energy and the light output in a NE-213 scintillator is not linear. The light output for protons as a function of proton energy has therefore often been measured [1-4)] in relation to the light output for electrons, which is linear for electron energies $E_e \geq 100$ keV[5)] and may be expressed as $L^e = \alpha \cdot (E_e - E_o)$. E_e is the electron energy in MeV, E_o a parameter due to the nonlinear relation at low electron energies, L the relative pulse height and α the parameter normalizing the pulse height scale. For calculations and measurements $\alpha = 1 MeV^{-1}$ was used. Verbinsky[2)] and other authors[3-5)] used a value $\alpha = 1.25\ MeV^{-1}$ taken from a ^{22}Na pulse height spectrum.

The calibration points, which define the light output curve for electrons, are normally taken from the Compton electron spectra of such easily available γ-sources as ^{137}Cs, ^{22}Na, ^{65}Zn, ^{88}Y (fig. 1).

The maximum Compton electron energy given by $E_e = 2 \cdot E^2/(0.511 + 2 \cdot E)$ with E_e and the incident photon energy E in MeV is directly related to the Compton edge of the pulse height distribution.

The shape of a measured Compton electron spectrum of a NE-213 liquid scintillation counter strongly depends on the photon source geometry, the position of the source, the dimensions of the detector and the detector walls, the light output function and on the resolution of the detector system.

Different estimates have therefore been made[5-8)] to determine the position of the Compton edge in a measured spectrum. It is shown that a more accurate determination is given comparing a measured with a calculated spectrum.

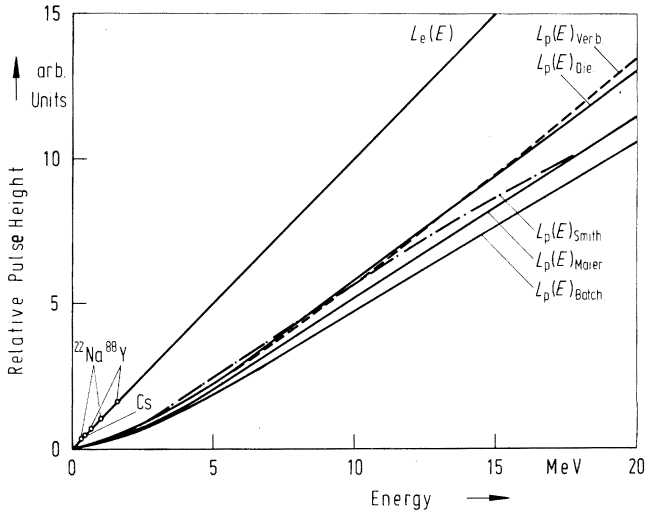

Fig. 1 Relative pulse height of a NE-213 liquid scintillation detector for electrons and protons measured by different authors[1,2,3,4)].

CALCULATIONS

A Monte-Carlo code was written for photons incident on an organic scintillator. The code calculates the response function of the detector nomalized to the undistorted fluence of incident photons at the center of the sensitive scintillator volume.

The photon source may be positioned anywhere outside the detector. The primary photon energy is restricted to $E \leq 3$ MeV. In this energy region only the photoelectric absorption and the photon scattering have to be considered for the calculation.

The detector consists of an organic liquid scintillator NE-213[+)] (or other organic scintillator material containing only H and C) filled into a cylindrical vessel and coupled via a glas window to a cylindrical acrylic

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light pipe with the same radius as the scintillator. The calculations were made for a NE-213 scintillator (ϱ = 0.873 g/cm^3, mole fraction: H 54.8 %, C 45.2 %), 5.08 cm in diameter and 5.08 cm long, shielded by an Al cylinder, 5.88 cm in diameter with a front plate, 0.16 cm thick, and connected to a polished light pipe (ϱ = 1.18 g·cm^{-3}, mole fraction: H 52.5 %, C 47.5 %) 2.5 cm in length. The Monte-Carlo code considers multiple scattering of photons from all materials and wall effects for all electrons including those from the walls and the light pipe which enter the scintillator volume. The relation $L_1 = \alpha \cdot (E - E_o)$ was used for energies $E \geq 40$ keV, continued with a polynomial $L_2 = (A \cdot E + B \cdot E^2)$ for $E \leq 40$ keV with $A = 1 - 50 \cdot E_o$, $B = 625 \cdot E_o$ and E, E_o in MeV.

For comparison with measured spectra a calculated spectrum has to be folded by a Gaussian function describing the resolution of the detector system. The values of the

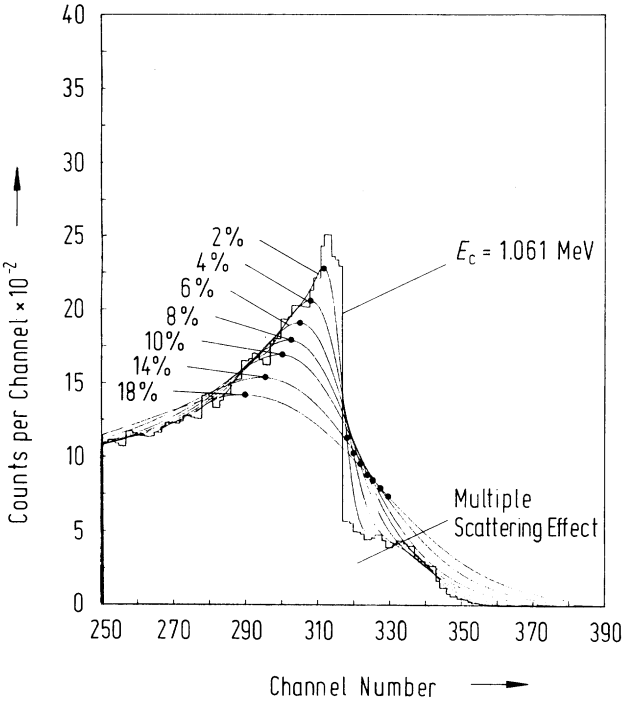

Fig. 2 Part of calculated Compton electron spectrum from a ^{22}Na source, E = 1.275 MeV and the same spectrum folded with resolutions between 2 % and 18 %. The points always denote the positions of the maximum L_{max} and the half maximum $L_{1/2}$.

variance σ^2 and the resolution width ΔL (full width half maximum) of the Gaussian function are pulse height dependent and correlated to the detector design. The pulse amplitude resolution of a scintillation detector has been treated in detail by Birks[9] and other authors[10,11]. The relative resolution width $\Delta L/L$ can be fitted by the empirical estimate

$$\Delta L/L = (A^2 + B^2/L + C^2/L^2)^{1/2}$$

The value of parameter A limits the resolution of the detector system at large pulse heights. Local variations of the photon transmission from the light emitting center at the scintillator to the photocathode of the multi-

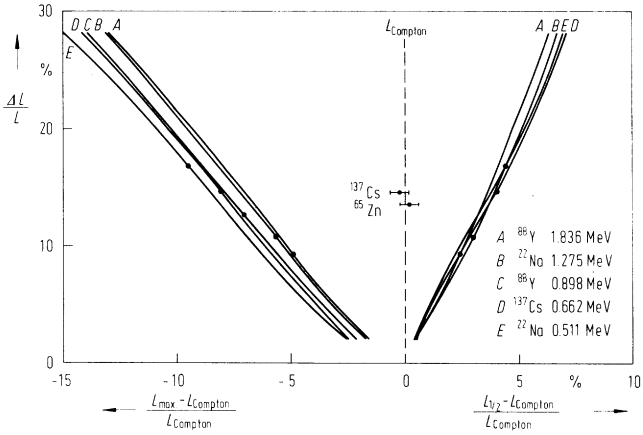

Fig. 3 The position of the maximum L_{max} and of the half maximum $L_{1/2}$ in a Compton electron spectrum relative to the position of the Compton edge $L_{Compton}$ as a function of the relative resolution of the scintillation detector at $L_{Compton}$ for various energies.

NE-213 detector: 5.08 cm x 5.08 cm ø. Results of the coincidence measurement are shown for ^{137}Cs and ^{65}Zn.

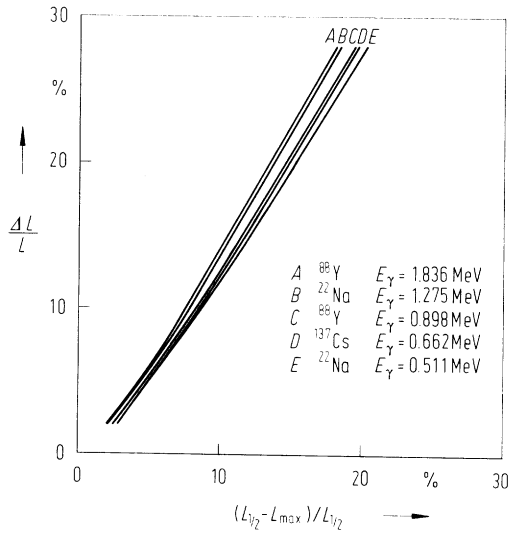

Fig. 4 Relative resolution $\Delta L/L$ (ΔL full width half maximum) versus $(L_{1/2} - L_{max})/L_{1/2}$ for various photon energies.

mental spectrum in the region of the Compton maximum. The experimental data were best fitted with E_o = 5 keV. Similar calculations have been made for other photon sources, e.g ^{88}Y, ^{22}Na, ^{65}Zn and ^{203}Hg and the value of E_o has always been confirmed. This is in agreement with earlier statements[4,13,15] that the energy intercept E_o is small for organic scintillators. Flynn[5] experimentally obtained a value E_o = 20 keV, F. T. Porter[16] obtained E_o = 5 keV for anthracene.

A further check of the calibration accuracy was made using the coincidence method[4,6]. The experimental setup is shown in fig. 7. Two NE-213 scintillation detectors were set up opposite each other, 30 cm apart, and a small photon source was positioned in front of detector 2. Photons from the source, which were backscattered at about 180° from detector 1, were seen by detector 2.

Background from unwanted coincidence events was greatly reduced by window conditions in both channels of the coincidence circuit. Only pulses from detector 2 corresponding to the Compton maximum of the 180°

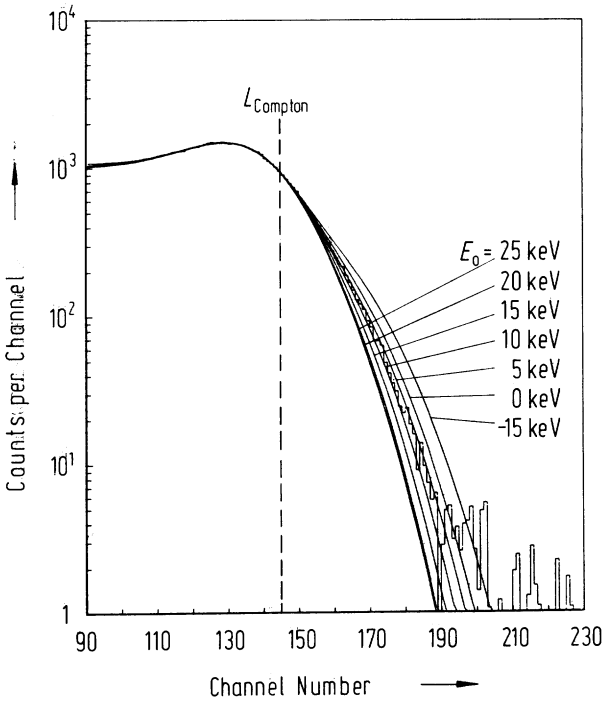

Fig. 6 Calculated pulse height spectra from a ^{137}Cs source with different E_o in the light output function for electrons in the scintillator,
$L = \alpha \cdot (E-E_o)$, α = 1 MeV^{-1}, E, E_o in MeV, compared with a measured spectrum.

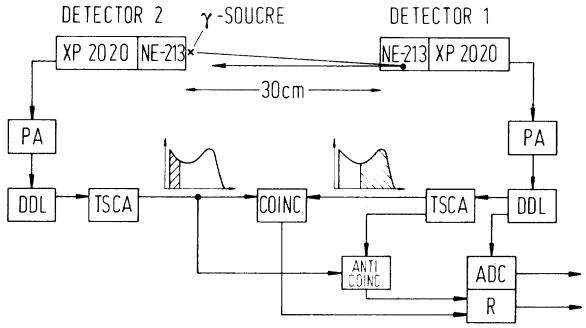

Fig. 7 Schematic diagram of the detector assembly and the electronic modules for γ-coincidence measurements
NE-213 liquid scintillator,
XP 2020 photomultiplier,
PA preamplifier,
DDL main amplifier,
TSCA timing single channel analyser,
ADC analog digital converter,
R routing unit.

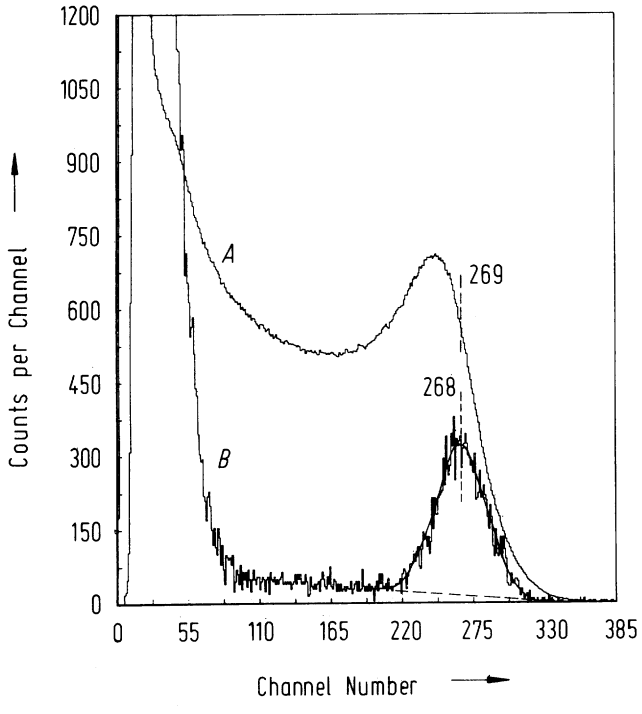

Fig. 8 Spectra from a ^{137}Cs source
A spectrum of detector 1
B spectrum of detector 1 measured in coincidence with detector 2
The channel numbers 268 and 269 indicate the position of the Compton edge obtained from the spectra.

plier contributes mostly to the value of A[12]. Contributions to B are due to all effects that show statistical variations, such as the photon emission in the scintillator or photoelectron and secondary electron production in the multiplier. The noise of the multiplier and the electronic system determines the value of C and may usually be neglected.

With the detector described above in detail, pulse height distributions of proton recoils from monoenergetic neutrons incident to the detector were measured for neutron energies between 1 MeV and 20 MeV. From the shape and the position of the upper edge of the proton recoil spectra the relative resolution was extracted. The values were best fitted by the function with the parameters A = 4.9, B = 9.5 and C = 0.5.

Fig. 2 shows a detail of a calculated spectrum with photons of ^{22}Na, E_γ = 1.275 MeV, incident on the detector parallel to the cylinder axis and the same spectrum folded with various resolutions. The position of the maximum L_{max} and of the half maximum $L_{1/2}$ in the pulse height distribution may easily be extracted from an experimental spectrum. Their position relative to the position of the Compton edge Compton depends on the resolution. Calculations were carried out for various photon energies. Fig. 3 shows a diagram of $(L_{1/2}-L_{Compton})/L_{Compton}$ and $(L_{max}-L_{Compton})/L_{Compton}$ as a function of

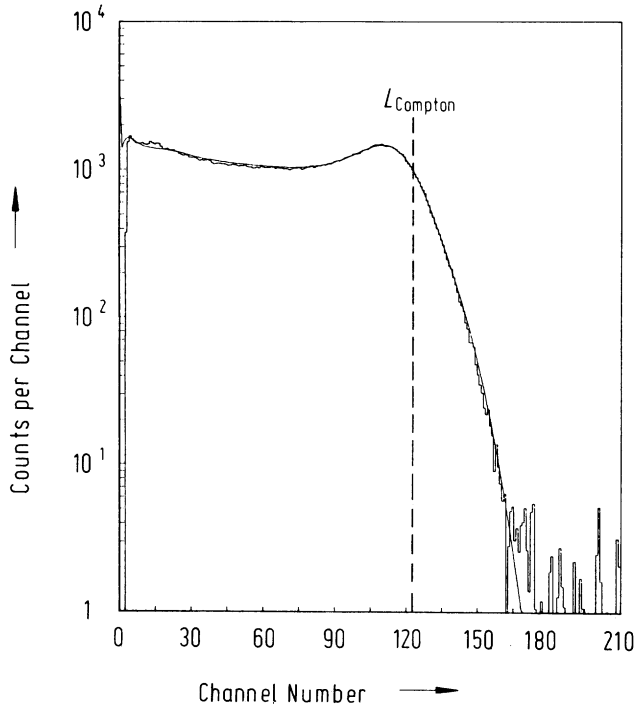

Fig. 5 Calculated and measured pulse height spectrum from a ^{137}Cs source, E_γ = 0.662 MeV.

$\Delta L/L$ and the photon energy. The shift with varying photon energy is small, but the dependence of the resolution on the pulse height has to be considered. Therefore no constant values for the positions of L_{max} and $L_{1/2}$ relative to $L_{Compton}$ can be given for the calibration of a detector system by different photon sources.

The determination of the Compton edge position in a measured spectrum is possible by extracting the values of L_{max} and $L_{1/2}$ and using two diagrams as follows. In fig. 4 the relative resolution width at the Compton edge is shown as a function of $(L_{1/2}-L_{max})/L_{1/2}$ for some incident photon energies. Obtaining from this the value of $\Delta L/L$, the relative position of the maximum L_{max} and the half maximum $L_{1/2}$ to the Compton edge may be taken from fig. 3.

Similar diagrams have to be calculated for detectors with other dimensions.

MEASUREMENTS

The calculations were checked by comparing theoretical with experimental spectra. As Lurie[13] has mentioned, regarding the photon source, care has to be taken in order to avoid a high number of degraded photons incident on the detector. Standard photon sources made at the PTB were used[14]. The radioactive material was packed between two welded polyethylene foils, each 0.024 cm thick, which were supported by an Al ring, 0.3 cm thick, with an inner diameter of 2.0 cm and an outer diameter of 3.0 cm. If necessary, the ring may be removed.

The source was positioned at the cylinder axis at a distance of 20 cm from the center of the scintillator. The detector described above was connected to an XP 2020 photomultiplier tube[++]. Conventional analog electronics and a LABEN 8215 ADC were used.

A measured spectrum with ^{137}Cs, E_γ = 0.6616 MeV is shown in fig. 5 along with a calculated and folded spectrum. The agreement particularly in the region of the Compton peak is good. The discrepancy at the low end of the spectrum is due to the fact that the ^{137}Cs source emits low energy photons, Ba - K_α and Ba - K_β lines which are not included in the calculation.

Only the parameter E_o of the relation $L = \alpha \cdot (E - E_o)$ was varied for fitting the measured spectrum. The shape of the spectrum at the upper region, above the Compton edge, which is due to multiple scattering effects in the detector, is very sensitive to the value of E_o. Fig. 6 shows results of calculations with ^{137}Cs varying E_o from -15 keV to 25 keV. The spectra were folded by a Gaussian function with the resolution width of the detector and then normalized to the experi-

backscattered primary photons were selected. The signal of the coincidence unit triggered a router changing the subgroup of the memory, where the pulse height of the signal from detector 1 had to be stored.

The full Compton electron and the coincidence spectrum of detector 1 are therefore accumulated simultaneously via the same ADC and are comparable without any normalization.

Measurements were performed with ^{137}Cs and ^{65}Zn. Spectra of ^{137}Cs are shown in fig. 8. The coincidence spectrum B near the Compton edge was fitted by a Gaussian function plus a linear function for background in order to determine its maximum.

The agreement of the position of this maximum with the position of the Compton edge, which was determined from spectrum A by the aforementioned method, is excellent. Similar results were obtained with ^{65}Zn. They are shown in fig. 3. The deviation from the calculated value is less than 0.5 %.

CONCLUSION

It has been shown that the organic NE-213 scintillation counter, which is commonly used as neutron detector, can be calibrated by photons with an uncertainty less than 1 %. The accurate position of the Compton edge may be derived from the maximum and the half maximum in a Compton spectrum using a diagram which has to be calculated only once for a given detector system.

Using this calibration care has to be taken of the stability of the detector system, which is often influenced by the gain shift of the photomultiplier caused by changes in count rate or temperature. These effects may be reduced applying more stable photomultipliers or by simultaneous accumulation of a neutron spectrum and a photon spectrum in different subgroups of a memory using the n-γ discrimination properties of NE-213 to separate the spectra.

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