KERNFORSCHUNGSZENTRUM

KARLSRUHE

November 1967 KFK 714

Institut für Angewandte Kernphysik

A High-Resolution Ge(Li) Anti-Compton Spectrometer for Radiative Neutron Capture Spectroscopy

W. Michaelis, H. Küpfer

GESELLSCHAFT FÜR KERNFORSCHUNG M. B. H.

KARLSRUHE

NUCLEAR INSTRUMENTS AND METHODS 56 (1967) 181–188; © NORTH-HOLLAND PUBLISHING CO.

A HIGH-RESOLUTION Ge(Li) ANTI-COMPTON SPECTROMETER FOR RADIATIVE NEUTRON CAPTURE SPECTROSCOPY

W. MICHAELIS and H. KÜPFER

Institut für Angewandte Kernphysik, Kernforschungszentrum Karlsruhe

Received 10 July 1967

A Ge(Li) anti-Compton spectrometer for the energy range up to 3 MeV is described which allows for the special conditions of (n,γ) spectroscopy and which gives improved performance compared to previously reported devices. The system consists of a planar 4.9 cm^3 Ge(Li)diode, a 50 cm dia. × 40 cm plastic scintillator and a 4″ dia. × 6″ NaI(Tl) detector at scattering angle 0°. The anti-coincidence method together with a pulse-shape discrimination technique very effectively suppress the Compton background under the peaks. The energy resolution is 2.15 keV fwhm at 0.662 MeV. Typical capture spectra are presented to illustrate the performance of the system.

1. Introduction

The study of nuclear structure by investigating radiative neutron capture reactions has become more and more attractive during the last few years. This trend may be attributed to the fact that the information which can be obtained is very sensitive to the specific properties of nuclear excitations.

The earlier work in this field suffered from inadequate resolution of the gamma-ray detectors. Considerable progress has been achieved by the development of magnetic pair^1) and Compton^2) spectrometers and most of the data now available in the high-energy region have been collected with these instruments^3). Bent-crystal spectrometers^4) with excellent performance have been designed for studying low-energy capture spectra. The recent development of lithium-drifted germanium detectors^5) perhaps represents the most significant breakthrough in experimental technique. These detectors are effective over almost the entire range of capture gamma-ray energies. Above 1 MeV their resolution is definitely superior to that of all other spectrometers and even in the energy range from 0.6 to 1.0 MeV germanium diodes may compete in resolution with the best bent-crystal spectrometers operating under optimum conditions.

A disadvantage of the germanium detectors is their inferior peak to background ratio resulting from the Compton effect. Additional difficulties arise in the energy range from about 1.5 to 3 MeV where the full-energy peak is comparable in intensity to the double-escape peak^6). Fortunately the coincidence capability of the Ge(Li) counter allows its use in more sophisticated instruments. 3-crystal^5) and even 5-crystal^7) pair spectrometers with a Ge(Li) diode as the primary detector have been successfully applied in the high-energy region. In the lower energy range up to 3 MeV the Compton background may be suppressed by using an anticoincidence mantle around the Ge(Li) detector^{6,8}).

Kantele and Suominen^9) have described such a device with a large NaI(Tl) annulus. A system which is also capable of being used as a pair spectrometer is reported by Orphan and Rasmussen^{10}). The Ge(Li) counter is mounted between two NaI(Tl) detectors, each of these crystals having a 1″ radius semi-circular slot cut in its face.

In the present paper a spectrometer is described which was optimized as an anti-Compton device and which particularly allows for the special conditions of (n,γ) spectroscopy. In the energy range up to 3 MeV the performance is superior to that of other systems reported to date.

2. Design

A schematic lay-out of the spectrometer is given in fig. 1. For large scattering angles the anti-Compton shield consists of a cylindrical plastic scintillator NE102 A with 50 cm dia. by 40 cm length. The scintillator has three wells. A vertical one with 3 cm radius is located 19.5 cm from the face and contains the cold finger with the Ge(Li) detector and the first stage of the preamplifier. The incident gamma rays pass through a 1.5 cm radius horizontal well on the scintillator axis. A third well from the rear with 11.2 cm dia. is used for placing a 4″ dia. × 6″ NaI(Tl) detector directly behind the vacuum chamber of the semiconductor diode. This design offers the following advantages:

1. The NaI(Tl) counter insures a strong absorption of gamma rays scattered in forward direction. This reduces very effectively the contribution of the ever present high-energy radiation to the background under the peaks. The absorption in the jacket material surrounding the NaI(Tl) crystal has no influence on the overall performance since the gamma rays scattered in

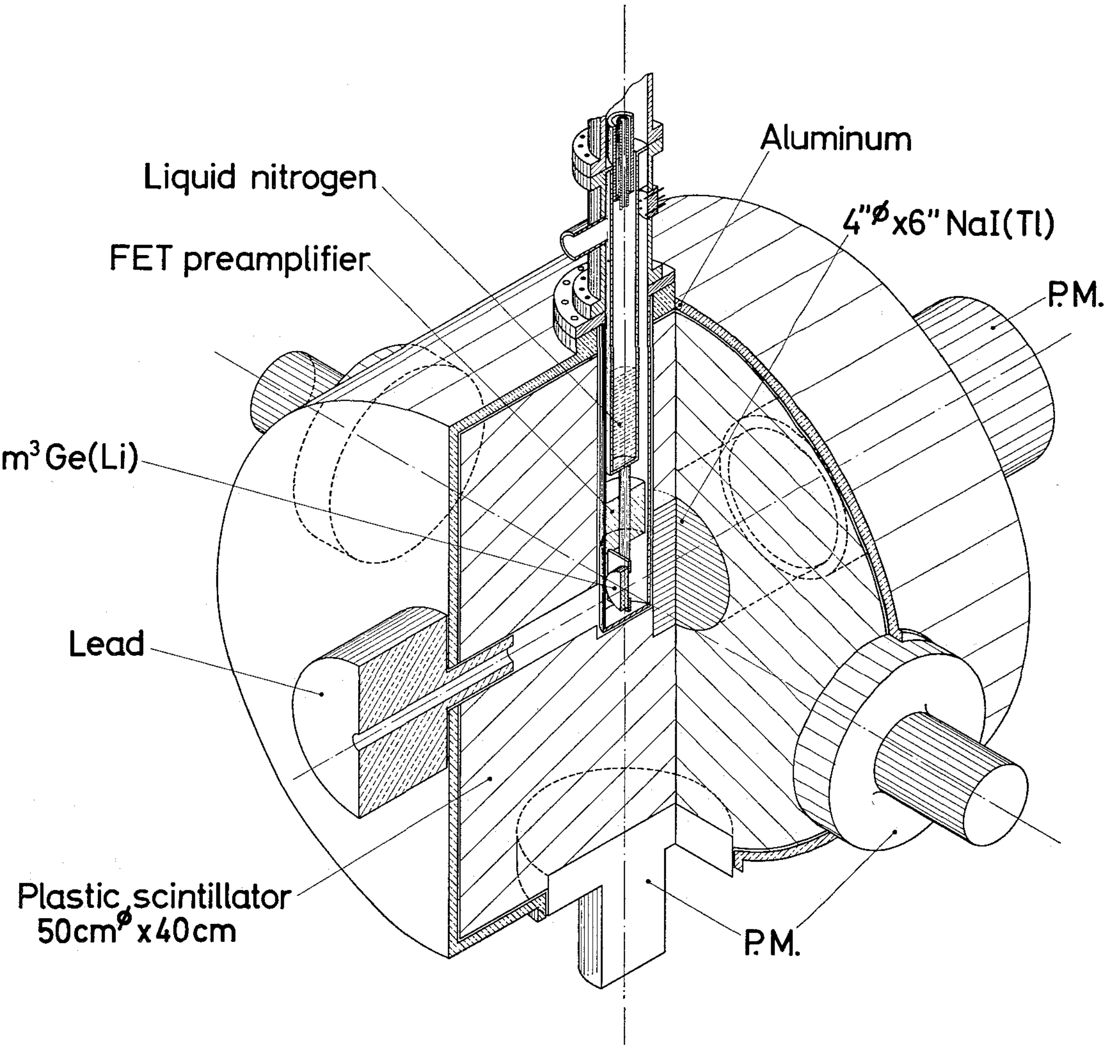

Fig. 1. Schematic view of the anti-Compton spectrometer setup.

forward direction have lost only a small fraction of their energy.

2. The plastic scintillator can be used unencapsulated and the reflector, in form of a water based emulsion paint, can be kept very thin. Thus the harmful absorption of soft backward-scattered gamma rays between the Ge(Li) detector and anti-Compton shield can be minimized. The solid angle for photons escaping at angles around 180° is very small and is certainly negligible.

3. The spectrometer is less expensive than other devices which use large NaI(Tl) shields.

A disadvantage of the system described here may be the fact that the device is not very suitable for being used as a pair spectrometer. However, since a 5-crystal pair spectrometer[7]) has already been working at the Karlsruhe reactor FR2 for several years, this was not a significant point for the design of the apparatus.

The absorption probability for Compton-scattered 2.2 MeV gamma rays in the anti-coincidence shield is between 86 and 94% depending on scattering angle. Because of the "shadow" of the NaI(Tl) crystal a length of 40 cm for the plastic scintillator is sufficient. The encapsulated Ge(Li) diode is mounted on a 1.5 mm thick copper plate which has a circular hole with a diameter corresponding approximately to the sensitive area of the detector. In this way the amount of absorbing material near the diode is minimized without suffering loss of adequate thermal contact. The thickness of the aluminum vacuum jacket is reduced at the lower end to 0.6 mm.

The plastic scintillator is viewed by three EMI 9618 B

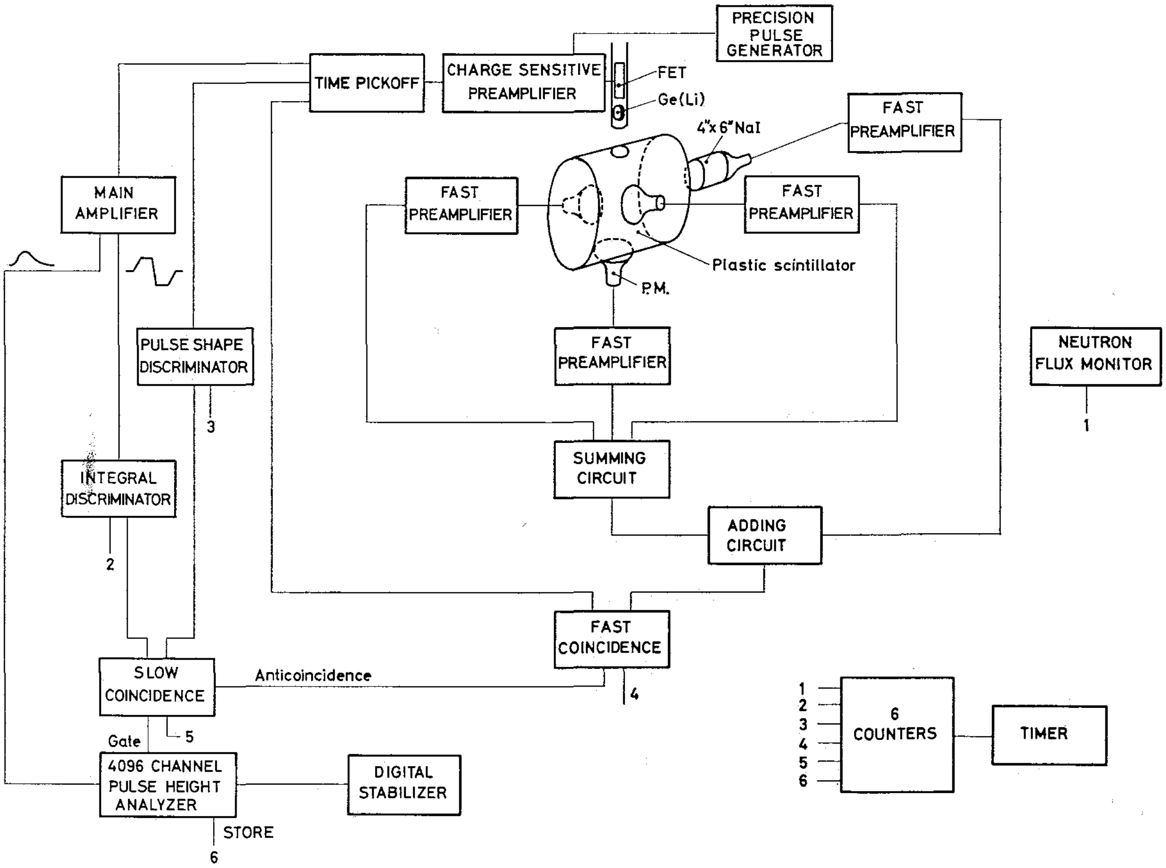

Fig. 2. Electronics block diagram.

photomultipliers with 5″ dia. photocathodes. Appropriate plane areas on the mantle were provided by the manufacturer. The NaI(Tl) crystal is mounted on a multiplier of type RCA 7046. The germanium diode presently used is an encapsulated planar detector with 7 mm depletion depth and 7 cm^2 sensitive area. The detector is operated at a reverse bias of 450 V and has a leakage current of less than 1 nA. Its capacity is about 25 pF.

The whole assembly is mounted in a 50.2 cm i.d. aluminum container. It is heavily shielded on all sides by 10 cm lead and 20–30 cm paraffine mixed with boric acid. The main body of the 25 liter liquid nitrogen dewar remains outside of the shield. The neutron beam has 30 mm dia. and passes through the paraffine in front of the entrance collimator for the gamma rays such that the beam axes for neutrons and gamma rays are perpendicular to each other. The flux at the target position is slightly less than 10^8 $n/cm^2 \cdot sec$. Scattered neutrons are kept off the spectrometer by a double-wall polyethylene tube filled with 7 mm of packed ^6LiH. The instrument is located together with four other experiments at a tangential channel of the FR2. This beam hole passes through the heavy water of the reflector. Collimation of the neutron beam is done in such a way that the external targets are irradiated only by neutrons emerging from a 75 mm long 50 mm dia. graphite scatterer placed in the center of the channel. A cooled bismuth single crystal is used to reduce the gamma radiation in the beam.

3. Electronic circuits

A block diagram of the electronics used for the spectrometer is shown in fig. 2. Those components which are significant for the performance of the system will be briefly discussed here.

The charge sensitive preamplifier for the semiconductor detector has an input stage consisting of two paralleled field-effect transistors[11,12]). These transistors (2N3823) are operated at 140° K to give optimum noise performance. The temperature is maintained by means of a temperature divider in the cryostat.

Timing signals from the germanium diode are obtained by utilizing a leading edge trigger device[13]) which is connected between preamplifier and shaping amplifier. This procedure insures that the energy resolution is not affected by the time pickoff system. Such resolution degradation is observed with circuits which are used between detector and preamplifier. The leading edge technique is preferable to crossover timing since the time walk caused by variations of the collection function is minimized.

Of particular importance is the application of a pulse shape discrimination to the preamplifier output pulses. The circuit which has been described in a recent paper[14]) is sensitive to a slow time-constant component in the charge carrier collection. Pulses containing such a component are rejected. By this method the background under the peaks can be reduced without affecting the peak intensity and the energy resolution. The tunnel diode discriminator which is included in the circuit has to be adjusted to a triggering threshold as low as possible. Therefore, large noise pulses may occasionally produce after-pulses at the discriminator output. These pulses occur when the preamplifier signals return to the baseline, i.e., about 60 μsec after the leading edge. In order to prevent unwanted gating signals a slow coincidence circuit is provided which is triggered by the pulse shape discriminator and by the output pulses from an integral pulse height analyzer.

The photomultiplier pulses are fed into preamplifiers of the current amplifier type with high gain-bandwidth capability. An amplifier stage with common load sums up the signals from the three multipliers viewing the plastic scintillator. In an adding circuit consisting of emitter followers the pulses are added to the signals from the NaI(Tl) detector and then fed into a tunnel diode discriminator. The fast coincidence system is of the Rossi type and similar to a circuit described previously[15]).

The pulse height spectra are taken with a 4096 channel analyzer. Resolution loss due to gain and zero shifts is minimized by the use of digital stabilizers. For zero shift compensation gamma rays from a ^{57}Co source of appropriate strength are superimposed on the capture spectrum. Gain compensation is achieved by means of a high precision mercury switch pulser[16]) which is also used for testing purposes. This procedure makes the stabilizing system independent from the structure of the gamma-ray spectrum and allows a very precise energy calibration. For the pulse generator signals the storage circuit of the pulse height analyzer is disabled by a suitable signal.

4. Performance

With the Ge(Li) diode described above the energy resolution amounts to 2.15 keV fwhm for the ^{137}Cs 662 keV gamma ray. The Compton suppression is very effective yielding a ratio of photopeak to total height of the background of about 40:1 at the Compton edge and of about 100:1 for smaller scattering angles. Towards pulse height zero only a slight increase of the background is observed. Sectional displays of spectra from ^{137}Cs and ^{60}Co are shown in fig. 3. The predominant fraction of the remaining events near the Compton edge is due to absorption of scattered photons in the 0.5–1.0 mm window of the detector and in the 1.5 mm thick capsule. Thus it is reasonable to assume that the performance of the spectrometer can be further improved by using an unencapsulated diode with a thin entrance window.

Perhaps even more important than the ratio of photopeak to Compton distribution for low-energy gamma rays is the suppression of the background caused by the presence of high-energy radiation. In figs. 4–6 typical capture spectra are presented to illustrate the actual situation in a neutron capture experiment. The examples show both the energy resolu-

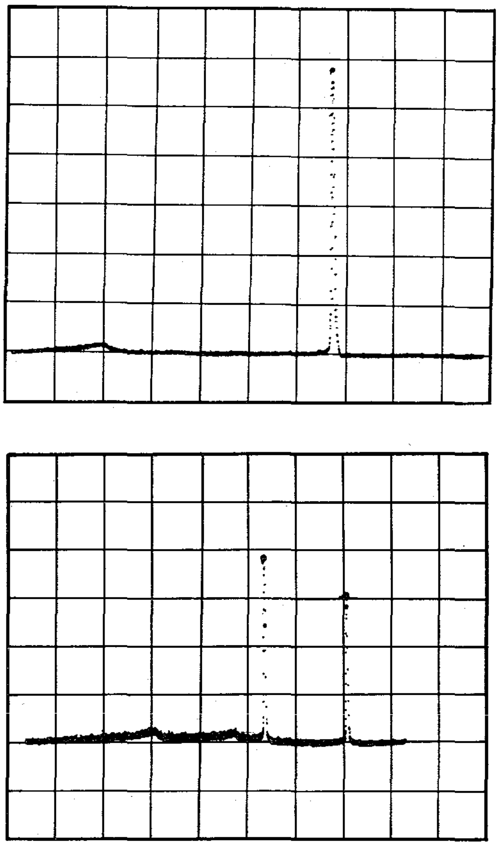

Fig. 3. Sectional display of the pulse height spectra from ^{137}Cs and ^{60}Co.

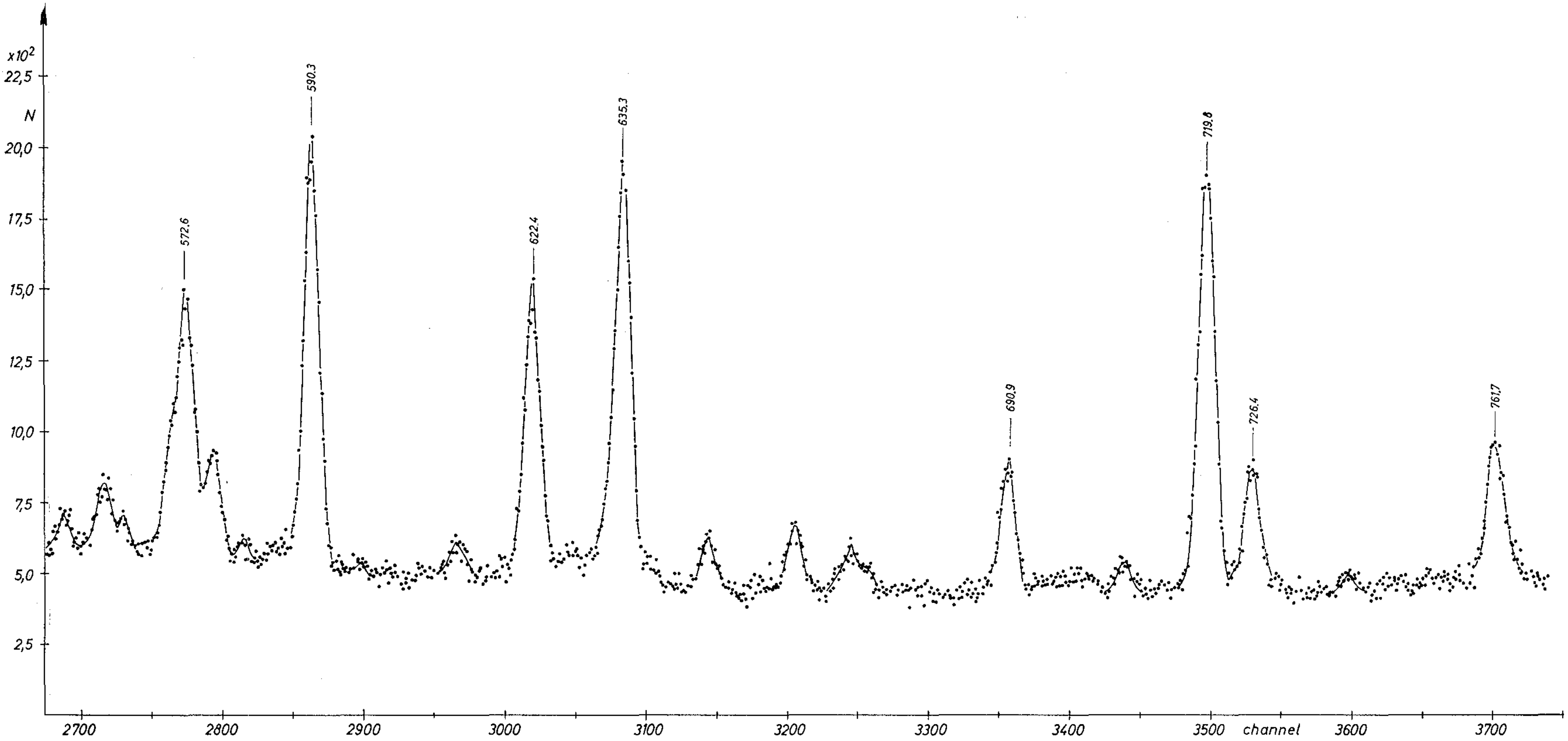

Fig. 4. Section of the gamma-ray spectrum from neutron capture in 19.5% enriched ^{168}Yb taken with the anti-Compton spectrometer. Energy range 552 keV to 769 keV. Channel width 200 eV.

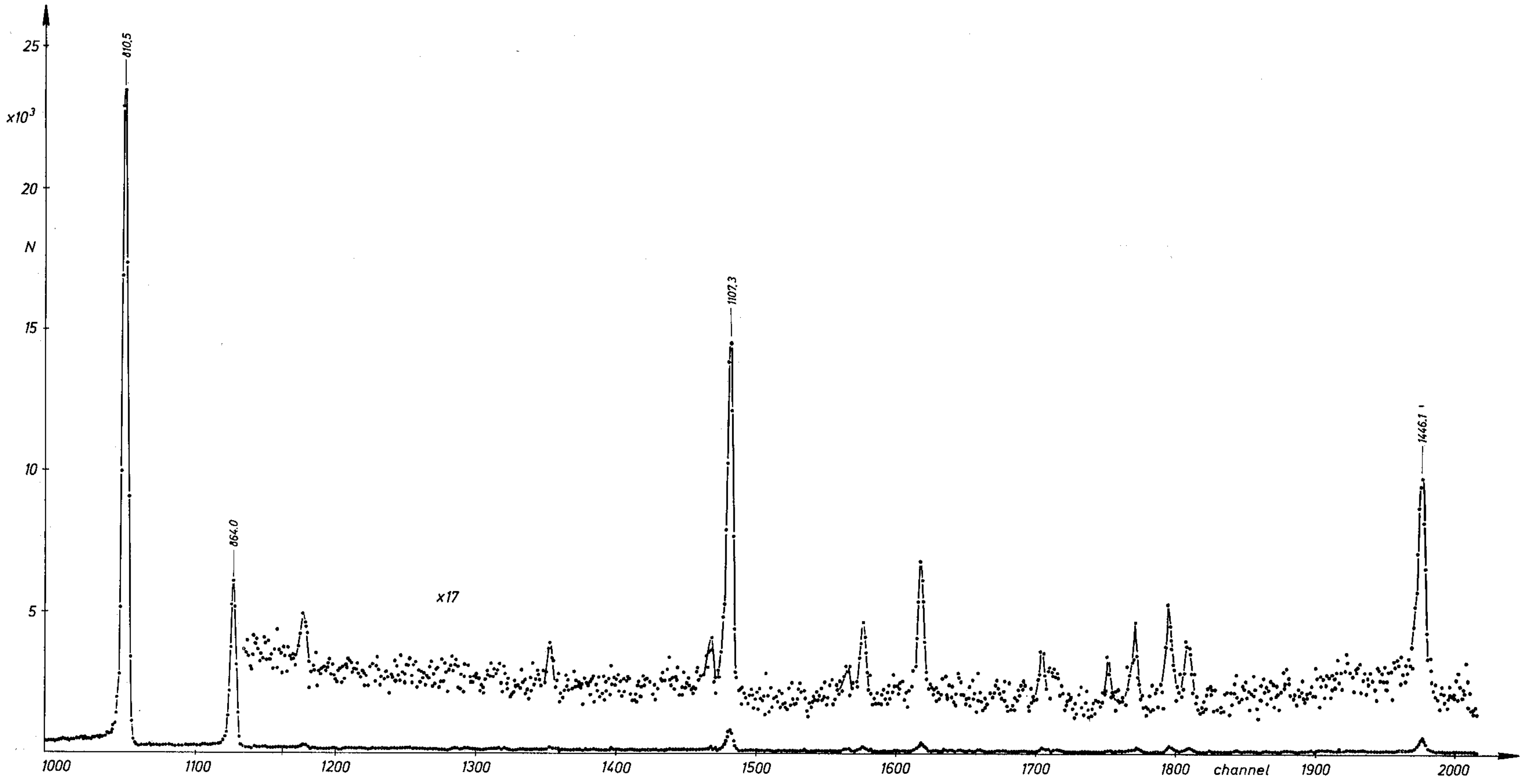

Fig. 5. Section of the gamma-ray spectrum from neutron capture in a sample of 90.7% enriched ^{57}Fe. Energy range 800 keV to 1500 keV.

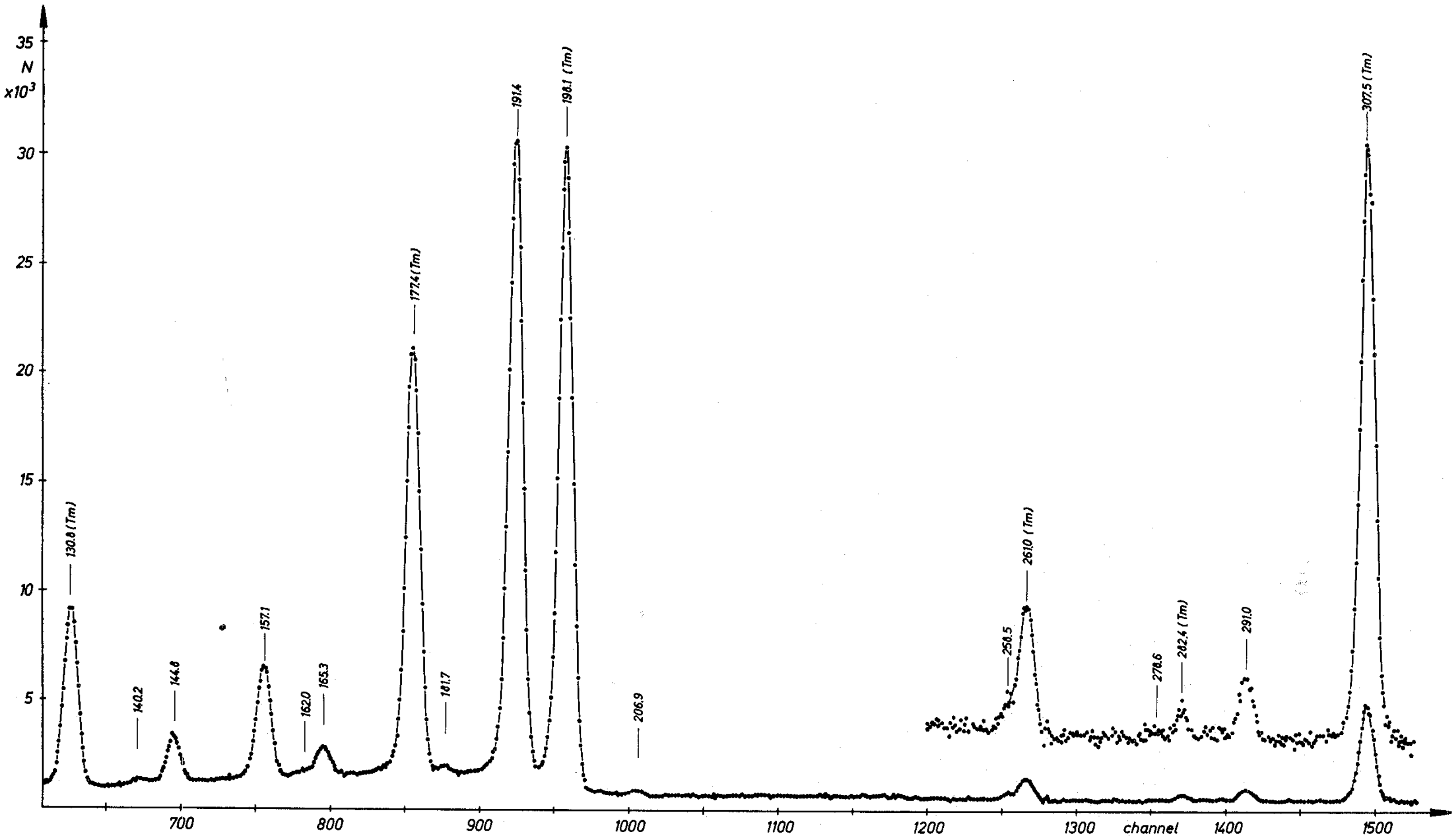

Fig. 6. Low-energy portion of the gamma-ray spectrum from neutron capture in ^{168}Yb. Energy range 130 keV to 340 keV.

tion capabilities and the high sensitivity for the detection of weak gamma rays in the presence of intense radiation. The energy values given in figs. 4–6 are those obtained from a coarse analysis of the spectra and do not reflect the utmost efficiency of the spectrometer. The performance may be well characterized by the fact that in the gamma ray spectrum from neutron capture in a sample of 95.6% enriched ^{166}Er more than 200 gamma lines could be detected in the energy range from 150 keV to 2000 keV. It is worth-while to note that also in the capture spectra the increase of the background towards lower pulse heights is very small (fig. 6). This allows the application of the spectrometer down to 100 keV. The suppression of single and double escape peaks is nearly complete.

The spectrometer was constructed aiming at an accuracy of 100 eV or better for gamma rays with well-defined spectral peaks. This accuracy will permit the application of the combination principle to excitation energies up to 3 MeV. For making full use of the spectrometer capabilities detailed analysis of the spectra by means of a computer program is required. Very promising results have been achieved utilizing the following empirically determined representation of the line shape:

$$y = A\exp\{-\lambda(x-x_0)^2\}, \quad \text{for } x \geqq x_0 - b,$$

$$y = A[\exp\{-\lambda(x-x_0)^2\} - Bx_{\mathrm{cor}}\exp(x_{\mathrm{cor}})], \quad \text{for } x < x_0 - b,$$

with

$$b = (\lambda^{-1}\ln 2)^{\frac{1}{2}}$$

and

$$x_{\mathrm{cor}} = (x - x_0 + b)/b.$$

Detailed studies for optimizing the analysis are in progress.

References

1) G. A. Bartholomew, P. J. Campion, J. W. Knowles and G. Manning, TID 7547 (1957) 252.

2) L. V. Groshev, A. M. Demidov, V. N. Lutsenko and A. Malov, Izv. Akad. Nauk SSSR, Ser. Fiz. **24** (1960) 791.

3) L. V. Groshev, A. M. Demidov, V. N. Lutsenko and V. I. Pelekhov, Atomn. Energ. (USSR) **4** (1958) 5; *Atlas of gamma-ray spectra from radiative capture of thermal neutrons* (Pergamon Press, London, 1959).

4) O. W. B. Schult, U. Gruber and B. P. Maier, Kerntechnik **7** (1965) 101.

5) G. T. Ewan and A. J. Tavendale, Can. J. Phys. **42** (1964) 2286.

6) W. Michaelis and H. Schmidt, KFK 429 (1966); Proc. IAEA Panel (Vienna, June, 1966).

7) G. Markus, W. Michaelis, H. Schmidt and C. Weitkamp, Z. Physik **206** (1967) 84.

8) W. Michaelis, U. Fanger, D. Lange, G. Markus, H. Schmidt and C. Weitkamp, KFK 562 (1967).

9) J. Kantele and P. Suominen, Nucl. Instr. and Meth. **41** (1966) 41.

10) V. J. Orphan and N. C. Rasmussen, Nucl. Instr. and Meth. **48** (1967) 282.

11) K. F. Smith and J. E. Cline, IEEE Trans. Nucl. Sci. **13**, no. 3 (1966) 468.

12) U. Tamm, KFK 509 (1967).

13) W. Michaelis, Nucl. Instr. and Meth. (to be published).

14) U. Tamm, W. Michaelis and P. Coussieu, Nucl. Instr. and Meth. **48** (1967) 301.

15) W. Michaelis, H. Schmidt and C. Weitkamp, Nucl. Instr. and Meth. **31** (1964) 93.

16) F. Horsch, KFK 558 (1967).