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SPECTRAL PERFORMANCE OF A Ge(Li) PULSE HEIGHT SPECTROMETER AT HIGH EVENT RATES

by

H. MEYER and H. VERELST

1969

Joint Nuclear Research Center
Geel Establishment - Belgium

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The features of the spectrometer are described and performance limitations are discussed. Limitations are introduced especially by the detectors, if high peak-rate-to-peak-width ratios are desired.

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ABSTRACT

For γ-ray spectroscopy with Ge(Li) detectors high event rates are often desirable, not only for their application in coincidence experiments but also because of the presence of large Compton background. Modern instrumentation techniques were applied and a fast servostabilized pulse height converter[14] has been used for the measurement of γ-ray spectra up to event rates of 300 kHz.

The features of the spectrometer are described and performance limitations are discussed. Limitations are introduced especially by the detectors, if high peak-rate-to-peak-width ratios are desired.

KEYWORDS

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GAMMA SPECTROMETERS
GERMANIUM
LITHIUM
SEMICONDUCTOR COUNTERS
PERFORMANCE

Spectral performance of a Ge(Li) pulse height spectrometer at high event rates*)

General considerations

In the past years many efforts have been undertaken to utilize fully the high resolution capabilities of Ge(Li) detectors in γ-ray experiments. The drawback of such detectors, their low peak efficiencies (full energy-, escape peaks) decreasing with energy, have led to extensive studies to avoid resolution degradation at high event rates. [1, 2]

The general aim consists in reaching maximum resolution, i. e. minimum peak width, and maximum peak-to-background ratios at maximum peak rates. Only a compromise concerning the choice of dominant characteristics of a spectrometer system, will allow optimum conditions.

Small planar Ge-detectors permit good resolution but involve high Compton backgrounds. Coaxial Ge-detectors have worse resolution but better efficiencies, i. e. lower background.

Spectral response is strongly influenced by the pulse shaping networks of the amplifiers preceding a pulse height converter. By the application of pole-zero cancellation of network parameters[3] resolution degradation caused by pile-up of signals on long pulse tails has been reduced to a large extent.

The signal width used for pulse height analysis and the realizable pulse shapes are also of great importance for obtaining a maximum peak rate-to-peak width ratio. For instance, greater final shaping time constants allow better electronic resolution and smaller influences of charge collection time spread on resolution because of detector imperfections. Small shaping time constants reduce the influence of pulse pile-up distortions on resolution and background.

Desirable conditions, concerning the influence of pile-up on spectral performance, would be given for a signal width, not greater than the minimum necessary evaluation time for complete charge collection and maximum signal to noise ratio, i. e. the measuring time-to-signal width ratio should approach unity. For instance, standard RC filters have a low ratio, more complex filters, producing a symmetrical pulse shape similar to a cusp or triangle like RLC filters proposed by Blankenship et al. [4] give a ratio close to 0. 5. With time variant filters[5] a ratio of 0. 5 can also be approached; since the filter parameters are determined by a control signal, such a method should allow an easy adaption of the filter performance to varying experimental conditions.

Up to now studies to obtain optimum spectral performance at high rates have taken into account to a less extent the limitations imposed by imperfections of detector crystals[6-8] and fabrication techniques[9]. Incomplete charge collection, resulting from too short measuring times, can have a dominant influence on spectral performance at high γ-ray energies; i. e., charge loss fluctuations

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*) Manuscript received on 2 December 1968.

have to be smaller than a fraction of 0.1% to reach a peak width (FWHM) of 0.1%. Increased measuring times should allow to avoid the charge losses from temporary trapping effects[10] or to reduce losses if the charge collection is slowed down because of inhomogeneous fields. Influences of the dead layer edges should also be taken into account.[8]
At high γ energies not only the resolution degradation from small charge losses itself but also their increased probability of occurrence must be considered; at high energies the ionized charge per event is distributed over a larger fraction of the sensitive detector volume.

Pulse shape discrimination techniques will allow to reject signals from analysis which are piled up by others - especially background signals. In this way also the influence of incomplete charge collection on the resolution can be reduced. Pulse shape discrimination limits the maximum peak rate for a chosen shaping network and detector. Higher rates can be obtained only by the application of detectors with greater efficiency and (or) by the use of smaller measuring times involving worse resolution.

Peak shifts at high rates caused by capacitive coupling networks - normally situated at the output side of amplifiers to reject temperature dependent dc shifts - can be avoided by the application of suitable zero level restoration networks[2, 12, 13]. Relatively simple circuits[2], which do not degrade the signal-to-noise ratio, can be applied for the analysis of unipolar pulses. Long coupling time constants should be chosen to avoid pile-up noise. If a servostabilized amplifier-pulse height convertor system is used, residual shifts can also be servoed out since the used reference pulses might shift in the same way as the spectrum to be analysed.

A restorer would not be necessary for bipolar pulses. But in general such a pulse shape will reduce the maximum usable rate because of a small measuring time-to-signal width ratio; a lower signal-to-noise ratio from bipolar pulse shaping can be avoided to a certain extent if methods of weighted signal sampling are applied.[11]

High rate measurements could also be limited by the speed of pulse height converters. However, with modern techniques and elements converters with small processing times can be realized. Analogue window selection for analysis in limited energy regions can improve the situation.

A fast pulse height converter has been developed[14] equipped with a servostabilizer to obtain high stability also at high energies and to avoid residual peak shifts at high rates.

The unit contains simple pulse shape inspection circuitry to reject signals with non-uniform shape because of their distortion by pile-up or caused by delayed charge collection in the detector.

γ-spectra were measured, up to high event rates, with Ge(Li) detectors of own production. Both the performance of the instrumentation and the influence of detector imperfections on high rate limitations are demonstrated.

Experimental setup

Fig. 1 shows the general lay-out of the instrumentation used for γ-spectroscopy up to high event rates. The system consists of a preamplifier with charge sensitive input loop, a main amplifier, ac coupled near its output and equipped with a baseline restorer, a pulse height converter with pile-up inspection circuitry at its input and a store. The servo control unit in the converter delivers electronic reference pulses to the preamplifier input.
As basic element for signal amplification, a standard operational amplifier had been designed (Fig. 2). The main features of the unit are: high input impedance, low noise because of field effect transistors at the input, good zero level stability vs. temperature, small nonlinearity (0.01%, closed loop conditions, signal levels up to > ± 10 V) and high slewing rate (> 300 V/ μsec).
Only the input circuitry of the charge sensitive loop is different from the standard design; four uncooled Fet's in parallel are used to obtain a high signal-to-noise ratio also for detectors with greater capacity.

To assure a negligible degradation of the signal-to-noise ratio by the amplifier stages connected to the charge sensitive loop (influence of low frequency noise and hum), but also to avoid nonlinearity effects from a pile-up of long tail pulses, predifferentiation of the signals is performed directly after the charge sensitive loop and final differentiation after the first stage of the main amplifier. Pulse rates, up to > 300 KHZ can be applied; all amplifier stages have a great dynamic range.

Pure unipolar pulses are obtained by pole-zero cancellation of network parameters. For final pulse shaping a network designed by Blankenship et al.[4] has been preferred to a simple RC filter to obtain a better measuring time-to-pulse width ratio for high rate measurements.
A clean unipolar pulse shape, down to better than 0.1% of the signal amplitude has been reached without special efforts (Fig. 3).

The ac coupling near the amplifier output rejects the influence of a temperature dependent zero level shift of the dc-coupled amplifier on the spectrometer performance, especially at high gain settings.
A restorer version has been chosen[2] which will not degrade the signal-to-noise ratio already at low pulse rates. A coupling time constant of 10 msec is applied to avoid an important influence of pile-up noise on the energy resolution up to high rates (~ 50% duty cycle) and γ-energies. A residual mean shift can be held small, particularly by the high input impedance of the circuit.

Signals are rejected from analysis if their rising edge is piled up by tails of preceding signals or by the rising edge of a signal arriving later. For that purpose inspection circuitry has been applied being an integral part of the developed pulse height converter. Two inspections are performed, first, the converter-free for analysis will only open the input gate if there is no signal level above the noise; second, if a signal, arriving after gate opening, has a zero-to-peak time, greater than a prescribed value, it will be rejected by the shape inspection circuit.

Measurements

The spectrometer performance was measured with ^{60}Co γ-rays at various input rates (Figs. 4, 5, 6). Two detectors of typical quality with different volumes and two shaping networks were chosen for the measurements.

Detectors:

1) Planar type: Geli 20a, 8mm sensitive depth, 2.5 cm^3 sensitive volume
2) Double ended coaxial type: Geli 17, 7-9 mm sensitive depth, 16 cm^3 sensitive volume.

Shaping networks:

RLC Filter, noise corner time constant, 0.5 μsec. and 1.0 μsec.

The best resolution at lower rates is obtained with the small detector and the greater shaping time constant (Fig. 4a), as to be expected. At the highest rates the smaller shaping time constants give better results: the peak width broadening due to the nonideal performance of the pulse inspection circuits must be of less importance because of the smaller duty cycle. For the same reasons, also the peak-to-background ratio is greater for the smaller time constant at the highest rates (Fig. 4b).
The highest peak rates can be achieved with the coaxial detector (Fig. 5a); if one defines the ratio, peak rate-to-peak width, as a quality factor, the highest value is obtained with the coaxial detector and 0.5 μsec shaping time constant (Fig. 5b).
Because of the available servo stabilizer peak-shifts were smaller than 0.04% up to the highest rates (Fig. 5c). However, the regulation rate will be reduced at high input rates since piled up regulation pulses are rejected in the same way as the signals from radiation.

For one detector the spectral shape of the 1.33 MeV peak at various rates is shown in Fig. 6. The measurement at 150 KHZ without pulse inspections shows the efficiency of that circuitry.

The possible influence of the detector quality on the spectral performance can be demonstrated by measuring the resolution at various pulse shapes and detector bias voltages (Fig. 7).

The reduction of the signal-to-noise-ratio with decreasing shaping time constants (Fig. 7a) is small in comparison with the resolution degradation introduced by the radiation. A factor F^x has been derived from the measurements which becomes the Fano factor (F) if an ideal detector would be available.

$$F^x = \frac{(R_g^2 - R_{el}^2)}{2.36^2 \cdot \varepsilon E}$$

R_g = Resolution [FWHM, keV] with radiation of an energy E [MeV]

R_{el} = electronic resolution [FWHM, keV]

ε = energy conversion factor $\simeq$ 2.9 eV per unity charge for germanium.

For the stronger increase of F^x for shaping constants, < 1 µsec, which is to a first order independent of bias voltage and energy, temporary trapping and edge effects might be responsible introducing an increase of charge collection time spread.
F^x will become greater at low bias voltages mainly due to an increase of the charge collection time. The spread of the charge collection time is equivalent to a fluctuation of charge losses since it is converted by the filter networks into a fluctuation of signal amplitudes. The worse results at higher energies demonstrate the increasing probability of such loss fluctuations introduced by the bigger charge clouds.
It should be noted, that the results given for one detector are typical also for other detectors fabricated from different crystals.

Conclusions

It has been shown that an acceptable high rate performance with a Ge(Li) spectrometer of modern but standard design can be reached if the right compromise between various influencing parameters is chosen. Especially the strong influence of the detector quality on experimental results must be taken into account for further improvements. Faster and more complex equipment for pulse shape inspection should reduce resolution degradation at the high rate limits.

Acknowledgements

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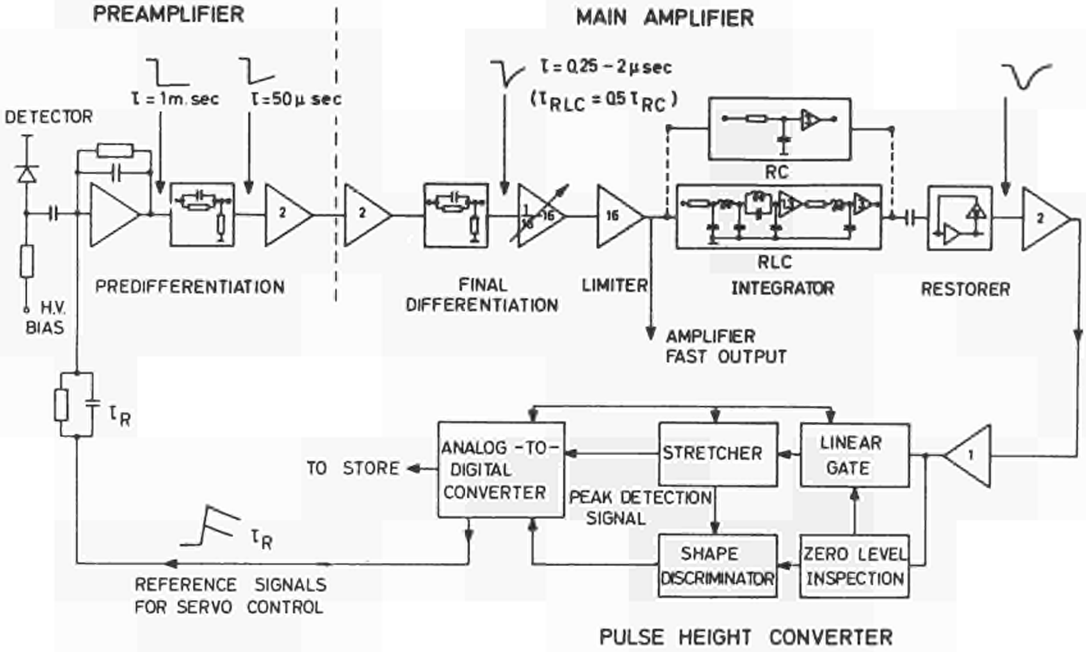

Fig.1 GELI SPECTROMETER, EXPERIMENTAL SET UP

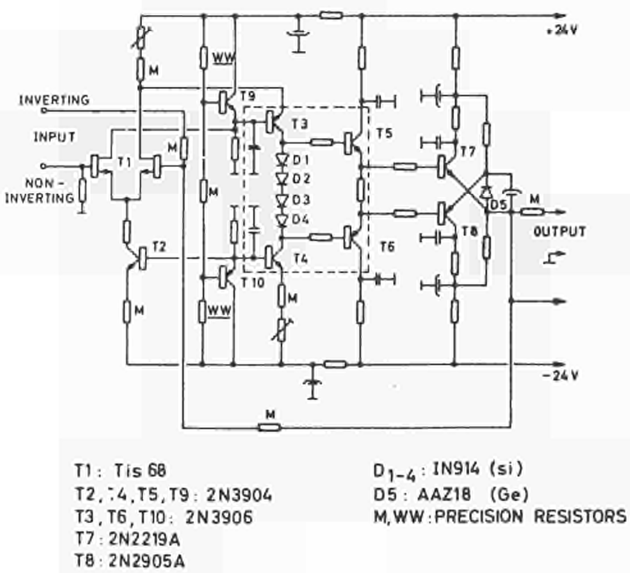

Fig.2 STANDARD OPERATIONAL AMPLIFIER FOR HIGH RESOLUTION SPECTROMETERS CIRCUIT DIAGRAM

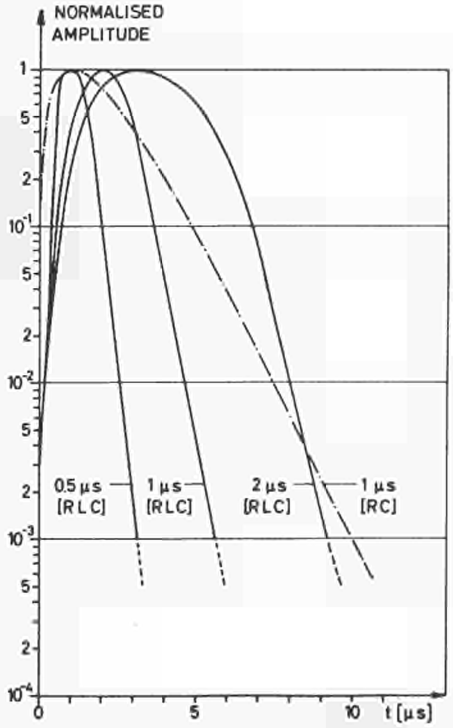

Fig.3 PULSE SHAPE FROM AMPLIFIER WITH DIFFERENT SHAPING NETWORKS (RLC FILTER, RC FILTER)

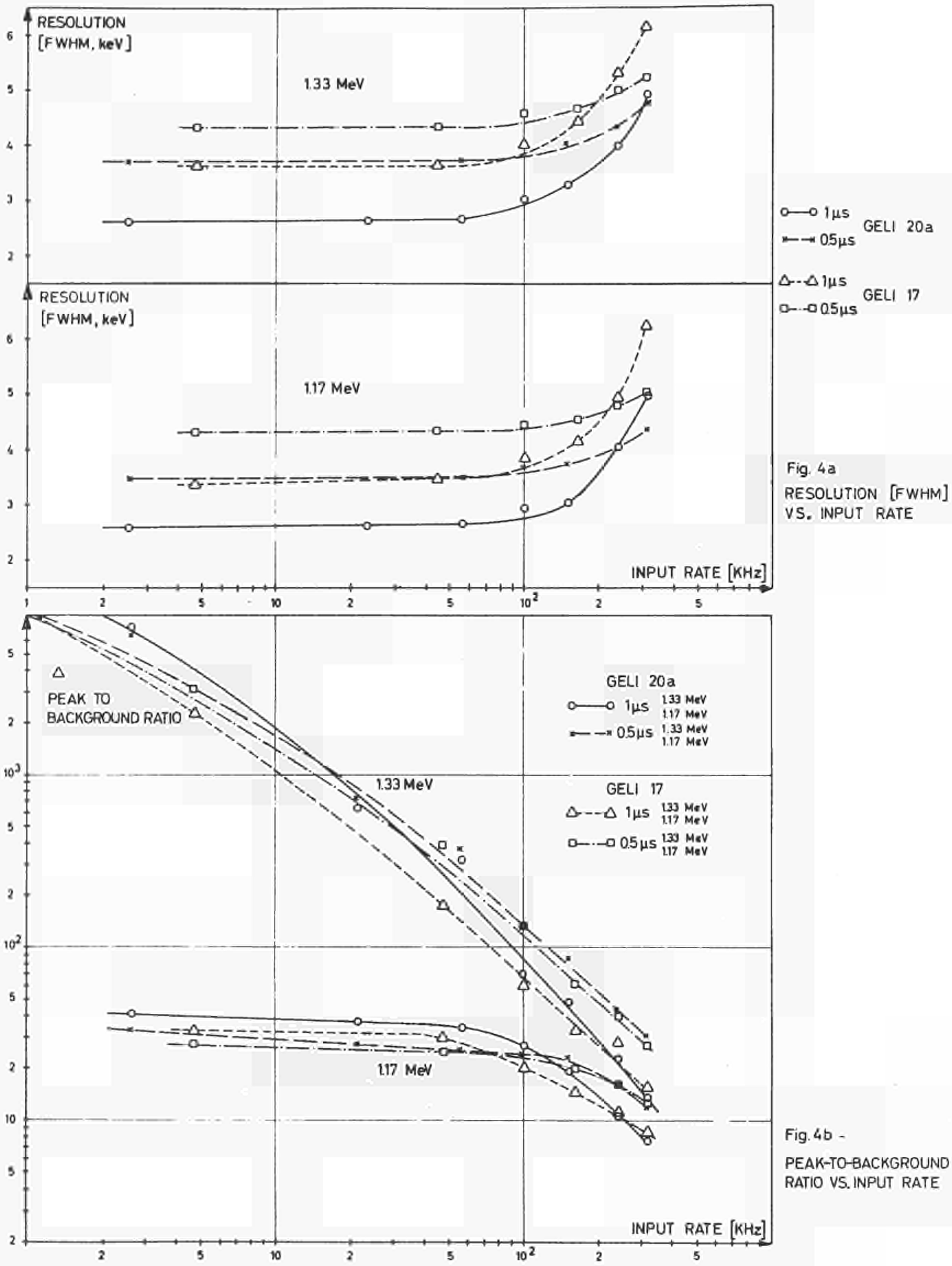

Fig. 4a
RESOLUTION [FWHM]
VS. INPUT RATE

Fig. 4b -
PEAK-TO-BACKGROUND
RATIO VS. INPUT RATE

Fig. 4 SPECTROMETER PERFORMANCE VERSUS INPUT RATE

Detectors: GELI 20a [2.5 cm^3, planar]; GELI 17 [double ended coaxial, 16 cm^3]
^{60}Co γ-rays, full energy peaks at 1.17 and 1.33 MeV
Pulse shaping: RLC Filter, noise corner time constant, $\tau = 0.5; 1 \mu s$
Pulse shape inspection circuitry: properly adjusted.

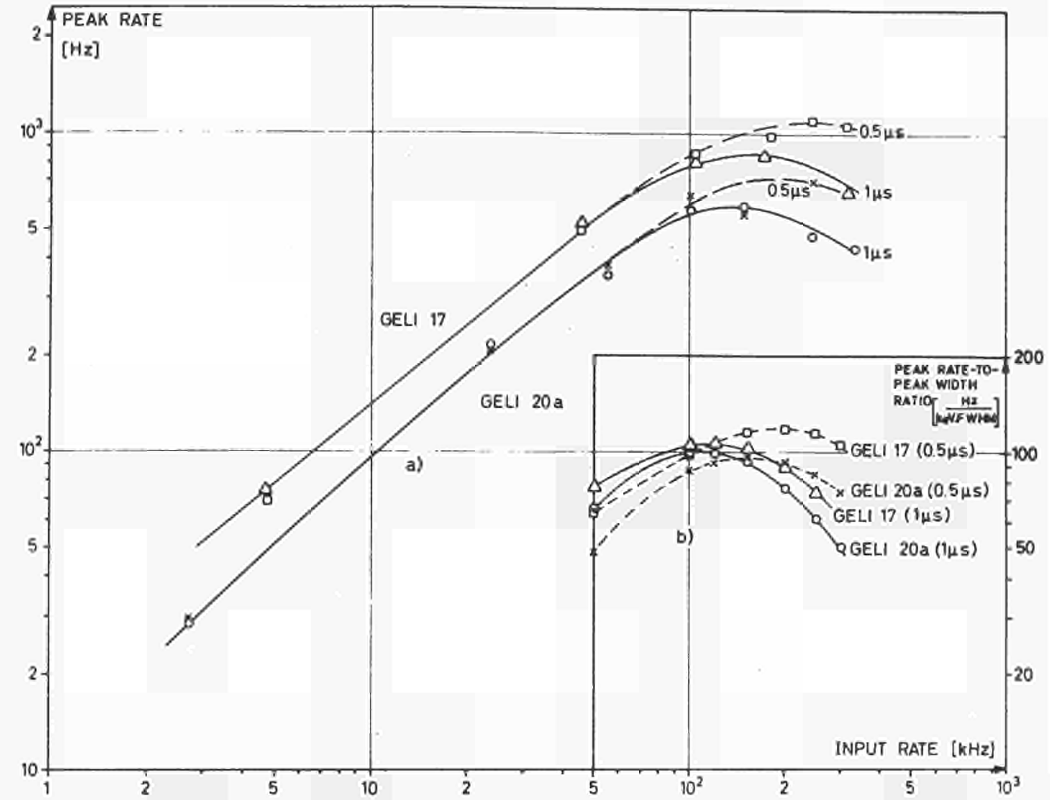

Fig. 5a PEAK RATE VS. INPUT RATE
[PEAK RATE = SUM OF PEAKS AT 1.17 AND 1.33 MeV]

Fig.5b PEAK RATE-TO-PEAK WIDTH RATIO VS INPUT RATE
[MEAN VALUES OF PEAK RATES AND PEAKWIDTH AT 1.17 AND 1.33 MeV WERE TAKEN]

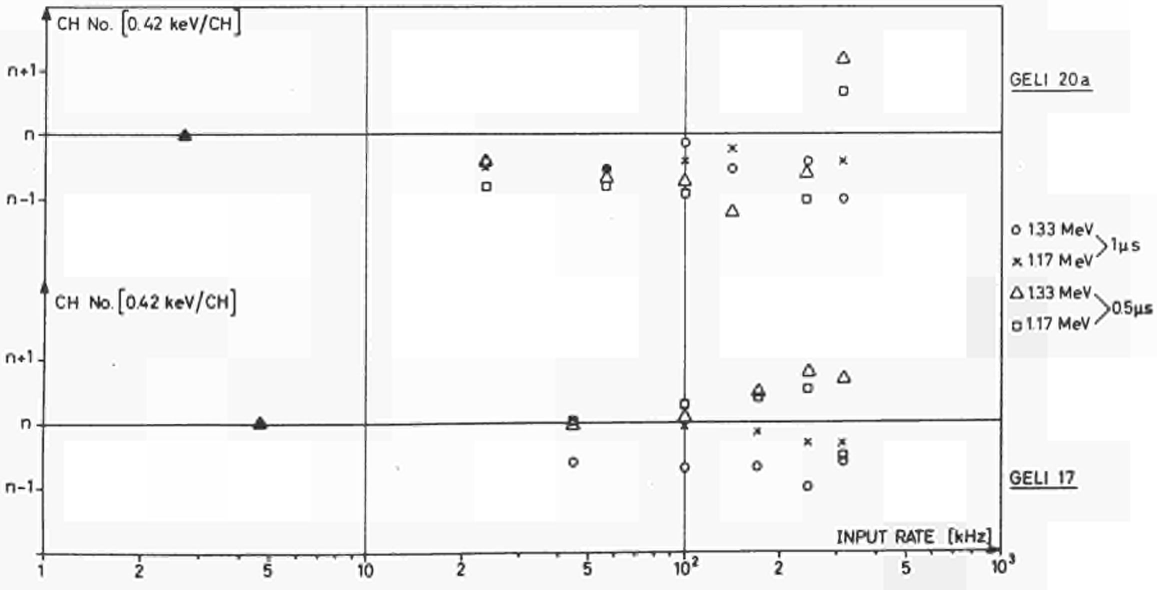

Fig.5c RESIDUAL PEAK SHIFT VS INPUT RATE

Fig.5 SPECTROMETER PERFORMANCE VERSUS INPUT RATE
(EXPERIMENTAL CONDITIONS AS IN Fig. 4)

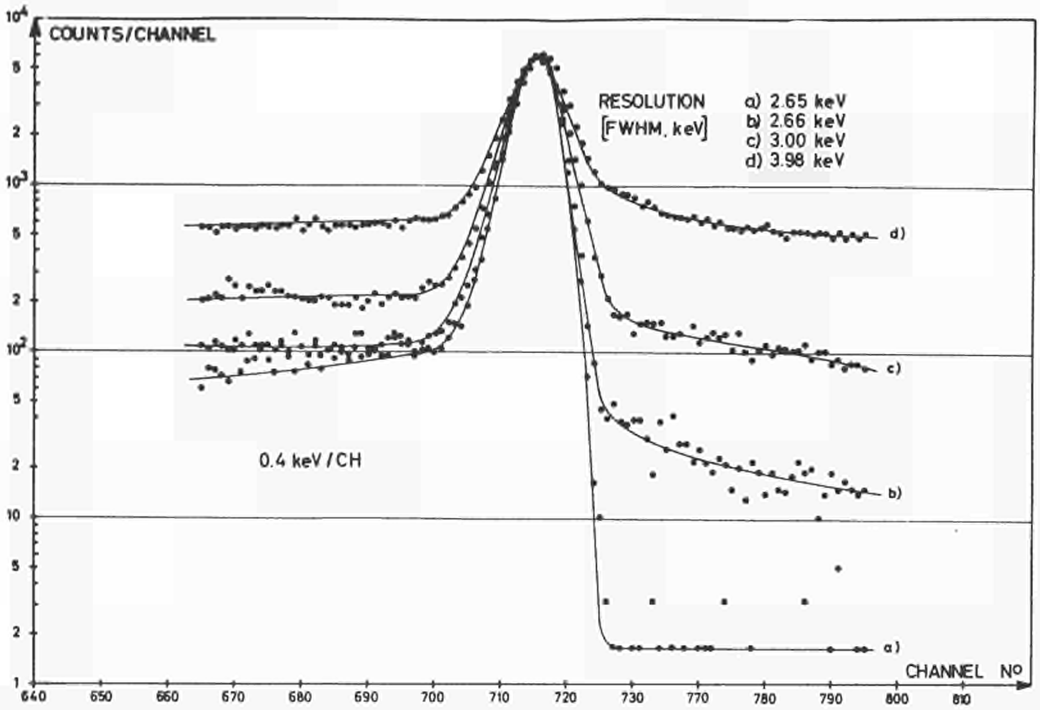

Fig.6. SPECTROMETER RESOLUTION AT DIFFERENT INPUT RATES [^{60}Co 1,33 MeV PEAK]

Detector: GELI 20a [2.5 cm^3 planar] Pulse shaping: 1µs, RLC Filter

With pulse shape inspection: 2.66 KHz a)
56 KHz b)
150 KHz c)
Without pulse shape inspection: 150 KHz d)

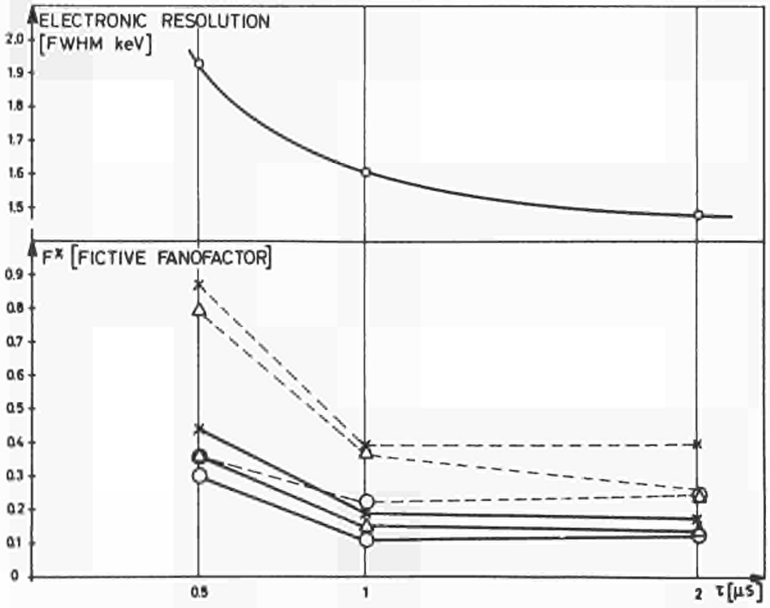

Fig. 7a ELECTRONIC RESOLUTION VS. PULSE SHAPE
[Influence of detector bias neglegible]

Fig. 7b FICTIVE FANO FACTOR F* VS. PULSE SHAPE AT DIFFERENT γ-RAY ENERGIES

Fig.7 DETECTOR RESOLUTION VERSUS PULSE SHAPE

Detector: GELI 20b [2.6 cm^3 planar, 8mm sensitive depth]

Pulse shaping: RLC Filter, τ = 0.5 ; 1 ; 2 µS noise corner time constant

> To disseminate knowledge is to disseminate prosperity — I mean general prosperity and not individual riches — and with prosperity disappears the greater part of the evil which is our heritage from darker times.
>
> Alfred Nobel

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