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A Ge(Li)–NaI(Tl) SYSTEM FOR GAMMA-GAMMA ANGULAR CORRELATION MEASUREMENTS

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Abstract: A Ge(Li)–NaI(Tl) system for coincident and directional gamma-gamma angular correlation measurements is described. The system was checked by measuring the lifetime of the 0.482 MeV level in ^{181}Ta by the delayed coincidence method and by measuring the anisotropy for the 1.172–1.332 MeV cascade gamma trasition in ^{60}Ni. The results are in very good agreement with previous measurements.

1. Introduction

Very extensive measurements of nuclear decay schemes and of properties of nuclear levels have been performed by studying gamma-gamma angular correlation with scintillation counters. Many systems with two or more scintillation counters with fast-slow electronic time and amplitude analysing systems including fast time-to-amplitude converters have been built. They have been used to determine the lifetimes, spins, parities, branching ratios, mixing ratios of multipolarities, magnetic dipole and electric quadrupole moments of the excited states and extra nuclear perturbing fields at the place of the parent nuclei, (see, for examples, refs. [1, 2, 3, 4]). Scintillation counters with organic or plastic scintillators have the property of extremely fast timing which allows measurement of time intervals between successive radiations of about 0.1 ns. Scintillation counters with NaI(Tl) scintillators do not allow such fast timing, but owing to their superior total energy peak efficiency and relatively good energy resolution, they have been most frequently used in this type of measurements.

The development of Ge(Li) semiconductor detectors with an extremely good energy resolution has recently allowed a much more detailed analysis of spectra in nuclear transitions. Many transitions of close energy have been resolved, and many weak transitions, previously masked by other intensive transitions have been found.

In comparison with NaI(Tl) scintillation counters, Ge(Li) counters of a large volume (20 to 40 cm^3) have a lower but comparable photopeak efficiency, except at higher gamma ray energies. A more serious disadvantage of

these detectors is the limitation in fast timing. Output pulses from Ge(Li) detectors of large volume vary in shape depending on the position at which the »ionization« (production of electron-hole pairs) due to incident radiation occurs. The discrimination of pulses at a high fixed level introduces a large variation of the delay of timing pulses, and is the main reason why »zero crossing« timing gives a time resolution of approximately 30 ns. The timing can be improved with the leading edge technique setting the discriminator level as low as possible (just above the noise).

Improved timing with a Ge(Li) detector can be obtained at the expense of its volume, which results in lower photopeak efficiency. In our laboratory special care was taken to obtain good time resolution in a system with a NaI(Tl) scintillation counter and a Ge(Li) planar detector. The system represents a compromise, as the low photopeak efficiency limits the use of the Ge(Li) detector to gamma rays of lower energy if a reasonable coincidence counting rate is to be expected. However, a good timing of the system has been obtained, combined with the very good energy resolution of the Ge(Li) detector, which offers many applications in nuclear decay studies.

2. *Description of the apparatus*

An Ortec Model 8033 Ge(Li) planar detector of 2.5 cm² × 3 mm thick was used as stationary detector. A Harshaw Model 6D4 NaI(Tl) crystal of 1½ in.

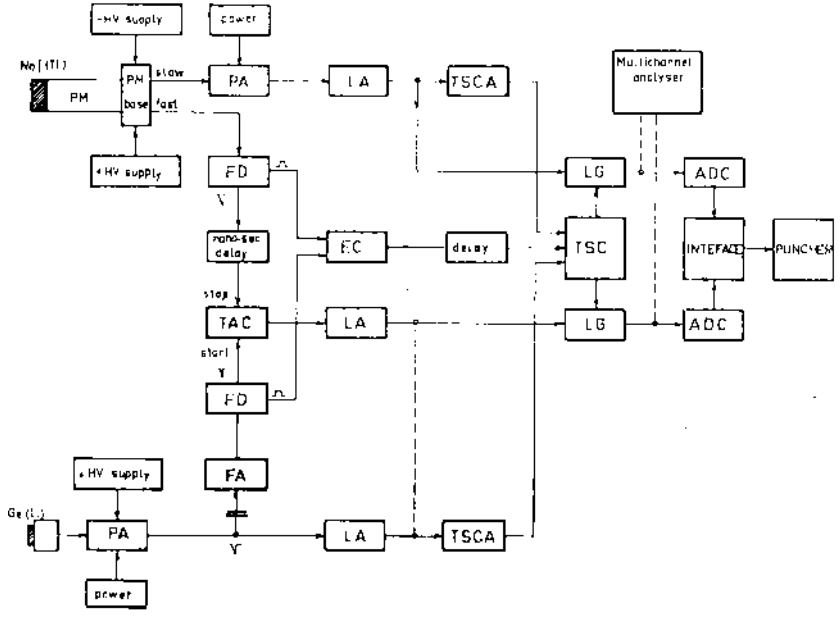

Fig. 1. Block scheme of the Ge(Li)–NaI(Tl) system.

diam. × 1 in. thick, mounted on an XP1020 photomultiplier served as movable detector. The angle between the detectors could be changed from 22.5° to 337.5°.

A transistorized fast-slow electronic time and amplitude analysing system, built in our laboratory, was used with the above detectors (Fig. 1). The pulse from the Ge(Li) detector was led to a pre-amplifier (PA) with a rise time of 40 ns, a noise contribution of 2.4 keV at 30 pF and a noise slope of 0.05 keV/pF. The PA output branches to the fast and slow channel. After shaping and amplification in a fast amplifier (FA), the fast pulse was directed to a fast discriminator (FD) whose negative output was used as the starting signal for the time-to-amplitude converter (TAC). The positive output was led to a fast coincidence (FC) unit. The XP1020 photomultiplier base assembly was made according to Dolan *et al.*[5]. It was fed from two high-voltage supplies with the grounded ninth dinode to prevent coupling between the initial and final stages of the phototube. Slow signals were taken from the seventh dinode (Dolan *et al.*[5] used the sixth dinode). We did not observe any nonlinearity in our pulse height distribution (see Fig. 2) for different positive and negative voltages of the high voltage supplies. The negative fast pulses from the phototube base were led to the FD, whose negative output was delayed in the nanosecond delay. This pulse served as the stop signal for the TAC unit. Positive pulses from the FD were directed to the FC unit. This unit has a variable re-

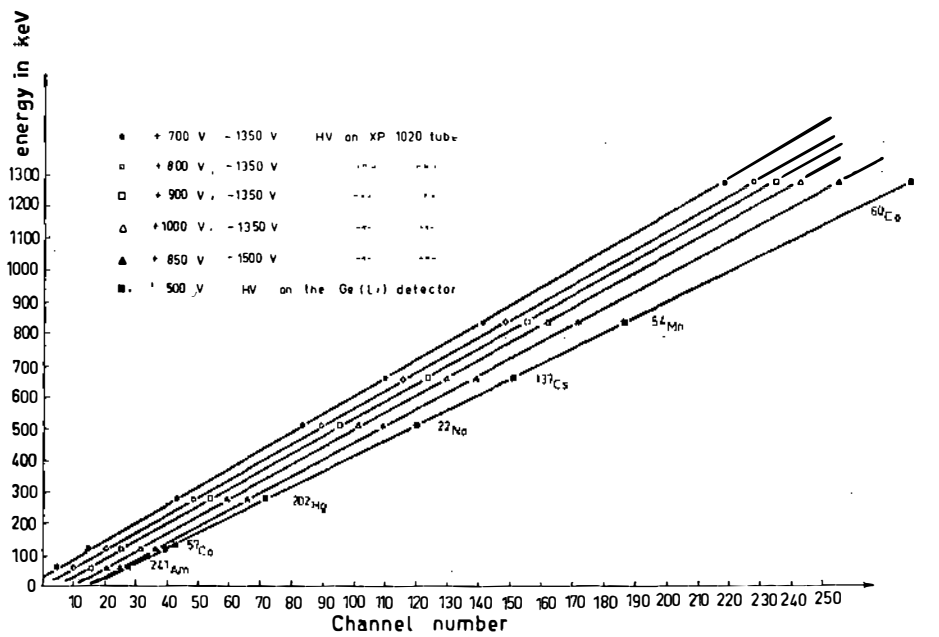

Fig. 2. Linearity check of the NaI(Tl) detector for several operating voltages, and of the Ge(Li) detector at normal operating voltage.

solving time from 10 to 200 ns which determines the width of the time spectrum, as seen from the TAC unit. The slow channels are identical. The pulses from the pre-amplifiers were led to linear amplifiers (LA), and bipolar output pulses from these were directed to timing single channel analysers (TSCA). In these units parts of either spectrum could be selected for analysis, or alternatively other parts could be inhibited. The slow coincidence (SC) with four coincidence and two anticoincidence inputs has a variable resolving time from 0.4 to 2.5 μs. It transmitted information about energy and time correlation between pulses detected in both detectors if FC and TSCA conditions were fulfilled. The two-dimensional time-energy or energy-energy data were transmitted by gates when opened by the SC, to the analog-to-digital converters (ADC). The data were registered on punched tape with a fast Westrex puncher. The analysis of the data was performed in the SDS-930 computer using a special two-dimensional »HASH Code Program«[6] prepared for mega-channel analysis.

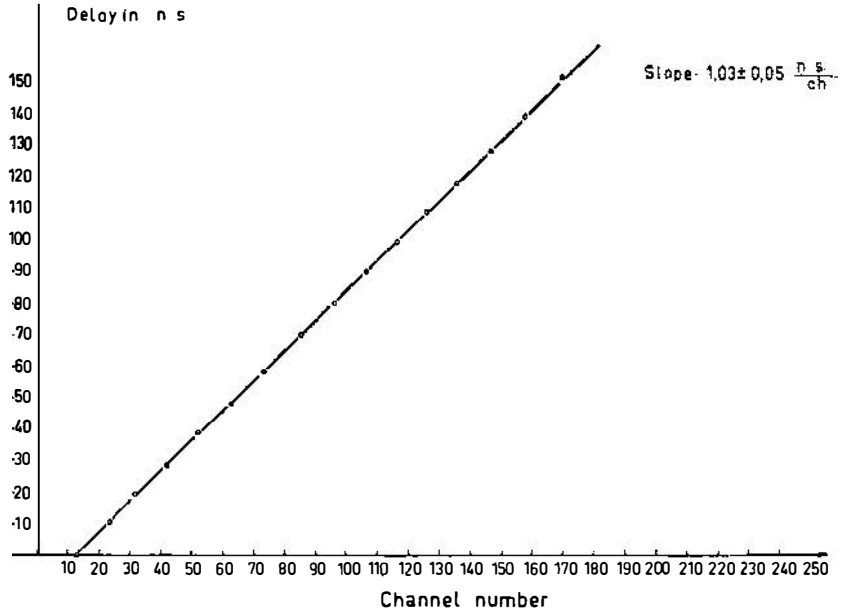

Fig. 3. Linearity check of the TAC unit.

3. Characteristics and experimental tests of the Ge(Li) NaI(Tl) system

The linearity of slow channels was tested carefully for a variety of positive and negative high voltages feeding the XP1020 phototube. The results are shown in Fig. 2. The linearity check of the Ge(Li) slow channel was performed at 500 V which is the highest operating voltage recommended by the manufacturer.

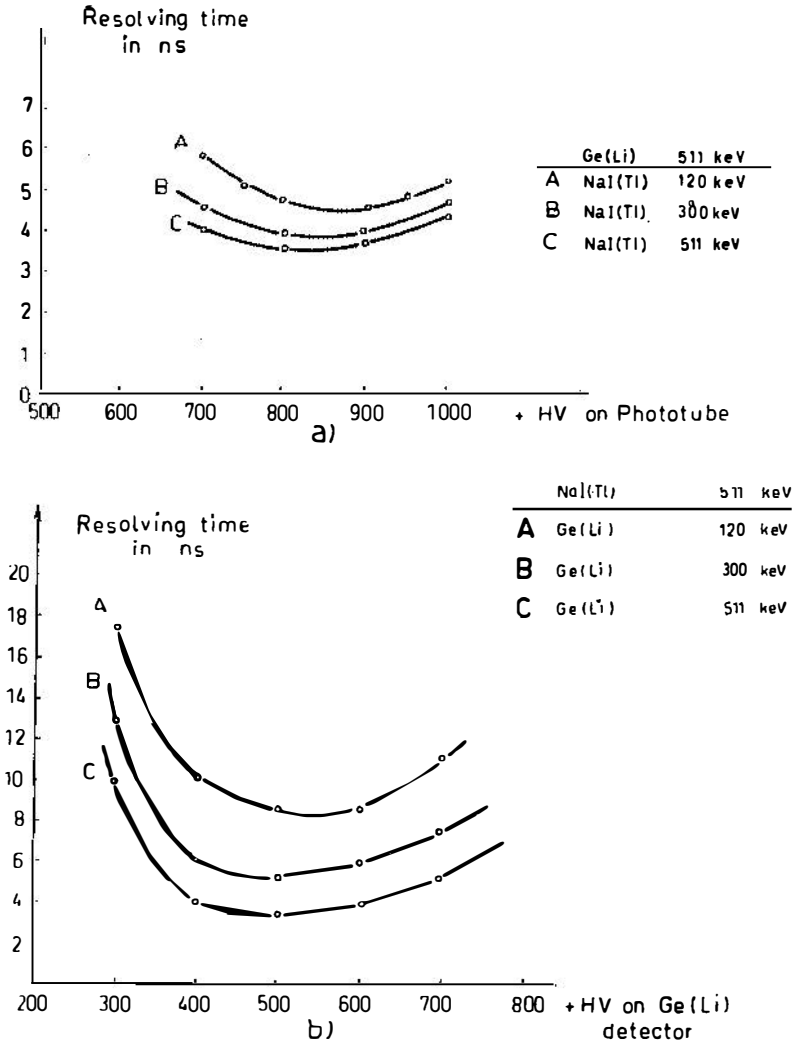

Fig. 4. Measurement of the FWHM of the prompt coincidence curve at three energies selected in the TSCA and for different operating voltages on the a) XP 1020 photomultiplier, b) Ge(Li) detector.

The linearity of the TAC response was checked using delay cables RG 58 A/U with a specific delay of 5 ns/m, in steps of approximately 10 ns. The results are shown in Fig. 3. The resolving time* of the Ge(Li)–NaI(Tl) system was measured as a function of energy and high voltage on the XP1020 phototube. A ^{22}Na source was used, and the energy selected in the Ge(Li) TSCA was at the annihilation peak, 511 keV. Three energy channels were selected

* (FWHM of the prompt coincident curve).

in the NaI(Tl) TSCA. The results are shown in Fig. 4a. Figure 4b shows the dependence of the resolving time on the high voltage on the Ge(Li) detector. The best voltages that give the minimum resolving time are +850 V on the PM base and +500 V on the Ge(Li) detector. The optimum resolving time of 3.6 ns obtained with our system is comparable with the value of 1.9 ns[5] obtained with NaI(Tl)–NaI(Tl) crystals on XP1020 tubes also with the 0.511 MeV annihilation quanta from ^{22}Na.

The complete system was checked in two measurements. The lifetime measurement of the 0.482 MeV level in ^{181}Ta was performed by registering the time spectrum in the multichannel analyser, as shown in Fig. 5. For that purpose the 0.133 MeV photopeak in the Ge(Li) slow channel and the 0.482 MeV photopeak in the NaI(Tl) slow channel were selected. In Fig. 6 the same spectrum is compared with the prompt coincident curve obtained with the ^{22}Na source with the same energy settings at 0.133 MeV and 0.482 MeV, respectively. Our result for the lifetime of the 0.482 MeV level is $(11.2 \pm 0.4) \cdot 10^{-9}$ s, which is in very good agreement with other measurements[7, 8, 9].

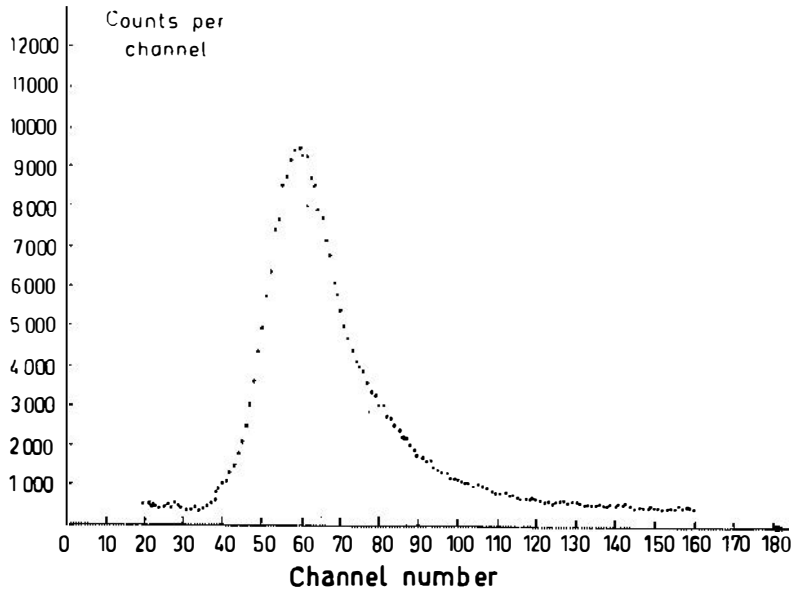

Fig. 5. Time spectrum for the 133–482 keV cascade in ^{181}Ta.

The other check of the system was the measurement of the anisotropy for the 1.172–1.332 MeV ^{60}Co cascade. The time spectra measured at 90° and 180° are shown in Fig. 7. We collected 5925 coincidence counts, for $\Theta_1 = 90°$ and 6732 for $\Theta_2 = 180°$ (after subtraction of accidental coincidences). The angle was changed every two hours to avoid systematic errors, caused by possible

electronic drifts. Twenty runs were performed at each angle. The ratio of accidental to true coincidences was approximately one tenth. We obtained the mean anisotropy

$$\bar{A} = + 0.139 \pm 0.021 .$$

After the finite solid angle corrections the anisotropy of the cascade gamma transition in ^{60}Co was

$$A = +0.156 \pm 0.023 ,$$

which is in good agreement with the theoretical value of $A_{\text{th}} = +0.16667$ and the adopted experimental result of $A_{\text{exp}} = + 0.167 \pm 0.001$[3].

The rather large error is due to the relatively poor counting statistics. It was a consequence of the relatively high energy of the 1.172 MeV gamma ray selected in the Ge(Li) channel, which resulted in a low coincidence counting rate due to very low efficiency.

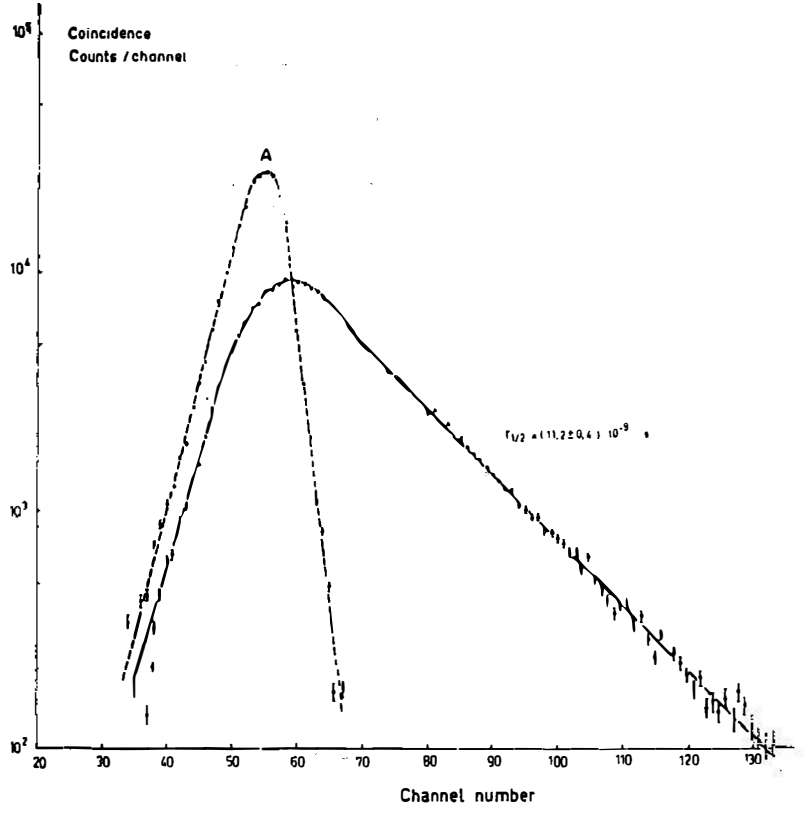

Fig. 6. Time spectrum – logarithmic scale – for A – prompt coincidences with a ^{22}Na source and B – delayed coincidences for the 133 keV – 480 keV cascade in ^{181}Ta.

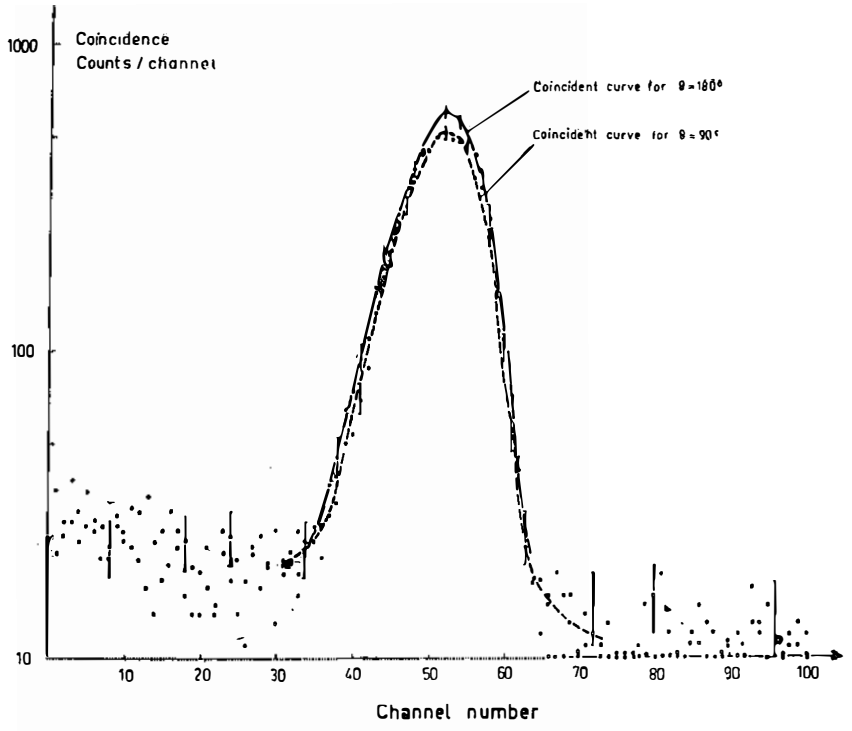

Fig. 7. Time spectra in the measurement of the anisotropy of the 1.17 MeV – 1.33 MeV cascade in ^{60}Ni at 90° and 180°.

The stability of the system was tested by the chi-square test. The chi-square value calculated for twenty individual anisotropy values A_i was

$$\frac{\chi^2}{n-1} = \frac{1}{(n-1)} \sum_i \frac{(\bar{A} - A_i)^2}{(\Delta A_i)^2} = 0.728, \qquad n-1 = 19$$

References

1) S. Devons and H.J.B. Goldfarb, Angular Correlations, in Encyclopedia of Physics 42 (ed. S. Flügge; Springer, Berlin 1957, p. 362);
2) M. Deutsch and O. Kofoed-Hansen, Gamma Rays, in Experimental Nuclear Physics 3 (ed. E. Segrè, J. Wiley & Sons N. Y. 1959 p. 373);
3) R. M. Steffen, Advances in Physics 4 (1955) 293;
4) H. Frauenfelder and R. M. Steffen, in K. Siegbahn, Alpha-Beta – and Gamma-Ray Spectroscopy, North Holland Publ. Co., Amsterdam 1965;
5) K. W. Dolan, J. P. Hurley and J. M. Mathiesen, Nucl. Instr. Meth. 39 (1966) 232–248;
6) V. Bonačić, Thesis, University of Zagreb, 1968;
7) Nuclear Data Sheets;
8) I. Bergström, E. C. O. Bonacalza, A. Jech, M. Perez, P. Thieberger, Nucl. Instr. Meth. 8 (1960) 151;
9) S. Goredetzky *et al.*, Proc. of the Gatlinburg Conf. 1961 on Electromagnetic Lifetimes and Properties of Nuclear States, Nucl. Sci. Series Report 37, p. 79.

ŠISTEM ZA MJERENJE KUTNIH GAMA-GAMA KORELACIJA S Ge(Li) – NaI(Tl) DETEKTORIMA

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Sadržaj

Opisan je Ge(Li) – NaI(Tl) sistem za određivanje kutnih gama-gama korelacija i mjerenje koincidentnih spektara. Provjera cjelokupnog sistema izvršena je mjerenjem života uzbuđenog stanja 0,482 MeV u ^{181}Ta metodom zakašnjelih koincidencija i određivanjem anizotropije za kaskadni gama prijelaz 1,172 – 1,332 MeV u ^{60}Ni. Dobiveni rezultati vrlo dobro se slažu s ranijim mjerenjima.