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# A MULTIPLICITY DETECTOR FOR ACCURATE LOW-ENERGY CAPTURE MEASUREMENT

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Abstract: A 16-segment NaI gamma multiplicity detector has been set up at the 25-m flight station of the Rensselaer Polytechnic Linear Accelerator Laboratory that is designed for accurate low-energy capture measurements. The detector consists of two 10-liter annuli of NaI placed coaxially and end-to-end, with each annulus optically divided into eight pie-shaped segments with a photomultiplier coupled to each segment. Capture data are recorded as a function of the multiplicity of the event (1 to 16) and the total gamma energy deposited into the NaI system. Multiplicity data for thermal neutron capture in Au and Cd are presented.

Neutron Capture detector, gamma ray multiplicity spectra

## Introduction

There is need for accurate neutron capture cross section data in the energy range from approximately 0.01 to 100 eV for application to the design of advanced thermal reactors. A high efficiency NaI gamma ray multiplicity detector was selected as having the best overall properties to achieve the required accuracy in terms of low cross section error and adequate neutron energy resolution. A multiplicity detector, as first reported by Muradyan and coworkers[1,2], is a highly efficient $4\pi$ gamma ray detector optically divided into many segments; data are recorded as the number of segments detecting gamma rays (in coincidence) vs neutron time of flight. Measurement of multiplicity will enable background (low-multiplicity) to be accurately subtracted from capture (medium-multiplicity) and enable capture to be separated from fission (high-multiplicity). Multiplicity can be used to provide information on the spins and parities of neutron resonances.

Muradyan et al.[1] used NaI for their multiplicity detector. More recently $BaF_2$[3,4] and BGO[5] have been used to take advantage of their higher density and, in the case of $BaF_2$, faster timing characteristics. Faster timing is required for high-energy neutron capture measurements.

## Detector Design

A detector for time-of-flight (TOF) measurements must have a timing resolution that is small compared to the inherent time dispersion from the linac pulsed neutron source and should have a minimum response to neutrons scattered by the capture sample. For $\leq$ 100 eV neutrons, the timing dispersion from the 2.5-cm-thick moderator is $\geq$ 160 ns. NaI has a time resolution of $\leq$ 25 ns which adds very little to the overall timing uncertainty of TOF measurements. Scattered neutrons of $\leq$ 100 eV can easily be shielded from a NaI detector by relatively thin (about 1-cm-thick) shields of B-10, so inscattered neutrons are not a problem. In addition, NaI has good gamma ray energy resolution so that the 478-keV gamma ray from B-10 capture can easily be discriminated against. The problem of fast neutrons entering a NaI detector and being captured in the iodine will be over before the arrival of $\leq$ 100 eV neutrons, and can readily be separated by TOF. However, these captures do lead to iodine activation which adds to the ambient background. Finally, the technology of NaI scintillators is well established and large volumes of specialized geometries can be fabricated relatively inexpensively. NaI was selected for this multiplicity detector as the best overall choice.

It was decided to do some preliminary measurements with a 5-liter two-segment annular NaI detector at 15- and 25-m flight paths to optimize the design of the final multiplicity detector. Signal-to-background ratios of this detector were studied with representative capture samples using different annualr liner materials. For multiplicity 2 and a total gamma ray energy $\geq$ 600 keV, a peak-to-back-ground ratio of $\geq$ 250:1 was achieved in low-energy resonances and neither capture (from scattered low-energy neutrons) nor iodine activation was a problem below 100 eV. The background at 5 eV was determined to consist about equally of ambient and machine-dependent background. The upper curve in Figure 1 shows a typical TOF spectrum taken with this detector at a 15-m flight path with a rare earth Hf capture sample of thickness $6.8 \times 10^{19}$ atoms/cm$^2$. The lower curve has a $2.2 \times 10^{21}$ atoms/cm$^2$ Hf filter in the beam, and the signal-to-background ratio at the 7.78 eV resonance is $\geq$ 600:1.

It was decided that a 16-segment annular NaI detector would be sufficient to detect both capture and fission events with good multiplicity separation. The size of the detector is a compromise between the high efficiency obtained from a large volume and the high background associated with a large volume. We selected a 20-liter volume based on the preliminary results with the 5-liter detector described earlier. This detector is placed at the 25-m flight station of the RPI linac. Drawings of the multiplicity detector system are shown in Figures 2 and 3. The NaI detector is surrounded by a lead shield and has a computer-controlled sample changer. The detector consists of two 10-liter annuli of NaI placed coaxially and end-to-end, with each annulus optically divided into eight pie-shaped segments with a photomultiplier coupled to each segment. The overall dimensions of the NaI are 30.5-cm length, 30.5-cm outer diameter and 8.9-cm inner diameter. The lead shield is 15 cm thick. A 0.6-cm-thick B-10 annular liner is placed inside the NaI detector to absorb low-energy neutrons scattered by the capture sample. A computer-controlled sample changer can cycle up to eight samples (one at a time) into the detector so that linac-produced fluctuations in neutron intensity can be averaged out.

The data to be recorded as a function of TOF are the multiplicity of the event (1 to 16) and the total gamma ray energy (deposited in all the NaI segments). The anode signals from the 16 photomultipliers are amplified and split into two routes. The multiplicity route sends the amplified signals to 16 fast threshold discriminators set ≤ 100 keV; this sets the minimum gamma ray energy in a NaI segment that will be counted. The outputs of these discriminators are passed to a majority logic unit which in turn goes to an ADC whose output is a 4-bit binary word; this word is sent to the computer and represents the event multiplicity. The total gamma ray energy route sums the 16 amplifier outputs with a fan-in system, sends the sum signal to a linear amplifier, passes the amplifier output to a quad discriminator, sends the discriminator to a majority logic unit which produces a 2-bit binary word; this word goes to the computer and represents the event total gamma ray energy.

## Results

The NaI detector has been constructed by the Harshaw/Filtrol Corporation and has been received and tested at RPI. The sample changer and final shield are under construction, but the NaI detector has been placed in a temporary shield and preliminary data have been obtained. The resolution of the summed NaI signals is 10.5% FWHM for the 0.662-keV Cs-137 gamma ray. Figure 4 shows the summed signal spectrum for Co-60; the sum peak is quite evident, indicating the high efficiency of this detector for 1.17- and 1.33-MeV gammas. Figure 5 shows the multiplicity spectrum for Co-60 for a discriminator setting of 100 keV for each NaI segment and a 600 keV sum criterion. The multiplicity peaks at 2, as expected, and multiplicity 3 is slightly greater than 2. The sum of all counts shows that 90% of the Co-60 decays are counted with this detector. Similar results have been obtained for Cs-137 spectra as shown in Figures 6 and 7. The multiplicity peaked at 1, as expected.

Multiplicity data have been obtained for thermal neutron capture in Cd and Au, as shown in Figures 8 and 9. The Cd data shows a peak just below a multiplicity of 4. This compares with a peak occurring just above a multiplicity of 3 in the data of Muradyan et al.[1] for a 12-segment NaI detector. The slightly higher peak multiplicity observed in our 16-segment detector is probably a result of the larger number of segments. The Au data shows a peak just below a multiplicity of 3. Thermal capture in Au produces a harder spectrum of gamma rays than Cd and Au has a lower multiplicity than Cd, which is consistent with our data.

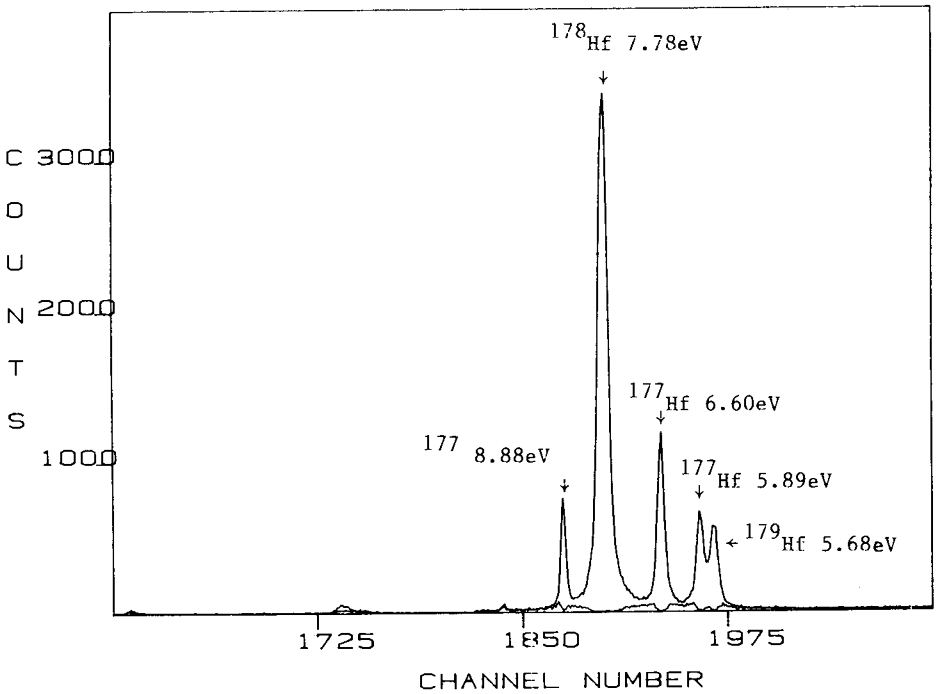


Fig. 1 A TOF spectrum for capture in Hf in the 5-liter two-section NaI detector operated at a multiplicity of 2.

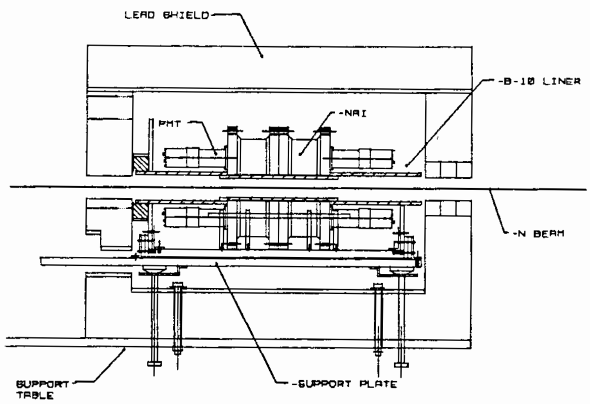


Fig. 2 Side view of the 20-liter NaI multiplicity detector, annular B-10 inner liner and 15-cm-thick lead shield.

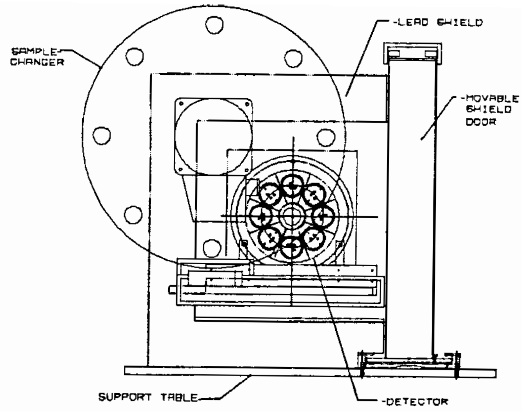


Fig. 3 Rear view of the 20-liter NaI multiplicity detector, 15-cm-thick lead shield and movable shield door, and the 8-position sample changer.

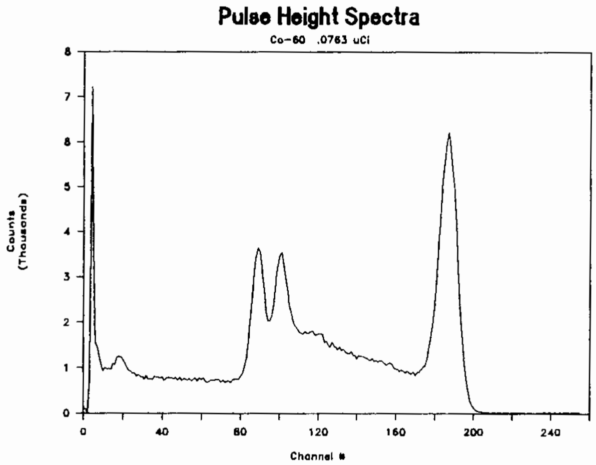


Fig. 4 The Co-60 pulse height spectrum for the sum-of-16 signals from the NaI detector.

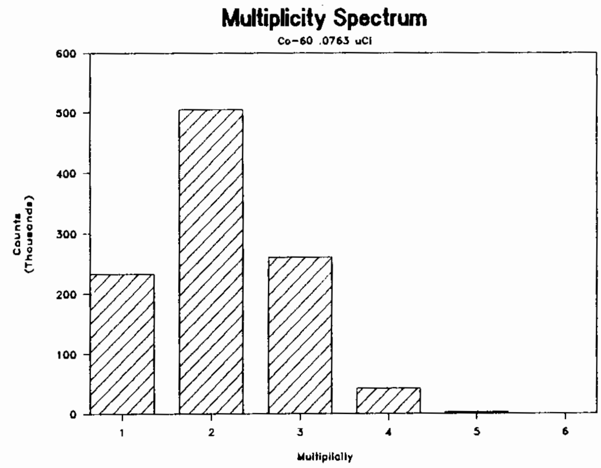


Fig. 5 The multiplicity spectrum for Co-60.

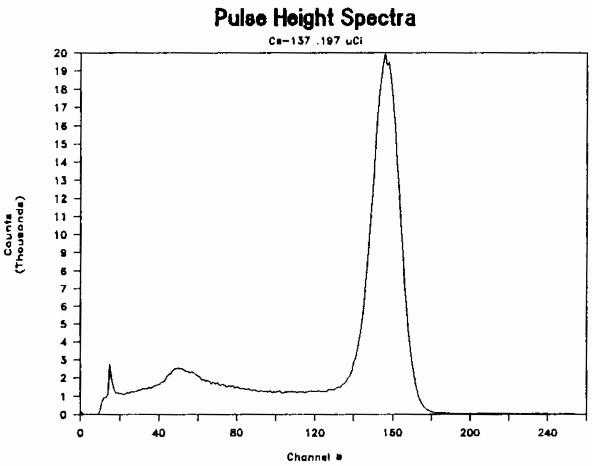


Fig. 6 The Cs-137 pulse height spectrum for the sum-of-16 signals from the NaI detector.

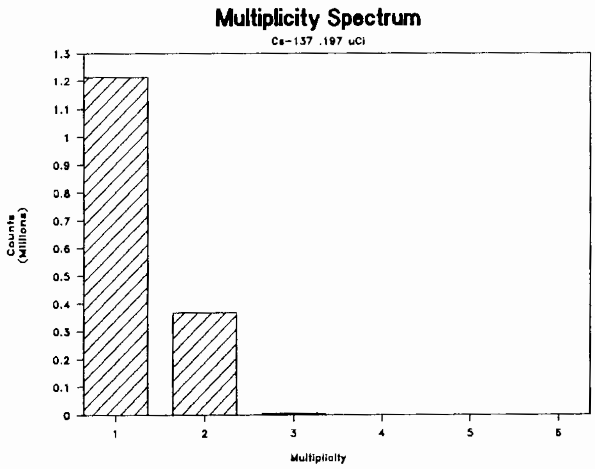


Fig. 7 The multiplicity spectrum for Cs-137.

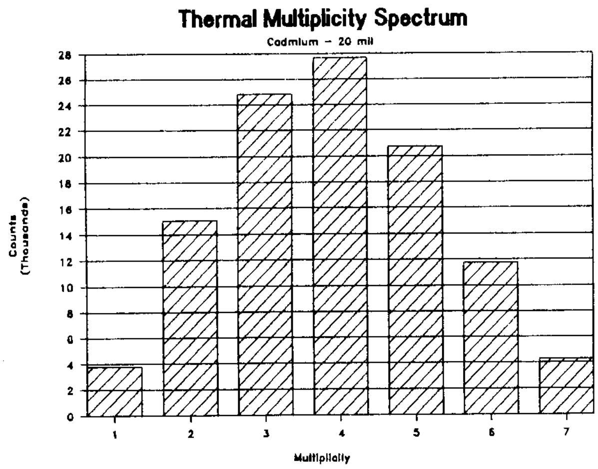

Fig. 8 The multiplicity spectrum for thermal neutron capture in Cd.

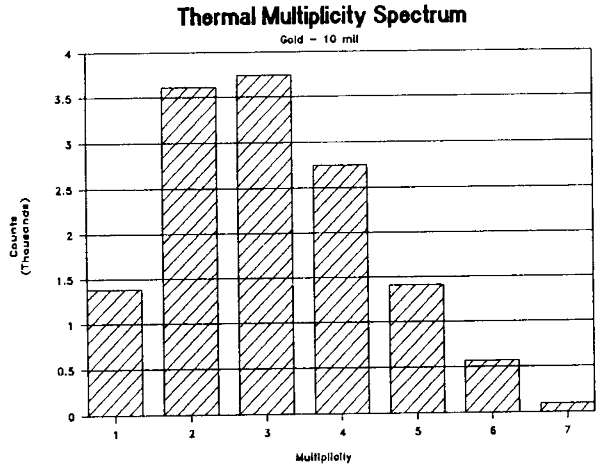

Fig. 9 The multiplicity spectrum for thermal neutron capture in Au.

## References


1. G.V. Muradyan, Yu.G. Shchepkin, Yu.V. Adamchuk and G.I. Ustroev, Preprint IAE-2634 (1976).
2. Yu.V. Adamchuk, M.A. Viskanyan, V.U. Juk, D.A. Markov, G.V. Muradyan, L.Yu. Prokofieva, G.I. Ustroev, A.D. Charitonov and Yu.G. Shchepkin, Proc. of IVth All-Union Conf. on Neutron Physics, Kiev, 1977, Publ. Moscow 2, 113 (1977).
3. K. Wisshak and Franz Kaeppeler, Proc. of Intl. Conf. on Nuclear Data for Basic and Applied Sciences, Santa Fe, May 1985, Gordon and Breach, Vol. 2, pg. 1319 (1985).
4. D. Wisshak, K. Guber, F. Kaeppler, J. Drisch, H. Mueller, G. Rupp and F. Voss (paper presented at this conference).
5. S. Yamamoto, K. Kobayashi and Y. Fujita (paper presented at this conference).