

## Low energy neutron physics research with a gamma multiplicity detector

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### ABSTRACT

A sixteen-segment NaI(Tl) multiplicity gamma ray detector is used at the Rensselaer Polytechnic Institute Gaertner LINAC Laboratory for neutron cross section measurements. This detector consists of an annulus of NaI(Tl) divided into two sets of 8 pie-shaped segments, each segment optically isolated and viewed by a photomultiplier. The neutron beam passes along the axis of the detector and impinges upon a sample placed in the center. Time-of-flight data are taken as a function of the number of sections which detect a gamma and which is defined as the detected multiplicity. This detector can simultaneously acquire neutron scattering, capture and fission data by placing suitable limits on the total detected gamma ray energy deposited in the detector. Scattering and capture measurements have been performed on samples of holmium, erbium, and tungsten and experimental results are presented. The experimental multiplicity for capture is analyzed by assuming the single particle model, stochastically calculating the gamma ray cascades from neutron capture, and transporting each gamma ray into the detector using the Monte Carlo method. The detection efficiency for neutron capture is over 90% and is relatively insensitive to different isotopes of the same element or different spins of the compound nuclear resonances. A status report on experimental and analytical activities at the Laboratory is presented.

### EXPERIMENTAL METHOD

A sixteen-segment NaI(Tl) gamma multiplicity detector has been developed for neutron cross section measurements. This detector has been described earlier<sup>1</sup> and will only be briefly discussed here. Figure 1 shows a cutaway view in which the two sets of optically-isolated 8-segment pie-shaped NaI(Tl) detectors surround a sample in the middle of the detector. The

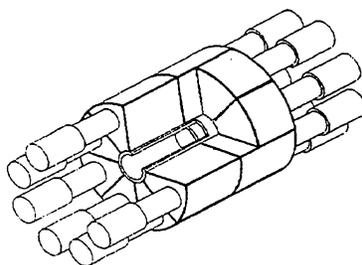


Figure 1. Sixteen-segment NaI(Tl) multiplicity detector.

neutron beam is collimated along the axis of the detector and neutron-induced gamma ray data are taken as a function of the number of segments which receive  $\geq 100$  keV of energy deposited provided the total energy deposited into all 16 segments exceeds a pre-selected threshold level. Capture data are taken in two modes: resonance-energy measurements record events with a total-energy-deposited threshold of  $E_{\text{total}} \geq 1$  MeV, while thermal measurements require  $E_{\text{total}} \geq 2$  MeV. The higher threshold of thermal measurements is used to suppress the beta-decay background from iodine activation in the NaI(Tl). Scattering data are taken with a total-energy-deposited window of 360 to 600 keV, where the scattered neutrons are detected by capture in a  $^{10}\text{B}_4\text{C}$  annulus inside the detector.

This detector is located at a 25m flight station. Samples are cycled into the detector by an 8-position sample changer. An electronic clock with a resolution of 31.25 ns is used to measure the neutron time-of-flight. The clock is coupled to an HP 1000 computer which records all the data, controls the sample changer and essentially runs the experiment. The electron LINAC typically operates with an electron energy of 60 MeV and with pulse widths from 40 to 100 ns for resonance energy measurements, and 1  $\mu\text{s}$  for thermal measurements.

The time-of-flight data are first subjected to a “consistency check” in which data are only accepted when the recorded detector counts and beam monitor counts fall within a range of statistical fluctuations. Data are then dead-time corrected and summed. To determine capture yields, i.e., the number of captures per incident neutron, the neutron flux and detector efficiency must be determined. The flux is measured with a  $^{10}\text{B}_4\text{C}$  sample and a total-energy-deposit window of 360 to 600 keV, and detector efficiency is determined by saturated capture in a low-energy resonance. Capture yield data are analyzed with the ORNL Bayesian code SAMMY<sup>2</sup> or the Harwell code REFIT<sup>3</sup> to obtain R-matrix resonance parameters.

### DETECTOR MULTIPLICITY

The detector response is modeled by sampling capture gamma ray cascades for electric and magnetic dipole and quadrupole transitions using the Weiskopf single particle model, including hindrance factors<sup>4</sup>, and transporting the gamma rays through the detector with the MCNP Monte Carlo code<sup>5</sup>. Energy deposition in each segment is determined for each cascade, and events are scored when at least one section has  $\geq 100$  keV deposited in it and all 16 segments have  $E_{\text{total}} \geq 1$  MeV or  $\geq 2$  MeV, respectively, for resonance or thermal capture measurements. The resulting multiplicity spectra can be compared with experimental spectra. The calculation also determines efficiency as the fraction of non-zero scores.

Figure 2 shows the calculated efficiency for detecting neutron capture in,  $^{165}\text{Ho}$ ,  $^{166}\text{Er}$ ,  $^{167}\text{Er}$ ,  $^{182}\text{W}$ ,  $^{183}\text{W}$ ,  $^{184}\text{W}$ , and  $^{186}\text{W}$  with  $E_{\text{total}} \geq 1$  MeV. The error bars are 1-sigma statistical errors from the Monte Carlo calculations. The hindrance

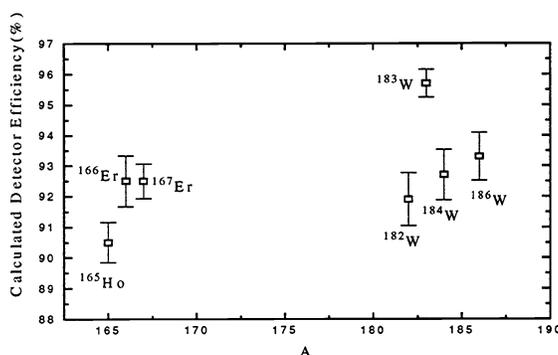


Figure 2. Calculated detector efficiency for various target materials, threshold energy = 1.0 MeV

factors were chosen as the best match to the measured multiplicity spectra. The efficiencies range from a low of 90.5% for  $^{165}\text{Ho}$  to 95.7% for  $^{183}\text{W}$ . Thus the multiplicity detector is a high efficiency detector which is relatively insensitive to the differences in nuclear cascades resulting from neutron capture in different isotopes.

Figure 3 compares the average detected multiplicity  $\langle \nu \rangle$  for calculated and measured spectra from neutron capture in Ho, Er, and W. The measured multiplicities were determined by averaging data from several resonances and sample thicknesses. The calculated multiplicities include hindrance factors which have been adjusted within the range of published values to agree as closely as possible with measured multiplicity spectra. Calculated average multiplicities for tungsten are systematically higher than those from measurements.

The single particle model is most representative physically in the cases of nearly closed nuclear shells. None of the

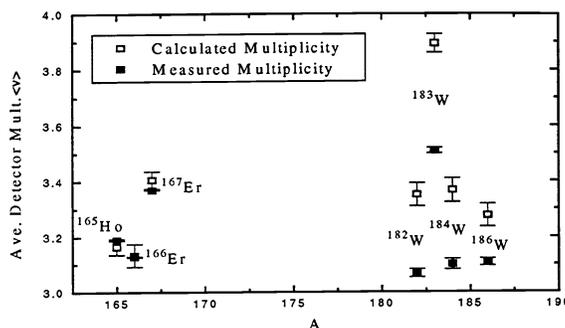


Figure 3. Calculated and measured average detector multiplicity for various target materials, threshold energy = 1.0 MeV.

isotopes examined are near one of the “magic numbers” of protons or neutrons indicating closed nuclear shells. Hindrance factors are used to account for collective effects and, in the case of the rare earths holmium and erbium, account for strong electric quadrupole character of neutron capture radiations. The application of hindrance factors was not successful in the calculations made for tungsten. The reason for the systematic difference between calculated and measured tungsten multiplicity is presently under investigation.

In Figure 3, the tungsten calculations show the same trend as the data with respect to larger multiplicities for  $^{183}\text{W}$  than other tungsten isotopes. For both erbium and tungsten, different isotopes of the same element show different multiplicities. This fact can be used to identify the isotope causing a resonance. These calculated efficiencies and multiplicities serve as a guide for the interpretation of experimental data.

#### EXPERIMENTAL RESULTS

Capture ( $E_{\text{total}} \geq 1 \text{ MeV}$ ) and scattering ( $360 \text{ keV} < E_{\text{total}} < 600 \text{ keV}$ ) measurements have been performed simultaneously in tungsten metallic samples ranging in thickness from 0.3 to 20 mils (1 mil = 0.001 in). The data have been summed over all multiplicities and the results are plotted in Figure 4 for 5 mil thick tungsten over the neutron energy range from 3 to 30 eV. The capture data (solid line) have been normalized to saturated capture in the 4.16 eV resonance in  $^{182}\text{W}$ ; the

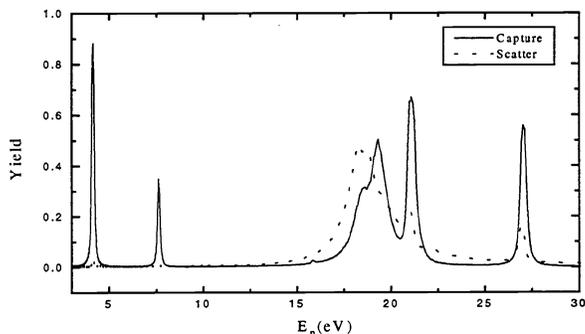


Figure 4. Capture and scattering spectrum for 5 mil W metal.

scattering data (dashed line) have not been normalized but, for the sake of plotting, have been assumed to have the same efficiency as capture.

The 4.16 eV resonance in  $^{182}\text{W}$  is 3% scattering and the 7.65 eV resonance in  $^{183}\text{W}$  is 2.5% scattering, and this is evident in the relatively small scattering peaks. The 27.1 eV resonance in  $^{183}\text{W}$  is about 25% scattering and this is reflected in the relative size of the scattering and capture peaks. There is a strong scattering resonance in  $^{186}\text{W}$  at 18.8 eV which is saturated and this leads to the complex doublet in capture which results from strong multiple scattering in the sample. In addition, the  $^{182}\text{W}$  resonance at 21.1 eV falls very close to the 18.8 eV resonance, so that the line shapes for these two resonances in 5 mil tungsten are complex; the thinner sample data separate these resonances into more distinct peaks.

Figure 5 shows the counting spectrum for different multiplicities from the 7.65 eV resonance in  $^{183}\text{W}$ ; these data are for the 5 mil sample. Background has been subtracted from these results so that Figure 5 shows net capture counts in each multiplicity. An average multiplicity, such as that shown in Figure 3, is formed by an area-weighted average over all resonances, such as that shown in Figure 5, within the same isotope. Note that the most probable multiplicity shown in Figure 5 is  $\nu=3$ , followed closely by  $\nu=4$ ,  $\nu=2$ , etc. Correspondingly, the average measured multiplicity for  $^{183}\text{W}$ , as shown in Figure 3, is  $\langle \nu \rangle \cong 3.5$ .

#### CONCLUSION

The sixteen-segment NaI(Tl) multiplicity detector is a high-efficiency, high-resolution detector well suited for neutron cross section measurements in the low-energy resonance region. It may also be used for fission cross section measurements.

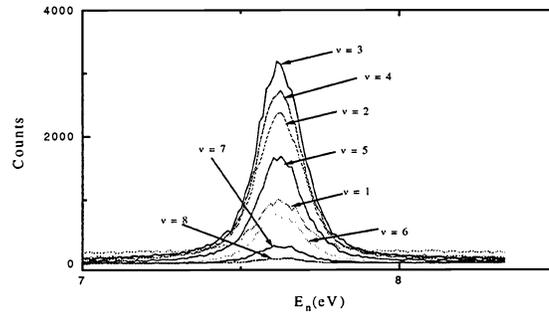


Figure 5. Multiplicity spectra for 5 mil thick W near 7.65 eV resonance.

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