KAPL-P-000164
(K97045)
CONF-9704252--

NEUTRON TIME-OF-FLIGHT MEASUREMENTS AT THE RENSSELAER LINAC

R. C. Block, J. A. Burke

April 1997

KAPL ATOMIC POWER LABORATORY SCHENECTADY, NEW YORK 10701

Operated for the U. S. Department of Energy
by KAPL, Inc. a Lockheed Martin company

DISCLAIMER

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Proc. of Int'l. Conf. on Nuclear Data for Science & Technology, Gatlinburg, Tennessee, May 9-14, 1994.

NEUTRON TIME-OF-FLIGHT MEASUREMENTS AT THE RENSSELAER LINAC

RC Block, Y Danon, RE Slovacek, CJ Werner, G Youk

Rensselaer Polytechnic Institute, Department of Nuclear Engineering and Engineering Physics, Gaerttner Linac Laboratory, Troy, New York 12180-3590

JA Burke, NJ Drindak, F Feiner, JA Helm, JC Sayres, KW Seemann(retired)

Knolls Atomic Power Laboratory, P.O. Box 1072, Schenectady, New York, 12301-1072, USA.

ABSTRACT

Neutron transmission measurements of Ho, Er, Tm and Au samples have been made from thermal to several hundred eV and the data have been fitted with the SAMMY program. A 16-section NaI multiplicity detector has been used to measure simultaneously capture and scattering partial cross sections. These measurements are used to obtain accurate resonance parameters over this energy range for samples of Mo, Ho, Er, Tm and Au.

I. INTRODUCTION

A neutron time-of-flight (TOF) facility has been developed at the Rensselaer Polytechnic Institute Gaerttner Linac Laboratory for neutron total and partial cross section measurements. This facility has been designed for accurate measurements up to a few hundred eV. A new thermal-energy neutron target has been constructed to enhance measurements in the few meV region; this target is designed for use with a cryogenically cooled moderator. Transmission measurements are made at 15m and 25m flight stations using ^{6}Li glass scintillator detectors. Partial cross section measurements are made at a 25m flight station with a 16-section NaI(Tl) scintillation multiplicity detector. Measurements were carried out for Mo, Ho, Er, Tm and Au.

II. ENHANCED THERMAL TARGET

A new Enhanced Thermal Target (ETT), references (1) and (2), was developed to enhance the neutron intensity in the thermal and sub-thermal energy range. The Monte Carlo Neutron Photon (MCNP) code (3) was used to design this target and it was constructed so that it could be used either at room temperature or with a cryogenically-cooled moderator. Fig. 1 shows the flux with the ETT (at room temperature) both with and without a 3.81-cm-thick polyethylene moderator compared with the flux from the standard 'bounce' target that has been used at the Gaerttner Linac Laboratory for over 20 years. The ETT flux with the polyethylene

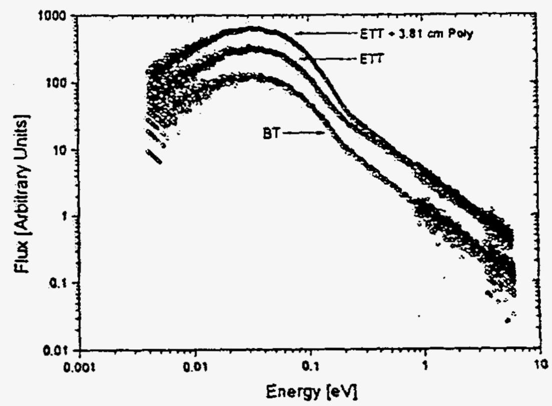

Fig. 1. Neutron flux measured at 15m with the bounce target (BT), lower curve; enhanced thermal target (ETT) without moderator and at room temperature, middle curve; and ETT with 3.81-cm-thick polyethylene moderator at room temperature, upper curve.

moderator is approximately 6 times greater than that from the bounce target in this thermal energy range. The ETT has been used for transmission measurements up to approximately 20 eV. Above 20 eV the bounce target has been used for both transmission and partial cross section measurements because of the superior resolution from this target.

III. MULTIPLICITY DETECTOR

The multiplicity detector is shown in Fig. 2. It consists of 16 optically isolated sections of NaI(Tl) forming a cylindrical annulus. The Na(Tl) annulus is a 30.5 cm by 30.5 cm (12 in by 12 in) right circular cylinder with an 8.9 cm (3.5 in) through hole along its axis. The cylinder is split across its axis into two rings, and each ring is divided into 8 equal pie-shaped segments. Each segment is viewed by an RCA 8575 photomultiplier. This detector has a total volume of 20 liters of Na(Tl) and has an efficiency of approximately 75% for a 2 MeV gamma.A photograph of this detector

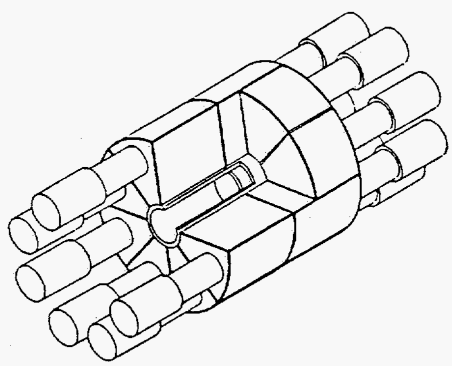

Fig. 2. Sixteen-section NaI multiplicity detector.

just outside of its 15-cm-thick (6 in) lead shield is shown in Fig. 3. It is located on a flight path approximately 25 meters from the pulsed neutron source.

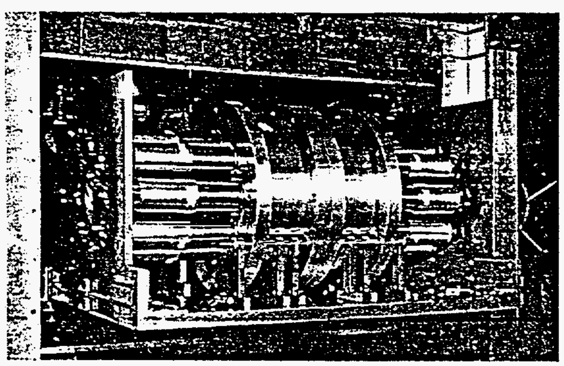

Fig. 3. Photograph of multiplicity detector.

Samples of 5.08 cm (2 in) diameter are positioned in the center of the multiplicity detector by a computer-controlled 8-position sample changer. An annular boron liner is placed inside the annulus to suppress scattered neutrons from entering the Na(Tl) segments. Initially, powdered ^{10}B (95.5% enriched) was used for the liner; recently this has been replaced by a solid ^{10}B carbide annular liner which effectively suppresses scattered neutrons below 1 keV from entering the detector.

For capture measurements the multiplicity detector is operated with a 100 keV threshold on each segment to indicate a detected event. The signals from all segments are summed and a 1 MeV threshold is used to define the capture event. The 1 MeV threshold was selected to discriminate against 477 keV gamma rays resulting from scattered neutrons absorbed in the boron liner. The data are then stored vs time of flight (TOF) by the number (from 1 to 16) of segments which fire (above 100 keV) provided the total energy is in excess of 1 MeV. An electronic clock can resolve events with a minimum of 31.25 ns resolution and the TOF data are collected into an HP-1000 computer using 8192 channels per spectrum with time compression. Thus each capture sample requires 16 x 8192 = 131k channels; if 8 samples are used in a measurement, then appoximately 1M channels are required per run. A detailed description of the detector and the electronics are described in reference (4).

For scattering measurements the multiplicity detector is operated to detect the 477 keV gammas from scattered neutrons that are absorbed in the boron. For this measurement two total energy thresholds are used: 360 keV and 1 MeV; each segment is still operated with a 100 keV threshold. The data are now stored in two groups of 16 TOF spectra, with the 360 keV to 1 MeV total energy events stored in one group as scattering data and the >1 MeV events stored in the other group as capture data. Thus scattering and capture data are obtained simultaneously and now 2 x 16 x 8192 channels of data are stored per sample and, for an 8-sample run, approximately 2M channels of data are required per run. A description of the detector and electronics is contained in reference (5).

The operation of this multiplicity detector for both capture and scattering measurements is similar to that of Muradyan and co-workers (6-8)

IV. RESULTS

A. Capture and Scattering

Capture measurements were carried out with the Rensselaer Linac for Ho, Er, Tm and Au samples and simultaneous capture and scattering measurements were carried out for Mo, Er and Au samples. The linac was typically operated with a pulse width of 100 ns at 175 pps with a Cd overlap filter for measurements above 0.5 eV and at 36 pps without an overlap filter for measurements into the thermal region.

The result of a partial cross section measurement is the yield, i.e. the number of partial events per incident neutron. Thus the incident neutron flux must be determined along with the detection of partial events. For the measurement of flux a $^{10}B_4C$ sample is placed inside the multiplicity detector and the counts from two sections of Na(Tl) are recorded with a total energy threshold of 360 keV. Only two sections of Na(Tl) are used because of the very high counting rates from all 16 sections. The boron sample is effectively black up to 100 eV and MCNP calculations have been carried out to determine the efficiency for detecting the 477 keV gamma ray over neutron energies from thermal to several keV. From these measurements the relative neutron flux is determined; this is then normalized to saturated capture or scattering in the materials being measured. In the absence of a saturated resonance in the material being measured, the neutron flux is normalized to capture and scattering in the 4.9 eV Au resonance.

A typical set of TOF spectra for capture in the 4.9 eV Au resonance is shown in Fig. 4 for multiplicities 1 through 7. We note that the counting rate peaks for multiplicity 3 with an average muliplicity slightly greater than 3. Since background events are due predominantly to single gamma rays and peak in multiplicity 1, one can see the inherent separation of capture from background . When all mulitplicities are summed, the signal-to-background ratio is over 300:1, thus enabling high-accuracy capture measurements to be made with this detector. Since the efficiency for a single 2 MeV gamma ray is approximately 75%, the efficiency for detecting a capture event in which 3 or more gamma rays are emitted is >98% and thus this detector is very efficient for capture measurements.

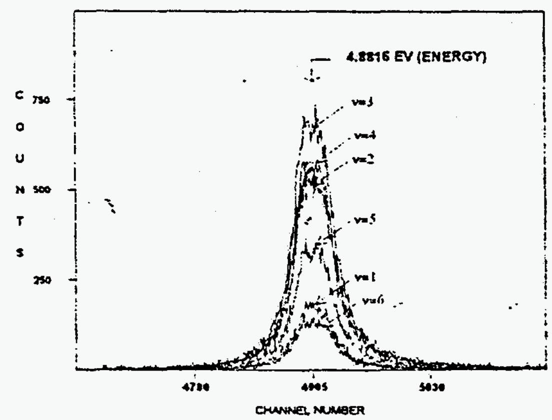

Fig. 4. Multiplicity spectra for 0.060-mm-thick Au near the 4.9 eV resonance.

A typical spectrum is shown in Fig. 5 for capture in a 0.018-mm-thick sample of metallic Er; the smooth curve is a SAMMY (9) fit to the experimental data, and as can be seen, the two curves are indistinguishable for each other. These data were taken with the linac operating at 36 pps. The capture data were summed over all 16 multiplicities and the background, determined with an empty aluminum sample holder, was subtracted. Capture measurements have been carried out for metallic samples of Ho 0.10- and 0.30-mm thick; Er 0.018- 0.027- 0.058-and 0.130-mm thick; and Tm 0.10- and 0.25-mm thick. The relative neutron flux was determined by measuring the counting rate with the $^{10}B_4C$ sample and normalizing this relative flux to saturated resonances in these nuclei.

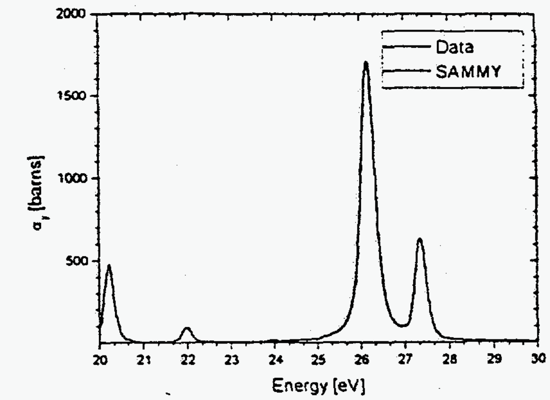

Fig. 5. A SAMMY fit to Er capture data near 25 eV.

A simultaneous capture and scattering measurement is illustrated in Fig. 6 for a 0.127-mm-thick Mo metallic sample. The data in Fig. 6 have been summed over all 16 multiplicities; however, the scattering data peak at multiplicity 1 while the capture data peak near multiplicity 3. Here we see the 160 eV and 131 eV Mo resonances which are, respectively, resonances which are mostly capture and mostly scattering. Note that the scattering peak dominates at 131 eV, whereas the capture peak dominates at 160 eV and the scattering peak is lost in the background. This measurement shows that the mulitplicity detector is sensitive to scattering, as well as capture, and will enable simultaneous accurate measurements of capture and scattering. We expect that fission measurements can also be made simultaneously with this detector, since the multiplicity and total energy deposited by fission are quite distinct from capture and scattering.

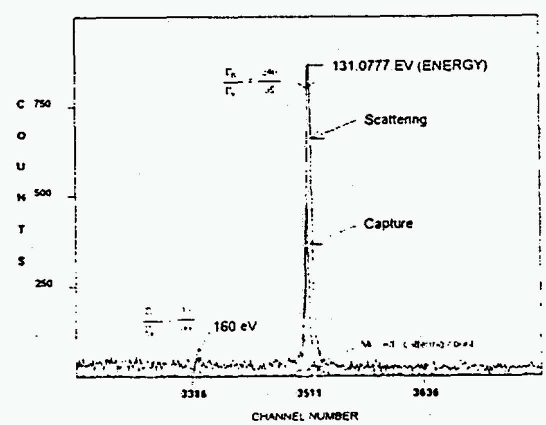

Fig. 6. Scattering and capture TOF spectra for a 0.127-mm-thick Mo sample near 130 eV.

Another characteristic of these capture and scattering data is the displacement of the scattering peak to greater time of flight than the capture peak. This is the result of the increased flight path of the scattered neutrons in going from the sample to the annular $^{10}B_4C$ liner; the average increase in the flight path for scattered neutrons is about 7 cm. Measurements on the 0.4 eV doublet of resonances in Er, where capture exceeds 99%, show that approximately 3% of the capture events fall into the scattering channel; this capture contamination will be reduced in the future when the upper sum energy discriminator setting (now at 1 MeV) is optimized for scattering measurements.

B. Transmission

Early transmission measurements of H, C and Au had been carried out by Vescovi et al. (10,11) with the bounce target and a 15m flight path: these data had been reduced to total cross sections and the Au data were analyzed for resonance parameters (10,11,12) using both the REFIT (13) and SAMMY codes. Measurements with the new ETT were carried out below 20 eV on metallic samples of Ho, Er and Tm and isotopically enriched Er-166 and Er-167 oxide samples. Here the emphasis was on thermal and sub-thermal measurements and on determining the potential scattering in the epithermal region between resonances. A typical transmission and SAMMY fit are shown in Fig. 7 for Ho.

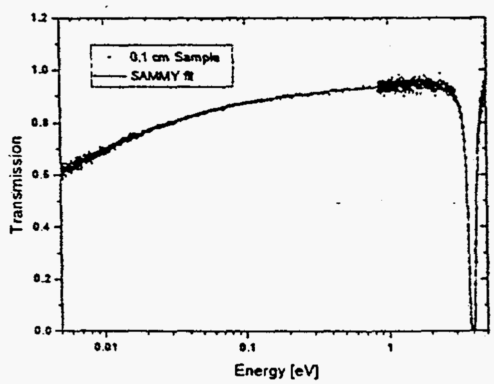

Fig. 7. Thermal transmission data obtained at 15m with the enhanced thermal target and with a 1-mm-thick Ho sample. The solid curve is the SAMMY fit.

Paramagnetic scattering was determined for Ho, Er and Tm by subtracting ENDF-VI capture and potential scattering cross sections from the measured total cross section; the result for Ho is shown in Fig. 8 along with the theoretical scattering based on Mattos form factors (14). Table I compares our measurements with theoretical and evaluated (15) paramagnetic scattering at 0.0253 eV. Our measurements are in agreement with theory for Ho, are lower for Er and are higher for Tm. Our Tm result is in agreement with the result presented in BNL-325 (15).

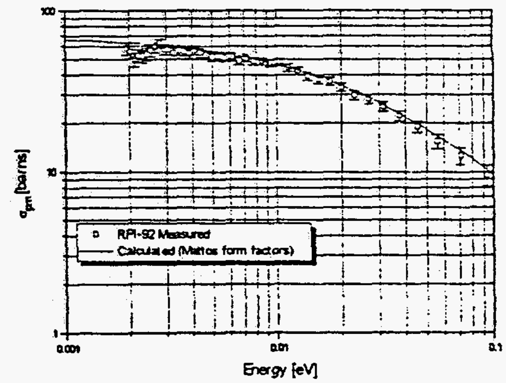

Fig. 8. Ho measured and calculated paramagnetic scattering.

TABLE I. Paramagnetic scattering in barns at 0.0253 eV for Ho, Er and Tm.

	Ho	Er	Tm
Theory (Mattos form factors (11))	29.5	25.5	17.3
Measured	28.8 ±1.9	19.3 ±3.0	23.2 ±2.5
Mughabghab et al. (12) (Measured)	24.6 ±2.4	26.1 ±2.5	23.3 ±3

Transmission measurements on samples of Ho, Er, Tm and Au have been carried out at the 25m flight path. Fig. 9 shows results for 0.018-, 0.064-, 0.127-, 0.254-, and 0.508-mm-thick Au samples and corresponding SAMMY fits near the 4.9-eV Au resonance. Table II shows the preliminary Au resonance

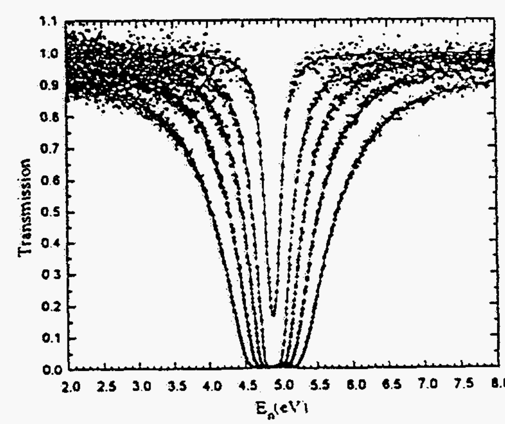

Fig. 9. Transmission data obtained at 25m with 0.010-, 0.060-, 0.127-, 0.254- and 0.508-mm-thick Au samples. The solid curves are SAMMY fits in which all of the data were fitted sequentially to obtain a single set of parameters.

parameters determined from only the transmission measurements along with ENDF-VI (16) and BNL-325 (15) parameters. Simultaneous analyses, incorporating both capture and transmission data, are currently being performed on Ho, Er and Tm using the SAMMY and REFIT codes to obtain resonance parameters.

TABLE II Au resonance parameters.

ENDF/B-VI			RPI		
E [eV]	Γ_γ [meV]	Γ_n [meV]	E [eV]	Γ_γ [meV]	Γ_n [meV]
4.906	122.5	15.2	4.890 ±0.001	122.5	14.80 ±0.01
58.1	112	4.4	57.921 ±0.002	112	4.353 ±0.04
60.3	130	68.0	60.099 ±0.001	130	66.5 ±0.2
78.4	130	16.7	78.271 ±0.002	130	16.56 ±0.09

V. CONCLUSION

Capture, scattering and transmission measurements are now being routinely carried at the Gaerttner Linac Laboratory with emphasis on accurate measurements over the thermal region and up to a few hundred eV. The capture and scattering measurements were obtained simultaneously with a multiplicity detector; it is anticipated that scattering, capture and fission data can all be obtained at the same time with this detector.

REFERENCES

1. Y. Danon, R.E. Slovacek, and R.C. Block, "The Enhanced Thermal Neutron Target at the RPI Linac," Trans. Amer. Nucl. Soc. 68, 473 (1993).

2. Y. Danon, "Design and Construction of the RPI Enhanced Thermal Neutron Target and Thermal Cross Section Measurements of Rare Earth Isotopes," PhD Thesis, Rensselaer Polytechnic Institute, Troy, NY (1993).

3. "MCNP, A General Monte Carlo Code for Neutron and Photon Transport, Version 3B," LA-7396-M, Rev. 2, Los Alamos National Laboratory, September, 1986.

4. R.C. Block, P.J. Marano, N.J. Drindak, F. Feiner, K.W. Seemann and R.E. Slovacek, "A Multiplicity Detector for Accurate Low-Energy Neutron Capture Measurements," Proc. of Int'l Conf. on Nuclear Data for Science and Technology, Mito, Japan, p. 383 (1988).

5. R.E. Slovacek et al., "Neutron Cross Section Measurements at the Rensselaer Linac," Topical Conference on Advances in Reactor Physics, Knoxville, TN, April, 1994.

6. Yu.V. Adamchuk, M.A. Voskanyan, G.V. Muradyan and V.A. Stepanov "Study of the Neutron Resonances of ^{238}U with Anomalously Large Fission Widths," Sov. J. Phys. 54, 1 (1991).

7. M.A. Voskanyan, G.V. Mozolev, G.V. Muradyan, V.A. Stepanov and L.P. Yastrabova, "Unusual Neutron Resonances of ^{238}U," Sov. J. Phys. 55 1290 (1992).

8. G. Georgiev, Yu.S. Zamyatnin, L.B. Pikelner, G.V. Muradyan, Yu.V. Grigoriev, T. Madjarski and N. Jeneva, "Determination of ^{147}Sm and ^{148}Sm Resonance Parameters," Nuclear Phys. A565 643 (1993).

9. N.M. Larson, "Updated User's Guide for SAMMY: Multilevel R-Matrix Fits to Neutron Data Using Bayes' Equation," ORNL/TM-9179/R2, Oak Ridge National Laboratory (1989).

10. P.J. Vescovi, "High Accuracy Neutron Transmission Measurements in the Resonance Energy Range 1 eV to 100 eV," Master's Thesis, Rensselaer Polytechnic Institute, Troy, NY (1990)

11. P.J. Vescovi, R.C. Block, R.E. Slovacek and M.A. Babineau, "High Accuracy Neutron Total Cross Section Measurements," Proc. of Topical Meeting on Advances in Reactor Physics, Charleston, SC, Vol. 1, p. 230 (1992).

12. M.A. Babineau, "R-Matrix Analysis of ^{197}Au Transmission Measurements from 1 eV to 250 eV," Master's Thesis, Rensselaer Polytechnic Institute, Troy, NY (1991).

13. M. Moxon (private communication).

14. M.C. Mattos, J. Chem Phys. 48, 520 (1968)

15. S.F. Mughabghab, M. Divadeenam and N.E. Holden, "Neutron Cross Sections," Academic Press (1984).

16. ENDF-VI, Evaluated Nuclear Data Files, Version VI, Brookhaven National Laboratory.