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NEUTRON FILTERS FOR PRODUCING MONOENERGETIC NEUTRON BEAMS

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Neutron transmission measurements have been made on high-purity, highly-enriched samples of ^{58}Ni (99.9%), ^{60}Ni (99.7%), ^{64}Zn (97.9%) and ^{18}W (94.5%) to measure their neutron "windows" and to assess their potential usefulness for producing monoenergetic beams of intermediate energies from a reactor. Transmission measurements on the Los Alamos Sc filter (44.26 cm Sc and 1.0 cm Ti) have been made to determine the characteristics of the transmitted neutron beam and to measure the total cross section of Sc at the 2.0 keV minimum. When corrected for the Ti and impurities, a value of 0.35 ± 0.03 b was obtained for this minimum.

[^{58}Ni , ^{60}Ni , ^{64}Zn , ^{18}W , ^{45}Sc , σ_T , 0.05-5000 keV, neutron filters]

Introduction

Neutron filters of thick samples (~50 cm) of iron, (also ^{56}Fe), scandium, silicon and ^{238}U have been used for many years at several reactors to produce monoenergetic neutron beams with energies of 24, 2.0, 140 and 0.186 keV, respectively. Often it is necessary to add a secondary material in the beam (such as Al with an iron filter) to reduce the intensity of other energy neutrons from secondary windows. These monoenergetic neutron beams have been used for basic nuclear physics research, such as average resonance capture gamma ray spectroscopy and for accurate bench-mark type measurements at specific energies. The neutron filter technique has been combined with a pulsed neutron source such as ORELA to measure the inelastic neutron scattering of ^{238}U and to utilize less intense neutron groups from higher energy windows in the filter for detector development.

An international filter beam project^{2,3} has been proposed to produce beams of intermediate energies which could be used for many applications. These include calibration and development of instruments, fundamental radiobiology, and boron neutron capture radiotherapy for brain tumors. Earlier studies^{4,5} proposed several isotopes which might be useful as filters. Transmission measurements on some of these isotopes were undertaken at ORELA and are reported in this paper.

Knowledge of the cross section at the 2.0-keV minimum in ^{45}Sc is important in order to determine the optimum thickness of Sc to be used as the filter. Early measurements indicated that this cross section was very small (<0.1 b); hence, very thick filters could be used with little loss of 2.0 keV neutrons. However, recent measurements have reported values from 0.71 ± 0.03 ,⁵ 0.26 ± 0.07 ,⁶ and 0.24 ± 0.07 ⁷ b for this minimum. It was hoped that a measurement on the Los Alamos Sc filter would contribute to the solution of the discrepancy.

Experimental Method

The transmission measurements were made using a 12 mm thick, 111 mm dia. ^6Li glass scintillator located 78.203 m from the ORELA water moderated Ta neutron target. The linac was operated at 800 Hz with a pulse width of 30 nsec. The samples were located at 9 m and were alternated with a blank holder and background samples on a 30 minute cycle. The metallic samples of ^{58}Ni , ^{60}Ni , ^{64}Zn , and ^{18}W , were carefully prepared by P.R. Kuehn, Target Center, ORNL, to minimize the oxide and water content of the samples. The Sc sample (44.26 cm Sc and 1.0 cm Ta) was loaned by E.T. Jurney, LANL. The Sc_2O_3 was heated to remove water and the sample was prepared in an inert atmosphere to prevent absorption of water.

Data Analysis

The time-of-flight spectra were corrected for the dead-time of the time digitizer, a time dependent back-

ground due to neutron capture in the water moderator (17.6 μsec capture decay time), and a constant room background. The contributions of the 1 cm of Ti and the air displaced by the Sc sample were applied to the measured transmission of the Los Alamos Sc filter in order to obtain the total cross section of Sc.

Results and Discussion

The transmissions of the ^{58}Ni ($N = 0.60$ a/b, 99.9%) and ^{60}Ni ($N = 0.65$ a/b, 99.7%) filters are shown in Figures 1 and 2. The transmissions for the lowest energy windows are in agreement with predictions⁸ based on resonance parameters. When such thick samples are used, small amounts of oxygen or water can reduce the transmission significantly. For a $1/E$ reactor flux, the relative importance of each window can be estimated from the plot of transmission vs log energy.

Fig. 1. Transmission of ^{58}Ni ($N = 0.60$ a/b, 99.9%).

Fig. 2. Transmission of ^{60}Ni ($N = 0.65$ a/b, 99.7%).

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The transmissions of the ^{64}Zn ($N = 0.35$ a/b, 97.9%) and ^{184}W ($N = 0.41$ a/b, 94.5%) filters are shown in Figures 3 and 4. These measurements are useful for confirming the theoretical calculations and giving information on the higher energy windows. The measured transmissions of the lowest energy windows for both these filters are considerably lower than those calculated from the resonance parameters and the enrichments of the samples. An analysis for oxygen in the ^{64}Zn metal, showed that the oxygen content of 0.8% would only account for about 15% of the discrepancy. Hence, the discrepancy is most likely due to hydrogen in the form of a hydroxide. The presence of hydrogen in the ^{184}W sample is also suspected, since the metal was plated out of an aqueous solution.

Fig. 3. Transmission of ^{64}Zn ($N = 0.35$ a/b, 97.9%).

Fig. 4. Transmission of ^{184}W ($N = 0.41$ a/b, 94.5%).

The transmission of the Los Alamos Sc + Ti filter is shown in Figure 5. The cross section of Sc in the region of 2 keV compared to that reported by ENL/RPI is shown in Fig. 6. The cross section of Sc derived from the Los Alamos filter at the 2-keV minimum is 0.41 ± 0.02 b. Spectroscopic analysis of the Los Alamos sample showed the presence of Mn (105 ppm), Ta (70 ppm), V (40 ppm) and Er (20 ppm) impurities. After correcting for the Mn impurity (but not for the possible presence of hydrogen or oxygen) a value of 0.36 ± 0.03 b was obtained. This is considerably lower than the ENL/RPI value of 0.71 ± 0.03 b which had been corrected for hydrogen, oxygen, and tantalum impurities.

Fig. 5. Transmission of Los Alamos Sc Filter (44.26 cm Sc + 1.0 cm Ti, ($N_{\text{Sc}} = 1.736$, $N_{\text{Ti}} = 0.057$)).

Fig. 6. Total cross section of "impure" Sc.

Transmission measurements on the Sc_2O_3 sample when corrected for the oxygen contribution (measured by using samples of BeO and O), gave a value of 0.47 ± 0.04 b, uncorrected for any impurities in the sample. Our value of 0.36 ± 0.03 b for the LANL Sc is somewhat higher than the recently reported values of 0.26 ± 0.07^6 and 0.24 ± 0.07^7 b but significantly lower than the value obtained for the BNL Sc.

Conclusions

Neutron filters at reactors for producing monoenergetic neutron beams of intermediate energies have been useful in the past and will continue to be in the future. Neutron filters of isotopes such as ^{50}Ti , ^{64}Ni , ^{64}Zn and ^{184}W have unique characteristics, and will probably be used for special applications. Neutron filters combined with a pulsed neutron source is also a valuable technique.

There is still some uncertainty in the minimum of the total cross section of ^{56}Fe at 2.0 keV because of the possibility of impurities in the sample. Experimenters planning to use thick filters should obtain highly pure samples since thick samples are needed, and the transmission of the filter they plan to use should be measured.

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