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NEUTRON ELASTIC AND NON-ELASTIC SCATTERING STUDIES IN TENS OF MeV REGION

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Abstract - Experimental data have been obtained on the neutron elastic scattering cross sections for 55, 65 and 75 MeV neutrons, and non-elastic scattering cross sections for 40 to 80 MeV neutrons using the ^{7}Li(p,n) neutron source at TIARA of Japan Atomic Energy Research Institute and the TOF method. Data were obtained for C, Si, Fe, Zr, and Pb of natural elements. Elastic scattering data were obtained for 25 laboratory angles between 2.6 and 53.0 that clarified the angular distributions and angle integrated values. The data obtained were compared favorably with recent LA150 data library.

INTRODUCTION

Neutron scattering plays a fundamental role in neutron transport. Therefore, precise data are required for the neutron transport analysis in the nuclear and shielding design of high energy accelerator systems, and in the protection from high energy cosmic radiations. In the neutron shielding benchmark experiment for 67 MeV neutrons, data are reported which suggest serious problem in the neutron scattering data built in the transport code [1].

The data for the neutron elastic and non-elastic scattering are important also as the reference data for nuclear data evaluation because they provide the constraints for the reaction cross section and the neutron optical model potential (OMP) which are the basic tool for the evaluation.

For these reasons, reliable experimental data are required for the elastic and non-elastic scattering of fast neutrons over a wide energy region. In the energy region above 25 MeV, however, only very few experimental data have been reported partly because of lack of a mono-energetic neutron source suitable neutron scattering experiments in the energy region.

We have set up a new experimental arrangement for the measurement of neutron elastic scattering angular distributions at the 40-90 MeV ^{7}Li(p,n) quasi-mono-energetic neutron source in TIARA of Japan Atomic

Energy Research Institute (JAERI) [2], and carried out measurement for C, Si, Fe, Zr and Pb of natural element at 55, 65 and 75 MeV employing the time-of-flight (TOF) method to select elastically scattered neutrons. By taking advantage of a wide space at the TIARA facility, data can be obtained with good angular resolution for a wide angular range (2.6-53.0°). The data clarified the angular distribution and provided the angle-integrated one.

In addition, using the source and the transmission method with a "close geometry", we have measured too the non-elastic neutron cross sections for five elements mentioned above in the 40 to 80 MeV region. The results were consistent with those derived from our elastic-scattering data and the well known total cross section.

The data were compared with the data files, built in data in the code, and systenmatics and evaluated data.

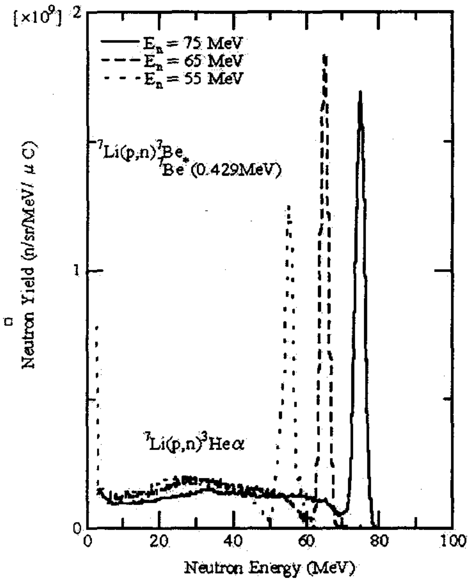

Fig.1. The source neutron spectra at TIARA

EXPERIMENTAL FACILITY

The experiments were carried out at TIARA, JAERI. At TIARA, a proton beam from a K=110 AVF cyclotron is transported to a ^{7}Li target (99.8%, ~ 2 MeV energy loss). Protons after the target are bent by a deflection magnet into a shielded Faraday cup. Proton beam current was around 1.5μA. As shown in Fig.1, the source neutron spectrum consists of a peak due to the ^{7}Li(p, $n_{0,1}$) processes and a continuum component attributed to multi-body breakup processes [2]. The neutron production rate was monitored with a beam current in the beam dump Faraday cup, and the count rates of fission chambers placed around the target. The neutron yield and the energy spectrum were reported in Ref. [2].

ELASTIC SCATTERING EXPERIMENT

Figure 1 shows a layout of the setup for the neutron elastic scattering experiments. Details are described in Ref.3, 4. We adopted the TOF method to select the elastic scattering of the peak neutrons. Large iron blocks were used to shield background neutrons due to scattering around the collimator exit. Scattering samples were located ~10 m from the target. In this geometry, angular resolution was very good but the energy resolution was not adequate to separate the elastic neutrons from the inelastic ones because of relatively short flight path for secondary neutrons. Therefore, experimental data were corrected for the effect of inelastic neutrons by use of the evaluated nuclear data LA150 that proved to be adequate as described in the later section. The contribution of the continuum source neutrons to the elastic scattering

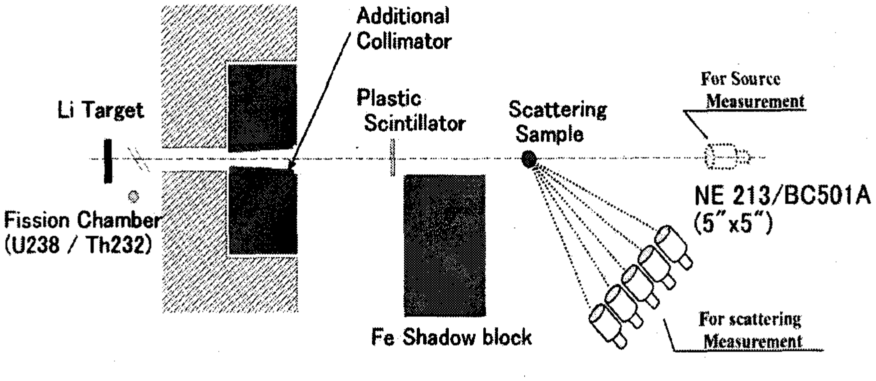

Fig. 2. The experimental arrangement.

of peak neutrons could be ignored (< 1 %). The absolute cross-sections were determined relative to the incident neutron flux by measuring the flux with the detectors for scattered neutrons. In this method, the uncertainty introduced by the error of the detector efficiency is very small because the energies of incident neutrons and scattered neutrons are very close.

Neutron spectra were measured using five liquid scintillation detectors, NE213 and BC501A of 12.7-cm-diam × 12.7-cm-long, incorporated with n-γ discrimination. The TOF spectra were obtained at five laboratory angles concurrently and total angular points were 25 between 2.6° and 53° . In front of each detector, a lead plate (8 mm thick, equivalent to the range of 100 MeV protons) was attached to stop charged particles. The flight paths were around 5 m at very forward angles and ~ 2 m for other angles. Owing to the well-collimated neutron beam and the relatively long sample-detector distances, it was possible to obtain data at very forward angle up to 2.6° . The angular spreads of the detector were around 0.7° for the most forward angles and 1.7° for the backward angles, resulting in very good angular resolution. We employed a CAMAC system for the data acquisition. A set of three data for TOF and two pulse-height data (total and slow components) was acquired event by event for each detector. The detector anode signals were fed into a QDC (charge-to-digital converter) and integrated by two different integration gates for n-Ɣ discrimination, total component and for a slow component. The TOF spectrum was obtained from the time difference between the anode signals and a cyclotron RF signal by using a TDC (time-to-digital converter).

The scattering samples were cylinders of natural elements, carbon (5-cm-diam × 8-cm-long), silicon (4- cm-diam × 4-cm-long), iron (4-cm-long × 6-cm-long), zirconium (3-cm-diam x 5-cm-long) and lead (3-cm-diam x 6-cm-long). The sample sizes were chosen as a compromise between the scattering yield and the sample-size effects. Samples were hung by nylon strings connected to a pulse-driven motor to enable remote control.

Measurements were done for samples and sample-out to eliminate sample independent backgrounds. Scattering angles were changed by rotating the detector array around the scattering sample. To deduce absolute cross-sections, we also measured the incident neutron beam directly by the scintillation detectors. In the course of experiment, a thin plastic scintillator at the collimator exit monitored the stability of RF signals by measuring the source neutron TOF spectrum. Normalization between foreground and background runs was made using counts of fission chambers, and the beam current in the beam dump Faraday cup. They generally agreed within 3%.

The TOF spectra were deduced by off-line analysis of the event-by-event data with n-뷁 discrimination and pulse-height biasing. The pulse- height bias was set so as to avoid the interference of the frame overlap. In the case of the experiment at En = 75 MeV with the RF of 20 MHz, a bias of 40 MeV was chosen. The detector efficiency was calculated by a revised version of the SCINFUL code [5].

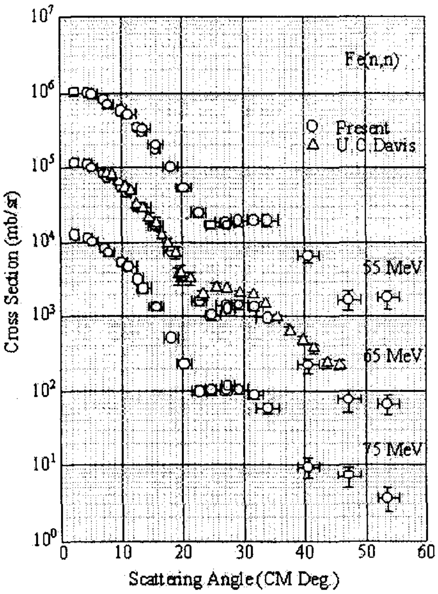

Fig. 3. The results for iron in comparison with the data of U. C. Davis group

The data were corrected for the effects of (1) the inelastic scattering and (2) the finite sample size, i.e. the flux attenuation and multiple scattering. The contribution of inelastic scattering was estimated by calculating the fraction of the elastic neutrons to the (elastic + inelastic) ones considering experimental energy resolution. Corrected results were obtained by multiplying the correction factor with raw data [6]. In this calculation, we employed the LA 150 [7] library that is an evaluated neutron and proton cross-section library up to 150 MeV. In the case of zirconium, the LA 150 data were not available, then (p,p′) experimental data were used. More details of data analysis are described in Ref.[3]. The elastic scattering angular distribution is strongly forward peaking, then inelastic neutrons do not affect the results appreciably at forward angles, but amount to 20 % around 30(and 40 % around 50(. The correction for sample size effects was done by Monte Carlo calculations described in Ref. [6], using the LA150 data.

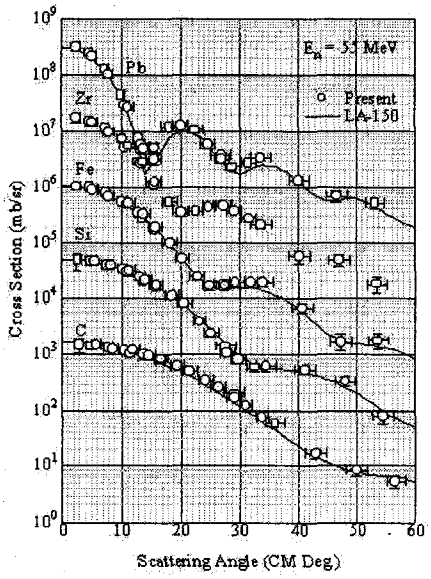

Fig. 4. The results at 55 MeV in comparison with LA 150

In Fig.2, our data for iron are shown in comparison with the data of U.C.Davis group [8,9] at 65 MeV. The U.C.Davis data were measured using a ^{7}Li(p,n) neutron source and a multi-wire recoil proton telescope [8].Our data are in general agreement with U.C. Davis data but show steeper forward peaking than the latter owing to better angular resolution. The present experiment provided, therefore, the neutron elastic scattering cross-section data over a wider angular range with better angular resolution.

Figure 3 shows the experimental results at 55 and 65 MeV in comparison with LA 150 [7]. The data at 75 MeV are shown in Ref. [4,3]. The LA150 data reproduce the experimental data generally well, although they underestimate the lead data in very forward angles by 10 to 20 %. As noted in Ref.[3], however, data in DLC 119/HILO 86 multi-group library, and cascade codes show very large differences from the present data and proved to be the cause of the problem found in the benchmark experiment [1].

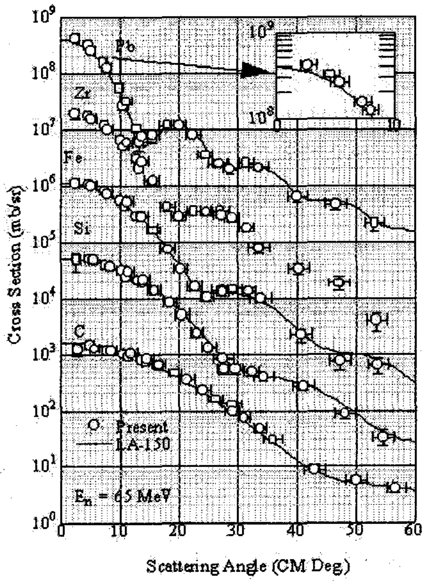

Fig. 5. The results at 65 MeV in comparison with LA 150

NON-ELASTIC SCATTERING EXPERIMENT

Non-elastic neutron cross sections were measured between 40 and 80 MeV employing the transmission method with a "close geometry" using the ^{7}Li(p,n) source. The experimental geometry is shown in Fig.6. A neutron beam was collimated to 1-cm in diameter with an iron collimator, and incident on the transmission samples. The samples were 2-cm in diameter with thickness giving transmission of 0.8 to 0.9 (3 - 4 cm).

A large area plastic scintillation neutron detector, 20-cm-diam and 7.6-cm thick, was placed 12 or 18 cm behind the sample. In this geometry, the detector subtended an angle of 30 to 40 deg. to the sample, and detected most (95 % typically) of the elastically scattered neutrons as well as transmitted neutrons. Thus, the neutron transmission data provides the non-elastic cross section after several corrections.

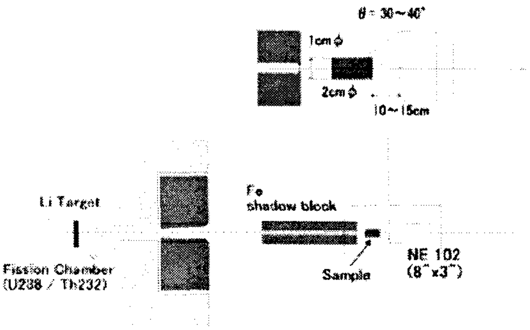

Fig. 6. The experimental geometry in non-elastic neutron cross sections measurements

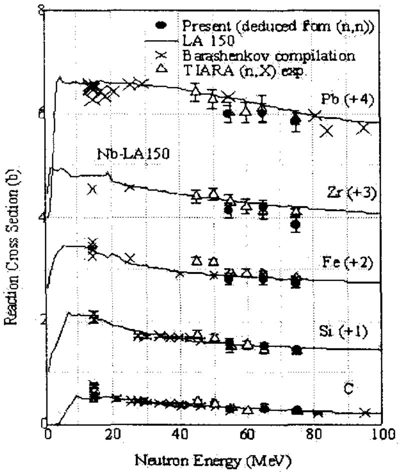

Fig. 7. The present results together with other experimental data and LA 150

Experimental data were corrected for the effects of 1) neutrons elastically- scattered outside the detector, 2) neutrons inelastically-scattered within the detector, and 3) neutrons elastically scattered into the detector but not detected due to multiple-scattering. The correction was done using experimental data or LA-150.

The present results are shown in Fig.7 together with other experimental data and LA150. The present results are consistent with those derived by subtracting our experimental elastic cross section from the well-known total neutron cross section. The fact confirms the validity of the experiments on elastic and non-elastic measurements. The LA150 data are in general agreement with the present one for C, Si, Fe but larger by about 15 % for Pb in the 50 -80 MeV region. This is also consistent with the observation in the comparison of the elastic scattering data that LA150 values of elastic scattering is smaller by about 15 % .

SUMMARY

Neutron elastic and non-elastic scattering cross sections were measured for 55, 65 and 75 MeV neutrons and 40-80 MeV neutrons, respectively, using the ^{7}Li(p,n) neutron source at TIARA, JAERI and the TOF method. For the elastic scattering, a new experimental arrangement enabled the data from very forward angle of 2.5° to 53° with very good angular resolution. Non-elastic scattering data were obtained with a transmission method and the results were consistent with the elastic-scattering data. The present data indicated that LA150 provides fairy good reproduction of the present experiment. Then, it is expected that LA150 will provide reliable prediction for neutron transport calculations for various purposes.

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