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TOTAL CROSS SECTION MEASUREMENTS FOR HIGH ENERGY NEUTRONS UP TO 75 MeV AND TRANSMISSION EXPERIMENT FOR THE NEUTRONS THROUGH CONCRETE SHIELD

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Abstract: This paper reports measurements of high energy (i.e., $E_n \leq 75$ MeV) neutron spectra transmitted through concrete shields. A collimated beam of neutrons induced by 75-MeV protons in a thick Cu target was utilized in the measurements. The beam was injected to concrete shields of 40 cm by 40 cm in cross section and 20, 50 and 100 cm in thickness and neutrons transmitted through the shields were detected by an NE-213 scintillator.

Monte Carlo calculations by MORSE were carried out with the DLC-87 Hilo multigroup cross sections. It was found in the comparison between the measured and calculated spectra that the calculation with the above data gave overestimation to the measured data by a factor of two to three, whereas the shape of the spectrum was reproduced well.

Total cross sections of C, O, Si, Fe, Mo and Pb were measured in the energy range 25-70 MeV by the same neutron beam. The obtained data agreed well with other measured data. Slight disagreement was observed between the DLC-87 data and the measured data.

(high energy neutron, transmission, concrete, benchmark test, accelerator shielding)

Introduction

At present time, the shield design of medium-energy accelerators up to a few hundreds MeV is being made/1,2/ based on the DLC-87 Hilo/3/ multigroup cross section data. The evaluation of the above cross section data was made depending on model calculations/3/ in particular in estimating elastic and nonelastic cross section data above 15 MeV. Since there is no neutron transmission experiment which can be utilized to benchmark cross section data in the energy range beyond 30 MeV, the accuracy of the shielding design made based on the above cross sections is not well known.

In our previous works/4,5/, the transmitted neutron spectra through a few materials were measured in the energy range up to 30 MeV and the DLC-87 data were found to give good agreement with the measured data.

The objective of this work is to extend the previous works to higher energy range up to 75 MeV. Transmitted neutron spectra through concrete shields are measured and the DLC-87 Hilo cross section data are benchmarked by the measured data. At the same time, the total cross sections of several materials relevant to the shielding are measured.

Experimental Method

The experiment was made at the AVF cyclotron facility of Osaka University. A 1-cm thick (i.e., proton stopping range) Cu target was irradiated by 75-MeV protons and generated neutrons in the forward direction were pulled out to an experimental room through a 7.5-cm diameter iron-lined concrete collimator of 50-cm thickness. The experimental setup for the transmission

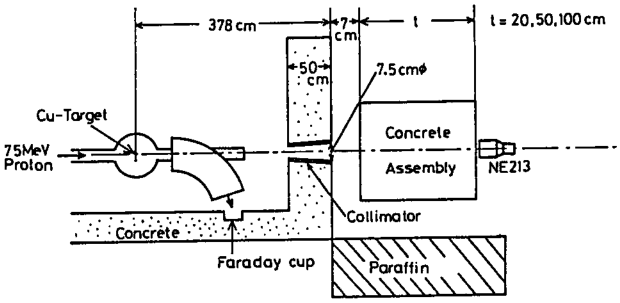

Fig. 1 Experimental setup for neutron transmission measurement

Table I Atomic Composition of Concrete

Element	Density(1/cm^3)	Element	Density(1/cm^3)
O	4.32E+22^a	Fe	4.45E+20
Si	1.25E+22	Mg	3.75E+20
Ca	3.50E+21	K	4.34E+20
H	1.41E+22	Na	7.44E+20
Al	2.29E+21		

^{a} Read as 4.32×10^{22}

neutron measurement is depicted in Fig. 1. Concrete systems of 40 cm by 40 cm in cross section and 20, 50 and 100 cm in thickness were set at locations very close to the collimator exit. The atomic density of the concrete was chemically determined as shown in Tbale I.

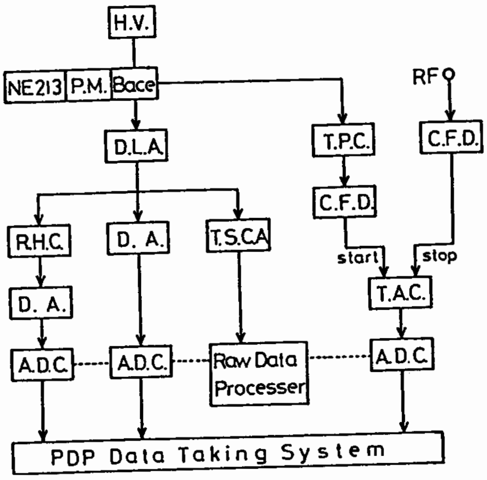

Fig. 2 Blockdiagram of measuring system

Transmitted neutrons were measured just behind the concrete system by a 3-inch (7.6 cm) diameter by 3-inch height NE-213 scintillator with an aid of a n-γ discrimination circuit. The background data was obtained in the same condition except the collimator was closed by an iron plug. Figure 2 illustrates the blockdiagram of the measuring circuits. Obtained pulse-height spectra were unfolded to neutron energy spectra by FERDO method/6/ with Monte Carlo calculated response data/7/.

The total cross section measurement was made in a similar experimental setup for natural elements of several shield relevant materials, i.e., C, O, Si, Fe, Mo and Pb. Water was utilized for the measurement of the O data. Thin samples of these materials up to 1-mfp thickness for 60-MeV neutrons were set at 30 cm from the collimator exit and the decrease in the neutron energy flux by the samples was detected by the time-of-flight method with the NE-213 being located 3.7 m down from the sample. The electronics circuits for the time-of-flight measurement are included in Fig. 2.

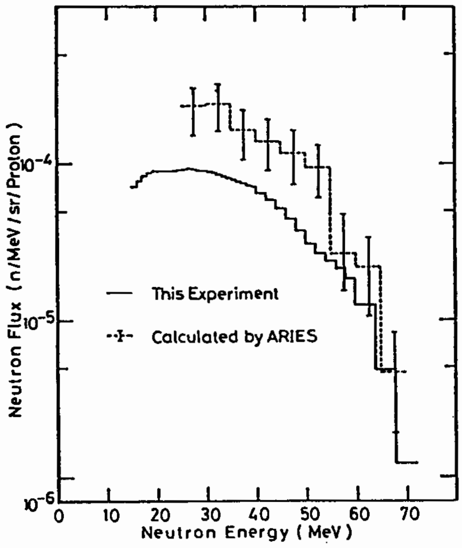

Fig. 3 Emitted neutron spectra from Cu target in the forward direction

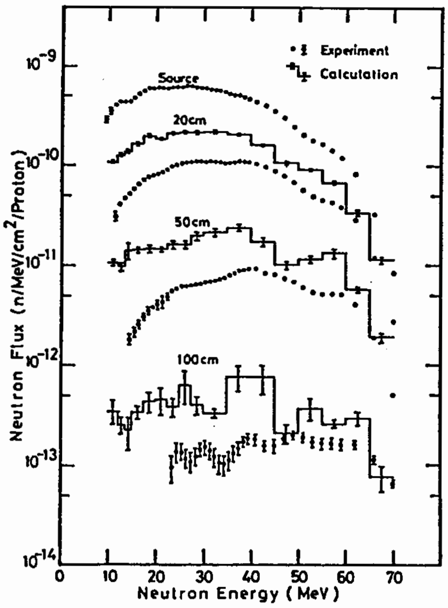

Fig. 4 Transmitted neutron spectra through concrete shields

Total cross sections of the materials were directly deduced from obtained attenuation curves of energy fluxes. The influence of scattered neutrons on the cross sections was tested represetatively for a 3-cm thick Fe sample by a Monte Carlo calculation with the DLC-87 cross section data. It was found in the energy range 30-70 MeV to be less than 0.5 %.

Results

Calculational Method

The neutron transport in the concrete system was calculated by the MORSE code/8/ with the DLC-87 Hilo multigroup cross section data in a geometrical model which simulated the experimental setup as closely as possible. The source spectrum measured without the concrete system was utilized in the calculation.

Results and discussions

Figure 3 shows comparison of the measured source spectrum with one computed by the ARIES code/9/ based on the empirical fits to the results of the intranuclear cascade evaporation model calculations/10/. Error bars of the measured spectrum provided by the FERDO are very small and not visible in the figure. However, the unfolded spectrum may include some more errors due to inaccurate knowledge on the response matrix of the scintillator at energies above 15 MeV. The factor of three overestimation is observed for the intranuclear cascade calculation as compared with the measured data. The spectral shape is well reproduced by the calculation.

Figure 4 shows comparison of measured and calculated transmitted neutron spectra through the concrete systems. The calculation overestimates the measured values by a factor of two to three, the trend being signified as the concrete thickness is increased. This is shown more clearly in Fig. 5 by the attenuation profile of the partial flux of the energy range $E_n \geqq 20$ MeV. The better agreement is seen for the flux of the higher energy range above 40-MeV.

The water content in the concrete may vary from time to time and this may affect the

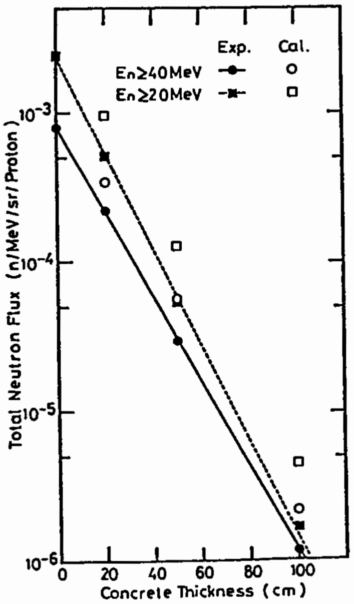

Fig. 5 Attenuation of neutron partial fluxes by concrete shield

attenuation feature of neutrons. A concrete block taken from the experimental system was heated up to 100°C and kept at the temperature for 1 hour to remove free water from the concrete. The decrease in the weight was 5.6 %. The neutron spectrum calculation was made without the above 5.6 % free water and the results are shown in Fig. 6. The variation in the spectra due to the neglection of the free water is not large. Since expected variation in the free water content at the room temperature is much smaller than 5.6 %, its influence on the neutron attenuation should be very small.

The attenuation of neutrons in the shield is described empirically by a removal cross section, σ_r;

$$\sigma_r = \sigma_t - \sigma_e - k\sigma_{non} , \qquad (1)$$

where σ_t is the total cross section, σ_e the elastic cross section, and $k\sigma_{non}$ the secondary neutron yield in the forward direction by nonelastic reactions.

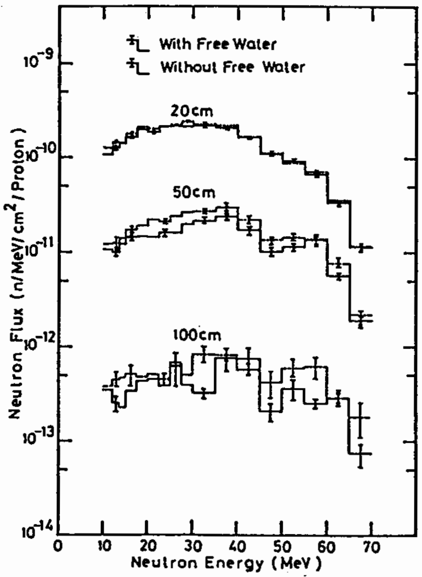

Fig. 6 Impact of free water content on transmitted neutron spectra

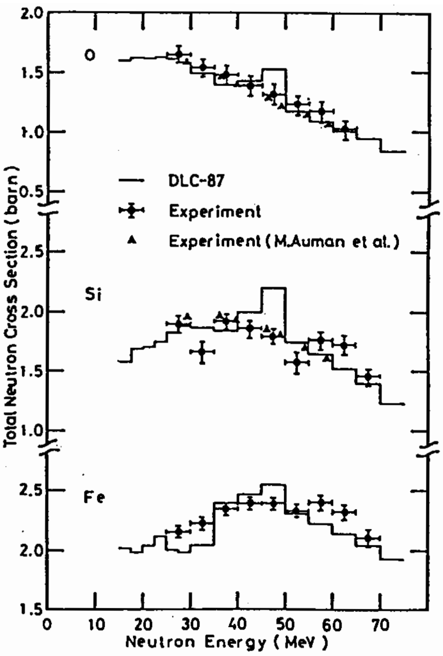

Fig. 7 Total cross sections of O, Si, and Fe

The total cross sections of major elements in the concrete, i.e. O, Si and Fe are shown in Fig. 7. The DLC-87 data agree well with measured values of this work and other experiment/11/ within experimental errors, except that slight overestimation is observed at energies 45-50 MeV for the three materials, and slight underestimation is seen at 25-35 MeV for Fe.

Since the total cross sections in the DLC-87 are in fairly well agreement with the measured data, the reason for the underestimation of σ_r should be in σ_e or $k\sigma_{non}$. As was seen in Fig. 3, the intranuclear cascade evaporation model, which the DLC-87 evaluation depended on in estimating σ_{non} values, tends to overestimate

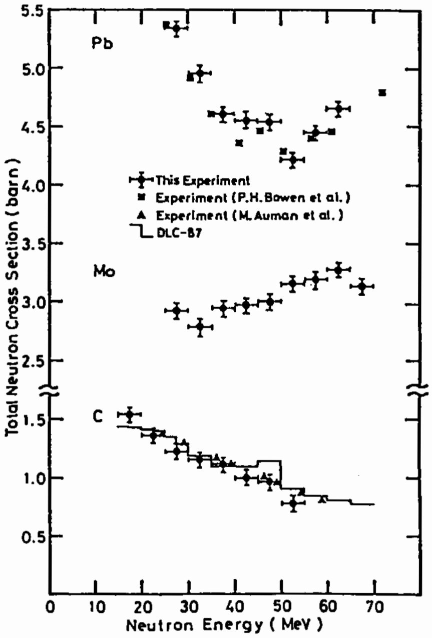

Fig. 8 Total cross sections of Pb, Mo, and C

the particle-emission yield in the forward direction. The angular distribution of the secondary neutron yield should be checked by measurements.

The results of the total cross section measurements for other elements are shown in Fig. 8. The present data for C and Pb are in good agreement with other measured data/11,12/. The DLC-87 data of C are slightly higher at 50 MeV.

Conclusions

The transmitted neutron spectra through the concrete were overestimated by the DLC-87 cross section data by a factor of two to three. Since the total cross section data in the DLC-87 agreed fairly well with the measured ones, the reason for the overestimation of the transmitted neutrons might be in the secondary neutron emission yield.

Slight discrepancies were observed, when the data were examined in more detail, in the evaluated total cross sections of the DLC-87 from the measured data around 30 and 50 MeV for Fe, Si, O and C.

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