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CALCULATION OF THE FLUX ATTENUATION AND MULTIPLE SCATTERING CORRECTION FACTORS IN TIME OF FLIGHT TECHNIQUE FOR DOUBLE DIFFERENTIAL CROSS SECTION MEASUREMENTS.

Abstract. Using Monte Carlo technique, a computer code which simulates the time of flight experiment to measure double differential cross section was developed. The correction factor for flux attenuation and multiple scattering, that make a deformation to the measured spectrum, were calculated. The energy dependence of the correction factor was determined and a comparison with other works is shown. Calculations for Fe^{56} at two different scattering angles were made. We also reproduce the experiment performed at the Nuclear Analysis Lab. for C^{12} at 25°and the calculated correction factor for this measured is shown. We found a linear relation between the scatter size and the correction factor for flux attenuation.

INTRODUCTION.

The measurements of double differential cross section in neutron induced reaction is performed using monoenergetic neutrons coming from a point source, that impinge a cylindrical scatter. The temporal spectrum of scattered neutrons is obtained in a detector place at some distance of the scatter. Varying the detector position it is possible to obtain the temporal spectrum for different scattering angles.

To reach good enough counting rate and signal to noise ratio, it is necessary to employ large scatter samples, but this produces flux attenuation and multiple scattering. Both effects cause deformation to the measured spectrum. For that reason, it is require calculation for these effects. There is a balance between the statistical requirements and the correction introduced to the measurements. For 1.5 MeV neutrons a 75% of transmission is a good value to get such balance, but this value is energy dependent.

In this kind of experiment it is very difficult to find the real flux in the sample, consequently the calculation is performed using the flux in the center of the sample when it is removed. Due to the scattering and the decreasing of the flux with the square of the distance, the flux is different at any point of the sample. The measured cross section is lower than the real one in a factor defined as the correction factor for flux attenuation.

By the other hand, the measured spectrum has the information for all the reaction where neutrons are present at the output channel, including multiple scattering process. However we are only interested in (n,n_o) and (n,n') reactions, but the score for the remainder reaction should be keep to compare with the experiment. This magnitude defines another correction factor, called multiple scattering correction factor.

Many papers have been dedicated to calculate these corrections [1-6], where analytical approximation or Monte Carlo method has been implemented. In our case, analytic method is useless and direct Monte Carlo simulation was performed. A Monte Carlo code was developed to simulate the experiment and it calculates the correction factors depending on the energy. We also compared with the measurements reported by Takahashi [7]. Finally we calculated the correction factor for a measurement done in our laboratory for C^{12} at 25° of scattering angle.

THEORETICAL FORMULATION.

Nuclear data require.

To obtain the correction factor it is necessary to make a numeric experiment that simulates the real one. If this process is successful, then from the initial set of data used, it is possible to determine the correction factor. To make the simulation, all the nuclear data involving neutron reaction are needed; it means data of total cross section, elastic and inelastic cross section, (n,xn), and fission cross section. Angular distribution for all this process and some of the excitation function and emission spectra also are required. All the data were obtained from the IAEA nuclear data library, ENDF format [8]. The data were tabulate with an energy step of 0.1 MeV, in the 0.1 to 15 MeV range.

Simulation of the experiment.

Our neutrons' source is a D+T neutron generator. The neutron spectrum and the spatial distribution of the neutrons coming from the source were calculated using the program CONO [9], which simulates the neutron generator output. When a neutron of define energy, weight, and spatial directions, reach the cylindrical scatter then begin the "history" of such neutron. This neutron is followed for the sample until it leaves the scatter or it will be absorbed on it. Every time the neutron interacts on the scatter the score is calculated and recorded. The score $S_j(E')$ represents the neutron density for the j reaction and it is define as follow:

$$S_j(E') = W_i \cdot \nu_j \cdot \sigma_j(\theta) \cdot \exp[-R/\lambda(E')] \cdot \varepsilon(E')$$

where:

W_i is the neutron statistical weight;

$\varepsilon(E')$ is the detector efficiency function;

ν_j is the number *x* for the reaction (n,xn);

$\sigma_j(\theta)$ is the angular distribution;

$\exp[-R/\lambda(E')]$ is the probability for the neutron escapes from the scatter with no further interaction. R is the remaining distance in the scatter and $\lambda(E')$ is the mean free path for a neutron of energy E' in such material.

The scattering energy E' was calculated using a relativistic kinematics for neutron reaction reported in the paper [10], for elastic and discrete level inelastic scattering. For the inelastic scattering to the continuum and (n,xn) process the energy was obtained from a random sampling using the emission spectra.

System resolution.

The scoring process produces a raw energy spectrum with no attention to the spectrometric resolution of the system. The temporal resolution of the system Δt could be obtained from the half width of the elastic peak in the measured temporal spectrum. Knowing this quantity, the flight distance X, the refraction coefficient of the scintillator h and the half width of the scintillator ΔX, it is possible to calculate the energetic resolution of the detector ΔE as a function of energy.

$$\frac{\Delta E}{E} = \frac{(E+M)(E+2M)}{M^2}\sqrt{\left[\frac{\Delta X}{X}(1-\eta\beta)\right]^2 + \left[\frac{\Delta\tau}{T}\right]^2}$$

$$E = M\left[1 \Big/ \sqrt{1-\left(\frac{X}{cT}\right)^2} - 1\right]$$

Then the spectrum is redistributed for each energy channel, sampling from a Gaussian distribution with a dispersion ΔE. In this way it was obtained a spectrum comparable with the experiment. Besides, it also modifies the correction factor, because of new neutrons appears in some part of the spectrum when there was no count before.

Correction factors.

The multiple scattering correction factor, $C_m(E)$, is obtained dividing the primary spectrum by the total one. The primary spectrum is formed by the neutrons that interacts ones in the scatter and the scattering processes are (n,n_0) and (n,n').

Various methods have been proposed [2-6] to calculate the correction factor for flux attenuation. We used a simpler and general method. It calculates the flux without sample F_0, considering the spatial distribution of the neutron beam for N neutrons. Subsequently, using the results of the simulation of N_i neutrons that interact ones on the sample, where $N_i < N$, the average flux on the sample is compute as:

$$F = \frac{N_i \cdot \lambda(\overline{E})}{V}$$

where $\lambda(\overline{E})$ is the neutron mean free path for the interaction average energy $\overline{E}$ and V is the scatter volume. Then the correction factor for flux attenuation is the fraction F_0/F. Finally the whole correction factor is:

$$\chi(E) = C_m(E)\frac{F_0}{F}$$

RESULTS AND DISCUSSION.

Figure 1 shows the comparison between the correction factor calculated by Takahashi [7] and our calculation. Takahashi used a nonmonocromatic spectrum, having a component in the lower part of the spectrum due to the neutron scattering on the target structure. For energies greater than 10 MeV the spectrum is continuum until 15 MeV, with a peak at 14.1 MeV, Fig 10. of Ref. [7]. Our calculation was performed using 14.1 MeV and the system resolution was considered as we mentioned above. The correction factors are very similar, taken into account that the data used in the simulation were different (Takahashi used the JENDL-3PR2, 1988). The differences in the lower part of the correction factor are because of the impurity on the Takahashi spectrum, but not present in this work.

Figure 2 shows the energetic conversion of the temporal spectrum measured at the Nuclear Analysis Lab for C^{12} at 25 degree of scattering angle and the simulation of the same experiment. In these spectra appear all the possible reaction in the experiment and it records all the events which the output was a neutron. Both spectra agree very well. This validates our calculation and then it is possible to use the correction factor calculated to correct the experiment. The correction factor for this experiment is shown in the Figure 3, and Figure 4 shows the contribution of multiple scattering process, in the lower part of the spectrum.

Figures 5 and 6 show the Monte Carlo calculation for Fe^{56} at two different scattering angles. At larger scattering angles the correction factor increases due to the decreasing of the scattering energy, hence, the interaction probability increase.

Figure 7 shows total and corrected angular distribution for the first excited level of Fe^{56}. The behavior is similar to the reported in other works [7], increasing the measured section at small angles, due to the isotropy of the multiple scattering component.

Finally, Figure 8 shows the dependence between the correction factor for flux attenuation and the scatter size. In the figure R is the cylinder radius and lambda is the mean free path. We obtain a dependence almost linear, and this type of graph is useful for choosing the optimum scatter size and minimizes the influence of the flux attenuation.

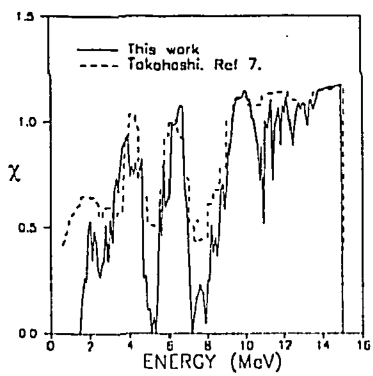


Fig. 1 Correction factors for C^{12} at 20°.

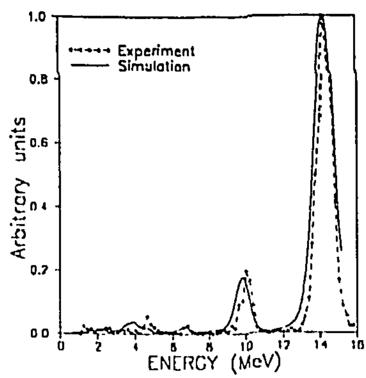
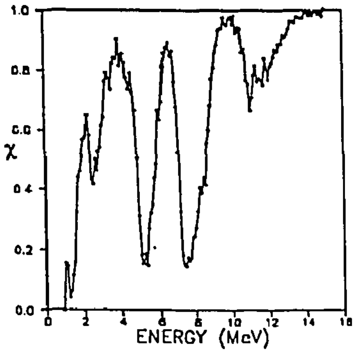


Fig. 2 Measured and calculated spectra for C^{12} at 25°.



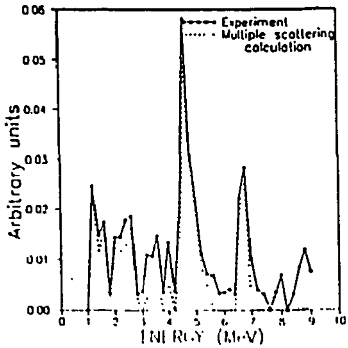
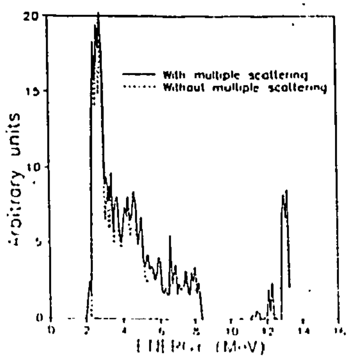


Fig.3 Calculated correction factor to the measured spectrum for C^{12} at 25°.

Fig.4 Multiple scattering contribution for C^{12} at 25°.



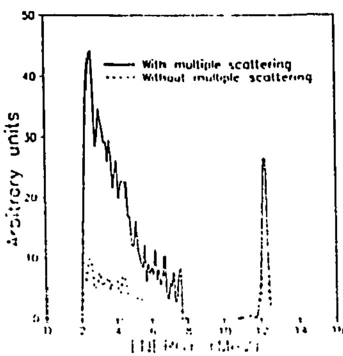


Fig.5 Calculated spectrum for Fe^{54} at 20°.

Fig.6 Calculated spectrum for Fe^{54} at 150°.

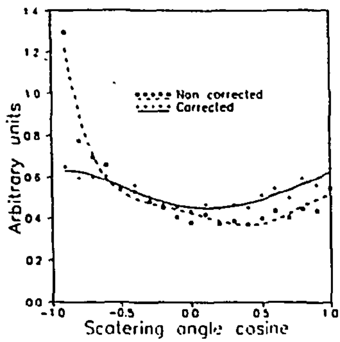


Fig. 7 Calculated angular distribution for Fe^{56}

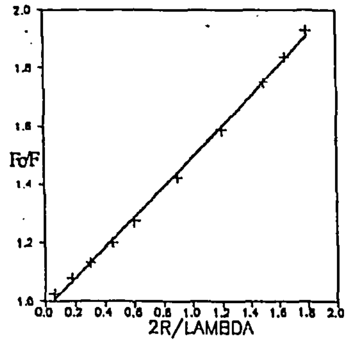


Fig. 8 Scatter's size influences on flux attenuation.

CONCLUSIONS.

It was developed a Monte Carlo code that simulates the interaction of a neutron beam with a cylindrical scatter and calculates the energy spectrum produced by this interaction. This program could be use to simulate experiments with time of flight technique and for other purpose relate to neutron transport problems.

We reproduced the results reported by Takahashi [7]. We compared the calculated spectrum for the C^{12} at 25° of scattering angle and the experimental one, obtaining a good reproducibility of the experiment. The correction factor for this measurement was calculated. Calculation for Fe^{56} was done at two scattering angles and the angular distribution for this nucleus was simulated and corrected. A linear dependence between the scatter size and the correction factor for flux attenuation was found.

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