Available at: http://publications.ictp.it IC/2010/064

United Nations Educational, Scientific and Cultural Organization
and
International Atomic Energy Agency

THE ABDUS SALAM INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS

STUDYING ANGULAR DISTRIBUTION OF NEUTRON FOR (p,n) REACTION FROM 0.5 GeV TO 1.5 GeV ON SOME HEAVY TARGETS ^{238}U, ^{206}Pb, ^{197}Au, ^{186}W

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MIRAMARE – TRIESTE
August 2010

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Abstract

The angular distributions of neutron are calculated for a spallation reaction induced by proton energy from 0.5 GeV to 1.5 GeV on target nuclei ^{206}Pb, ^{197}Au, ^{238}U, ^{186}W. In this report, we use nuclear data of JENDL-HE [1] with evaluated proton induced cross-sections up to 3 GeV. The obtained results have been discussed in detail.

INTRODUCTION

Studying neutron angular distribution from (p,n) reaction is very important for the reasons: From the obtained results, we will understand further (p,n) reactions on different target nuclei. Furthermore, (p,n) reactions have been proved [2] to be an excellent tool for studying spin-isospin excitation modes of nuclei. Angular distributions of the differential cross-section leading to the define states are analyzed with distorted wave Born-approximation.

There are many authors who have studied neutron angular distribution, for example, H.F. Arellano and W.G. Love have studied (p,n) reactions in the intermediate energy range [3,4,5,6,7]. These reactions are of great value in understanding the isovector modes of excitations of the nucleus, as well as the nuclear structure. As the experimental study for $^{6}Li(p,n)^{6}Be$ reaction has carried out at E_p = 50 ~ 80 MeV region of Kumagai et al. [4] that leading to states in the residual nucleus were measured. Petrovich and collaborator have reported [5] consistent folding model descriptions of nucleon elastic, inelastic charge-exchance scattering from $^{6,7}Li$ at 25-50 MeV….

In this work, we used nuclear data from available high energy [1] with the support of a simulation program to calculate angular distributions of the emitted neutron between angle 0^0 and 180^0 obtained on targets of ^{206}Pb, ^{197}Au, ^{186}W, ^{238}U with bombarding energies from 0.5 GeV to 1.5 GeV.

The obtained results will be compared with experimental data [9,10,12,13].

MODELING AND DISCUSSION

We have calculated the neutron emission cross-sections for a spallation reaction induced by proton energies from 0.5 GeV to 1.5 GeV on some targets using the MATLAB language with the nuclear data of JENDL-HE [1] based on the following general formula:

$$\sigma_i(E,E',\mu) = \sigma(E).y_i(E).f_i(E,E',\mu) \quad (1)$$

Where:

- i denotes one particular product
- E is the incident energy (eV)
- E’ is the energy of the product emitted (eV)
- σ(E) is the interaction cross section (barn)
- y_i is the product yield or multiplicity
- f_i is the normalized distribution with units (eV unit cosine-1)
- μ = cos θ ; μ [-1,+1]

We have the angular distribution of neutron calculated as follows:

$$\frac{d\sigma}{d\Omega} = \sigma(E\ )y(E\ )\sum_{i=1}^{32}\left\{(E_{i+1} - E_i)\frac{f_{i+1}(\mu, E\ , E'\ ) + f_i(\mu, E\ , E'\ )}{2}\right\} \tag{2}$$

With:

$\frac{d\sigma}{d\Omega}(barn/steradian)$: neutron production differential cross section.

The angular distribution of emitted neutrons from (p,n) reaction on targets ^{206}Pb, ^{197}Au, ^{186}W, ^{238}U in energy regions from 0.5 GeV to 1.5 GeV is illustrated in the following figures 1 to 6.

1) Angular distribution of neutron on different target nuclei with the same incident proton energy

a. Proton bombarding energy Ep = 0.5 GeV

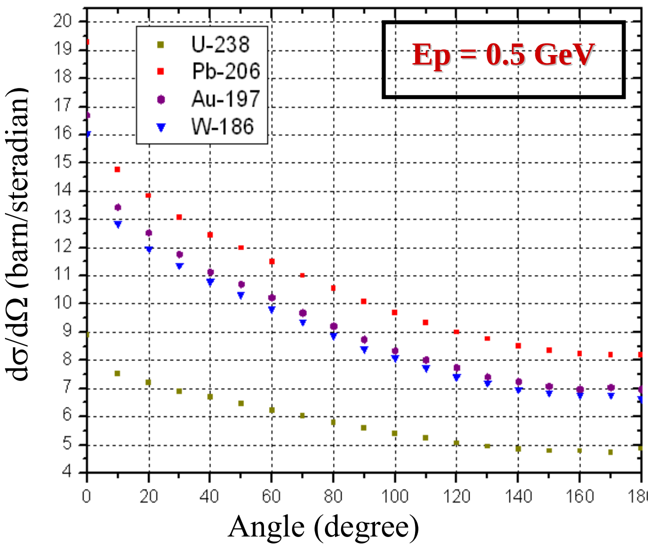

Fig.1: Neutron angular distribution from 0.5 GeV proton induced reaction on ^{238}U, ^{206}Pb, ^{197}Au, ^{186}W

We have the following remarks:

At 0.5 GeV, we can find:

- All the curves have the same behaviors but they have different values.
- The angular distribution of emitted neutron shows dominant forward angle emission with incident proton direction.
- Production cross section for reaction induced by 0.5 GeV on Lead target is the highest and the lowest is Uranium target.

b. Proton bombarding energy Ep = 0.6 GeV

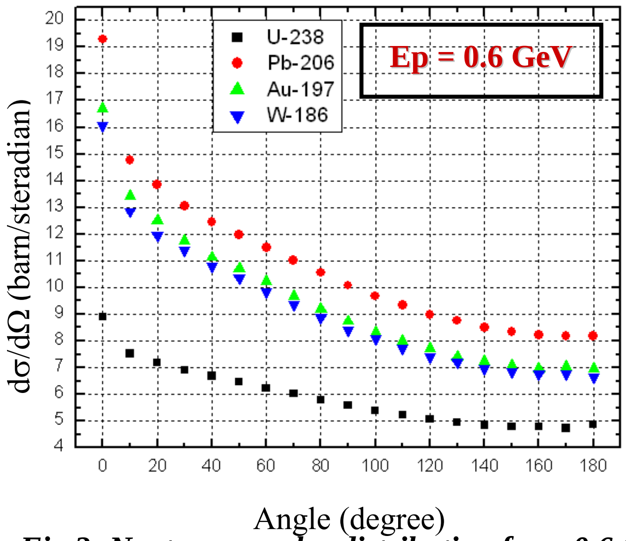

Fig.2: Neutron angular distribution from 0.6 GeV proton induced reaction on ^{238}U, ^{206}Pb, ^{197}Au, ^{186}W

From fig.2, we can see

- when incident proton energy increases, production cross section does too,
- production cross section for reaction induced by 0.6 GeV proton on Lead target is the highest, and Uranium target is the lowest.

c. Proton bombarding energy Ep = 0.7 GeV

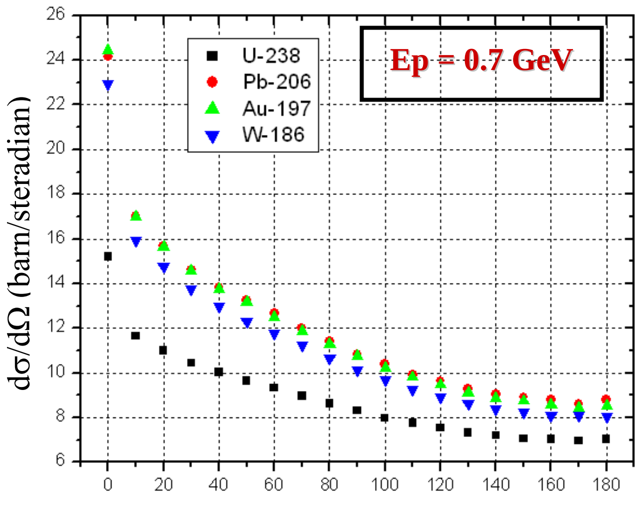

Fig.3: Neutron angular distribution from 0.7 GeV proton induced reaction on ^{238}U, ^{206}Pb, ^{197}Au, ^{186}W

From the calculation, we found that

At 0.7 GeV, production cross sections on Pb target coincide with production cross sections on Au target.

That means neutron production cross sections on Pb and Au targets are the same.

d. Proton bombarding energy Ep = 0.8 GeV

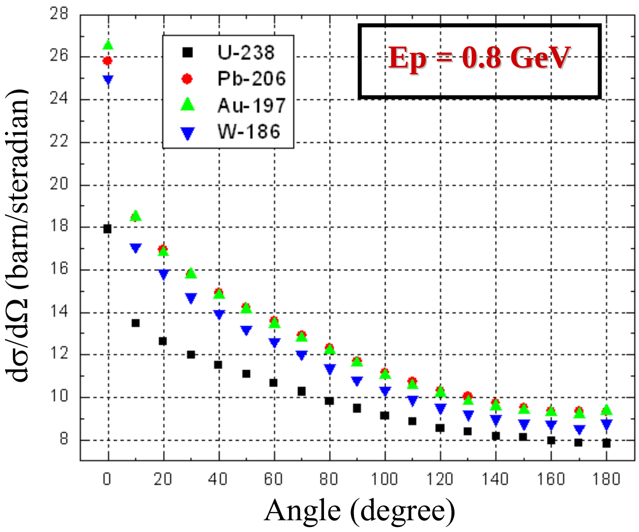

Fig.4: Neutron angular distribution from 0.8 GeV proton induced reaction on ^{238}U, ^{206}Pb, ^{197}Au, ^{186}W

Fig.4 shows that production cross sections on Pb and Au targets are the same.

e. Proton bombarding energy Ep = 1 Ge

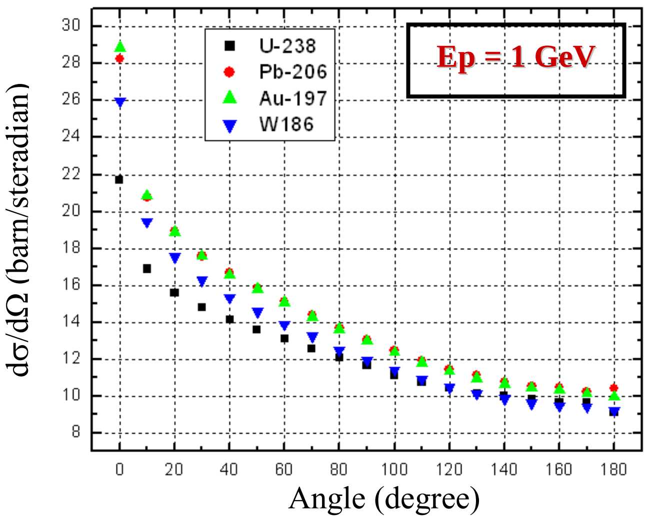

Fig.5: Neutron angular distribution from 1 GeV proton induced reaction on ^{238}U, ^{206}Pb, ^{197}Au, ^{186}W

Fig.5 shows that the production cross sections on Pb and Au targets are the same.

f. ***Proton bombarding energy Ep = 1.5 GeV***

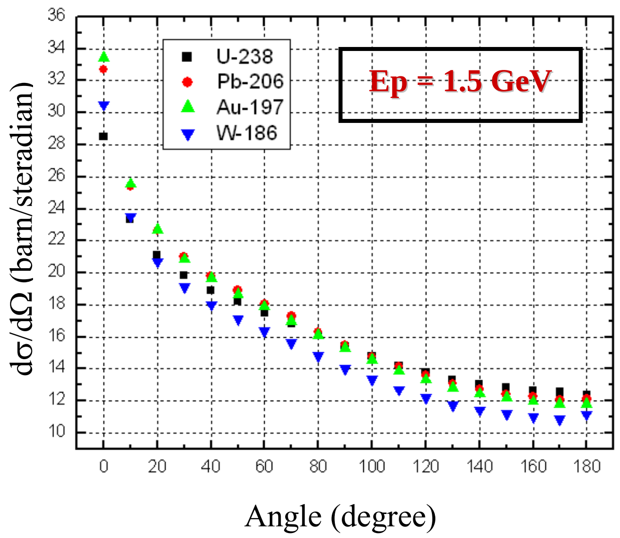

Fig.6: Neutron angular distribution from 1 GeV proton induced reaction on ^{238}U, ^{206}Pb, ^{197}Au, ^{186}W

2) Angular distribution of emitted neutron on the same target nucleus with incident proton energies

a. $^{206}_{82}$Pb ***target:***

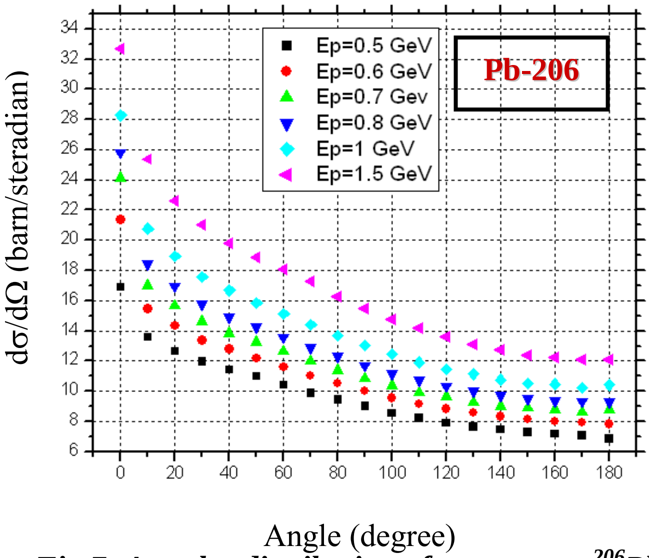

Fig.7: Angular distribution of neutron on ^{206}Pb target with incident proton energies

* At 0.5 GeV, we calculated:

Production cross section in the forward region is 16.8677 barn/steradian and back target region is 6.838barn/steradian, we have:

$$\frac{6.8385}{16.8677} = 0.4$$

That means: at 0.5GeV on Pb target, the production cross section at angle 0^0 is 2.464 times as much as the production cross section at 180°.

* At 0.6 GeV:

Production cross section in the forward region is 21.3549 barn/steradian and back target region is 7.8406 barn/steradian $\frac{7.8406}{21.3549} = 0.37$

* At 0.7 GeV:

Production cross section in the forward region is 24.1486 barn/steradian and back target region is 8.7872 barn/steradian $\frac{8.7872}{24.1486} = 0.36$

* At 0.8 GeV:

Production cross section in the forward region is 25.8251 barn/steradian and back target region is 9.3097 barn/steradian

$$\frac{9.3097}{25.8251} = 0.36$$

* At 1 GeV:

Production cross section in the forward region is 28.2696 barn/steradian and back target region is 10.4168 barn/steradian

$$\frac{10.4168}{28.2696} = 0.37$$

* At 1.5 GeV, we calculated:

Production cross section in the forward region is 32.7175barn/steradian and back target region is 12.1116barn/steradian $\frac{12.1116}{32.7175} = 0.37$

That means at 1.5 GeV on Pb target, the production cross section at 0^0 is 2.70 times as much as the production cross section at 180°.

b. $^{197}_{79}\mathrm{Au}$ ***target***

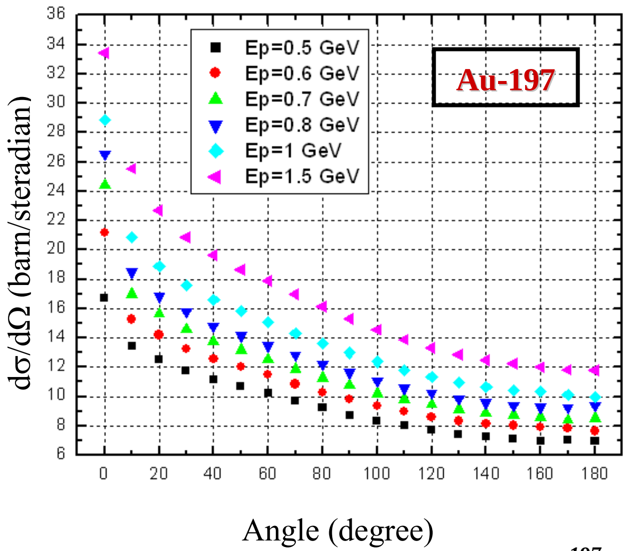

Fig.8: Angular distribution of neutron on ^{197}***Au target with incident proton energies***

* At 0.5 GeV, we calculated:

Production cross section in the forward region is 16.6932barn/steradian and back target region is 6.9706barn/steradian, we have:

$$\frac{6.9706}{16.6932} = 0.4$$

That means: at 0.5GeV on Au target, the production cross section at 0^0 is 2.39 times as much as the production cross section at 180°.

* At 1.5 GeV, we calculated:

Production cross section in the forward region is 33.4408barn/steradian and back target region is 11.8144barn/steradian

$$\frac{11.8144}{33.4408} = 0.35$$

At 1.5 GeV on Au target, the production cross section at 0^0 is 2.83 times as much as the production cross section at 180°.

c. $^{186}_{74}$W ***target***

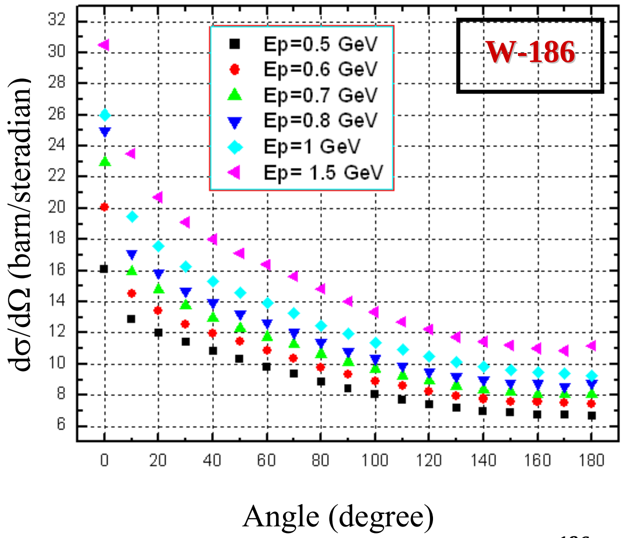

Fig.9: Angular distribution of neutron on ^{186}W target with incident proton energies

* At 0.5 GeV, we calculated:

Production cross section in the forward region is 16.0613barn/steradian and back target region is 6.6288barn/steradian, we have:

$$\frac{6.6288}{16.0613} = 0.4$$

That means: at 0.5GeV on Au target, the production cross section at 0^0 is 2.42 times as much as the production cross section at 180°.

* At 1.5 GeV, we calculated:

Production cross section in the forward region is 30.50331barn/steradian and back target region is 11.1737 barn/steradian

$$\frac{11.1737}{30.5033} = 0.37$$

At 1.5 GeV on Au target, the production cross section at 0^0 is 2.74 times as much as the production cross section at 180°.

d. $^{238}_{92}$U ***target***

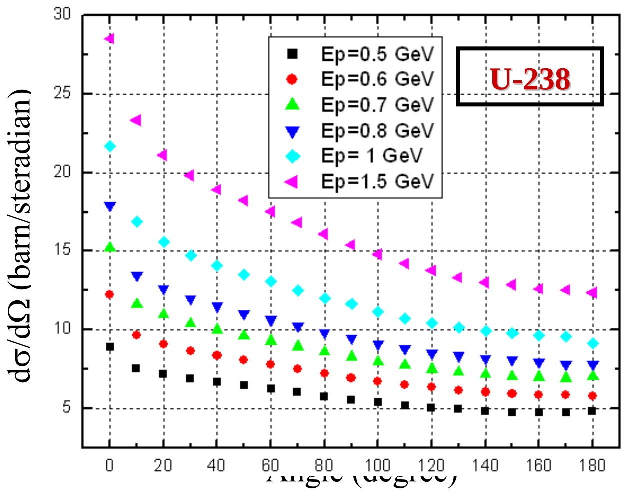

Fig.10: Angular distribution of neutron on ^{238}U target with incident proton energies

* At 0.5 GeV, we calculated:

Production cross section in the forward region is 8.9075 barn/steradian and region of back target is 4.865 barn/steradian, we have:

$$\frac{4.865}{8.9075} = 0.5$$

That means: at 0.5GeV on Au target, the production cross section at 0^0 is 1.8 times as much as the production cross section at 180°.

* At 1.5 GeV, we calculated:

Production cross section in the forward region is 28.5161 barn/steradian and region of back target 12.3856 barn/steradian

$$\frac{12.3856}{28.5161} = 0.43$$

At 1.5 GeV on Au target, the neutron production cross section at 0^0 is 2.3 times as much as the production cross section at 180°.

In short, from the calculation on some heavy targets with the bombarding energies from 0.5 GeV to 1.5 GeV, (figures 1 to 10) we can conclude that the neutron production cross sections in forward region are about 1.8÷2.5 times as much as the neutron production cross sections in back region of target.

3) Comparison with other works

From fig.11 a) the result of the group Sarkar and Maitreyee Nandy and others [11,12,13] we found that:

There is a big difference in the behavior and values between SDM model and the QMD model:

- QMD process shows a predominant forward angle emission;
- SDM process shows isotropic angular distribution with respect to the incident

proton direction.

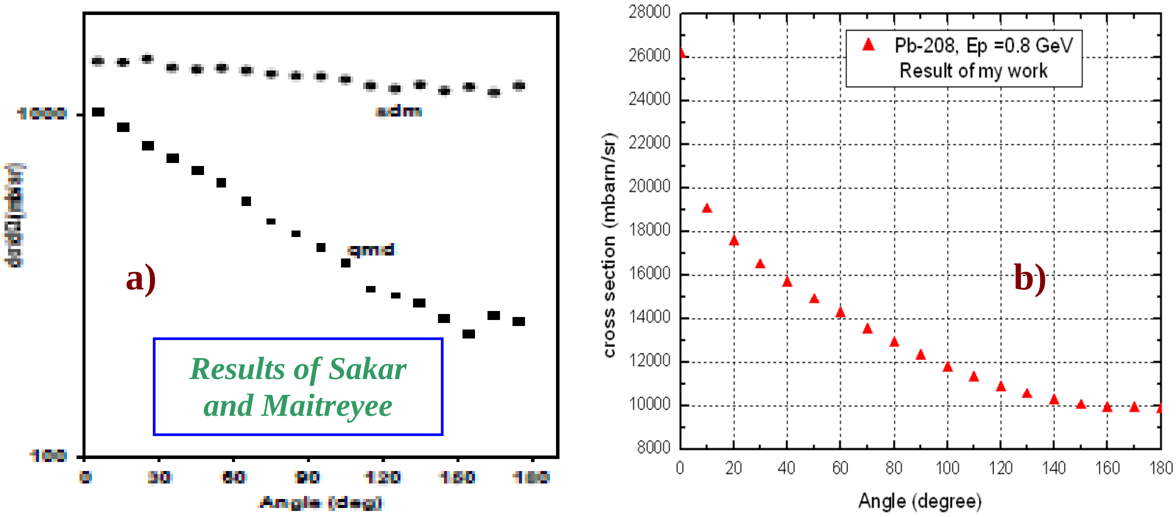

Fig.11: Angular distribution of emitted neutron on Pb-208 target with incident proton energy 0.8 GeV

The comparison between our result in fig.11 b) and results of Sakar and Maitreyee in fig.11 a) showed that

The behavior of the curve in our result is relatively like the behavior of the curve in the QDM model.

CONCLUSION

In this study, we calculated the angular distribution of neutrons emitted at angles from zero degree to 180 degree. From the investigation, we found that the neutron production cross sections in the forward region are about 1.8÷2.5 times as much as the neutron production cross sections in back region of some examined targets.

Our research could be used for designing the target and as well arranging fuel bars in the ADS [8,14].

Acknowledgments

This work was done within the framework of the Associateship Scheme of the Abdus Salam International Centre for Theoretical Physics, Trieste. Italy.

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