A study of neutron emission spectra and angular distribution of neutron from (p,n) reaction on some targets of heavy elements

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ABSTRACT

For the design of ADS (Accelerator Driven System), it is important to study neutron spectra and details of nuclear reactions induced by neutrons. Furthermore, neutron energy and angular distribution data are important for a correct simulation of the propagation of particles inside a spallation target and the geometrical distribution of the outgoing neutron flux. Many experimental results are available for thin targets and massive targets additional studies of neutron spectra and neutron production were investigated to design target for ADS with incident proton energies up to 3 GeV. In our study, the angular distribution and the neutron energy spectra are reported for the (p,n) reaction on target nuclei such as Pb, U, W with energy from 50 MeV to 350 MeV calculated with database of JENDL-HE 2007. We obtain a set of data about the angular distribution and energy spectra of produced neutrons on some heavy targets with energy ranges as stated above. From the results of neutron spectra, the paper also gives many comments to recommend a choice of materials for target and energies for accelerating proton beam . From the angle distribution of neutrons generated in (p, n) reactions on the different targets with the different energies of proton, the solutions to arrange the reflection bars in reactor proposed. A comparison is also made to improve the reliability for calculation of the paper.

Key words: *ADS, spallation reaction, neutron spectra*

INTRODUCTION

The spallation reaction is caused by bombarding a target with particles having energies above a few hundred MeV. This reaction produces a great number of neutrons, and is applicable to produce an intense spallation neutron source or transmuting long-lived radioactive wastes [1, 2].

The design of target is a key issue to be investigated when designing an ADS [3], and its performance is characterized by the number of neutrons emitted by (p, n) reaction.

This paper describes the calculation of spatial distribution and energy spectra of produced neutron performed on the proton beam with the energy of 50 MeV to 350 MeV.

Based on the JENDL-HE library [4] we obtain a set data about energy – angle spectra on Pb, U, W targets with ranges as stated above.

METHOD

We adopt the formula for calculating energy-angle double differential cross section of neutron from (p,n) reaction:

$$\frac{d^2\sigma\left(\mu,E_p,E_n\right)}{dE.d\Omega}=\sigma\left(E_p\right).y\left(E_p\right).f\left(\mu,E_p,E_n\right) \quad (1)$$

Where:

$\mu = \cos\theta$; $\mu[-1,+1]$,

E_p is the incident energy (eV),

E_n is the energy of the product emitted (eV),

σ is the interaction cross section (barn),

y is the product yield or multiplicity,

f is the normalized distribution with units (eV unit cosine^{-1}),

$\frac{d^2\sigma(\mu,E_p,E_n)}{dEd\Omega}$: energy-angle double differential cross section (barn/eV-sr).

RESULTS

Angular distribution of neutrons produced

For the proton induced reaction, we are interested in the neutron production. We use the data of JENDL-HE library to calculate for incident proton energies of 50, 100, 150, 200, 250, 350 MeV. Figures 1, 2, 3 show angular distribution of neutron produced from the (p,n) reaction on ^{238}U, ^{208}Pb, ^{186}W calculated at the energies from 50 MeV to 350 MeV:

All the curves have the same behaviors but they have different values.

The angular distribution of emitted neutrons shows dominant forward angular emission with respect to the incident proton direction.

Production cross section is the highest for reaction induced on lead target and the lowest for reaction induced.

When the incident proton energy increases, production cross section does, too.

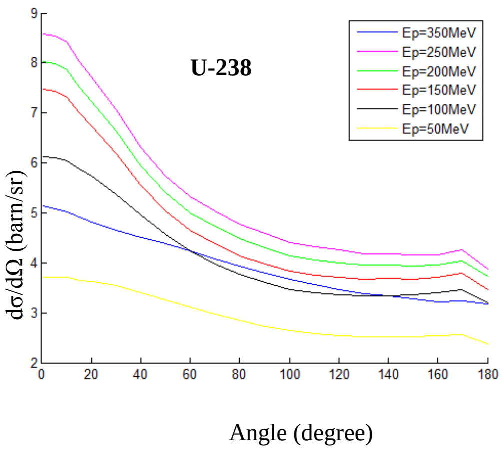

Fig. 1. Angular distribution of neutron produced on ^{238}U target with proton beam energy from 50 to 350 MeV

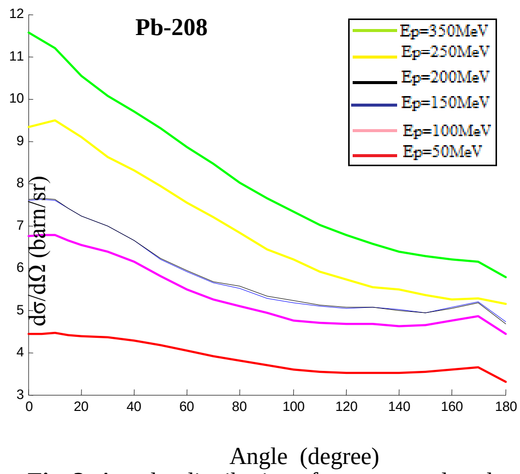

Fig. 2. Angular distribution of neutron produced on ^{208}Pb target with proton beam energy from 50 to 350 MeV

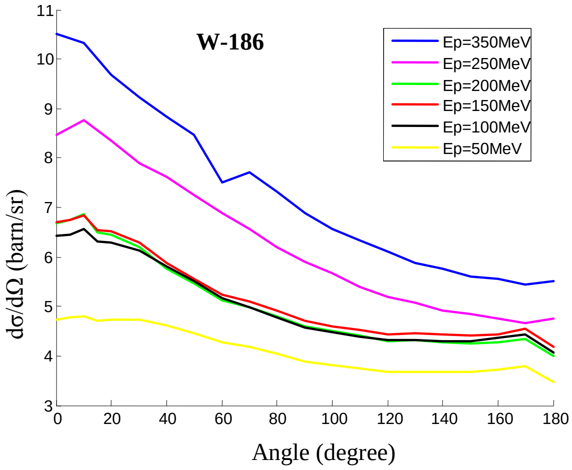

Fig. 3. Angular distribution of neutron produced on 186 W target with proton beam energy from 50 to 350 MeV

Comparison with the other published data

Up to now, we haven't found any papers studying about angular distribution of neutron in energy range of 50 MeV to 350 MeV. We use our model to calculate the angular distribution of neutron at 800 MeV and we make a comparison with the obtained result of P.K. Sarkar and Maitreyee Nandy [5] as following:

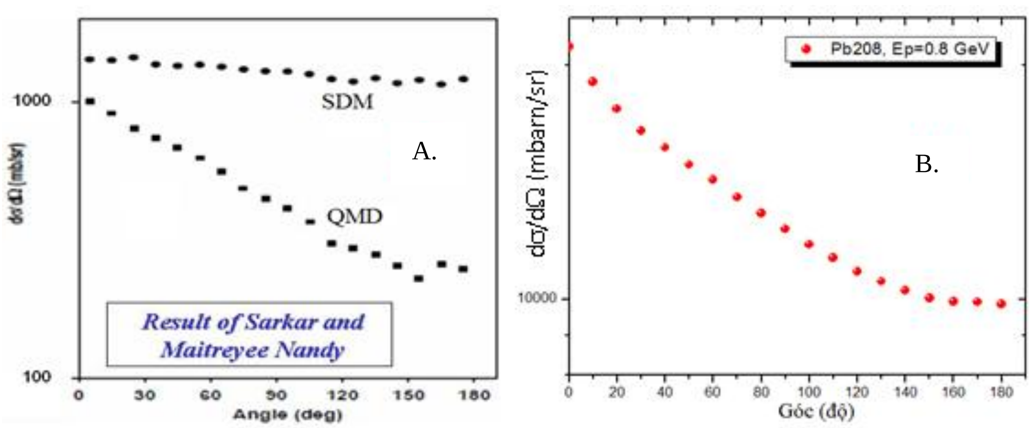

Fig. 4. A comparison of angular distribution of neutron on lead target with the value reported in literature at 800 MeV. A. The result of P.K. Sarkar and M. Nandy [5]. B. Our result

We can see that there is a significant difference between the two models QMD (Quantum Molecular Dynamics) and SDM (Statistical Decay Model). Fig. 4A shows a dominant forward angle emission for the QMD process while the neutrons from the SDM calculations have isotropic angular distribution with respect to the incident proton direction. Fig. 4B shows that the curve in our result is similar to that of the QMD process. We do not mention several important effects, the result shows a significant difference in value.

We are interested in the form of the curve. It means that our calculation model is good.

The neutron energic spectra

Figures 4–6 show the neutron spectra from the (p, n) reaction on ^{238}U, ^{208}Pb, ^{186}W calculated at the energies from 50 MeV to 350 MeV.

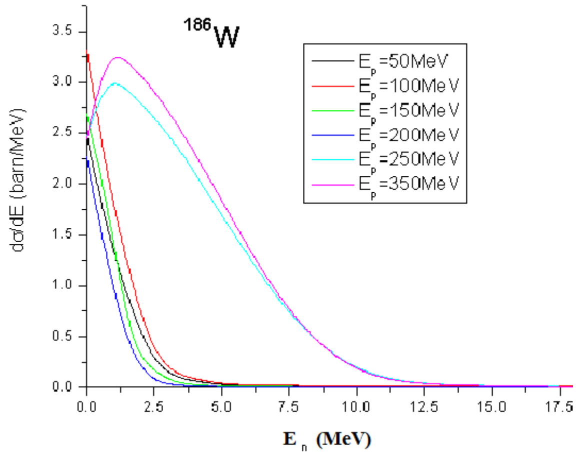

Fig.4. The neutron energic spectra produced on ^{186}W target with proton beam energy from 50 to 350 MeV

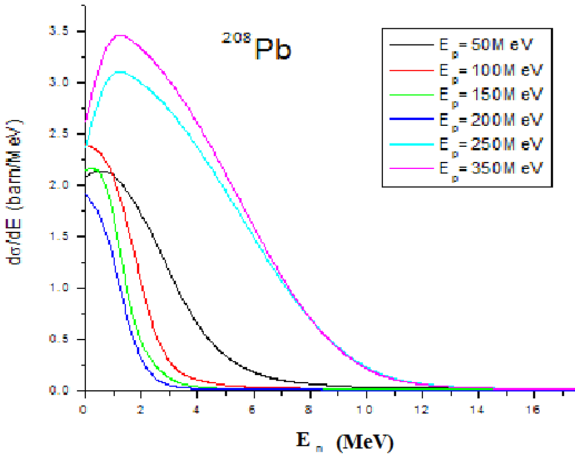

Fig.5. The neutron energic spectra produced on ^{208}Pb target with proton beam energy from 50 to 350 MeV

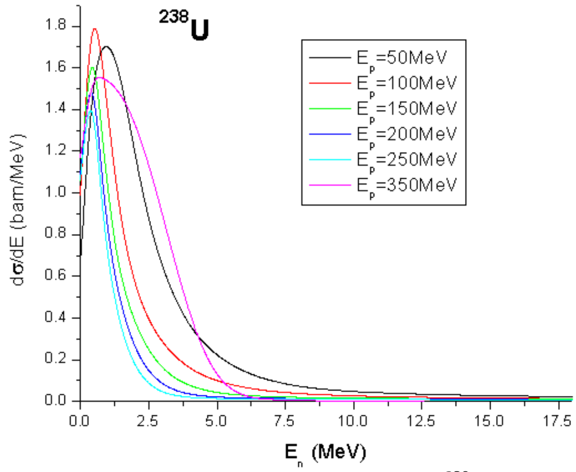

Fig.6. The neutron energic spectra produced on ^{238}U target with proton beam energy from 50 to 350 MeV

For the considered energy range of incident protons, we find that most of produced neutrons have the energy from 1 to 14 MeV. From Fig. 4 through Fig. 6, we have some remarks as follows: the neutron emission spectra produced by (p,n) reactions depend on:

Incident proton bombarding energy.

Different target materials.

With the same isotope of an element, if the proton bombarding energies are the highest, the neutron cross sections will be the largest. At the same bombarding energy, neutron emission cross sections depend on target materials.

Comparison with other published literature

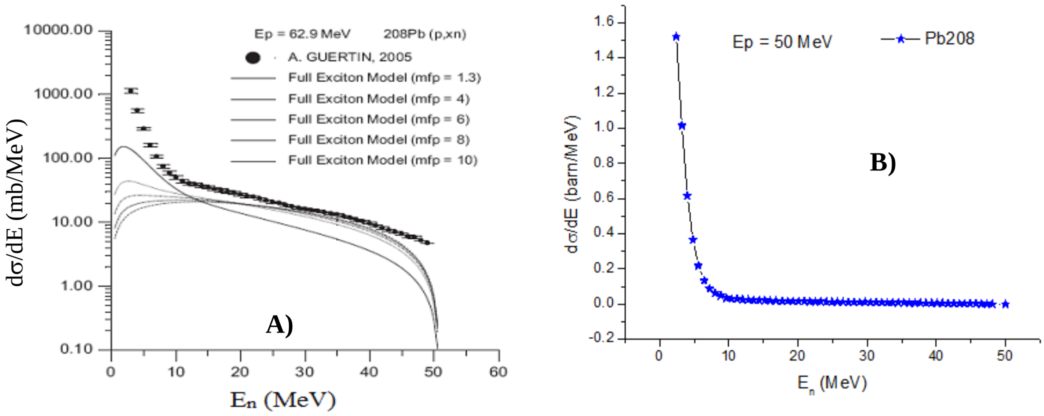

Fig. 7. The comparison of neutron emission spectrum of ^{208}Pb(p,n) reaction with the value reported in the literature at 62.9 MeV incident proton energy

It is clear that the forms of both Fig. 7A) and Fig. 7B) are similar.

CONCLUSION

We are interested in the cross section for the energic spectra and spatial distribution of neutron obtained for the incident proton energy of 50 to 350 MeV. We calculate the distribution of neutron escaped a heavy target at different angles from zero degree to 180^0 degree, so we know the dominant forward angular emission with incident proton direction and spatial distribution of produced neutrons to arrange fuel bars in ADS. Heavy nuclei as U, Pb, W were chosen as spallation target and obtained rather hard neutron energic spectrum (see Figures 4, 5, 6). This is the need to optimize the fission probability of Transuranic elements (TRU). Indeed, in the fast neutron flux provided by the ADS, all TRU can undergo fission, a process which eliminates them, while in a traditional reactor thermal neutron flux many TRU do not fission and thus accumulate as waste.

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Nghiên cứu về phổ năng lượng neutron và phân bố góc của neutron sinh ra từ phản ứng (p,n) trên một số bia nguyên tố nặng từ

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TÓM TẮT

Với thiết kế cho ADS (Accelerator Driven System) lò phản ứng điều khiển bằng máy gia tốc điều quan trọng nhất là nghiên cứu phổ neutron và phản ứng hạt nhân được gây ra bởi neutron. Hơn nữa, năng lượng neutron và phân bố góc của neutron là những dữ liệu quan trọng cho việc mô phỏng sự nhân neutron trên bia và sự phân bố không gian của thông lượng neutron sinh ra. Nhiều kết quả thực nghiệm về các bia mỏng và những nghiên cứu về phổ neutron cùng sản phẩm neutron trên các bia khối đã được khảo sát để thiết kế bia cho ADS với năng lượng proton tới lên đến 3 GeV. Từ kết quả của phổ neutron, bài báo cũng cho những khuyến cáo để lựa chọn vật liệu bia và năng lượng cho chùm proton.

Sự phân bố góc của neutron được tạo ra từ phản ứng (p,n) trên những bia khác nhau với năng lượng proton khác nhau và giải pháp sắp xếp thanh nhiên liệu trong lò phản ứng cũng được đề nghị. Trong nghiên cứu của chúng tôi, phân bố góc và phổ năng lượng neutron được báo cáo cho phản ứng (p,n) với các hạt nhân bia như Pb, U, W trong vùng năng lượng từ 50 MeV đến 350 MeV sử dụng dữ liệu hạt nhân của JENDL-HE 2007. Chúng tôi đạt được một bộ số liệu về phân bố góc và phổ năng lượng của neutron sinh ra trên một số bia nặng trong dải năng lượng từ 50 MeV đến 350 MeV. Một sự so sánh được thực hiện để tăng mức độ tin cậy cho mô hình tính toán của bài báo.

Từ khóa: *ADS, spallation reaction, neutron spectra*

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