CALCULATING THE NUMBER OF NEUTRONS EMITTED ON THICK HEAVY TARGETS WITH THE PROTON BOMBARDMENT ENERGY RANGE FROM 0.5 GeV TO 3.0 GeV

NGUYEN THI AI THU*

ABSTRACT

This research focuses on calculating the number of neutrons emitted from the spallation reaction with the proton energy range from 0.5 GeV to 3.0 GeV on thick heavy targets such as ^{204}Pb, ^{206}Pb, ^{207}Pb, ^{208}Pb, ^{180}W, ^{182}W, ^{184}W, ^{186}W, ^{235}U, ^{238}U, ^{197}Au. We propose a calculation model called the Screening effect model and use nuclear data of JENDL-HE for calculating with this model.

Keywords: Spallation, ADS, (p, n) reaction, sub-critical reactor.

TÓM TẮT

Tính toán số neutron sinh ra trên các bia nặng với năng lượng bắn phá của proton từ 0,5 GeV đến 3,0 GeV

Tính toán số neutron sinh ra từ phản ứng phát tán trong vùng năng lượng từ 0,5 GeV đến 3,0 GeV trên các bia ^{204}Pb, ^{206}Pb, ^{207}Pb, ^{208}Pb, ^{180}W, ^{182}W, ^{184}W, ^{186}W, ^{235}U, ^{238}U, ^{197}Au. Đề xuất mô hình được gọi là mô hình màn chắn trên bia để sử dụng thư viện hạt nhân năng lượng cao JENDL-HE trong tính toán.

Từ khóa: Spallation, ADS, (p, n) reaction, sub-critical reactor.

1. Introduction

Calculating the number of neutrons emitted from spallation reaction with different proton bombardment energies on different targets is the problem mentioned in this study. Our interest is in the number of neutrons emitted from spallation reaction with different incident proton energies on some targets used in designing the Accelerator Driven System (ADS). In the papers [1], [3], [4], [5] the authors showed different models to calculate emitted neutrons.

Different from the previous papers [1], [2], [3], [4], [5] in this work, we use immediately JENDL-HE nuclear data to calculate. Using this nuclear library helps reduce the volume of calculation significantly. To use effectively JENDL-HE nuclear data, we showed a calculation model – Screening effect model and especial content of this model will be presented in section II.2. First of all, in section II.1 we present the calculation of the number of neutrons emitted in spallation reaction when the target considered is homogeneous and the incident proton energy doesn't change during interactions between incident protons with target nuclei.

* Ph.D., Transport College - Ho Chi Minh City

2. Calculation model and results

The problem calculates the number of neutrons emitted from spallation reaction is made as follows:

Assuming that we have a cylinder target with d thickness and r radius, to calculate the number of neutrons emitted from spallation reaction on a definite target element, we use proton beam with E energy. The incident proton energy range is chosen from 0.5 to 1.5 GeV with 0.1 GeV energetic step. The reason of this choice is our calculation is directed toward designing target for ADS. Many reasons for the choice of this interesting energy region will be shown from obtained calculation results later. The energy region from 0.5 GeV to 1.5 GeV is interested in very much. The chosen targets to calculate in this work are ^{204}Pb, ^{206}Pb, ^{207}Pb, ^{208}Pb, ^{180}W, ^{182}W, ^{184}W, ^{186}W, ^{235}U, ^{235}U, ^{197}Au. The target thickness is of equal proton mean path length in each target material at each proton energy. To decrease the heat of remaining protons on target and to prolong the life time of targets, we choose such target length. The target diameter is equal to the incident proton beam diameter. In this problem, we choose the target radius of four centimeters.

The number of neutrons emitted from spallation reaction on a target is calculated by this formula:

$$N_n = N_p.N.d.\sum_{j}^{32}\frac{d\sigma(\mu, E_p, E_n)}{dE}$$

Where:

N_p is the number of incident protons (protons/s)

N_n is the number of emitted neutrons (neutrons/s)

N is distribution density of target nuclei (particles/cm^3)

d is the target thickness (cm)

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

σ (E) is the interaction cross section (barn)

E_p is the incident energy (eV)

E_n is the energy of the product emitted (eV)

In JENDL library, emitted neutrons are distributed at 32 energies.

In section II.1, we consider the homogeneous target in which the number of incident protons and the incident proton energy don't change during interactions between incident protons with target nuclei. This is a rough approximation and the defect of this model will be improved by the screening effect model presented in section II.2.

2.1. The homogeneous model

In this model, we consider that the number of initial incident protons (is N_0) doesn't change during interaction between incident protons with target nuclei. The target size was a constant for each proton beam energy. That means the target thickness (d) is chosen equal to proton mean path length ($\overline{R}_p$) in each material at each incident proton beam energy. The radius of the proton beam (r) was kept constant at 4cm and the number of neutrons emitted at proton energies range starting from 0.5 GeV up to 3.0 GeV was calculated by program written in MATLAB 7.0 language.

Now we will present our calculation results for the number of emitted neutrons in the lead (^{206}Pb) target case with proton energy range in starting from 0.5 GeV to 3.0 GeV as follows:

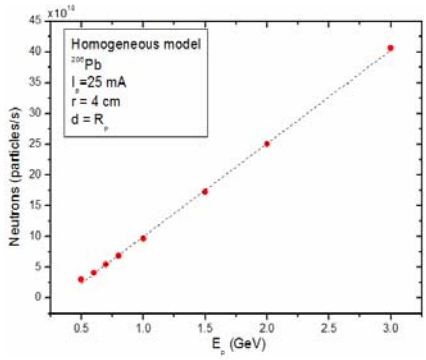

***Figure 1.** The number of neutrons emitted from spallation reaction calculated with ^{204}Pb bombarded with proton energies from 0.5 GeV to 3.0 GeV in homogeneous model*

From figure 1, we can see that the number of neutrons emitted is increasing with the growth of incident proton energy.

Calculations with different targets such as ^{238}U, ^{186}W, ^{197}Au are shown in figures 2, 3,4

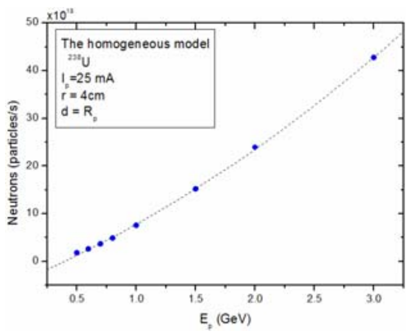

***Figure 2.** The number of neutrons emitted from spallation reaction calculated with ^{238}U in range of proton energies from 0.5 GeV to 3.0 GeV*

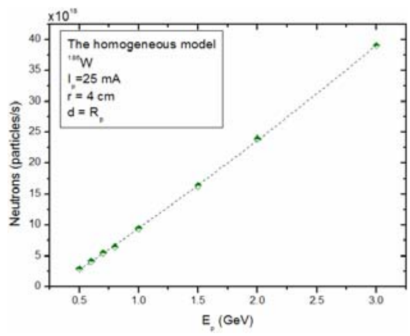

***Figure 3.** The number of neutrons emitted from spallation reaction calculated with ^{186}W in range of proton energies from 0.5 GeV to 3.0 GeV*

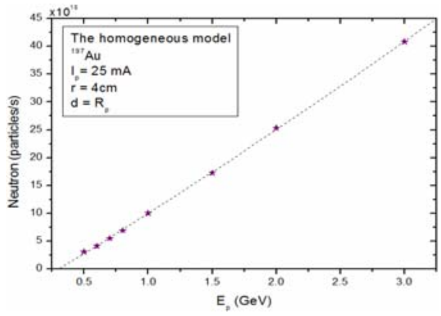

Figure 4. *The number of neutrons emitted from spallation reaction calculated with ^{197}Au in range of proton energies from 0.5 GeV to 3.0 GeV*

From calculation results we can draw a conclusion that the number of neutrons emitted from spallation reaction depends on the incident proton energies and target materials. The higher the incident proton energy is, the more the number of emitted neutron is.

2.2. The screening effect model

When proton beams enter a medium, their current intensity will reduce due to ionization effect, scattering effect….therefore their energy will also reduce. In section II.1 we haven't mentioned those effects and now in this section, assuming the target is divided into sub-layers at the value of energies that corresponds to neutron cross-section given by JENDL-HE library.

Obtained calculation results with lead target (^{206}Pb) are presented in fig.5 below:

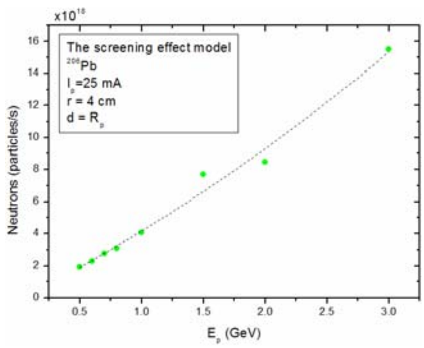

Figure 5. *The number of neutrons emitted from spallation reaction calculated with ^{206}Pb bombarded with proton energies from 0.5 GeV to 3.0 GeV in the screening effect model*

Comparing the results depicted in fig.5 with the results in fig.1, we can see that the calculation results in figure 1 are higher than those in figure 5 because when protons pass each sub-layer of target, proton energy decreases and the number of neutrons emitted decreases too. Fig.6 shows a comparison of the number of neutrons emitted in both models:

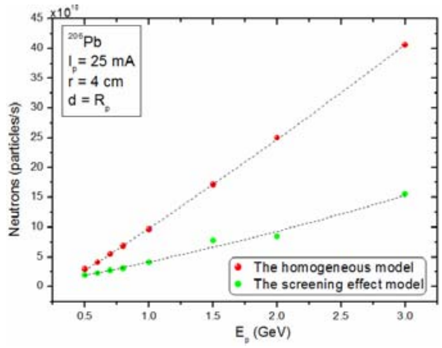

Figure 6. *A comparison of the number of neutrons emitted from spallation reaction calculated with ^{206}Pb bombarded with proton energies from 0.5 GeV to 3.0 GeV in the screening effect model and the homogeneous model*

Now, we compare our calculation results from screening effect model with the results of a different model –Sara T. Mongelli et al.[4]. In their work, the research group used two models such as IntraNuclear Cascade (INC) and evaporation model and they used LAHET code for calculating. Figure 7 below shows the comparison:

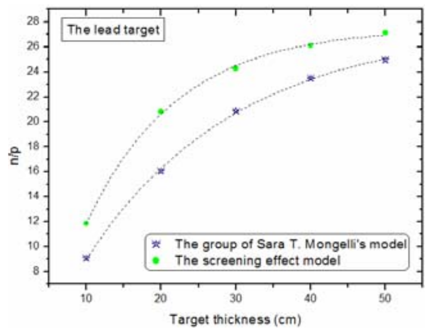

Figure 7. *A comparison of neutron multiplicity (n/p) per incident proton calculated by the research group of Sara T. Mongelli et al. and by the screening effect model*

Fig.7 is a comparison of neutron multiplicity (n/p) per incident proton between the results of Sara T. Mongelli et al. and the results of the screening effect model. Clearly, although the screening effect model hasn’t calculated effects yet, the collected calculation results haven’t been much different from the results calculated from complicated models of Sara T. Mongelli et al. This demonstrates that the screening effect model is better.

We also use the screening effect model to calculate the number of neutrons emitted from spallation reaction in ^{238}U, ^{186}W, ^{197}Au target cases in range of proton energies starting from 0.5 GeV up to 3.0 GeV and the results presented in figures 8, 9, 10 as below:

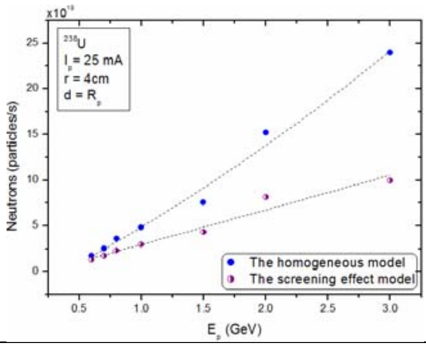

Figure 8. *A comparison of the number of neutrons emitted from spallation reaction calculated with ^{238}U bombarded with proton energies from 0.5 GeV to 3.0 GeV in the screening effect model and the homogeneous model*

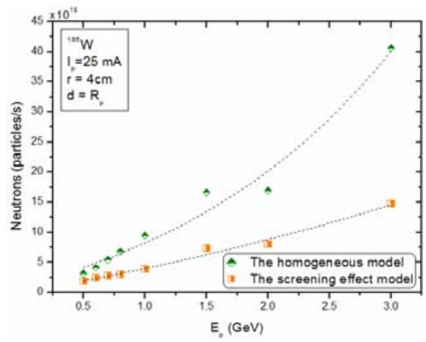

Figure 9. *A comparison of the number of neutrons emitted from spallation reaction calculated with ^{186}W bombarded with proton energies from 0.5 GeV to 3.0 GeV in the screening effect model and the homogeneous model*

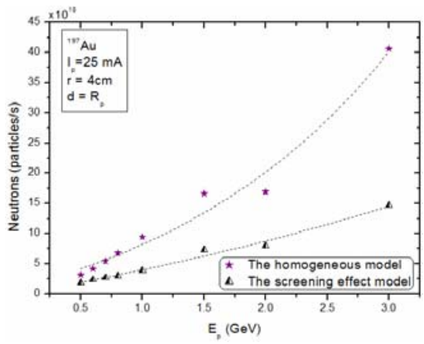

Figure 10. *A comparison of the number of neutrons emitted from spallation reaction calculated with ^{197}Au bombarded with proton energies from 0.5 GeV to 3.0 GeV in the screening effect model and the homogeneous model*

Based on the obtained results from fig.8, fig9, fig10, we can draw the following conclusions:

The number of neutron emitted varies as a function of the target nuclei and as the energy of the incident particle calculated with the screening effect model compared with homogeneous model, reaching saturation around 1.5 GeV. This problem can be explained as follows: when proton bombarding energy is high enough (about from 1.5 GeV and over), proton can immediately interact with nucleons of target nuclei. The probability of primary particles such as $\pi^{\pm}, \mu^{\pm} \ldots$ will increase. The higher the incident proton energy is, the more the energy for these channels will be spent. Hence, from these results we can see that ADS technology needs only accelerator energy roughly from 0.5 GeV to 1.5 GeV. This is the energy region that is interested in very much.

3. Conclusion

The number of neutrons emitted from spallation reaction calculated with different heavy targets bombarded with proton energy range starting from 0.5 GeV up to 3.0 Gev is very useful data for designing a target for ADS.

There are approaches to carry out this in works [3], [4], [5]. In this calculation, we suggest a simple calculation approach – We use JENDL-HE nuclear data with the screening effect model to establish our calculating and our approach reduces a volume of calculations significantly.

We hope this approach will be able to calculate spatial distribution of neutron from spallation reaction.

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(*Received: 12/4/2012; Revised: 28/9/2012; Accepted: 23/10/2012)*