Distribution of Neutrons from The Reaction (p, n) on the Liquid Lead Target in The Accelerator Driven System Reactor

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Abstract. This paper presents results of calculating energy distribution, angular distribution, neutron yield, the double-differential cross-section of the neutron as a proton beam, which produced from the accelerator, spallation on the liquid lead, thus providing the basis for the distribution of the target, calculating fuel ... for the accelerator-driven reactor system reactor. These results have shown that the produced neutron energy spectrum extends from thermal neutrons to fast neutrons, which have concentrated in 1MeV to 3MeV. These neutrons are produced at angles of 0º to 10º and turn decreased to the larger angles. This shows that neutrons tend to be produced forward in the direction of the incoming protons.

1. Introduction
The accelerator-driven reactor system reactor (ADSR) is a new studying in nuclear reactor technology. There are many studies (p, n) reactor for distribution the target. However, these are calculations for various solid targets [3][4][6][7][8][9][10][12][13]. The calculations in this paper in the study series of using liquid lead which is not only a coolant but also a spallation target for (p, n) reaction, from [6] to [10][16]. This paper presents results of calculating energy distribution, angular distribution, neutron-yield, the double-differential cross-section of the neutron as a proton beam, which produced from the accelerator, spallation on the liquid lead, thus providing the basis for the design of the target, calculating fuel ... for the accelerator-driven reactor system reactor.

2. Calculation and results
The proton beam interacts with the target to generate (p,n) nuclear reaction.
We have calculated the energy distribution of neutrons with the various angulars, neutron yield, the double-differential cross-section.

Calculation method [5]:

We have calculated the number of neutrons produced from (p,n) nuclear reaction based on (p,n) reaction cross section formula:

$$\sigma_i(\mu, E, E') = \sigma(E) \gamma_i(E) f_i(\mu E, E')$$

Where:
- $E_p$ is the incident energy
- $E_n$ is the energy of the product emitted (eV)
- $\sigma(E)$ is the interaction cross section (barn)
- $\gamma_i$ is the product yield or multiplicity
- $f_i$ is the normalized distribution with units (eV unit cosine$^{-1}$)

We use the JENDL-HE nuclear data to calculate. We write a calculator program based on the Matlab language and processing data by origin program. The results are shown below.

2.1. The energy distribution of the produced neutrons

The calculation results are shown in figure 2. The results show that when the proton energy varies with the levels of 250MeV, 350MeV, 500MeV, 600MeV, 700 MeV, 800 MeV, 1000 MeV, 2000MeV, 3000MeV. Neutrons produced have an energy spectrum ranging from 0 to 122 MeV, but concentrated in the energy range from 1MeV to 3MeV, then the number of neutrons decreases for higher energy levels. Calculations show that the neutron ratio of 1MeV to 3MeV for the 250MeV proton beam is 73.4%; for the 350MeV proton beam is 74.4%; this rate is 68.5%, 69.1%, 60.5% for proton beam with 500MeV, 1GeV and 2GeV.

The results also show that when proton energy is increased, the energy spectrum of neutrons changes to high energy.
Figure 2: The energy distribution of the neutrons produced in this work (a,b) and [7](c)

Calculation results are quite consistent with some research work of some other author. Typically, as author A. Krasa [7], when simulating an interaction (p, n) on a solid-lead target using the MCNPX program, the neutron generated energy concentration is 2MeV.

2.2. The angular distribution of neutrons produced

This section presents the results of calculation of the neutron ratio produced at angles to the total number of neutrons and the neutron yield at these angles. Neutrons were investigated in 19 positions, correspond with 19 angles from 0° to 180° as shown in figure 3.
Figure 3: The model defines the angular positions of the neutrons produced

Calculated results have shown in Figure 4.

Figure 4: The neutron distribution produced by the angles in this work (a,b) and [3](c)
In figure 4, we see that neutron generated focuses mainly on angles from $0^\circ$ to $20^\circ$, about 21.3% at 250 MeV; this rate is in turn 22%, 23.4%; 24.8%; 25% and 25.7% for 350MeV energy levels; 500MeV; 1GeV; 2GeV and 3GeV.

There have been many studies studying the distribution of neutrons by producing angles, typically as the works of Sarkar and Maitreyee Nandy [3]; the authors calculated the neutron angle distribution generated by the 600MeV proton spallation on the solid Pb208 by SMD and QMD models. Results based on the SMD model suggest that neutrons are almost uniformly distributed in all directions, while the QMD model shows that neutrons are produced more at angles from $0^\circ$ and decrease to larger angles. The results of this work are similar to the QMD model by Sarkar and Maitreyee Nandy.

2.3. The neutron yield produced by angles.
This part presents the results of the calculation of neutron yield at different angles from $0^\circ$ to $180^\circ$. Calculated results have shown in figure 5.

![Figure 5: The yield of neutrons have generated by the angles in this work (a,b)](image)

With the results of the computation, we see that with a proton beam energy level, at the smaller the angles, the greater the neutron yield, and this yield decreases towards the larger angles. As we compare this result with the calculations of [3], it is quite appropriate for angles of $90^\circ$ or higher, whereas in positions $0^\circ$ to $90^\circ$, there are large differences. This can be explained by calculations on two different types of solid and liquid targets.

Given the various energy levels of the proton beam, the higher the proton concentration, the higher the neutron yield, the results of the study on the solid target would have been similar, for examples the works by H. Nifenecker, O. Meplan, and S. David [4].

At all corners, the neutron-yielding neuron yields 13.7 neurons per proton, with the proton beam energy is 250 MeV, this value in turn increased to 17.3; 23.9; 25.6; 30.3 for the energy levels of the protons is 500MeV, 800MeV, 1000MeV and 1500MeV ... Compared with some other results on the solid target, is 20.5 when computed with the 1GeV proton beam.

2.4. The double-differential cross-section of neutrons
This part presents the results calculated the double-differential cross-section of neutrons in reaction $d^2\sigma (p, n)$ on lead target liquid used in ADSR, with the energy of the proton beam is 250MeV, 500MeV, 1000MeV and 2000MeV. Calculated results have shown in figure 6.
The results show that the double-differential cross-section of neutrons has concentrated at an energy level of about 2 MeV, which is consistent with the calculated neuronal energy distribution, which has presented in section 2.1.

Comparing the results with solid lead from X. Ledoux, F. Borne, A. Boudard et al. [1], as calculating the energy level of 1200 MeV, there is a similarity in the neutron energy range of 5 MeV or higher, and the energy range from 0 to 5 MeV varies considerably. This can be explained by calculations on two different types of solid and liquid targets.
Figure 6: The double-differential cross-section of neutrons with the energy levels: 250MeV, 500MeV, 1000MeV, and 1500MeV in this work (a,b,c,d) and [1](e,f)
3. Conclusions
The paper presents the results of calculating the neutron distribution in interaction (p, n) using a liquid lead as well as an interaction target and a coolant in an the accelerator driven system using thorium fuel (ADSR). These results have shown that the produced neutron energy spectrum extends from thermal neutrons to fast neutrons, which have concentrated in 1MeV to 3MeV. These neutrons are produced at angles of 0° to 10° and turn decreased to the larger angles. This shows that neutrons tend to be produced forward in the direction of the incoming proton.
These results are an important basis for designing positions of the fuel in ADSR and for the next calculations.

References
[1] X. Ledoux, F. Borne, A. Boudard, and et.al 1999 Phys. Rev. Lett. 82 22, 4412-4415.
[2] S S Kapoor 2002 Indian Academy of Sciences: 59 941.
[3] Pradip K. Sarkar and Maitreyee Nandy 2003 Springer 61 N4 675-684
[4] Nifenecker, H. 2003. Boca Raton: CRC Press
[5] M. Herman, Data 2003 ENDF/B VII
[6] Nguyen Thi Ai Thu, Nguyen Mong Giao, Chau Van Tao, Tu Thanh Danh 2008 IAEA - ICTP- IC067
[7] A. Krasa 2008 Czech Technical University
[8] Nguyen Mong Giao, Le Thi Thanh Truc, Nguyen Thi Ai Thu 2010 IAEA -ICTP- IC 057
[9] Nguyen Mong Giao, Tran Thanh Dung, Nguyen Thi Ai Thu, Chau Van Tao 2010 IAEA - ICTP- IC 056 1810-5408.
[10] Nguyen Thi Ai Thu, Nguyen Mong Giao, Tran Thanh Dung, Huynh Thi Xuan Tham 2010 NuSYM10 RIKEN Nishina Center
[11] Nguyen Thi Ai Thu, Nguyen Mong Giao, Tran Thanh Dung, Huynh Thi Xuan Tham 2010 IAEA -ICTP- IC 064
[12] Ciprian Zahan 2011 Intel Talent Search competition
[13] Nguyen Thi Ai Thu and Nguyen Mong Giao 2013 J. Physics (USA): Conf. S. 420 012062
[14] Nguyen Mong Giao, Nguyen Ai Thu 2014 IJESIT 3 3 153-155.
[15] Y L Zhang, X C Zhang, J Qi, Z Wu and L Yang 2013 J. Phys: Conf. S. 420 012064.
[16] Nguyen Mong Giao, Vu Thi Diem Hang, Tran Minh Tien. 2015 I.J.of Modern Phys and Application. 2 3 13-18.