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SCREENING EFFECT IN (pn) REACTIONS ON HEAVY ELEMENT TARGETS $^{206}_{82}Pb$, $^{308}_{92}U$, $^{184}_{74}W$, $^{197}_{79}Au$

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Abstract

We present a simple model to calculate multiplicities of the neutrons emitted in the interaction of a proton beam energy from 0.5 GeV to 1.5 GeV on some targets such as $^{206}_{82}\mathrm{Pb}$, $^{197}_{79}\mathrm{Au}$, $^{238}_{92}\mathrm{U}$ using the database of the JENDL-HE library. The results are compared with others Model and the available experimental data [3,6,8,9]. The agreement is satisfactory.

INTRODUCTION

One of the main problems of nuclear power nowadays is radioactive waste management. Some of the produced radioactive isotopes have a very long lifetime, potentially representing long term radiation hazards. Effective transmutation of these isotopes into the short lived or stable ones needs continuous neutron fluxes with intensity in the 10^{16} n/cm^{2} range [3]. Such intensity is approximately 100 times larger than intensities typically available in a large scale reactor.

In currently proposed Accelerator Driven Systems (ADS), the accelerator bombards heavy target with high intensity (about 100 mA) and energy around 1GeV proton beam to produce the above mentioned high intensity of neutrons. The neutrons can be further multiplied in a sub-critical reactor which surrounds the spallation target and in which long lived nuclear waste is transmuted.

Although the (p, n) reaction mechanism has been known for many years, the actual understanding is not sufficient when one has to face the design of the realistic target-blanket systems. Hence, new accurate studies of neutron production in proton induced reactions, as well as of neutron's propagation through different materials, are needed.

In the past, few experiment results were available for thin target [15], in which the incident proton beam is of equal energy and the target is considered homogeneous. Problems such as screening effect, the loss of projectile energy and the number of residual protons on target have not been mentioned yet, but for massive target additional studies of neutron spectra and cross-section are needed.

In this work, spallation neutrons were generated by bombarding about 50 cm long cylindrical target with the incident energy 1 GeV. Neutron multiplicities generated by an incident proton beam on $^{206}_{82}\mathrm{Pb}$ target of length 50 cm and the number of residual protons on target was calculated. The obtained results have been discussed and compared with the experimental data taken from literatures [8].

The main idea of this paper is the target is divided into layers to calculate the proton energy loss and neutron yields from (p, n) reaction on each sub-layer of target. This is the difference between our work and other work [9], [13], [16].

CALCULATION MODEL

All calculations previously considered that the target is homogeneous and the incident proton energy does not change during interaction with target nuclei which is called the homogeneous Model. For the concept, we used the JENDL-HE nuclear library to calculate the neutron multiplicity from spallation reaction on the targets $^{206}_{82}\mathrm{Pb}$, $^{197}_{79}\mathrm{Au}$, $^{238}_{92}\mathrm{U}$.

Calculation results from homogeneous model on the lead target with thickness from 10 cm to 100 cm shown in table 1 and figure 1 below:

Table 1: The neutron multiplicity on targets Pb-206

Thickness (cm)	Neutron multiplicity (n/p)	
	Homogeneous model	LAHET [6]
10	11.38784	9.08
20	26.02778	16.087
30	34.1632	20.859
40	45.55091	23.480
50	56.93696	24.954
60	68.32704	25.769
70	79.71456	26.028
80	91.10336	26.238
90	102.489	26.322
100	113.8784	26.417

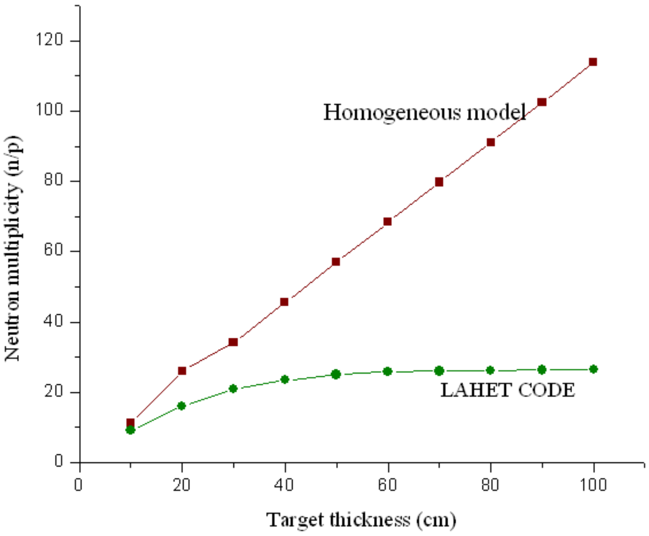


Figure 1: Neutron multiplicity on lead target in homogeneous and LAHET code model

The calculations have been compared with the calculated data from LAHET-International code [6].

From the obtained results, we can conclude that the homogeneous model used in this study does not give results in good agreement with the calculated data from international data.

To improve, we offer a new calculation model.

As we know, when protons enter a medium, they lose energy for interaction with target nuclei. This loss can be calculated from the Bethe Bloch formula.

Assuming the target is divided into n layers, proton energy comes to the target be E_0. Neutrons produced in the first layer are due to the interaction of proton with target. When passing the first layer, proton energy reduced to E_1- it is the incident energy at the second layer of target, where:

$$E_1 = E_0 - \frac{dE_0}{dx}$$

At that time, the number of neutrons produced in the second layer was N_{n_1}.

The interaction process will continue, lastly, the number of neutrons generated is:

$$N = \sum_{i}^{n} N_i$$

In this problem, we assume that the target thickness is 50 cm and divided into 50 layers, of 1 cm thickness each. Thus the number of neutrons generated is:

$$N = \sum_{i=1}^{50} N_i$$

With this model, we also used the JENDL library to calculate the neutron multiplicity on the target $^{206}_{82}\mathrm{Pb}$.

Calculation results from the new model on the lead target with thickness from 10 cm to 50 cm is shown in table 2, figures 2 and 3.

Table 2: The neutron multiplicity on targets Pb-204

Thickness (cm)	Neutron multiplicity (n/p)	
	New model	LAHET [6]
10	10.96838	9.08
20	18.85252	16.087
30	22.21581	20.859
40	23.92669	23.48
50	24.85607	24.954

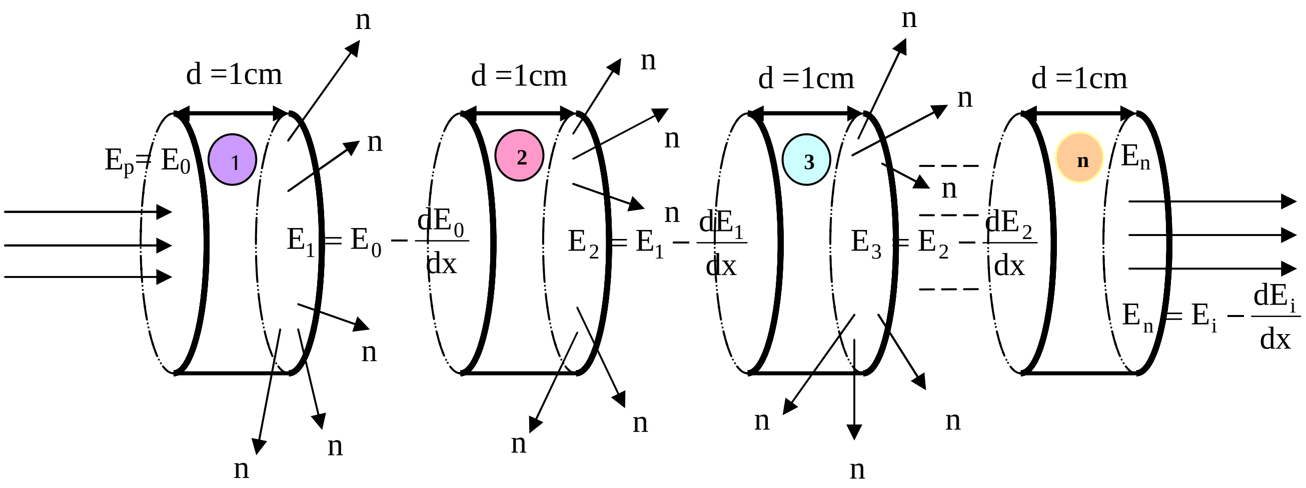


Figure 2: The envisaged model of spallation neutron target

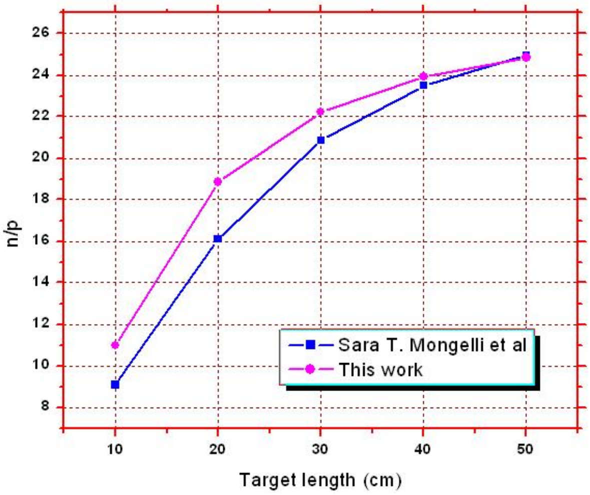


Figure 3: Spallation neutron yield on lead target in homogeneous model and LAHET code model

It is evident from the figure that the calculated values for Pb are in relatively good agreement with international code values. (The new model results relatively coincide with the LAHET code data using both the Bertini and the ISABEL model and with experiment data.)

We also calculate the number of residual proton after particle beam (Ep = 1 GeV) goes through x cm target thickness. Table 4 below illustrates this.

Table 4: Number of residual proton after particle beam goes through x cm target thickness

Target thickness (cm)	Number of residual proton (%)
10	57.2224
20	32.8
30	18.9056
40	11.0656
50	6.6176

We used the new model to calculate the spallation neutron yield on some targets $^{184}_{74}\mathrm{W}$, $^{197}_{79}\mathrm{Au}$, $^{238}_{92}\mathrm{U}$. The figures below illustrate neutron multiplicities generated by an incident proton beam at different energies on targets $^{206}_{82}Pb$, $^{197}_{79}Au$, $^{238}_{92}U$, $^{184}_{74}W$, $^{60}_{28}Ni$, $^{51}_{23}V$.

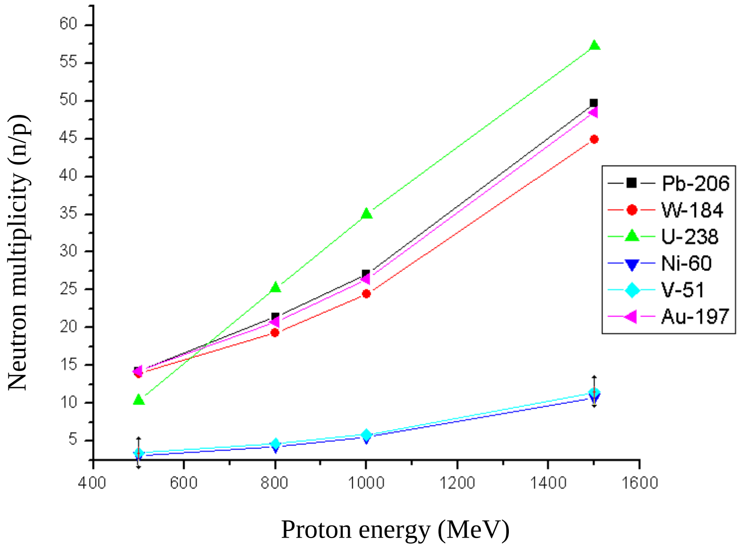


Figure 4: Neutron multiplicit on
Pb-206,W-184, U-238,Ni-60, V-51, Au-197 targets at 1500MeV

In figure 4, we show the values of neutron multiplicities obtained with incident energy 1500 MeV.

We made a comparison of neutron multiplicities on different targets, such as, ${}^{206}_{82}\mathrm{Pb}$, ${}^{197}_{79}\mathrm{Au}$ and ${}^{238}_{92}\mathrm{U}$ in case the same thickness (see figures 5 and 6 below)

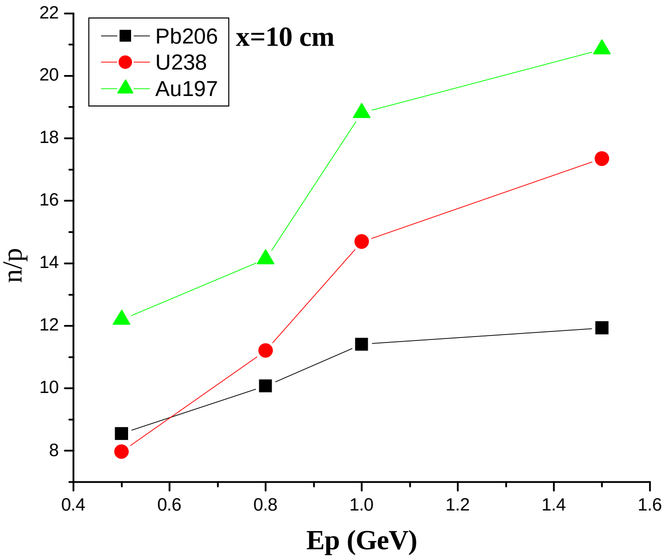


Figure 5: The neutron multiplicity on targets Pb-206, U-238, Au-197 at 10 cm thickness

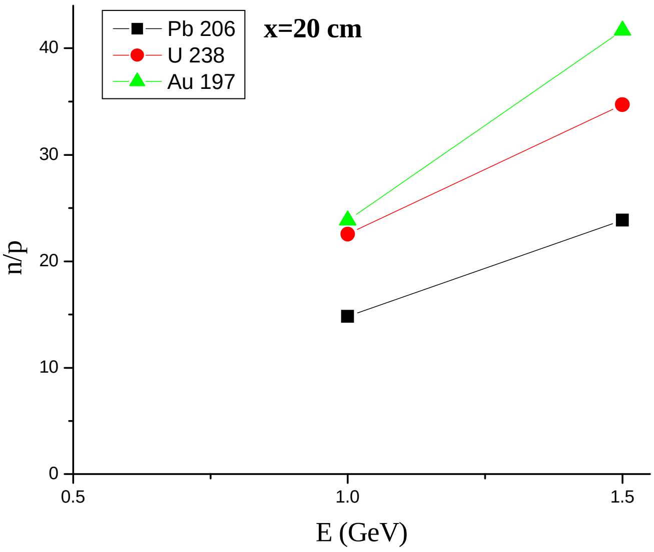


Figure 6: The neutron multiplicity on targets Pb-206, U-238 at 20 cm thickness

We can see that when target thickness increases, the neutron multiplicity increases. This proves that neutron multiplicity depends on target thickness.

Now, we consider the neutron multiplicity on targets Pb-206, U-238, Au-197 in case they have the same thickness. Figures 7, 8, 9 and 10 illustrate these

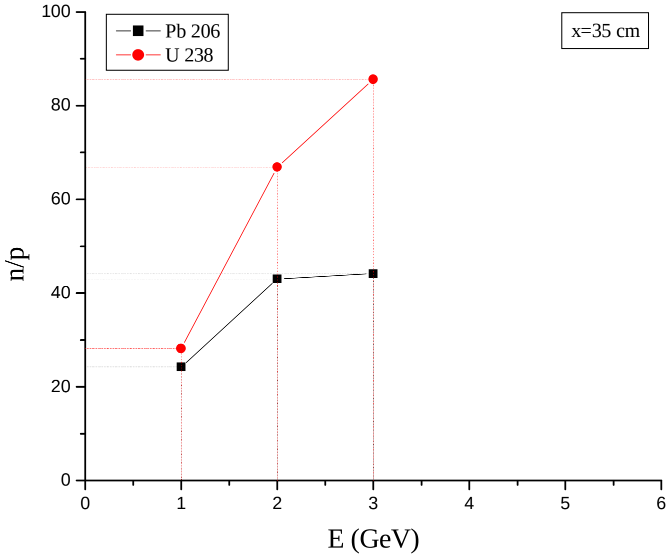


Figure 7: The neutron multiplicity on targets Pb-206, U-238 at 35 cm thickness

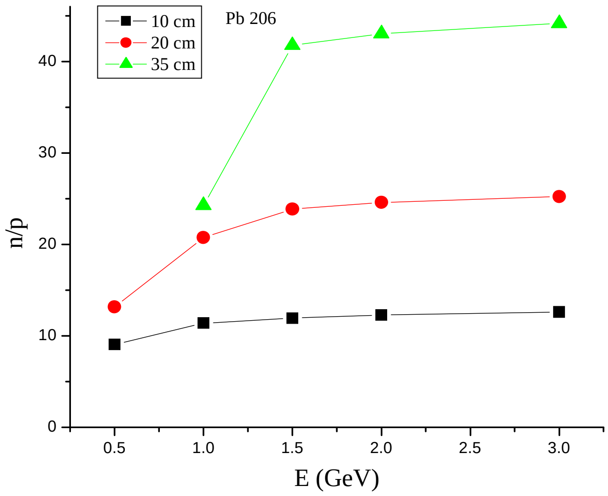


Figure 8: The neutron multiplicity on target Pb-206 at different thicknesses 10cm, 20 cm, 35 cm

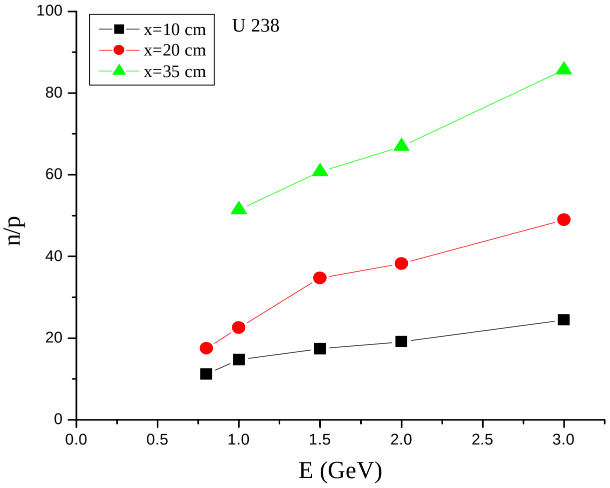


Figure 9: The neutron multiplicity on target U-238 at different thicknesses 10cm, 20 cm, 35 cm

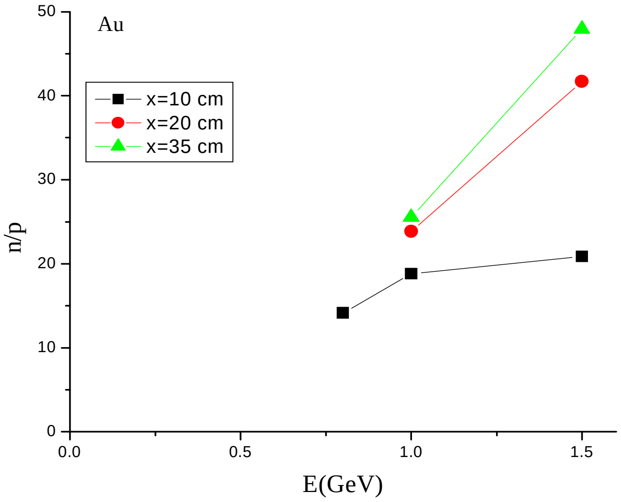


Figure 10: The neutron multiplicity on target Au-197 at different thicknesses 10cm, 20 cm, 35 cm

We have following remarks:

- The neutron multiplicity increases when the incident proton energy increases.
- When the thickness of targets increases, the neutron multiplicity increases with increasing of the incoming proton energy.
- From that point, we can draw that neutron efficiency depends on target material.
- At the proton energy (E_p) with the same target thickness, the value n/p increases linearly

Then we consider the neutron multiplicity on targets in the case of the same incident proton energy in figures 11 and 12

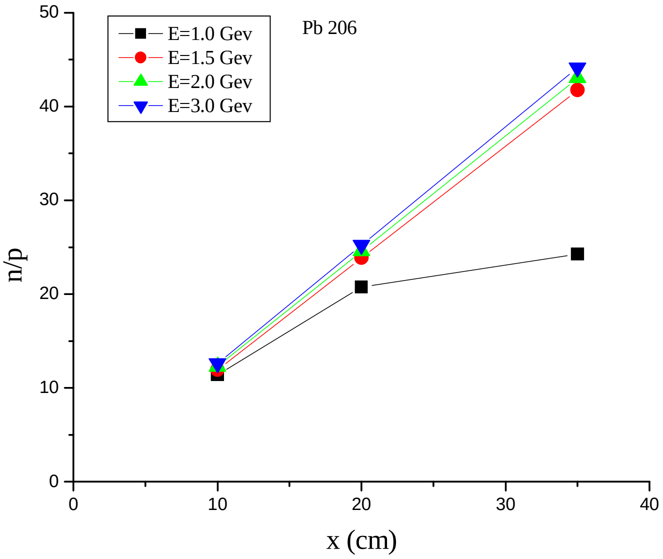


Figure 11: Spallation neutron yield on Pb-206 target at E_p = 1GeV, 1.5GeV, 2GeV, 3 GeV

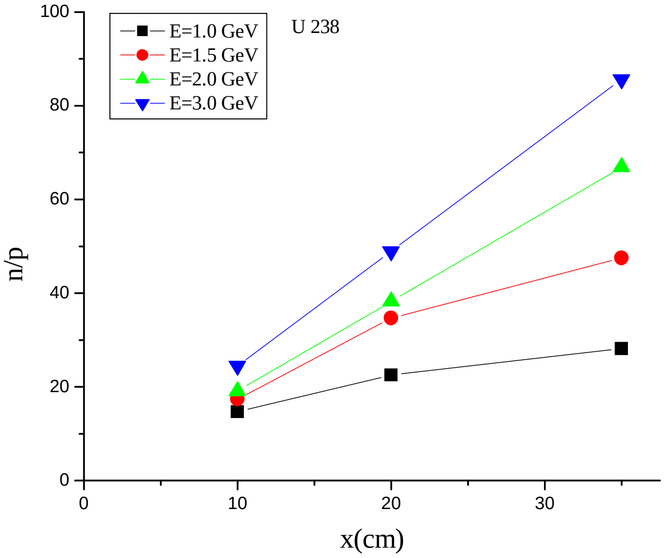


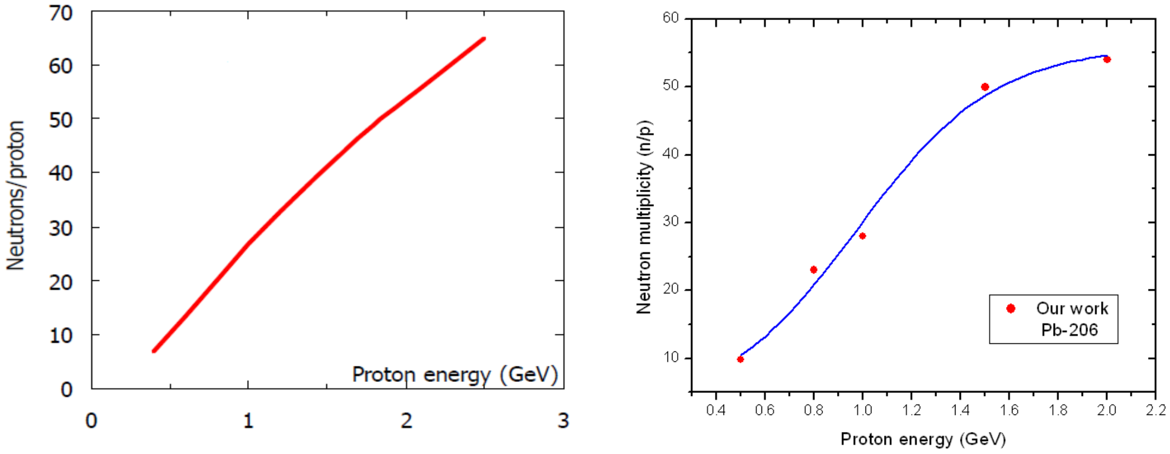
Figure 12: Spallation neutron yield on U-238 target at E_p = 1GeV, 1.5GeV, 2GeV, 3 GeV

From the above figures, we can see that the neutron multiplicity increases with the incident particle energy.

In short, the spallation neutron yield depends strongly on the target composition and geometry, and on the energy of the impinging proton.

Figures 13 and 14 show a comparison of spallation neutron yield between the calculation results with the measured data of Doctoral Thesis of Marcus Eriksson-Department of Nuclear and Reactor Physics, the Royal Institute of Technology- Stockholm 2005. The calculated results are good agreement data.

Comparison with other works



(a) Result from Doctoral Thesis of Marcus Eriksson [8]

(b) Result from this work

Figure 13: Spallation neutron yield as function of incident proton energy on lead target

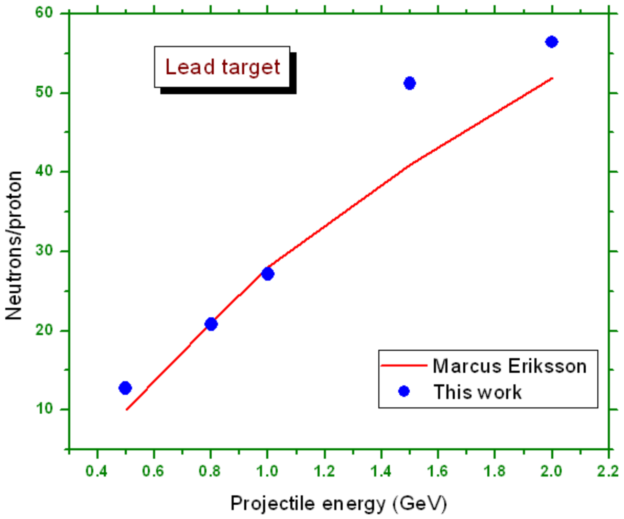


Figure 14: Comparison between result of Marcus Eriksson and this work result

CONCLUSION

This paper gives the extended initial results of the target study using the database of JENDL-HE library for simulation of particle interactions with different materials with the aim to choose and design an optimal target in respect to spallation neutron yield.

The result of our simulation supplies a larger number of produced neutrons; this may be attributed to the fact that in the simulation all neutrons are counted, already in the experiment the detectors do not measure all neutrons.

Acknowledgments

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