Conceptual Design of Target-Moderator for Cyclotron driven Compact Thermal Neutron Source

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1. Introduction

Differently from X-rays, neutron beam has unique characteristics that cross-section is not dependent on atomic number, and even isotopes have different cross-sections. Therefore, neutron beam has been utilized to analyze complex materials. In this paper, neutron target systems applicable to these low and intermediate energy of accelerators have been designed using Monte Carlo simulations. For 10, 13, 15, 20, 25 and 30 MeV of proton beams, optimal thicknesses of targets and moderators were decided and neutron beams were characterized. Thicknesses of targets were optimized by considering neutron yield and hydrogen blistering effect, and thicknesses of moderators were optimized by confirming neutron yield and spectrum of thermal neutron beam.

2. Methods and Results

Accelerator driven compact neutron source is consisting of accelerator and target-moderator-reflector assembly (TMRA). Charged particles, electron, proton or heavy ions, are accelerated by the linac or cyclotrons, and bombarded at the target material, and neutrons are produced by the charged particle reactions. The energy of produced neutrons at the target by charged particle reactions are laid in the region of fast neutron. The energy of neutrons are reduced from fast to thermal at the moderator. The reflector contributes to increase the flux of neutron at the wanted position by reflecting leaking neutrons.

Applications of neutron beams are different according to the energy of neutron. Fast neutrons are utilized to irradiation tests, epithermal neutrons are used to BNCT, and thermal neutrons are used for neutron scattering and imaging. Therefore, application oriented TMRA design is necessary.

3. Results and Discussion

3.1 Target

In this paper, beryllium is chose for target material because of its mechanical properties good to be handled. To confirm neutron yields according to the target thickness, Monte Carlo simulations were conducted using MCNP6.1[1]. 1 mA of proton beam was bombarding the target. Figure 1 shows the geometry of simulation, and figure 2 shows the results of simulations. As shown in figure 2, the neutron yield is saturated at the certain depth. It is because of the threshold energy of charged particle reaction which produces neutron. For beryllium, threshold energy of neutron production by proton bombardment is 2.1 MeV. From the depth which the energy of incident proton is reduced less than 2.1 MeV, neutrons does not produced any more.

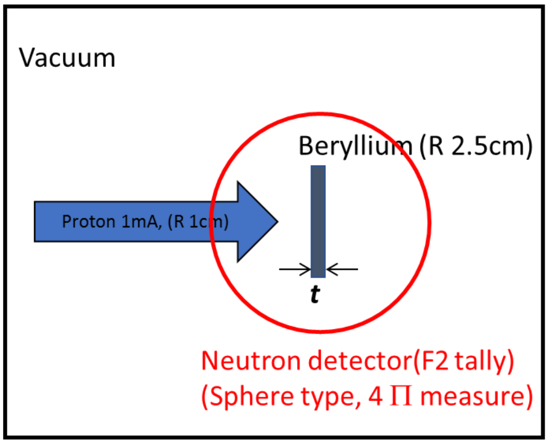

Fig. 1 A geometry of MCNP simulation for target

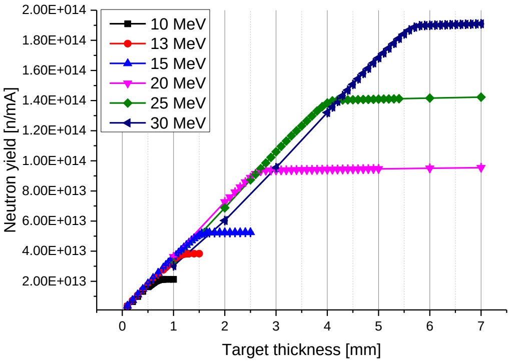

Fig. 2 Target thickness vs. neutron yield for 4Π direction @ 1mA of proton beam

When protons are stopped in the target, they become hydrogen gases. If the gases are stored inside of the target material, the blister of target is occurred. Therefore, it should be considered at the target design. Since proton is stopped around the range, blistering occurs around the range of proton. To consider blistering effect, range simulation was conducted using SRIM code[2]. Table 1 shows the results on range simulation. To prevent blistering effect clearly, 90 % of range(R) minus struggling(dR) was chosen as optimal thickness of the target.

Table 1 Results on range calculation

Proton energy [MeV]	R[mm]	dR[mm]	R-dR [mm]	90% of (R-dR) [mm]
10	8.03E-01	1.13E-02	7.92E-01	0.72
13	1.29E+00	2.07E-02	1.27E+00	1.14
15	1.66E+00	2.58E-02	1.64E+00	1.5
20	2.79E+00	3.85E-02	2.75E+00	2.5
25	4.18E+00	5.85E-02	4.12E+00	3.8
30	5.82E+00	8.13E-02	5.74E+00	5.2

3.2 Moderator

In this paper, polyethylene was chose as moderator material. To confirm fluxes and spectra of moderated neutrons Monte Carlo simulations were conducted. Analogous with target simulation, the current of bombarding proton was set to 1 mA. Figure 3 shows the geometry of simulations. In this paper, cooling system for target was not considered.

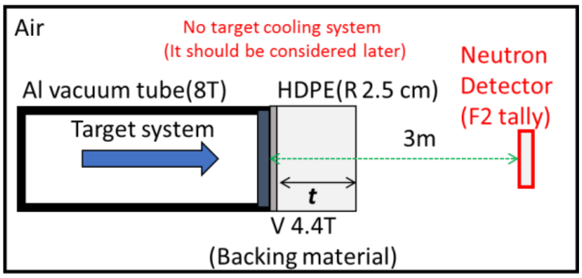

Fig. 3 A geometry of MCNP simulation for moderator

Simulation results are represented in from figure 4 to 6. Neutrons which have the energy less than 100 meV were grouped as thermal neutrons. As shown the figure 4, 5 and 6, the flux of total neutrons was decreasing along to the increase of moderator thickness, but the flux of thermal neutrons was maximized at 4 cm for all cases.

4. Conclusions and Future works

By Monte Carlo simulations, the optimal thickness of target and moderator was found. Further studies on the moderation performance with other materials and the optimal dimension of reflector will be conducted.

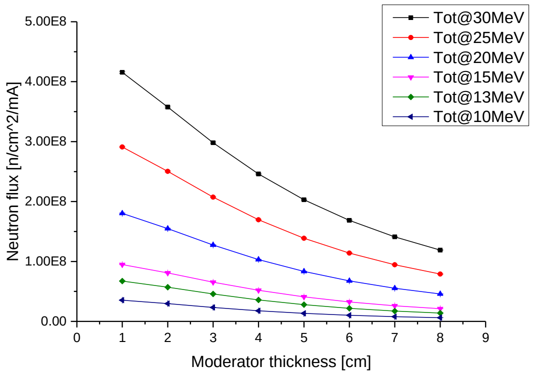

Fig. 4 Moderator thickness vs. neutron flux @ 3 m way from the target

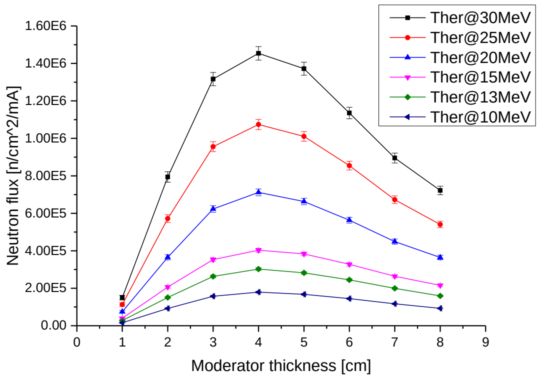

Fig. 5 Moderator thickness vs. thermal neutron flux @ 3 m way from the target

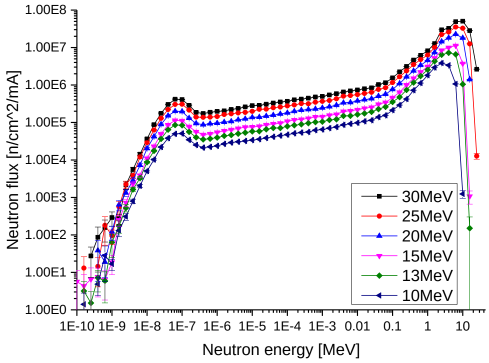

Fig. 6 Neutron spectra after moderation @ 3 m way from the target

REFERENCES

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[2] J.F. Zeigler et al., "SRIM-The Stopping and Rage of Ions in Matter(2010)", Nuclear Instruments and Methods in Physics Research Section B, 268-11(2010) pp.1818-1823