Design of an Improved Lithium Target System for Accelerator-Based BNCT

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1. Introduction

A popular reaction considered as a neutron source for accelerator-based BNCT is ^{7}Li(p,n)^{7}Be because a rapid rise of the cross section near the threshold of 1.88 MeV provides large quantities of relatively low-energy neutrons. The neutrons produced by 2.5 MeV protons impinging on a lithium target have the maximum energy of approximately 800 keV in the forward direction. Therefore, they allow users to get epithermal neutron beams for BNCT with less moderation than those of higher energy produced by other reactions such as ^{9}Be(p,n)^{9}B, ^{9}Be(d,n)^{10}C, and ^{13}C(d,n)^{14}O.

Unfortunately, while the ^{7}Li(p,n)^{7}Be reaction is excellent neutronically in BNCT, the melting point of pure lithium metal is very low (181 °C) and its thermal conductivity is also poor (85 W/m-K at 300 K). In the University of Birmingham, a lithium target system using submerged-jet cooling - in which a normally incident, high velocity water jet impinges through a water pool on the center of the target - has been implemented to overcome these difficulties. Although heavy water cooling was used to minimize neutron absorption, it seems to affect the neutrons produced from the target in the viewpoint of neutronics because the water flows into and out of the target co-axially.

In a previous study [1], a conceptual design of target system was proposed and it showed that the lithium target could be maintained up to about 100 μA proton beam. However, since the beam current required for BNCT is several mA, it needs to improve the target cooling. In this study, a new lithium target design was described and neutronic and thermal features of the target system were analyzed.

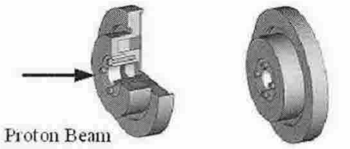
2. Methods and Results

2.1 Target System Design

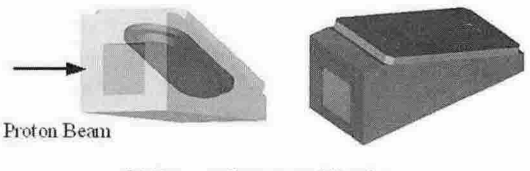
For target cooling, the peak heat flux (power per unit area) of proton beam on the target is an important parameter. Therefore, the first one approach to improving the target cooling is to expand the proton beam spot size on the target, thereby reducing the heat flux on the target. Since 2.5 MeV protons can be expanded to large diameter with static magnetic elements in beam transport systems, the incident proton beam size on the target was increased from 3 mm in the previous study to 30 mm in diameter. For the same purpose of reducing the heat flux, the lithium target was tilted with the normal direction of its surface meeting the incident direction of proton beam at the angle of 70 degree. The heat flux is decreased by cosine 70°. The tilted target also increases the effective thickness of target for the incident protons.

The second one approach is to increase the heat transfer rate from the back of the target. The main factor affecting the choice of lithium target backing is thermal conductivity. Additional factors taken into account are the neutron activation cross section, chemical compatibility with lithium, and resistance to corrosion by the water coolant. In result, an 1 mm thick copper was considered as the backing material when lithium is boned mechanically on copper.

The cooling type of water was also changed. Instead of the indirect cooling by water circulating around the target and aluminum holder, the direct cooling by 1 mm thick water channel in contact with the copper backing was employed. Finally, the neutron producing target system was designed in the form of a lithium disk bonded on a water-cooled copper backing and surrounded by the aluminum holder. Figure 1 shows the previous conceptual and present improved designs of the target systems.



(a) Previous Conceptual Design



(b) Present Improved Design

Figure 1. Lithium Target Systems

2.2 Thermal Hydraulic Analysis

The finite difference code FLUENT was used to model the 3-D thermal hydraulics. It was assumed that the power density was uniform within the proton beam spot area on the target surface.

Figure 2 shows the lithium target modeling and the temperature distribution on the lithium surface. For the proton beam current of 1 mA, it was predicted that the maximum temperature of the lithium target was 47.54 °C when the water flow rate in the coolant channel was 0.67 kg/sec.

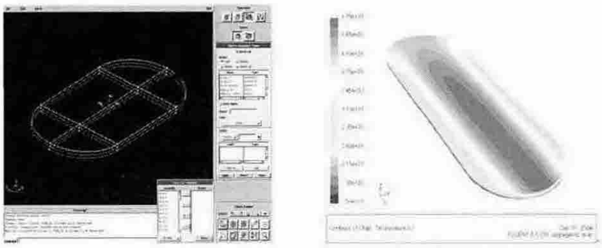


Figure 2. Target Modeling and Temperature Distribution on the Lithium Surface.

2.3 Neutronic Analysis

The neutronic characteristic of the improved target design was analyzed using MCNPX code, and compared with the previous target.

For the same target thickness (100 μm) as the previous design, the neutron yield was increased by about 4% due to the longer effective thickness. However, since the improved target system is designed with the direct water cooling as well as additional other structures on the neutron path, it is expected that the neutrons emitted from the target system could be reduced a little for the forward direction. The calculations predicted that the total neutrons out of the target system could be decreased by about 6% for the forward direction.

Figures 3 and 4 show the angular distribution of the normalized neutron flux for the forward direction, in each target design. While the neutron flux distribution from the previous target system is concentrated symmetrically on the forward direction of the target as one's expectations, the neutrons from the improved target system was more scattered due to coolant, copper backing, and aluminum holder. However, if a reflector of beam-shaping assembly is incorporated, the neutrons will be reflected in the forward direction.

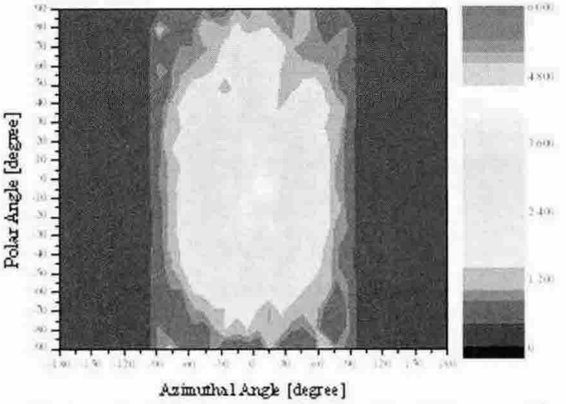


Figure 3. Angular Distribution of Normalized Neutron Flux out of the Previous Target System for Forward Directional Neutrons

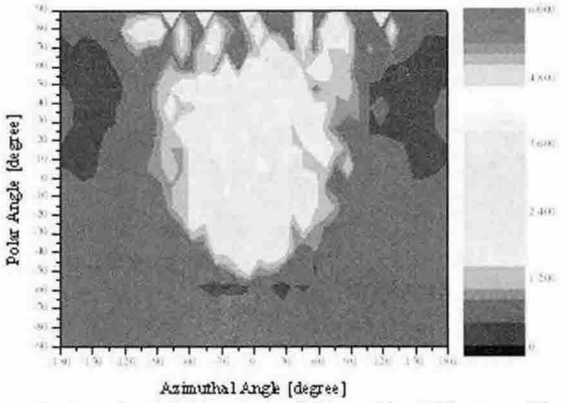


Figure 4. Angular Distribution of Normalized Neutron Flux out of the Improved Target System for Forward Directional Neutrons

3. Conclusions

The design and analyses results showed that, for 2.5 MeV proton beam of 30 mm diameter, the 100 μm thick lithium target backed by the water-cooled copper could run sufficiently to 1 mA.

The next step is a detailed neutronic and dosimetric evaluation of the neutron flux from the beam-shaping assembly. The construction and testing of an optimal target design will be discussed.

Acknowledgement

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References

[1] S. Park, "A Conceptual Design of Neutron Producing Target for Accelerator-Based BNCT and a Development of Target Cooling Method," *Proceedings of the Korea Nuclear Society 2003 Autumn Meeting*, October 30-31, 2003.