A Study on Thermal Optimization of Lithium Target Design for Accelerator-Based BNCT

Shane PARK[a,*], Sang Hoon JUNG[a], Chi Young HAN[b], Soon Young KIM[b], Jong Kyung KIM[a]
Gyoo Dong JEUN[a], Min Goo HUR[c], and Jong-Seo CHAI[c]
[a] *Department of Nuclear Engineering, Hanyang University, Seoul, Korea*
[b] *Innovative Technology Center for Radiation Safety, Seoul, Korea*
[c] *Korea Institute of Radiological & Medical Science, Seoul, Korea*
[*] E-mail: psi@thlab.hanyang.ac.kr

1. Introduction

For accelerator-based BNCT, ^{7}Li(p,n)^{7}Be reaction is prevalently used as a neutron source because a rapid rise of the reaction cross section near the threshold of 1.88 MeV provides large quantities of relatively low-energy neutrons. However, lithium has very low melting point (180 °C) and poor thermal conductivity (85 W/m-K at 300 K) so that it needs an efficient cooling.

To overcome these defects, many kinds of methods have been attempted in other researches. In BINP (Budker Institute of Nuclear Physics), a rotating target design with liquid metal cooling was presented. In the latest research of BINP, the target diameter changed to larger size of 10 cm and many lines of groove was engraved to the target to increase the heat transfer area from proton beam. 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 target has been implemented. In LBNL (Lawrence Berkeley National Laboratory), very closely spaced and narrow coolant passages cut into the aluminum were used to cool a thin layer of lithium on an aluminum backing.

As a result of literature survey and qualitative study [1,2], the temperature distribution of lithium target depends mainly on the heat generation density of target. To reduce the heat density, ideas of increasing proton beam diameter and slanting target have been proposed in a previous study [2]. In this study, various kinds of proton beam diameter, beam current and target slope were evaluated for thermal optimization of the previous target design.

2. Methods and Results

2.1 Key Elements of Lithium Target Cooling

It is noted that the proton beam current required for efficient BNCT is several mA. In lithium target, it is not easy to remove sufficiently the heat produced from the proton reactions only with a general cooling system such as that of beryllium target because much larger amount of coolant injection is required. Therefore, it is important to find the key elements which affect cooling efficiency.

As a result of the previous study, the first of key elements is the proton beam diameter. Since 2.5 MeV protons can be extended to large diameter with static magnetic elements in beam transport systems, it is not difficult to increase the incident proton beam size up to a few centimeters in diameter. The second is target slope. If a lithium target is slanted to enlarge the proton beam projection area, the enlarged heat generation volume reduces overall heat generation density. Figure 1 shows lithium targets slanted from 90° to 20° against the incident direction of proton beam.

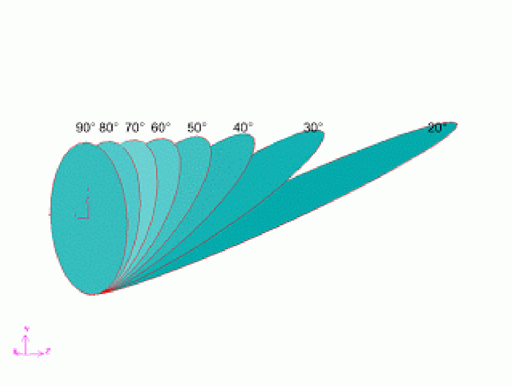


Figure 1. Lithium Target Slanted from 90° to 20° by 10°

2.2 Calculation Conditions and Method

The CFD (Computational Fluid Dynamics) flow modeling code, FLUENT, was used to model 3D thermal and hydraulic response of target. Basic conditions assumed for the calculations are as follows. The incident proton beam energy is 2.5 MeV. The inlet mass flow rate of coolant is 0.67 kg/sec (about 40 L/min) and the inlet temperature is 15 °C. It is also assumed that the power density is uniform within the proton beam spot area on the target surface. An 1 mm thick copper layer is attached tightly at the back of the target and the heat from target is extracted through the copper to the coolant flow. The coolant channel height is 1 mm.

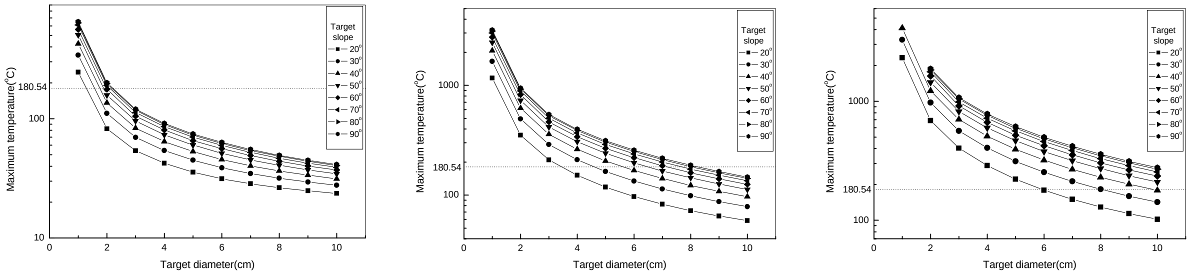
The proton beam size is changed from 1 cm to 10 cm in diameter by 1 cm, and the target is slanted from 90° to 20° by 10° against the incident direction of proton beam. The proton beam current is assumed to be 1, 5, and 10 mA.

2.3 Calculation Results and Discussion

Figure 2 shows the maximum temperature of the lithium target as a function of proton beam diameter for each target slope from 20° to 90°. As expected, the maximum temperature of the target is minimal at 20° slope. The bigger beam diameter causes the heat generation density to decrease and therefore results in lower maximum temperature.

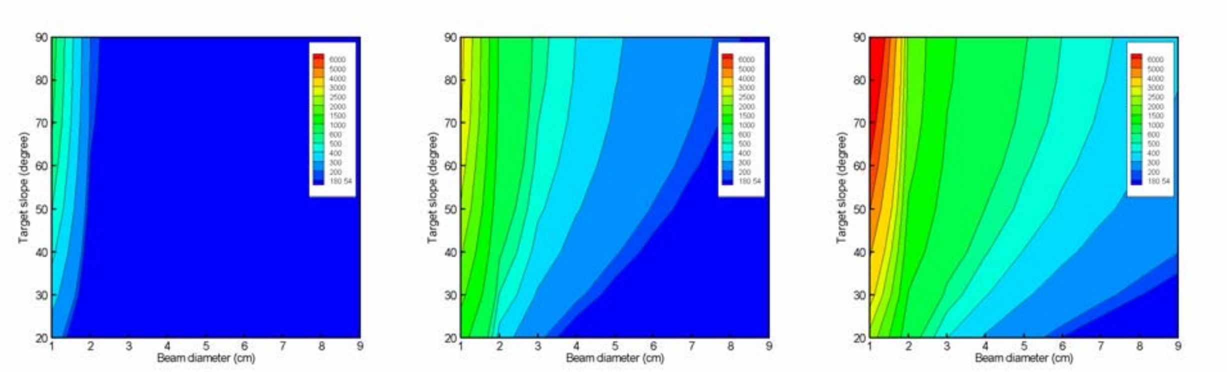
Considering the lithium melting point, it is noted that the proton beam of 2 cm diameter is at least required to maintain the target integrity for 1 mA beam current at 20°. For 5 mA, it is possible to use the target of 20° slope against the proton beam of 4 cm diameter and for 10 mA, the available minimum of proton beam diameter is 7 cm.

Figure 3 shows the contour plots of the maximum target temperature corresponding to proton beam diameter and target slope. Using these contour plots, it is possible to identify the feasible beam diameter and target slope.



(a) 1 mA (b) 5 mA (c) 10 mA

Figure 2. Maximum Temperature of Lithium Target as a Function of Proton Beam Diameter for Each Target Slope



(a) 1 mA (b) 5 mA (c) 10 mA

Figure 3. Contour Plots of Maximum Temperature of Lithium Target as a Function of Proton Beam Diameter and Target Slope

3. Conclusion

Thermal analysis on the lithium target design for accelerator-based BNCT shows that the water cooling is feasible if the proton beam diameter and target slope are in the available range of the contour plots generated from this study.

These results can be applied to new or advanced lithium target design of accelerator-based BNCT and future work will be focused to evaluate the detailed design of prototype target system and to do thermal analysis for feedback.

ACKNOWLEGEMENT

The authors wish to acknowledge the financial support from Ministry of Science and Technology of Korea, and support from the Innovative Technology Center for Radiation Safety (iTRS).

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.

[2] S. H. Jung, et al., “Design of an Improved Lithium Target System for Accelerator-Based BNCT,” *Proceedings of the Korea Nuclear Society 2004 Autumn Meeting*, October 30-31, 2004.