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Thermal Analysis of Thallium Solid Target of Cyclotron

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1. Introduction

Thermal analysis of Tl solid target for the mass production of ^{201}Tl radionuclide was studied by using CFX code[1]. ^{201}Tl radionuclide is produced by ^{203}Tl(p,3n)^{201}Pb($\rightarrow^{201}$Tl) reaction. Natural abundance of ^{203}Tl is 29.5% and its melting point is 304 °C. For the sake of target stability, the temperature distribution of the target is important information to determine major operational parameters of cyclotron. Tl solid target is irradiated by 28 MeV protons with the current of 200 μA, which is currently employed at KIRAMS for the production of ^{201}Tl radionuclide. ^{201}Tl production rate can be enhanced simply by using high current proton beam. In such a case, target damage must be avoided from increase of beam current. Therefore, the maximum temperature of the target must be estimated before increasing beam current.

2. Target System

Figure 1 shows the solid target system, which is used to high current cyclotron (cyclone30, IBA) in KIRAMS. Metal Tl is electroplated on a Cu substrate (500 μm thickness) with a thickness of 80 mg/cm^2, where a beam is irradiated. Diameter of a beam collimator is 10 mm and the direction of beam incidence is tilted by 84° from the normal direction of the target surface. Cooling water is flowing through a channel whose cross sectional dimension is 1.5 mm × 12 mm and inner diameter of both inlet and outlet are 60 mm [2].

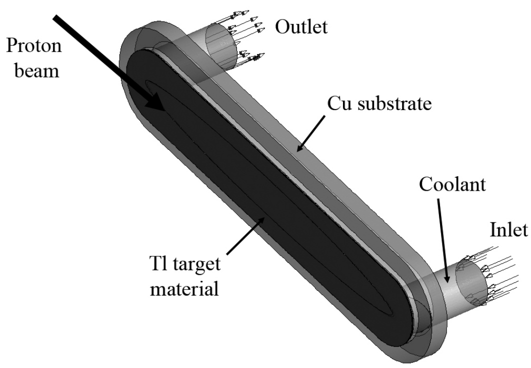

Figure 1. Schematic diagram of solid target system of cyclotron in KIRAMS.

3. Thermal-hydraulics Calculation

3.1. Calculation of heat generation from proton

SRIM code [3] was used in order to calculate the energy loss of proton beam in the target. From the results of energy loss calculation, Tl layer and Cu substrate were divided into five regions as shown in figure 2. Total power of incident beam is 5.6 kW (28 MeV, 200 μA). The deposited beam power was determined from the ratio of energy loss of proton in each region, except the reflected beam power (0.3 kW). The volumetric heat sources were obtained from distribution of the deposited beam power.

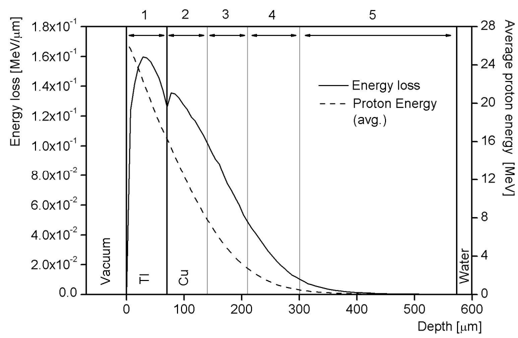

Figure 2. Energy loss of 28 MeV incident proton beam in the target calculated by using SRIM code (40,000 particles tracking).

3.2. CFX code simulation running with present beam conditions

The conditions for CFX code simulation is as follows. Coolant temperature at inlet was 15 °C and mass flow rate was 0.67 kg/sec (40 lpm). The walls except interface between Tl and Cu, interface between Cu and coolant, inlet and outlet were considered by an adiabatic condition. The irradiated area by energetic protons could be defined by projecting the circular shape of beam collimator onto the target with the angle of 6° from the surface, and the pre-calculated volumetric heat sources were defined along the direction of beam propagation. Single-phase flow was assumed and k-ε turbulence model was adopted. Steady-state condition was assumed and convergence condition was taken such that the residuals of momentum, mass, turbulence and heat transfer falls below 10^{-6}.

Figure 3 shows the results of temperature distribution obtained after running CFX code when the target was irradiated by 28 MeV protons with the current of 200 μA. The maximum temperature of Tl was about 80 °C. A particular area near the inlet was heated locally due to coolant plumb down that was observed on the target after irradiated.

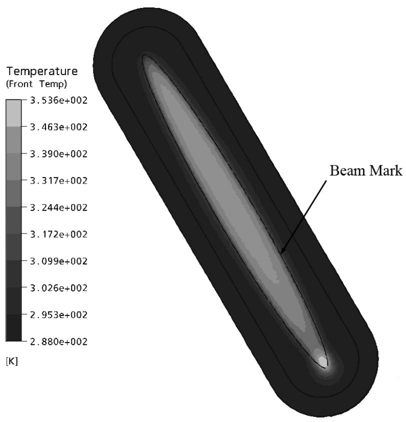

Figure 3. Analyzed temperature distribution of the Tl solid target irradiated by 28 MeV protons with the current of 200 μA.

3.3. Sensitivity for operational parameters

For the concern of Tl target temperature, it is important to check the extent of influence of operational parameters at the present beam condition. Therefore, sensitivity of the target was simulated with the variation of major parameters within ±10% ranges of nominal condition. Figure 4 shows the results of sensitivity simulation. The variation of the incident angle and the deposited beam power affected the maximum temperature mainly.

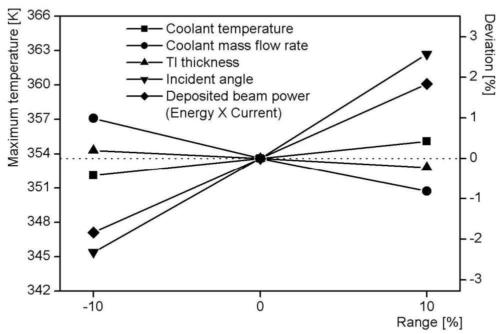

Figure 4. Result of the sensitivity simulation for variation of the major operational parameters.

3.4. Target temperature versus beam current

For the purpose of enhancing ^{201}Tl production rate, the increase of incident beam current is the most simple and straightforward method. In such a case, the target will be deposited more beam power from the increase of current. Therefore, the maximum temperature of the target should be estimated whether the beam current can be raised up to the limit of 300 μA. From the figure 5, the maximum temperature of the target increased linearly as the current increase. When the beam current was 250 μA, the maximum temperature was raised to 96.6 °C. However, for the current above 260 μA, the temperature of interface between Cu substrate and coolant might exceed 100 °C. In this simulation, the boiling condition of water was not included, so the uncertainty of the results has to be considered more carefully.

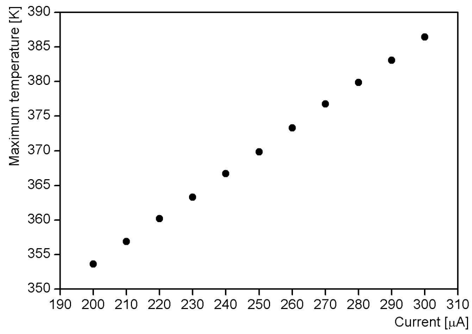

Figure 5. The maximum temperature of the target versus beam current.

4. Conclusion

The results of simulation by using CFX code indicated that the maximum temperature of Tl solid target was about 80 °C when target was irradiated by 28 MeV protons with current of 200 μA. The incident angle and the deposited beam power were most sensitive parameters which could influence the target temperature. As increase of beam current, the maximum temperature of target increased linearly. When beam current reached 250 μA, the maximum temperature of target was raised to 96.6 °C. The authors wish the results of this study useful information to cyclotron facility of KIRAMS for improving the production rate of ^{201}Tl.

REFERENCES

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[3] J. F. Ziegler, J. P. Biersack, "SRIM-2000, 40: The Stopping and Range of Ions in Matter", IBM-Research, Yorktown, NY 2000.