Thermal Properties of High Current Solid Target for High Power

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1. Introduction

Since extremely large quantities are involved in the commercial production of several radioisotopes, the proton beam intensities are pushed as high as possible to maximize production yields to several solid targets. The solid target designs employed at Korea Institute of Radiological and Medical Sciences (KIRAMS) [1] for the production of radioisotopes such as Ga-67 and Tl-201 is based on a system in which an enriched solid target material is plated onto a water-cooled backing plate. Therefore, target failure due to over-heated results in the loss of a substantial amount of expensive target materials. Hence, in practice, the beam current limit chosen for a particular target design tends to be rather conservative in order to prevent such failures.

Thermal properties of disk-type solid targets have been investigated by computer aid method in the case of irradiating proton currents up to 300 uA, which is employed to produce medical radioisotopes. In general, a higher intensity of proton beams is used to make higher yields of radioisotopes. However, higher currents carried high energies, which are generated much heat and caused the target materials melt. Therefore, it is useful to consider the modeling of heat transport in isotope production targets cooling with coolant by means of computer simulation before designing the target. In this study, the COMSOL Multiphysics [2] program was used to estimate the heat transfer in solid targets during high current proton beam irradiation. The SRIM (Stopping and Ranges of Ions in Matter) 2003 program [3] was used to calculate energy deposited into the target. The optimized proton currents to the target were determined by allowing maximal heat flows under the melting point of target materials.

2. Target Design and Cooling Configuration

The schematic solid target configuration is shown in Fig. 1. It is comprised of three enriched materials of Mg-24, Zn-68, and Ga-69, for the production of radioisotopes of Na-22, Cu-67, and Ge-68 (listed at Table 1), through which the cooling water is forced at a high velocity of 2 m/sec. The 100 MeV proton beam, which irradiates the target surface in a direction perpendicular to the surface, travels through the target materials where its energy is deposited by the interacting with ions. The heat generated in materials is then conducted to the surface where it is transferred to the cooling water and removed finally.

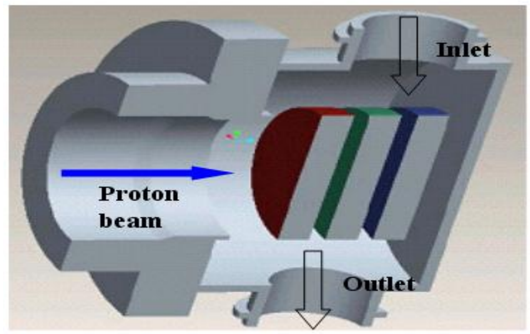

Figure 1. Schematic assembled configuration of three solid targets. The thicknesses of the three target materials, Mg (left), Zn (middle), and Ga (right), are 18 mm, 5 mm, and 2 mm, respectively (not scaled in the figure). 100 MeV proton beam is irradiated onto the target surface perpendicularly from the left side.

The optimum thickness of target materials is estimated from the nuclear cross-section data and SRIM calculation in order to yield high productions. The physical parameters of three targets used for the production of radioisotopes of Na-22, Cu-67, and Ge-68 are listed in the Table 1.

Table 1: List of target materials and characteristics

Isotopes	Na-22	Cu-67	Ge-68
Nuclear Reaction	p,n2p	P,2p	P,2n
Target Material	Mg-24	Zn-68	Ga-69
Half-life time	2.7y	2.6d	270 d
Thickness (mm)	18	5	2
Theoretical Yields (uCi/uAh)	27	150	32
Proton Energy (MeV)	90 - 70	65 - 45	30 - 10

3. Method of Thermal Analysis

A model of the target configuration is divided into a number of small elements, usually with a brick shape defined as nodes in three dimensions. The temperature at each node is then calculated, taking into account the thermal conductivity of the material and the thermal boundary conditions (heat regions and cooled surfaces) imposed on the target. A high level of accuracy in the calculations is achieved by choosing a large enough number of elements to model the target configuration.

Several parameters affect the temperature distribution in the target plate during bombardment: the cooling configuration itself, the thermal conductivity of the plate material, the cooling water temperature, the beam power density distribution, and heat coefficient between the water and the cooling-channel wall. The heat transfer is characterized by the following three mechanisms: conduction, convection, and radiation. The heat flux condition accounts for general conductive heat flux and a convective heat flux defined by a convective heat transfer coefficient. The convective flux boundary condition assumes that all energy passing through a boundary does so through a convective flux mechanism.

The power density (or intensity) of a proton beam is best represented by a 2-dimensional Gaussian profile distributed over an area of approximately 10 mm x 10 mm of the target surface. Since radioisotope production beams are usually collimated in order to protect sensitive components of the target, truncated distributions have to be used to model the heat load on a radioisotope production target.

4. Results and Discussion

The irradiated 100 MeV protons are lost kinetic energies as they pass through the target materials, as indicated in Fig. 2. The energies deposited in the target materials from the proton beam are estimated from the beam loss curve. The heat sources at the target materials are defined as the production of the energy loss and the beam intensity. Figure 3 shows the results of runs for 300 uA protons with water flow for the assembled targets of Mg, Zn, and Ga. The maximum temperature of the target is located at the middle of the target due to only a conductive heat flux occurs while both surfaces are subjected to higher convective heat flux transfer from the results, in which the middle of targets of Mg and Zn indicates higher temperature then both front and back faces. It is apparent that the temperature highly depends on convective parameter, thereby underlining the importance of having the ability to control it properly during bombardment.

5. Conclusions

The results of the parameter study are presented and discussed with the objective of maximizing the beam current limit of the solid target design employed at the 100 MeV proton beam. From the analysis of thermal modeling to target system where energy loss by incident particles are accounted on basis of known reference data, the maximum temperatures within the targets and cooling water versus beam current could be determined. Therefore, we can predicts and provides an understanding of temperature and velocity profiles within various target configurations

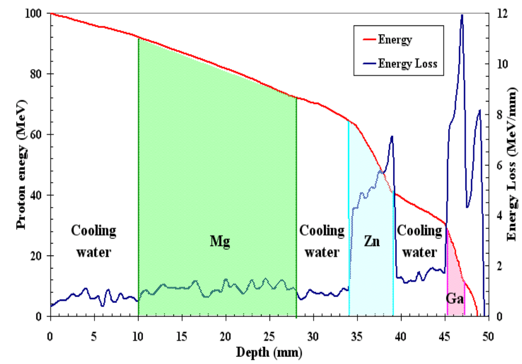

Figure 2. Energy (red) and energy loss (blue) of protons passing through targets as calculated by using SRIM. The thickness of each targets was determined the range of distances, where the proton losses 20 MeV in materials

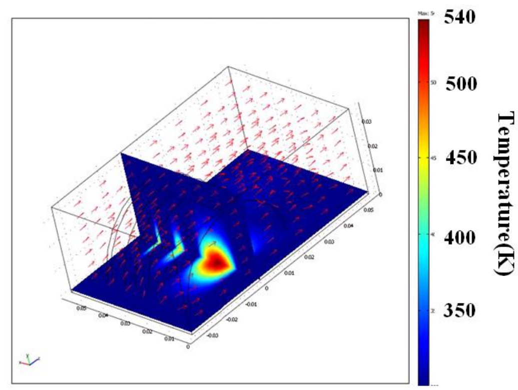

Figure 3. Simulation result for the temperature distribution in three different target materials: Mg (thickness 18 mm), Zn (5 mm), and Ga (2 mm). The temperature profile is shown hot at the middle of target materials.

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