ENCAPSULATED TARGET FOR ISOTOPE PRODUCTION CYCLOTRONS

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Abstract

The current solid isotope production targets [1] at TRIUMF can only be used to irradiate metallic materials with high melting points. In order to irradiate liquids, powders, and materials with low melting points, a new encapsulated target is being developed specifically for use on isotope production cyclotrons. This concentrically water-cooled target must withstand a 240 µA @ 30 MeV proton beam. The target is a round container with a pocket to hold the target material; the target material is encapsulated using a thin foil, which is electron-beam welded onto the target. The cooling and the heat-induced stresses of the target are being analysed using finite element methods. The results will then be compared with actual measurements obtained using surface embedded thermocouples. The paper discusses the results and the current status of the project.

1 INTRODUCTION

The development of the new encapsulated target by Applied Technology Group at TRIUMF was initiated due to the need for irradiation of powders, liquids, and other materials. This new target must isolate the target material from the rest of the system. The target also needs to be oriented horizontally in order to be able to hold liquids properly. Since it is necessary to keep the target material temperature as low as possible, a detailed study of the thermal performance target was undertaken. Using a Finite Element Analysis (FEA) modeling package, the target and the cooling system were investigated. The axis-symmetric property of the system allows the simplification of the FEA model. The heat load of the beam was modeled using a radial Gaussian distribution with truncated tails representing the beam spill.

2 TARGET DESIGN

The encapsulated target can be thought of as a upside down metallic petri dish with a diameter of 70 mm and a height of 12.7 mm. The top centre piece has a shallow recess for holding the target material, and the back is part of the coolant circuit. The encapsulation is achieved by electron beam welding a thin foil (~12-25 µm) to the periphery of the target. This new target allows the irradiation of liquids, powders and low melting materials. The target can be made out of one or two materials. The hybrid target has a stainless steel ring, which is silver-soldered to the silver or copper centrepiece. The thickness of this section is about 1.0 mm in the centre. The bimetallic construction enhances thermal performance and allows easy electron-beam welding of the foil. Figure 1a shows a hybrid copper target and Figure 1b shows a hybrid silver target with the encapsulating foil. A solid version of these targets, shown in Figure 1c, can be used to replace the existing targets used for electroplated material. This target does not require the foil or the shallow recess.

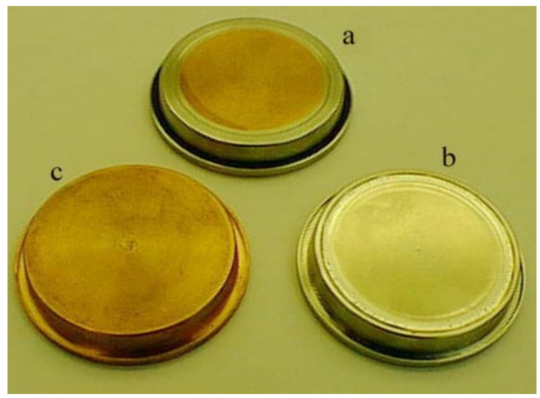

Figure 1: Encapsulated Targets

The target is positioned in the horizontal irradiation orientation by a remotely controlled actuator [2], which also creates a concentric coolant circuit against the back surface of the target as shown in Figure 2.

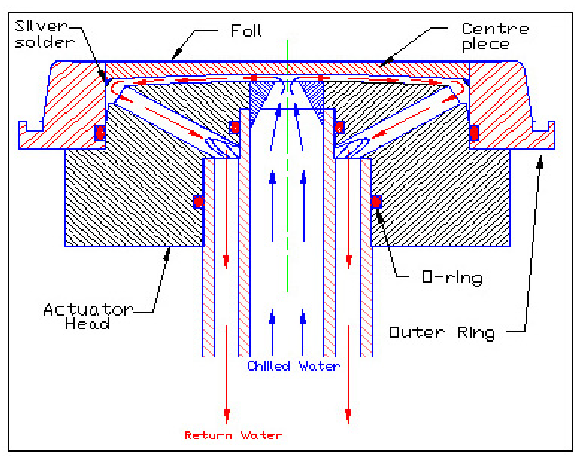

Figure 2: Target and Actuator Head cross section

The 30 MeV proton beam, which hits the target at an angle of 12.5°, is stopped in a relatively thin layer (~ 250 µm to 330 µm thick, depending on the target material) depositing all of its energy. The generated heat is then conducted to the water-cooled back of the target surface. Chilled water (14° C) enters the back of the target through the centre hole of the actuator head. The water spreads radially absorbing heat from the target and then drains through the holes on the outer rim of the actuator head. Flow rates of water range from 8 to 12 L/min.

3 TEMPERATURE PROFILE CALCULATIONS

Since the water and heat flow problems in the target are very complex, they cannot be solved analytically and therefore numerical methods in form of finite element analysis must be used. For the analysis of this target, EMRC's DISPLAY III/NISA II® package was used.

3.1 Beam Profile

The irradiation area on the target is a circle with the radius of 18.75 mm, hence the beam is collimated to protect the rest of the target. As a result, truncated distributions are used to model the heat load. A Gaussian distribution can represent the power density of the circular beam .The focus condition of the beam is usually defined in terms of the beam spill on the collimators. For the encapsulated targets, this spill is to be 16.7% – i.e. 8.3% truncated on each side – which reduces the beam current to 200 μA. The power density P of the proton beam, is represented by

$$P = \frac{P_0}{\sqrt{2\pi}\,\sigma} e^{\frac{-r^2}{2\sigma^2}} \quad \text{for } |r| \le 18.75$$

$$= 0 \quad \text{for } |r| \le 18.75$$

Where r is the radius, P_0 is the total beam power (7.5kW), and σ is the standard deviation, which was calculated to be 13.52 for the specified spill. Figure 3 shows the curve.

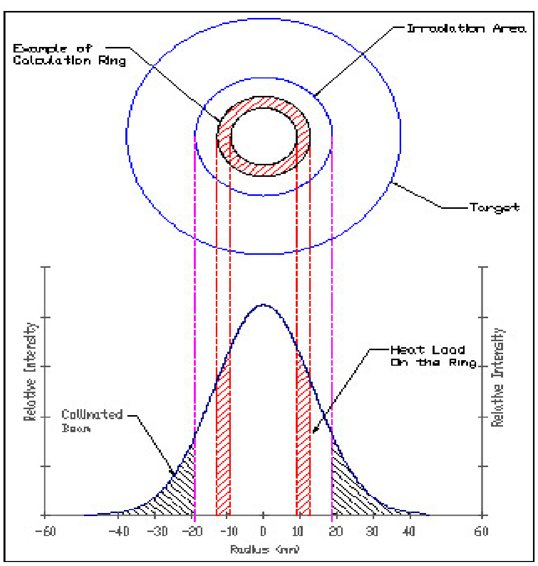

Figure 3: Proton Beam Power Density Curve

The heat load for each thin ring on the target is the area under the Gaussian curve between the ring's two radii. The beam profile also varies as the beam penetrates the material. The energy deposited in the material at regular length intervals, e.g. 0.10 mm, can be easily calculated using standard curves. An available computer code[1], was used to calculate the energy loss during penetration. The resulting two-dimensional heat profile is used in the FEA model.

3.2 FEA Model

The cooling circuit, target, and the heat load are axis-symmetric, and hence the FEA model can be simplified accordingly. The target and the coolant circuit are modelled using 3D axis-symmetric linear (4 node) quadrilateral solid and fluid elements respectively. The heat load on the target is then modelled as element heat generations distributed over the target and within three element layers (0.13 mm each) from the surface. Each element has three degrees of freedom per node: x and y water velocities and temperature. The boundary conditions for the fluid elements are no-slip conditions which dictate that water velocity at the walls is zero. The FEA analysis is performed with temperature-dependent conductivity for the target material and temperature-dependent thermal conductivity, density, specific heat, and viscosity for the water. Conjugate steady state fluid flow and heat transfer are performed for different combination of target material and cooling configurations.

3.3 Cooling Configurations

In order to find the optimal cooling configuration of the system, input parameters and configurations were varied individually in order to examine their effect on the thermal performance of the target. The different cooling configurations that were tried are as follows:

(1) Original design, coolant gap[2] of 1.0 mm
(2) Coolant gap of 0.5 mm
(3) Case (2) with a 2.0 mm diameter straight nozzle
(4) Case (2) with a 2.0 mm diameter tapered nozzle

For cases (1) and (2) the flow was assumed to be in the laminar region while for cases (3) and (4) transition or turbulence regions were assumed. The water flow rate was also varied from 8L/min to 12 L/min.

3.4 FEA Results

The FEA results from the first two configurations indicated a dead-water zone right at the centre of the target. This spot, which receives a large amount of heat

[1]The program does not take into consideration the possibility of proton scattering.
[2] The gap between the actuator head and the back of the target.

due to the Gaussian distribution, is the hottest spot of the target. By adding the nozzle to the cooling circuit, the dead water zone was eliminated which resulted in a 50% temperature drop. Figure 4 shows the temperature profile for case (4). The temperature contours are consistent with profiles expected from Gaussian heat loads. In the case shown the maximum temperature is 232° C but within 1.0 mm the temperature drops to 122° C. The thermal performance for copper and silver is almost identical and only the cooling configuration and water flow rate have significant effects on the temperature.

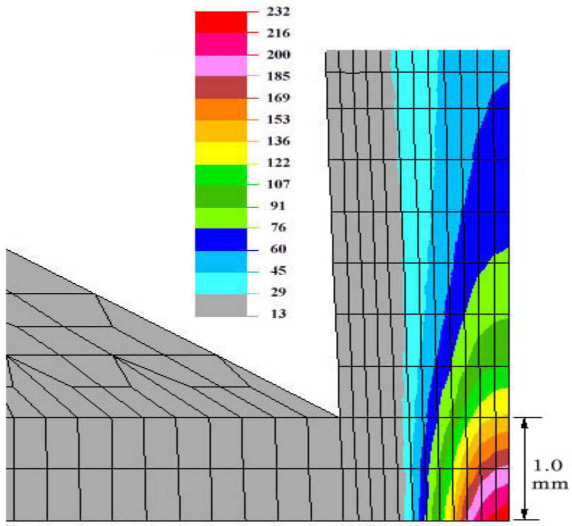

Figure 4: Target Temperature Profile (case 4)

As it can be seen from Table 1, for case (1) and (2), the water flow rate has significant effect on the temperature while for case (3) and (4) the temperature does not change. This is again due to the dead-water zone, which is very large in the first two cases but is significantly reduced in the other two cases by the use of a nozzle.

	8 L/min	**10 L/min**	**12 L/min**
1 mm Gap	511° C	N/A	450
0.5 mm Gap	483	N/A	464
Straight Nozzle	299	299	N/A
Tapered Nozzle	232	N/A	232

Table 1: Effects of Cooling Configuration and Flow Rate on Maximum Temperature

4 THERMAL PERFORMANCE TEST

In order to verify that the surface temperature of the encapsulated target during irradiation is predicted correctly by the FEA code, actual temperature measurements are needed. This task is accomplished by embedding a 0.80 mm diameter thermocouple (type K) below the surface of the centre of the target plate where the highest temperatures are expected. The test was conducted using the tapered nozzle configuration. Since an encapsulated target station [2] does not yet exist, the current solid target station had to be used for the tests. As a result the tests were conducted at currents of up to 150µA, and a water flow of 3 L/min.

4.1 Test Results

In order to have a direct comparison between the FEA output and the actual test results, FEA runs were done using the new parameters. The program predicted a temperature of 190°C at 150µA and 130°C at a current of 100µA. The measured temperatures at these currents, were 30°C and 45°C, respectively.

4.2 Discussion of the Results

The actual surface temperature can be as much as twice higher than that measured by the embedded thermocouple due to the fact the actual position of the junction is unknown and can be as much as 0.2mm below the surface. Another important factor is that the shape of the beam used in these tests is not similar to the modelled beam. The beam used for the solid target station is rectangular and is represented by a two-dimensional Gaussian curve [1], which results in less concentrated beam power. Also, the centre of the beam may not be aligned with the centre of the new target. As mentioned before, there can be a 100°C temperature difference between the centre point and a point 1.0 mm away. As a result of the above factors, the measured temperature may be 3 to 5 times less than the actual maximum temperature.

5 CONCLUSION

An encapsulated target was designed for irradiation of liquids, powders and non-metals. Using FEA modelling the thermal performance of the system was optimised to achieve the lowest temperature. The results obtained from both the FEA and the actual thermal tests indicate that the target is suitable for the desired use and it will withstand the specified proton beam.

6 ACKNOWLEDGEMENTS

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