Heat Modelling of Water Cooled Target Plates

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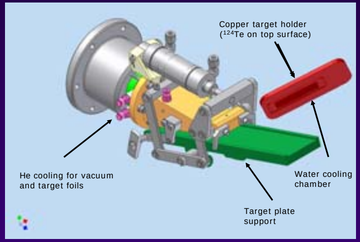
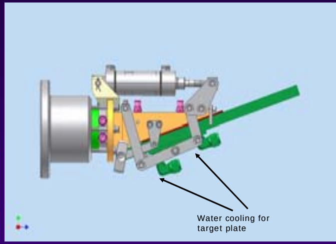
Introduction

Heat accumulation on cyclotron targets is a major concern as temperatures must remain below the targets melting point thus making the cooling mechanism an intrinsic part of cyclotron operation. A platinum electroplated copper holder containing the target substrate is water cooled while being irradiated by a 17.5MeV protons at less than 100µA.





Proper design of the copper plate will allow for higher proton beam currents and higher radionuclide production without fear of melting the target. Proper heat dissipation may also result in higher quality products.

Methods

Comsol Multiphysics 3.2a was used to model the copper target plate holders capacity for heat dissipation and fluid flow when exposed to a heat flux of approximately 9e6 W/m^2.

$$\rho C_p \frac{\partial T}{\partial t} + \nabla \cdot (-k \nabla T + \rho C_p T \mathbf{u}) = Q$$

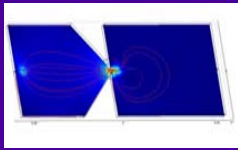
$$\rho \frac{\partial \mathbf{u}}{\partial t} + \rho(\mathbf{u} \cdot \nabla)\mathbf{u} = \nabla \cdot [-p\mathbf{I} + \eta(\nabla \mathbf{u} + (\nabla \mathbf{u})^T) - (2\eta/3 - \kappa)(\nabla \cdot \mathbf{u})\mathbf{I}] + \mathbf{F}$$
$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0$$

$$-\nabla \cdot (\nu + \nu_T)\nabla \mathbf{u} + (\mathbf{u} \cdot \nabla)\mathbf{u} + \frac{1}{\rho}\nabla p = \frac{1}{\rho}\mathbf{F}$$
$$\nabla \cdot \mathbf{u} = 0$$
$$(\mathbf{u} \cdot \nabla)k = \tau_{ij}\frac{\partial u_i}{\partial x_j} - \varepsilon + \nabla \cdot \left[\left(\nu + \frac{\nu_T}{\sigma_k}\right)\nabla k\right]$$
$$(\mathbf{u} \cdot \nabla)\varepsilon = C_{\varepsilon 1}\frac{\varepsilon}{k}\tau_{ij}\frac{\partial u_i}{\partial x_j} - C_{\varepsilon 2}\frac{\varepsilon^2}{k} + \nabla \cdot \left[\left(\nu + \frac{\nu_T}{\sigma_\varepsilon}\right)\nabla \varepsilon\right]$$

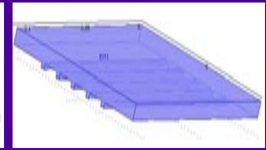
Equations for heat transfer, non-isothermal and turbulent flow

Different principals were incorporated into a copper block measuring 0.11x0.04x0.0032m to maximize heat removal during irradiation by a proton beam.

- Maximizing surface area exposed to moving water through fins
- Inducing turbulent flow in flowing water
- Increasing the velocity of the water with jets
- Proper positioning of impinging water jets

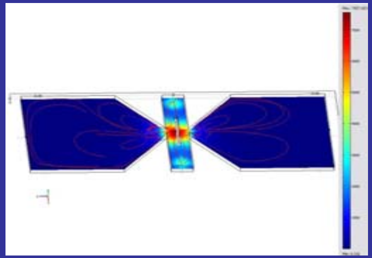


Water Jet Concept

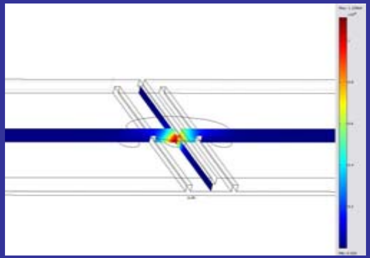


Fins Concept

Flow calculations were first run on different models to determine which produced the greatest amounts of turbulent flow. These models were then solved when coupled with general heat transfer equations to determine the maximum temperatures at different water flow rates. These flow rates ranged from 1L/min to 100L/min.



1st Copper Target holder with turbulent kinetic Energy



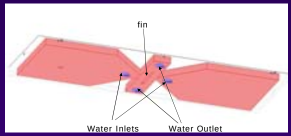
2nd Copper Target holder with turbulent kinetic Energy

Results

The models (center) were seen to be the most appropriate with respect to the amount of turbulent kinetic energy concentrated below the center of the plate where the maximum temperatures will occur. The optimal specifications are as follows:

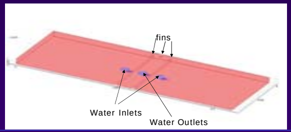
1st Copper Target

- 2 inlets 1cm away from center of plate
- 2 outlets at the ends of center chamber
- 2mm wide entrance to chamber (nozzle)
- 1mm thick fin in the center of the chamber



2nd Copper Target

- 2 inlets 0.9cm away from center of plate
- 1 outlets directly below center
- 2-1mm thick fins on the bottom, 5mm from inlets
- 1mm thick fin on the top center



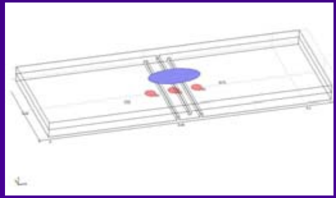
Conclusion

The models shown (center) were seen to have the best cooling efficiency based on the maximum turbulent kinetic energies produced. The nozzles in the first model increase water velocity that impinges on a fin which causes an abrupt stoppage and turbulence is induced. For the second model turbulence is also induced by the placement of fins in between the cross flow of two inlets and right above an outlet. The center fin also theoretically increases heat transfer by increasing the surface area for conduction.

Further Steps

Comsol is a very versatile program with many adjustable parameters which can make it difficult to obtain solutions to complex models. Increasing knowledge of the program will help solve more complex models in the future and to achieve the following goals:

- Solve coupled heat transfer and flow models for the target plate
- Determine max/min flow rates for "threshold" heat dissipation
- Further explore different target designs, materials and coolant options



Future Models

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