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Title: Mo100 to Mo99 Target Cooling Enhancements Report

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Mo100 to Mo99 Target Cooling Enhancements Report:

Preliminary Optimization Study of Cooling with High Flow Blower and Variable Disk Thickness, With and without Diffusers

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Summary

Target design requirements changed significantly over the past year to a much higher beam current on larger diameter disks, and with a beam impingement on both ends of the target. Scaling from the previous design, that required significantly more mass flow rate of helium coolant, and also thinner disks. A new Aerzen GM12.4 blower was selected that can deliver up to 400 g/s at 400 psi, compared to about 100 g/s possible with the Tuthill blower previously selected.Further, to accommodate the 42 MeV, 2.7 mA beam on each side of the target, the disk thickness and the coolant gaps were halved to create the current baseline design: 0.5 mm disk thickness (at 29 mm diameter) and 0.25 mm coolant gap. Thermal-hydraulic analysis of this target, presented below for reference, gave very good results, suggesting that the target could be improved with fewer, thicker disks and with disk thickness increasing toward the target center. The total thickness of Mo100 in the target remaining the same, that reduces the number of coolant gaps. This allows for the gap width to be increased, increasing the mass flow in each gap and consequently increasing heat transfer. A preliminary geometry was selected and analyzed with variable disk thickness and wider coolant gaps. The result of analysis of this target shows that disk thickness increase near the window was too aggressive and further resizing of the disks is necessary, but it does illustrate the potential improvements that are possible.

Experimental and analytical study of diffusers on the target exit has been done. This shows modest improvement in requcing pressure drop, as will be summarized below. However, the benefit is not significant, and implementation becomes problematic when disk thickness is varying. A bull nose at the entrance

does offer significant benefit and is relatively easy to incorporate. A bull nose on both ends is now a feature of the baseline design, and will be a feature of any redesign or enhanced designs that follow.

Baseline Target Design

The baseline target design is made up of 82 disks 0.5 mm thick and separated by 0.25 mm gaps for helium coolant flow. 2.71 mA of 42 MeV electron beam strickes both side of the target. Beam spot is 1.2 cm FWHM. Total heat load in the target is about 150 kW, out of 228 kW total beam power. Disk heating as a function of axial position, and the radial distribution of heating, was calculated using the MCNPX Monte Carlo code. Helium coolant is supplied at 20°C and at 400 psi (2.758 MPa). 18 psi (0.125 MPa) head is assumed available to drive the flow through the target, so the helium exit boundary condition is 2.633 MPa. For this baseline, the calculated mass flow rate is 281 g/s. Figures 1, 2 nd 3 below show average channel velocity, resulting temperature contours and peak temperature, respectively. Because of symmetry, only ½ of the target, 41 disks, are shown. The target window is excluded from this analysis. Note the higher temperature of the first disk. This is because of a reduced flow, caused in turn by a developing boundary layer within the approaching helium flow at the housing wall. This can be corrected by a step change in the wall that trips the boundary layer.

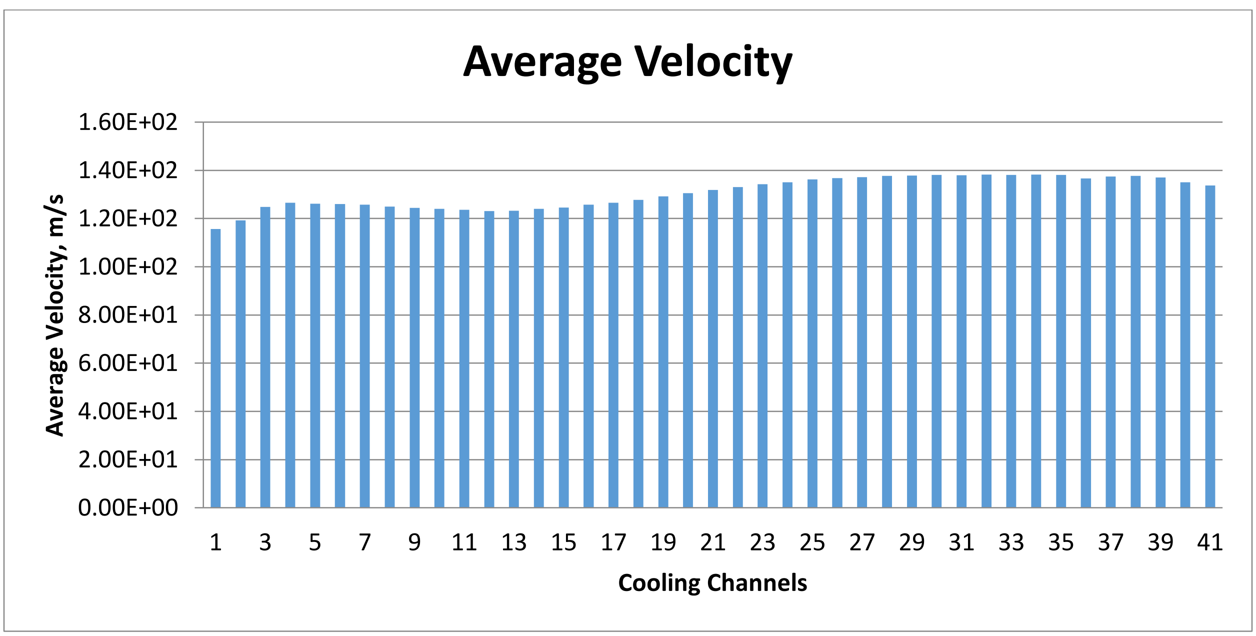

Figure 1. Helium velocity in the channels.

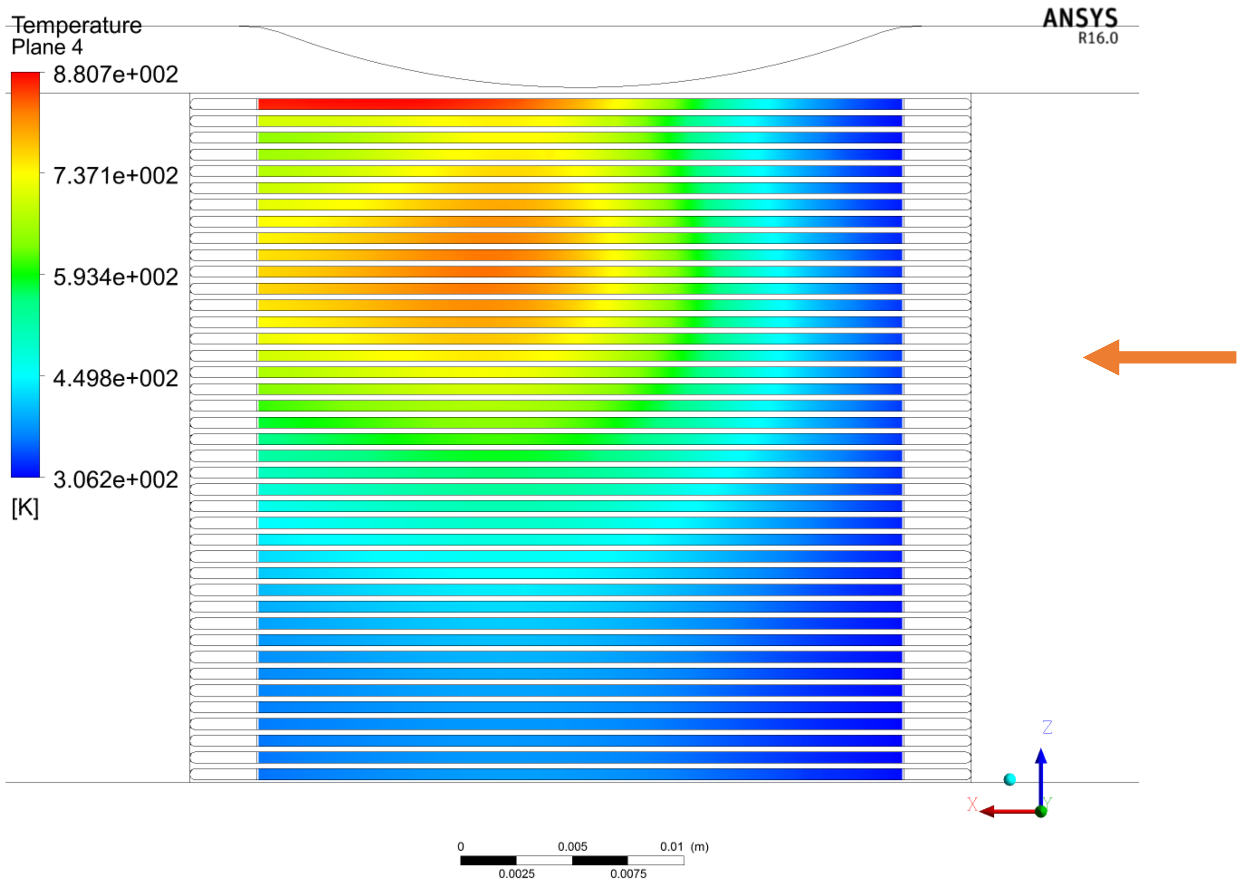

Figure 2. Temperature contour plot in the flow direction (red arrow).

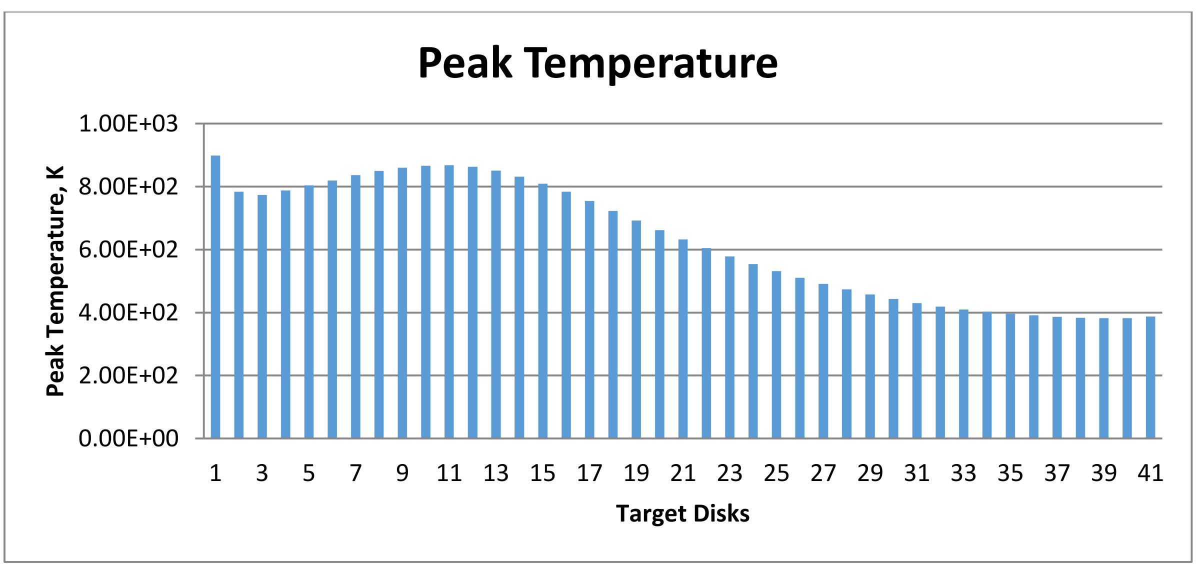

Figure 3. Peak temperature of each disk.

Peak temperatures below 900 K are very encouraging and indicate that thicker disks are possible. There is no firm maximum on disk temperature to which the design is constrained, but it is prudent to stay at or below ½ the melt point of 2890 K, or 1445 K. Also, the blower can deliver up to 400 g/s under these conditions, so the coolant gap can be increased.

Exit Diffusers

The analysis above was with a bullnosed entrance and exit on each disk. The bullnose entrance is a standard enhancement to reduce pressure drop in a flow area contraction. Typically, this is not particularly effective at the exit, rather a diffuser is used to slowly transition form the smaller to larger flow area. Experimental and analytical investigation shows that the benefit in a multi-channel flow configuration such as this is relatively small. This is illustrated in the plot of Figure 4. While not insignificant, the contribution to lower pressure drop is less than the bullnose entrance, and the feature is more difficult and costly to machine. Rather than incorporate diffusers, a bullnose is used on both ends. The symmetric design thus eliminates any possibility of loading the target in the holder in the wrong direction! Further, as we move to variable disk thickness, at the optimum diffuser angle the diffuser length would vary with disk thickness. That design and fabrication becomes rather unwieldy.

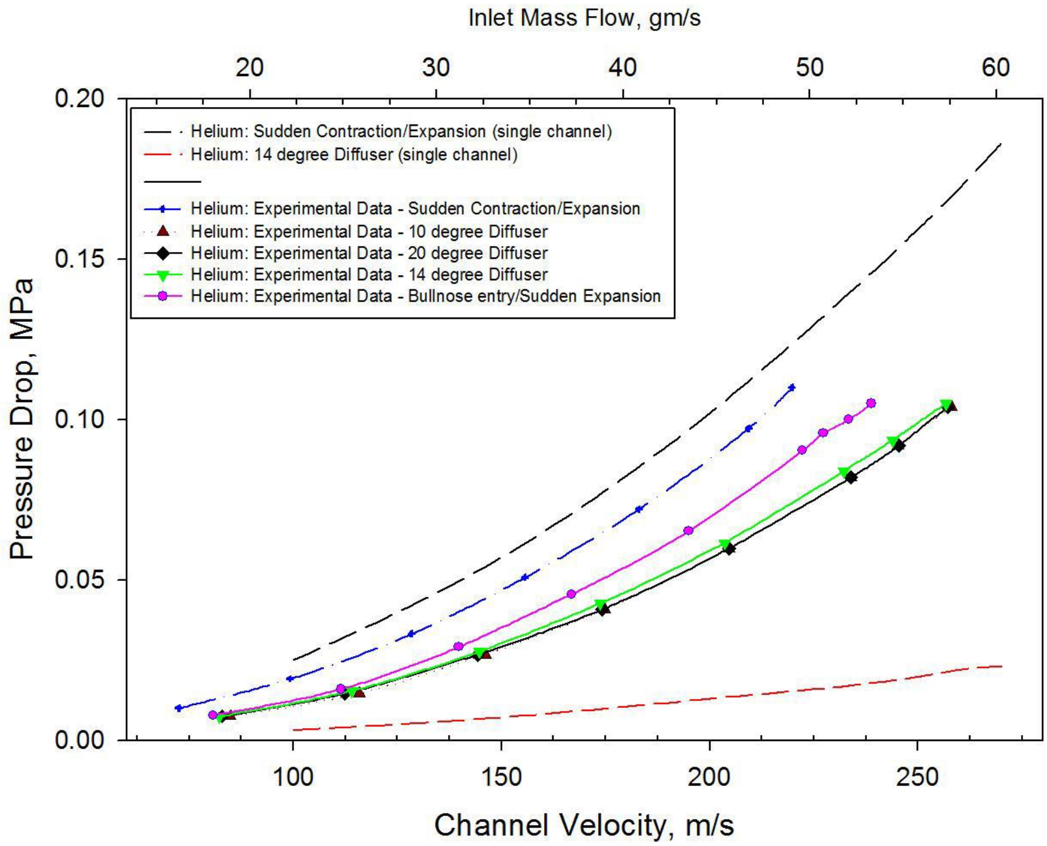

Figure 4. Analytcial and experimental results for various entrance and exit geometries. Experiments conducted at 280 psi.

Preliminary Variable Disk Study Results

As a first investigation of a variable disk thickness design, first the heat load on each disk was increased by increasing its thickness with the goal of approaching the 1445 K peak temperature. Second, the gap width was increased to approach the 400 g/s available, and also adjusted for the fact of the now reduced number of disks. The resulting geometry is as follows:

- **Target Geometry**
  - Dia. 29 mm
    - Disk 1 & 24: 1.2 mm
    - Disk 2-6 & 19-23: 1.1 mm

— Disk 7 & 18: 1.2 mm

— Disk 8 & 17: 1.4 mm

— Disk 9 & 16: 1.6 mm

— Disk 10 & 15: 2.2 mm

— Disk 11 & 14: 3.2 mm

— Disk 12 & 13: 4.5 mm

- 0.70 mm cooling channels (width)

The calculation results, again using volumetric heating numbers produced using the MCNPX code, are illustrated in Figures 5-7. The helium velocity has increased as intended, with an average velocity around 225 m/s (Figure 5)and a total mass flow rate of 410 g/s. The effective heat transfer coefficient is relatively unchanged from the baseline cooling conditions because the larger hydraulic diameter reduces the benefit of higher velocity in the same propostion in this case.

However, the increase in disk thickness is too generous in that he peak temperatures are unacceptable. Disks 1, 2 9 and 10 need to decrease in thickness to about 1 mm, while disks 3 through 8 need a larger thickness reduction to 0.7 or 0.8 mm. This change of course requires more disks in order to keep the total target solid thickness the same. This in turn will reduire a coolant channel width reduction, probably to about 0.5 mm. A systematic computational optimization is needed.

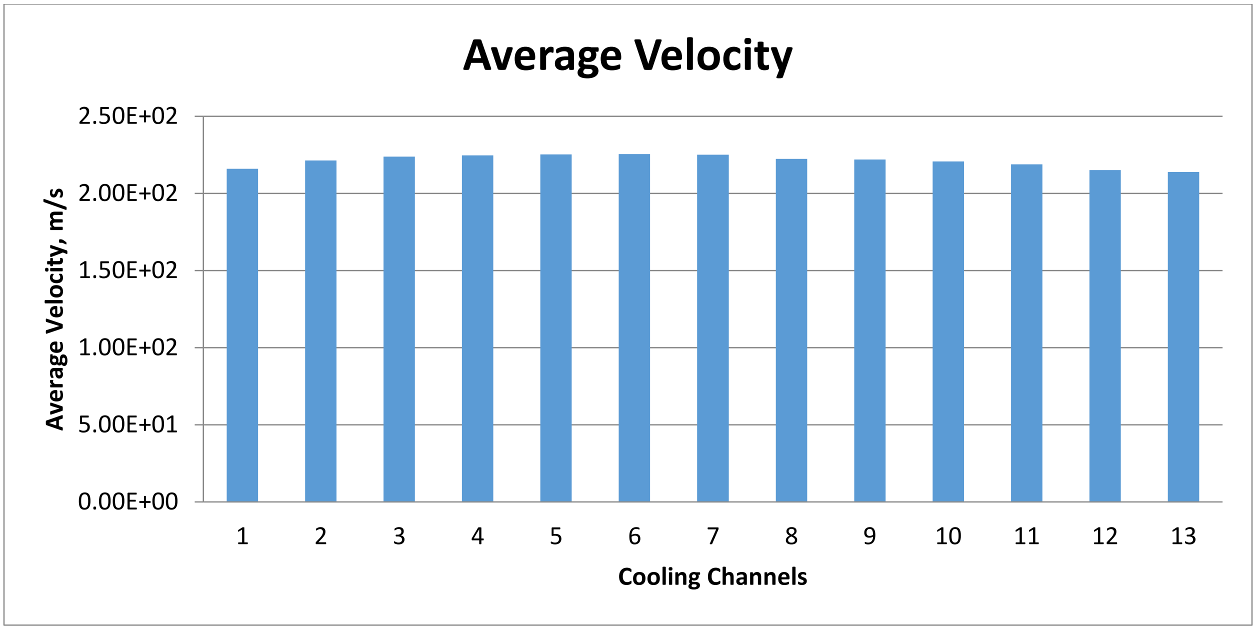

Figure 5. Coolant average velocity in the channels for the 0.7 mm gap width and variable disk thickness design.

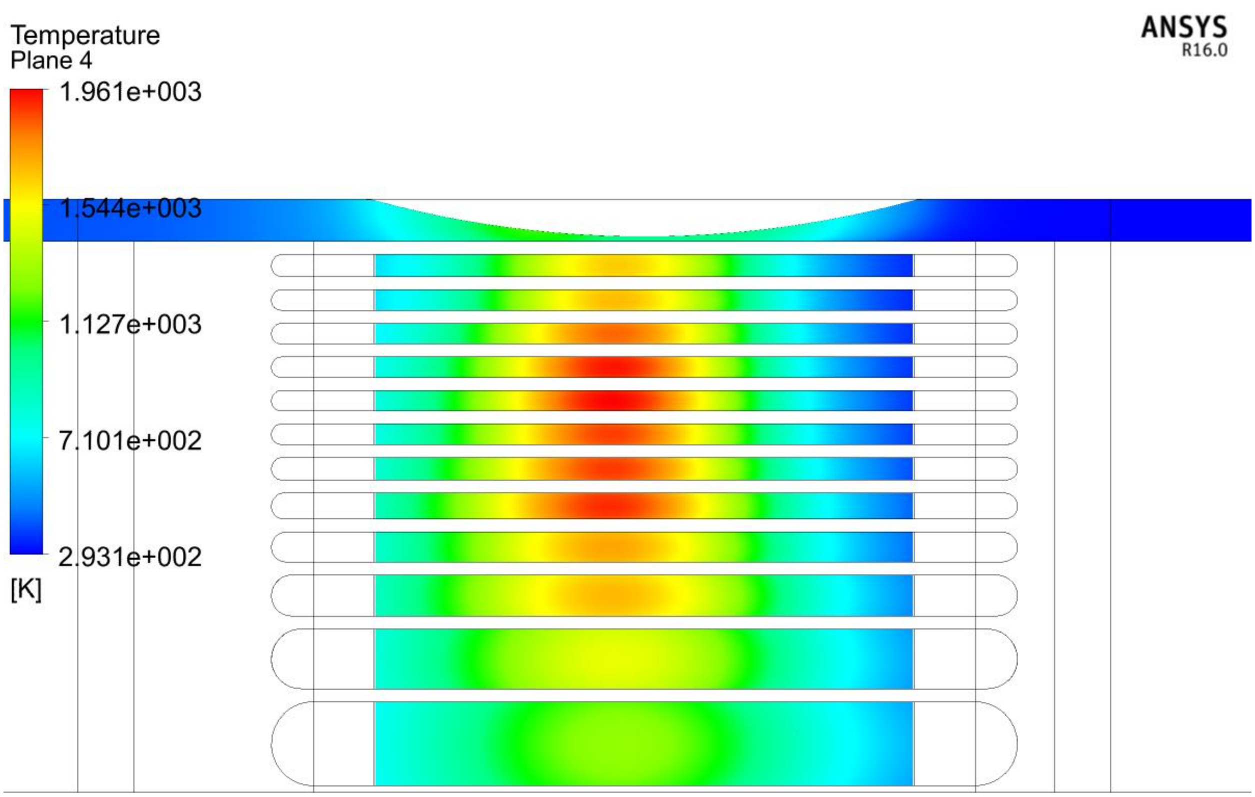

Figure 6. Temperature contour plot.

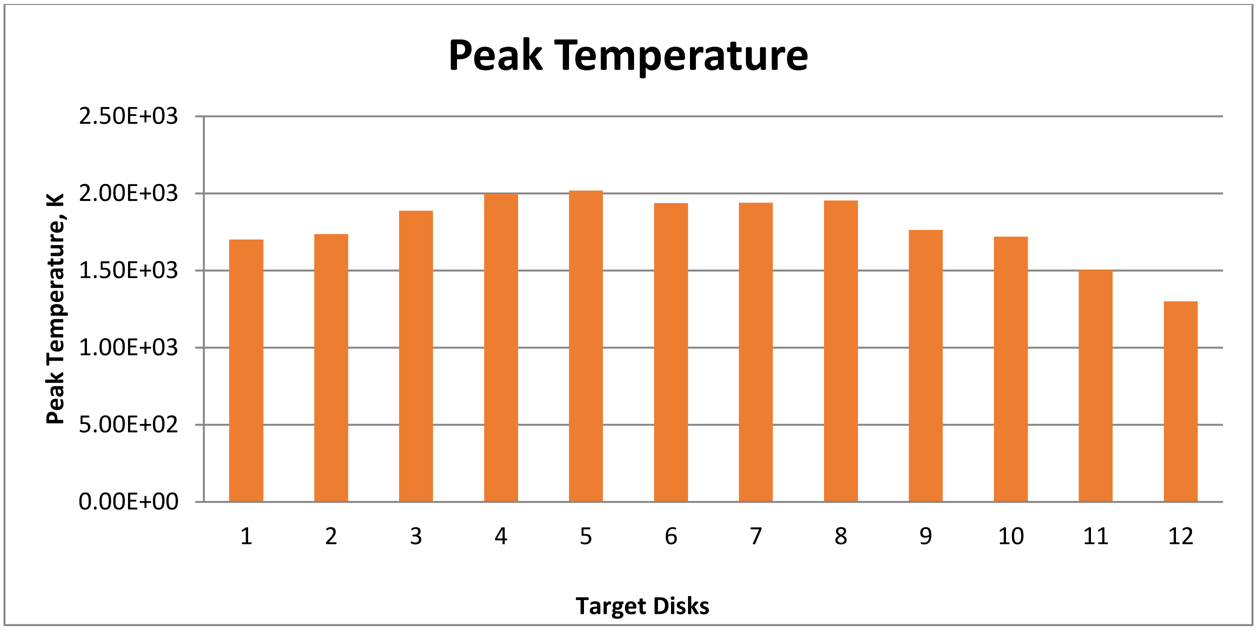

Figure 7. Peak temperature in each disk.

Conclusions

While it is imperative that the design be verified experimentally, analytical results, benchmarked against sub-scale experiments, indicate that the baseline design of the target meets the requirements for Mo99 production using the solid Mo100 target with conversion via electron beam induced gamma-n reaction. Significant improvements are possible by adjusting the disk thicknesses and the coolant gap width. The preliminary design of a variable disk thickness target presented above misses the mark a bit but does bound the possibilities and sets the stage for future iterations.

That stated, target optimization must consider a number of other factors, including material cost, percent of material recovery (recycle) after each post irradiation separation, window stress and temperature, disk stress and beam spot size and shape. As the design progresses, a more complete an comprehensive optimization strategy will be employed.