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Title: 29 mm Diameter Test Target Report

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29 mm Diameter Test Target Design Report

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Introduction

The Northstar target for Mo99 production is made up of Mo100 disks in a stack separated by coolant gaps for helium flow. A number of targets have been tested at ANL for both production of Mo99 and for thermal-hydraulic performance. These have all been with a 12 mm diameter target, even while the production goals have increased the diameter to now 29 mm. A 29 mm diameter target has been designed that is consistent with the ANL beam capabilities and the capabilities of the helium circulation system currently in use at ANL. This target is designed for 500 μA at 35 MeV electrons. While the plant design calls for 42 MeV, the chosen design point is more favorable and higher power given the limits of the ANL accelerator. The intended beam spot size is 12 mm FWHM, but the thermal analysis presented herein conservatively assumed a 10 mm FWHM beam, which results in a 44% higher beam current density at beam center.

Design

The new 29 mm target is designed to maintain the same helium flow to maintain the same heat transfer coefficient on the target and window. That target had 25 disks 1 mm thick, with 26 coolant channels 0.5 mm thick, or 126 mm2 flow channel total area. This flow area is preserved in a 10 disk target at 29 mm diameter, with 11 coolant gaps. The total disk thickness is limited by the target holder which is mounted to a stalk, the size of which is the basis for the cask design.

The disk thickness varies within the target, as shown in Figure 1, with 5 disks 1 mm thick, 3 at 1.5 mm thick and 2 at 2 mm thick. The target on the stalk is shown in Figure 2, illustrating the limit on target thickness imposed by the target width.

The window design is shown in Figure 3. Made of Inconel 718 as for previous windows, the center thickness is 0.025” (0.635 mm). The pressure side is flat, while the external vacuum side is radiused to increased strength as the beam power diminishes radially.

One additional design change has been introduced. For the previous tests on 12 mm disks, the helium tubing into and out of the target was round tubing until just before and after the target, where a tapered transition to the required rectangular cross-section is required. In the current design, the round to rectangular transition is made at the vacuum boundary entrance, or the brim of the top hat design (Figure 4). The effect of upstream entrance conditions has not been previously investigated.

Figure 5 shows the top hat assembly with the target installed and surrounding shielding. Top hat size is unchanged from the preceding experiments, so the shielding also remains the same.

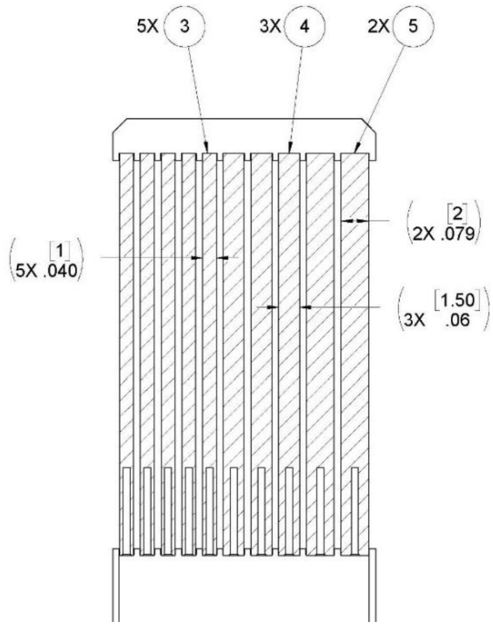

Figure 1. Cross-section view of the target disks in the disk holder. Dick thickness increases with distance from the beam entry window.

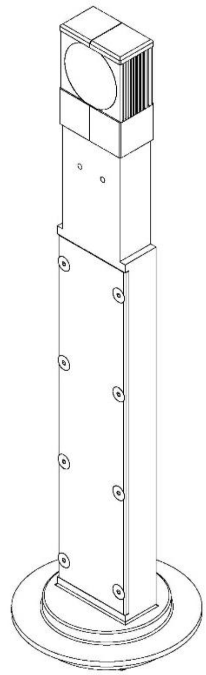

Figure 2. Target as mounted on the stalk. Target is loaded into position from below to facilitate removal by gravity into a cask.

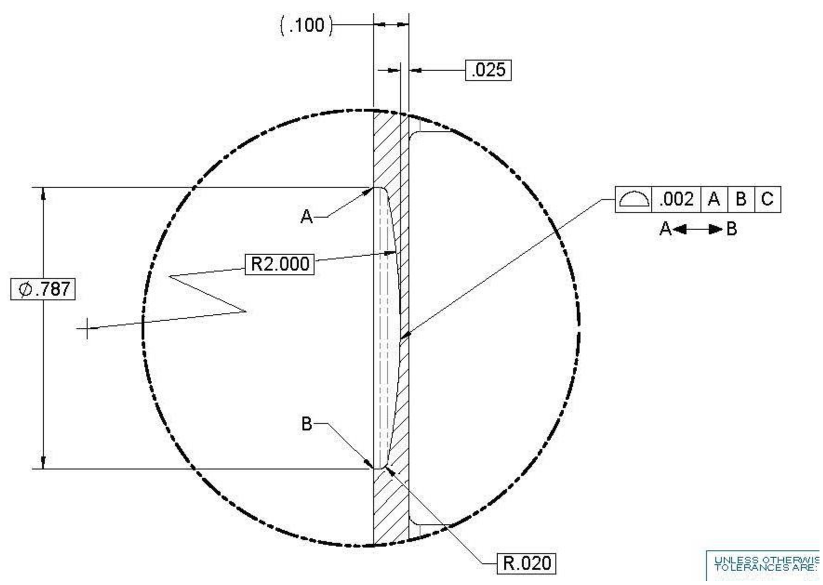

Figure 3. Beam entry window detail.

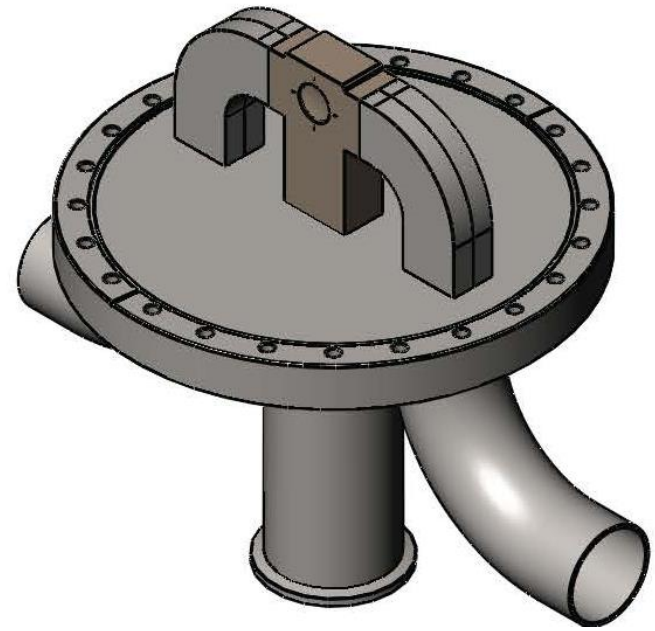

Figure 4. Plumbing configuration into and out of the target. Rectangular entrance and exit geometry matches the channel within the target holder.

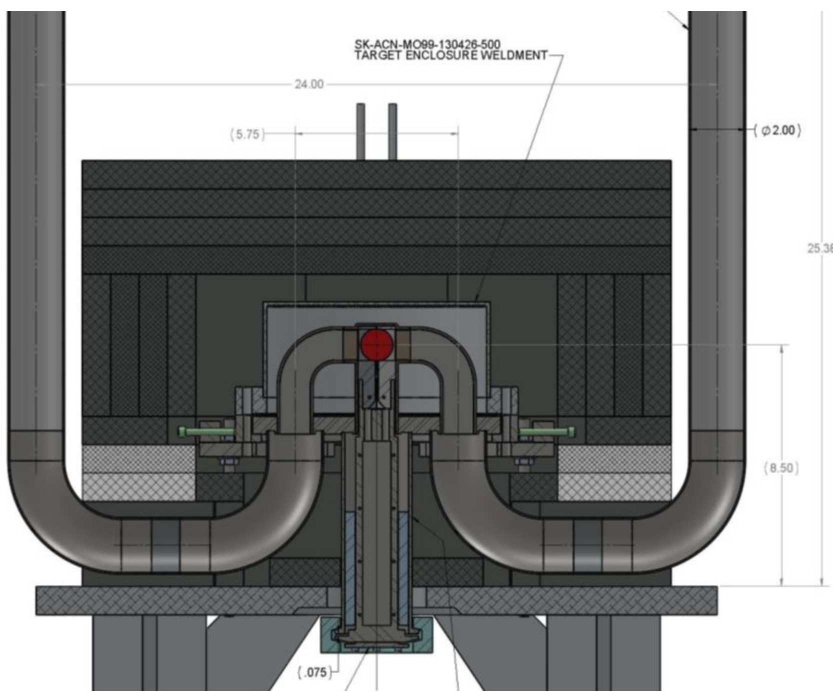

Figure 5. Cross-section view of the overall assembly. The top hat connects to the beam pipe vacuum. Target is illustrated in red. Pb shielding surrounds the top hat enclosure.

Analysis

MCNPX was used to establish the heating in the window and disks at the design current and energy of 500 μA and 35 MeV. While the intended beam spot size is 12 mm, historically a smaller beam spot is the experimental reality. With that in mind, the analysis was done for a 10 mm FWHM beam, which delivers volumetric heating 44% higher at the peak as compared to 12 mm FWHM. The radial distribution of heat thus established was analyzed using ANSYS conjugate heat transfer code. As blower pressure rise defines our flow limits, inlet and outlet pressure are the boundary conditions on the helium flow in this analysis, 1.965 and 1.8615 MPa (285 and 270 psi), respectively.

Helium velocity in the channels is nominally 242 m/s, shown in Figure 6, with a resulting mass flow rate of 117 g/s. temperature profile through a target center section is shown in Figure 7, and peak temperature in the window and disks is shown in the bar chart (Figure 8).

Stress analysis in the window is a combination of primary pressure induced stress and secondary thermal expansion induced stress. By ASME BPVC, the primary stress must be less than the material UTS/3.5 at the temperature of the location where that stress is indicated. Primary stress only is shown in Figure 9. Peak stress is 255 MPa at the window center where the temperature is highest. UTS at 320 C for annealed 718 Inconel is 828 MPa, based on recent measurements, resulting in allowable stress of 237 MPa. This is slightly below calculated stress, but the difference is small and the analysis was done for a beam spot considerably smaller than the design. Further, ASME code is a very conservative standard for a short-lived experiment.

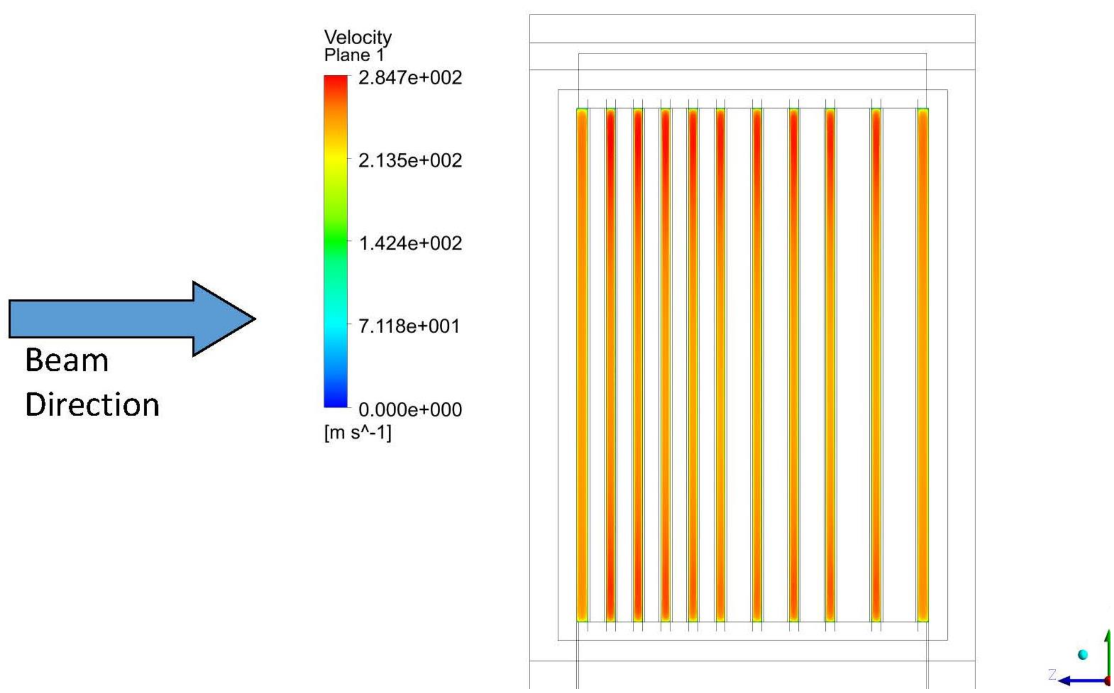

Figure 6. Helium velocity through the channels between disks.

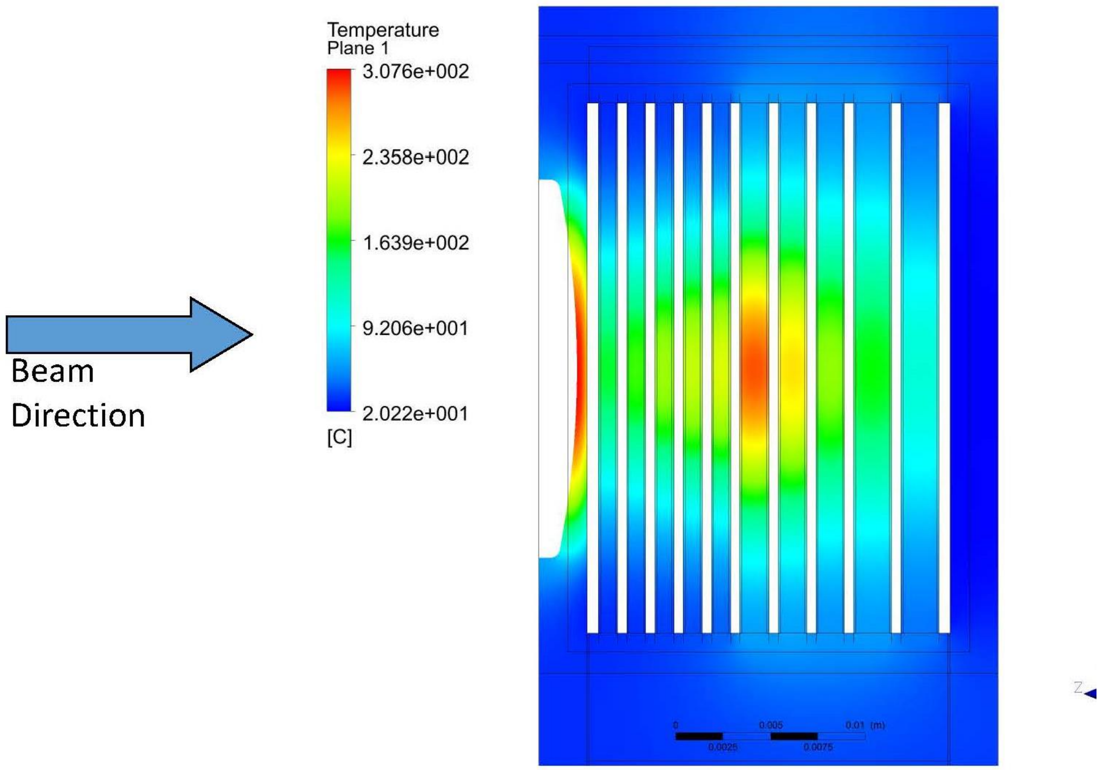

Figure 7. Temperature profiles in the disk and window. Section cut is through the center normal to the helium flow direction.

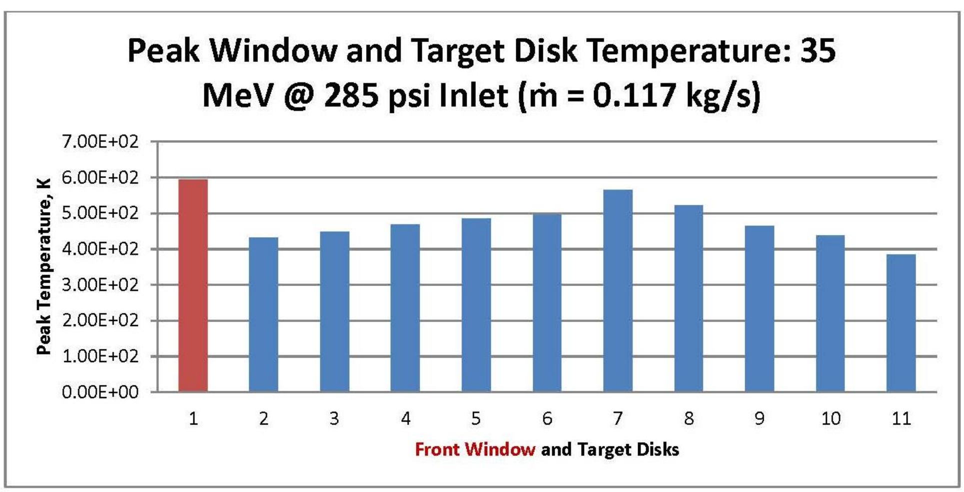

Figure 8. Bar chart illustrating peak temperature in the window and each disk.

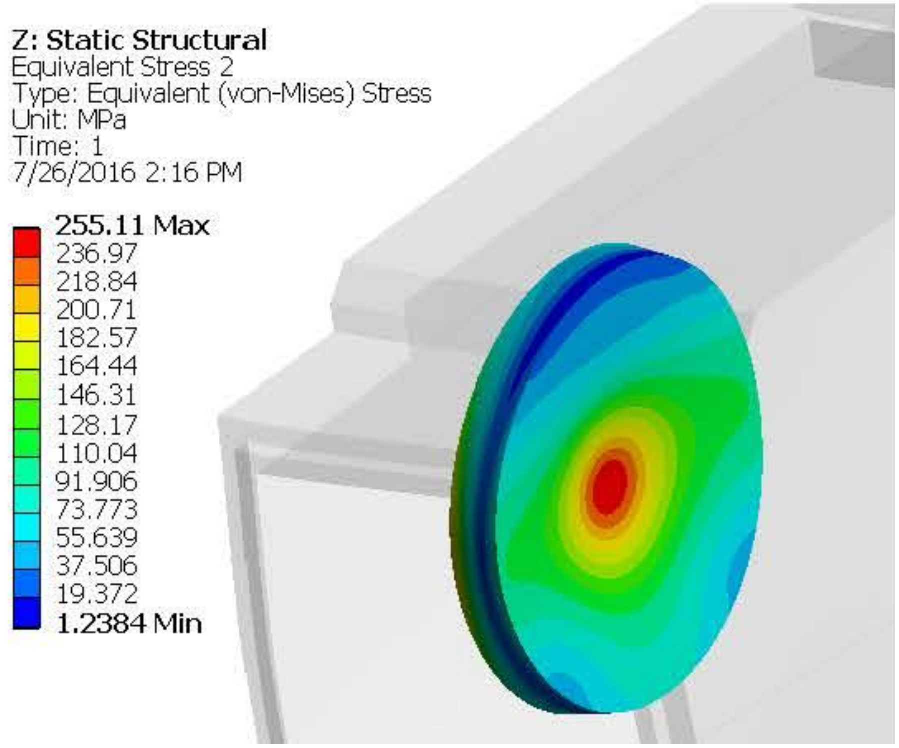

Figure 9. Window primary stress analysis result.

The combined thermal plus pressure induced stress is shown in Figure 10. By code, this combined stress must be less than 3 times the allowable stress, 711 MPa. This is clearly the case. This result indicates that a slightly thicker target, at center, would decrease primary stress while maintaining the thermal and combined stresses within ASME allowables. The current design is considered sufficient, no further iterations on the geometry will be done.

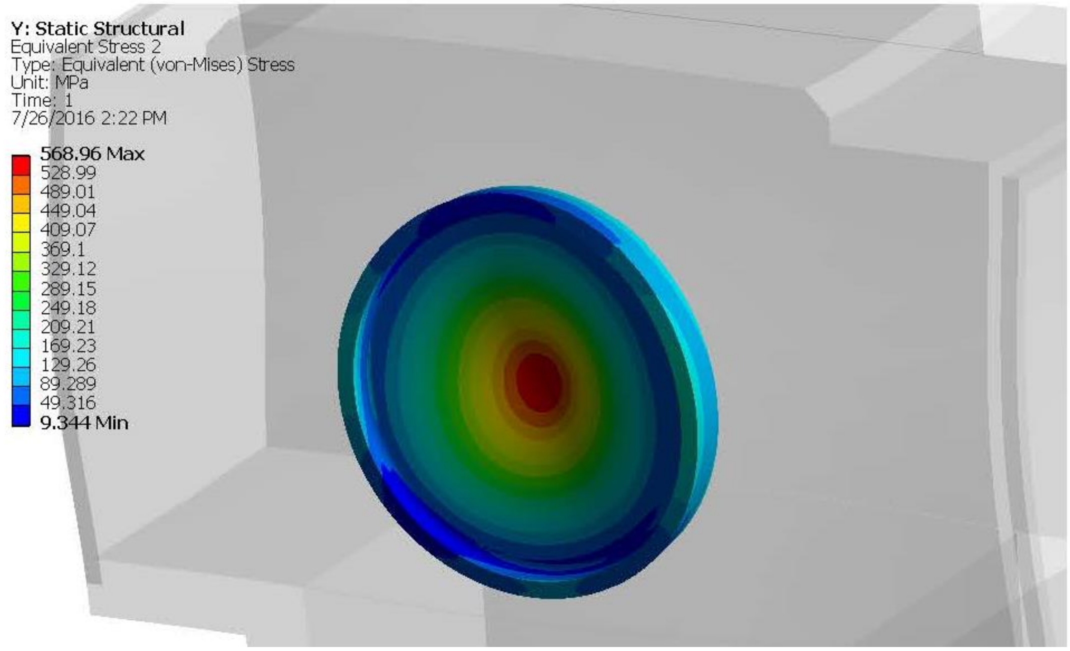

Figure 10. Combined primary and secondary (pressure and thermal) stresses.

Conclusion

A 10-disk, 29 mm diameter target has been designed for testing in the ANL electron beam at 35 MeV and 500 μA. This will be the first test of a target at this diameter, and also the first test of a target with varying disk thicknesses. A third variation from tests up to now is the rectangular flow channel approach and exit to the rectangular target holder. This is in contrast to an abrupt round to rectangular transition just at the entrance an dexit, as has been used previously.