LA-UR-16-22211
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Intended for: Report

Issued: 2016-05-27 (rev.1)

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Thermal Test on Target with Pressed Disks

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3/16/16

Introduction

A thorough test of the thermal performance of a target for Mo99 production using solid Mo100 target to produce the Mo99 via a gamma-n reaction has previously been conducted at Argonne National Laboratory (ANL). The results are reported in "Zero Degree Line Mo Target Thermal Test Results and Analysis," LANL report Number LA-UR-15-23134 dated 3/27/15. This target is comprised of 25 disks 1 mm thick and 12 mm in diameter, separated by helium coolant gaps 0.5 mm wide. These are contained in an Inconel 718 housing, which in turn is contained in an in-beam vacuum vessel affectionately known as the top hat (Figure 1). The electron beam strikes the target window and the disks inside the housing, shown in red in Figure 1, while the helium coolant flows normal to the beam direction via the connecting pipes shown in the figure.

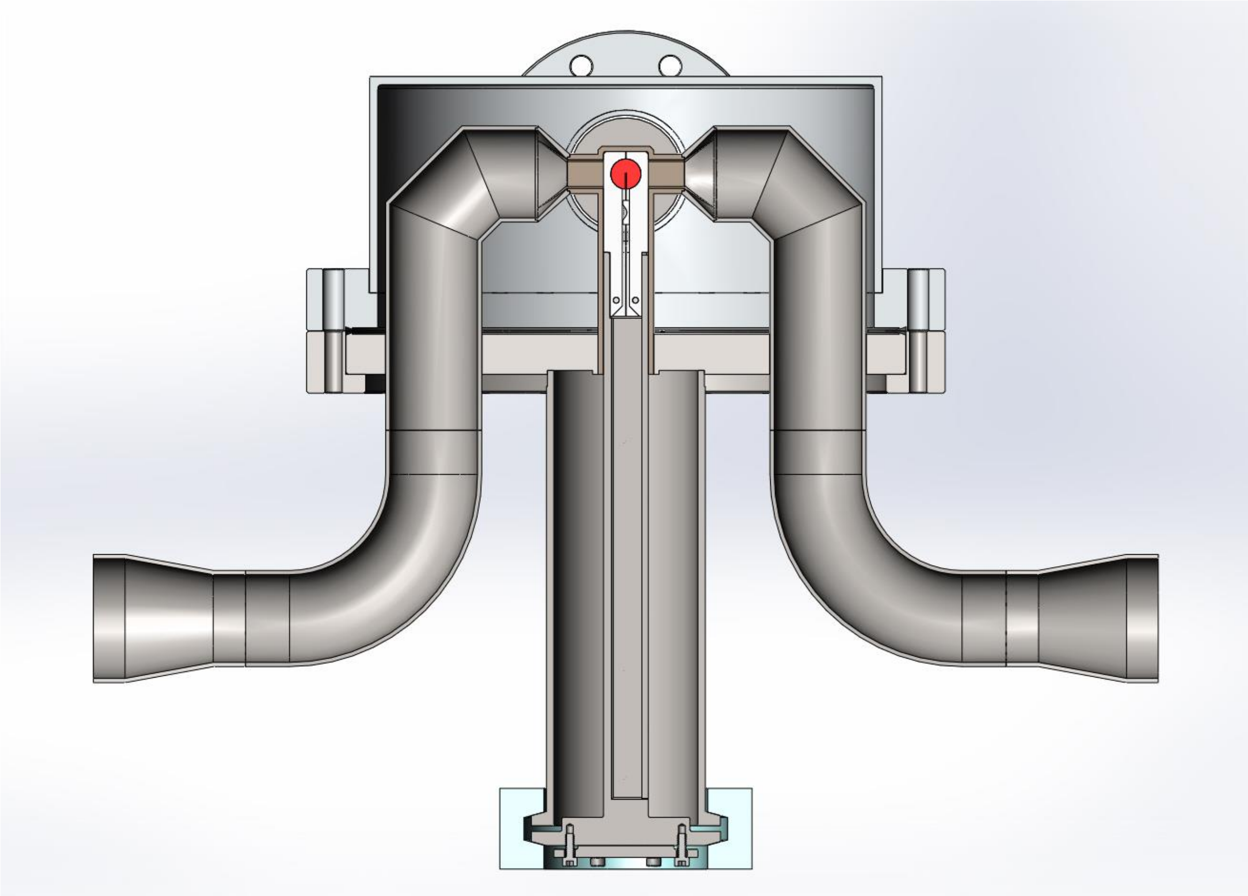

Figure 1. Cross-section view of the target within the top hat.

The test reported in the above referenced report was conducted with natural Mo disks all cut from commercial rod purchased from H. C. Starke. The production plant will have Mo100 disks pressed and sintered using a process being developed at Oak Ridge National Laboratory (ORNL). The structural integrity of press-and-sinter disks is of some concern. The test reported herein included 4 disks made by the ORNL process and placed in the high heat, and therefore high thermal stress, region of the target.

Target Details

The beam heating profile heavily favors the disks at the front of the target. For thermal tests, the disks here are typically instrumented with thermocouples imbedded in the disk to the center by inserting a 0.5 mm sheathed thermocouple in a hole and establishing thermal contact with the disk with indium. In this experiment it as desired to induce maximal thermal stress in the ORNL disks but not compromise their strength with the thermocouple hole. That said, it was important to instrument the first disk as an indication of window temperature as a supplement to the IR camera temperature measurement on the vacuum side of the window. Disks 2 through 5 were ORNL press-and-sinter disks, with thermocouples in disks 4 and 5. Disks 6 through 8 were natural Mo also instrumented, while the remaining disks were natural Mo uninstrumented. The disk holder, with 6 protruding thermocouples, is shown in Figure 2.

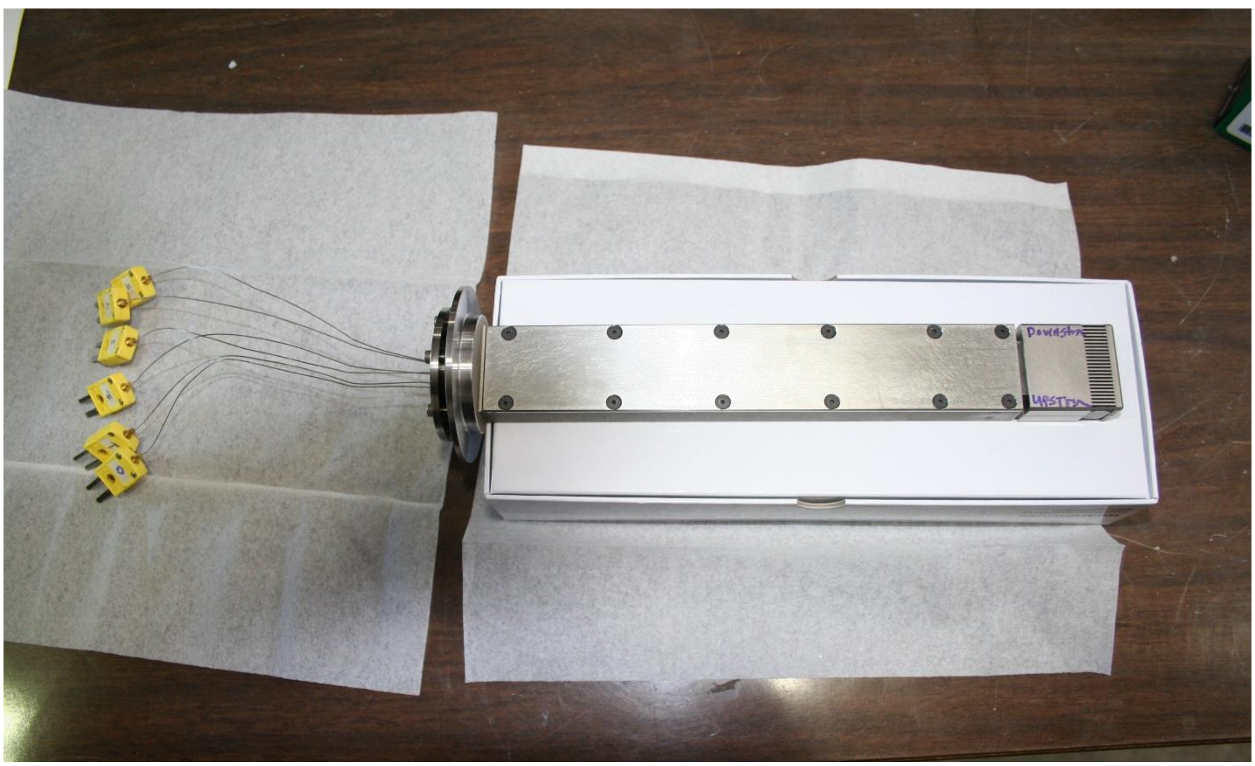

Figure 2. Target mounted to insertion stalk, with thermocouples.

Test Results

The electron beam energy was 23 MeV for these tests. Beam spot size was 3.5 mm horizontal and3 mm vertical, FWHM. Helium pressure and flow rate were 1.9 MPa (275 psig) and 94 g/s. Tests were conducted first by a ramp increase in beam power from 3 kW to 11 kW (Figure 3). The power increase at approximately 1800 s and 67 kW was caused by a slight correction in beam centering on the window, based on the OTR measurement. This is shown in detail in Figure 4. This illustrates quantatively the impact on beam position has on this type of experiment result. Figure 5 presents the average temperature data for each disk as a function of power.

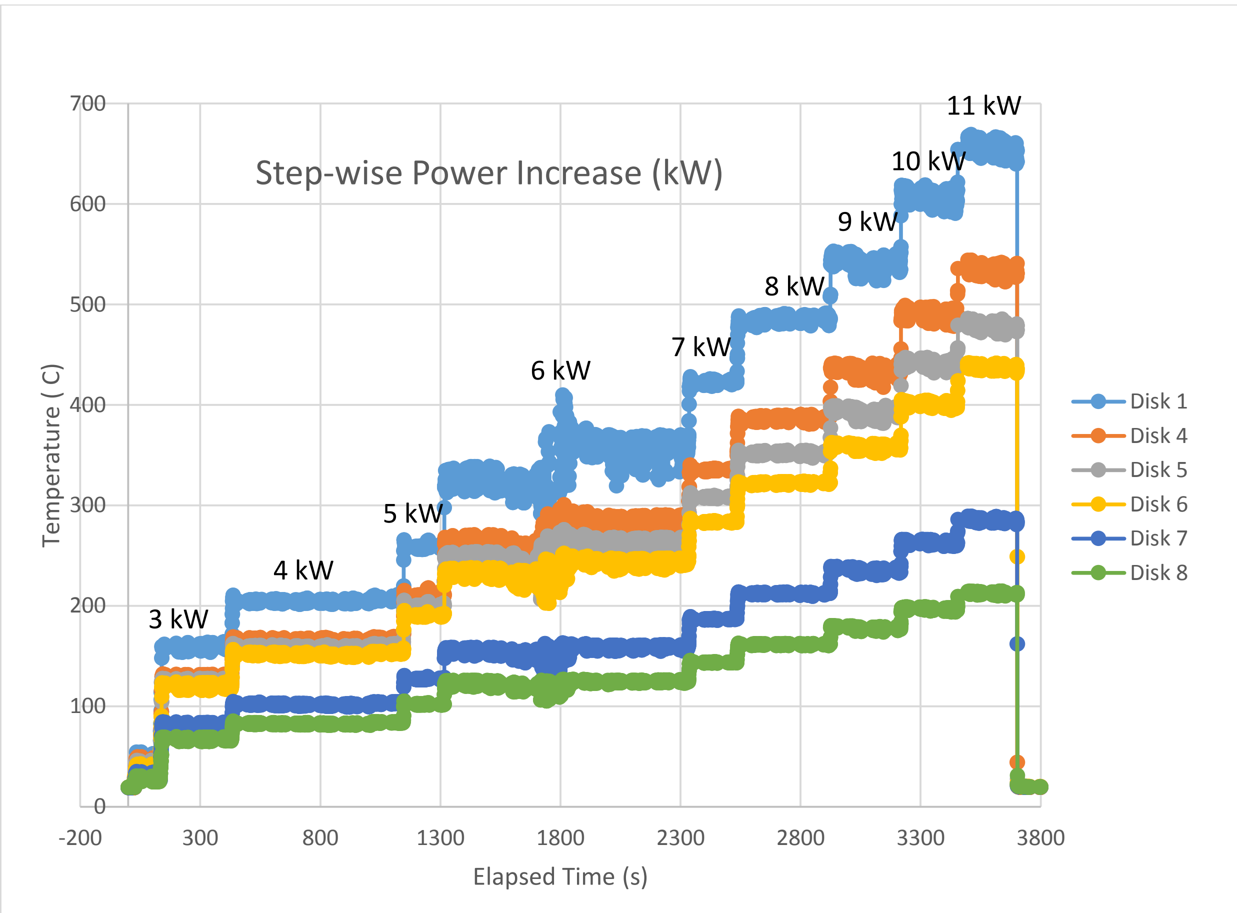

Figure 3. Temperature response of the instrumented disks, increasing with beam power.

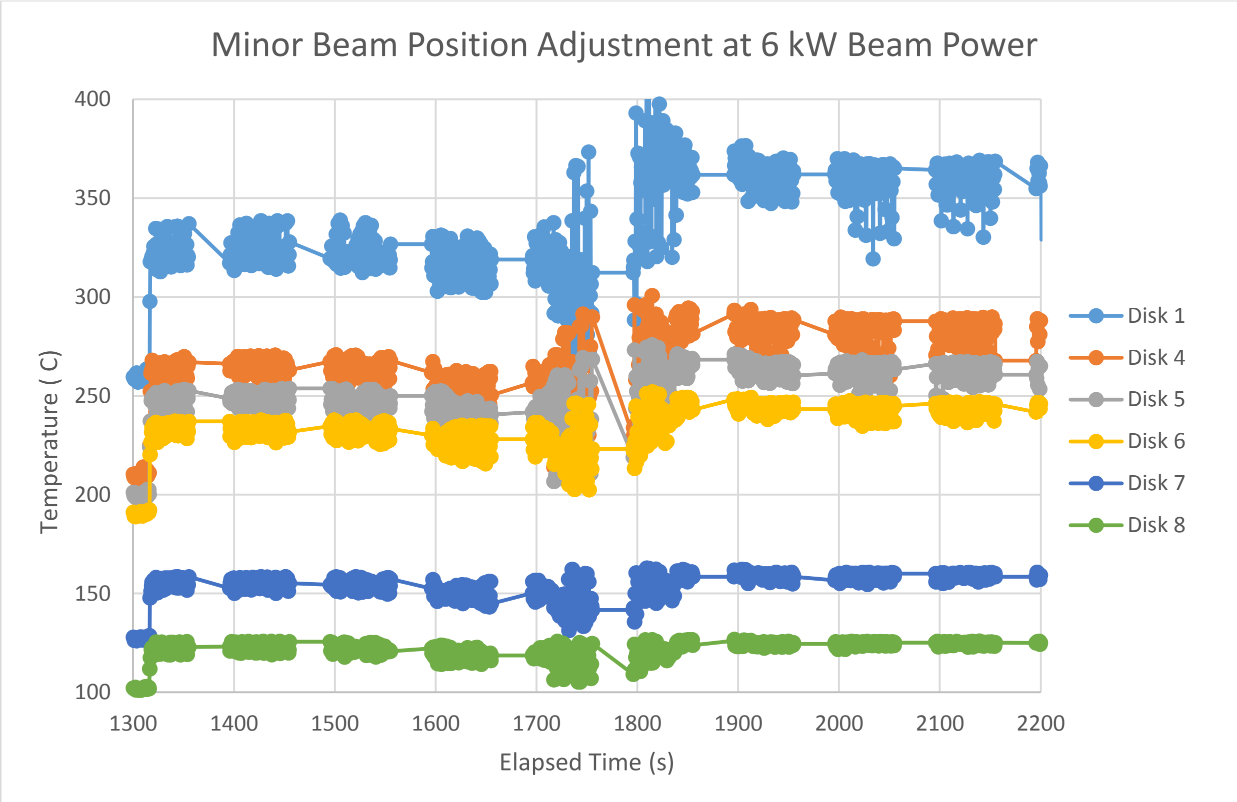

Figure 4. Effect of beam position on temperature measurement at disk center.

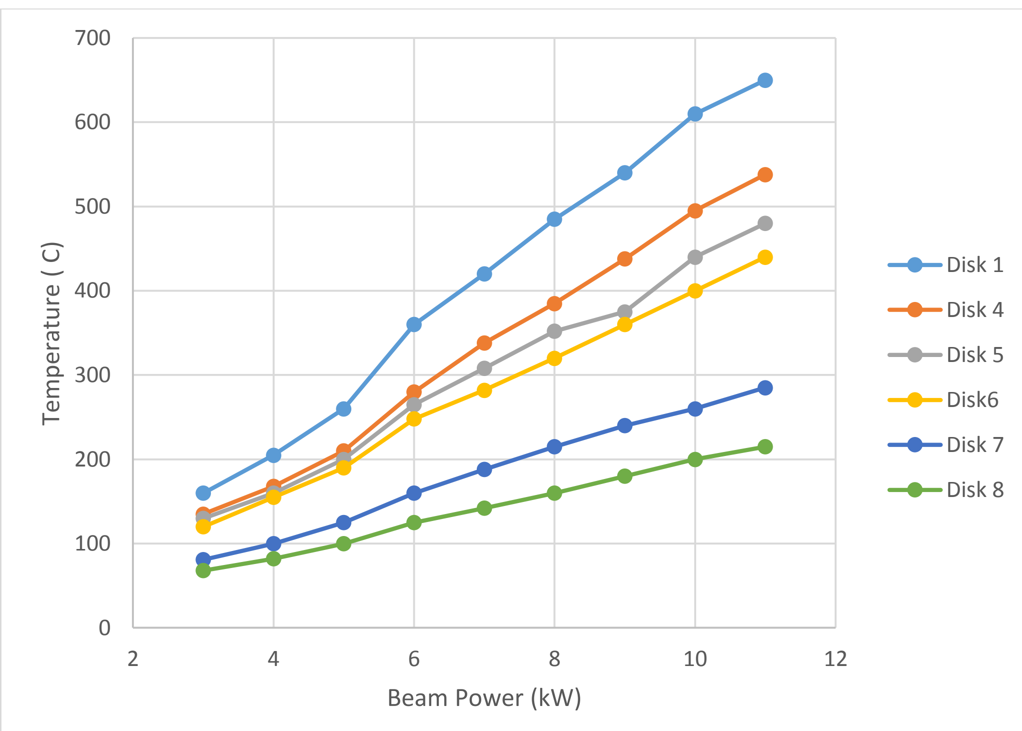

Figure 5. Disk temperature as a function of beam power.

One factor that may impact plant operation is beam on ramp. An instantaneous beam-on startup procedure may stress the target and possibly cause failure. A 9 kW instant-on was performed during this test (Figure 6). The data acquisition speed was once every 0.368 seconds. Figure 6 shows that in that time the disk has reached 360 C, about 2/3 of the final temperature and therefore about 1 time constant. There was no evidence of any damage to the disk or the target as a result of this thermal pulse. This type of test needs to be repeated at higher volumetric heating rates consistent with the plant projected operating conditions, and with faster data collection rep rate.

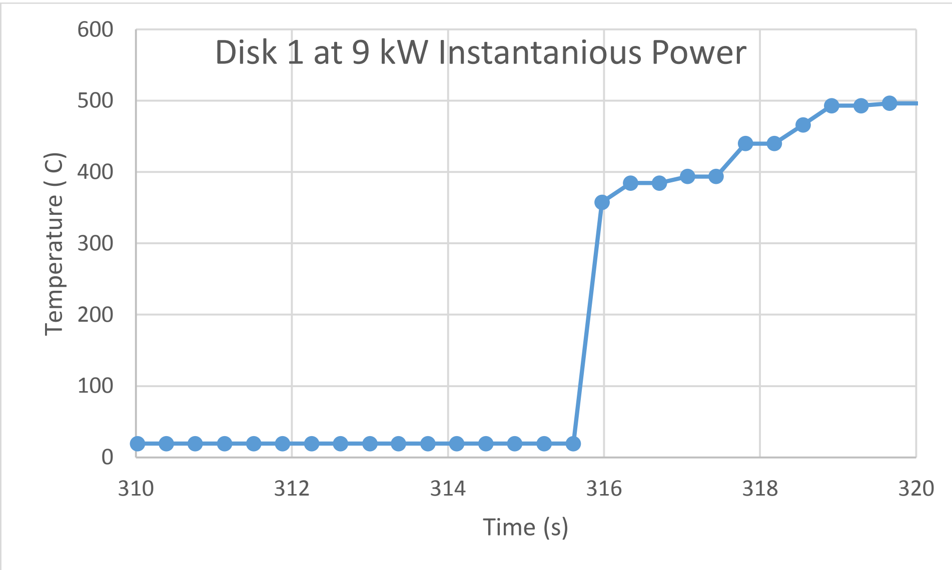

Figure 6. 9 kW instantaneous power temperature response of the first disk.

Finite Element Analysis Results

The finite element results, based on MCNPX prediction of disk heating and numerical calculation of flow and heat transfer, are shown in Figure 7. The reduced density of the pressed disks (90% of theoretical) was accounted for in the MCNPX heating numbers. For the disks, the calculated heat transfer is slightly better than the measured value. A temperature contour plot is shown in Figure 8.

The calculated window temperature is significantly higher than the temperature of the first few disks. There are several factors influencing window temperature. The lower energy is depositing a higher volumetric heat load in the window than the plant design current of 42 MeV. While volumetric heating at the window center is comparable to that in the first disk, the high thermal conductivity of the molybdenum disk allows for significant radial conduction of heat away from the center hot spot, relative to the Inconel window. Axial heat flux at dead center for the window is 698 W/cm^2 compared to 558 W/m^2 for disk 1.

Another important factor is that the window heat transfer coefficient is lower than that on the first disk. Using the FE results for heat flux and temperature, the calculated heat transfer coefficient under these conditions is 8640 W/m^2-C, compared to 9550 W/m^2-C on disk 1. This is an 11% reduction in heat transfer. Regardless of window size or shape, geometry changes or added geometric features to eliminate or even reverse this heat transfer reduction need to be investigated.

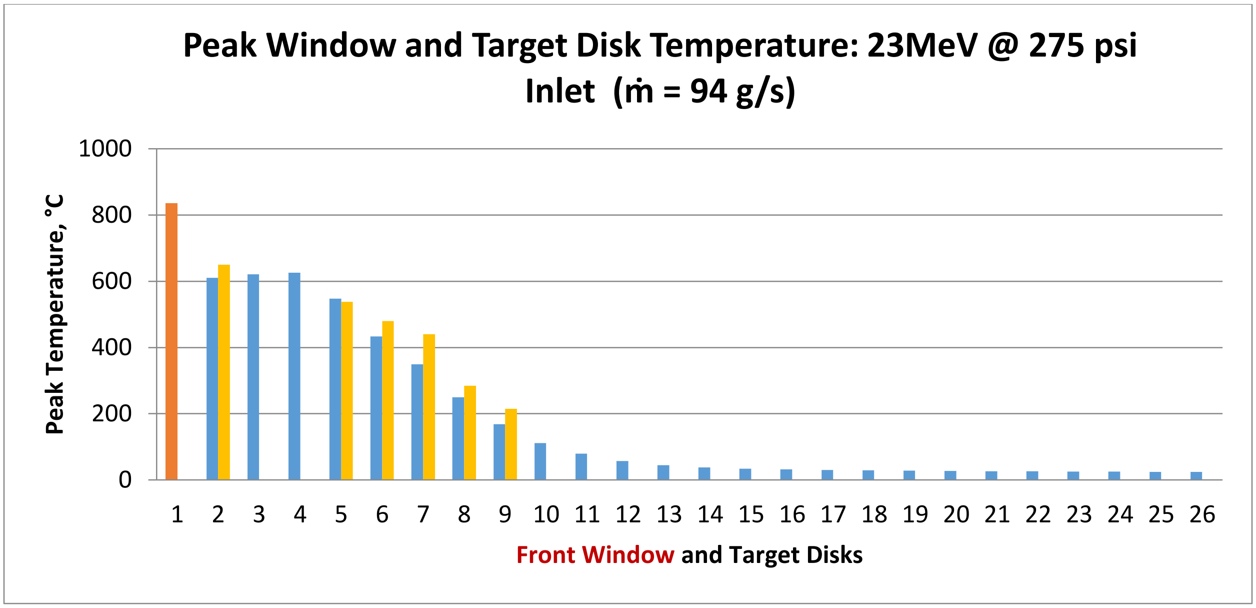

Figure 7. Calculated temperatures in blue, along with measured temperatures in orange.

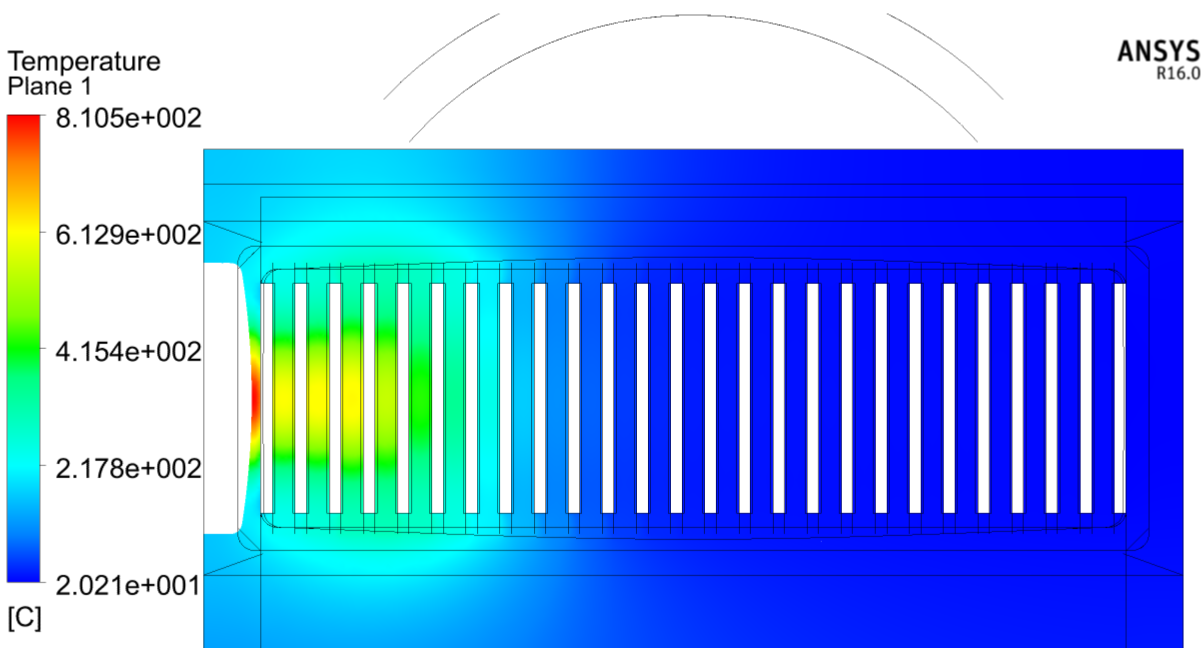

Figure 8. Temperatures in the disks and window, cross-section view through the target center, normal to the helium flow direction.

The temperature contour in the first pressed disk, disk 2 in the target stack, is shown in Figure 9. The resulting thermal stress is shown in Figure 10. Figure 10 shows some stress-strain curves for Mo at certain temperatures. Extrapolating to around 620 C, the 0.002% yield stress for Mo is around 420 MPa, much higher than the calculated stress. As there was no change in flow or heat transfer during the tests, any structural deficiencies in the pressed-powder disks was not evidenced by this test.

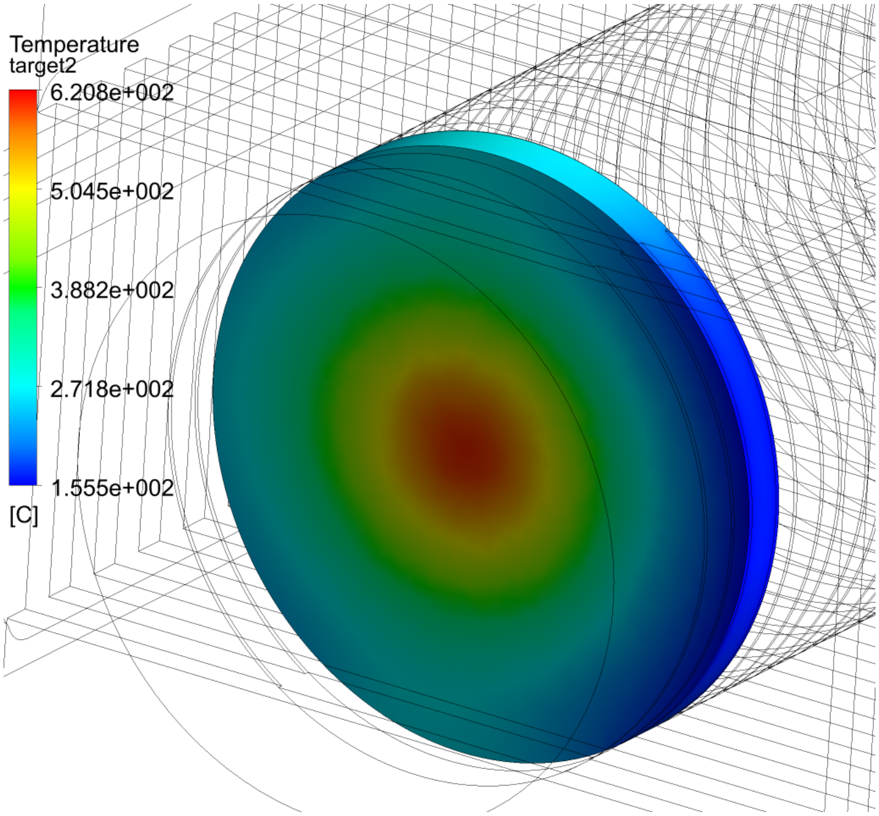

Figure 9. Pressed and sintered Disk 2 temperature profile.

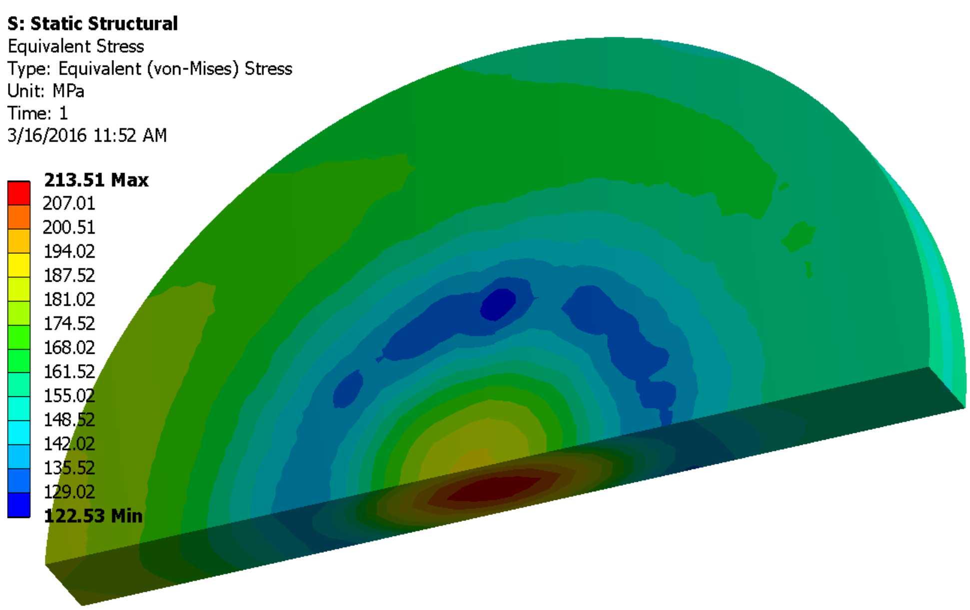

Figure 10. Disk 2 thermal stress state.

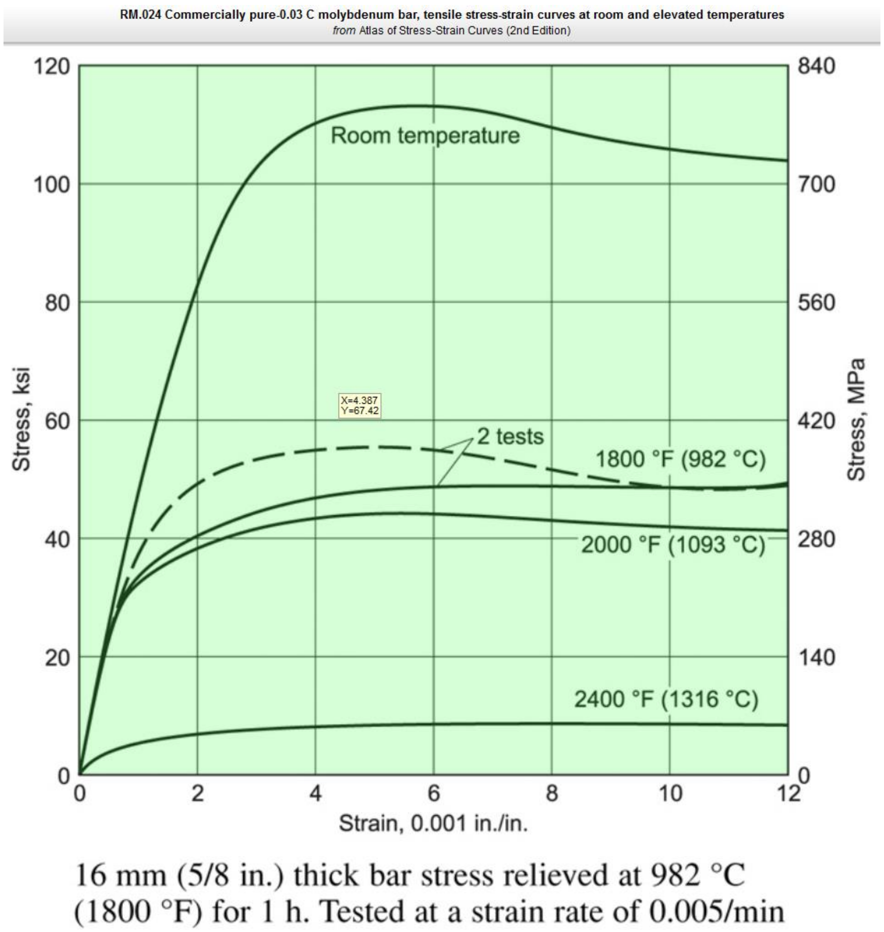

Figure 11. Molybdenum stress-strain curves.

Conclusion

The thermal stress test of pressed-and-sintered disks resulted in no mechanical failures. The induced thermal stresses were below yield stress for natural Mo, indicating that up to that stress state no inherent deficiencies in the mechanical properties of the fabricated disks were evident. Similarly, up to the capability of the accelerator a thermal pulse (instantaneous heating) of the disks resulted in no evidence of structural deficiency. Perhaps the most important result of the test was the observation, by calculation, that the heat transfer at the window was below expected. Design changes should be considered to enhance that heat transfer, independent of window size or shape.