Fermilab

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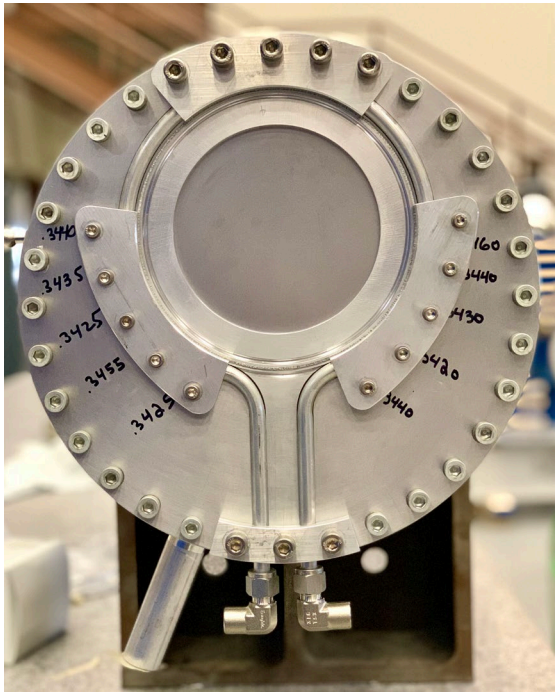
NuMI-NOvA Target DS Beryllium Beam Window Megawatt Modifications



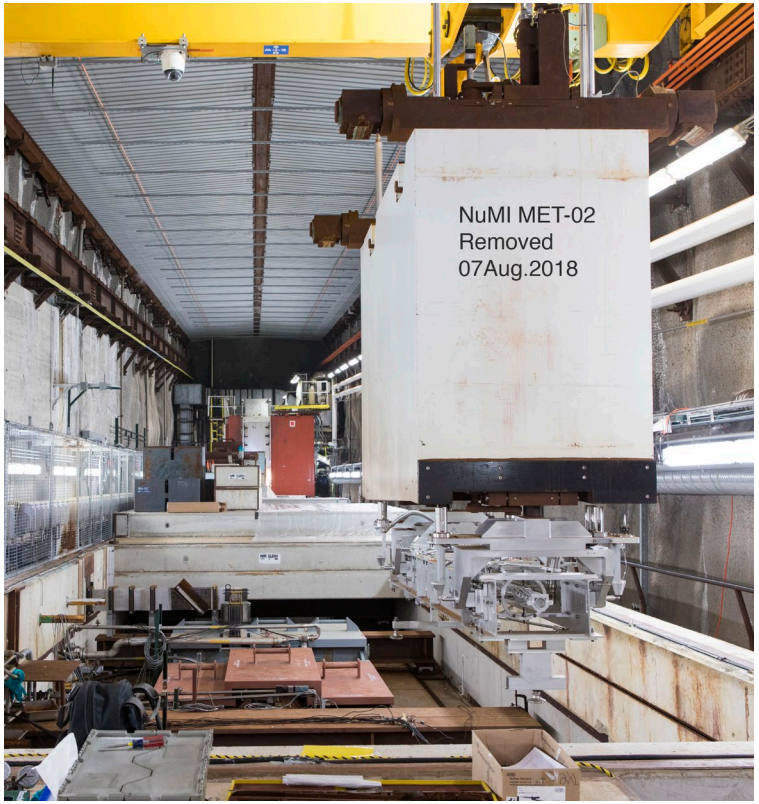
Yun He

NBI 2019

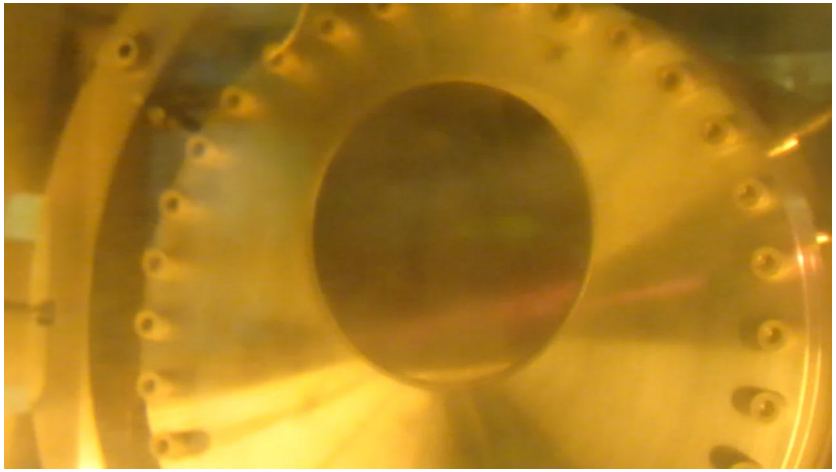
October 24, 2019

Let's look at the NOvA Target Failures First

- MET-01 had a helium leak on the DS Be window (11x10^{20} POT, 3 years)
- Again, MET-02 had a helium leak on DS Be window



String blown by helium gas



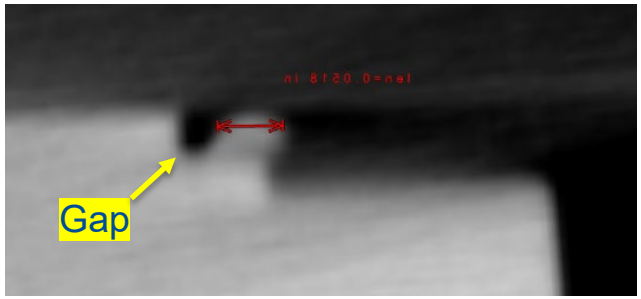
- MET-03 had a leak on DS Be window during leak check of assembly process
- Replaced with a window of new design, MET-03 had been running well until it was replaced by the Megawatt target MET-05 this summer

Outline

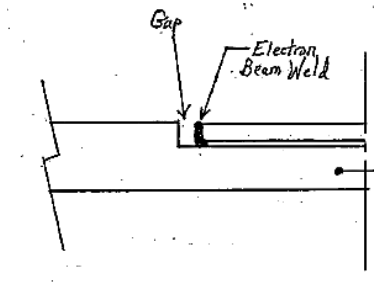
- Investigation on NOvA 700 kW Target DS Be Window Failures
- Design Improvements to DS Be Window
- Initial FEA for 1 MW Beam Power
- Further Temperature Studies for 1 MW
- Thermal-structural tresses w/ Cooling Loop
- Implementation of Ω-loop on the Be Window
- MARS Simulations for 1 MW
- Beam 6mm-off-center Accident Condition
- MET-05 with New DS Be Window

Investigation on DS Be Window Failures (Kris Anderson)

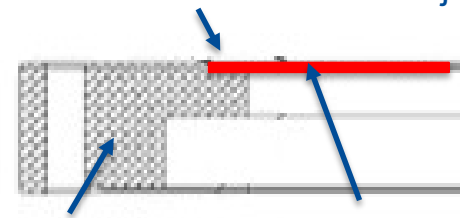
- Leak at the edge of window near electron beam welded joint
- CT scan on spares shows a gap between Be disk and Al flange (6061-T6) in some segments
- EBW joint design not optimized



Kris Anderson's note



Dissimilar thickness at the EBW joint



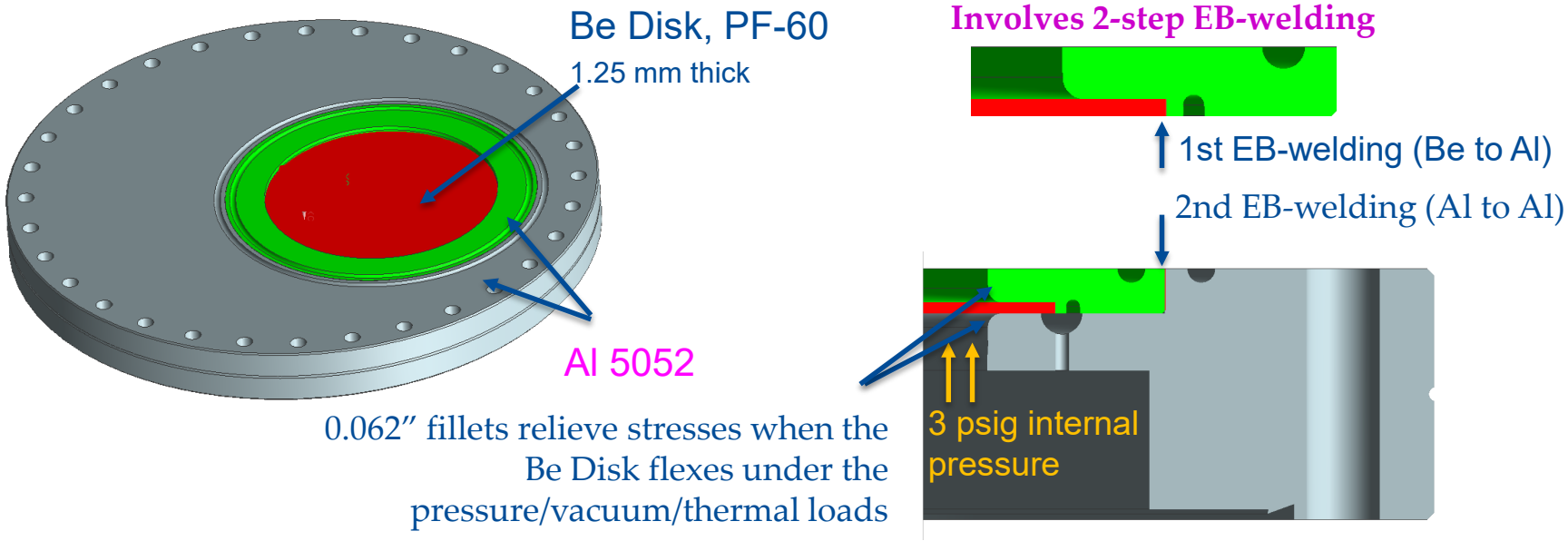
Al 6061-T6 1.25 mm thick Be, PF-60

Loading condition:

- Internal pressure 3 psig (w/ safety relief valve set at 10 psig)
  - During beam operation, target canister is filled with helium gas to prevent the target graphite material from oxidation as well as reduce differential pressure on the Be Windows
- External pressure under vacuum
  - During low intensity beam scans, target canister is evacuated in order to improve the signal-to-noise ratio of the Budal monitor
  - During leak checking
- Beam induced thermal heat loads

Failure mode: cycling stress + EBW quality

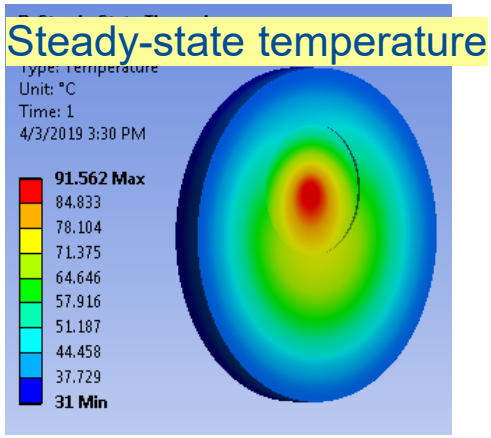
Design Improvements to DS Be Window (Yun He)

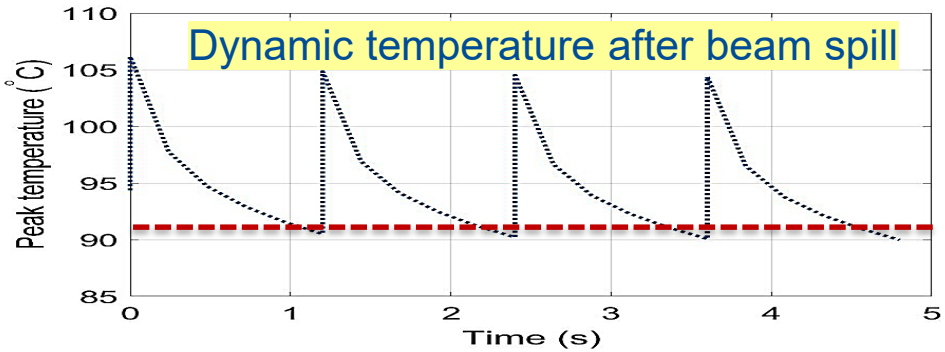


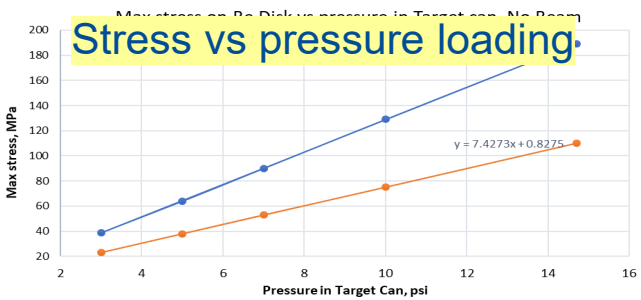
- Uses 5000 series aluminum (more compatible than Al 6061-T6 for Be-Al EBW)
- Welding grooves eliminates dissimilar thickness at the EBW joint
  to allow materials to be fully melt before the heat is transferred away in the flange
- Sandwich structure provides protection/support of the Be-Al EBW joint
  Under vacuum or internal pressure, and also improves thermal contact
- FEA (under vacuum, 10 psig steady state or after beam spill)
- E-beam welding sample testing
  Leak checking / pressure testing / thermal testing / CT scans

Initial FEA for 1 MW Beam Power (Kavin Ammigan)

- at steady state and immediately after a beam pulse under internal pressure at 5 psig (normal operation) and 10 psig (worst condition), respectively.
- Another set of simulations were performed for no beam under different internal pressure at 0, 3, 5, 7, 10, and 14.7 psig, respectively.







Int. pressure (psig)	Beam	T_{max} (°C)	Internal surf. $\sigma_{equiv, max}$ (MPa)	External surf. $\sigma_{equiv, max}$ (MPa)
5	Off	25	64 (edge)	61 (edge)
10	Off	25	129 (edge)	122 (edge)
5	SS + Pulse	100	206 (center)	172 (edge)
10	SS + Pulse	100	239 (center)	232 (edge)

- Peak equivalent stresses are marginal to the material allowable strength
- Beam heating is the stress driver

Further Temperature Studies for 1 MW

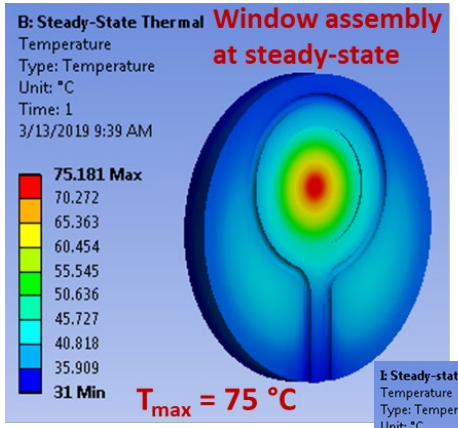
- Main stress driver: beam-induced peak temperature in the central region of beryllium disk

  Pressure loads are similar for 700 kW vs. 1 MW

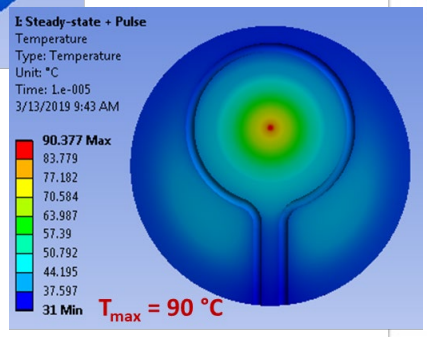
- Scoping analysis: show the added active cooling by a cooling loop around the Be disk is effective in lowering the temperature and resulting stresses.

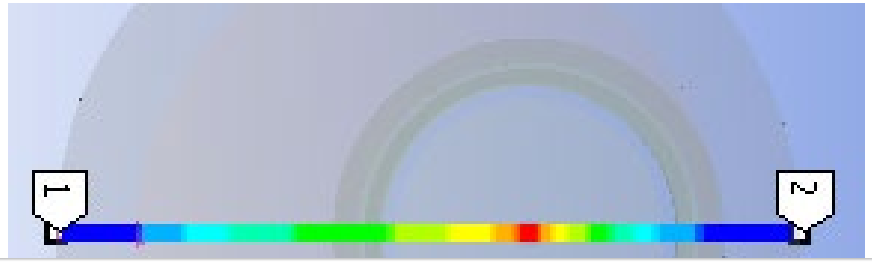
Embedded cooling tube to Al flange

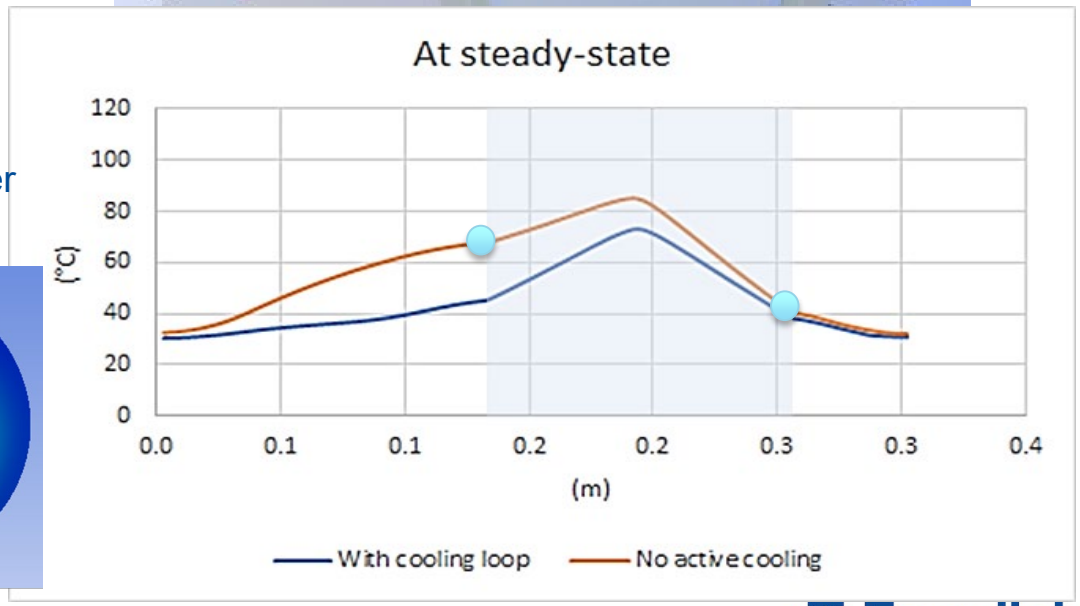
- OD = 0.375”, ID = 0.25”
- 0.5 GPM of water at 31 C



Temperature immediately after beam spill

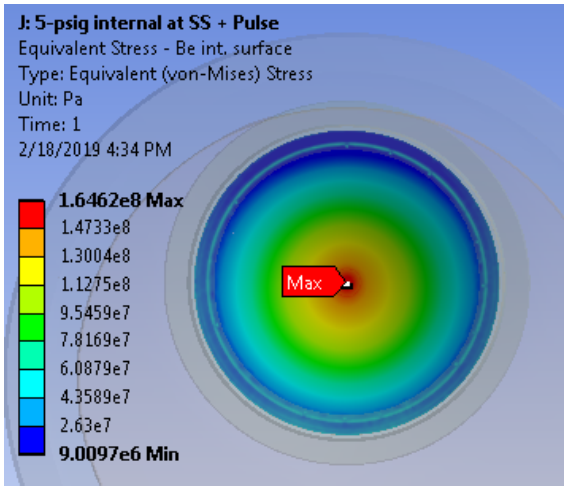


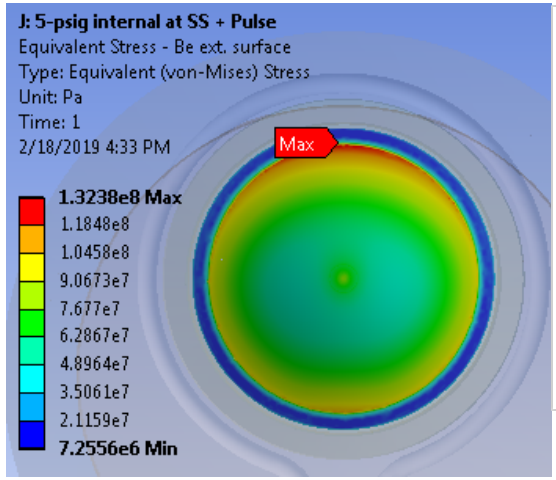


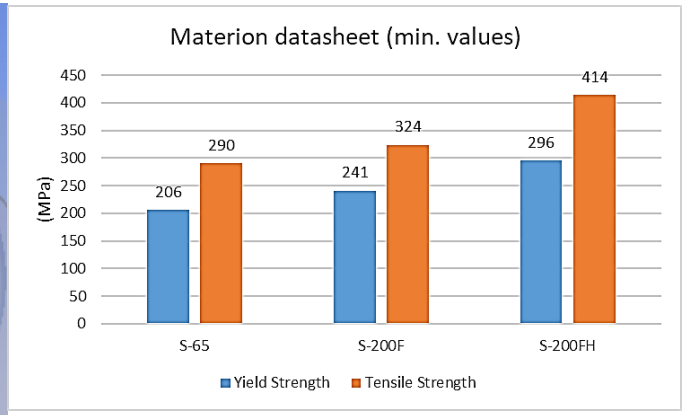


Thermal-structural tresses w/ Cooling Loop

5 psig internal pressure, immediately after beam spill at steady-state







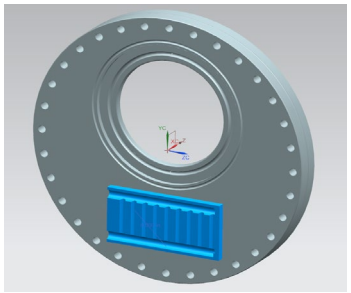
Beryllium strength properties (at RT)

Int. pressure (psig)	Beam	T_{max} (°C)	Internal surf. $\sigma_{equiv,\ max}$ (MPa)	External surf. $\sigma_{equiv,\ max}$ (MPa)
5	SS + Pulse	89	174 (center)	135 (edge)
10	SS + Pulse	89	206 (center)	196 (edge)

Normal operation

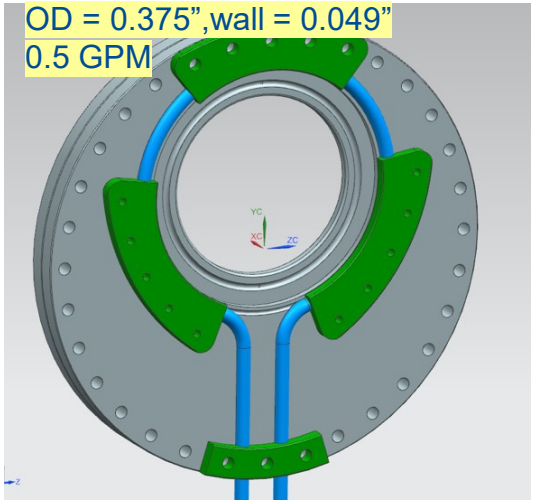
- Stresses now below YS of other Be grades

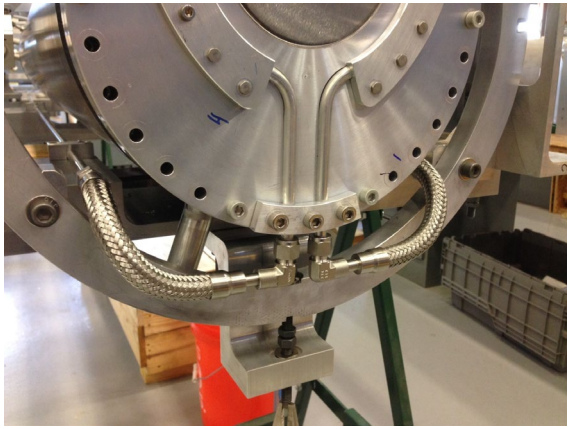
Implementation Ω-loop on the Be Window (Cory Crowley)



Ω-loop cooling

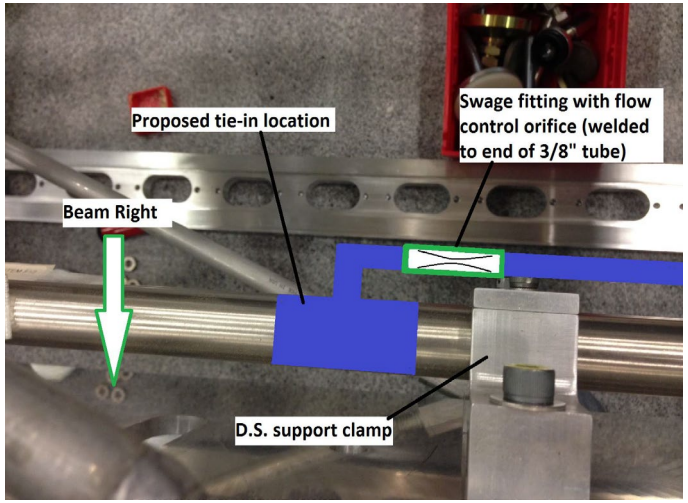
- more effective cooling
- avoiding aluminum welds in a high energy deposition region





Other options considered

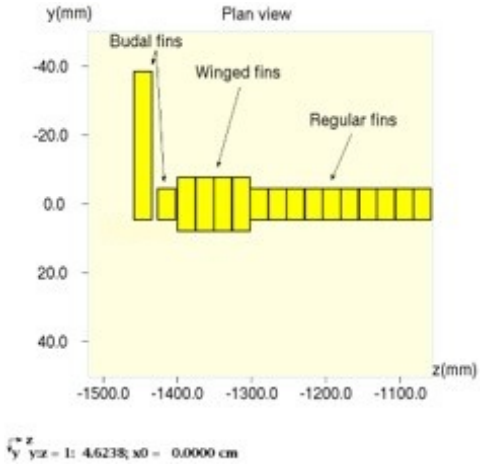
- Ditch cut – provides symmetric cooling
- Chill plate – involves welding

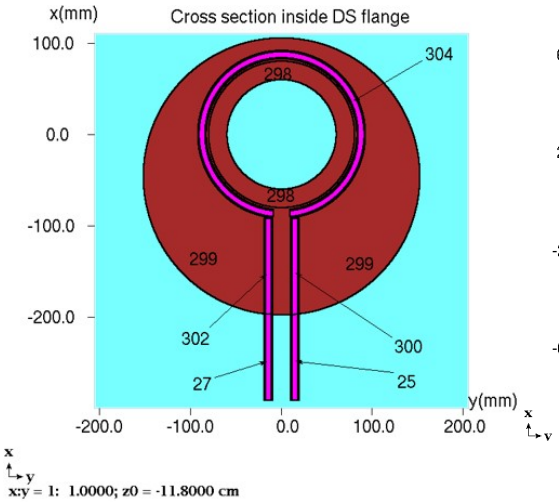


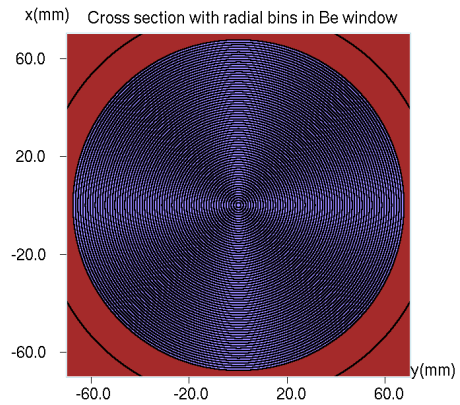
- Cooling loop supply & feed is provided by a tee connection on the target rail cooling loop immediately upstream of the last line clamp set.
- This tee pair for the supply & feed has the advantage of utilizing only stainless welds to complete the new flow loop, as the remaining loop connections and routing can be accomplished by swage fittings on single run tube lengths.

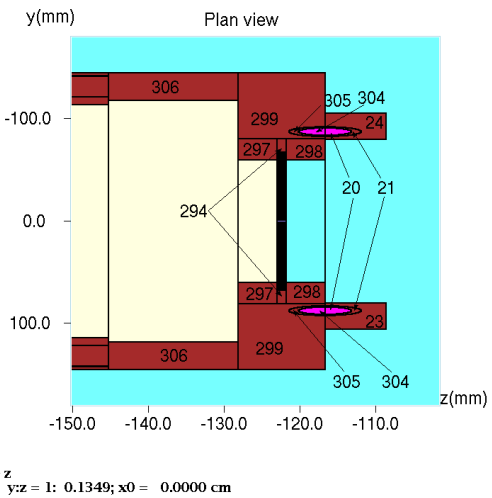
MARS Simulations for 1 MW (Igor Rakhno)

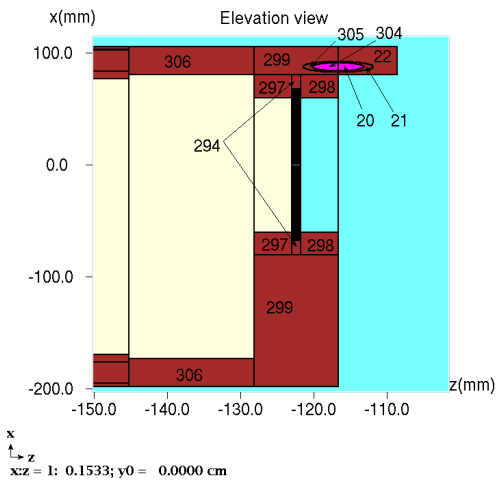
- Target fin size 9.0 mm (from 7.4 mm), w/ 4 winged fins US

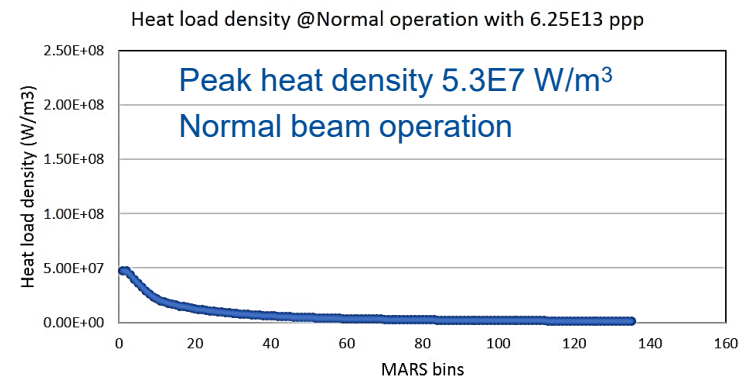








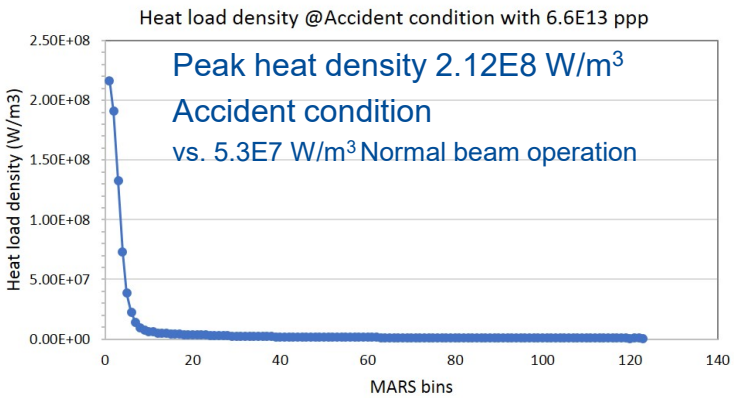


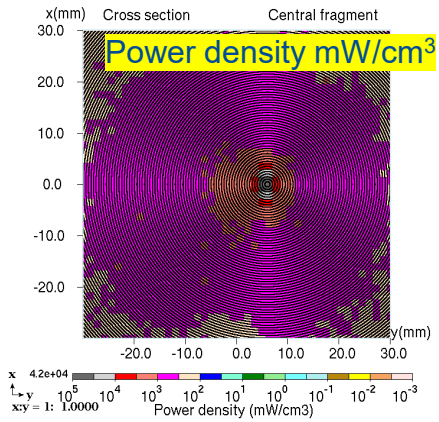


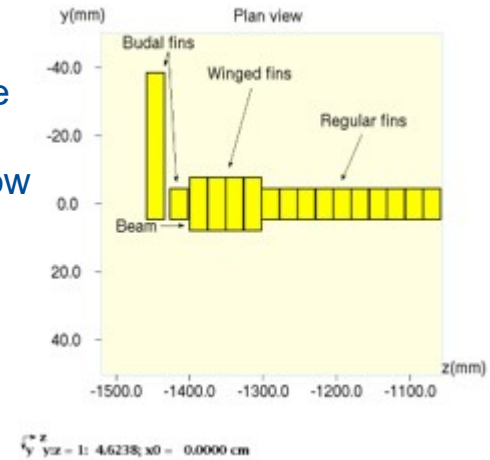
Beam 6mm-off-center Accident Condition

Worst Scenario:

- beam misses the budal fin, travels directly between the exterior of the 9mm wide fins and the 15mm ID in the baffle.
- This means just the 4 winged fins interact with beam prior to it striking the window
- Peak protons/spill of 6.6E13 used in this analysis, 5 psig internal pressure

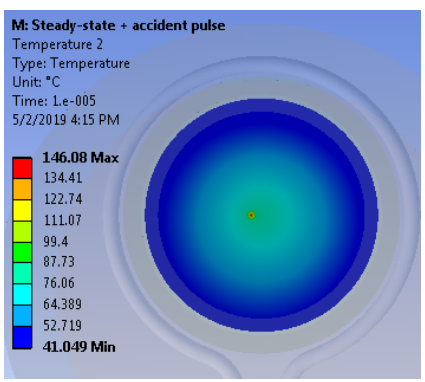


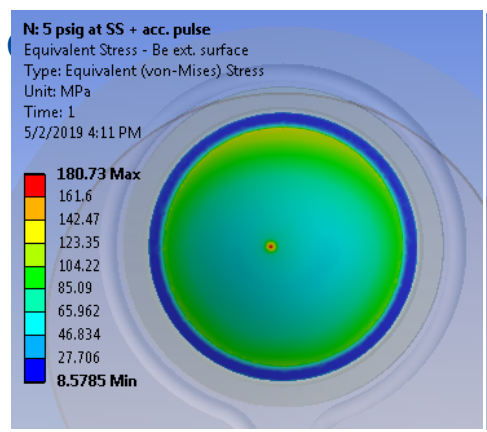


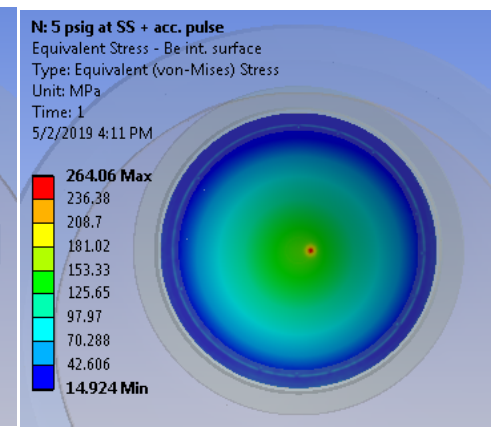
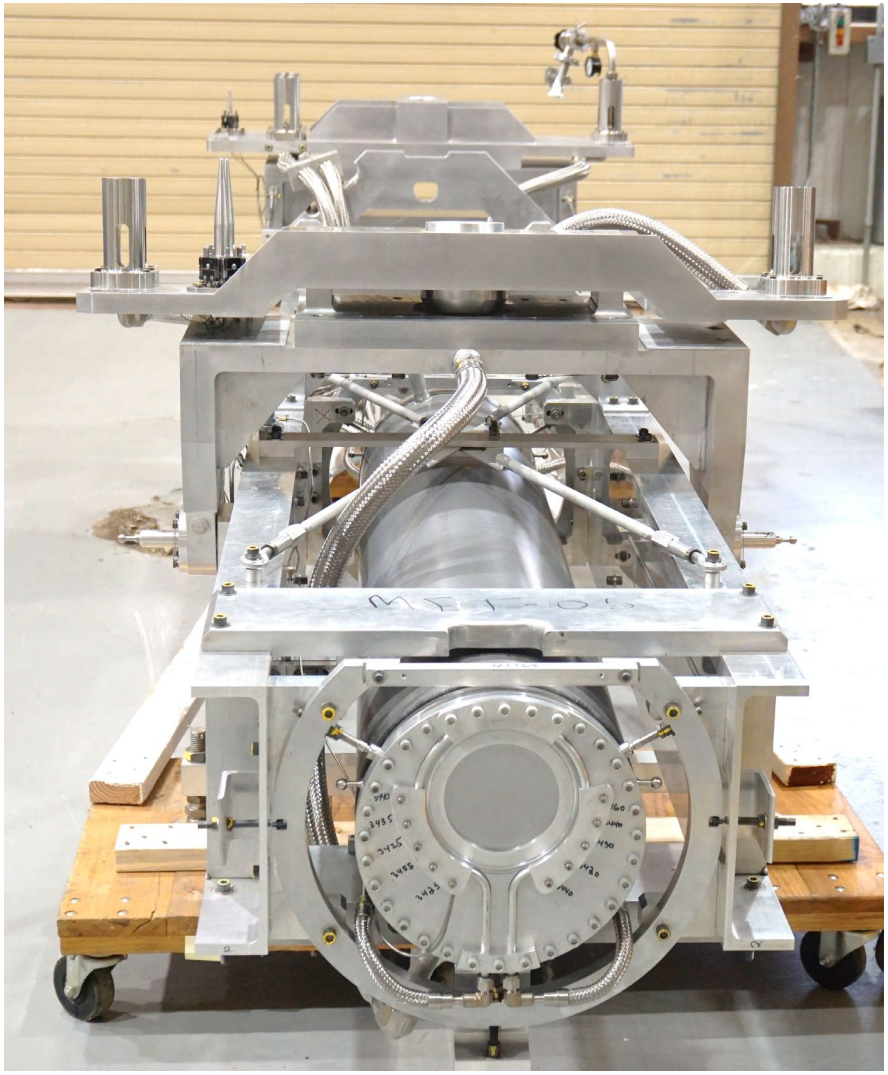


Peak σ_{equiv} = 180 MPa (center)
Peak σ_{equiv} = 264 MPa (center)

Peak steady-state temperature: 77° C
Peak steady-state + accident pulse temperature: 146° (







MET-05 with New DS Be Window