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LBNF Baseline Target Design

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Outline

- Current 1.2 MW Design
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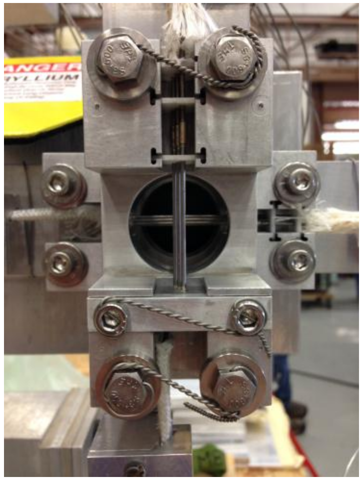
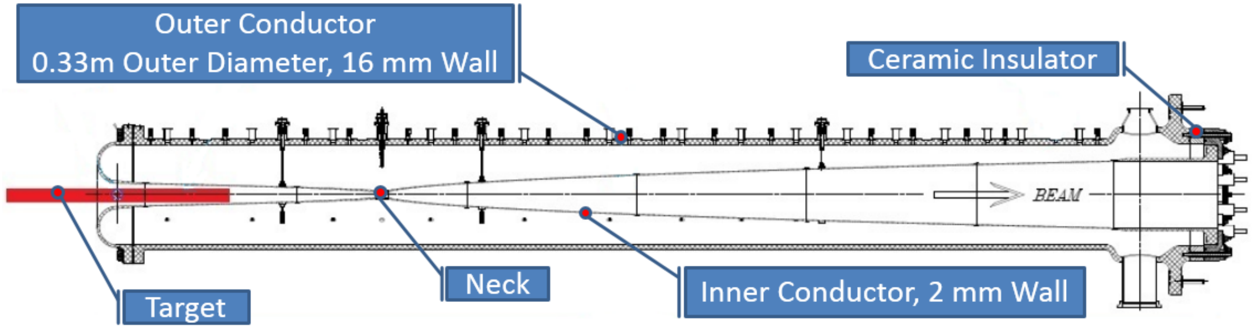
  - Beam Parameters
  - Preliminary Target Core & Can Layout
- Analysis Efforts
  - Target Core
  - Containment Tube / D.S. Window Results Summary
- Fabrication Considerations
  - Prototyping
  - Target Carrier Integration
- Baseline Design Summary
  - Conclusions for 1.2 MW Operation
  - Opportunities for Collaboration / Improved Designs

LBNF 1.2MW Target Main Design Requirements

- Support 1.2 MW beam operation at all primary beamline proton energies (60, 80, & 120 GeV).
- Utilize the existing target carrier frame for design carryover / cost savings.
- Must be compatible with existing Horn 1 design.
  - Sets limits on target size due to EDEP effects.
- Incorporate vertical and horizontal beam position thermometers, as employed on the NOvA Medium Energy Target.
- Assure sufficient fatigue life for all components based on the expected operational lifetime.
- Ease disassembly during target decommissioning / autopsying efforts.
- Improve target retraction / insertion drive mechanisms for reliability.





LBNF 1.2MW Target Design

- Beam Parameters

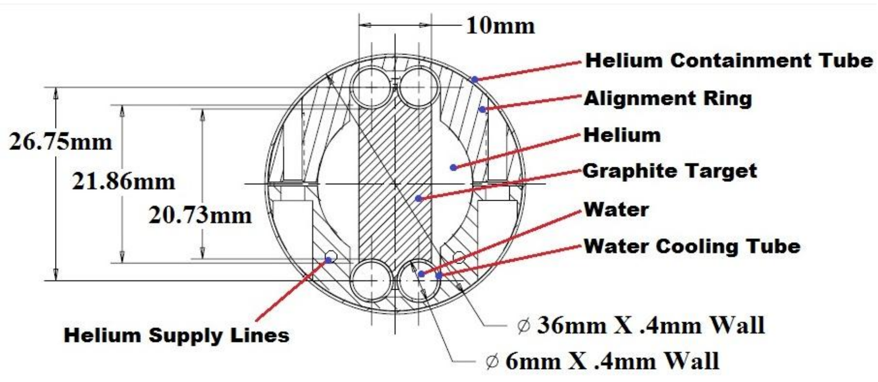
Pulse Width	**10µs**
Cycle Time	.7s (60 GeV)– 1.2s (120 GeV)
Beam Sigma	Tunable 1.0mm – 4.0mm (1.7mm Nominal)
Protons Per Cycle	7.5E+13
Max. Beam Power	1.2 MW

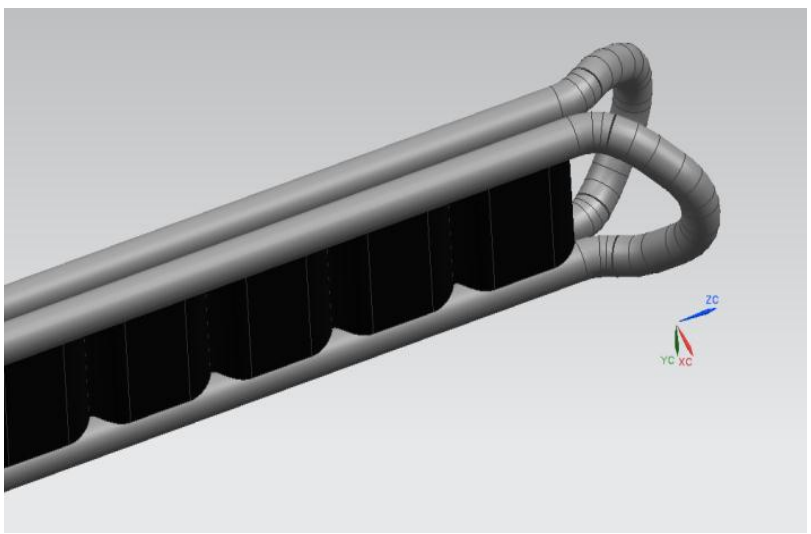
- Maximum DPA in the target is 1.16E-21 DPA / proton.
  - 24/7/365 operation yields 2.29 DPA/yr.
  - 1.5E+7 seconds/yr of operation yields 1.09 DPA/yr.

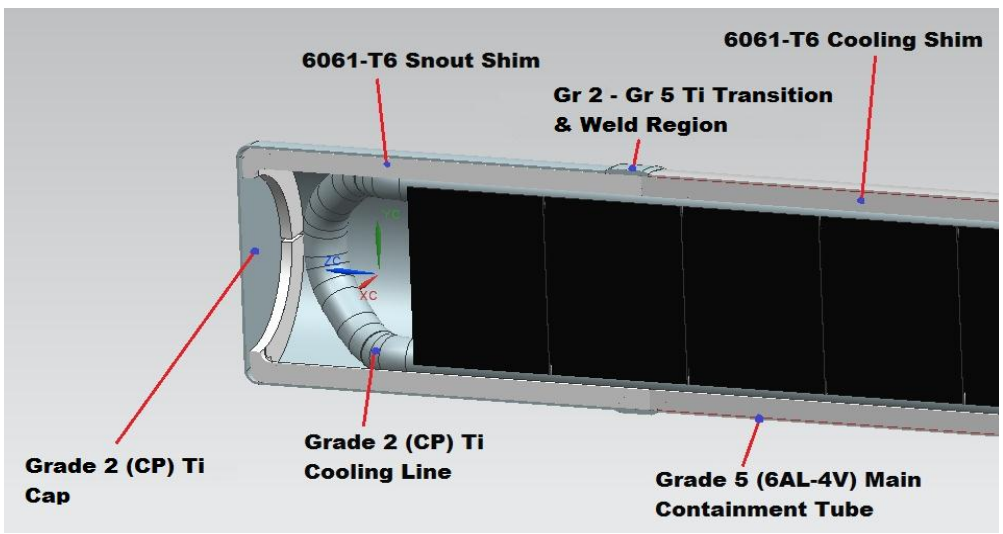
- For comparison, NuMI 400kW (1.1mm beam sigma, 6.4mm wide target fins) maximum DPA is 2.5E-21 DPA/proton.

LBNF 1.2 MW Target Design - Target Core

- Fin width increase from 6.4mm to 10mm.
- Added helium cooling lines through alignment rings.
- Containment tube diameter increase from 30mm to 36mm.
- Twin 6mm OD X .4mm wall cooling lines for heat removal.

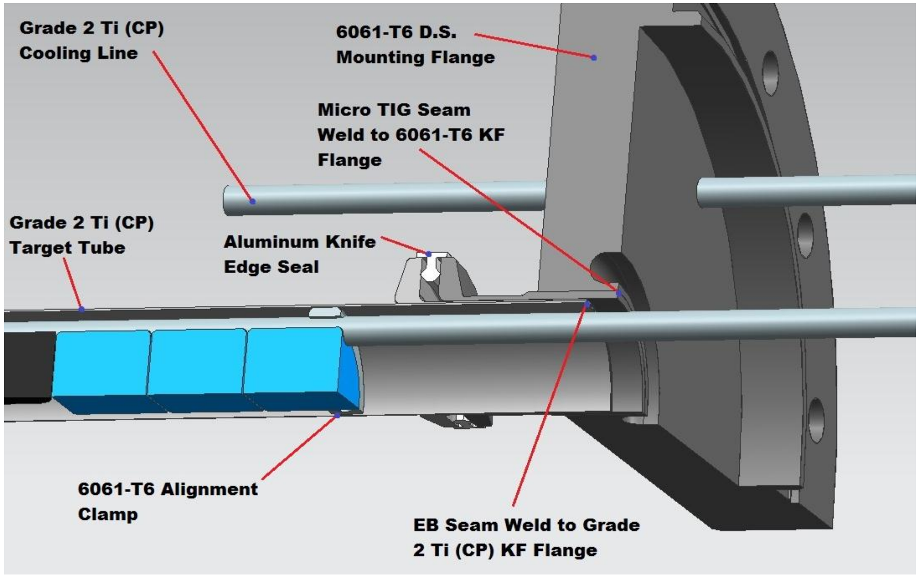


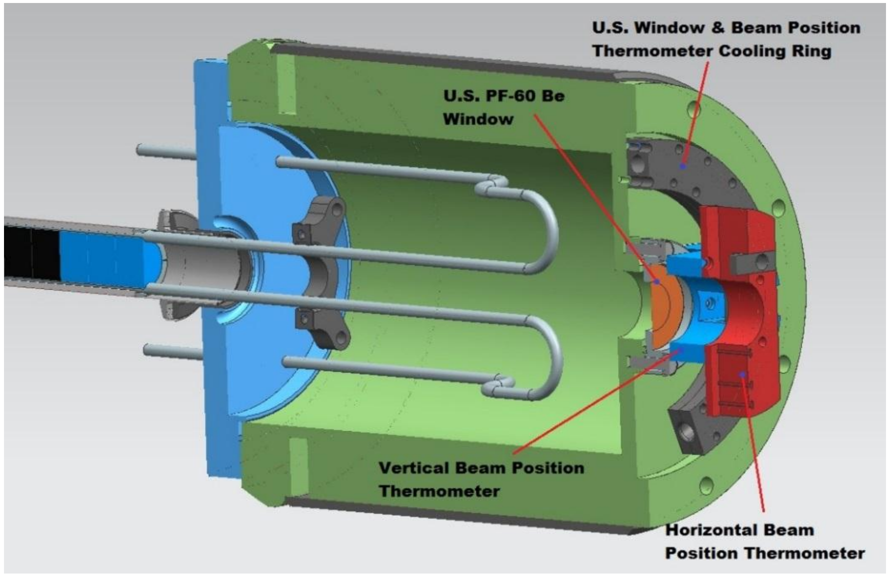




LBNF 1.2 MW Target Design - Target Can

- Assembled with nesting NW40 (KF40) flanges + aluminum knife edge seal.
- No dissimilar material bonding / welding issues
- Seam welds at tube ends on identical metals required for complete sealing & vacuum operation.
- Single chain clamp connection for ease of assembly and hot handling disassembly if needed.





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LBNF 1.2 MW Target Design – Containment Tube

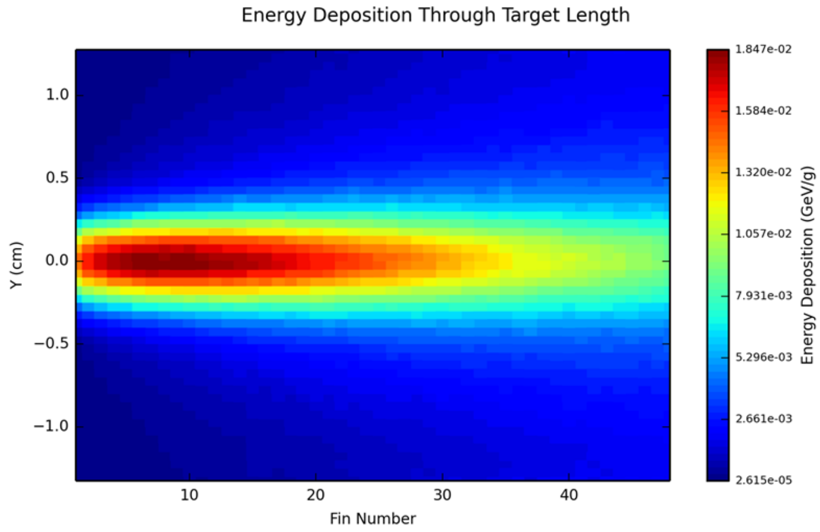
- Why Not Beryllium?
  - Expense / Risk
  - 10 Month lead time per tube (optimistic).
  - Single vendor
  - Large operational costs.
    - **Estimated 2 - 2.5 targets per year could result in $1M+ per year for a single piece part on a single beamline component.**

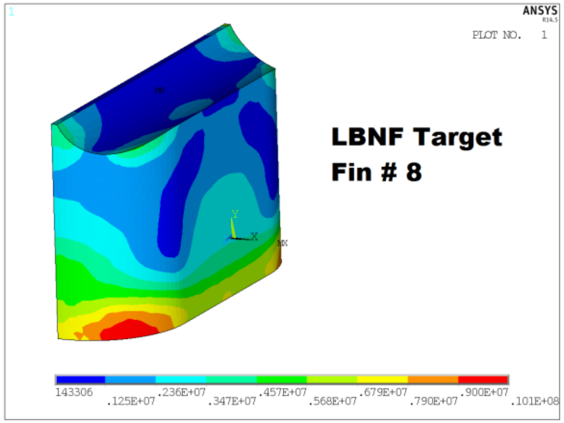
Item	Part Description	Quantity	Unit Price	Ext Price
*10	PS-200 (S-200F) Machined 2 Beryllium Tube Sections: 0.5mm wall thickness x Ø36mm x 0.6 meters long, electron beam welded to achieve a 1.2 meter long tube, with a beryllium window electron beam welded on one end and an aluminum flange on the other Similar to Drawing No. F10034871	1	$351,914.00	$351,914.00
*20	PS-200 (S-200F) Machined Beryllium Tube: 0.5mm wall thickness x Ø36mm x 1.2 meters long, with an electron beam welded beryllium window on one end and an aluminum flange on the other Similar to Drawing No. F10034871	1	$269,843.00	$269,843.00

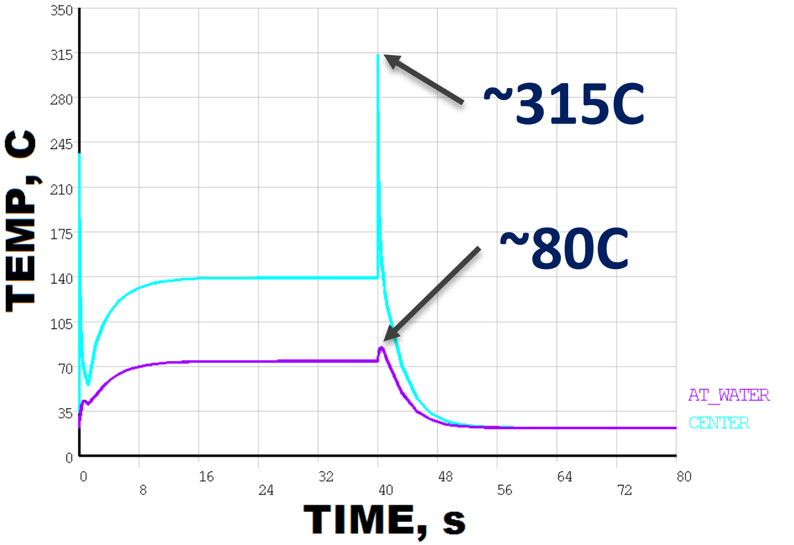
- Advantages of Titanium
  - Orders of magnitude cheaper to produce.
  - Much shorter lead times
    - Easier to procure / fabricate / weld.
    - Large vendor base (Fermilab & collaborators included).
  - Engineering limits can be overcome with good design choices.
  - Initial time investment has large savings potential compared to beryllium containment tube.

Analysis - Target Core

- MARS Energy Deposition
  - 1 & 3 sigma EDEP peaks at fin 8.
  - Total heat load ~12kW.
    - ~11kW to graphite
    - ~1kW to Titanium / Water
- Fin 8 Stress / Temperature
  - Fin 8 examined due to highest temperature and largest temperature gradient.
  - Maximum Von-Mises stress is ~10 MPa while yield is near 80 Mpa.

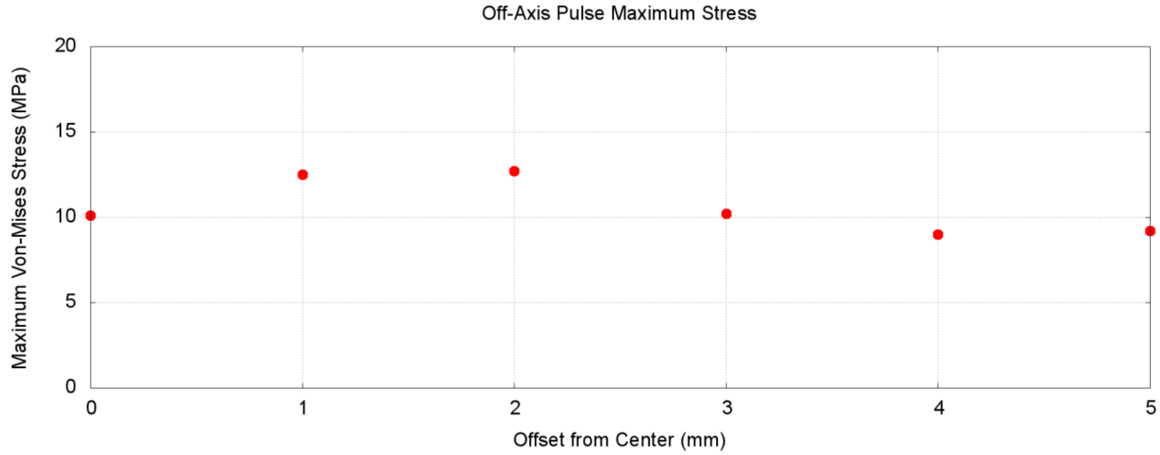


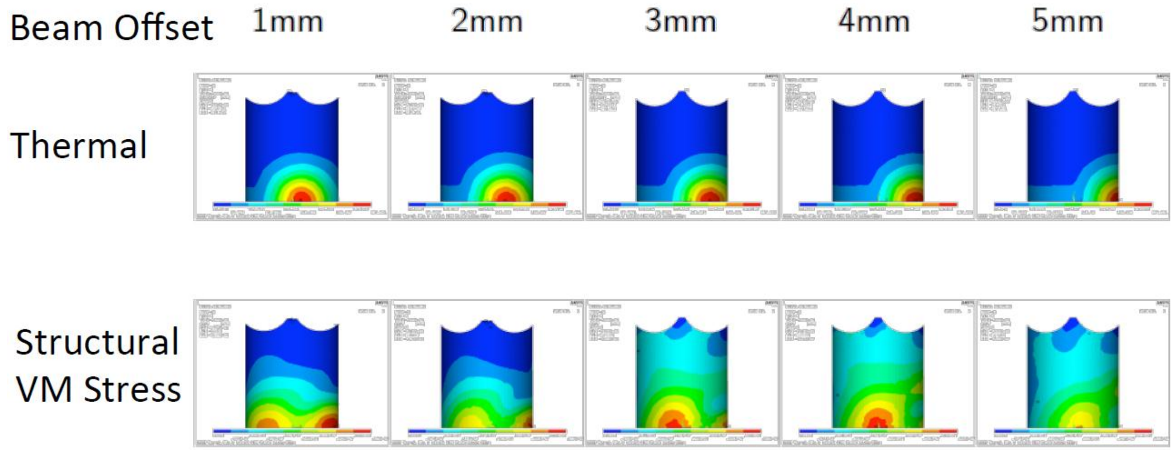




Analysis - Target Core

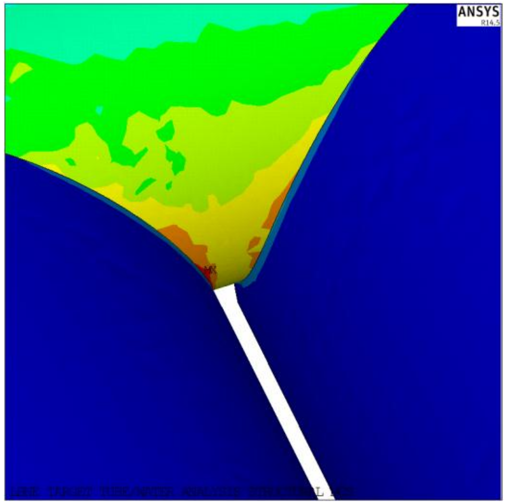
- Expected stresses from a single off-center pulse in the X-direction.
- Worst case found to be a 2mm beam position offset.
- Yields a ~ 25% increase in stress, but would be a single pulse only event.
- Well below yield and does not require fatigue analysis.





Analysis - Target Core

– Water lines
  - Gr. 2 Ti water lines are chosen based on the NuMI / MINOS Low Energy Target Cooling Circuit report from RAL.
  - Highest stress is actually located at interface between the graphite fins and outer wall.
  - Stress concentration introduced by the sharp transition between fin & water line – S.F. of 2.4 to titanium fatigue as modeled.
  - More realistic refinement included a .005” fillet introduced by the brazing process for a more realistic evaluation of the safety factor.
  - Increased fatigue safety factor to 3.2



Location	Material	Stress	Criteria	Safety Factor
Worst Case Fin	Graphite	10.5 MPa	UTS - 80MPa	7.6
Fin, Off-Center Pulse	Graphite	12.7 MPa	UTS - 80MPa	6.3
Water Line No Fillet	Ti Grade 2	126 ± 36 MPa	Goodman @ 90C	2.4
Water Line With Fillet	Ti Grade 2	103 ± 22 MPa	Goodman @ 90C	3.2

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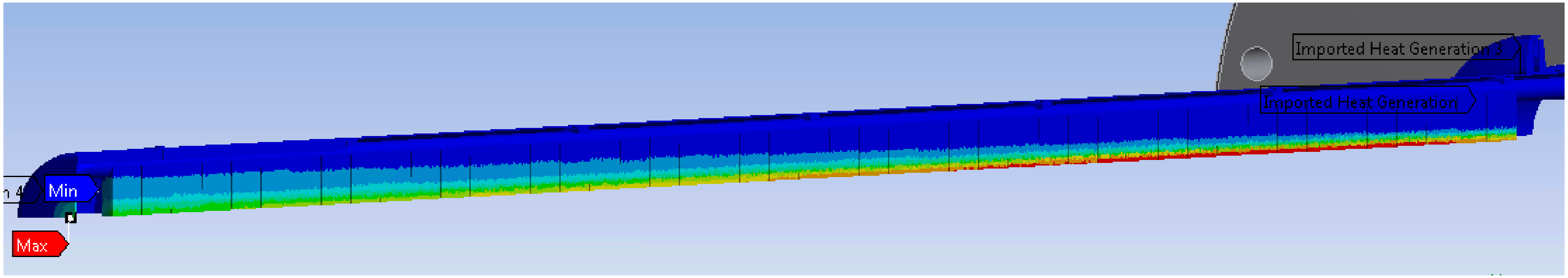
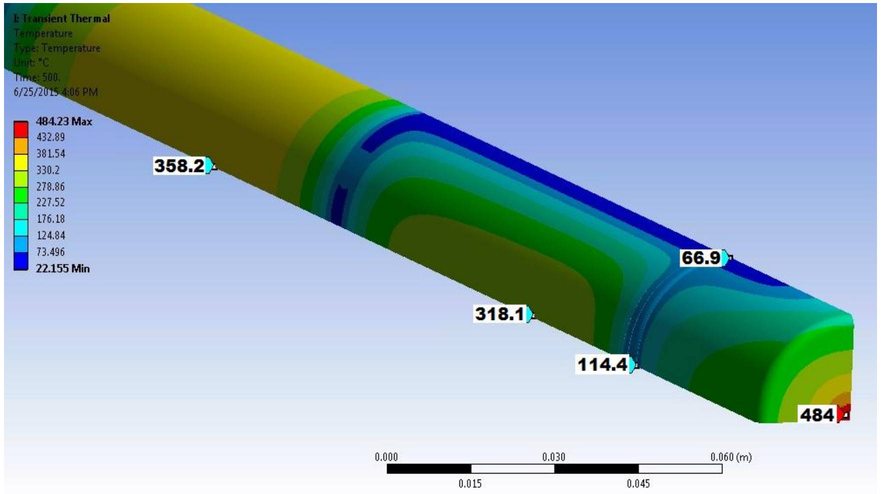
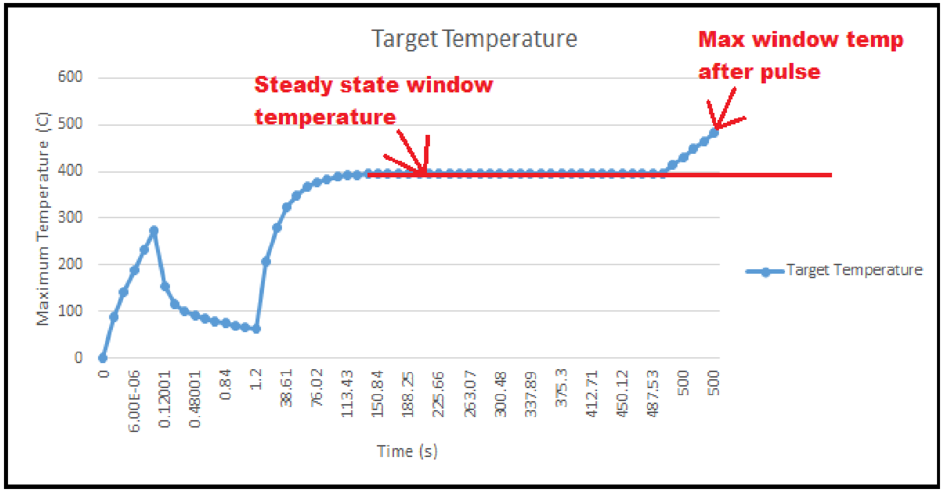
Analysis - Containment Tube / D.S. Window



- Maximum containment tube temp with Gr. 5 Ti ~360C.
- Maximum D.S. window temp with Gr. 2 Ti ~480C.
- Transition weld / cooling ring temps range from ~67-114C.





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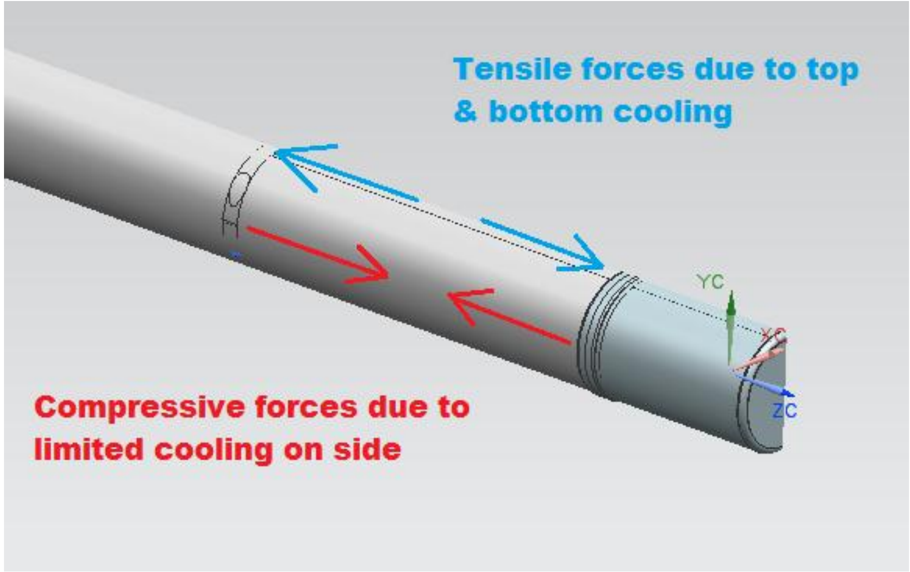
Containment Tube / D.S. Window

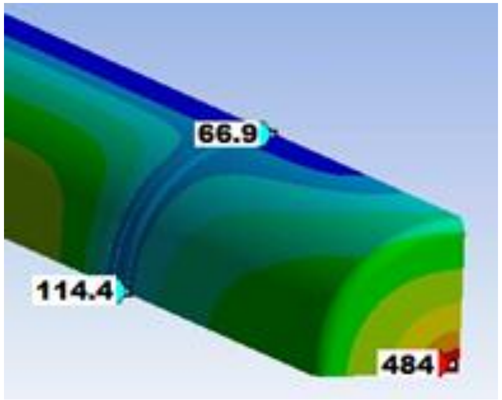
- Containment tube Summary

- Thermal stresses are unavoidable with this design due to symmetric, but non-uniform cooling.
- Alternate cooling methods add mass to target core & produce unacceptable beam heating in horn 1 I.C.
- Not a limiting factor of the design.



- Window / Cap Summary

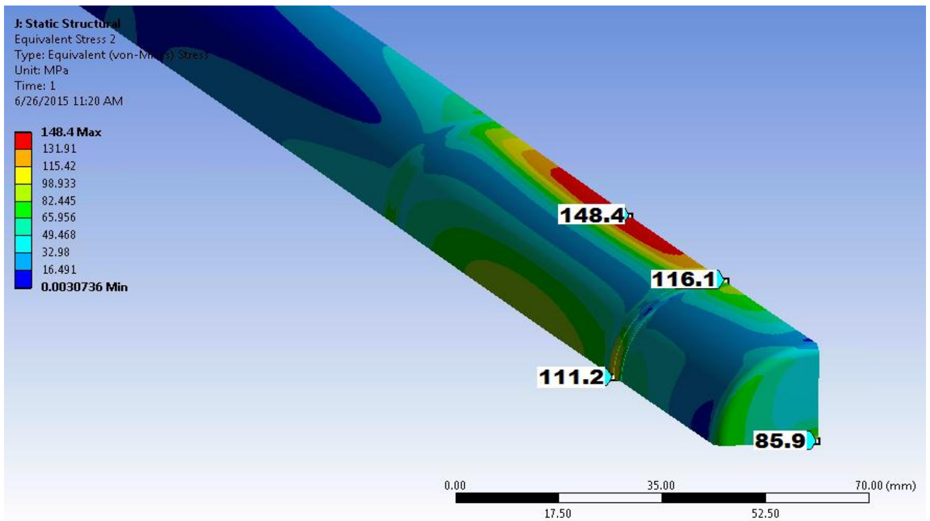
- Max steady state temp of ~400C & max transient temperature of ~480C at beam spot could be problematic.
- TiN / TiAlN / TiCrN coating with higher oxidation resistance would have to be utilized.

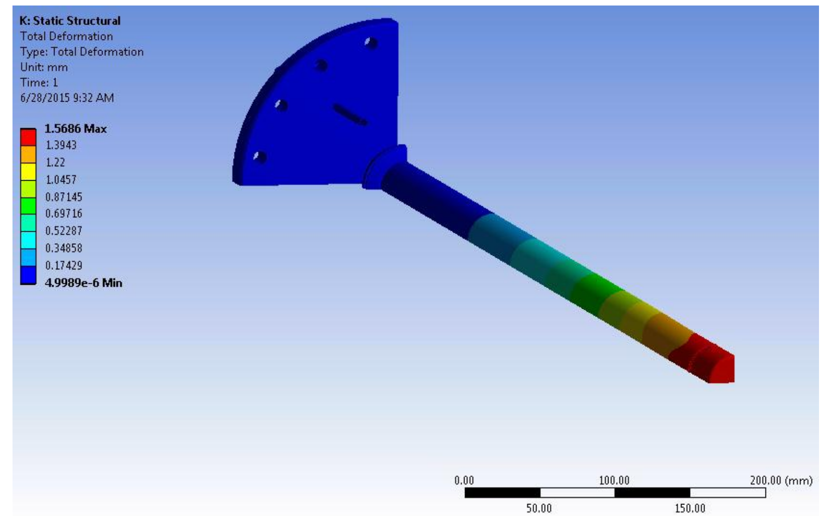


Analysis - Containment Tube / D.S. Window

- Containment tube Summary

- Max Von-Mises stress is 148 MPa at top edge of Gr. 5 containment tube.
- Steady state heating lengthens target by ~1/16” (1.5mm).

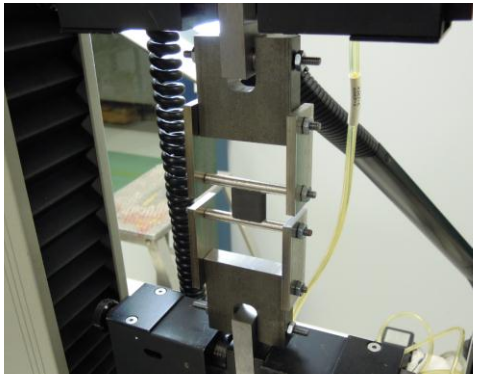




Component	Goodman Safety Factor @ 1.0E+8 Pulses
Grade 5 Ti Target Support Tube	4.34
Transition Weld*	3.09
Cap / Window @ Transition Weld*	2.96
Grade 2 Ti Window	1.64

Note * - Temperature limitations do not apply since location is at cooling ring

Fabrication Considerations – Prototyping

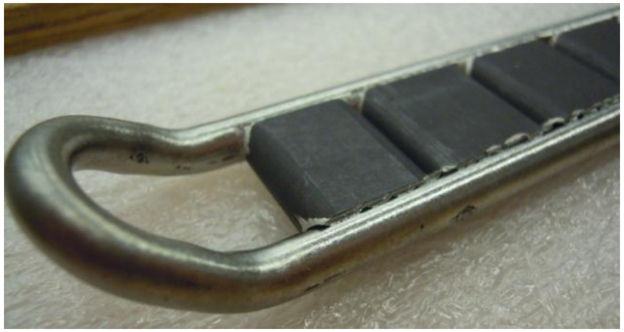


- Completed Efforts

- Full length prototype was successfully produced.
- The prototype core is a drop in replacement for a NuMI LE target due to 6.4mm fin width and single cooling loop turn around.
- Brazing Fixture design was refined & can be adapted to the 1.2 MW 10mm wide fin / twin cooling loop target with minimal modifications.
- Excellent wetting & adhesion using TiCuNi braze foil.

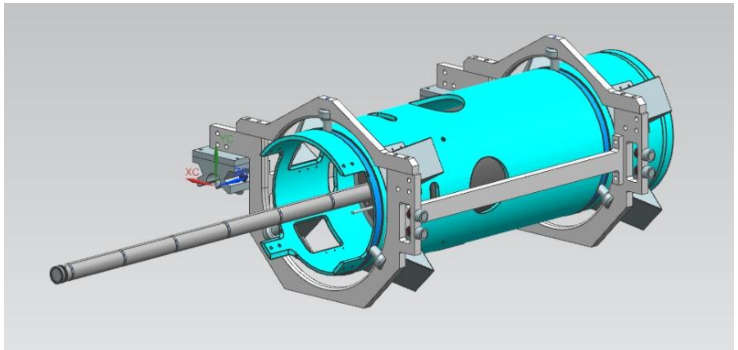
- Future Efforts

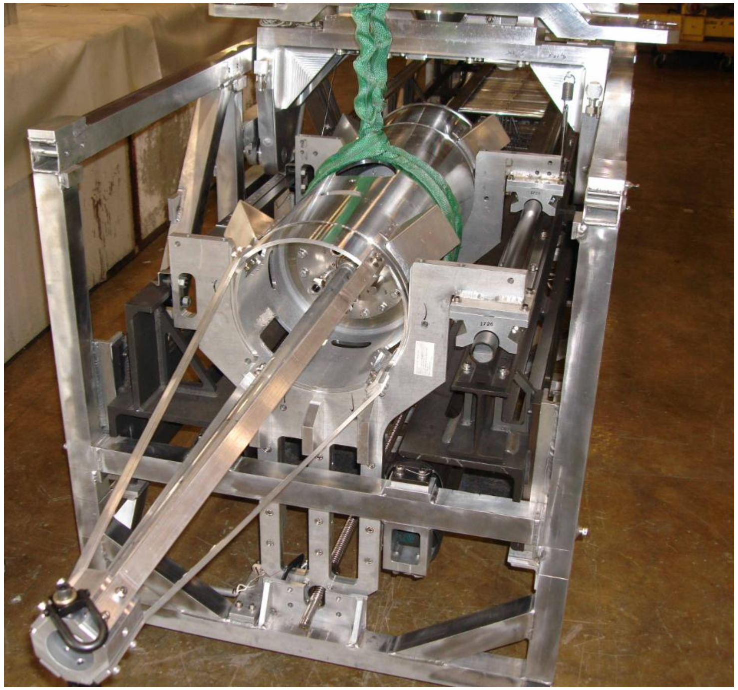
- Alternative D.S. window materials.
  - Glassy Carbon
  - Max phase material
  - Hybrid window
  - ZXF-5Q + metallized coating.
- Test different coatings on welded Gr. 2 to Gr. 5 sample.
- High temperature heat cycling of aluminum knife edge seal.



Fabrication Considerations – Target Carrier Integration

- Carrier assembly must be able to accept the modified target with minimal design changes.
- Additional water and helium cooling lines must be added to existing utilities for core & can cooling.
- Miniaturization & relocation of ceramic electrical breaks.
- Rigid aluminum coiled tube for utilities supply must be replaced with braided flexible lines.
- Drive mechanism redesign required for operational reliability.





Conclusions for 1.2 MW Operation

- Target Components

- Current target core & containment tube design is capable of 1.2 MW operation.
- D.S. Window design can be improved with better / newer materials or combinations of materials.

- Carrier components

- Carrier frame from NuMI design can be retained.
- Replacement target core assembly will fit in existing drive frame.
  - Altered electrical isolation due to higher horn voltages.
  - Requires miniaturized waterline electrical isolators.

- Integration with Horn 1

- Increased EDEP from larger containment tube / target fin / cooling loop count is balanced by reduction of current pulse width in the horn.
- At limits for both target core assembly and Horn 1 I.C. design.
  - Cannot decrease current pulse width in horn any further. Voltages too high.
  - Cannot add much more mass to target design. Additional EDEP increase does not work well with heat load already on the I.C.

Opportunities for Collaboration / Improved Designs

– Current 1.2 MW Design

- Continuation of titanium containment tube analysis.
  - 60 & 80 GeV heat load check & detailed stress analysis.
- D.S. Window analysis
  - Material & dimensional analysis iterations.
  - Off axis beam spill scenario.
  - Prototyping
- Beryllium fin material / bonding methods to titanium

– Possible 1.2 MW+ Design

- Optimized Target / Horn system for 1.2 MW+ beam operation.
  - Material studies / selection.
  - Prototyping of target fin / cooling / window
- New target carrier assemblies
  - Alternate modifications to NuMI / NOvA carrier assemblies.
  - Possible new design.
- Must work with Horn group to create a compatible design.