Beryllium

For Target and Beam Window Applications

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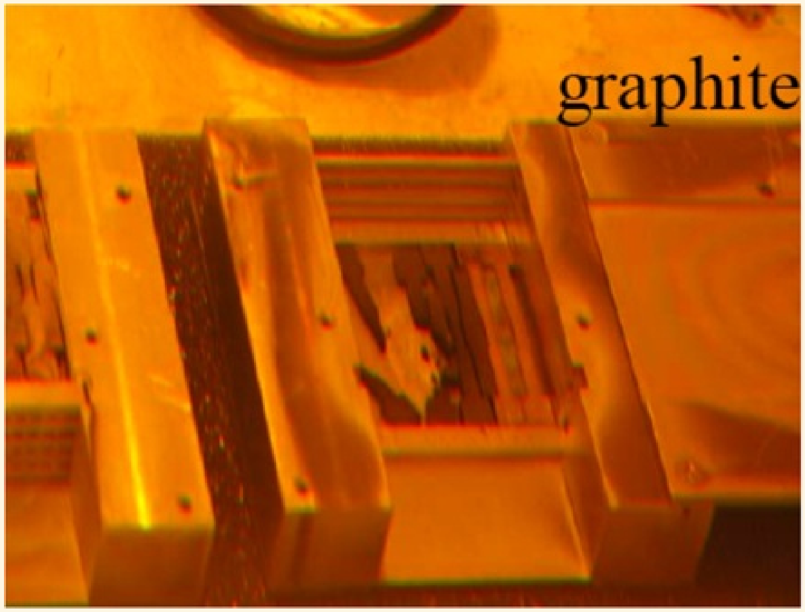
Why Beryllium?

Graphite radiation damage issues caused LBNE to look at Beryllium for target use

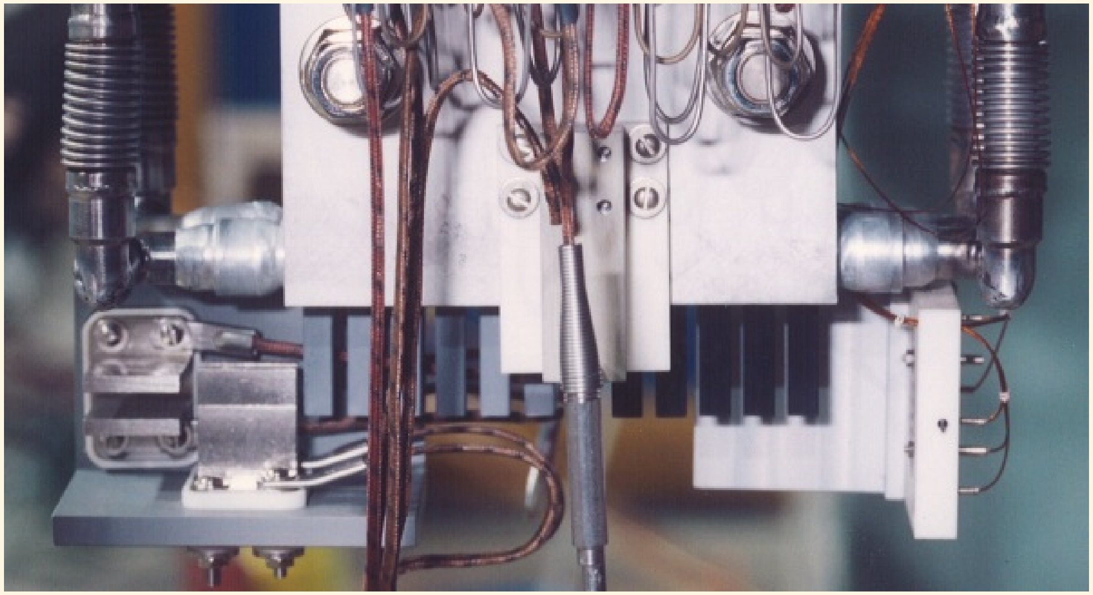


Benefits of Beryllium

- Possibly longer target lifetime
- Good thermal shock performance but less than C
- Similar in density to C
- High thermal conductivity

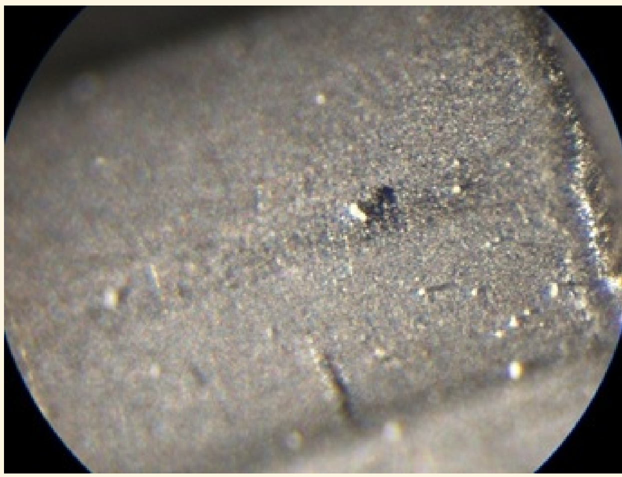
1999 NuMI Prototype Target

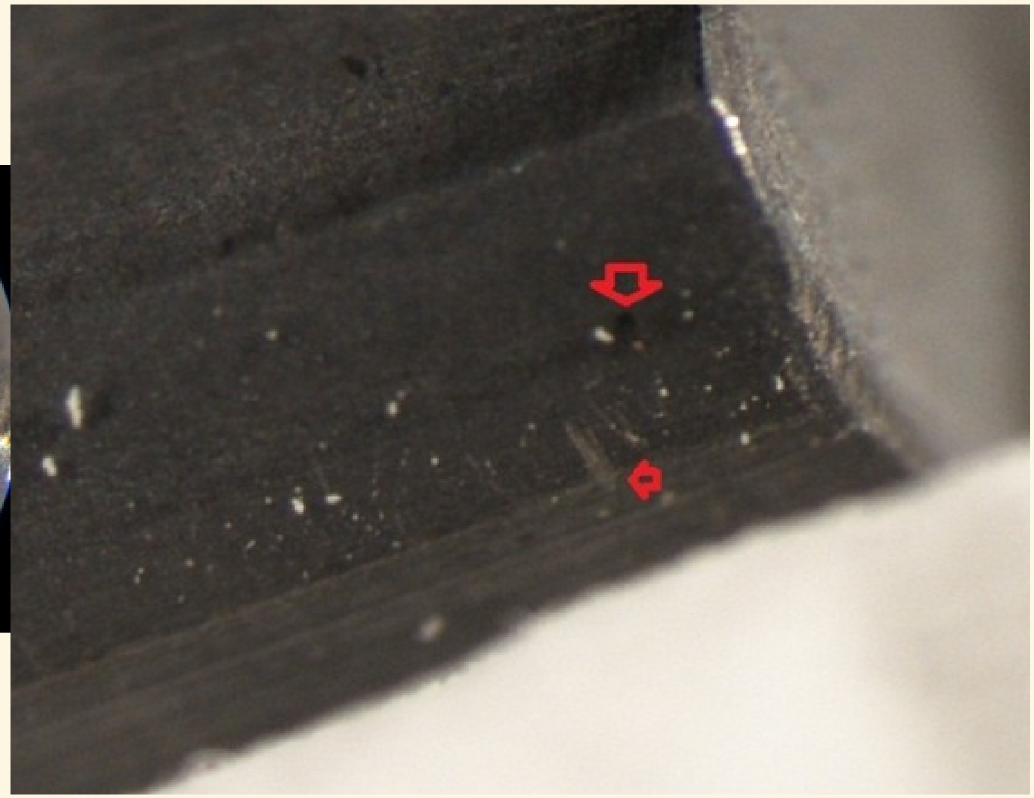
Beam sigmas of 0.16, 0.22mm - 1e13 POT/pulse - 180 pulses



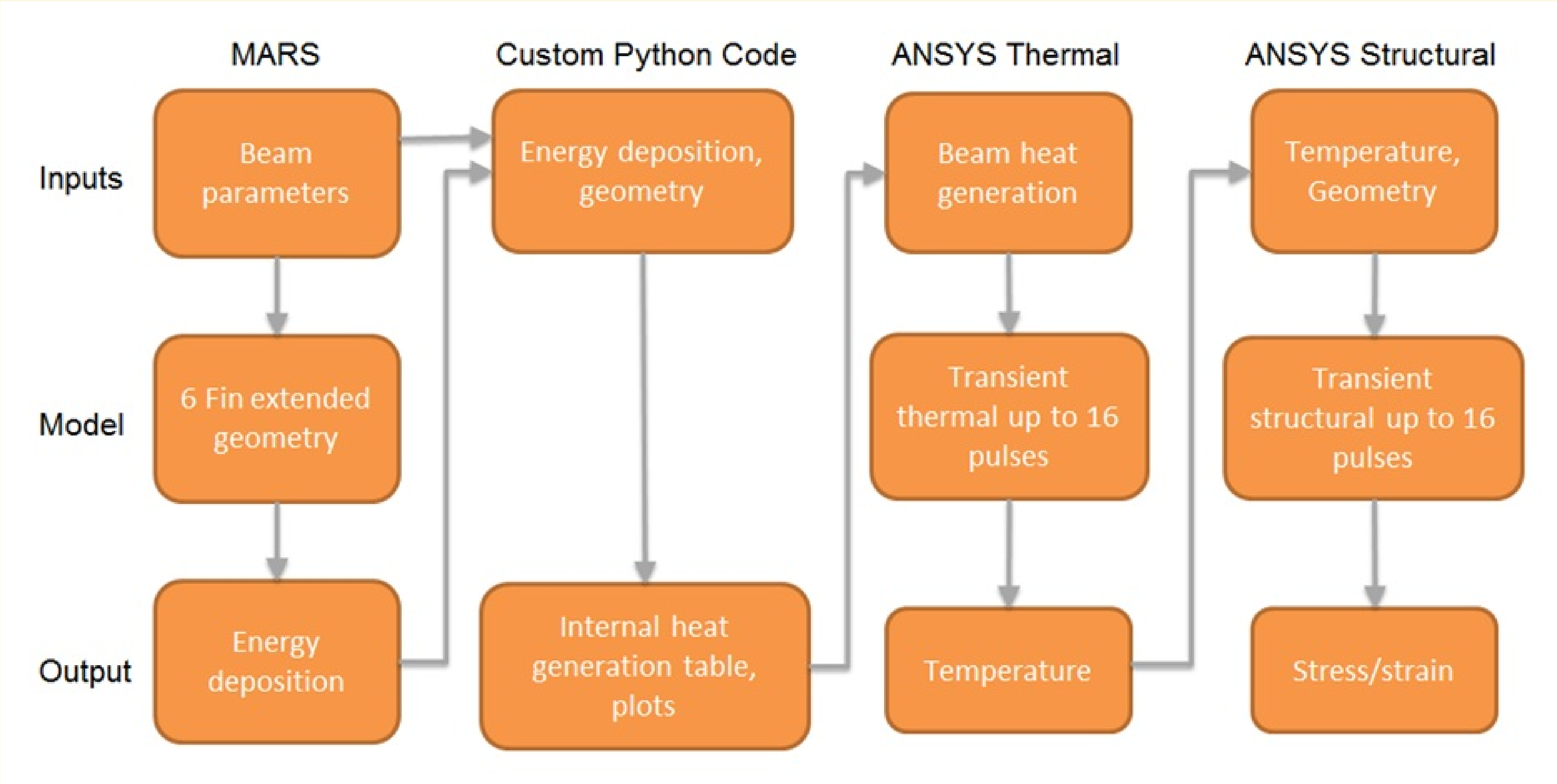
1999 NuMI Prototype Target Test

Light microscope images show a "dark spot" on upstream side of first fin, but no marks on other fins.



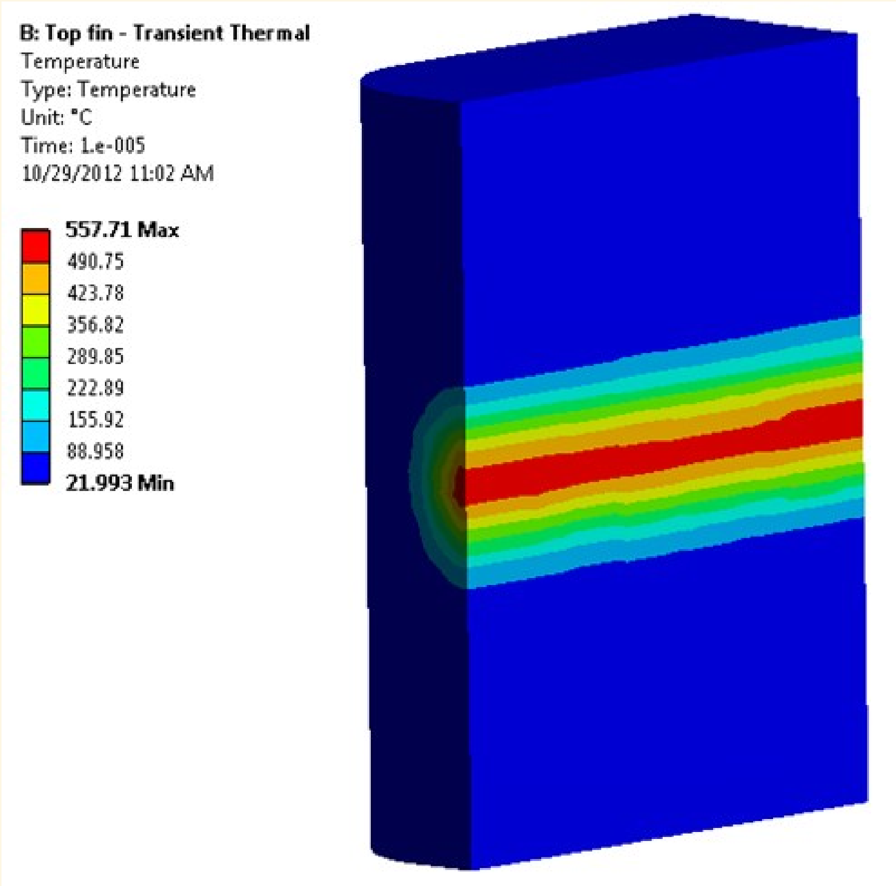


1999 NuMI Test Modeling



1999 NuMI Test Modeling Results - 1

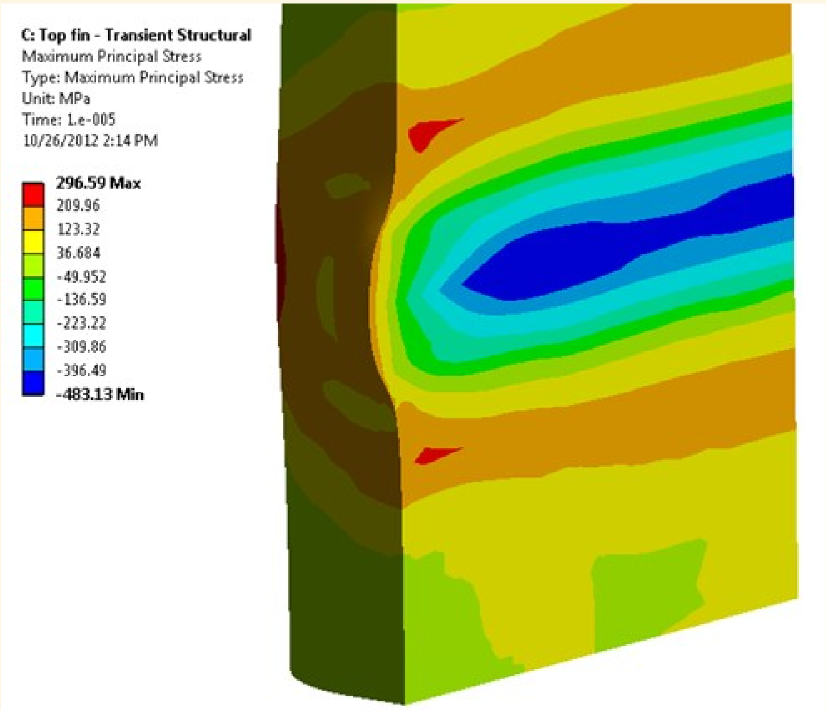
Resulting temperature from MARS energy deposition
Maximum temperature is ~560°C



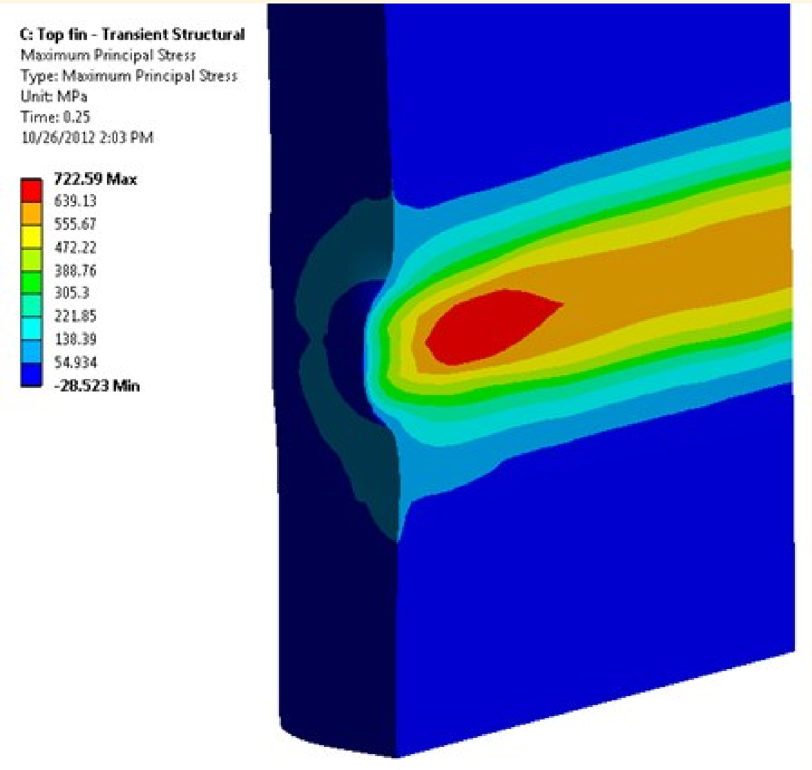
1999 NuMI Test Modeling Results - 2

Maximum principal stress - typical views

- Deformations shown at 50x
- Bulge is ~5μm high, 1mm in diameter after 16 pulses

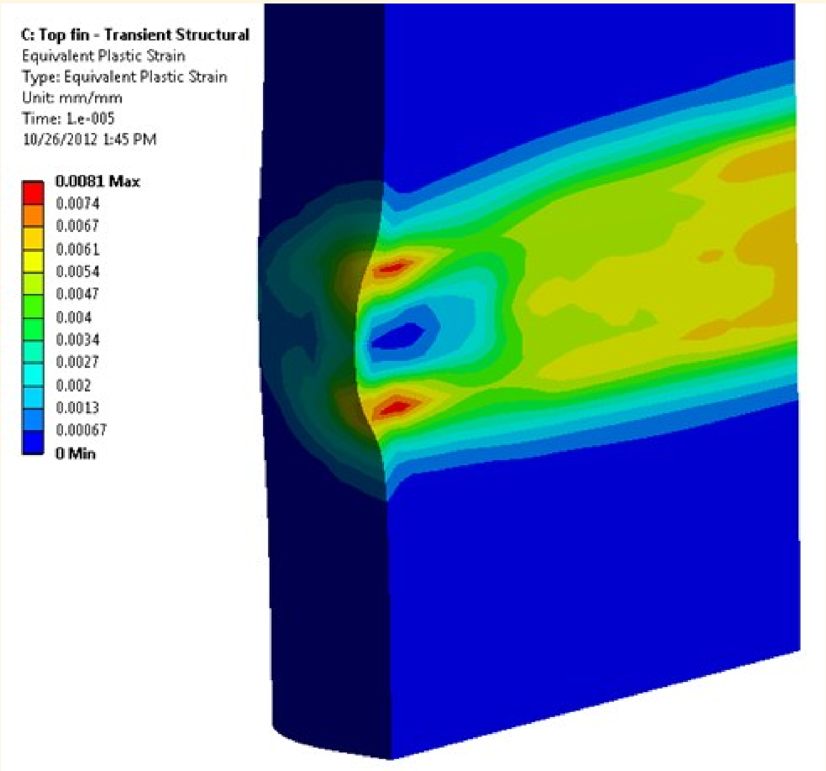


End of pulse - 560°C

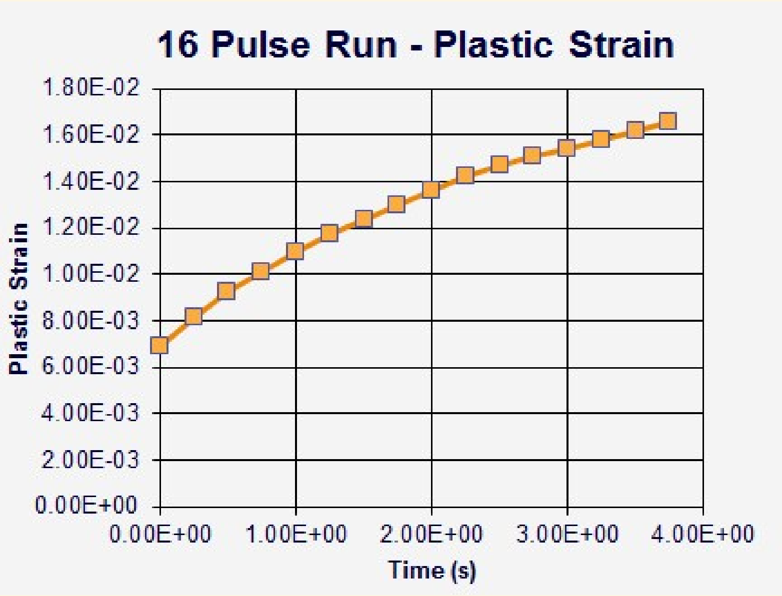


End of cooldown - 22°C

1999 NuMI Test Modeling Results - 3



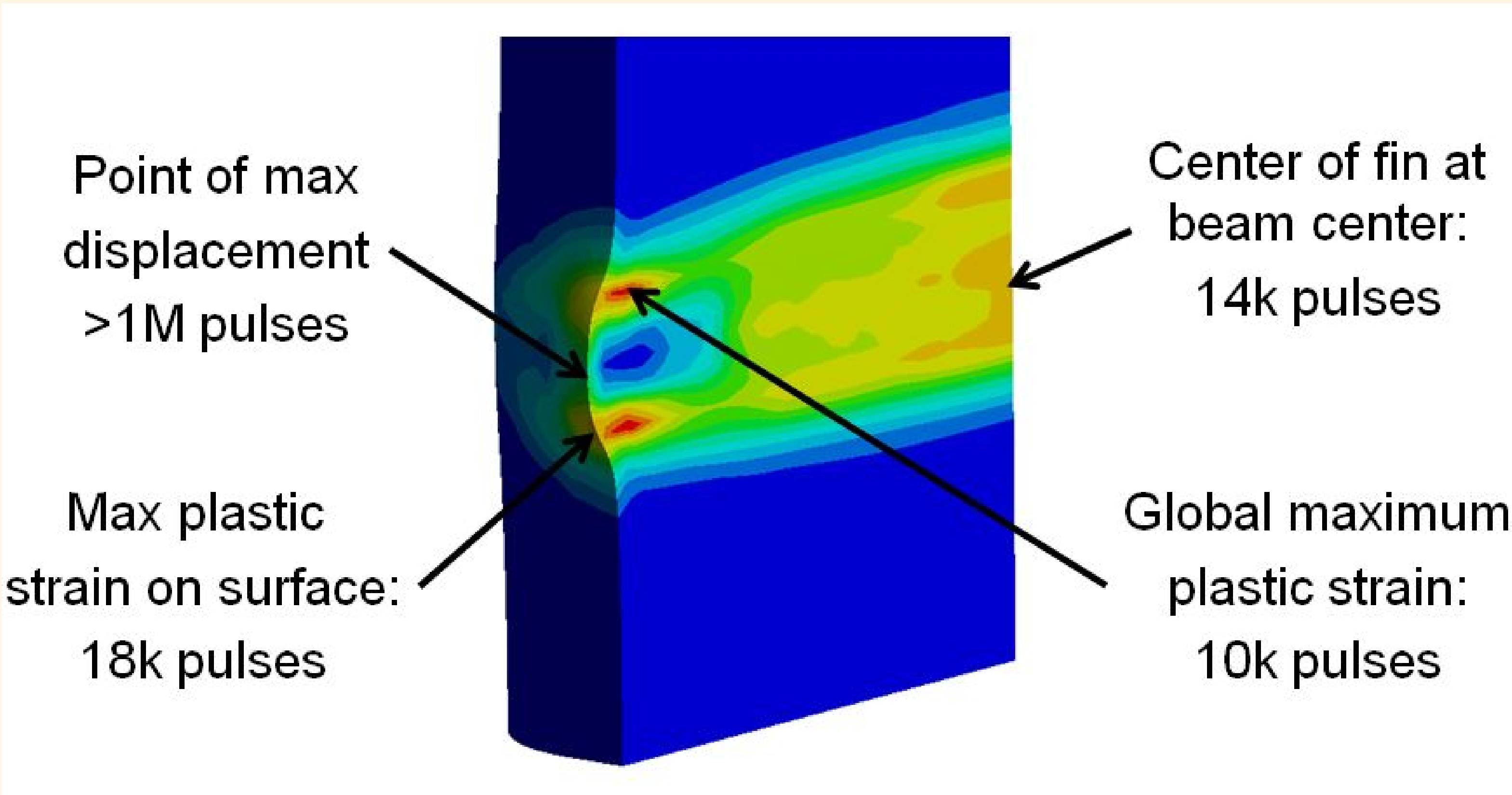
Plastic strain - end of pulse 1



Plastic strain vs time at maximum point

1999 NuMI Test Modeling Results - 4

Estimates of life from plastic strain cycling using the Coffin-Manson relation



Something is wrong here..

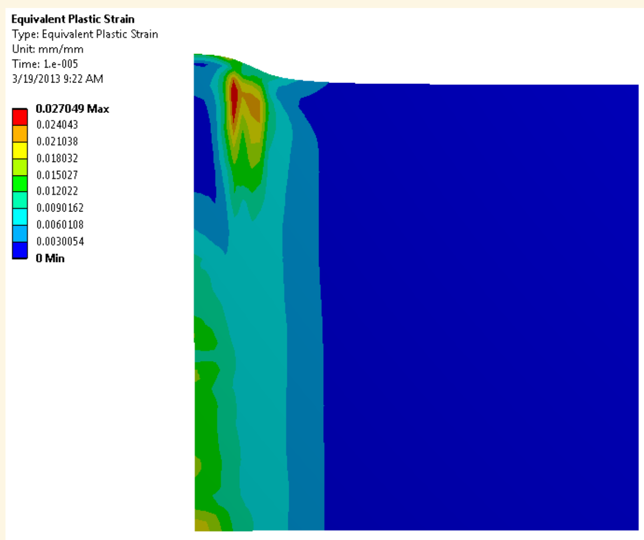
Other Beryllium components have seen millions of comparable beam pulses without failure.

- Thickness does not play a large role
- Need better material properties and models - strain rate, dynamic vs static
- Incorporate damage/fracture (AUTODYN, LS-DYNA)
- Incorporate DPA effects (long term)

Fracturing Beryllium...

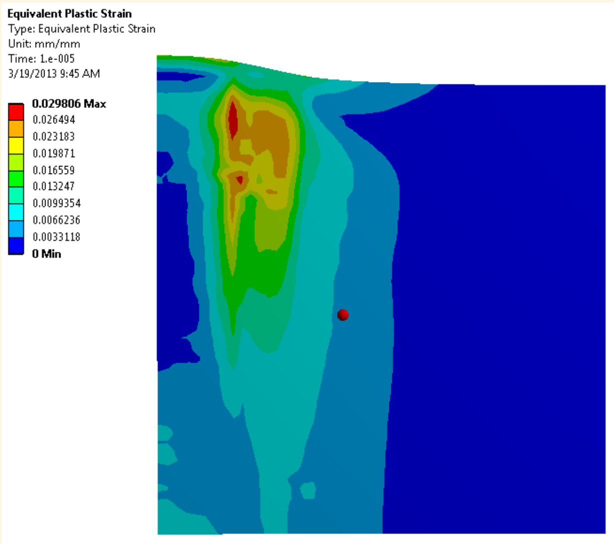
With one shot of a Gaussian beam centered on a chunk of material?

- Axisymmetric model of 5mm thick Beryllium subject to the same beam as the 1999 NuMI target test & lithium lens windows
- Scaled energy deposition so temperatures were close to melting - 1100°C (approx a factor of two)
- Maximum equivalent plastic strain of 2.7%



Does this go to 11?

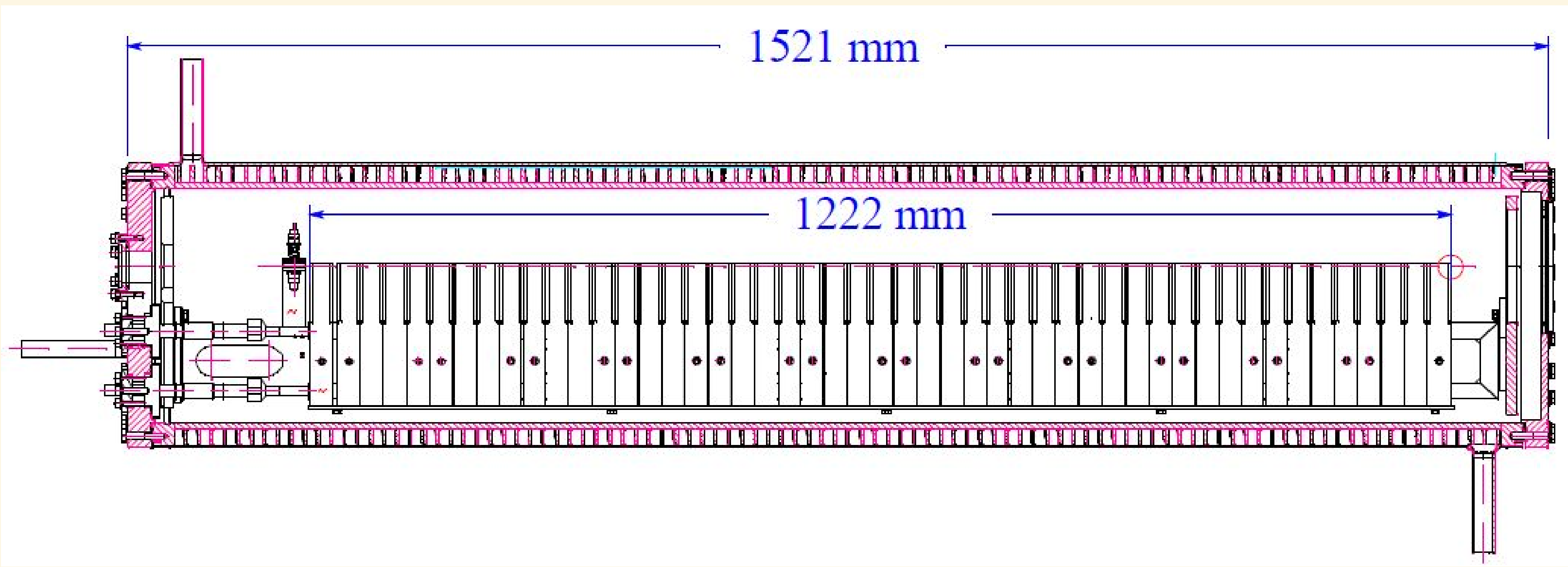
- Doubled the size of the beam while holding EDep constant (a 4x increase in beam power) to determine effects of a larger spot size
- Minimal effect on plastic strain - 2.9% max



The NOvA Target

A candidate for an in-beam Beryllium test

The NOvA target is made up of 48 graphite fins arranged in a row along the direction of beam travel



Cross section view of NOvA Target

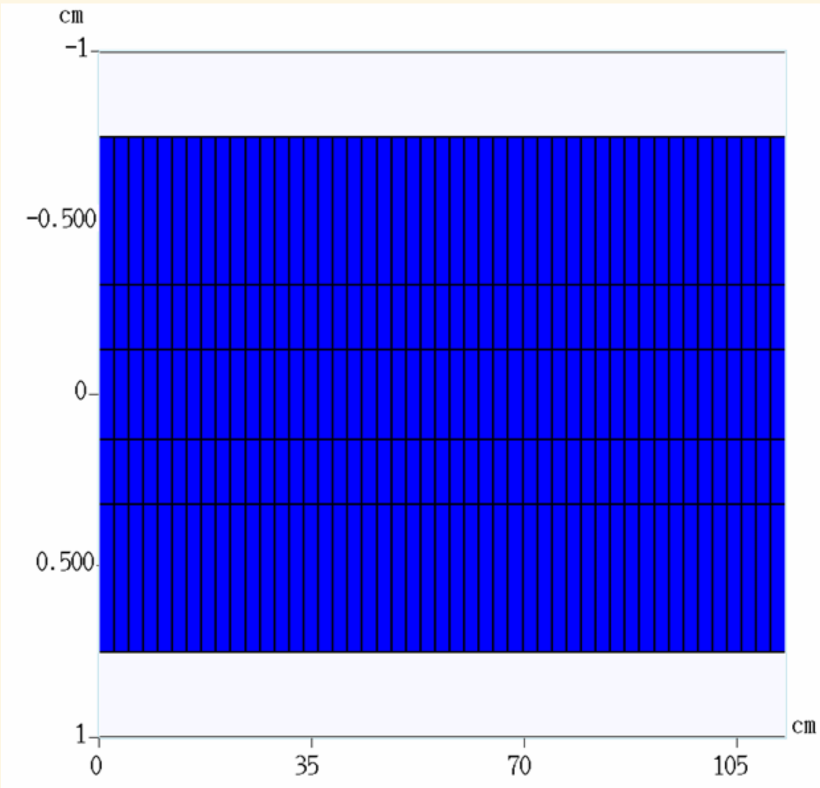
Be fins in NOvA Target

Goal: Replace 2-3 fins of the NOvA target with Beryllium fins

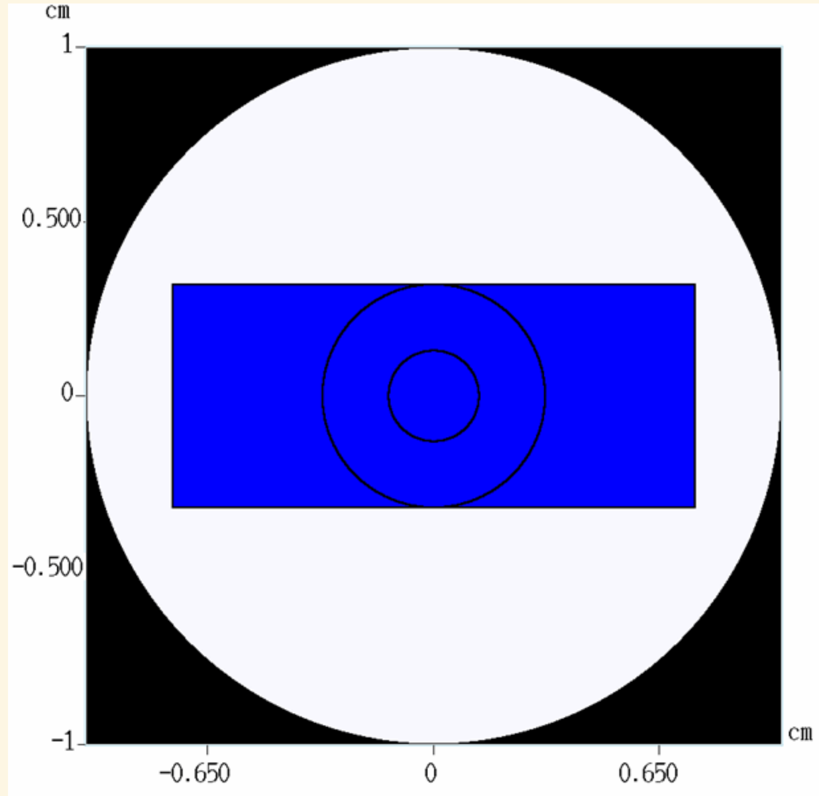
- Maximum energy deposition in the 1-sigma beam radius
- Maximum energy deposition in the 3-sigma beam radius
- Other points of interest?

MARS Setup

Divided into three zones: 1-sigma radius, 3-sigma radius, and remaining fin



Y-Z Model Setup

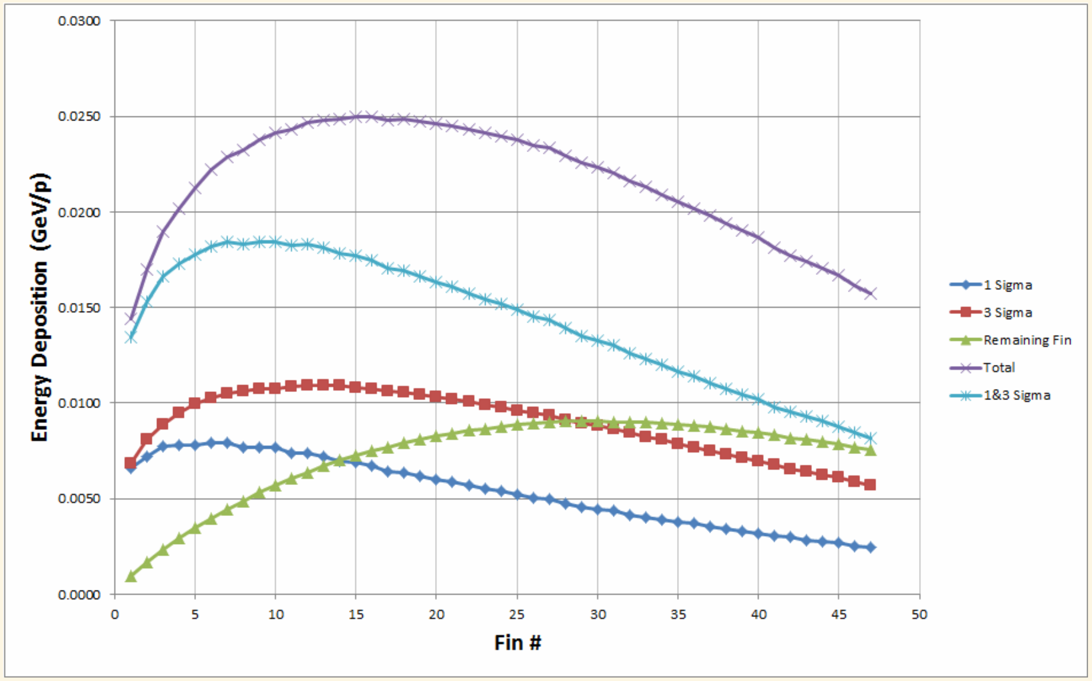


X-Y Model Setup

MARS Results

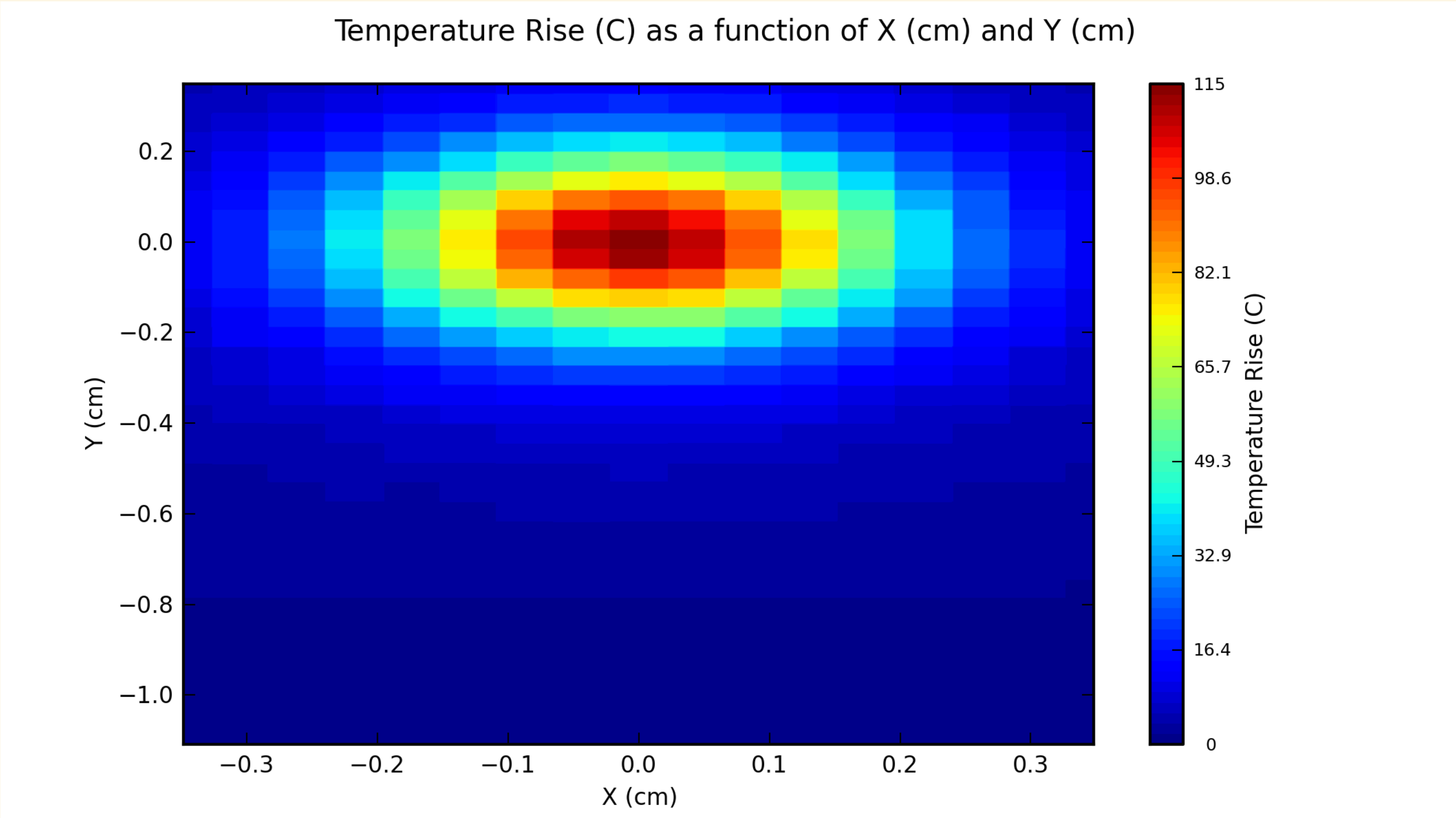
Fins of interest: **6, 10, 17**, 30

Used the energy deposition in these fins as the input for ANSYS thermal runs



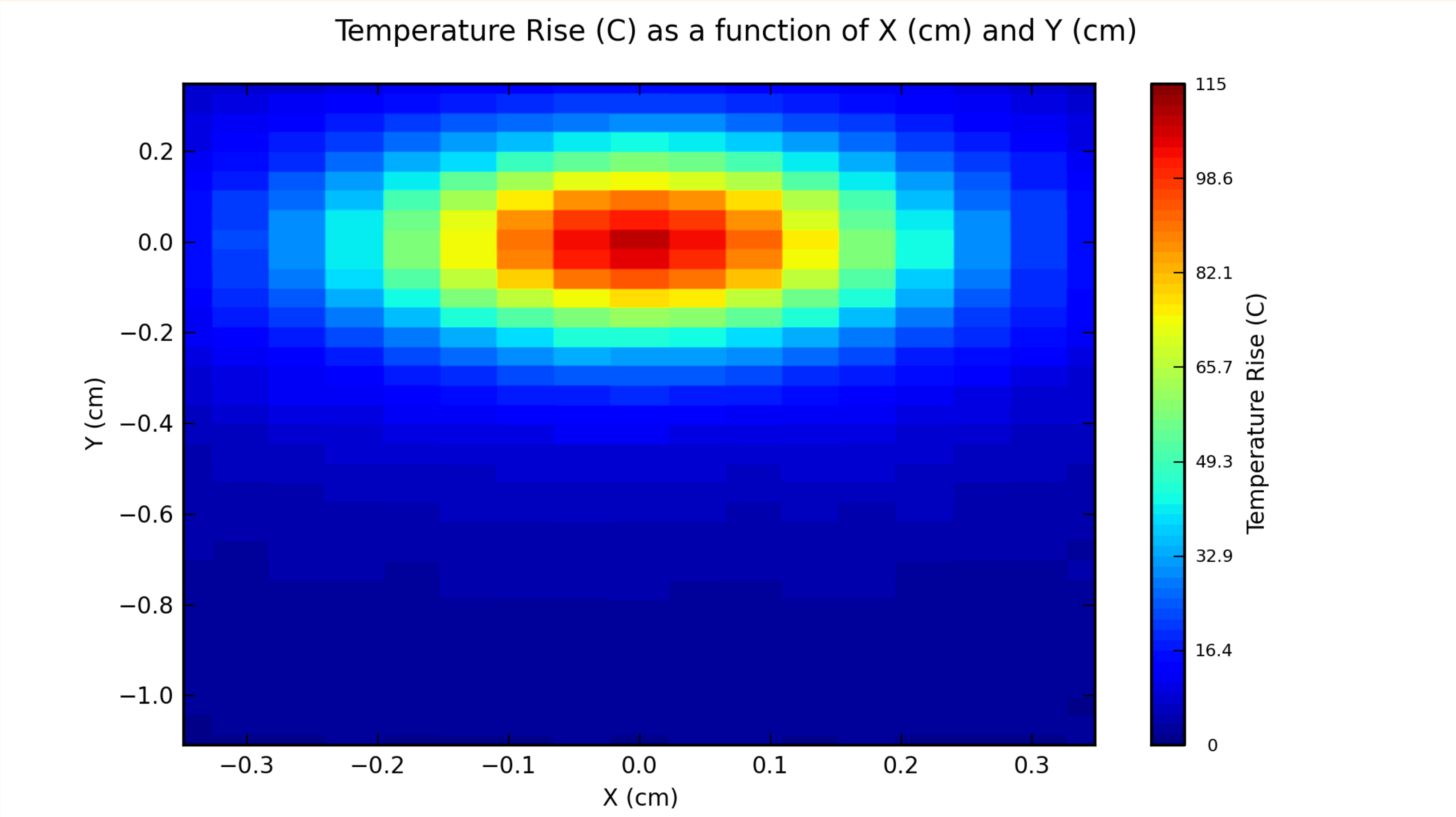
MARS ΔT Prediction - Fin 6

Max ΔT: 115°C



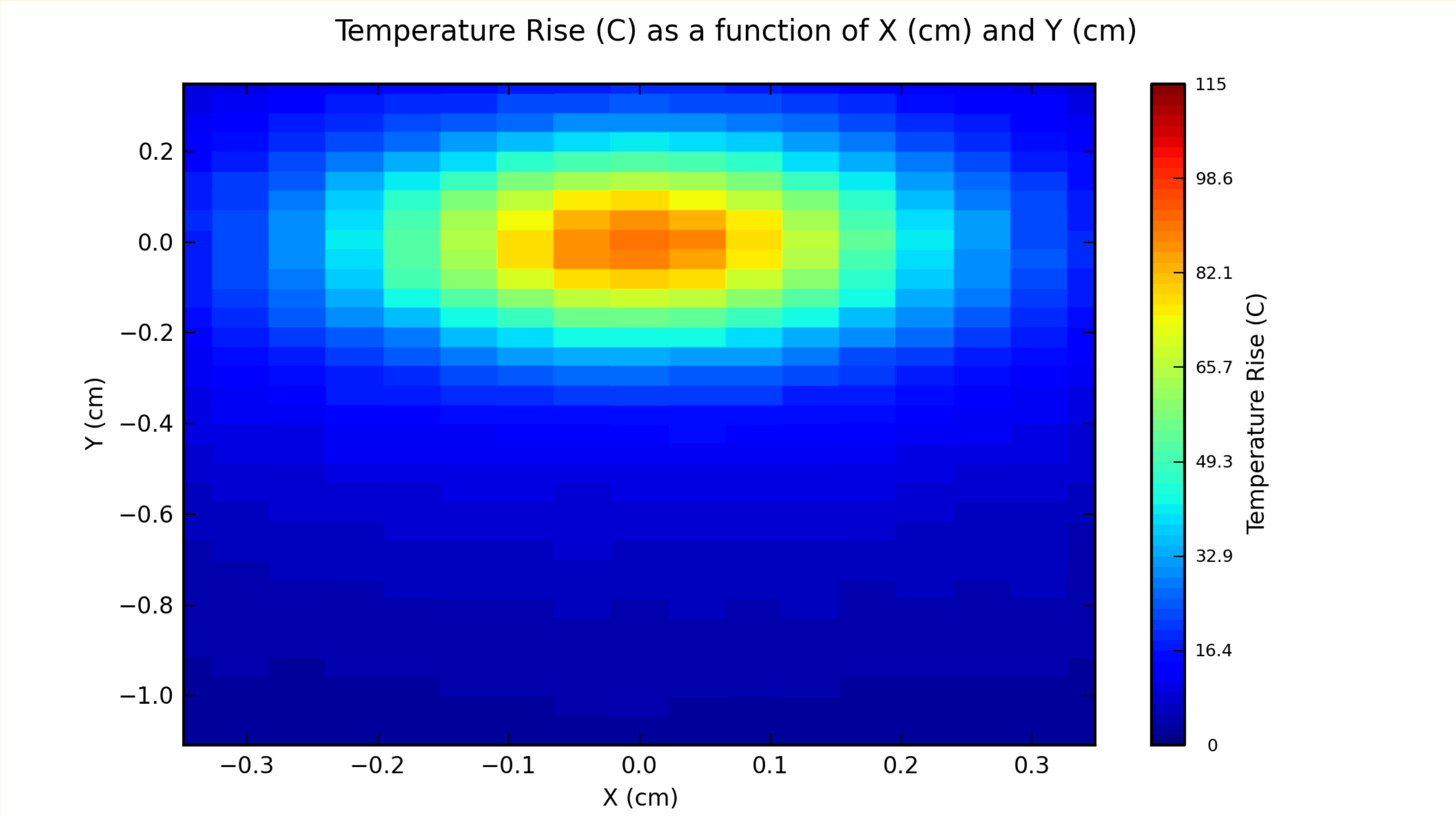
MARS ΔT Prediction - Fin 10

Max ΔT: 108°C



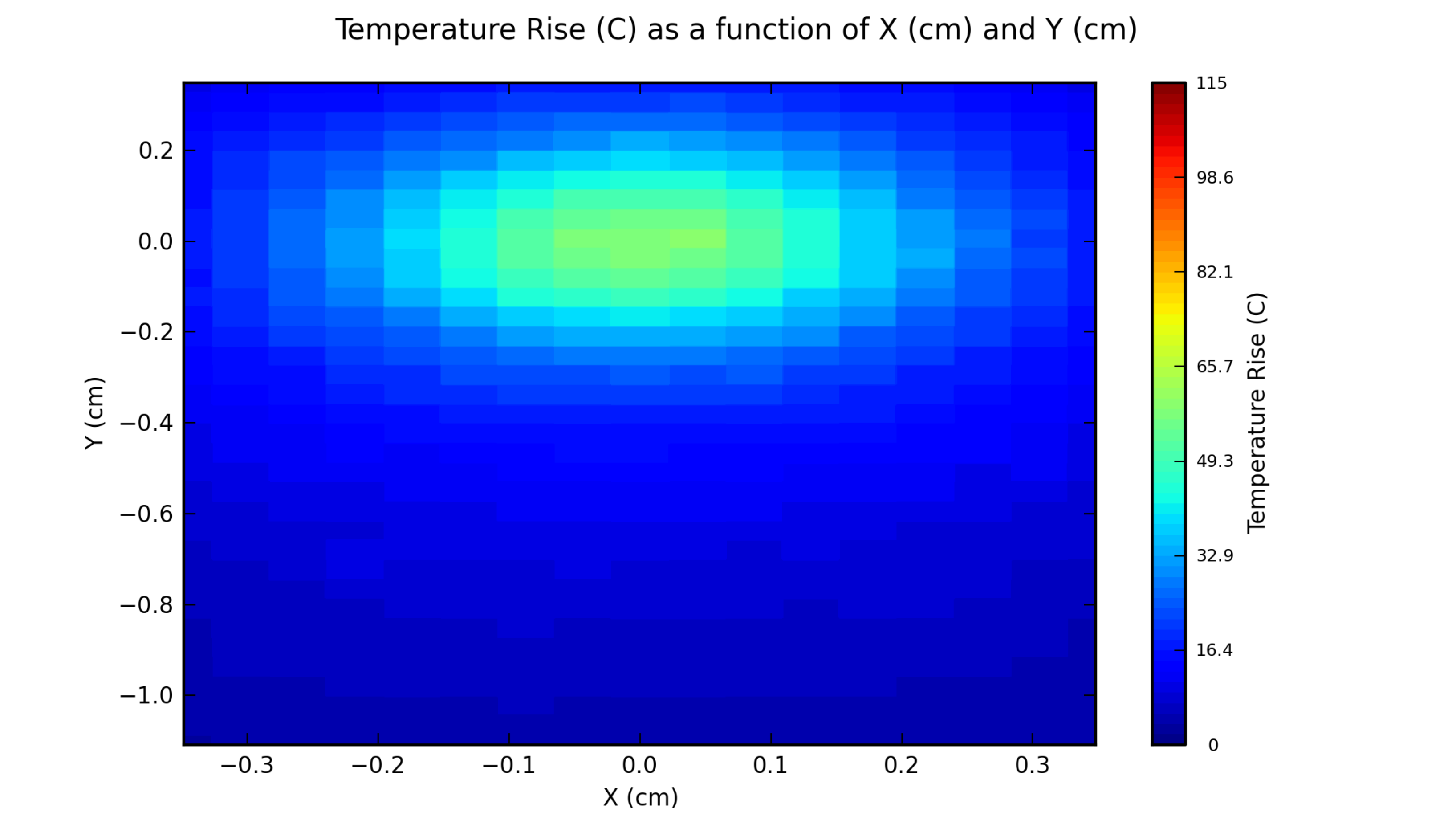
MARS ΔT Prediction - Fin 17

Max ΔT: 91°C



MARS ΔT Prediction - Fin 30

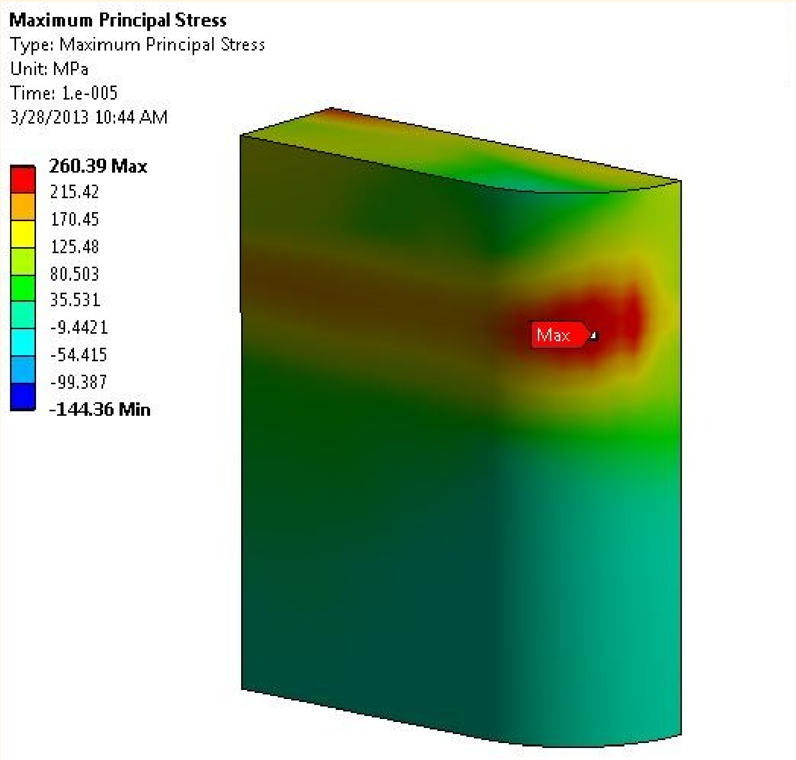
Max ΔT: 58°C

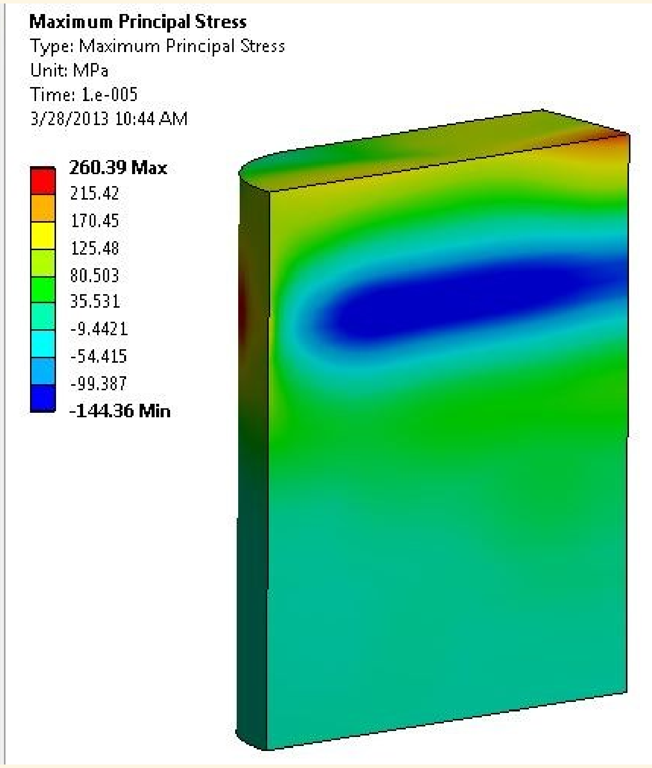


ANSYS Results - Fin 6

ANSYS ΔT - 111°C (MARS ΔT - 115°C)

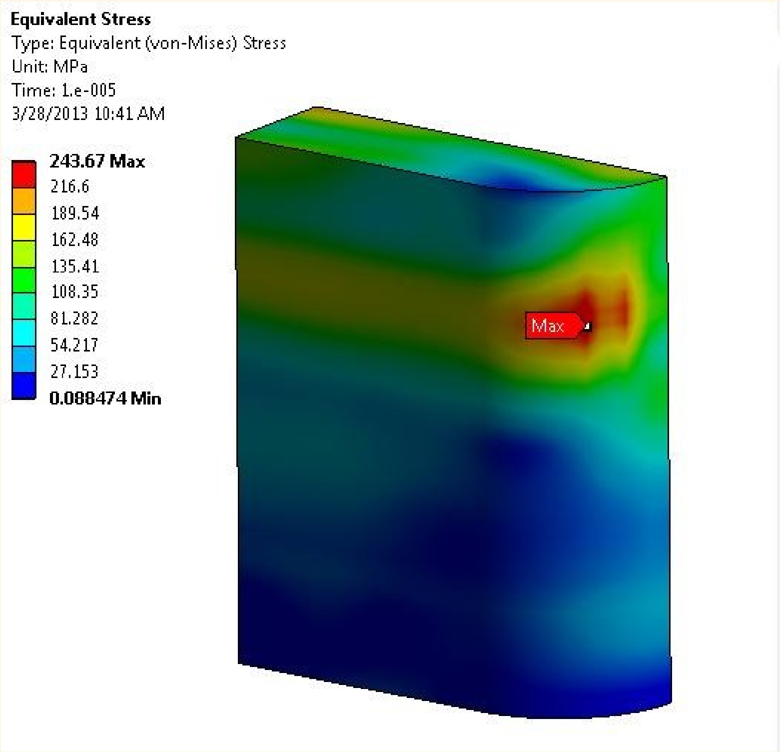
Principal stresses: Compressive in beam spot, tensile buildup at fin edge.

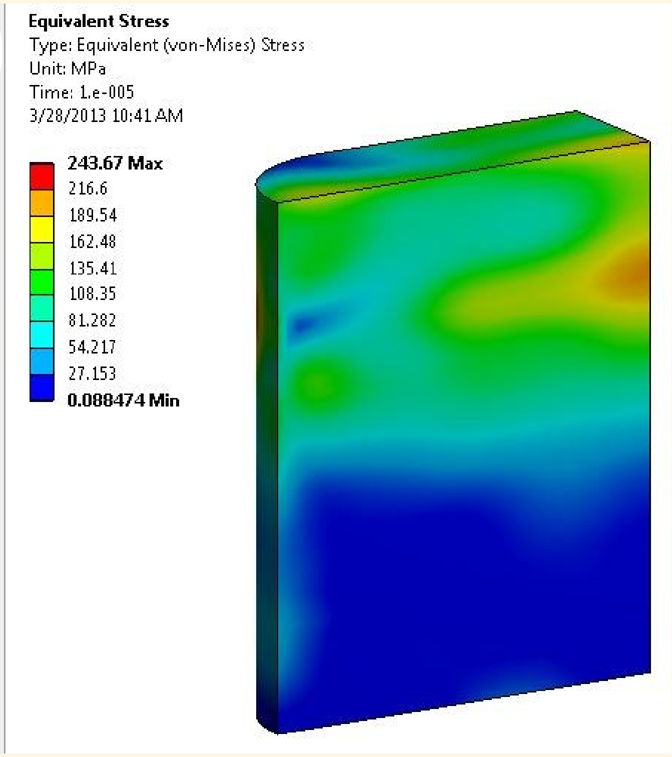




ANSYS Results - Fin 6

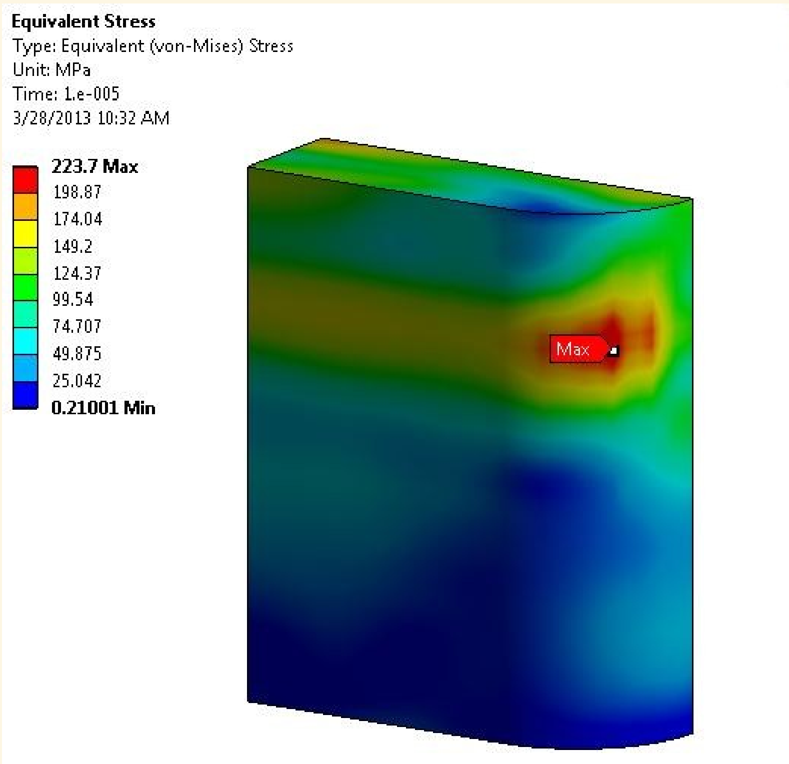
Von Mises Stresses: Below yield (~250MPa at this temperature) in all areas

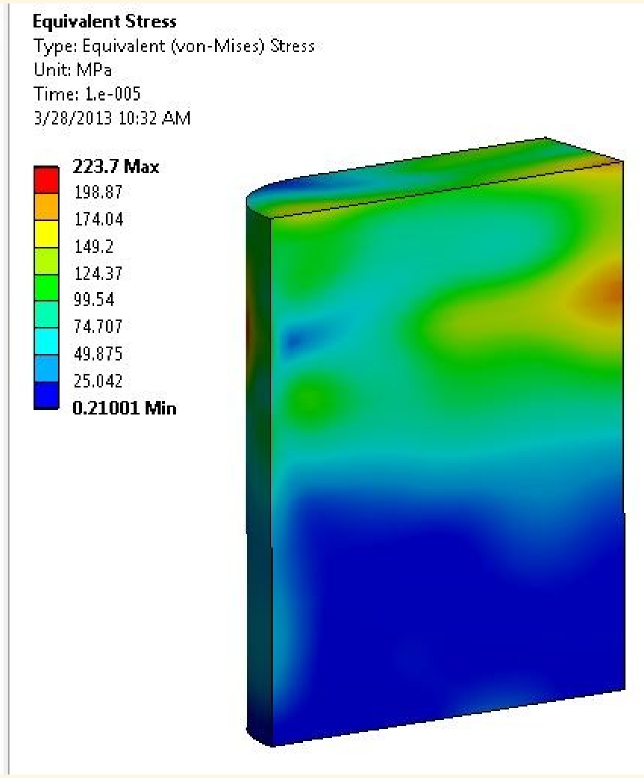




ANSYS Results - Fin 10

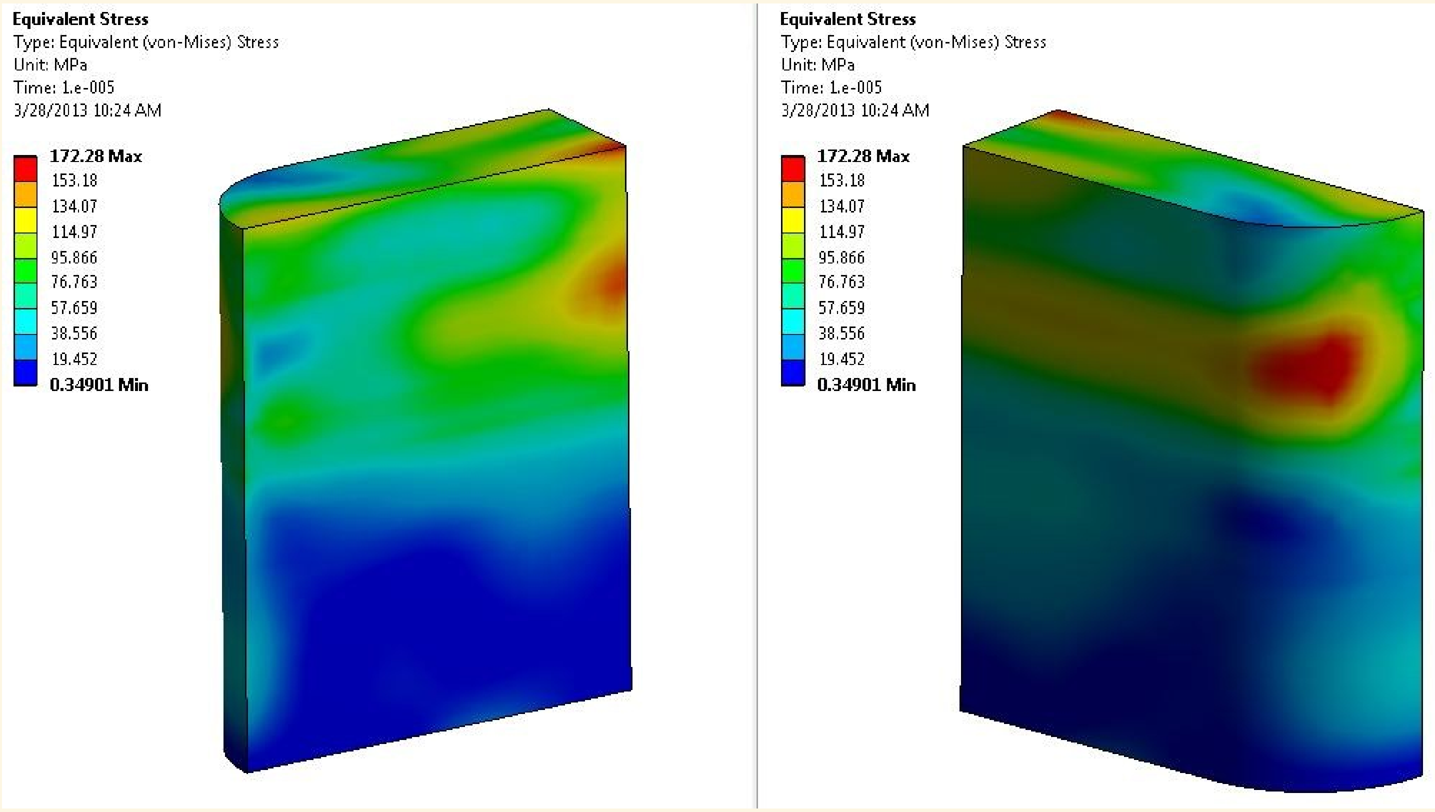
VM Stresses





ANSYS Results - Fin 17

VM Stresses



NOvA Fin Analysis To-Do

- Look at steady state stresses and add those to transient
- Add in multiple pulses
- Analyse dynamic stresses

Conclusions

- Black marks on 1999 NuMI target test are not likely directly caused by 'thermal shock'.
- Optimize methods to correctly model fatigue failure for Beryllium.
- Further study of methods to determine Be mechanical properties for high strain rates and temperatures.
- Results are looking good for an in-beam test of Beryllium on the NOvA target.

END

Any Questions?