High Intensity Beam Test of Beryllium for Target and Beam Window Applications

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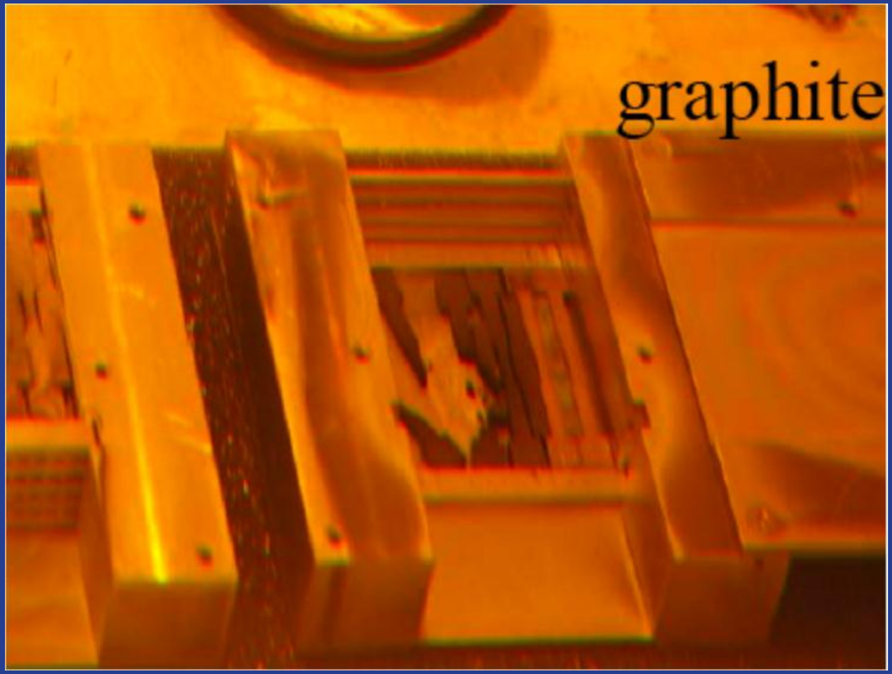
Fermilab

Why Beryllium?

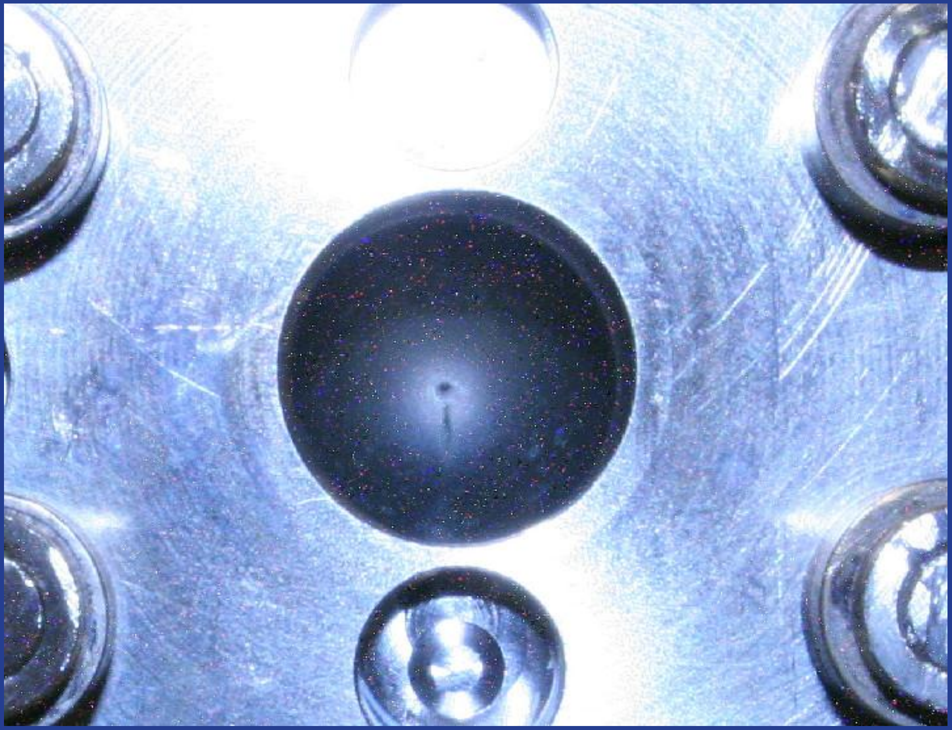
- Graphite radiation damage issues caused LBNE to look at Beryllium for target use.
  - Complete structural failure at 10^{21} p/cm^2 during BLIP run.



- Simulations with beryllium components do not seem to line up with the ‘real world’.

Beryllium tests and past uses at FNAL

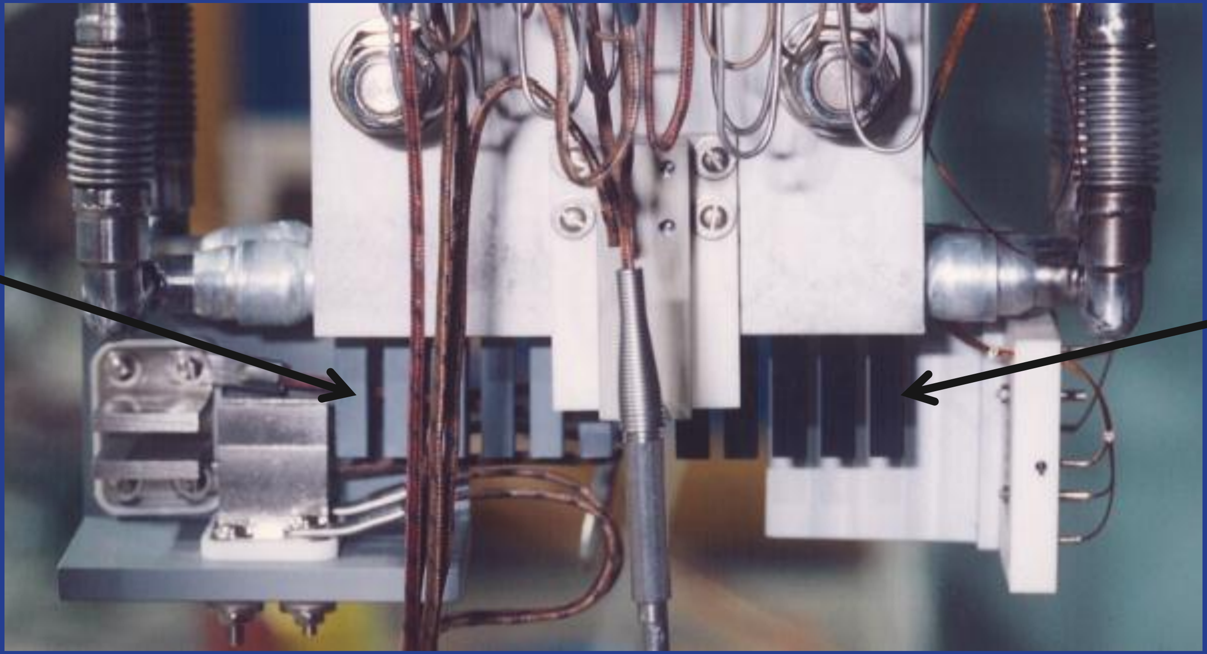
- Beam windows
- Pbar Lithium lens windows
  - Possible damage seen at 0.15mm sigma spot size, no damage at 0.19mm sigma.



Beryllium test

- 1999 testing of NuMI prototype target

Be Fins Upstream

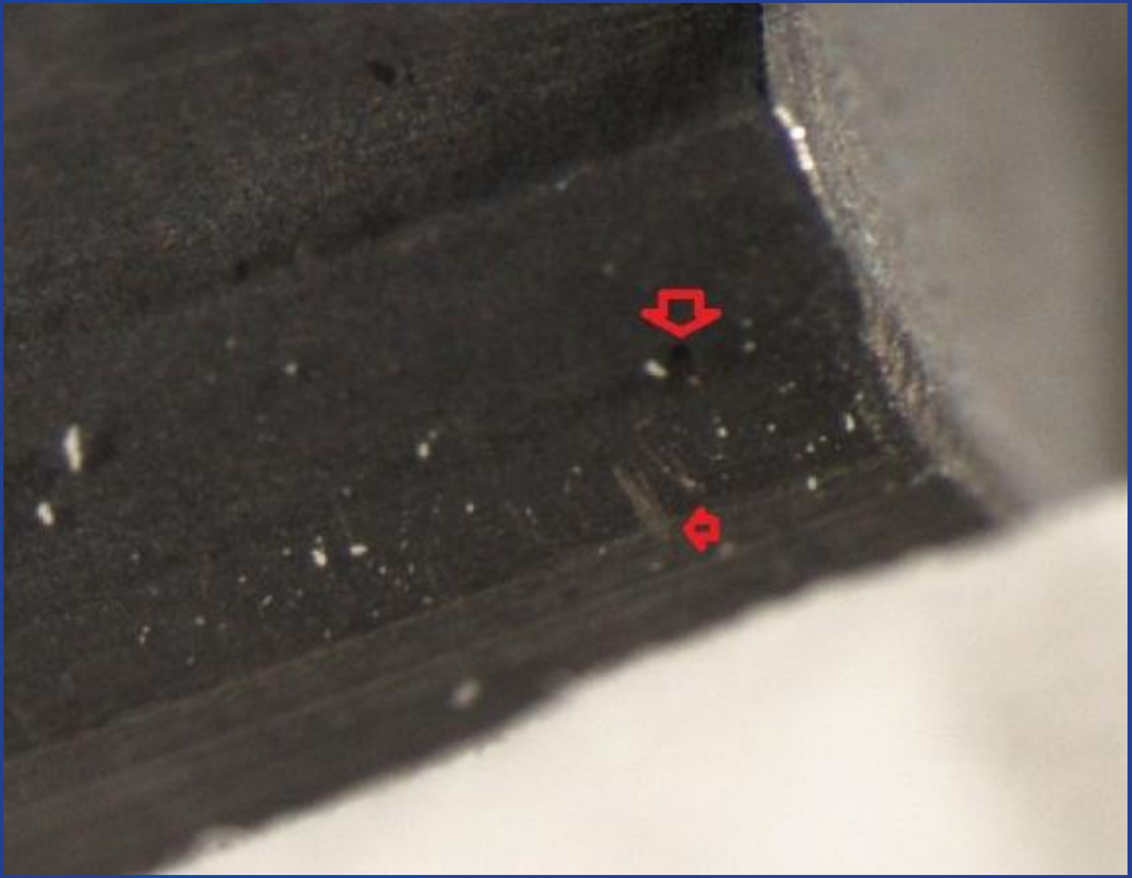


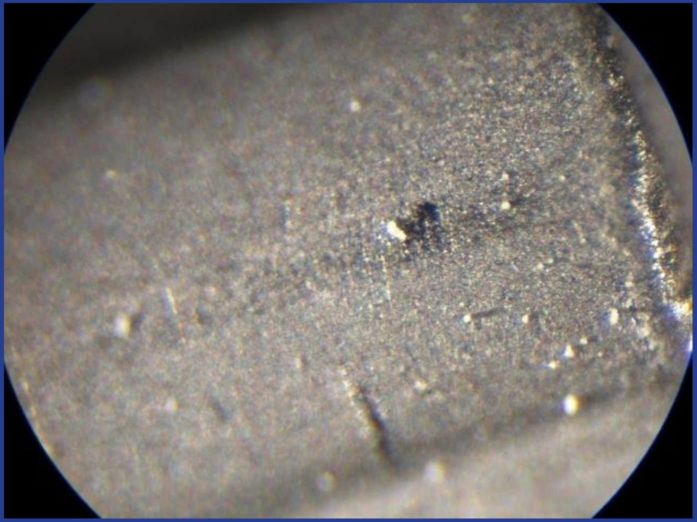
Graphite Fins DS

- Beam sigmas of 0.16mm, 0.22mm in x,y at 120GeV
- 180 pulses, 1.03e13 POT/pulse, 10us pulse
- Each fin is approx 2mm x 6mm x 25mm

1999 NuMI Test – Physical Inspection

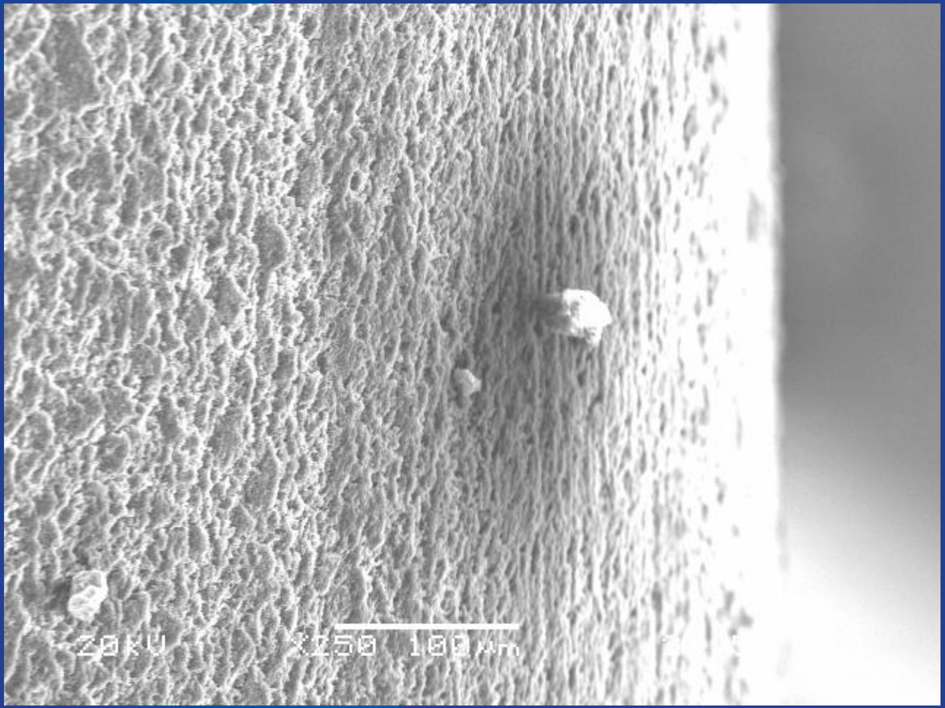
- Light microscope images show 'dark spot' on first fin, upstream side.
  - No marks on other upstream or downstream faces.

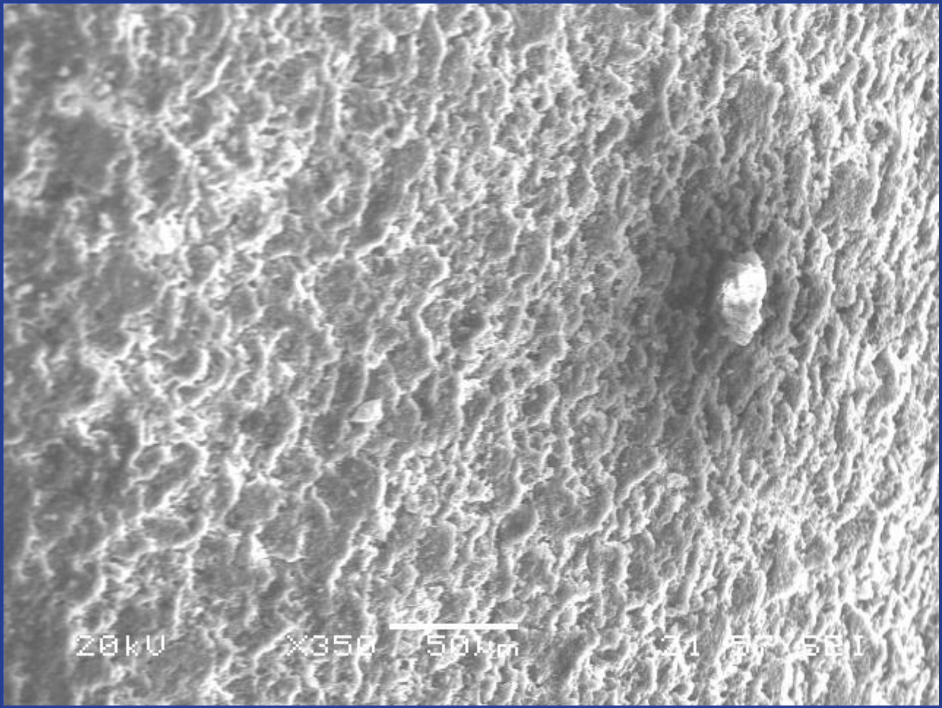




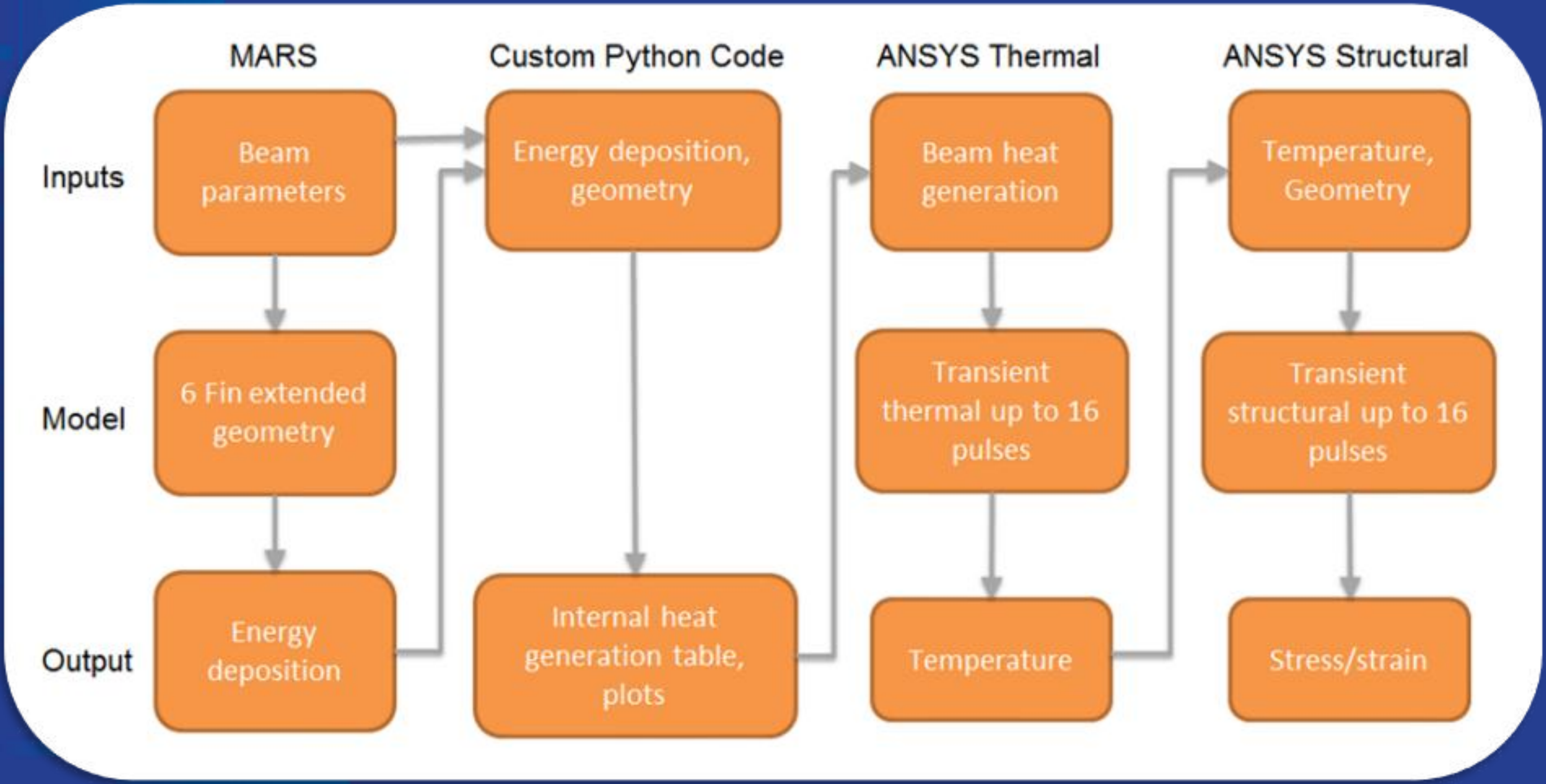
1999 NuMI Test – Physical Inspection

- SEM images of the spot (left).
  - Also found another spot (right) with similar discoloration.





1999 NuMI Test – Modeling



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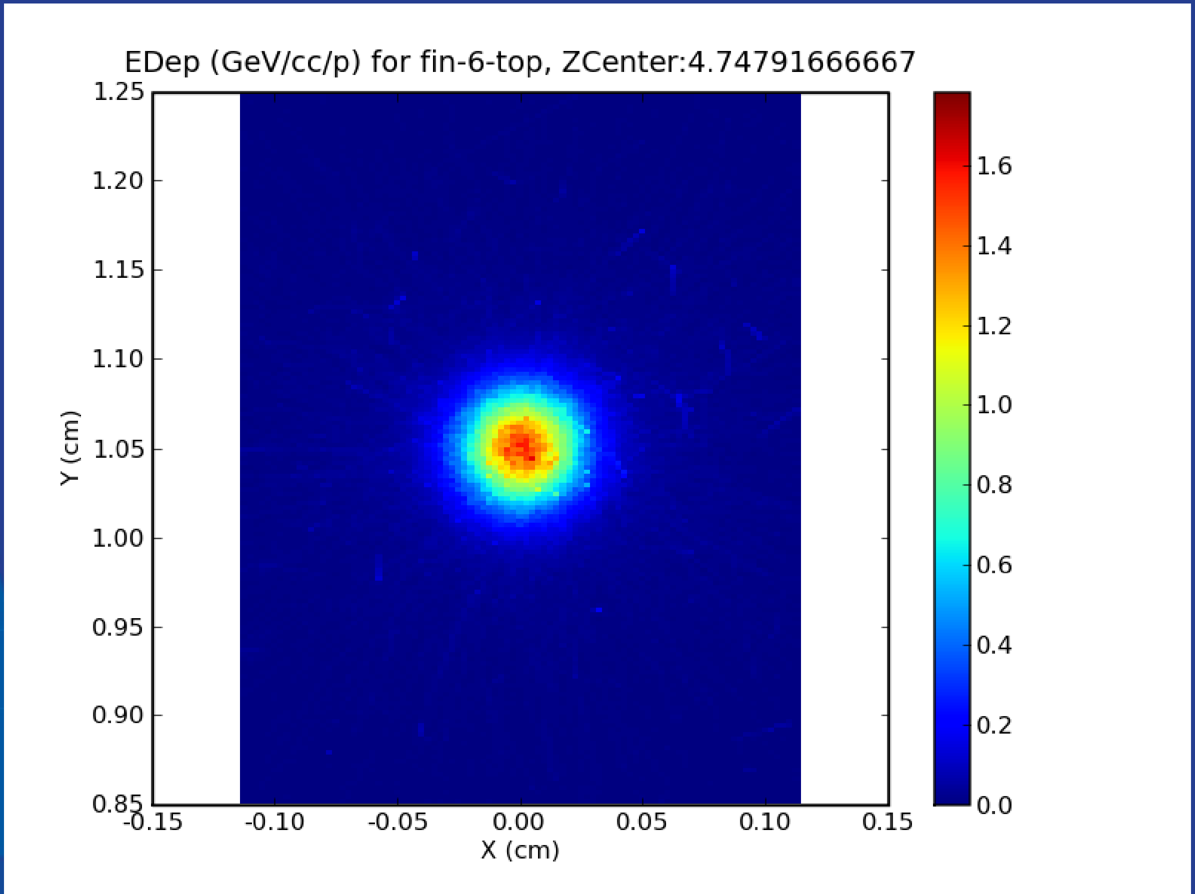
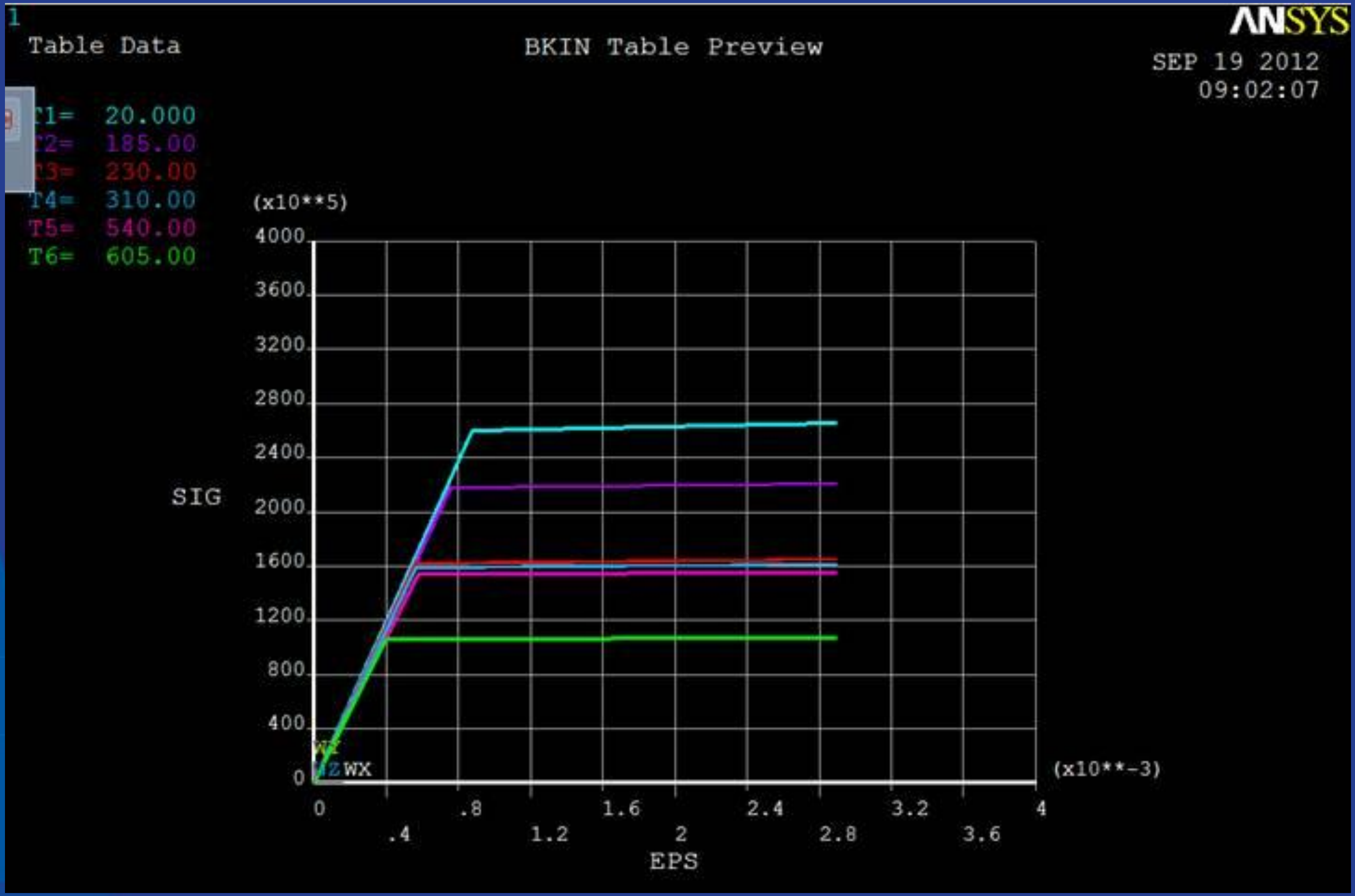
Output from MARS and Python Script

- Parse MARS output for energy deposition values.
- Build a list of locations and corresponding EDep.
- Generate ANSYS input tables and plots for verification.



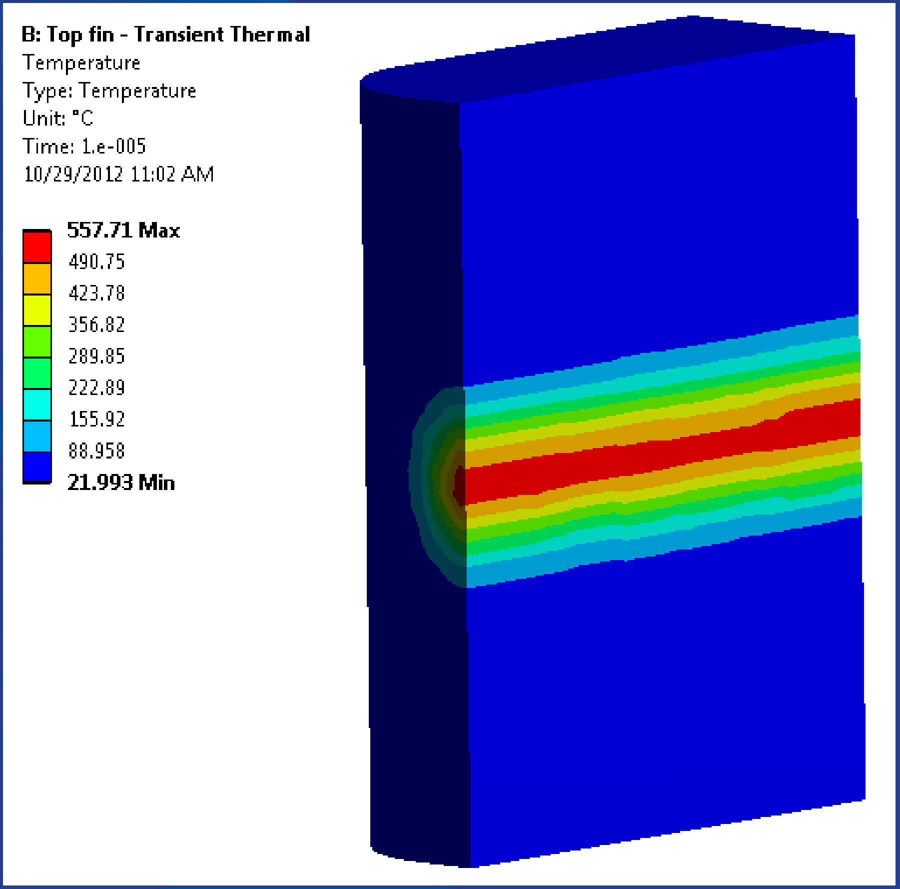
ANSYS Beryllium Material Properties

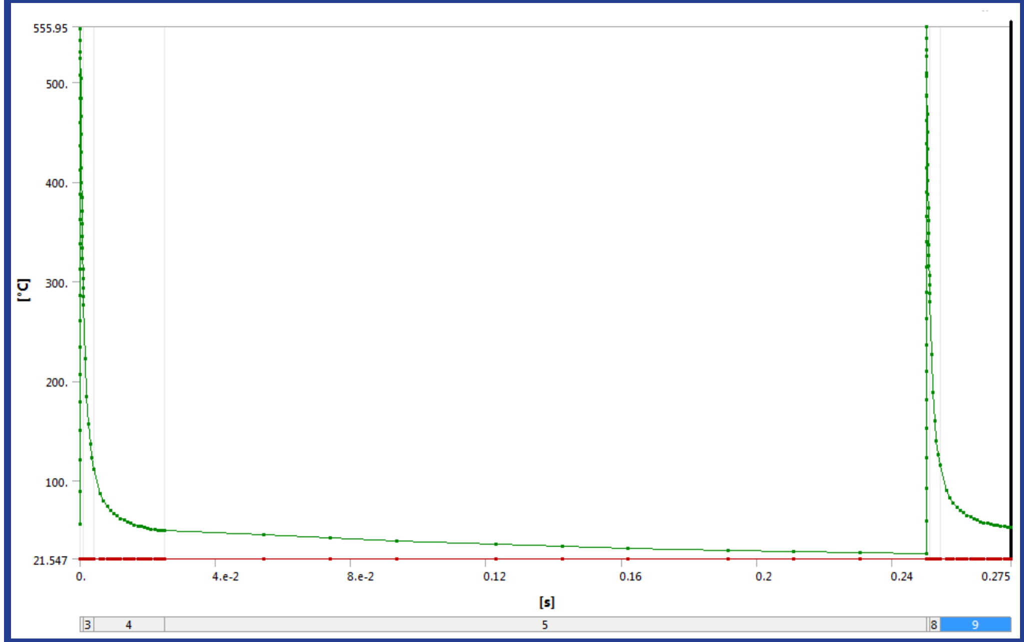
- Temperature dependent material properties used up to 600°C.
  - Bilinear Kinematic Hardening



1999 NuMI Test – ANSYS Thermal Modeling

- Temperature from MARS energy deposition results
  - Maximum temperature approximately 560°C.
  - Let fin cool to 20°C before next pulse. Times are not ‘real’.

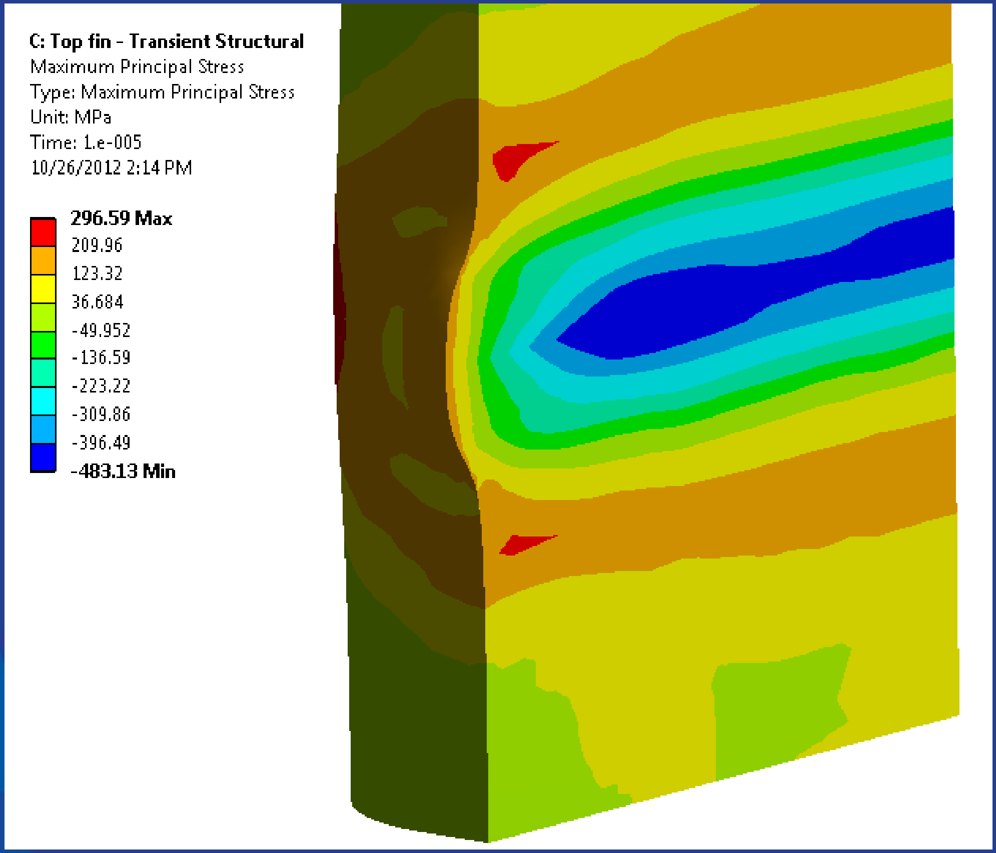




1999 NuMI Test - Modeling

- Maximum principal stress – typical views
  - Deformations shown at ~50x
  - Bulge is ~5μm high, 1mm in diameter after 16 pulses.

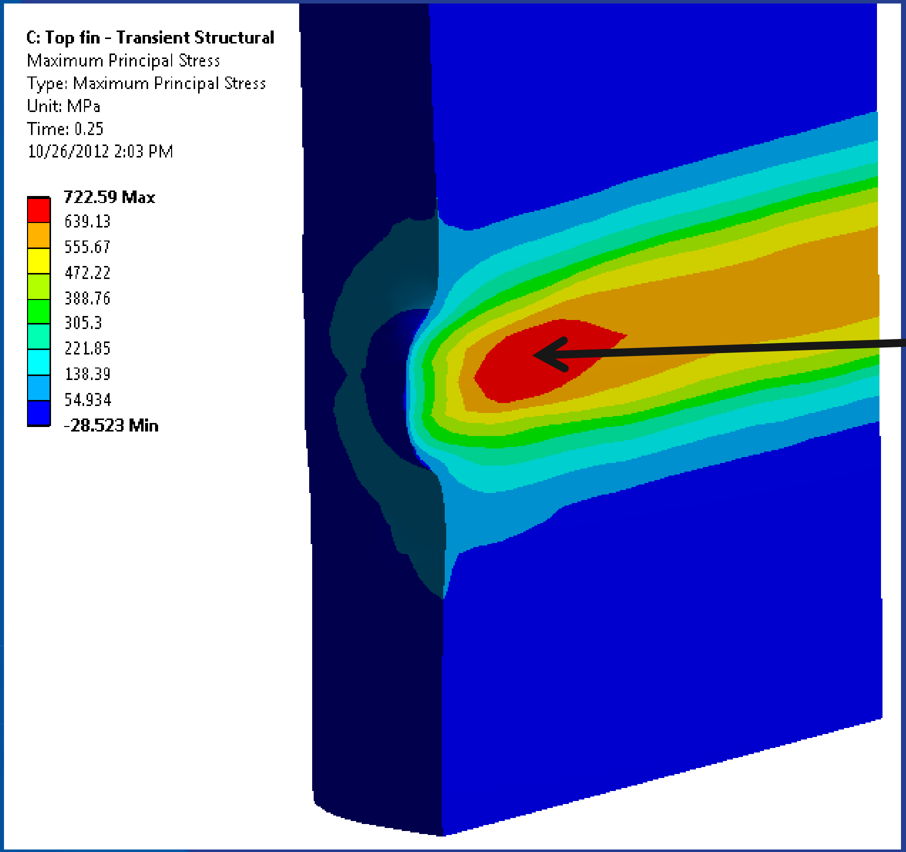
End of pulse – 560°C



1999 NuMI Test - Modeling

- Maximum principal stress – typical views

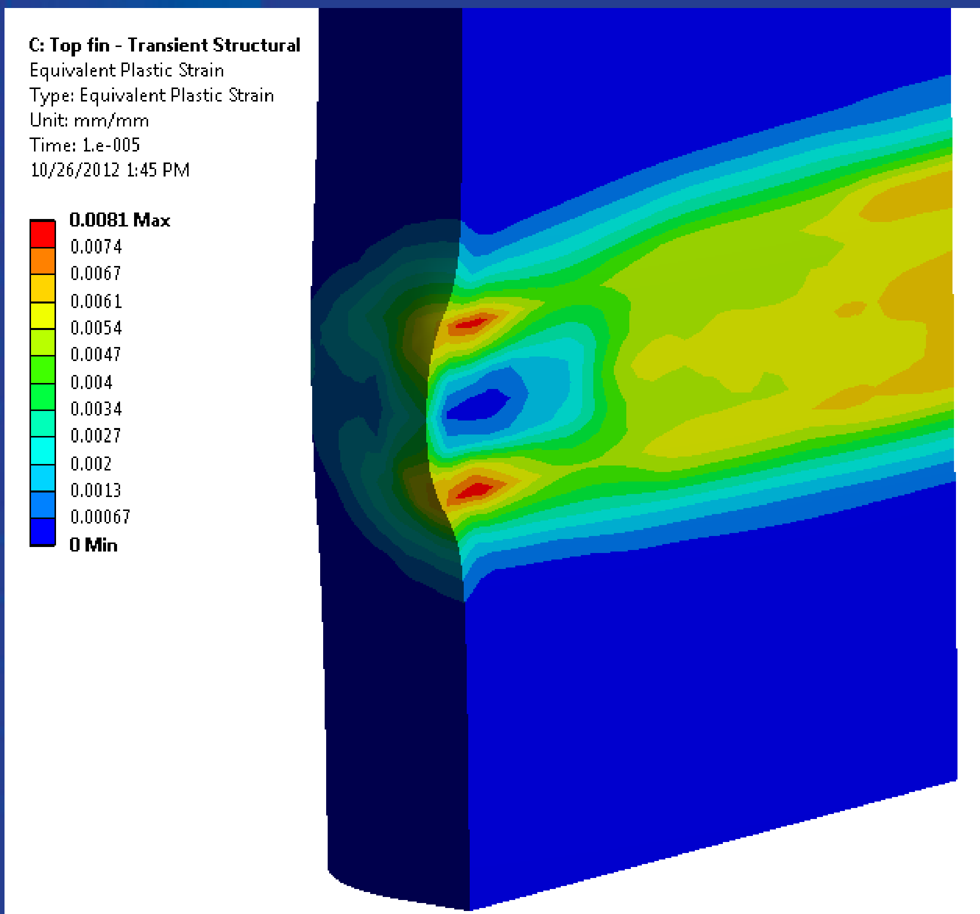
After cooldown to 22°C

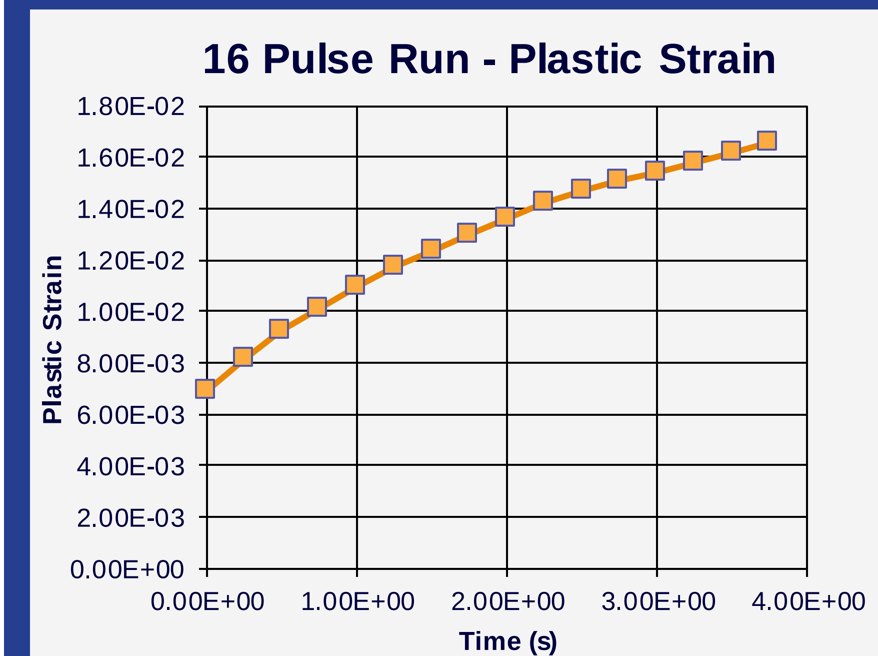


Large tensile preload for next pulse

1999 NuMI Test - Modeling

- Plastic strain – at end of 1st pulse



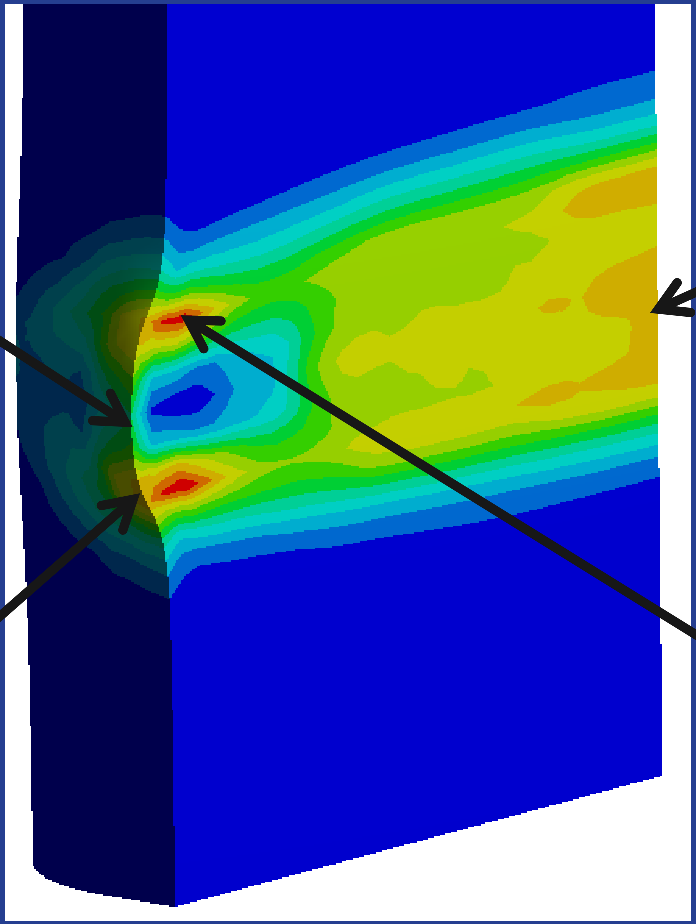


1999 NuMI Test - Modeling

- Estimates of life from plastic strain cycling:
  - Very conservative estimates from Coffin-Manson relation

Point of max displacement >1M pulses

Max plastic strain on surface: 18k pulses



Center of fin at beam center: 14k pulses

Global maximum plastic strain: 10k pulses

What's wrong here?

- Other Beryllium components have seen comparable beam for many more than 14,000 pulses without failure.

- Is thickness a factor?
  - Modeled a thin Be window (.5mm) and compared to a thick window (5mm used on Li lens).
  - Thin windows no not appear to fare better.

Areas for improvement

- Beryllium material properties
  - Strain rate dependency with temperature effects.
- Incorporating radiation damage
  - Lithium lens saw ~10M pulses, corresponds to 1DPA in beam center.
- Move to explicit dynamic simulation package
  - LS-DYNA, AUTODYN, etc
- Accurate failure mechanism
  - Need more data points with failures of Beryllium.
  - Any beryllium failures from audience?

Going forward

- Expand the NuMI test simulation to find number of pulses until plastic strain remains consistent.
- Sensitivity studies for NuMI test simulation:
  - Beam location, spot size, beam profile (gaussian, flat top, etc), fin geometry, simulation mesh size
- Look into the possible beryllium window failure in lithium lens.
- Ultimate goal:
  - Reliable prediction of Beryllium failure given beam parameters and geometry.

Thank you!