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

**MARS**
- Beam parameters
  - Model: 6 Fin extended geometry
  - Output: Energy deposition

**Custom Python Code**
- Energy deposition, geometry
  - Internal heat generation table, plots

**ANSYS Thermal**
- Beam heat generation
  - Transient thermal up to 16 pulses
  - Temperature

**ANSYS Structural**
- Temperature, Geometry
  - Transient structural up to 16 pulses
  - Stress/strain
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
Plastic strain - end of pulse 1

Plastic strain vs time at maximum point

1999 NuMI Test Modeling Results - 3
Estimates of life from plastic strain cycling using the 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
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
MARS Results

Fins of interest: 6, 10, 17, 30

Used the energy deposition in these fins as the input for ANSYS thermal runs
MARS $\Delta T$ Prediction - Fin 6

Max $\Delta T$: 115°C
MARS $\Delta T$ Prediction - Fin 10

Max $\Delta T$: 108°C

Temperature Rise (C) as a function of $X$ (cm) and $Y$ (cm)
MARS $\Delta T$ Prediction - Fin 17

Max $\Delta T$: 91°C
MARS $\Delta T$ Prediction - Fin 30

Max $\Delta T$: 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

Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 3/28/2013 10:22 AM

Max 223.7
198.87
174.84
149.12
124.37
99.54
74.707
49.875
25.052
0.21001 Min
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?