Graphite/Carbon-Carbon Composite Target R&D

Neutrino Factory and Muon Collider Collaboration
Targetry R&D Meeting

Dec. 15, 2000

Brookhaven National Laboratory

Tandem Library, Bldg 901A

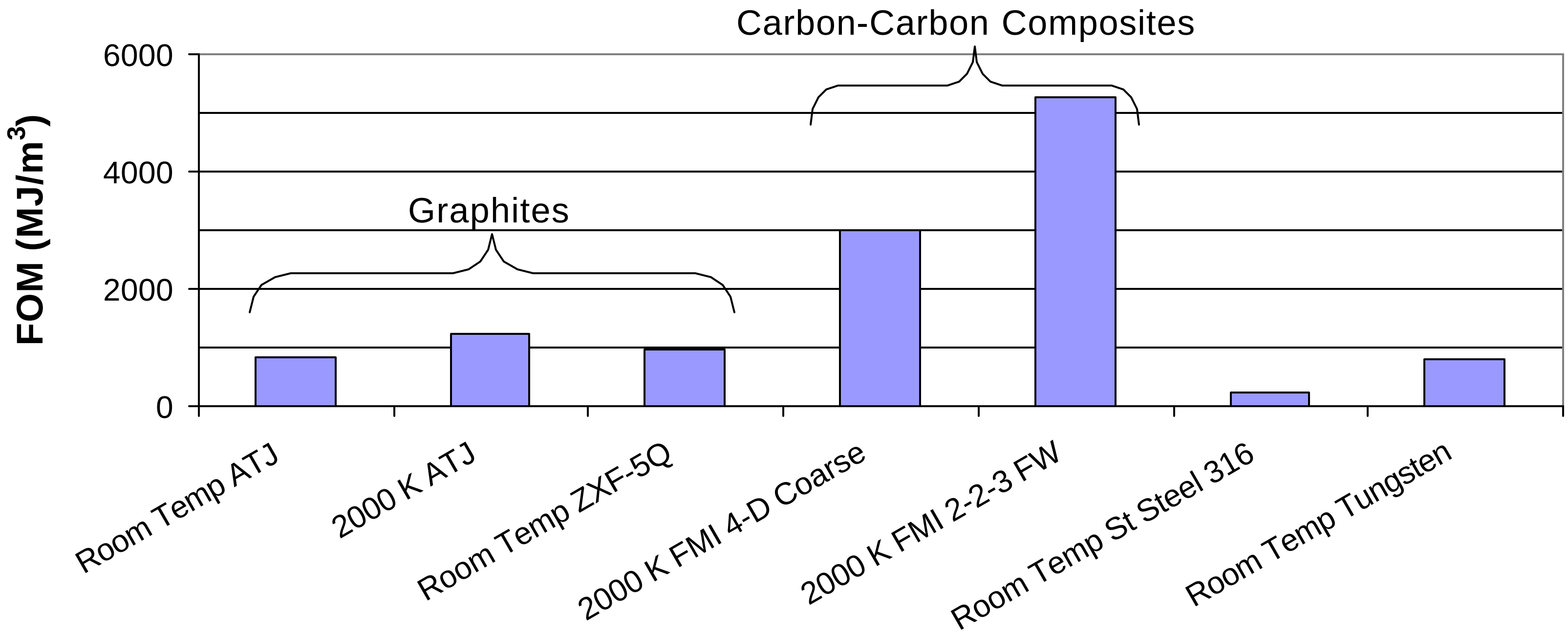
John Haines

R&D Will Address Two Key Issues for Graphite Targets

- Thermal Shock
  - Results from August 2000 WNR tests
  - Instrumentation for AGS tests
  - Test plan
- Sublimation
  - Test chamber
  - Test plan

Thermal Shock Resistance of Graphites and C-C Composites Is Excellent

Figure of Merit (FOM) = (density * specific heat * strength) / (thermal expansion coefficient * Young's modulus)



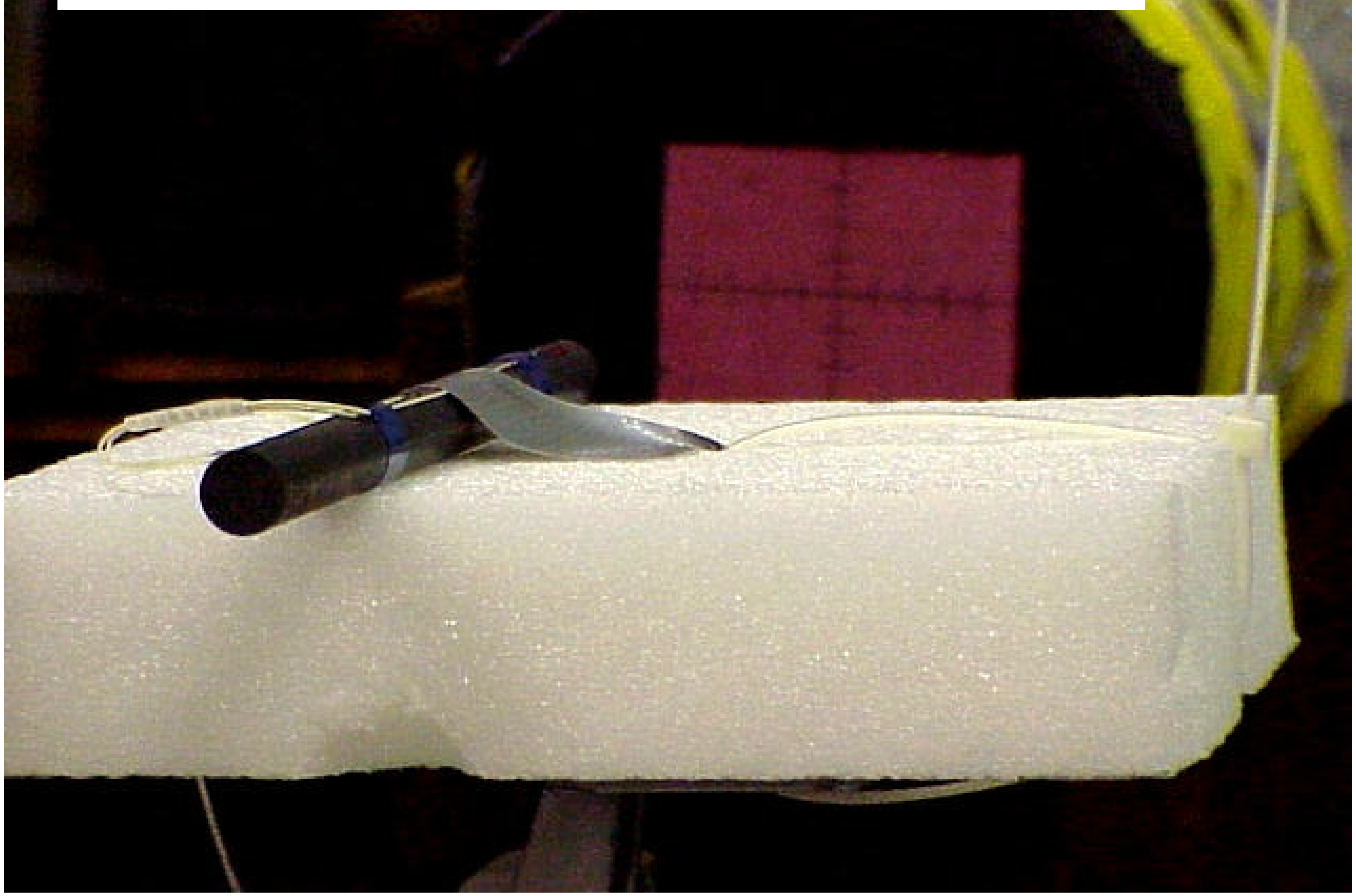
In this application carbon-based materials are even better since the heating/volume in carbon << heating/volume in W

Comparison of Thermal Shock Conditions

	WNR Tests	Proposed AGS Tests	Proposed AGS Tests	Neotrino Factory 1 MW	Neotrino Factory 4 MW
Proton energy (GeV)	0.8	24	24	16	16
Protons per pulse	2.8E+13	1.5E+13	1.5E+13	2.5E+13	1.0E+14
Gaussian Beam Sigma (mm)	10	1	3	3	3
Peak energy density (MJ/m^3)	3.1	350	75	11	44
Peak microstrain	16	835	-	-	-
Peak Stress (MPa)	0.13	7.5	-	-	-

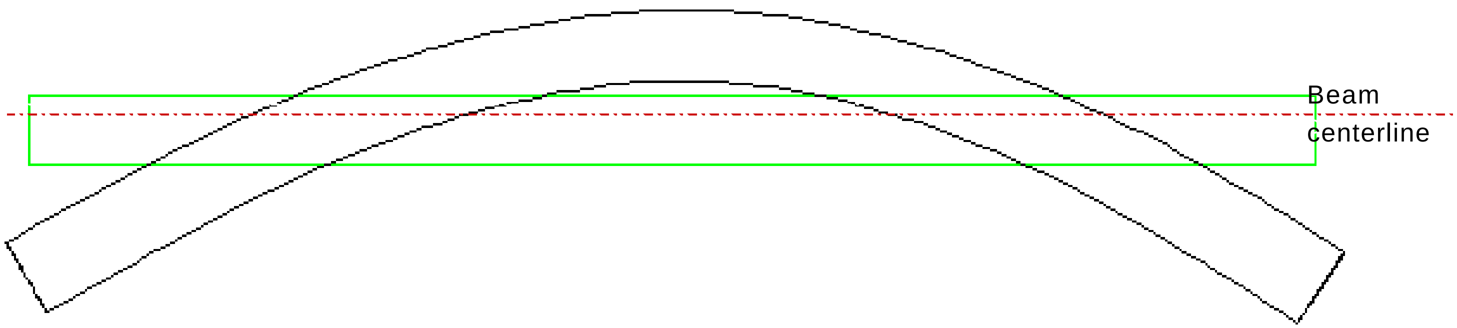
ATJ Graphite Strains Were Measured for Single Pulse Tests at LANSCE/WNR

- WNR proton beam (σ ~ 10 mm radius) centered at r = 4.9 mm on 8.0 mm radius ATJ graphite rod



Optical strain sensor technique was validated on simple graphite rod test

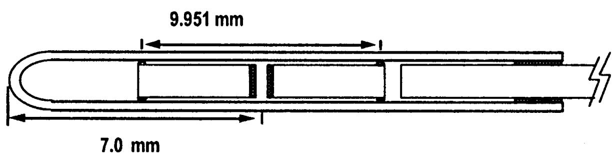
- WNR proton beam (σ ~ 10 mm radius) centered at r = 4.9 mm on 8.0 mm radius ATJ graphite rod
- Deflection at 12 ms amplified by 10^4



Optical Strain Gages Can Be Used in This Severe Environment

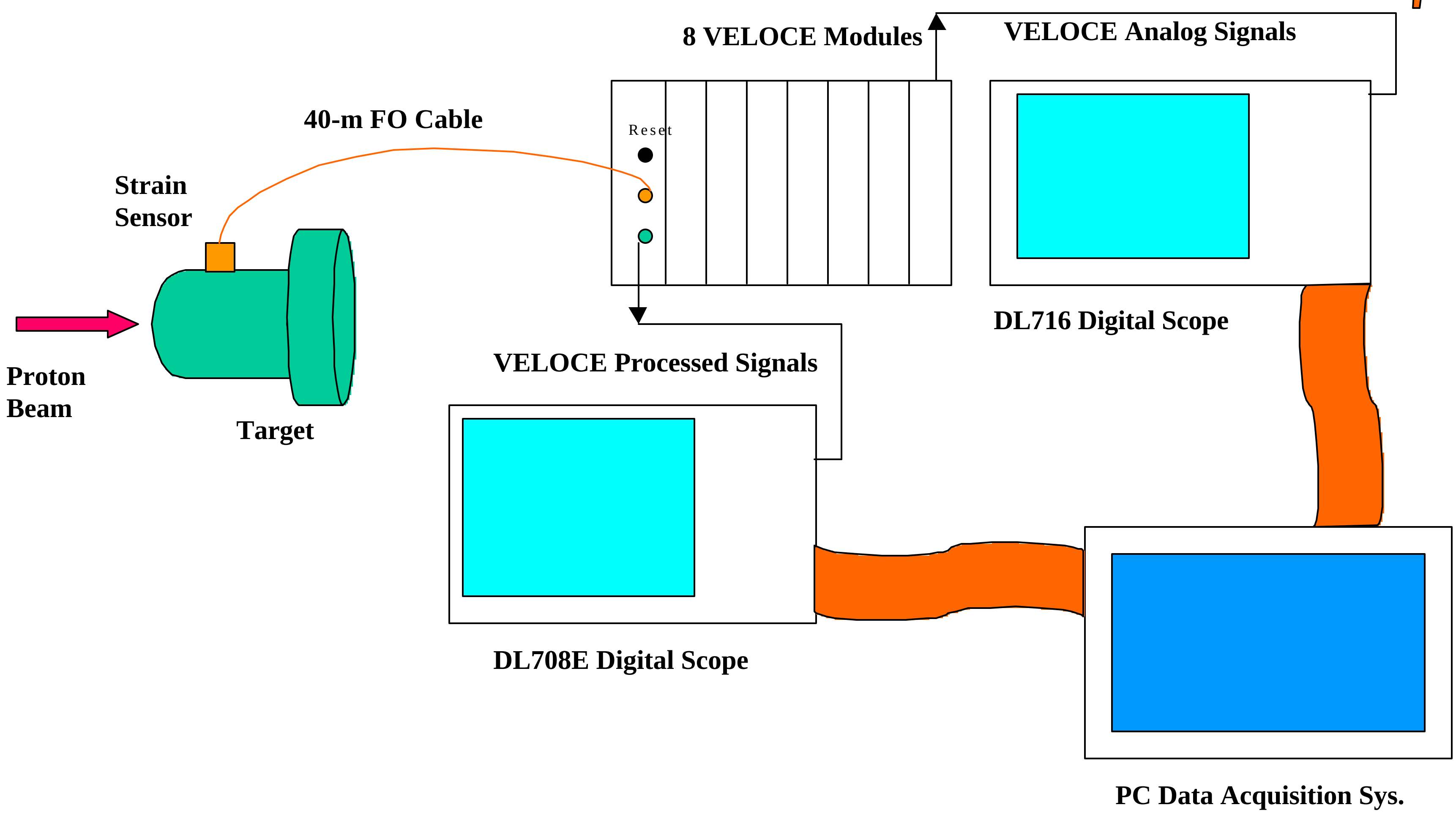
- Strain gauges based on miniaturized Fabry-Perot interferometer concept
  - Gauge length of a few millimeters
- Gauge is mounted on surface of interest
- Broadband light source centered at 860 nm wavelength reflects from two surfaces and two reflected signals analyzed by white light interferometry to produce two phase-related signals
- Interference fringes and calibration tracked by phase relationships of signals

Fiso Technologies' Fiber Optic Strain Gauge

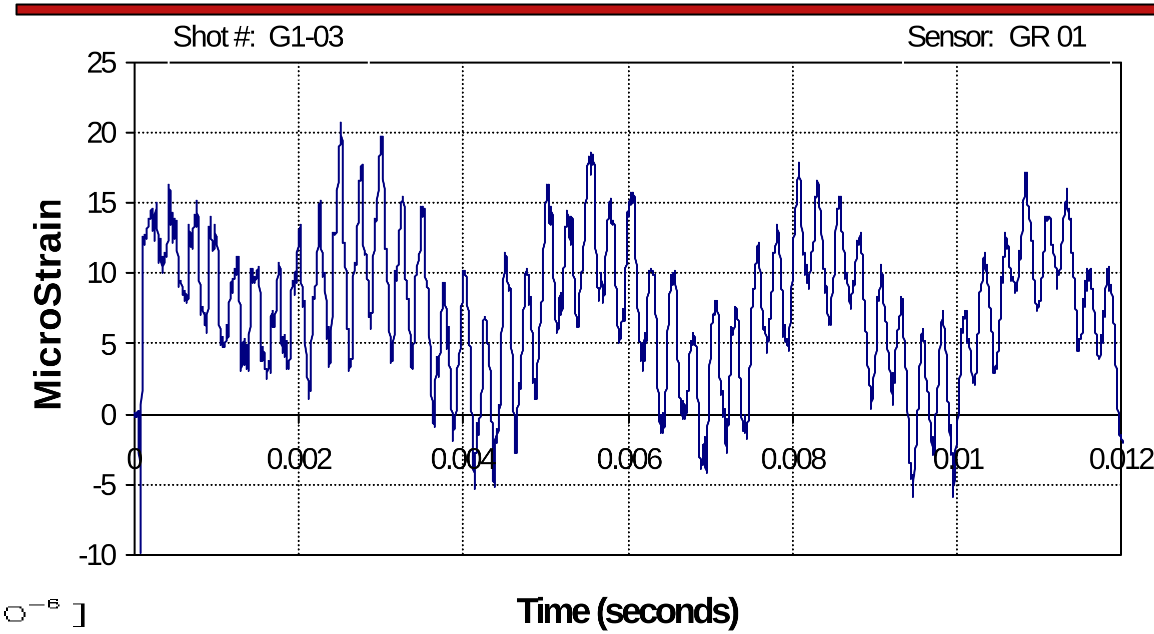


TYPE : NON-COMPENSATED
RANGE : -600 με to 600 με
GAGE FACTOR : N-1009951

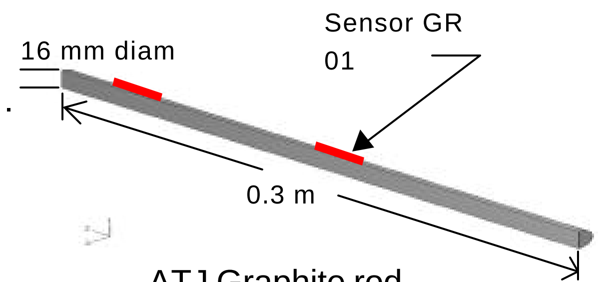
Strain Measurement System

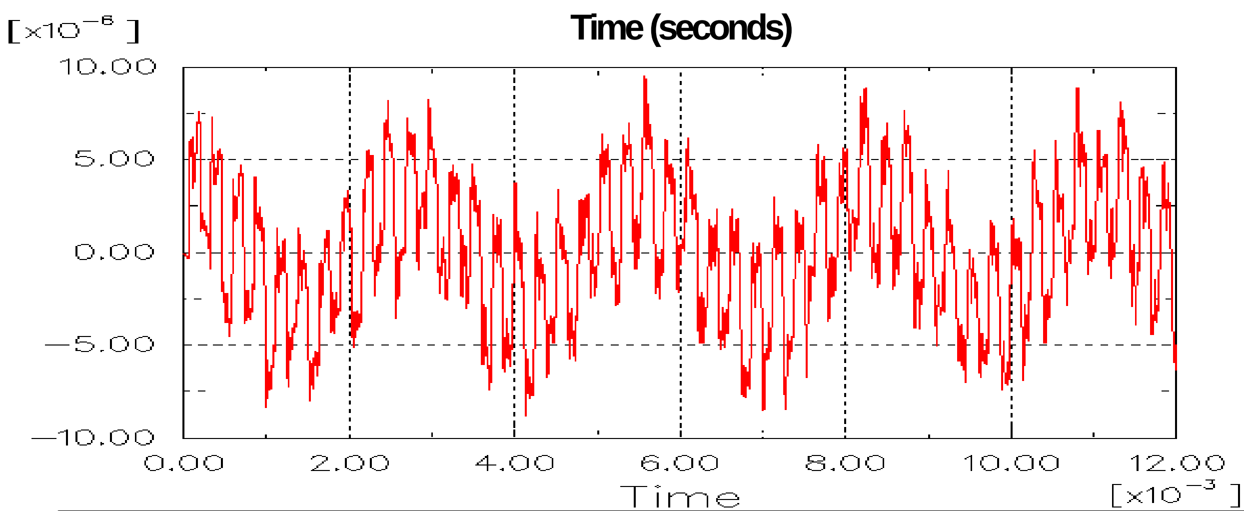


Measured Strained Data Agrees With Predictions



Measured data

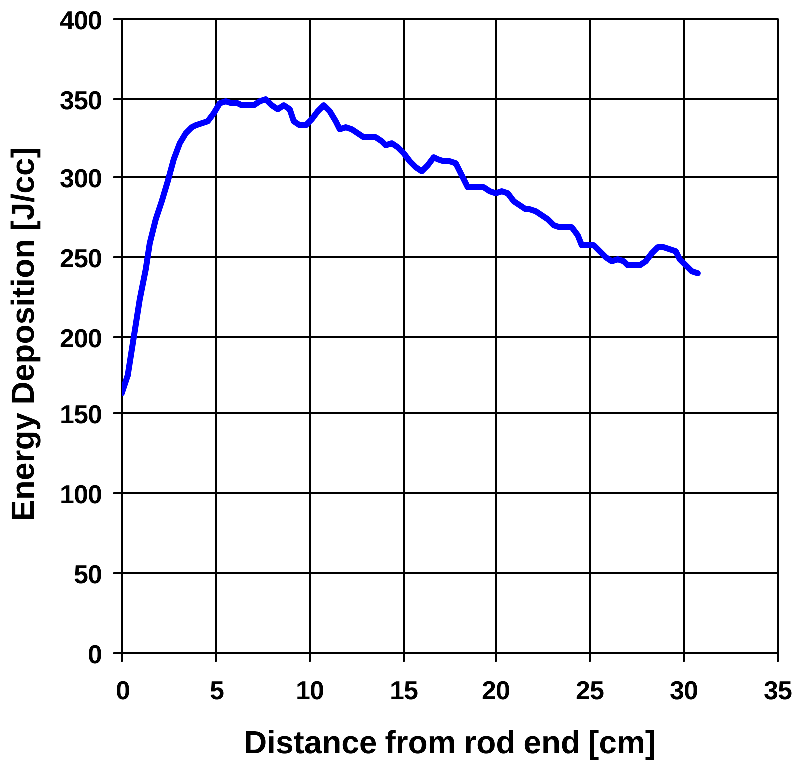




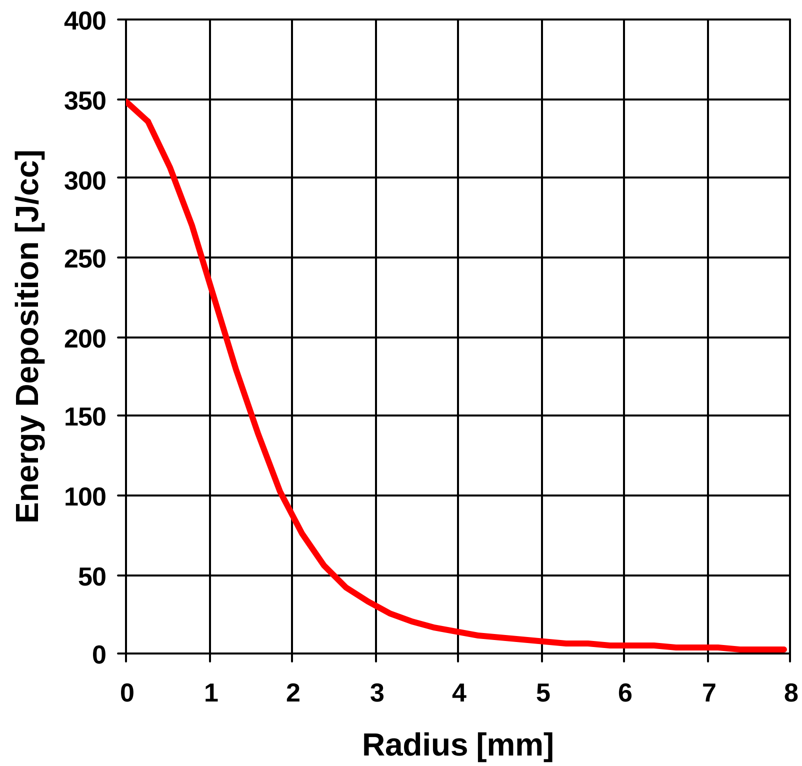
Calculation

1st bending mode from 1D modal analysis = 348 Hz

Energy Deposition in ATJ Graphite Rod
1.5 x 10^{13}, 25 GeV protons, s=1 mm



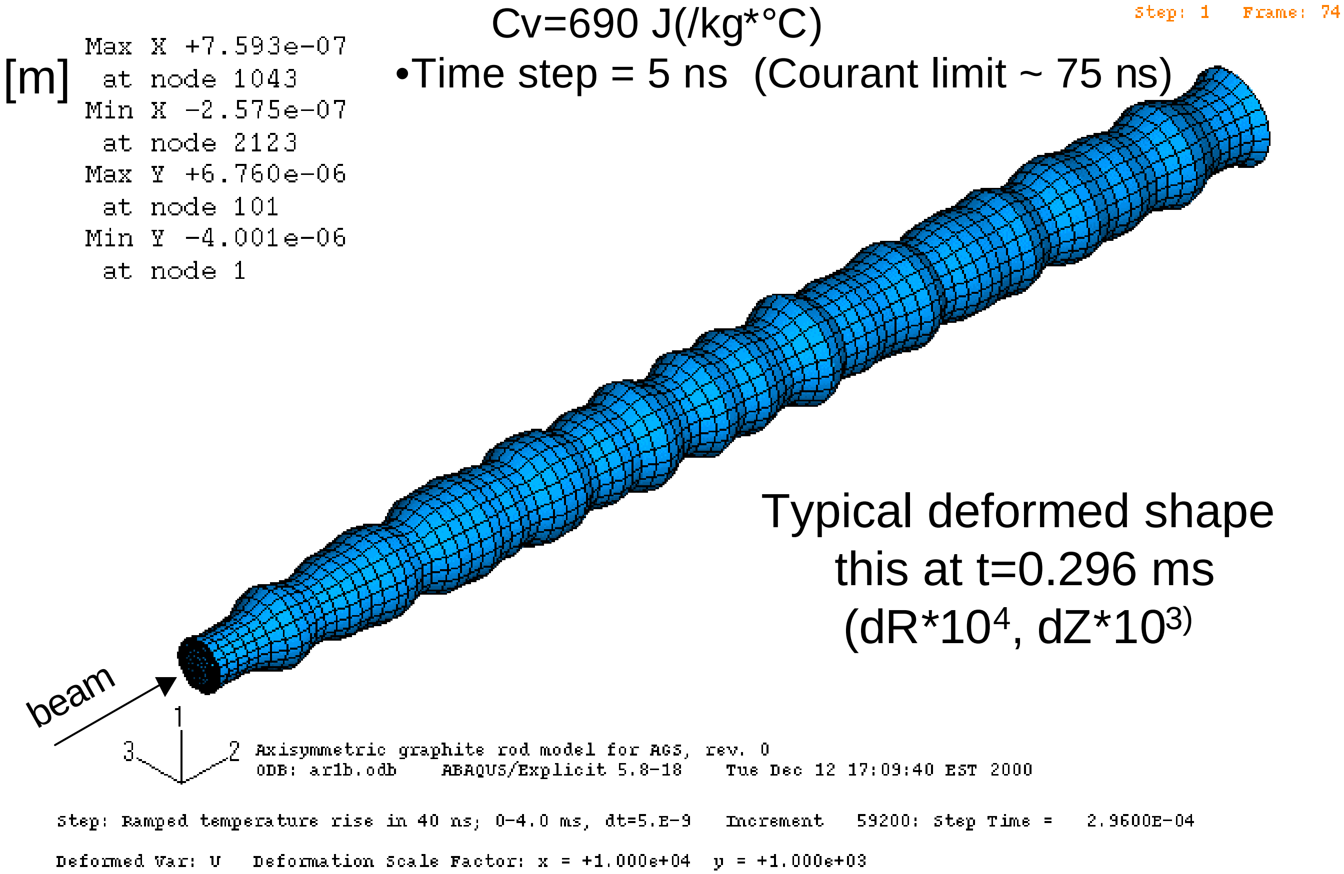
Energy deposition vs. length along rod axis



Energy deposition vs. radius at Z=5.5 cm

Axisymmetric Simulation of Graphite Rod Energy Deposited in 40 ns

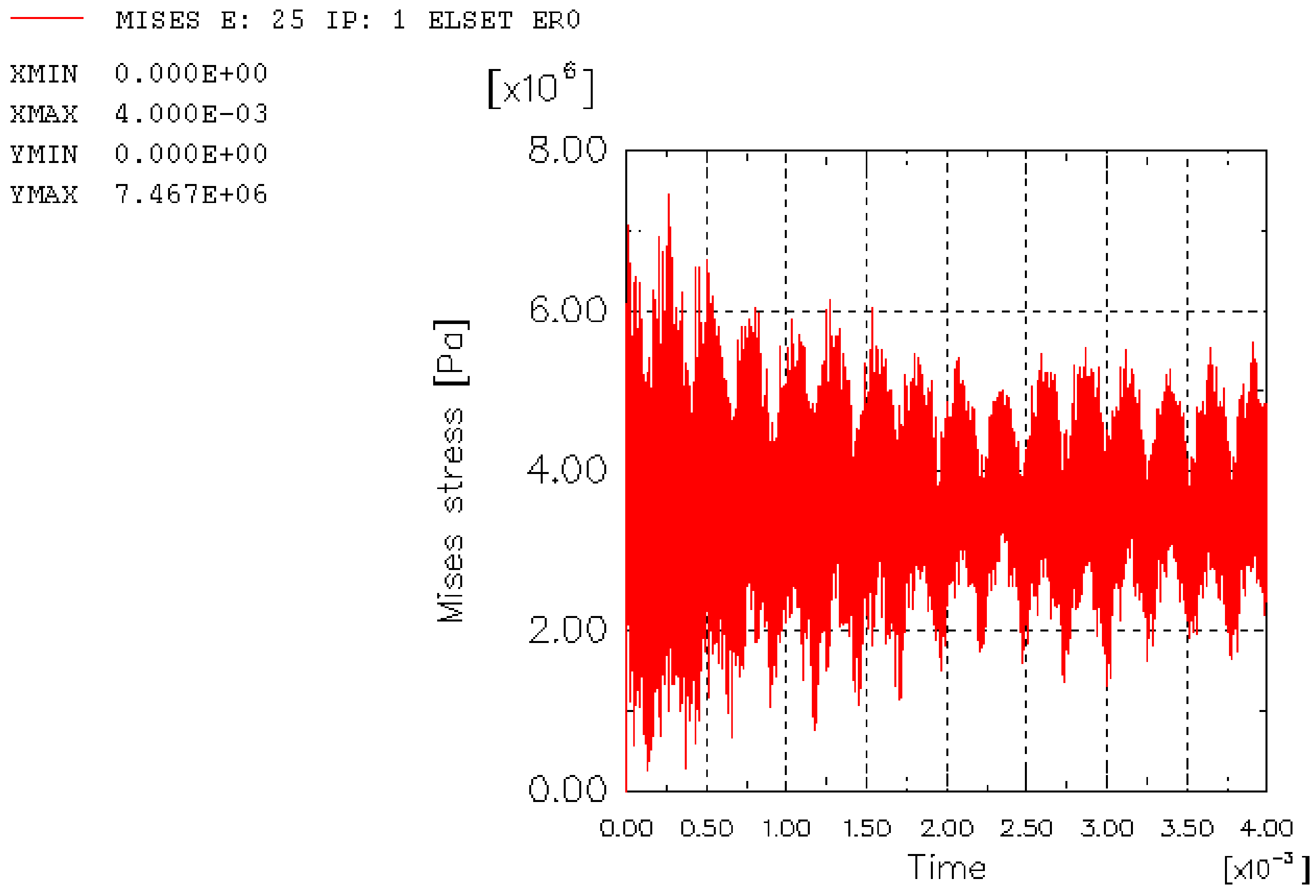
- ATJ graphite rod axisymmetric model
- Isotropic properties used:
  - E=9.6 GPa, ν=0.13,α=2.46e-6/°C, ρ=1.73 gm/cc
  - Cv=690 J(/kg*°C)
- Time step = 5 ns (Courant limit ~ 75 ns)



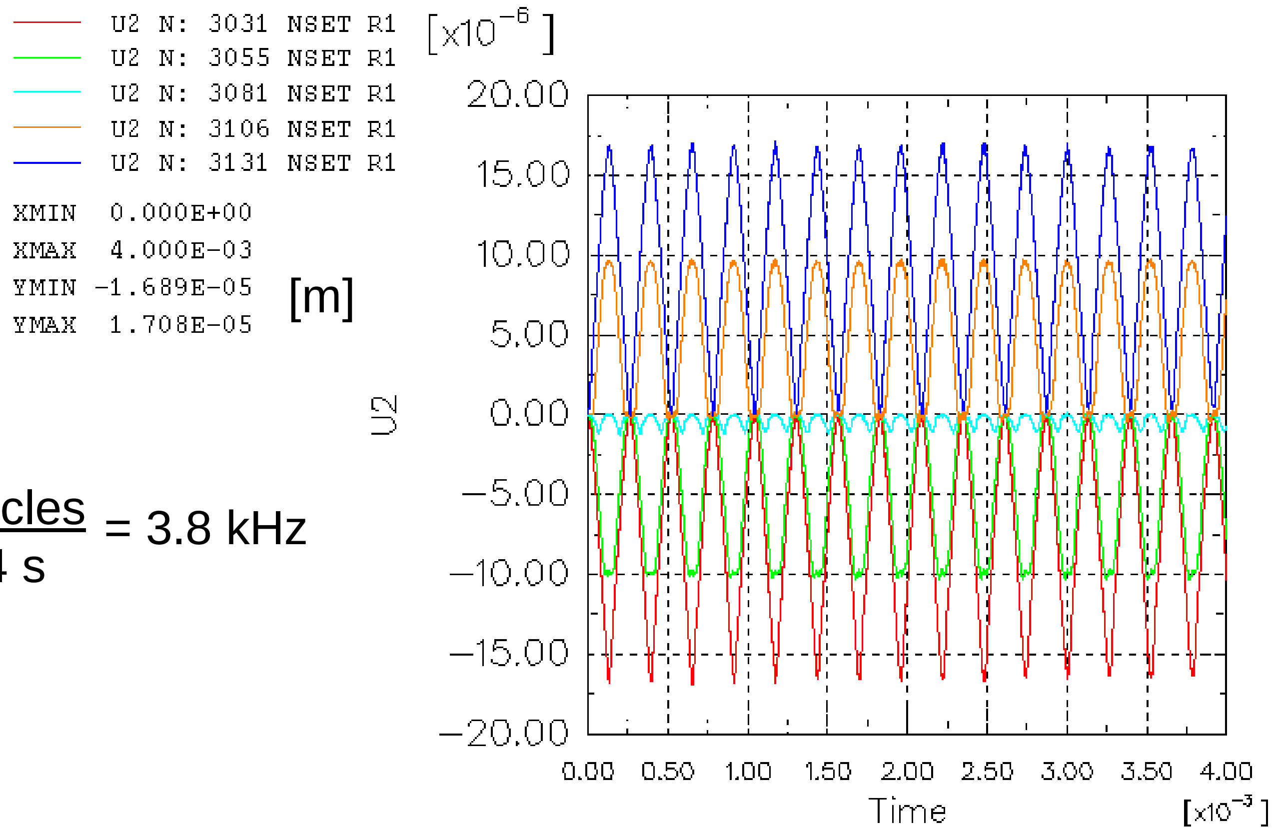
Typical deformed shape this at t=0.296 ms ($dR*10^4$, $dZ*10^3$)

Von Mises Stress at Element Near Location of Maximum Energy Deposition

Maximum stress < 10 MPa



Axial Displacement of 5 Equally Spaced Nodes Along Surface.



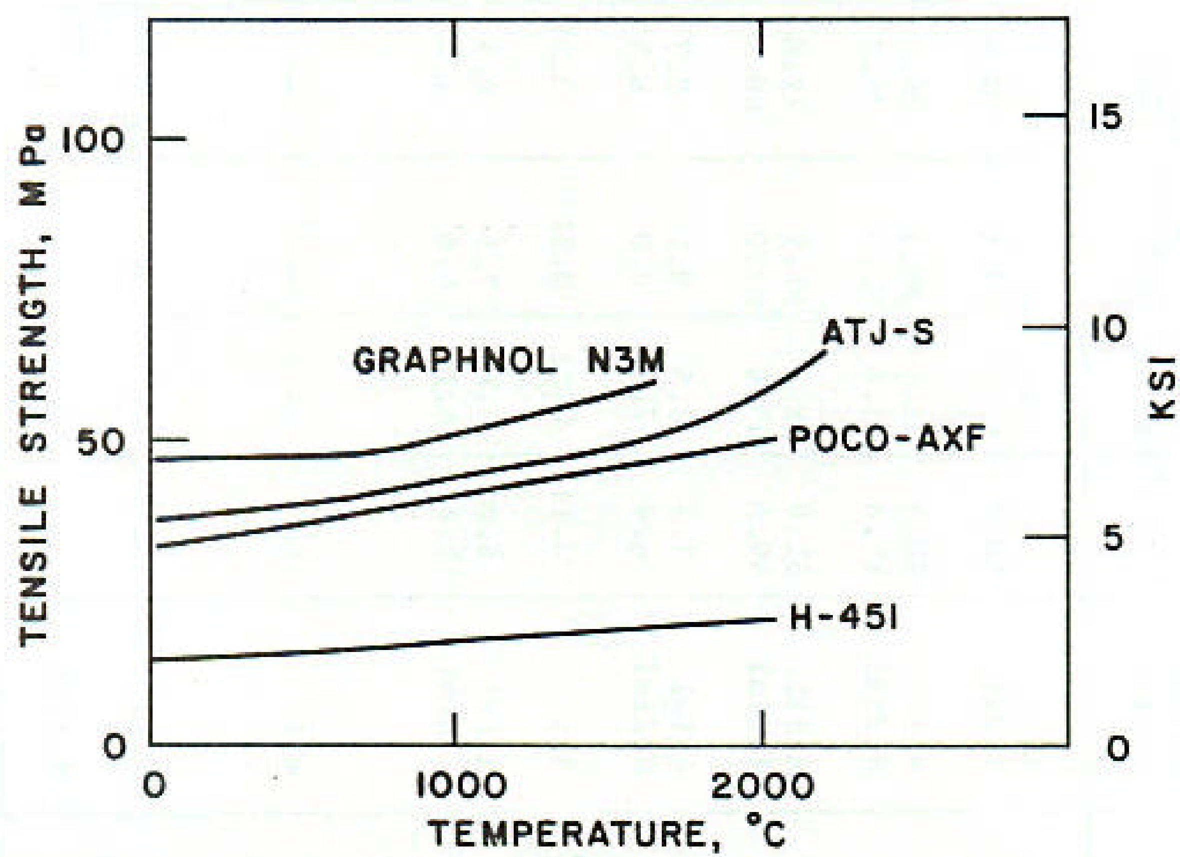
$$\frac{\text{15.2 cycles}}{\text{0.004 s}} = \text{3.8 kHz}$$

The longitudinal wave speed (uniform bar) is $c=(E/\rho)^{1/2}$ = 2356 m/s. The time for a wave to traverse the rod length is (0.3073 m)/(2356 m/s) = 130 µs, or 7666 hz. For the wave to reflect and traverse the length again, the frequency is 3833 hz

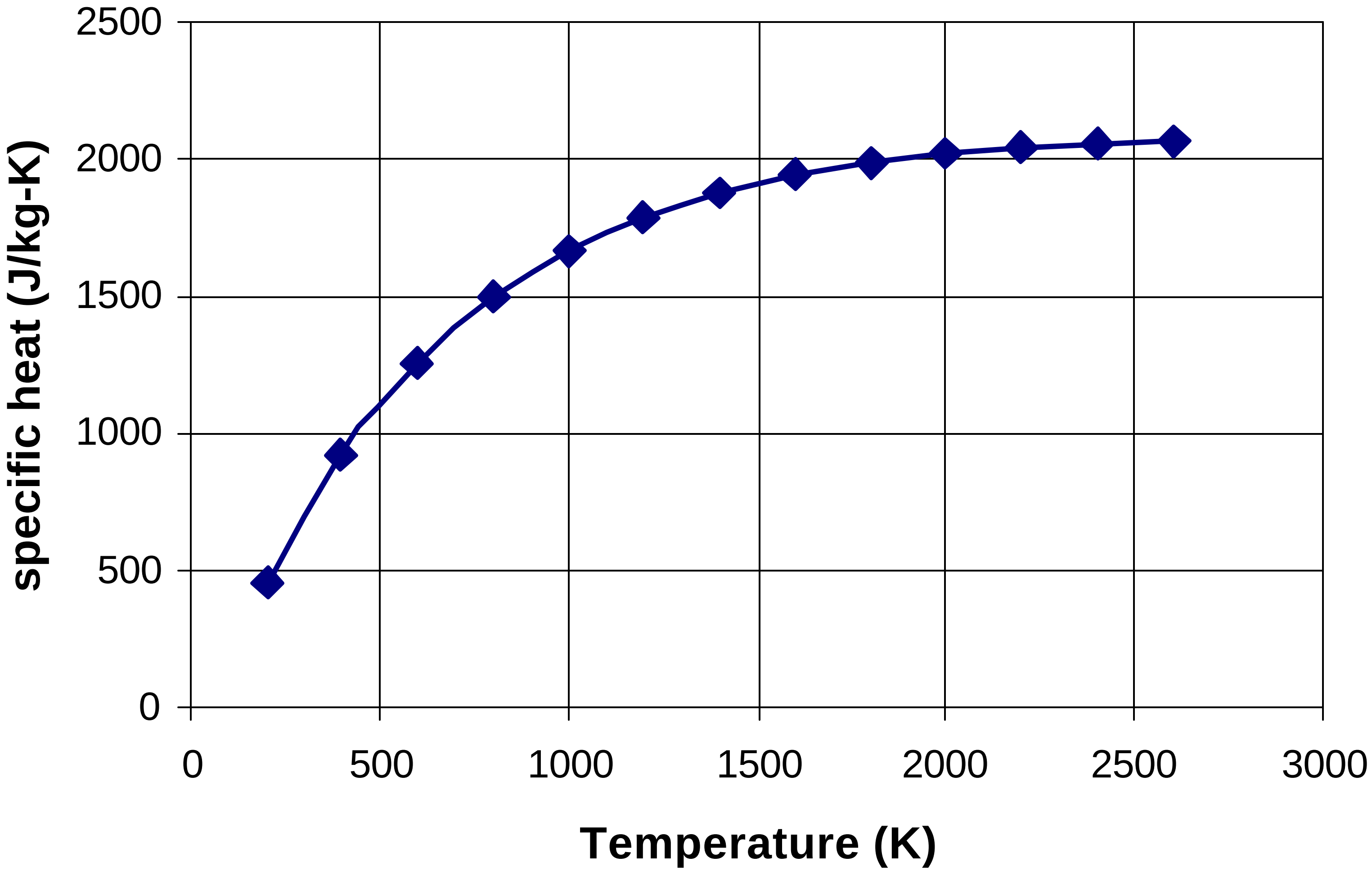
Thermal Shock Tests Should Be Conducted at Low Temperature

- Survival at room temperature ensures survival at high temperature
  - Strength and thermal shock resistance of graphite and C-C composites increases with temperature (very large increase in specific heat)
- Targets can be instrumented at low temperatures
  - Strains can be measured and models benchmarked
- High temperature tests are significantly more difficult
  - Vacuum chamber with heated samples in beam line

Graphite Becomes Stronger at Temperatures Up To ~ 2600 ºC



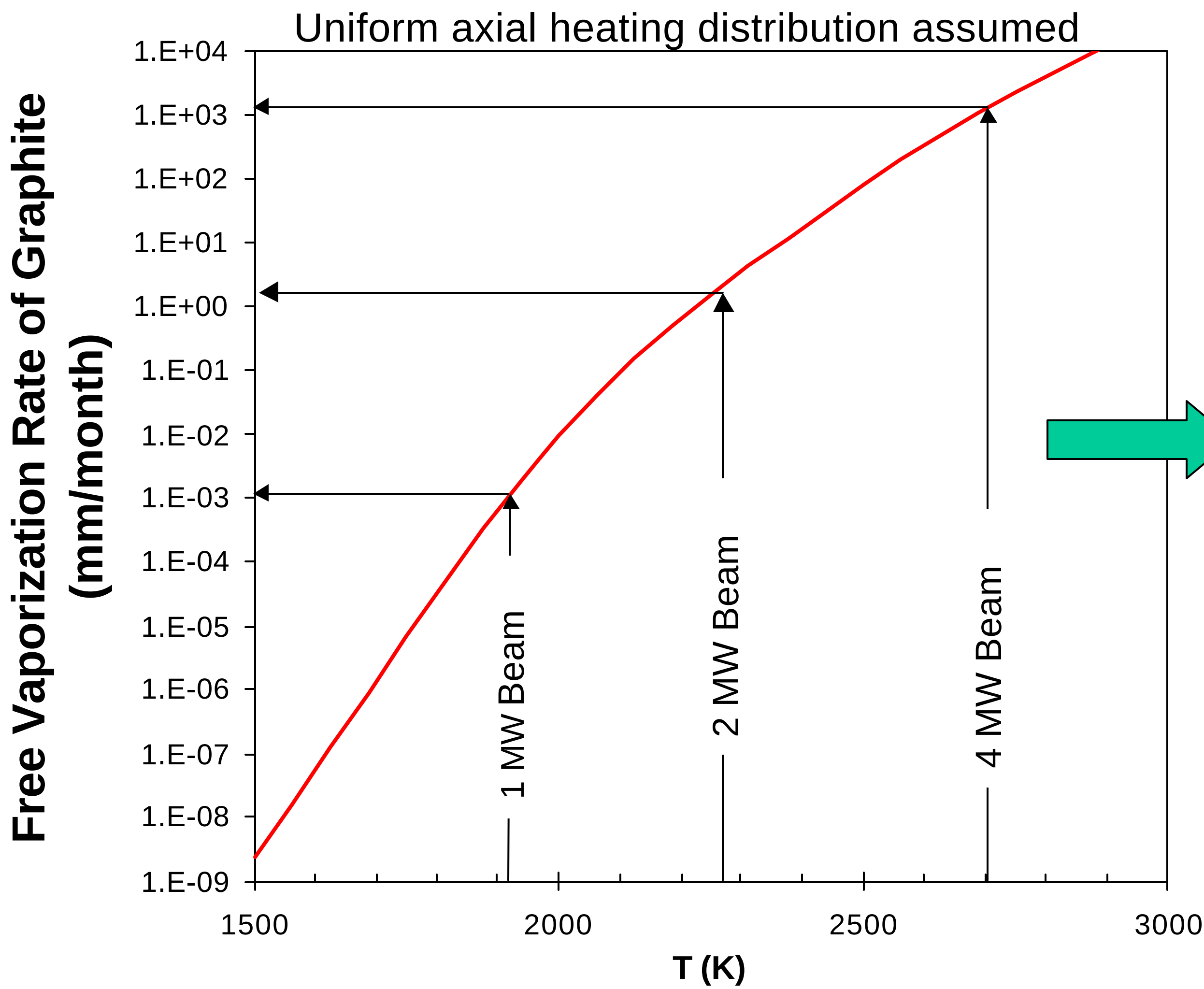
Temperature Rise Is Much Smaller with Graphite at Operating Temperature



Thermal Shock Test Plans

- Conduct tests with a graphite rod and a carbon-carbon rod
  - Graphite: 15 mm diameter, 0.3 m long
  - Carbon-carbon composite: As close to graphite size as possible within cost and schedule constraints
- Install eight optical strain sensors on each rod
  - Two at the front (180º apart), two in the back (180º apart) and four in the middle (90º apart)
  - All sensors oriented axially (radius of curvature too small for circumferential mounting)
- Install rods inside a simple secondary container
- Use 40 m long fiber optic cables
- Will someone measure beam profile?

Sublimation Must Be Inhibited to Achieve Reasonable Lifetimes for Radiatively Cooled Carbon Target



Sublimation rate in vacuum is excessive for beam powers > 1 MW

Use of He Atmosphere Is Proposed to Inhibit Carbon Sublimation

- Presence of helium reduces graphite sublimation
- Heat transport is still mainly by radiation
  - Conduction/convection heat transfer through helium is relatively insignificant
- Net erosion of graphite is limited by convection/diffusion of carbon from hot graphite to cooled vessel
- Tests required to validate approach and obtain quantitative data

Carbon Sublimation Test Plan

- Modify existing chamber for tests Dec ‘00- Jan 10 ‘01
- Fabricate heater/specimens Dec ‘00- Jan 10 ‘01
- Perform tests Jan 10 - April 9 ‘01
- Issue report April 23 ‘01

<table>
<tr><td rowspan="4">ATJ Graphite</td><td rowspan="2">Vacuum</td><td>2000 K</td></tr>
<tr><td>2300 K</td></tr>
<tr><td rowspan="2">1 atm He</td><td>2000 K</td></tr>
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<tr><td rowspan="4">C-C Composite</td><td rowspan="2">Vacuum</td><td>2000 K</td></tr>
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Carbon Sublimation Test Chamber