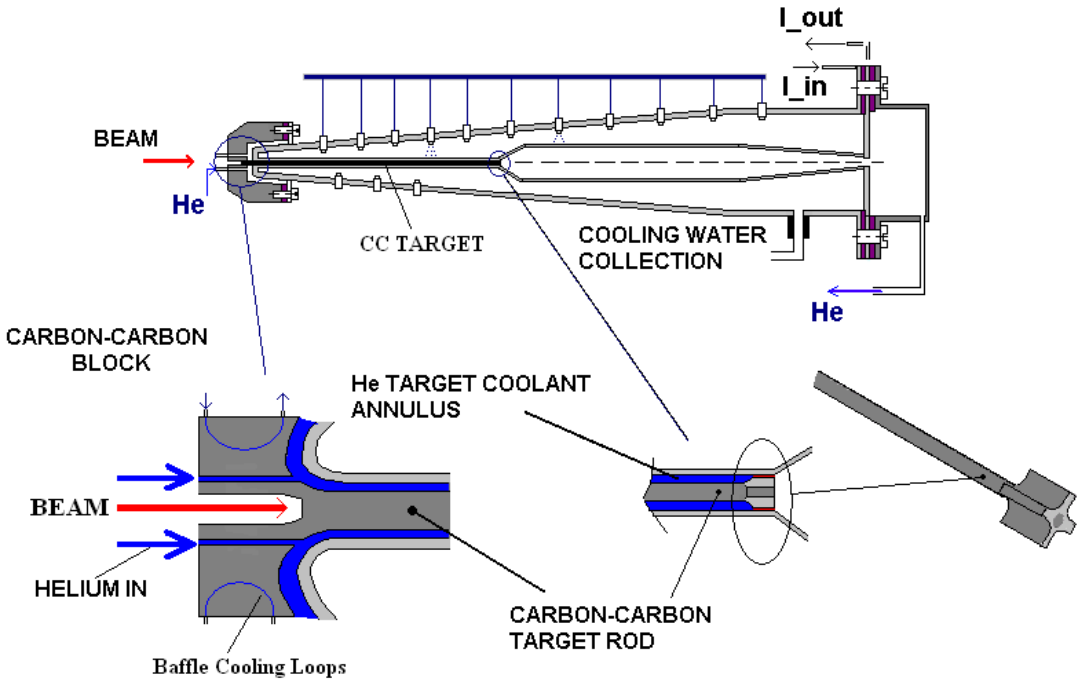
High Power Target R&D

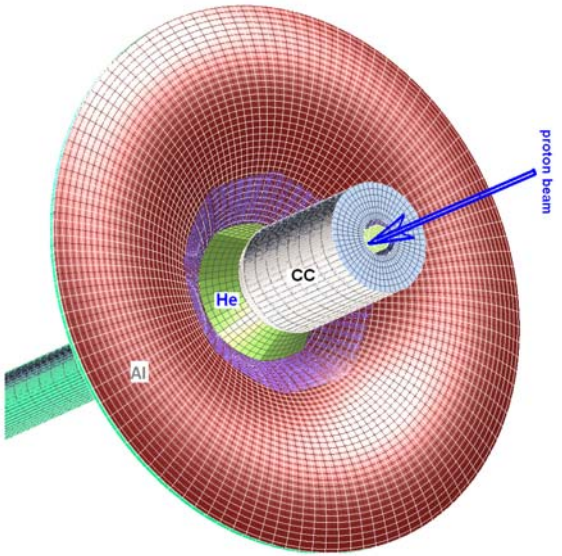
N. Simos, BNL

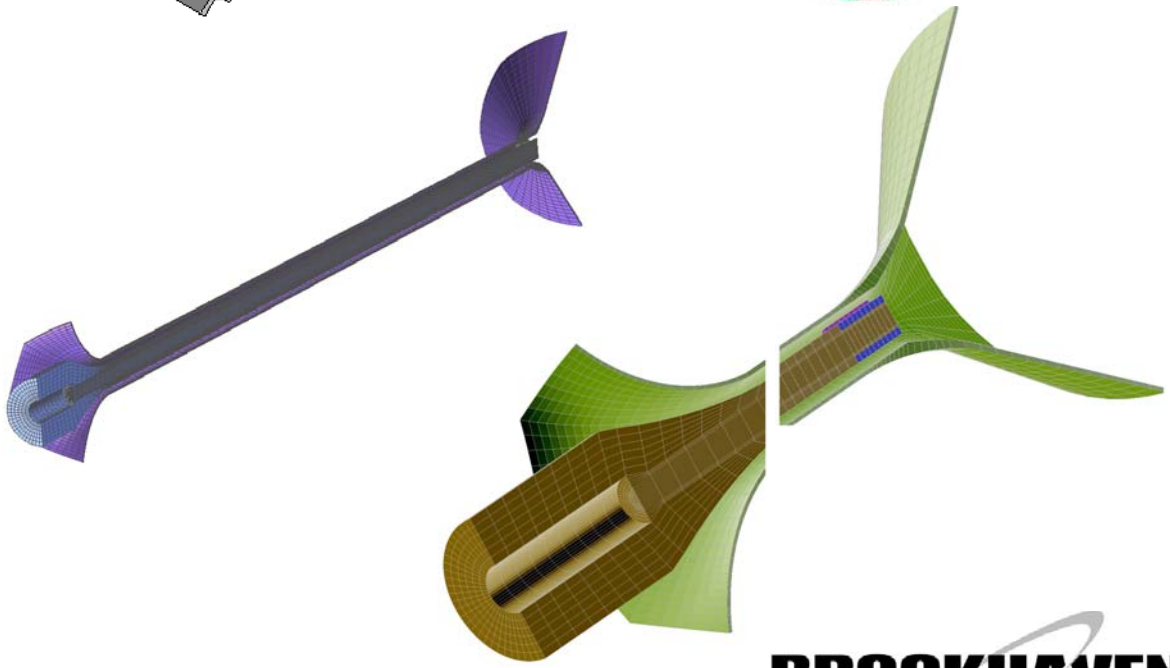
2nd Princeton-Oxford High Power Targetry Workshop

Nov. 6-7, 2008

Superbeam Target Concept







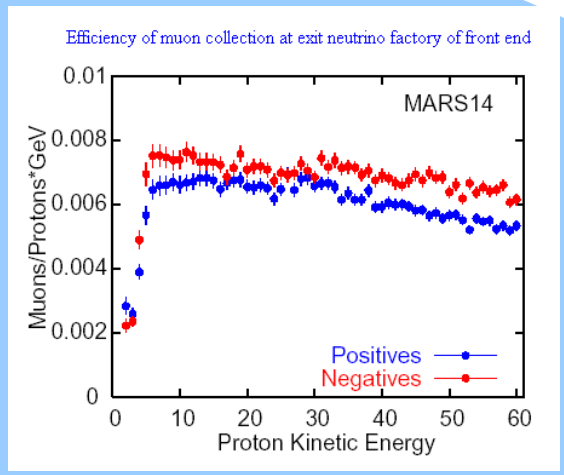
Parameter Space

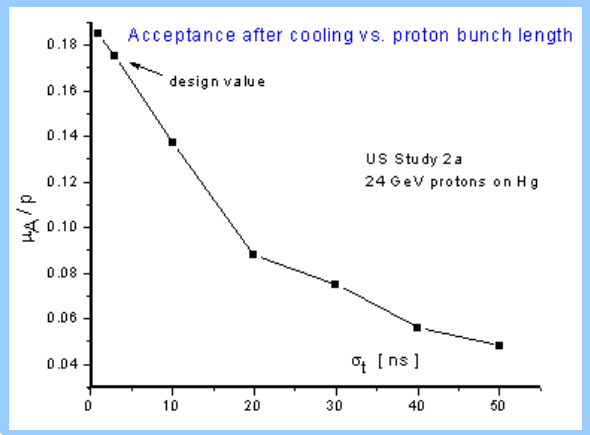
A happy medium between physics goals and engineering reality

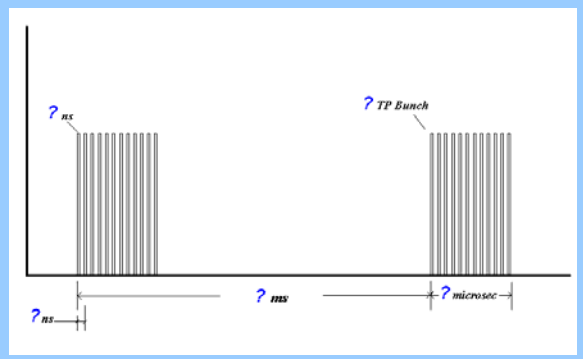
Protons per pulse required for 4 MW

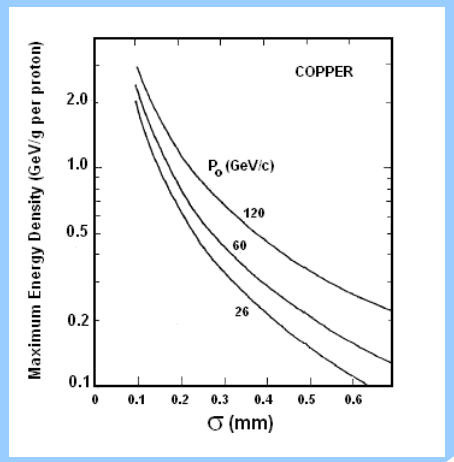
$$\bar{P}_{arc}(w) = E[eV] \times N \times e \times f_{rep}[Hz]$$

	10 Hz	25 Hz	50 Hz
10 GeV	250×10^{12}	100×10^{12}	50×10^{12}
20 GeV	125×10^{12}	50×10^{12}	25×10^{12}





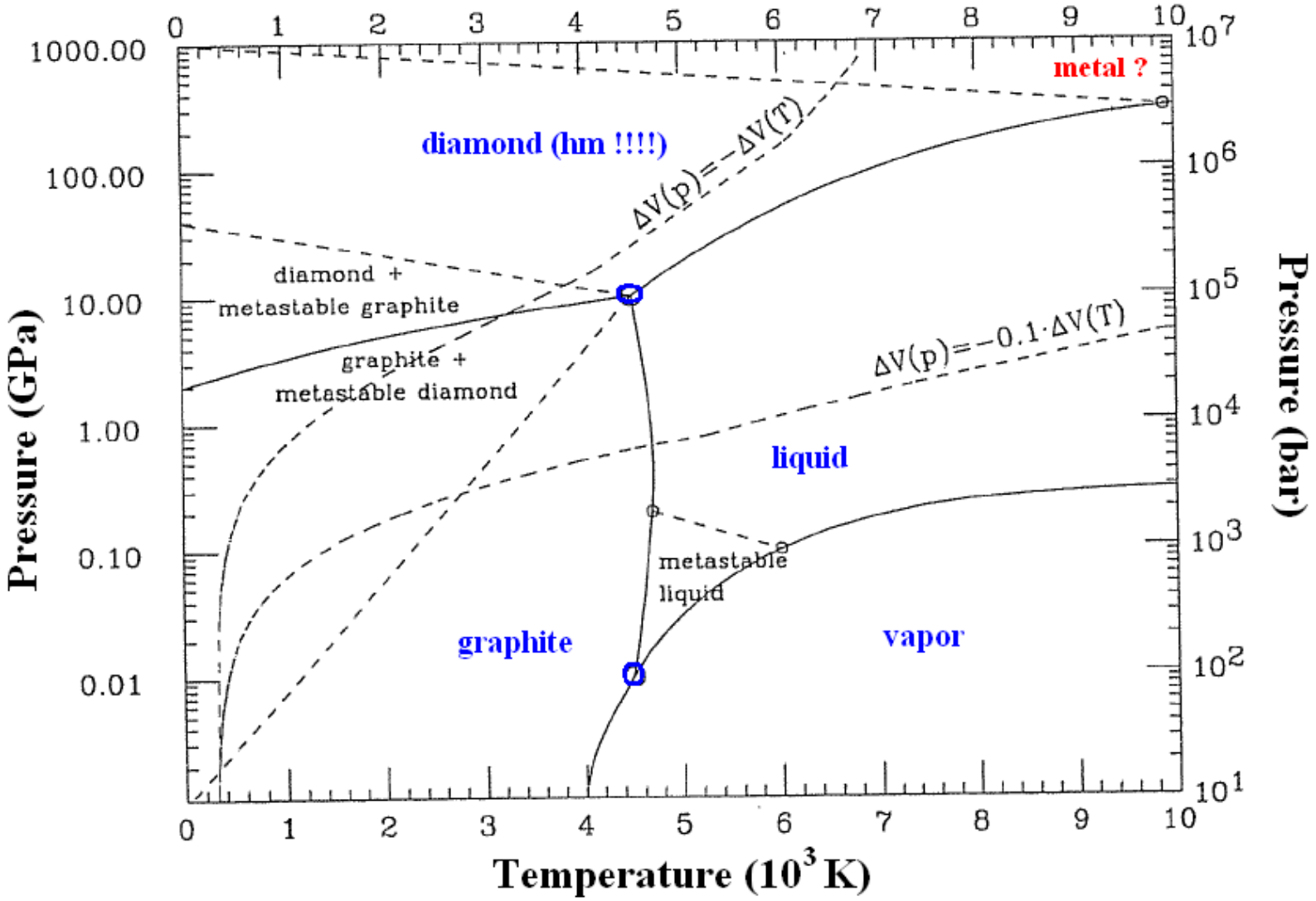




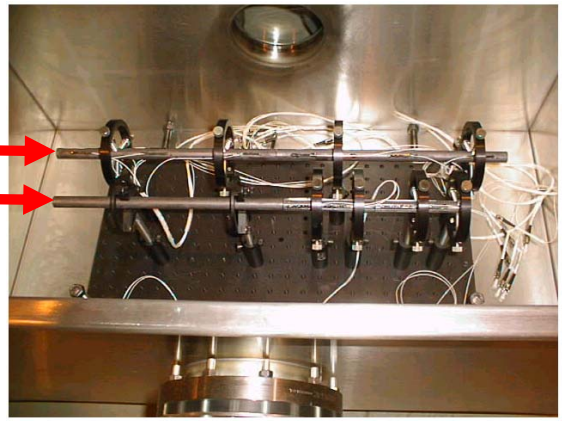
Overview of R&D Realized to-date on Solid Targets

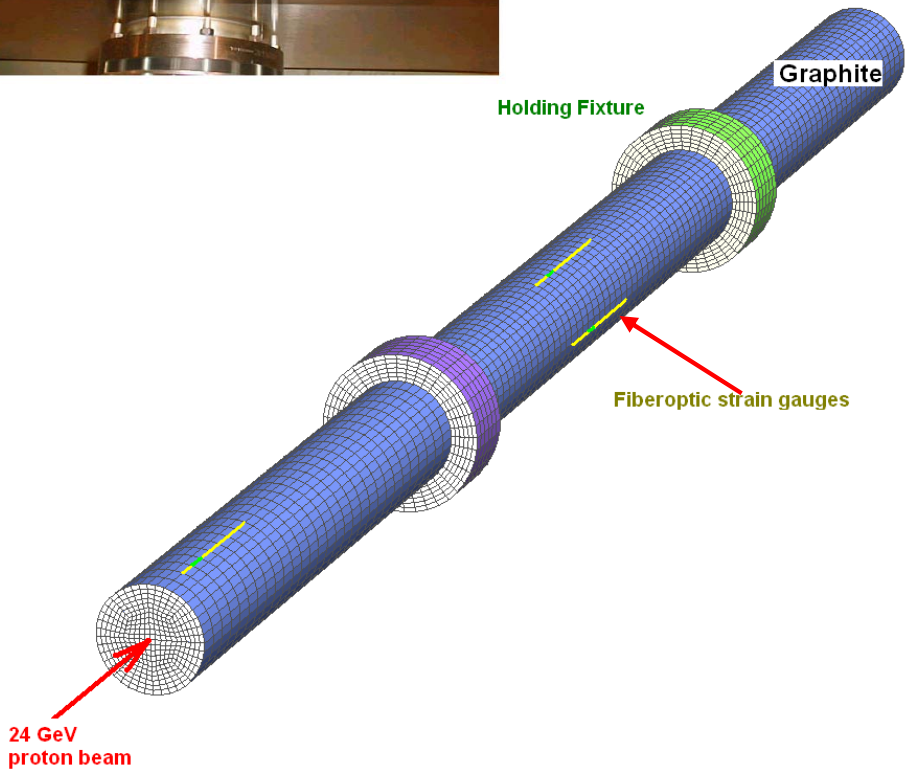
- Target Shock Studies
- Radiation damage Studies

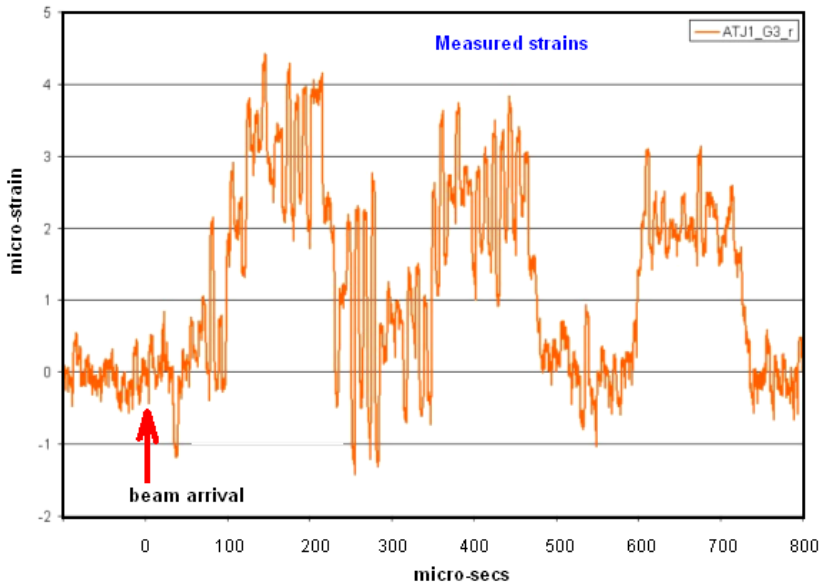
Solid Targets

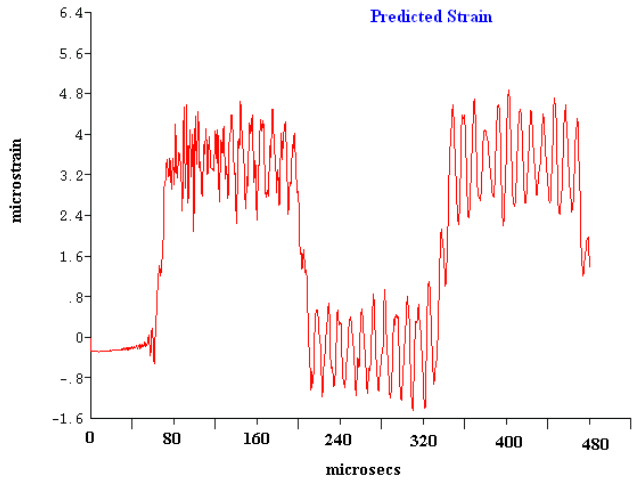


Target Shock Studies

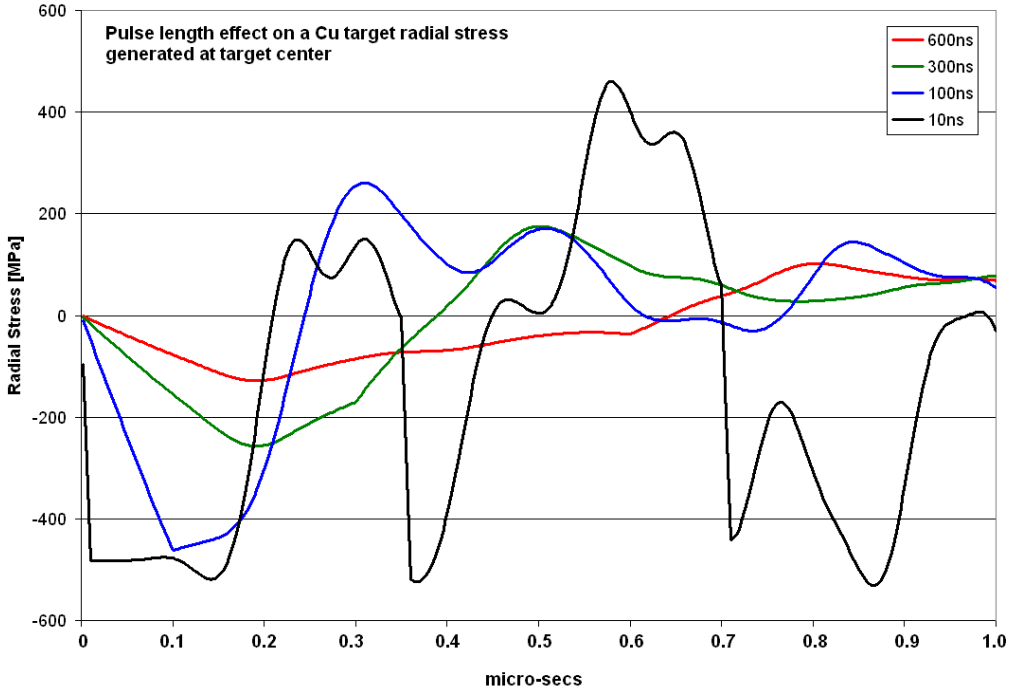


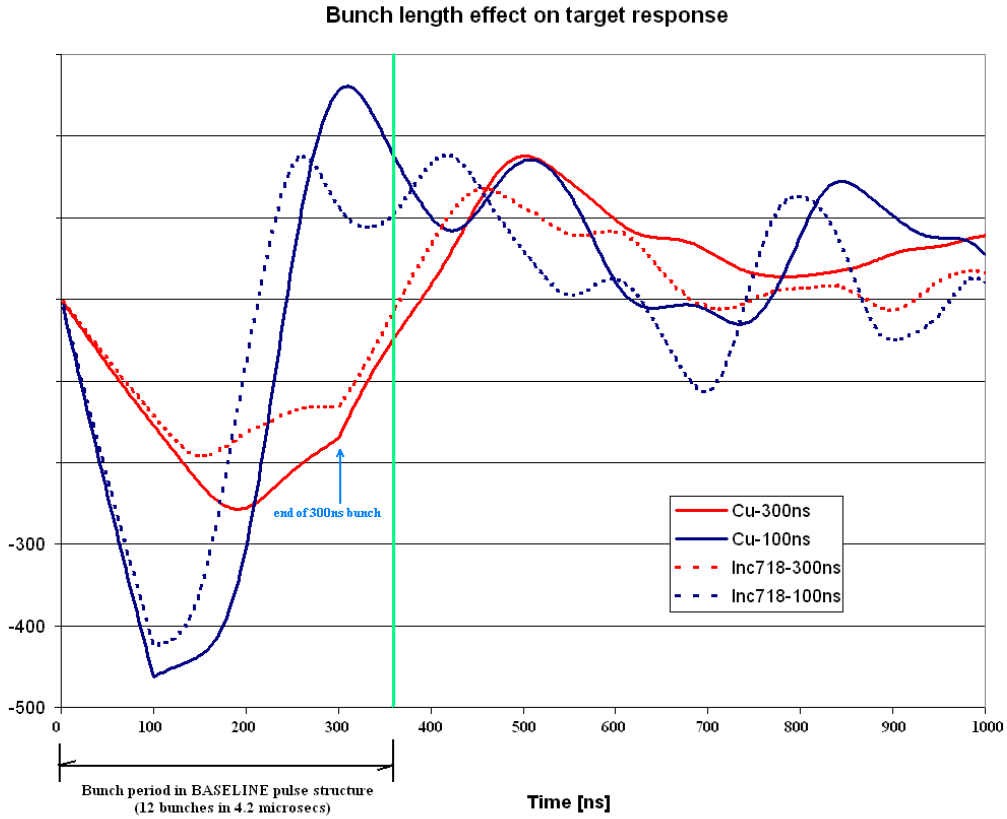




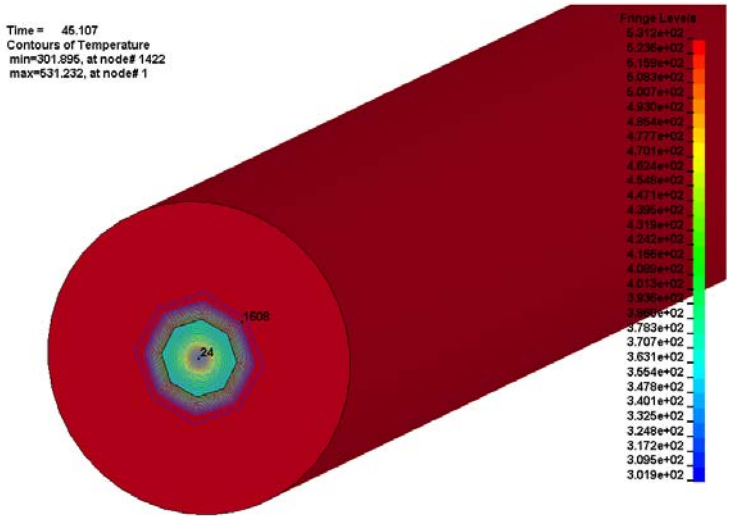


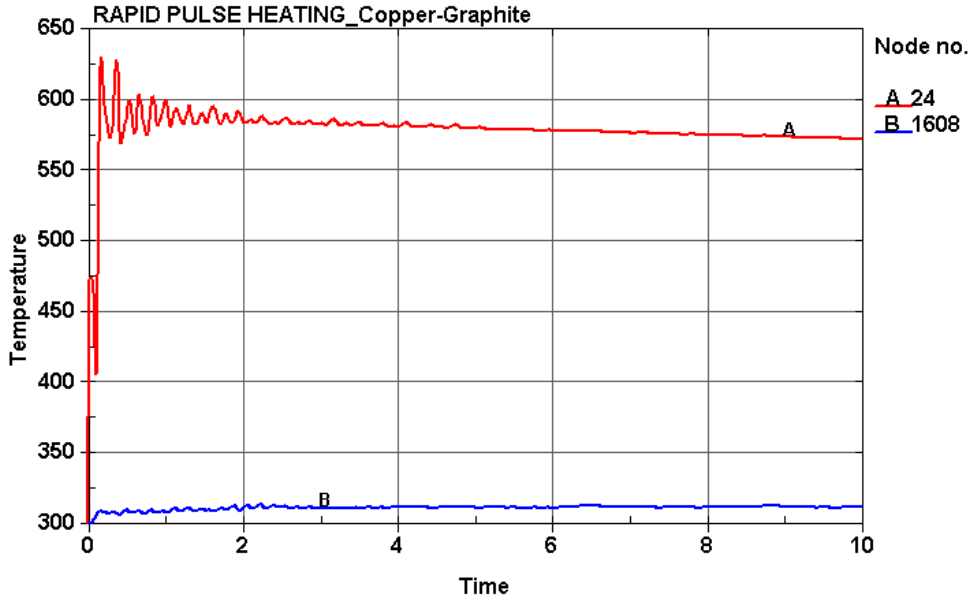
Pulse Structure

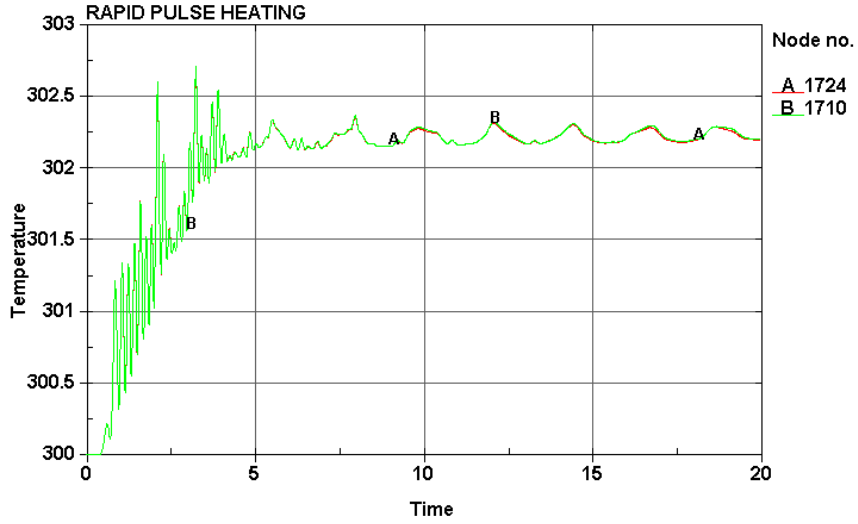




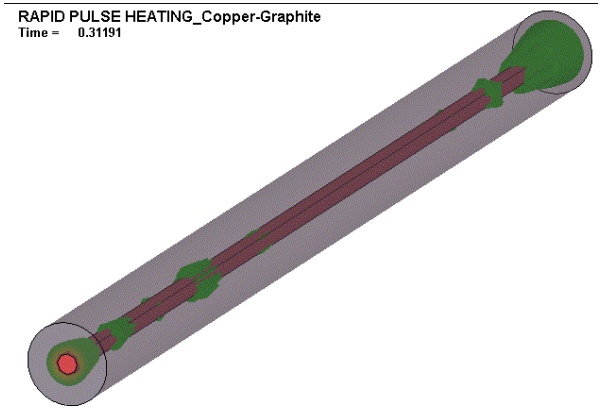
Beam-induced shock simulation

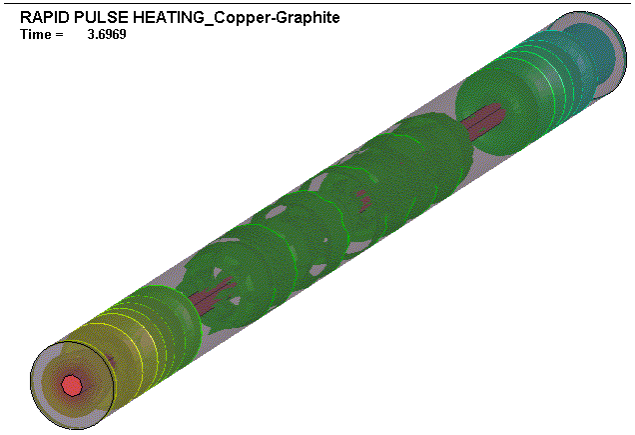


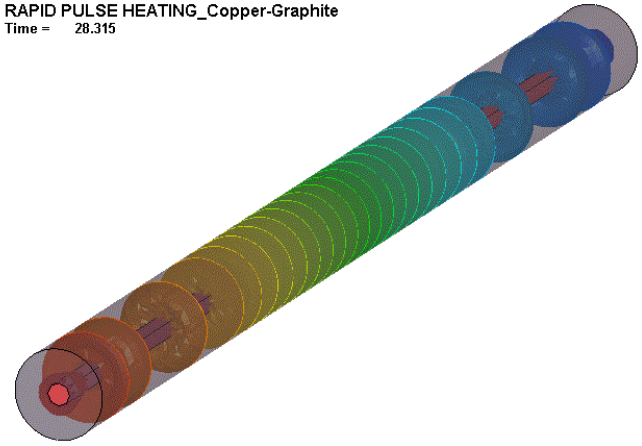


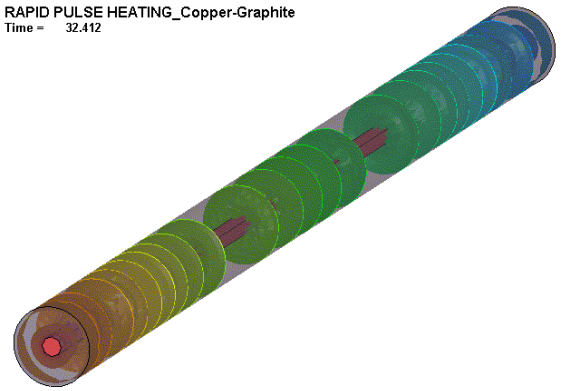


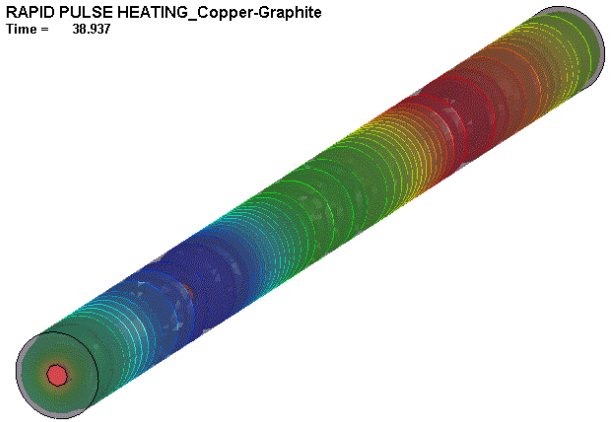
Beam-induced shock simulation

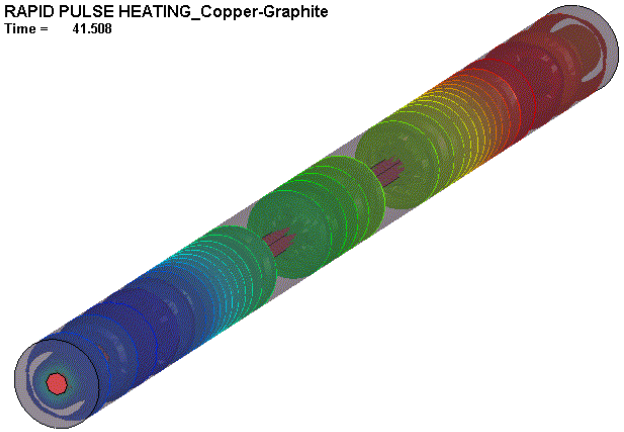




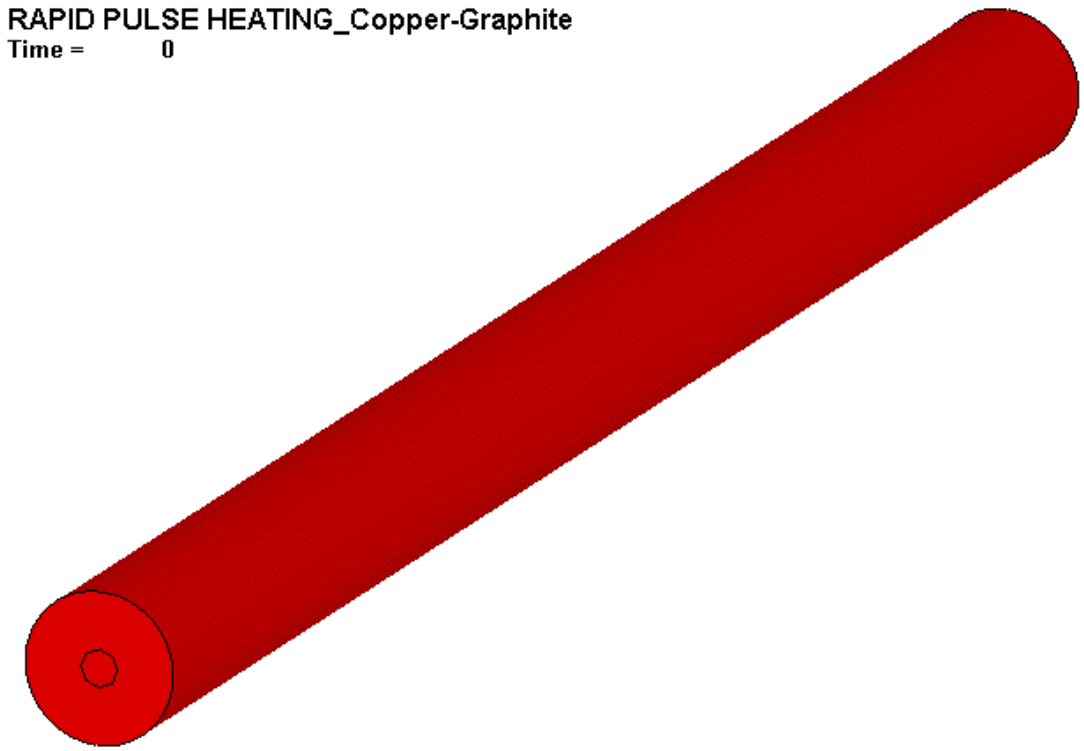




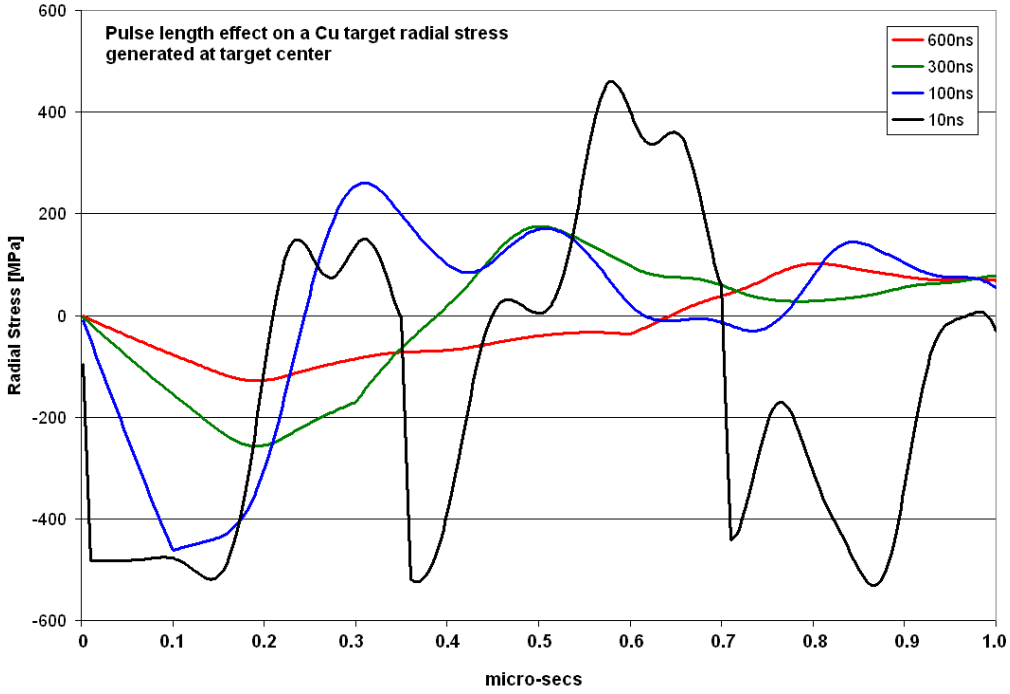


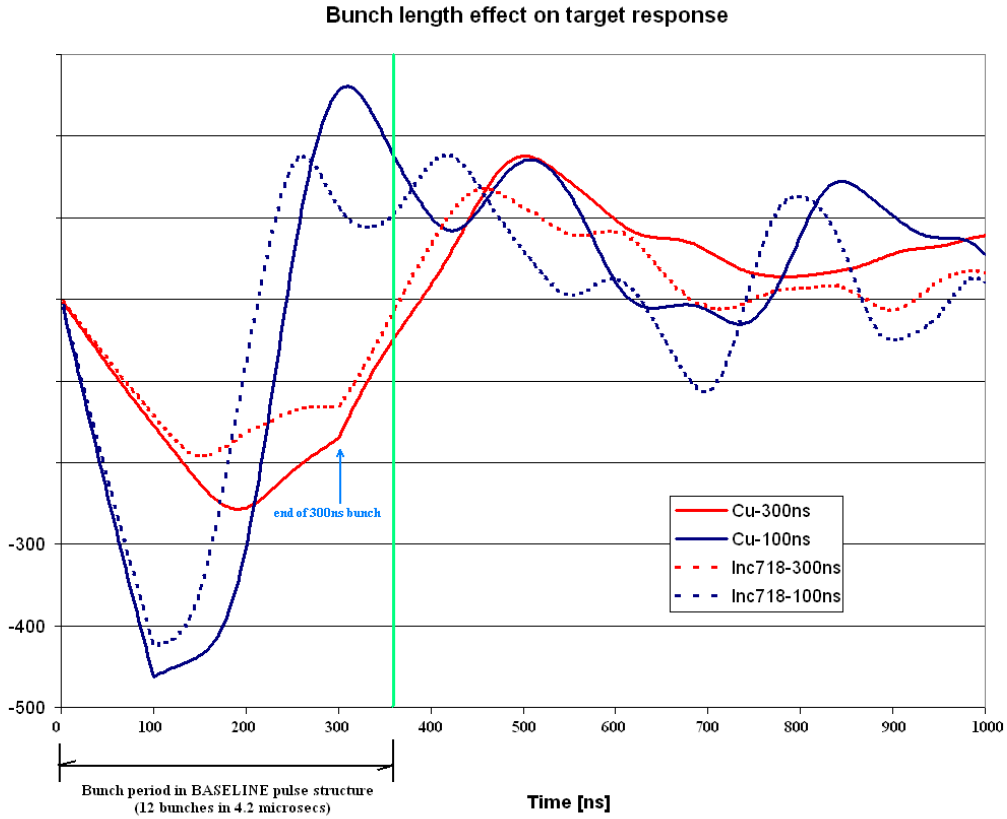


Beam-induced shock simulation



Pulse Structure

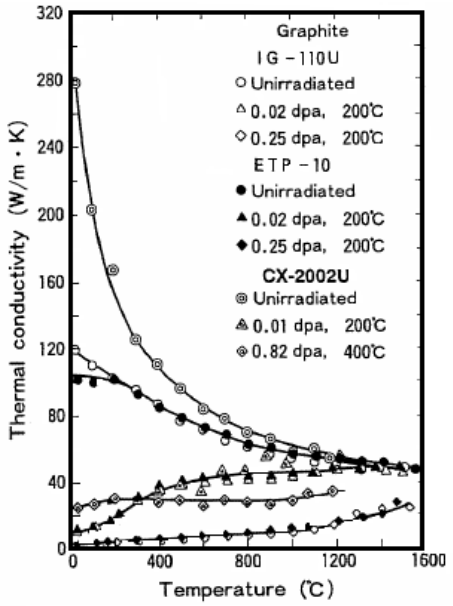


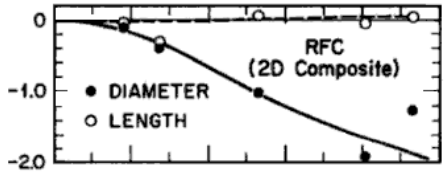


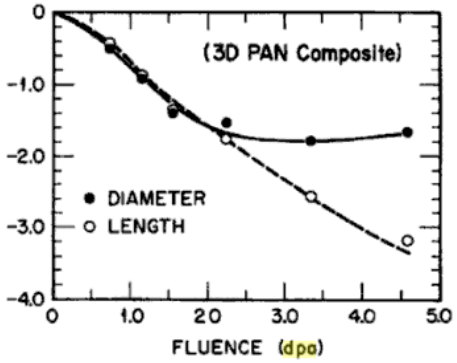
Solid Target Shock Studies

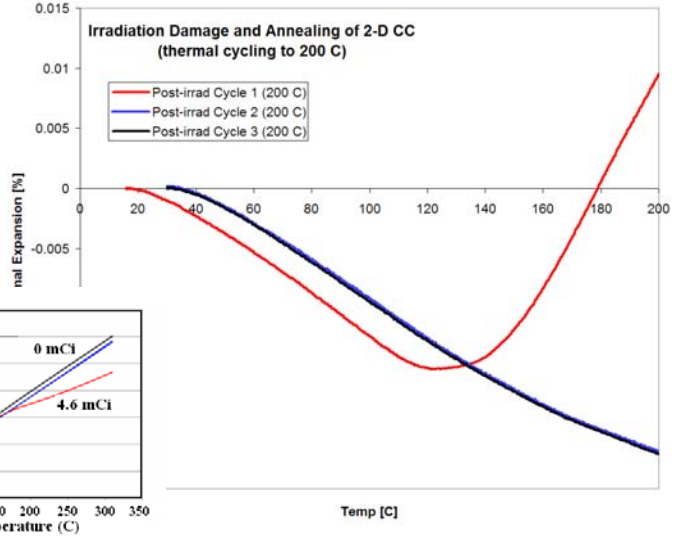
- Graphite and Carbon composites
- super-alloys

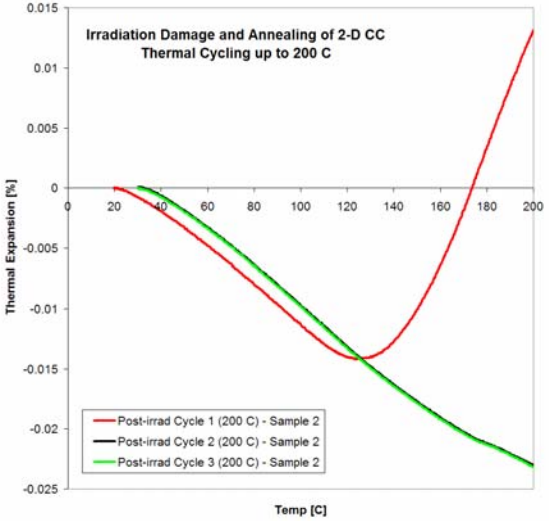
Graphite-CC experience

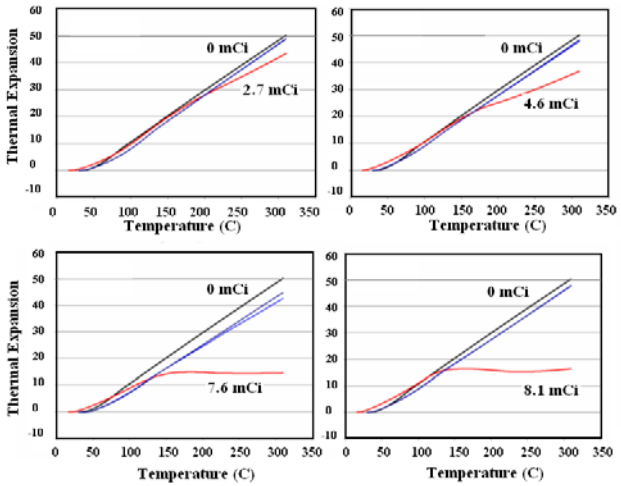




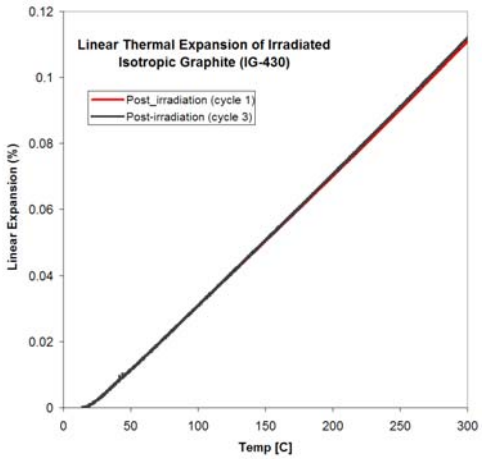


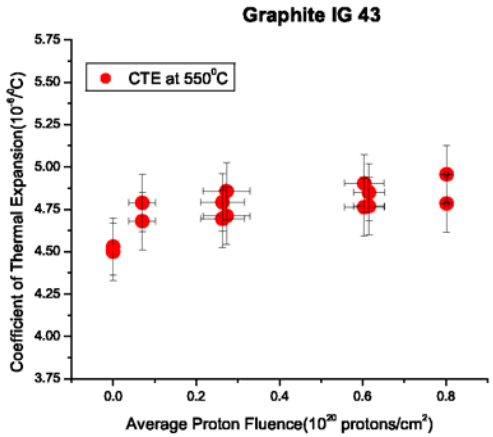


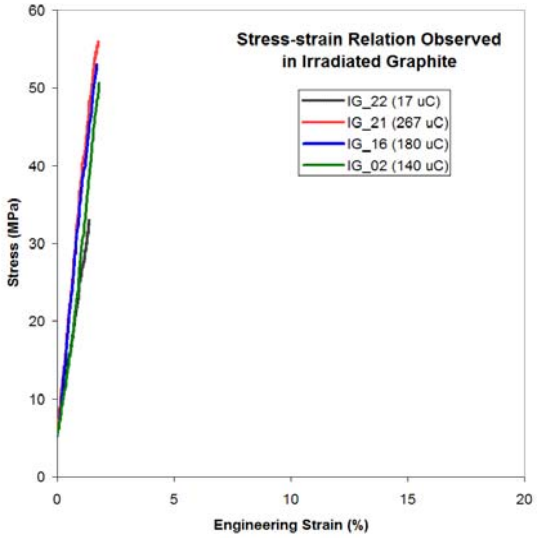


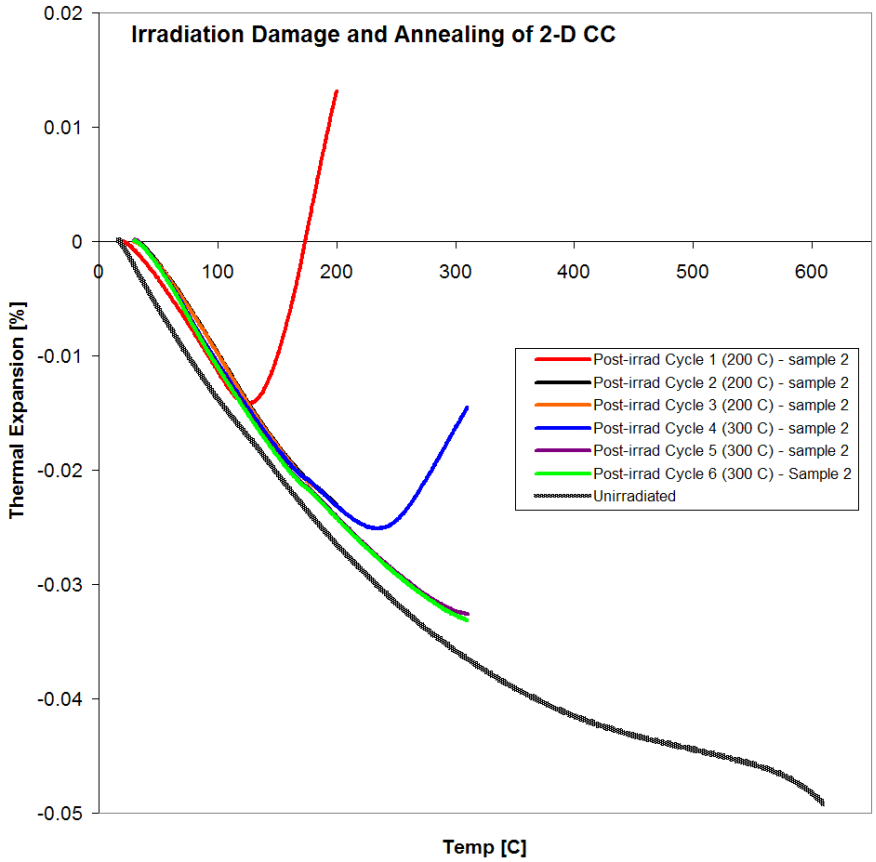


Graphite-CC experience

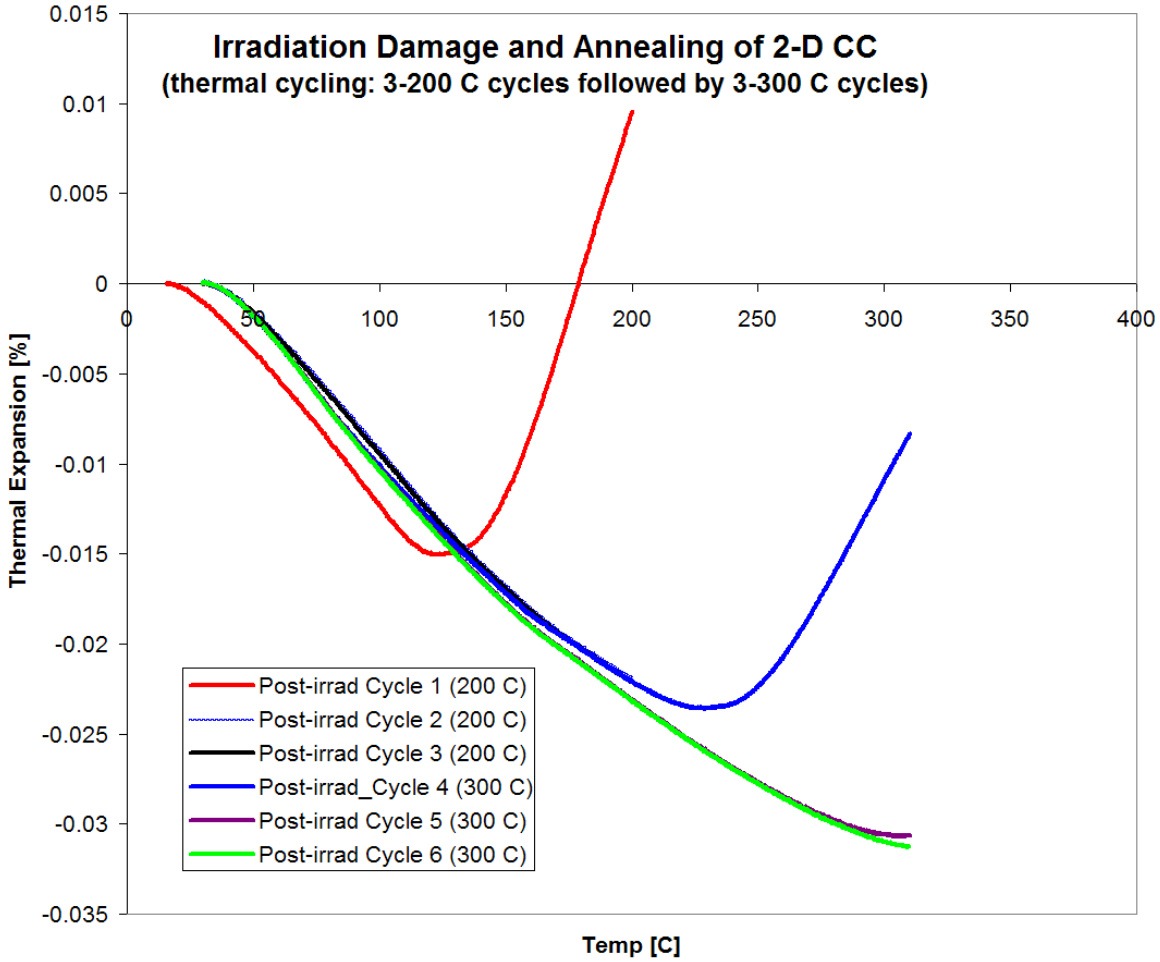


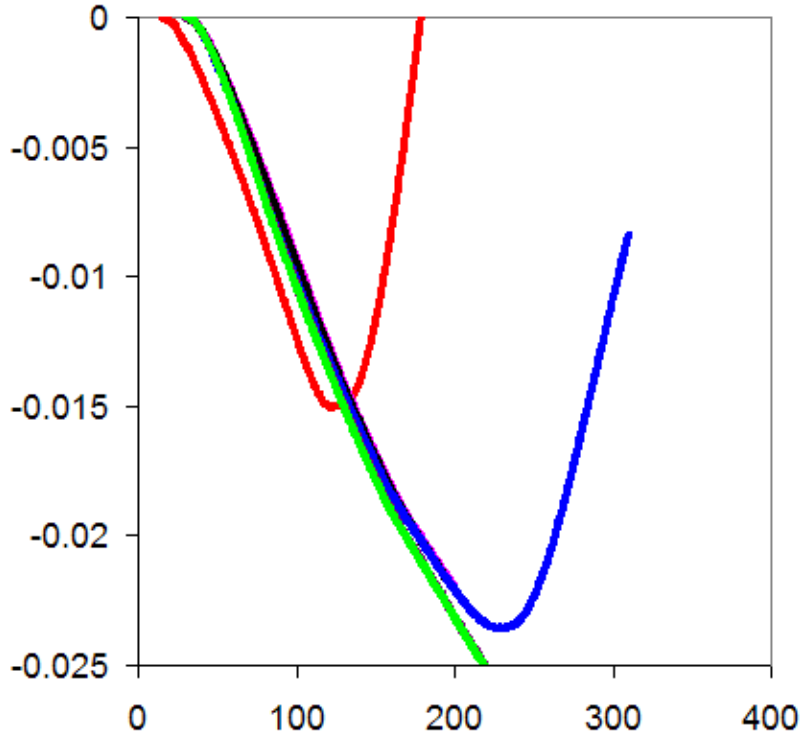




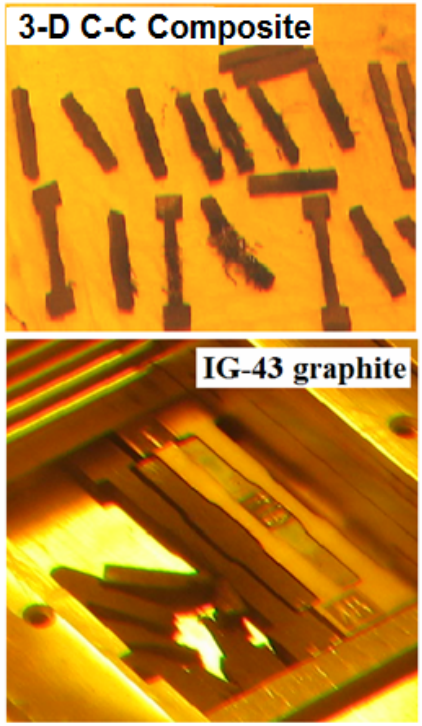


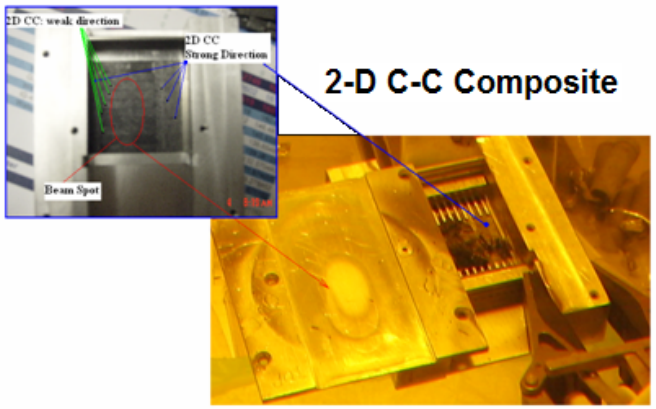
Graphite-CC experience

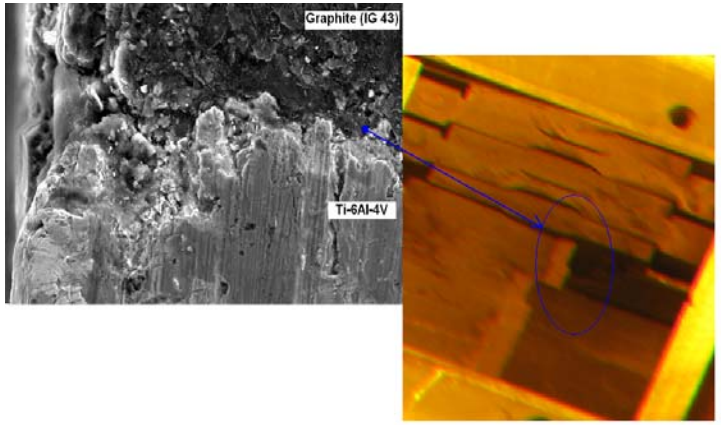




Graphite-CC experience





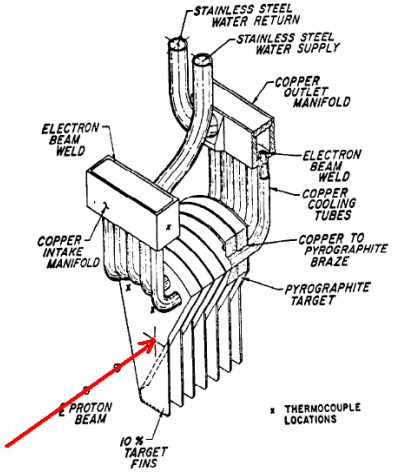


Accelerator (proton irradiated) experience to support this ????

Graphite-CC experience

Accelerator Experience:

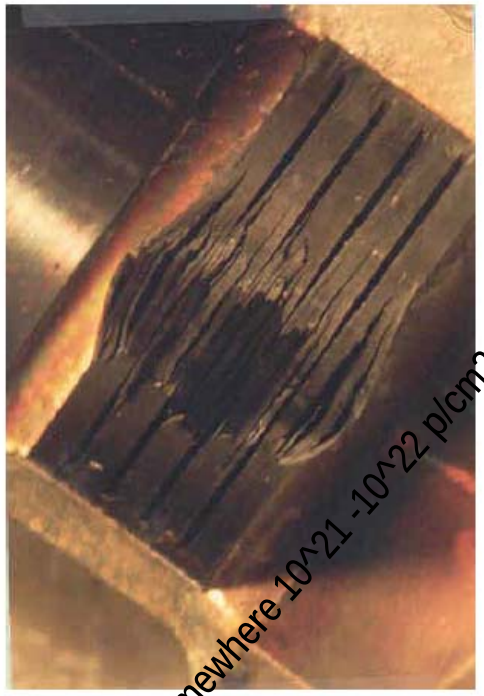
TRIUMF Target; LANL Target; PSI Target



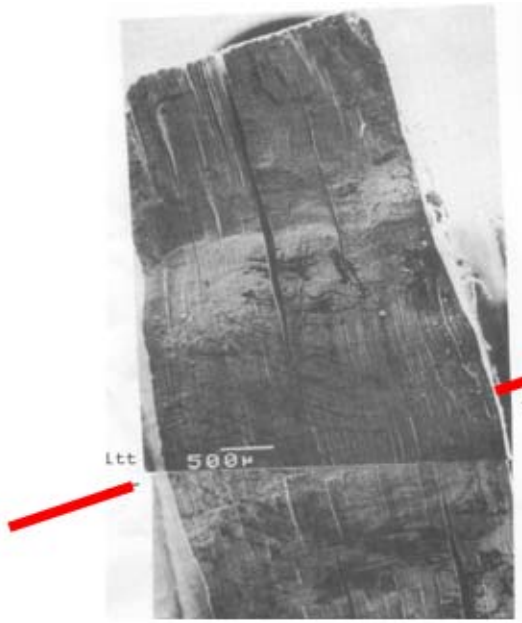
The cracks running through the plates develop at proton fluences above about 2×10^{25} P/m^2. Plates from targets irradiated to about 0.5 of this fluence show extensive delamination, but lack the macroscopic cracks across the a-b planes. These results indicate that pyrolytic graphite is very susceptible to delamination, as would be expected from the low tensile strength in the c direction.

= 10^21 p/cm2

Water-cooled/Edge-cooled TRIUMF target



Fluence: somewhere 10^21 -10^22 p/cm2



Swelling of the target after irradiation

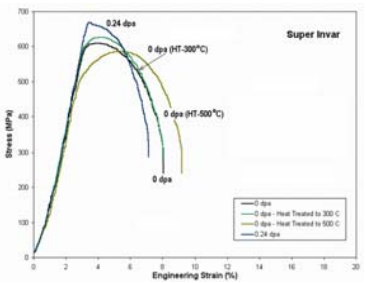
10^{22} p/cm2

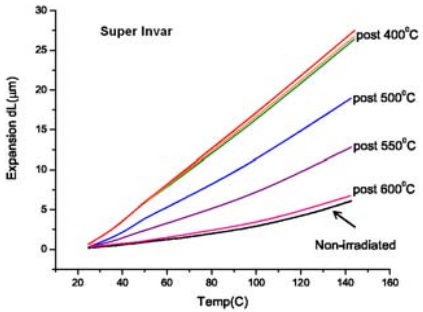
p

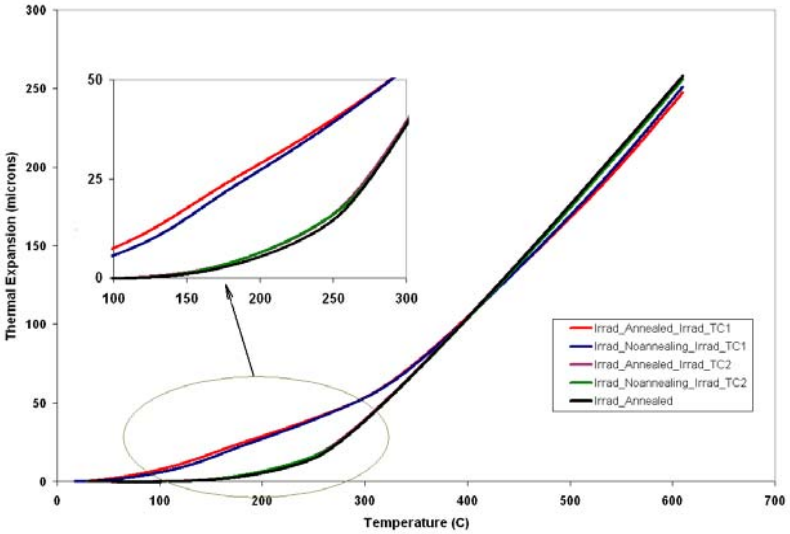
radiation-cooled

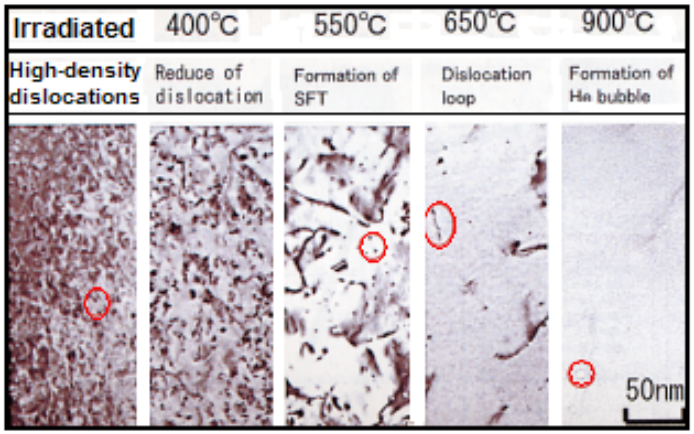
High operating temp ~1100 C

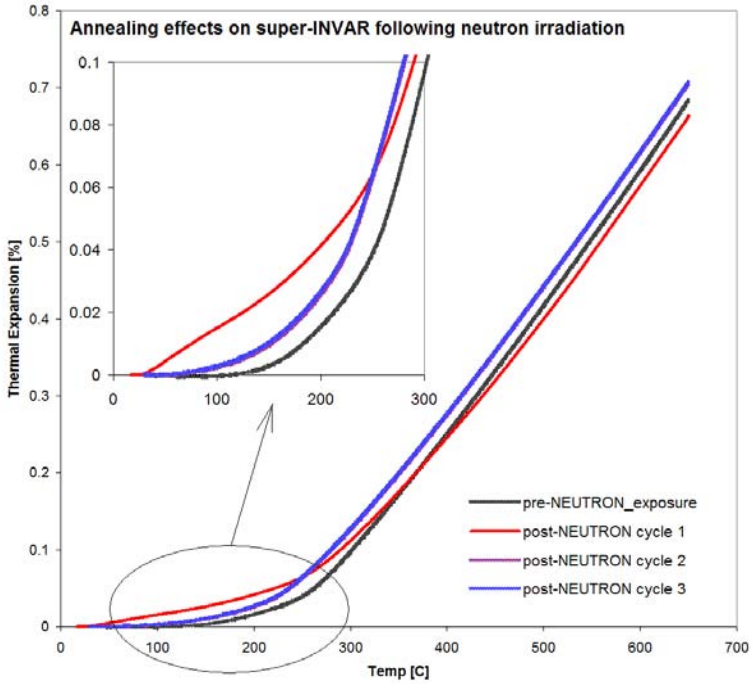
super-Invar


Super Invar
0.24 dpa
0 dpa (HT-300°C)
0 dpa (HT-500°C)
0 dpa
Stress (MPa)
Engineering Strain (%)

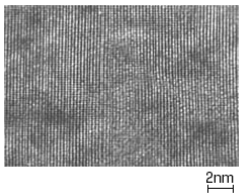

Super Invar
post 400°C
post 500°C
post 550°C
post 600°C
Non-irradiated
Expansion dL(μm)
Temp(C)

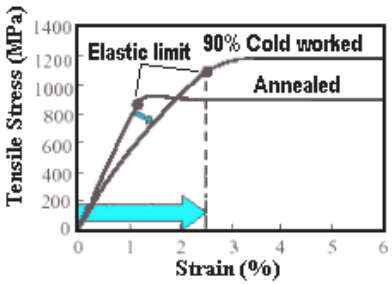

Thermal Expansion (microns)
Temperature (C)
Irrad_Annealed_Irrad_TC1
Irrad_Noannealing_Irrad_TC1
Irrad_Annealed_Irrad_TC2
Irrad_Noannealing_Irrad_TC2
Irrad_Annealed

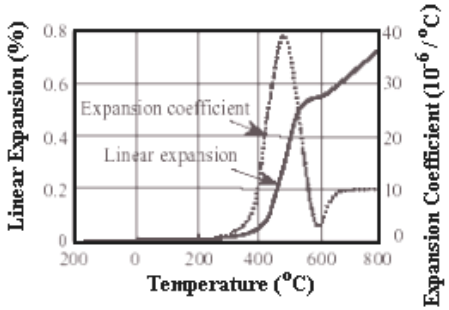

Irradiated
400°C
550°C
650°C
900°C
High-density dislocations
Reduce of dislocation
Formation of SFT
Dislocation loop
Formation of He bubble
50nm

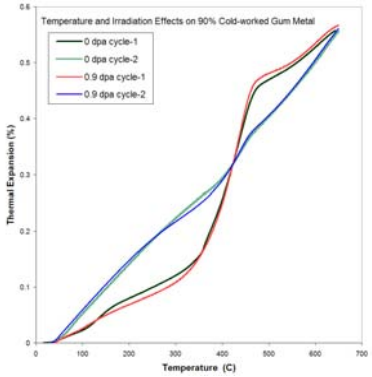

Annealing effects on super-INVAR following neutron irradiation
Thermal Expansion [%]
Temp [C]
pre-NEUTRON_exposure
post-NEUTRON cycle 1
post-NEUTRON cycle 2
post-NEUTRON cycle 3

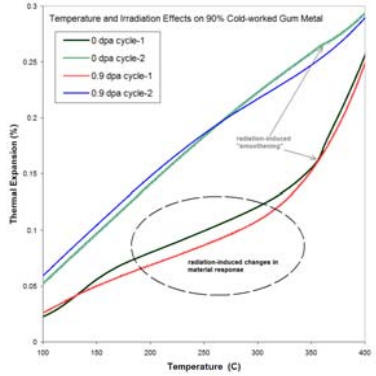
“Gum” metal

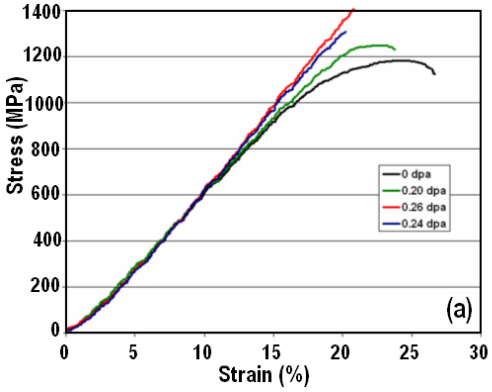

2nm

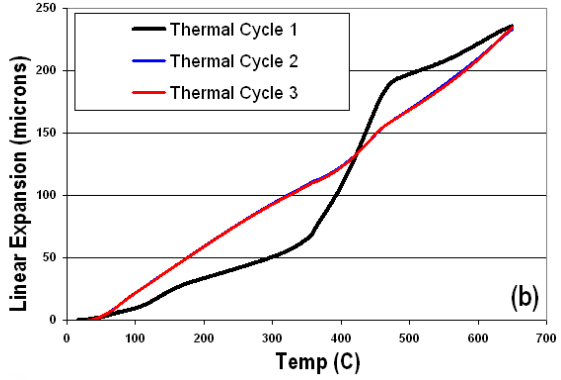

Tensile Stress (MPa)
Elastic limit
90% Cold worked
Annealed
Strain (%)

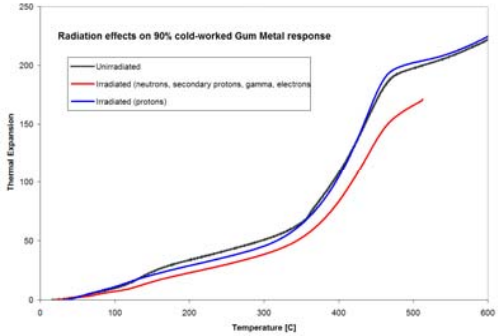

Linear Expansion (%)
Expansion coefficient
Linear expansion
Temperature (°C)
Expansion Coefficient (10⁻⁶/°C)


Temperature and Irradiation Effects on 90% Cold-worked Gum Metal
0 dpa cycle-1
0 dpa cycle-2
0.9 dpa cycle-1
0.9 dpa cycle-2
Thermal Expansion (%)
Temperature (C)

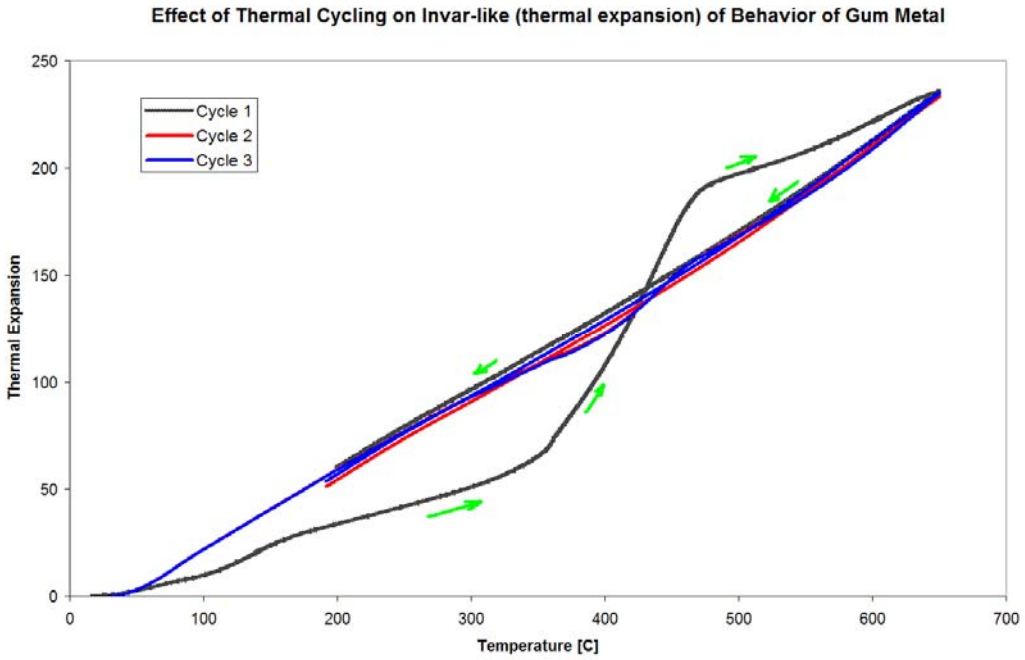

Temperature and Irradiation Effects on 90% Cold-worked Gum Metal
0 dpa cycle-1
0 dpa cycle-2
0.9 dpa cycle-1
0.9 dpa cycle-2
radiation-induced changes in material response
Thermal Expansion (%)
Temperature (C)

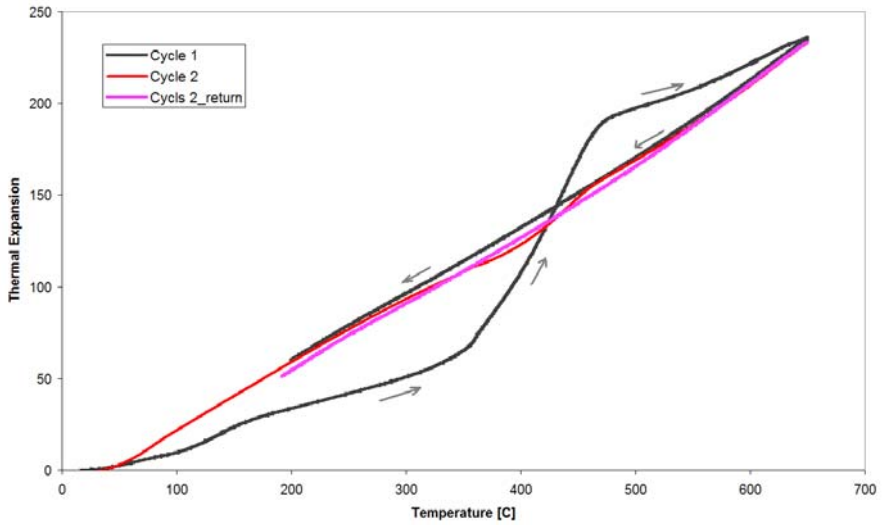

Stress (MPa)
0 dpa
0.20 dpa
0.26 dpa
0.24 dpa
(a)
Strain (%)

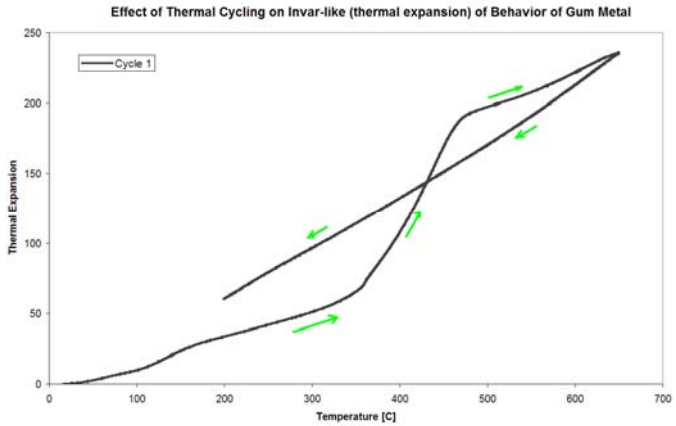

Thermal Cycle 1
Thermal Cycle 2
Thermal Cycle 3
Linear Expansion (microns)
(b)
Temp (C)

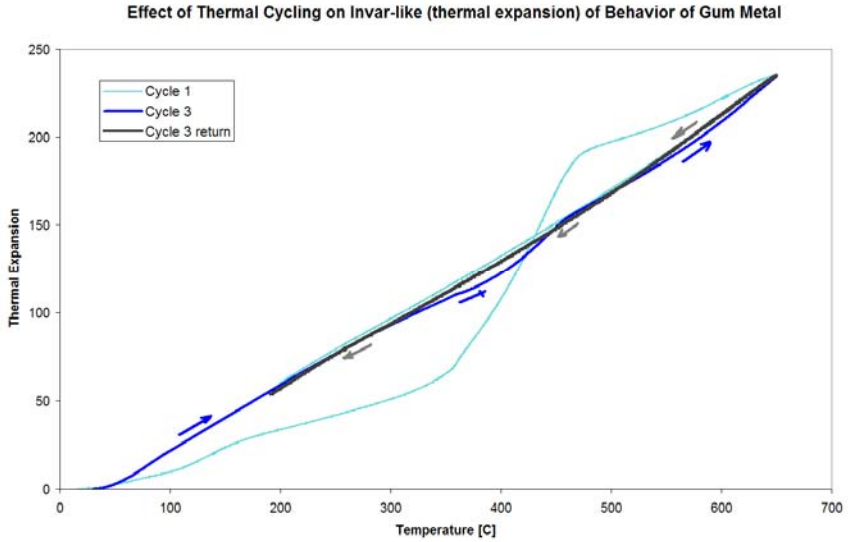

Radiation effects on 90% cold-worked Gum Metal response
Unirradiated
Irradiated (neutrons, secondary protons, gamma, electrons)
Irradiated (protons)
Thermal Expansion
Temperature [C]

Gum metal

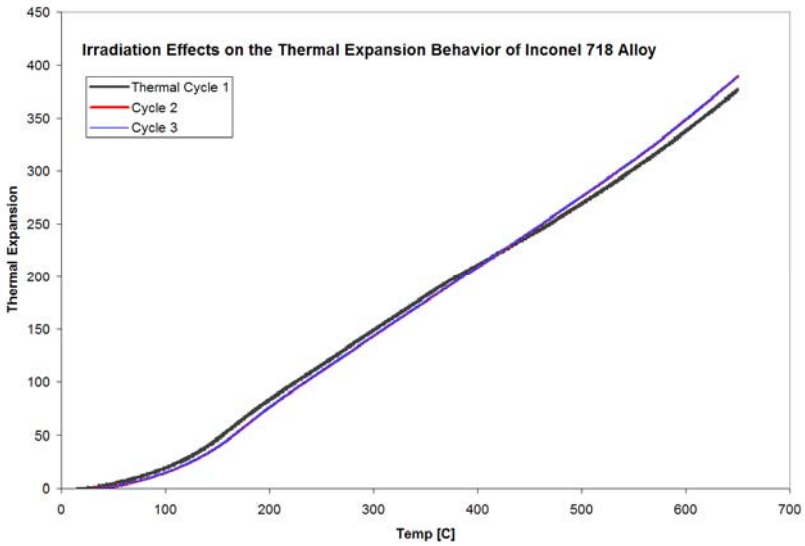

Effect of Thermal Cycling on Invar-like (thermal expansion) of Behavior of Gum Metal
Cycle 1
Cycle 2
Cycle 3
Thermal Expansion
Temperature [C]
0
50
100
150
200
250
0
100
200
300
400
500
600
700

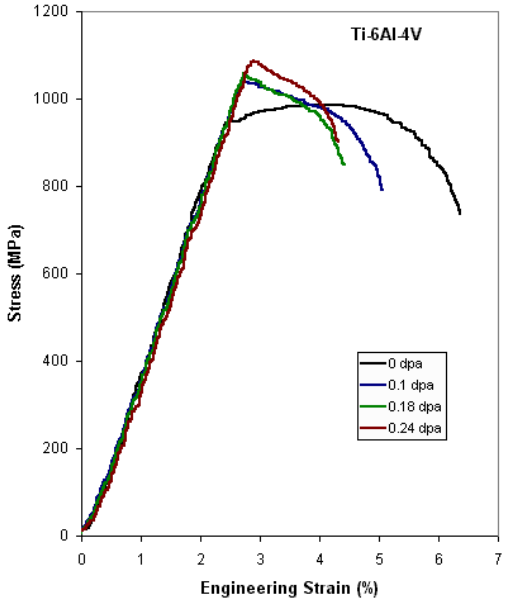

Cycle 1
Cycle 2
Cycls 2_return
Thermal Expansion
Temperature [C]
0
50
100
150
200
250
0
100
200
300
400
500
600
700

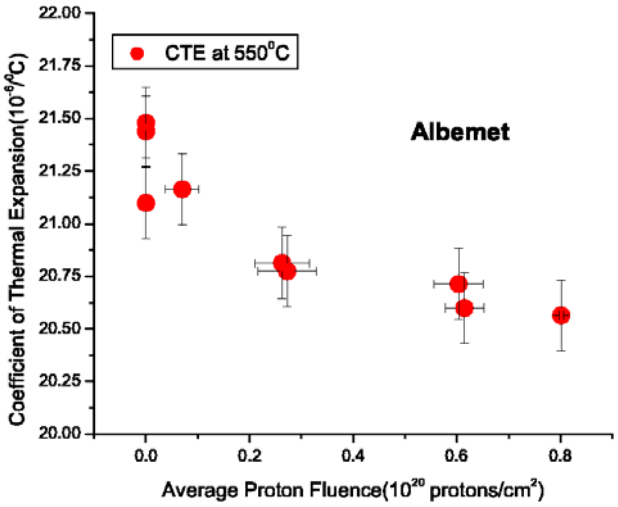

Effect of Thermal Cycling on Invar-like (thermal expansion) of Behavior of Gum Metal
Cycle 1
Thermal Expansion
Temperature [C]
0
50
100
150
200
250
0
100
200
300
400
500
600
700

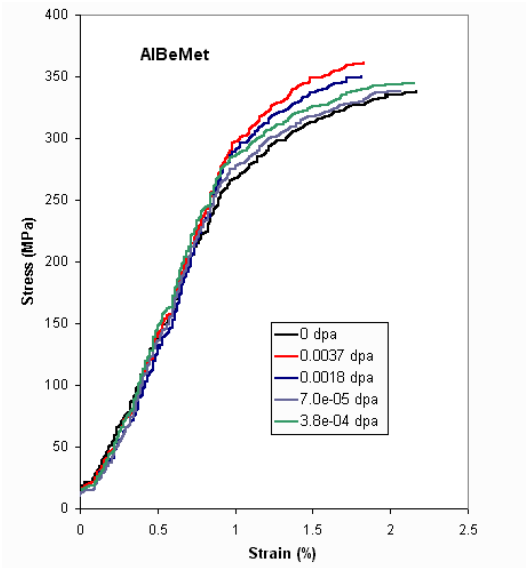

Effect of Thermal Cycling on Invar-like (thermal expansion) of Behavior of Gum Metal
Cycle 1
Cycle 3
Cycle 3 return
Thermal Expansion
Temperature [C]
0
50
100
150
200
250
0
100
200
300
400
500
600
700

Other alloys

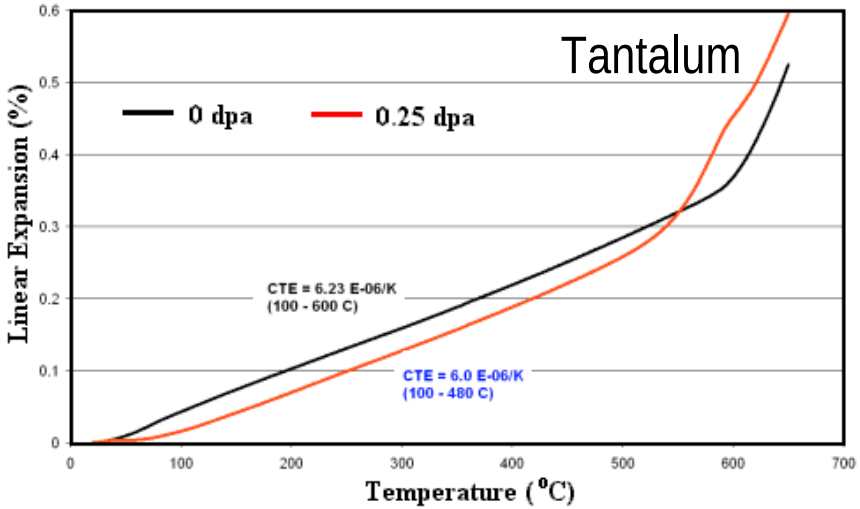


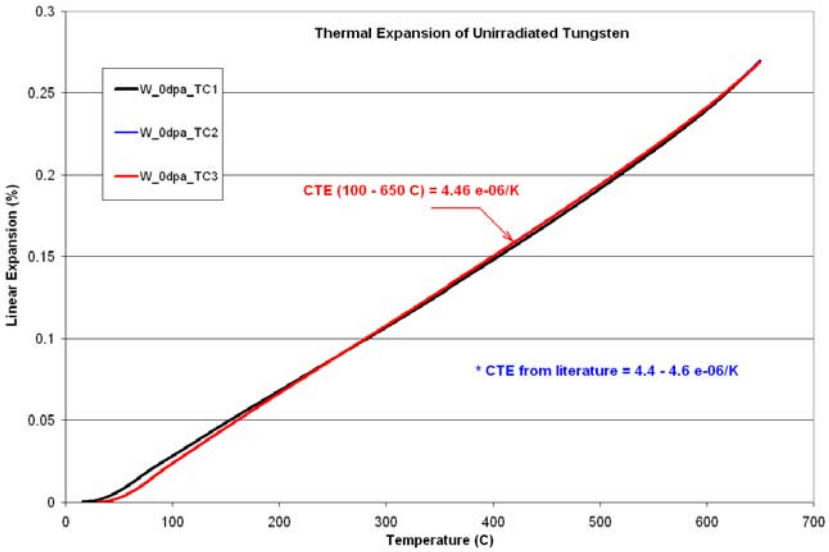


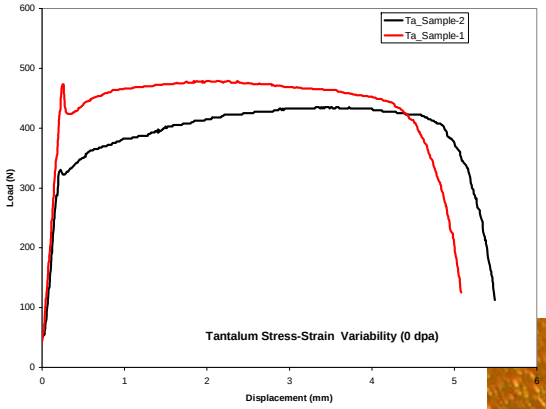


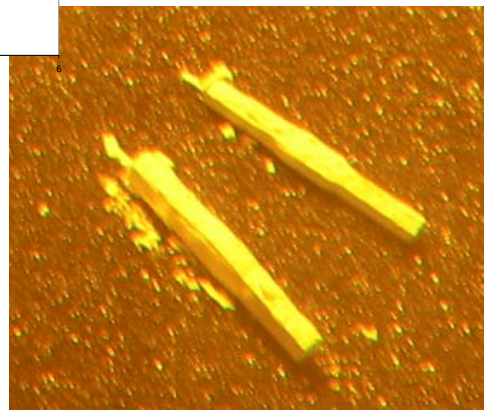


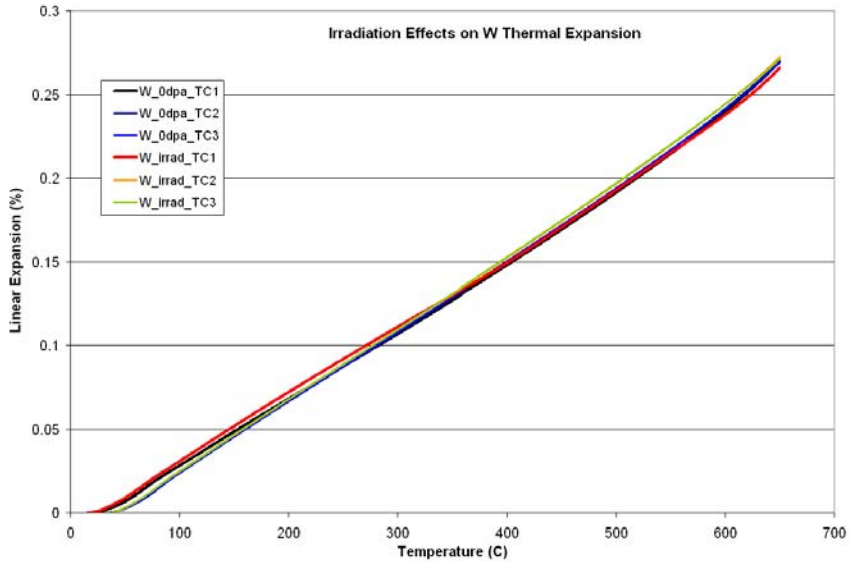
Radiation Damage Studies – High-Z Materials











Office of Science
U.S. DEPARTMENT OF ENERGY

BROOKHAVEN NATIONAL LABORATORY
BROOKHAVEN SCIENCE ASSOCIATES

Path forward

Protons on graphite/CC (> fluence threshold) under different environment (vacuum or helium)

Study of Albemet to high fluences

Understanding damage via photon scattering (effort under way) ……
maybe explore the effect of shock and fatigue on target material microstructure