Horn/Target Material Studies at BNL

Towards multi-MW Beam

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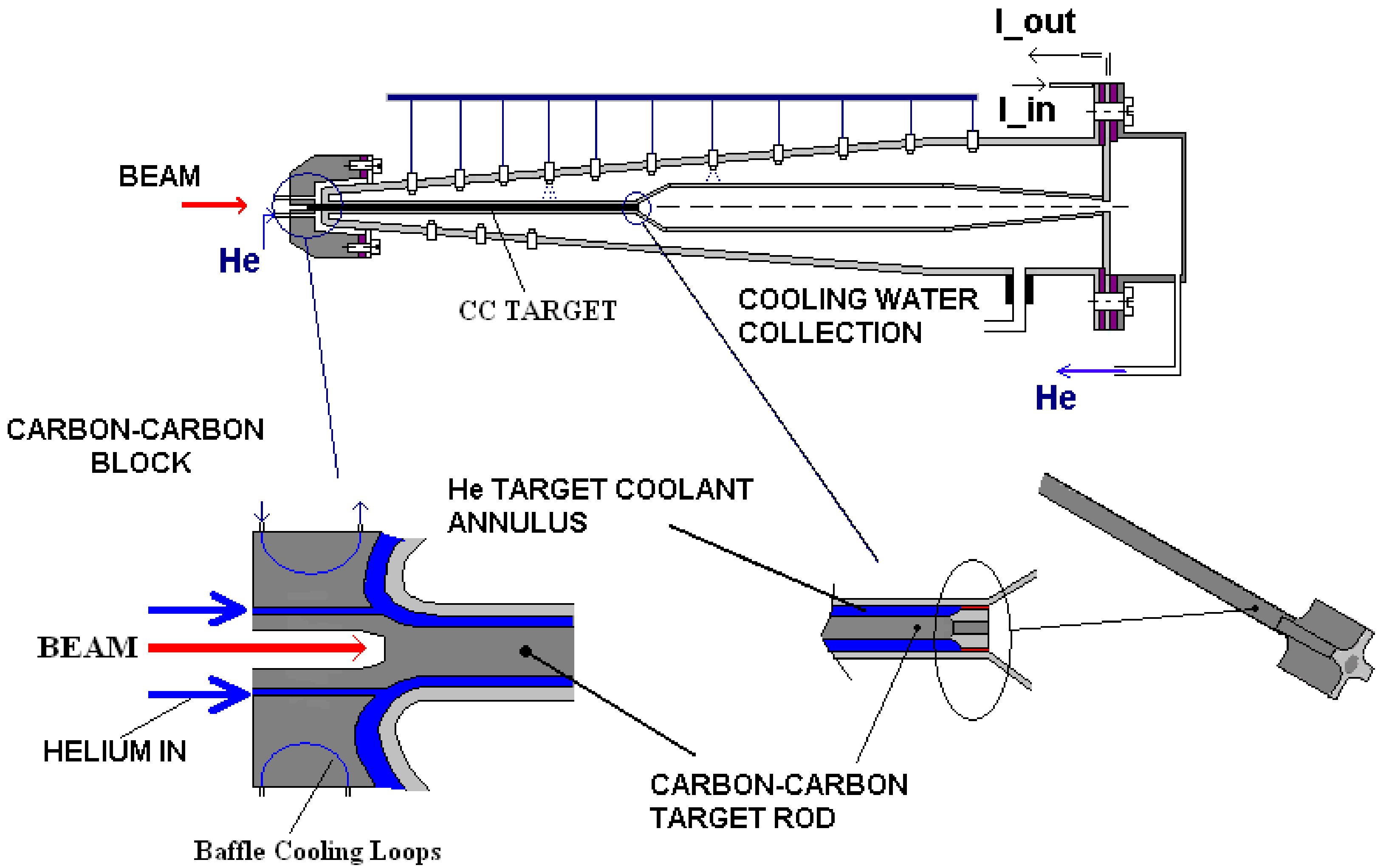
National Synchrotron Light Source II

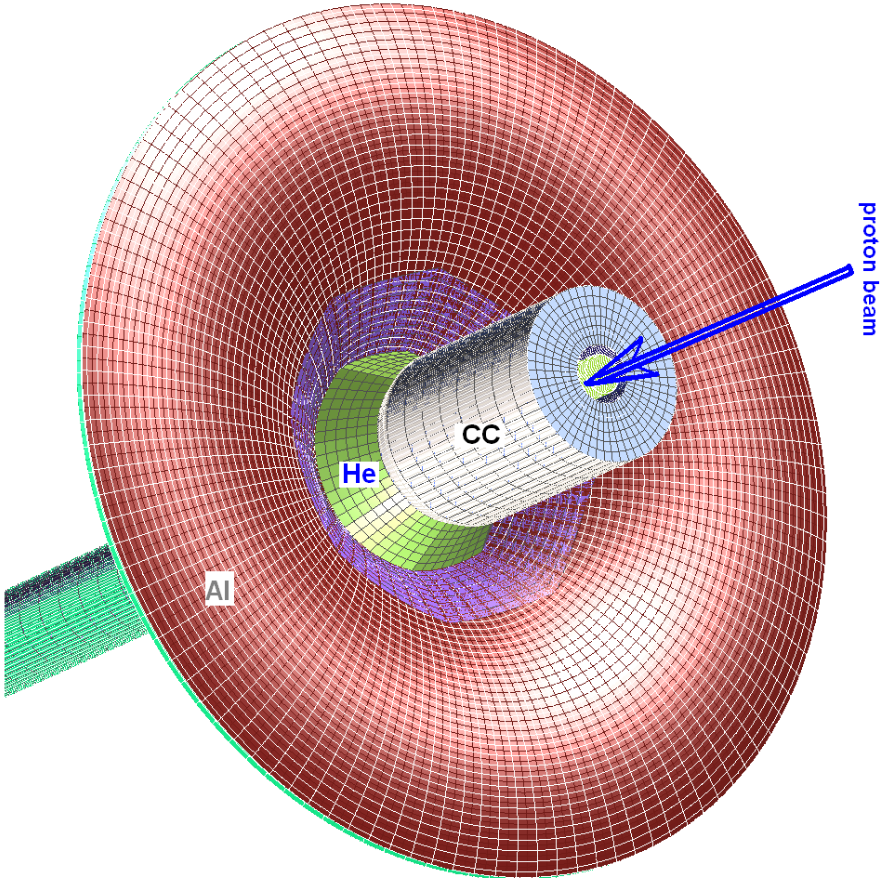
LBNE Science Collaboration
Meeting - FNAL July 15, 2009

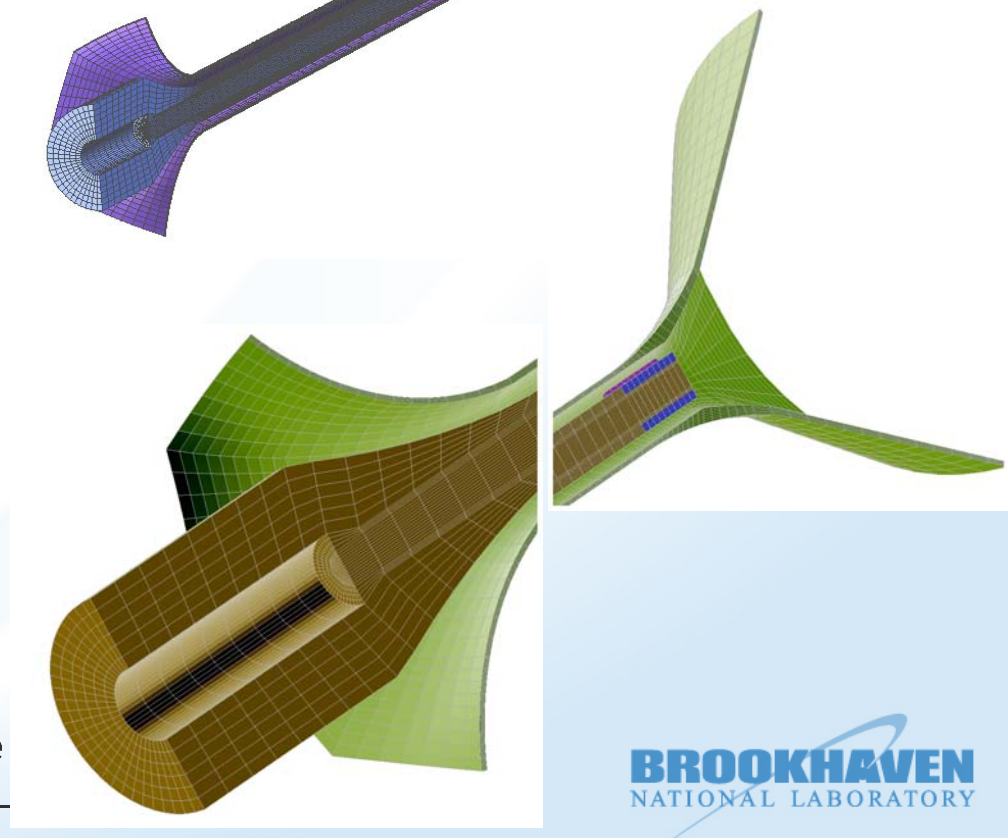
BROOKHAVEN NATIONAL LABORATORY

Superbeam Target-Horn Concept (from BNL Study)

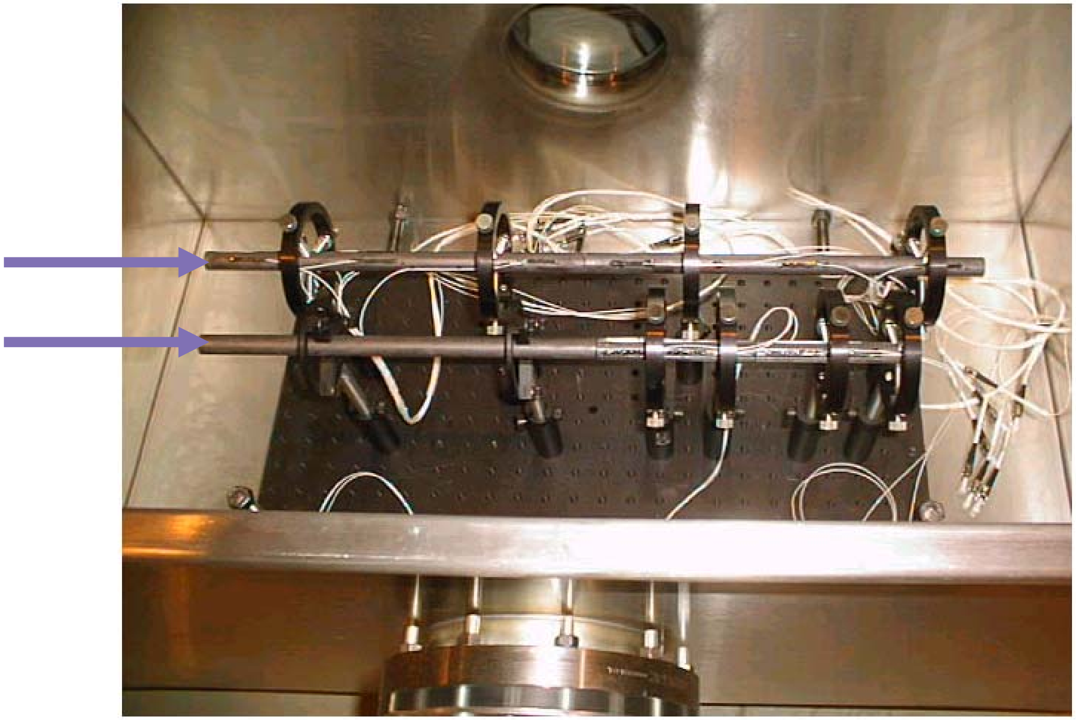


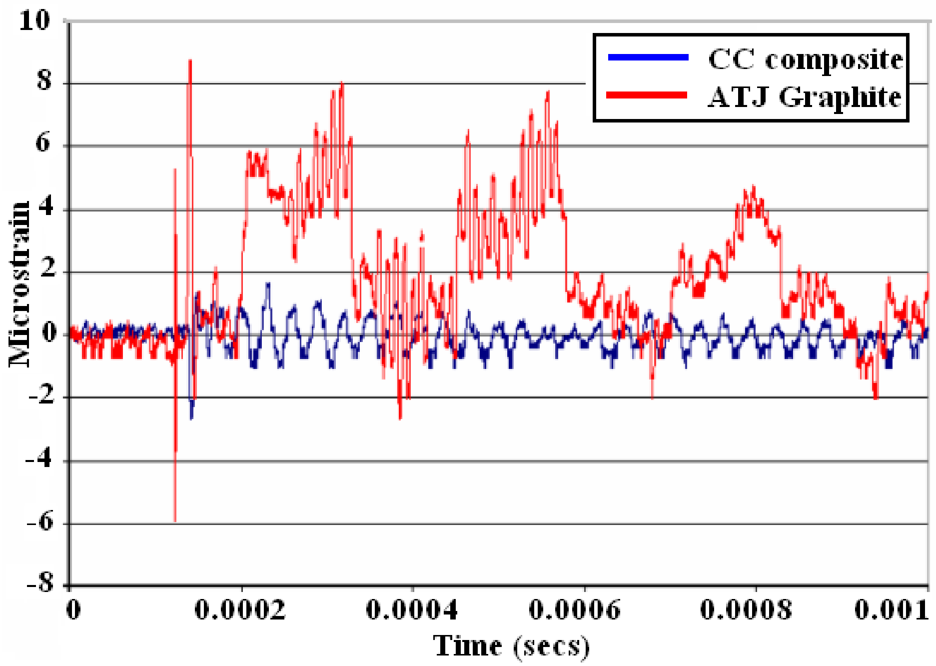
Superbeam Target-Horn Concept

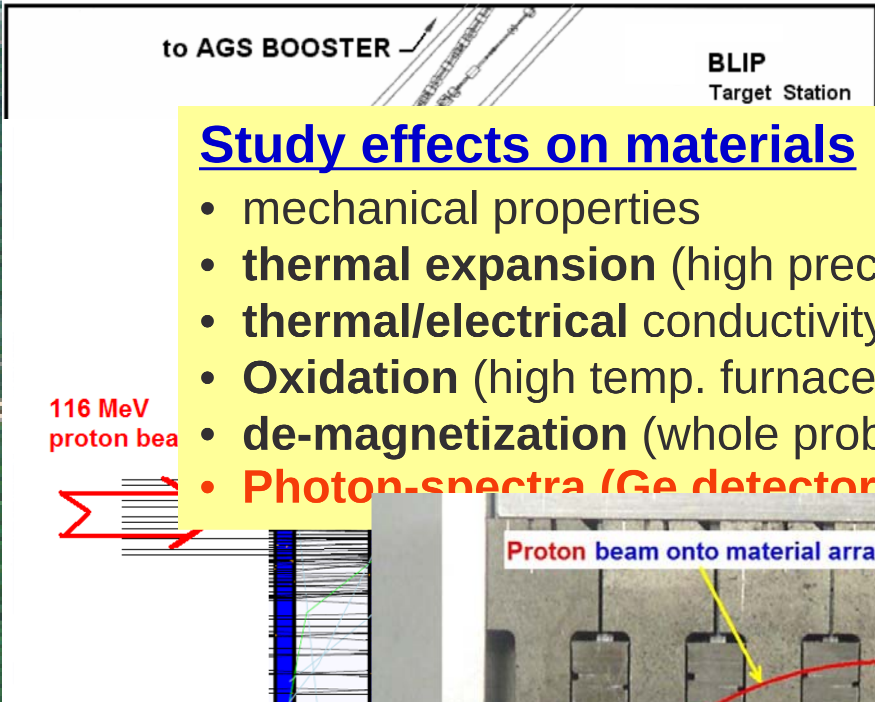


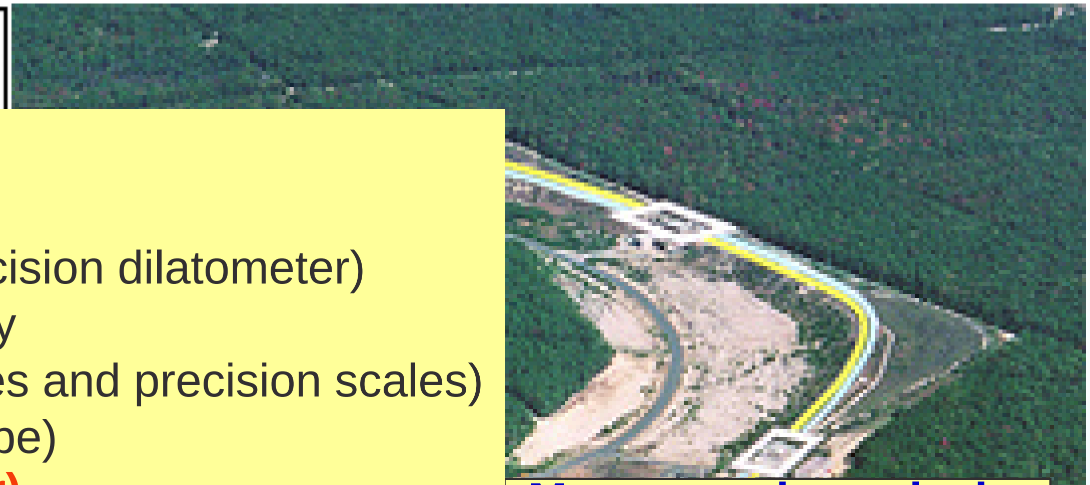


BNL Graphite and Carbon Composite Target SHOCK Test



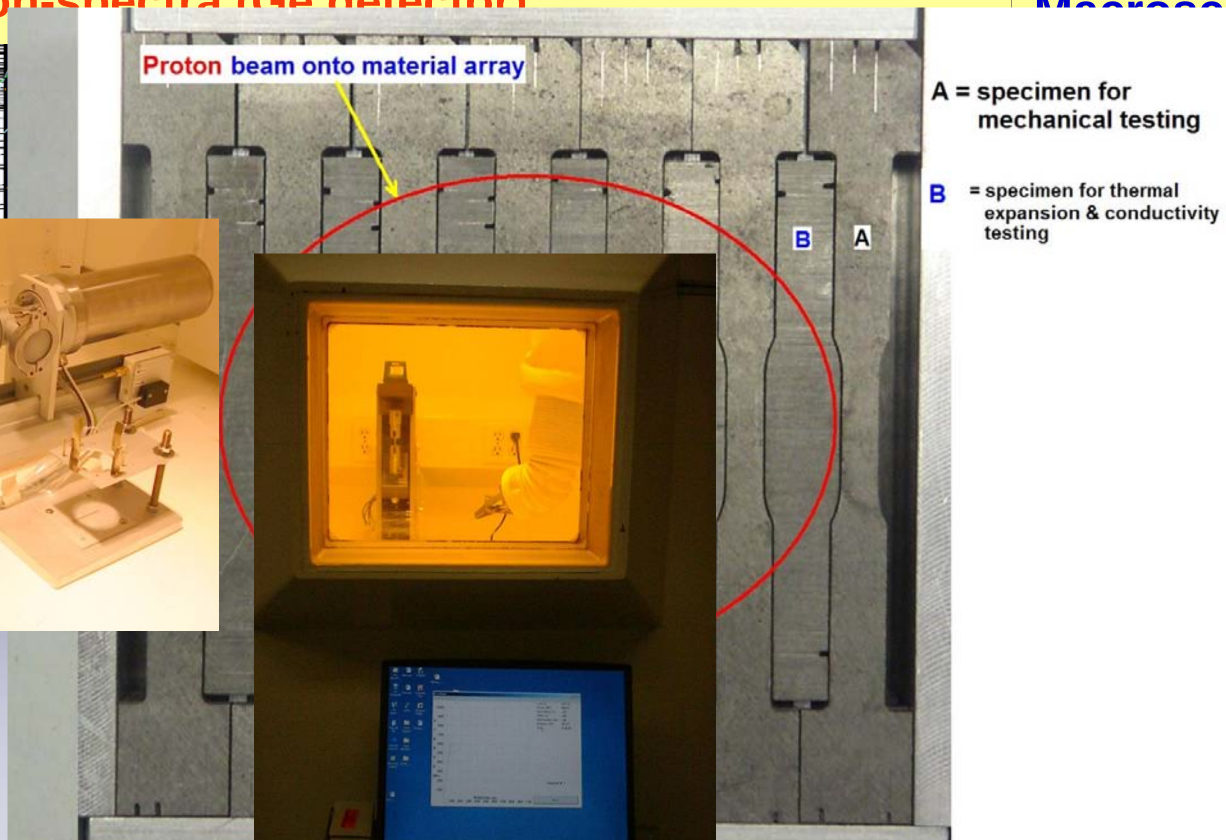




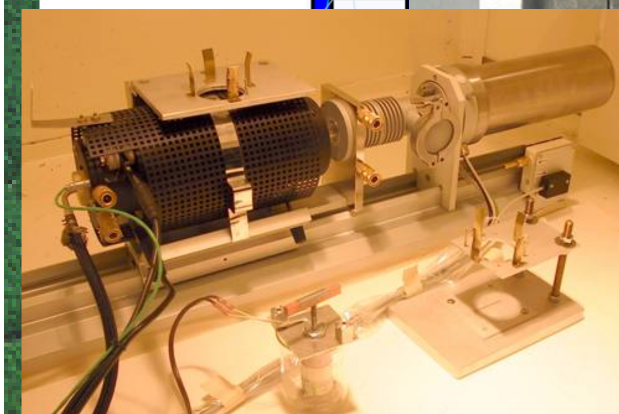


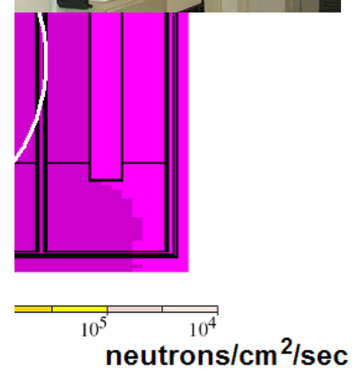
Study effects on materials

- mechanical properties
- **thermal expansion** (high precision dilatometer)
- **thermal/electrical** conductivity
- **Oxidation** (high temp. furnaces and precision scales)
- **de-magnetization** (whole probe)
- Photon-spectra (Ge detector)



Macroscopic analysis
L Hot Cells

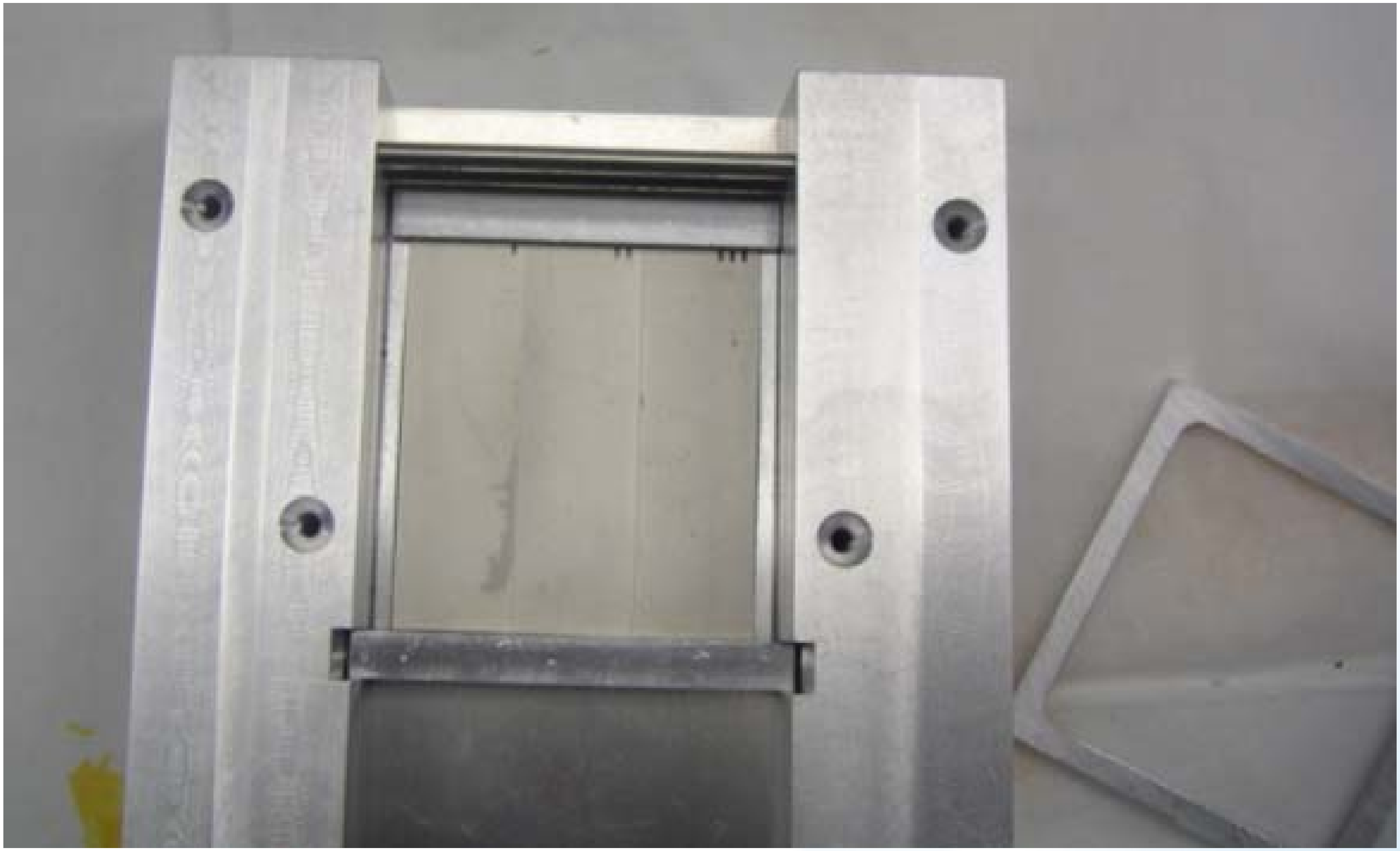




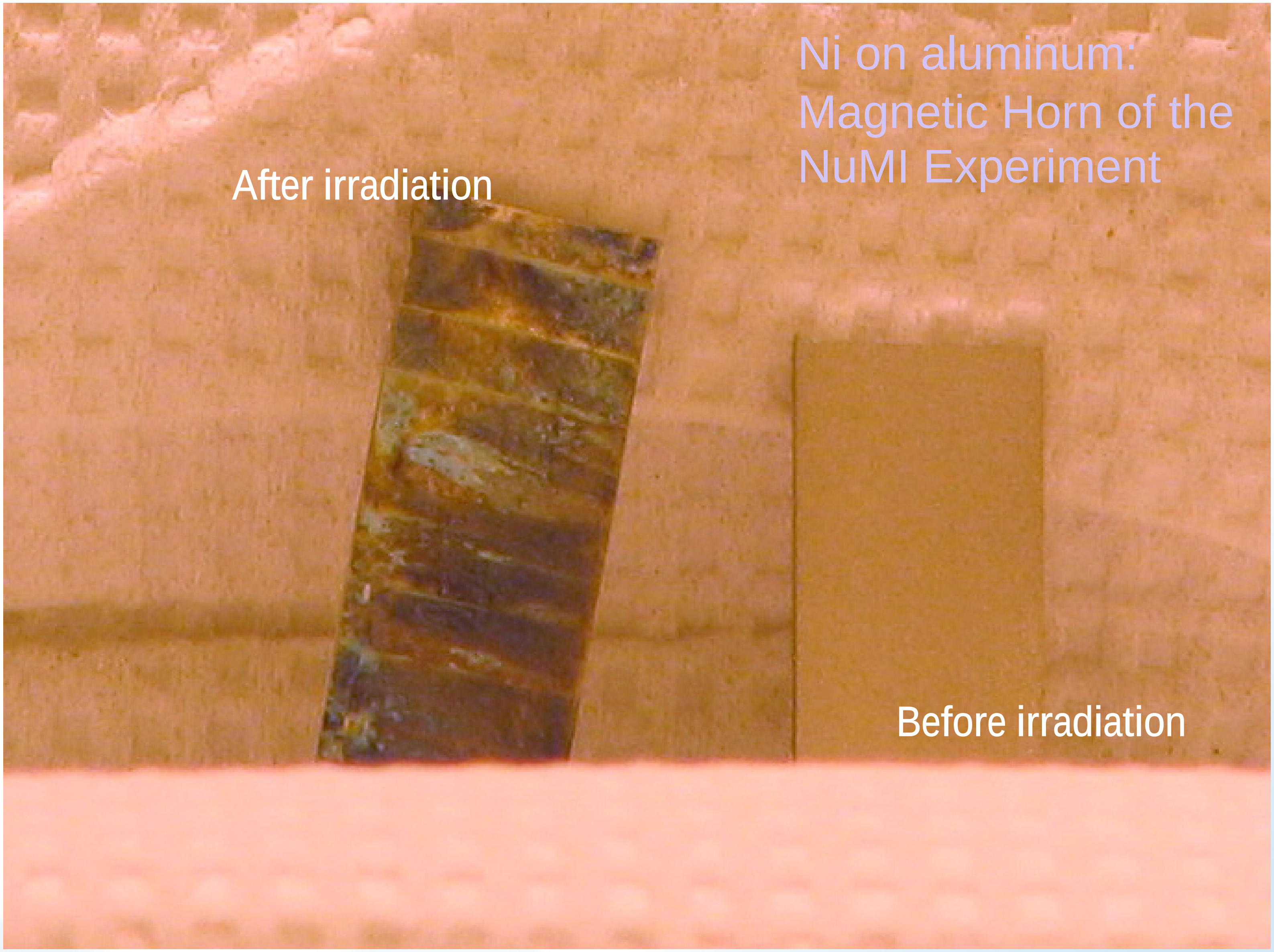
ation (by N. Mokhov, FNAL)

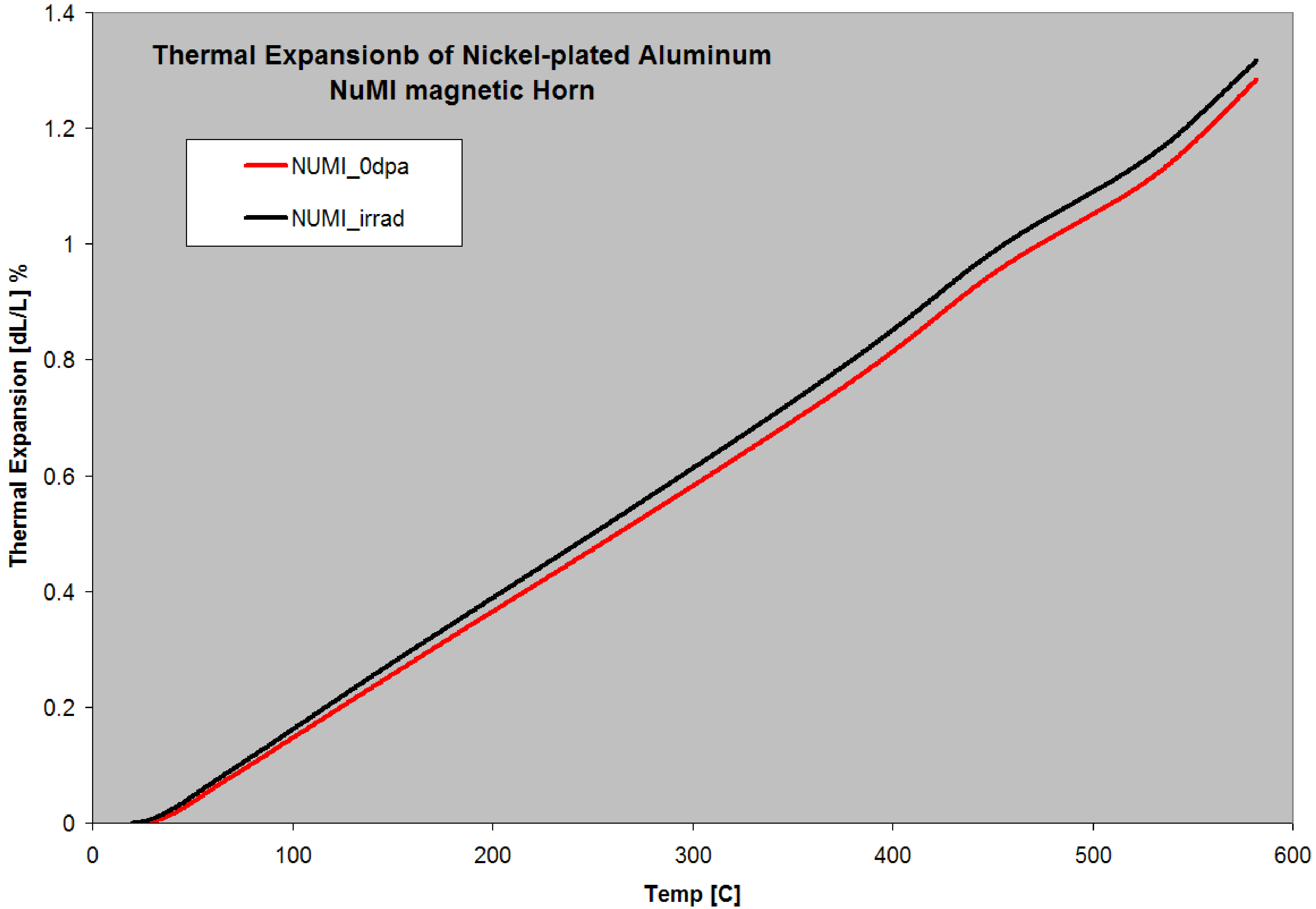
Horn Material Studies – NuMi Ni-plated Aluminum

Irradiation, temperature and corrosive environment effect on Ni film with aluminum substrate



Irradiation, temperature and corrosive environment effect on Ni film with aluminum substrate

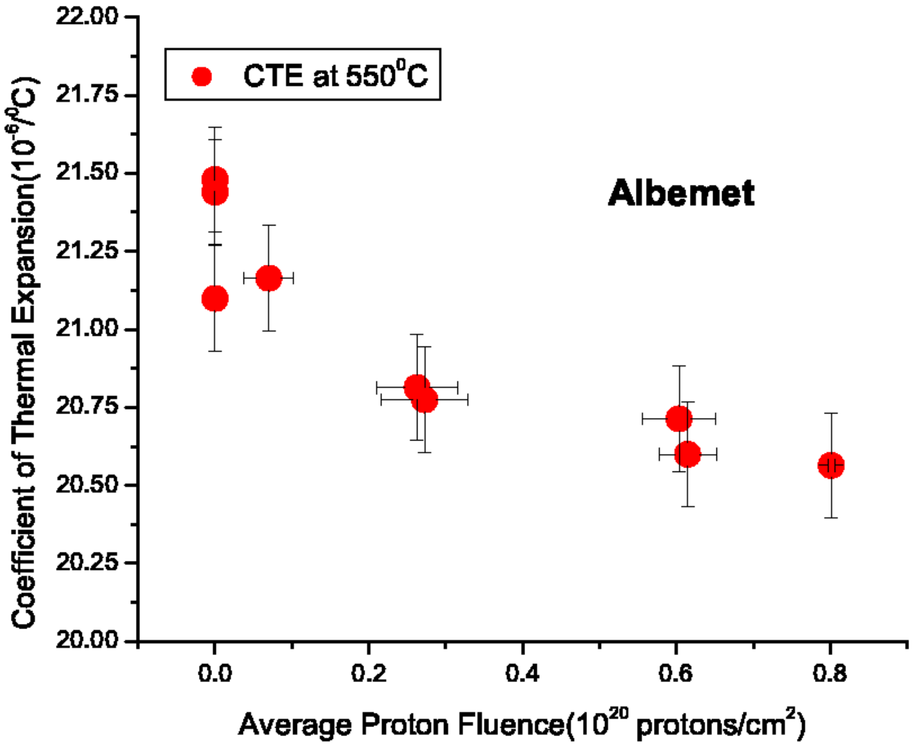


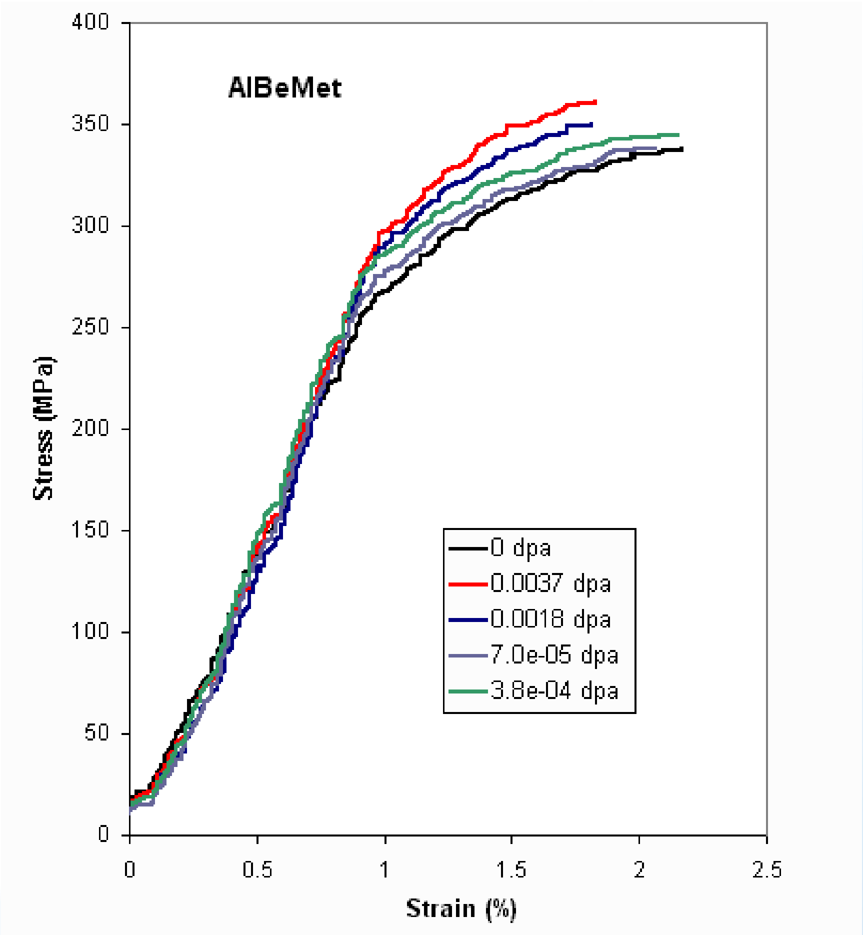

Thermal Expansionb of Nickel-plated Aluminum
NuMI magnetic Horn
NUMI_0dpa
NUMI_irrad
Thermal Expansion [dL/L] %
Temp [C]
0
0.2
0.4
0.6
0.8
1
1.2
1.4
0
100
200
300
400
500
600

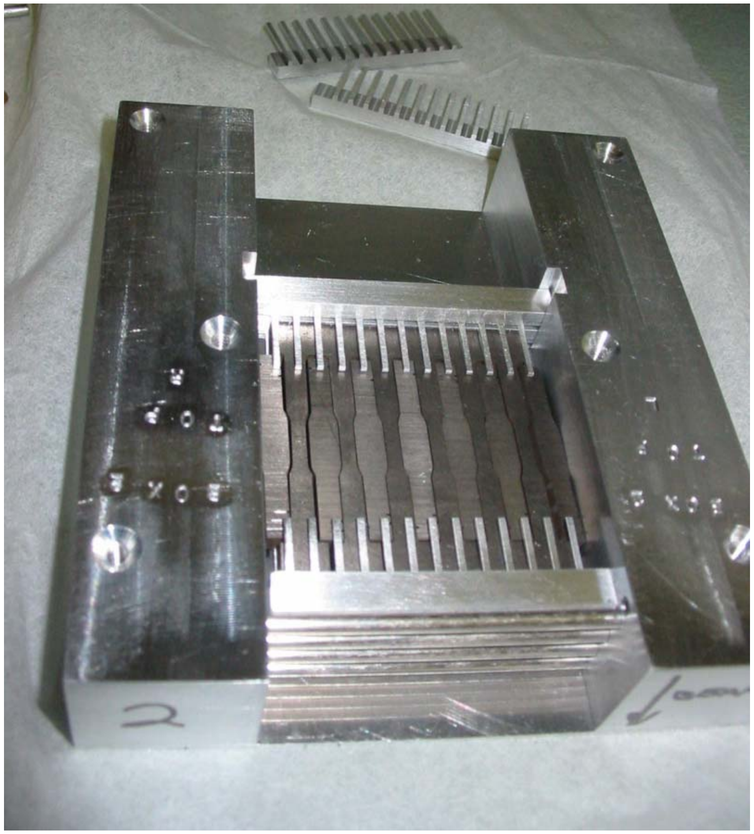
AlBeMet® Property Comparison

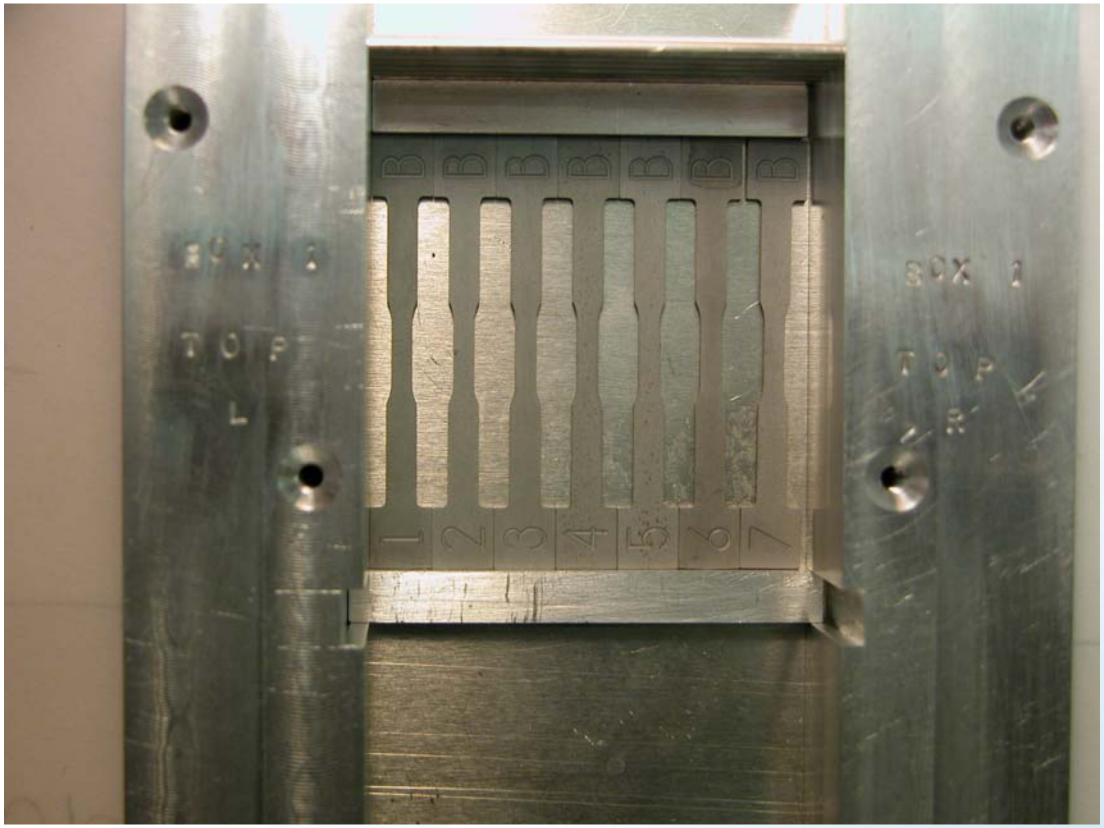
Property	Beryllium S200F/AMS7906	AlBeMet AM162H/AMS7911	E-Material E-60	Magnesium AZ80A T6	Aluminum 6061 T6	Stainless Steel 304	Copper H04	Titanium Grade 4
Density lbs/cuin (g/cc)	0.067 (1.85)	0.076 (2.10)	0.091 (2.51)	0.065 (1.80)	0.098 (2.70)	0.29 (8.0)	0.32 (8.9)	0.163 (4.5)
Modulus MSI (Gpa)	44 (303)	28 (193)	48 (331)	6.5 (45)	10 (69)	30 (206)	16.7 (115)	15.2 (105)
UTS KSI (Gpa)	47 (324)	38 (262)	39.3 (273)	49 (340)	45 (310)	75 (515)	45 (310)	95.7 (660)
YS KSI (Gpa)	35 (241)	28 (193)	N/A	36 (250)	40 (275)	30 (205)	40 (275)	85.6 (590)
Elongation %	2	2	< .05	5	12	40	20	20
Fatigue Strength KSI (Gpa)	37.9 (261)	14 (97)	N/A	14.5 (100)	14 (95)	N/A	N/A	N/A
Thermal Conductivity btu/hr/ft/F (W/m-K)	125 (216)	121 (210)	121 (210)	44 (76)	104 (180)	9.4 (16)	226 (391)	9.75 (16.9)
Heat Capacity btu/lb-F (J/g-C)	.46 (1.95)	.373 (1.56)	.310 (1.26)	.251 (1.05)	.214 (.896)	.12 (.5)	.092 (.385)	.129 (.54)
CTE ppm/F (ppm/C)	6.3 (11.3)	7.7 (13.9)	3.4 (6.1)	14.4 (26)	13 (24)	9.6 (17.3)	9.4 (17)	4.8 (8.6)
Electrical Resistivity ohm-cm	4.2 E-06	3.5 E-06	N/A	14.5 E-06	4 E-06	72 E-06	1.71 E-06	60 E-06

The AlBeMet Choice

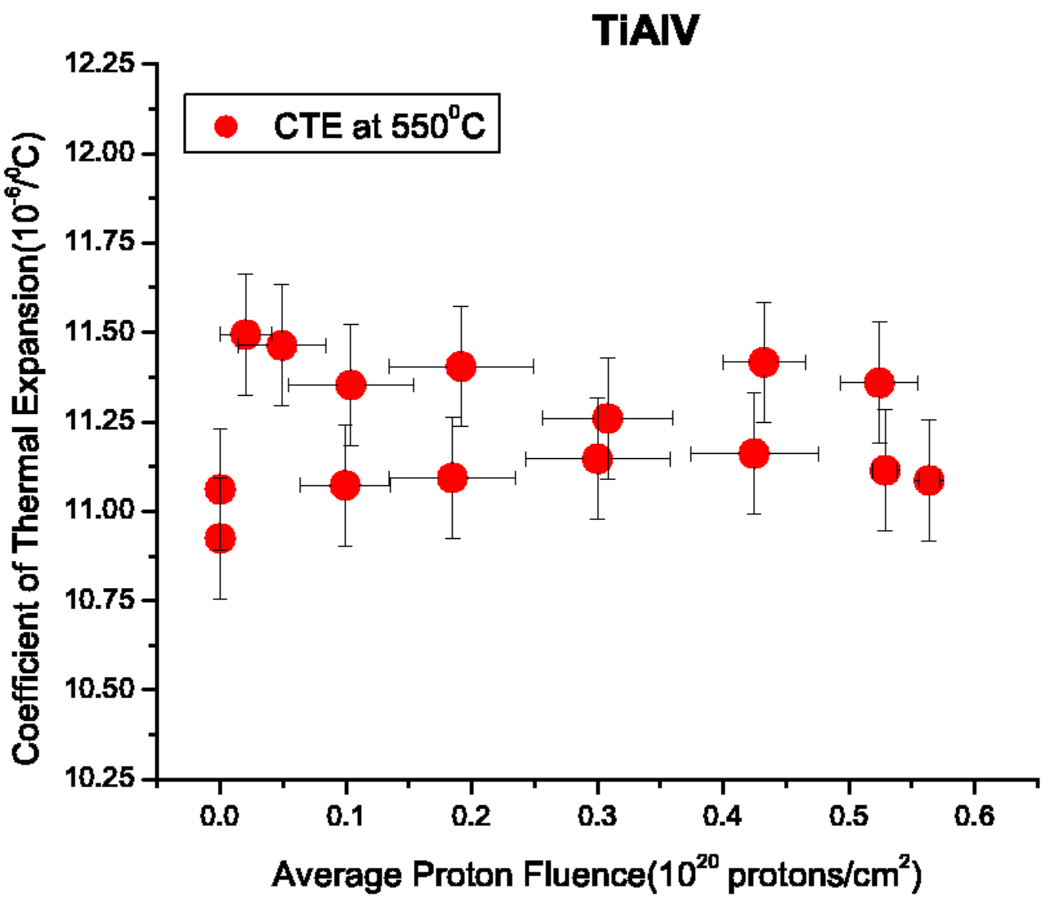


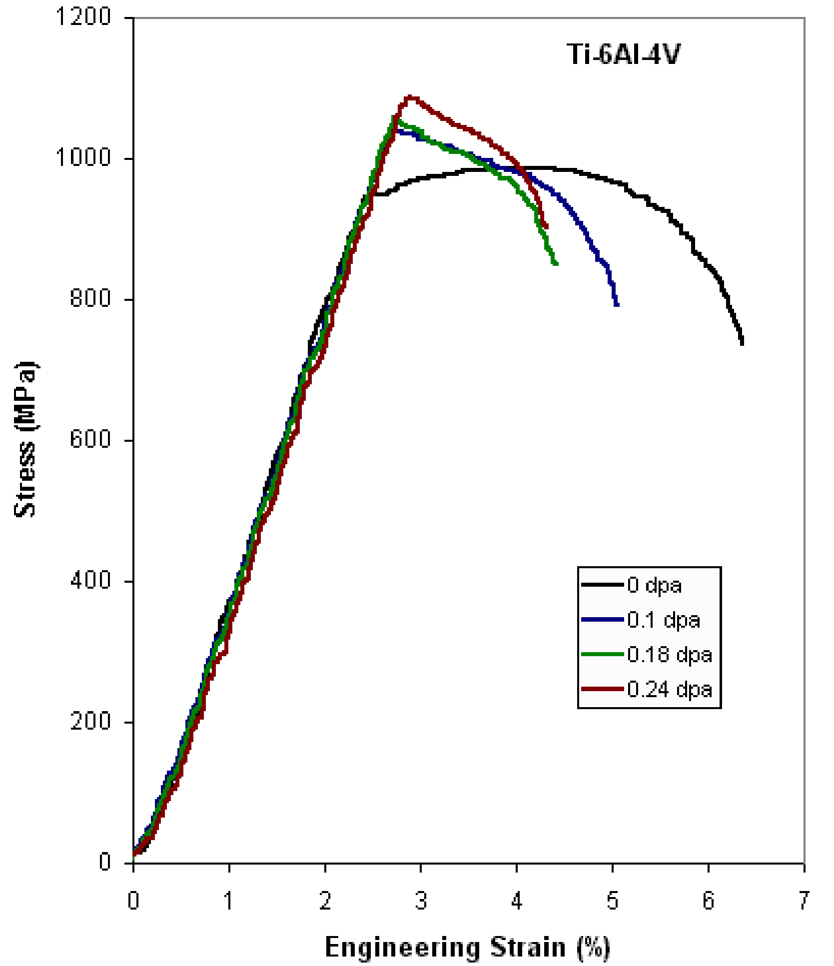





BOX 1
TOP
L
BOX 1
TOP
R
1
2
3
4
5
6
7

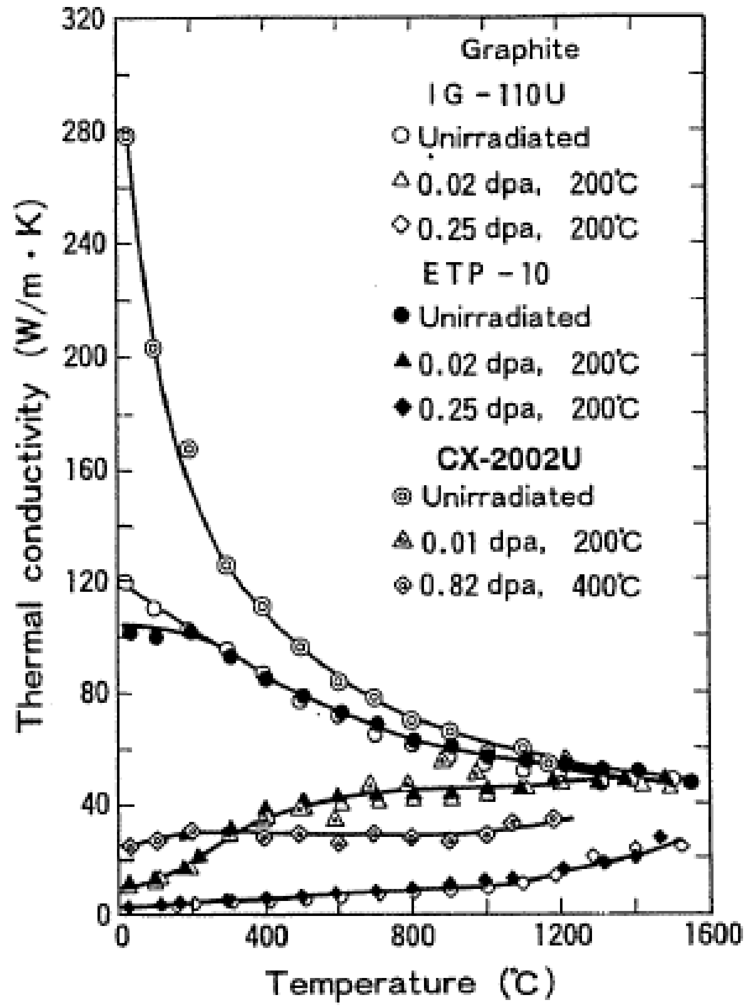
Radiation Damage of Ti-6Al-4V Substrate





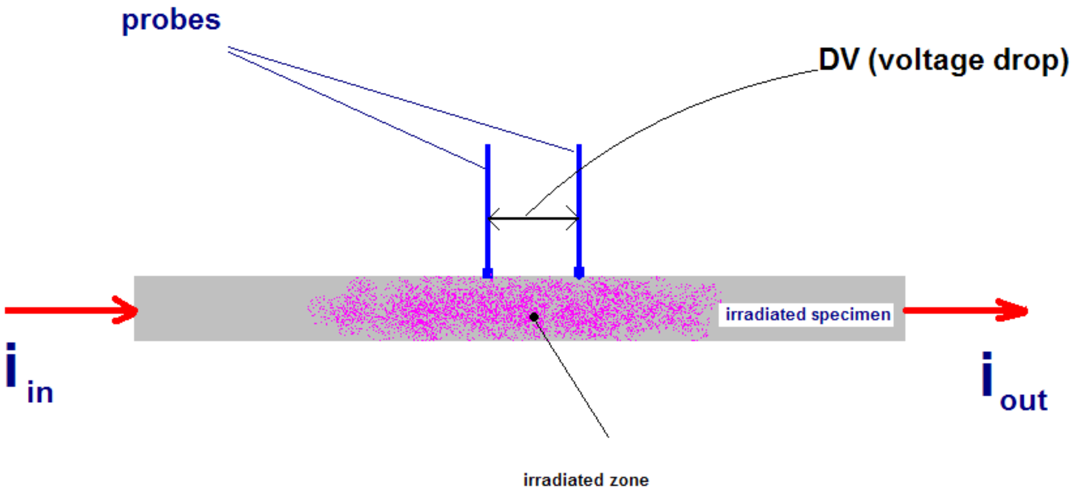
Resistivity-Conductivity Degradation

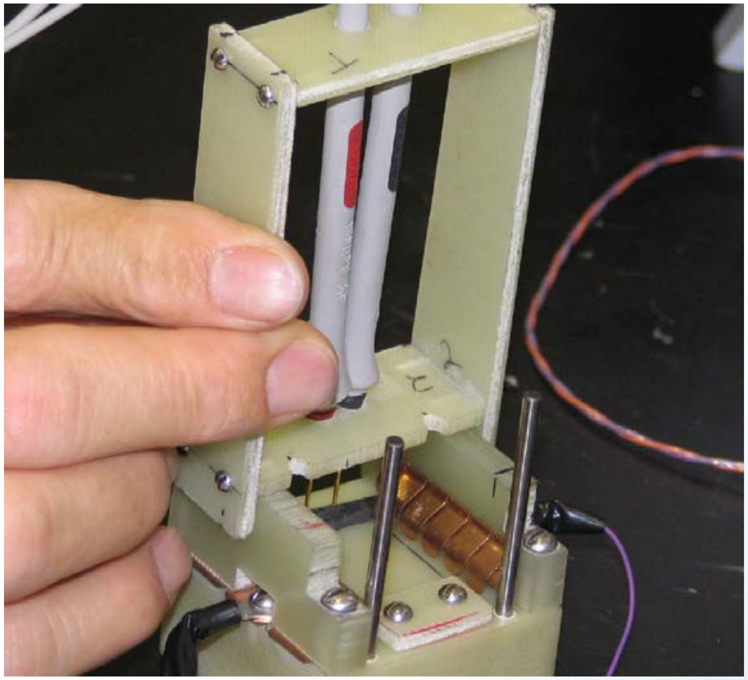
Thermal Conductivity and Radiation of Target

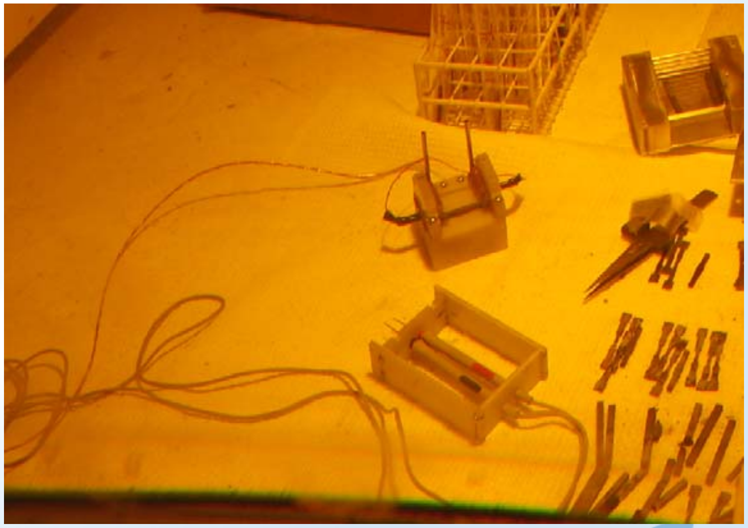


Thermal conductivity of neutron-irradiated graphites.

Electrical resistivity ➔ Thermal conductivity







Preliminary results

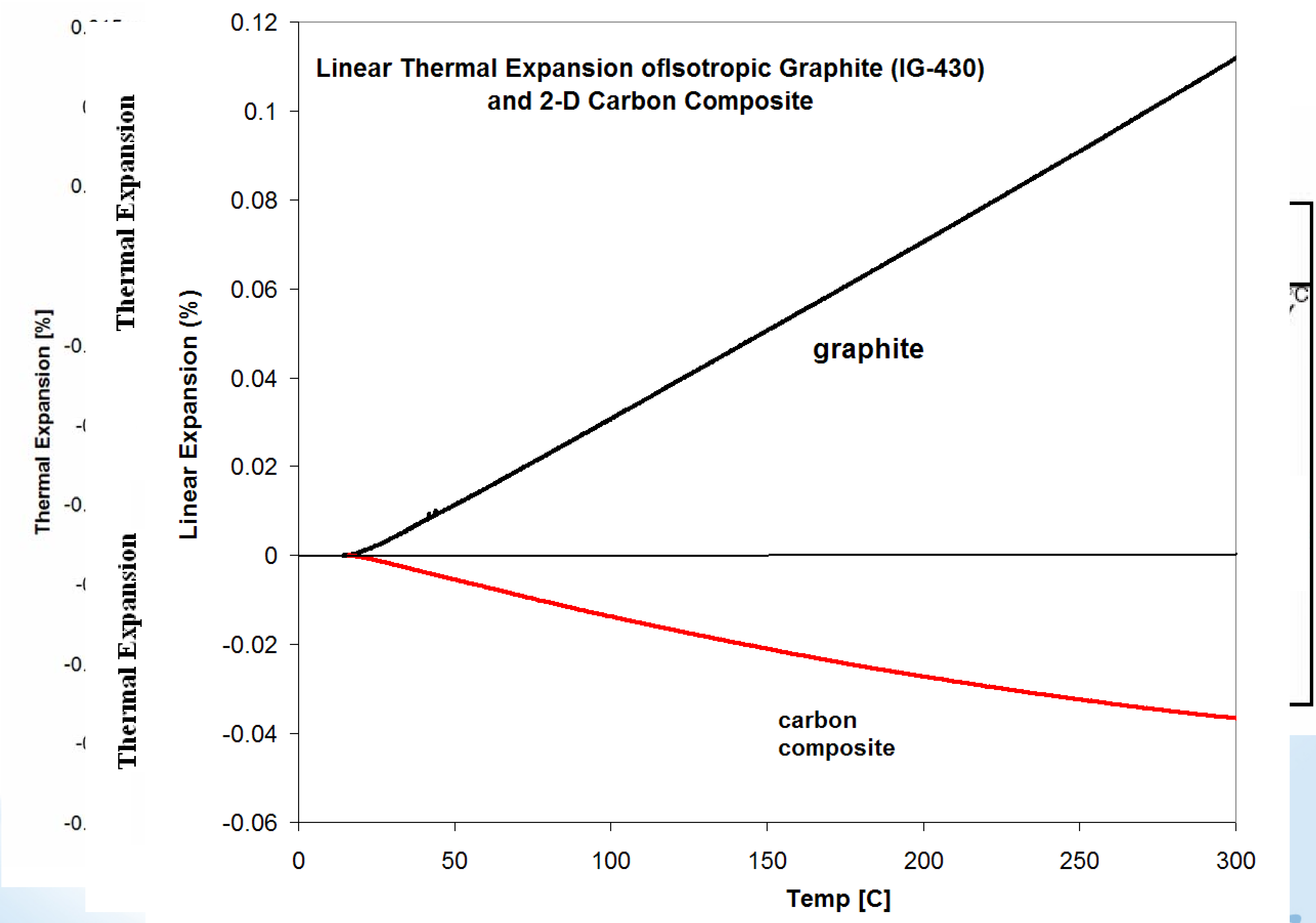
3-D CC (~ 0.2 dpa) conductivity reduces by a factor of 3.2

2-D CC (~0.2 dpa) measured under irradiated conditions (to be compared with company data)

Graphite (~0.2 dpa) conductivity reduces by a factor of 6 !!!!

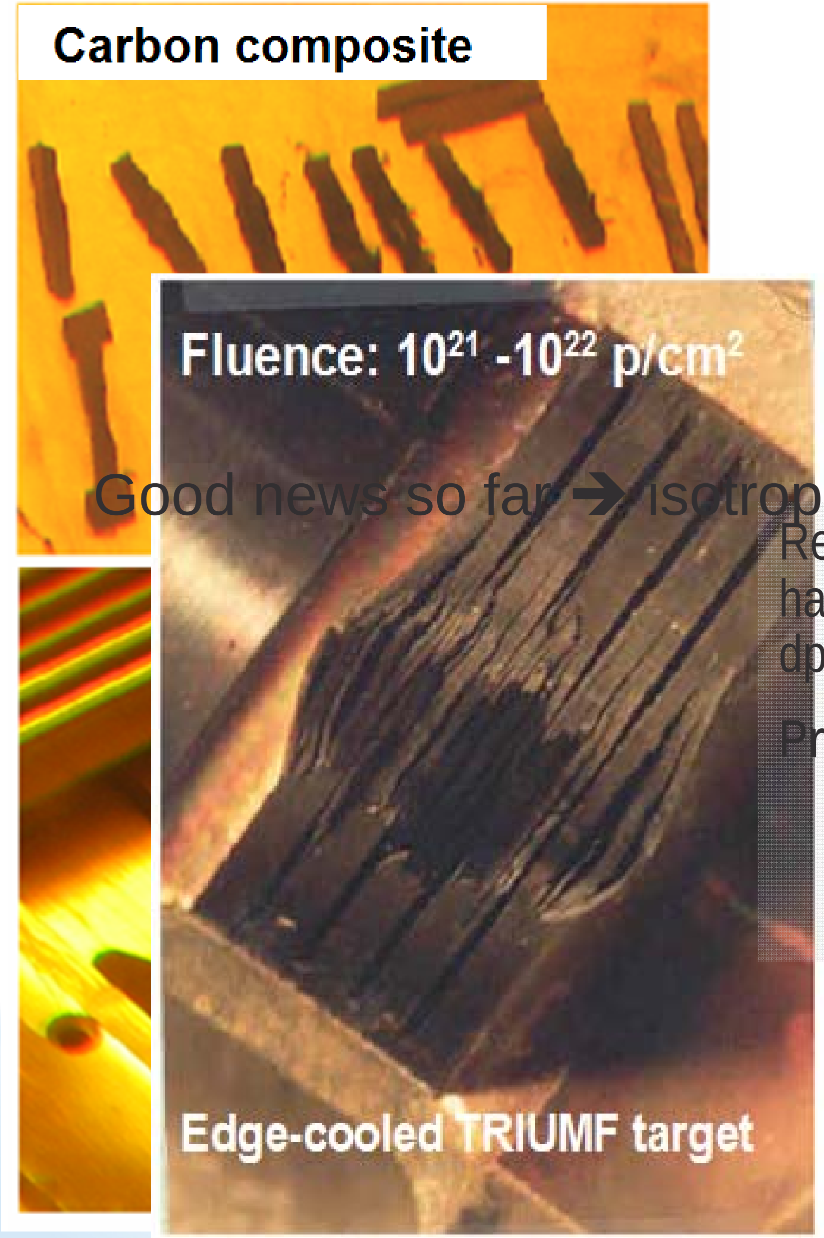
W (1+ dpa)	➔	reduced by factor of
Ta (1+ dpa)	➔	~ 40% reduction
Ti-6Al-4V (~ 1dpa)	➔	~ 10% reduction
Glidcop	➔	~ 40% reduction
AlBeMet (~0.4 dpa)	➔	within 10%

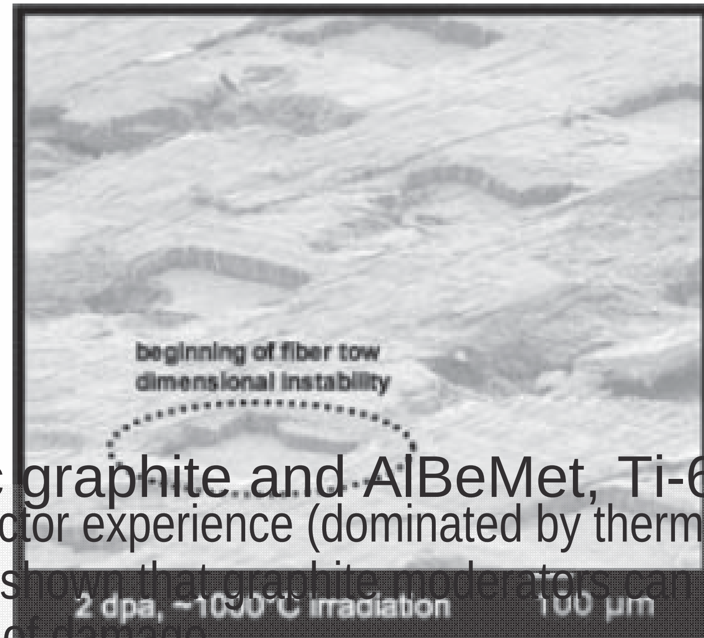
Graphite and carbon-carbon composites



While things seemed promising with carbon fiber composites

A THRESHOLD PROTON FLUENCE OF ~10^{21} protons/cm^2 HAS EMERGED





J-P. Bonal, et al., Graphite, Ceramics and Ceramic Composites for High-Temperature Nuclear Power Systems, MRS Bulletin, V. 34, 2009

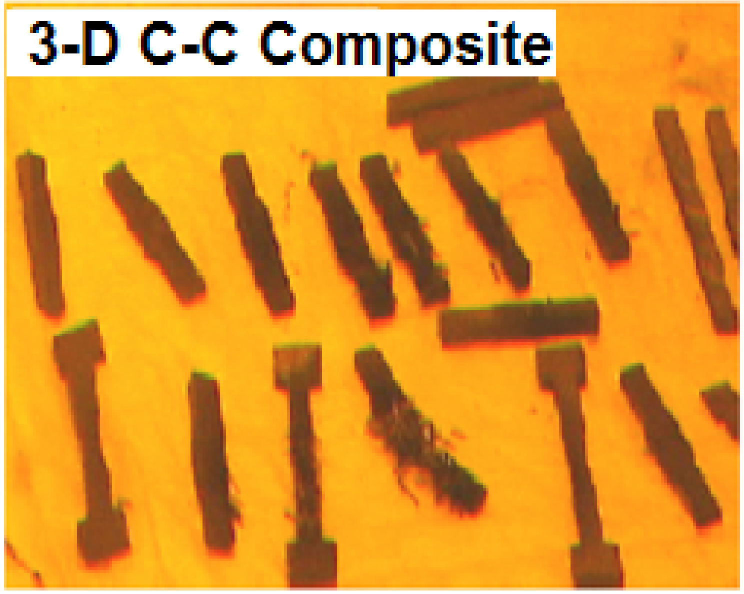
Good news so far → isotropic graphite and AlBeMet, Ti-6Al-4V

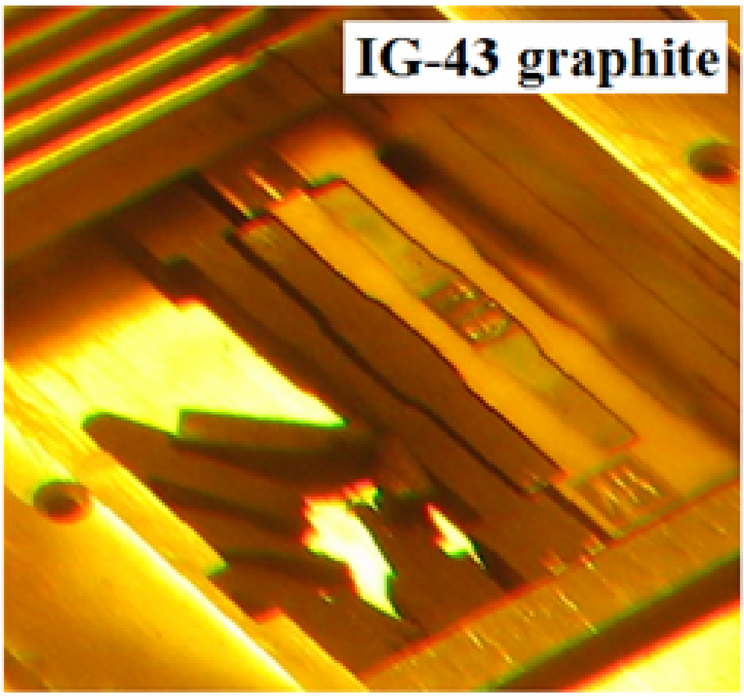
Reactor experience (dominated by thermal neutron flux) has shown that graphite moderators can withstand tens of dpa of damage

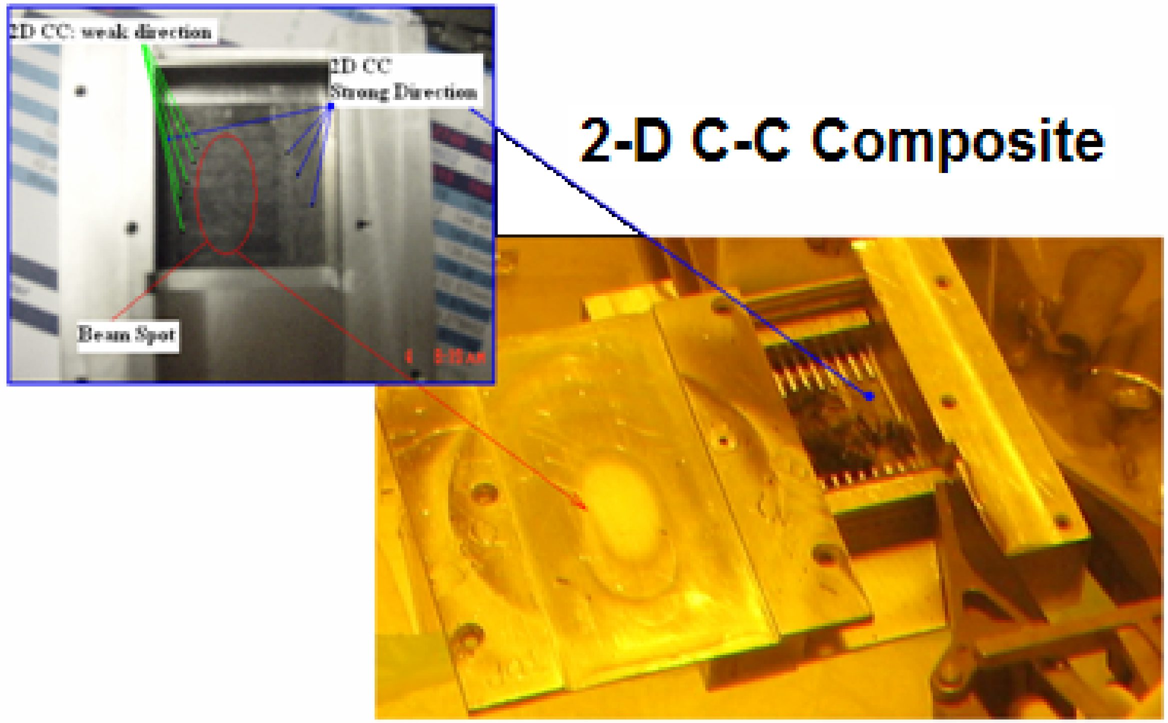
Premature degradation result of:

radiation rate?

or thermal neutrons vs. energetic protons ?





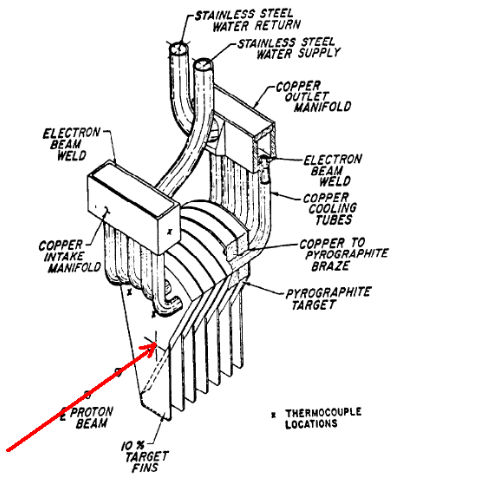


Threshold ~ 10^21 p/cm2

Graphite-CC experience

Accelerator Experience:

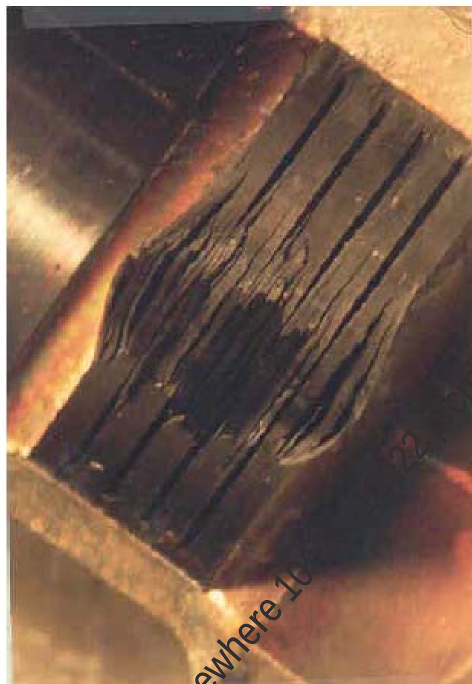
TRIUMF Target; LANL Target; PSI Target



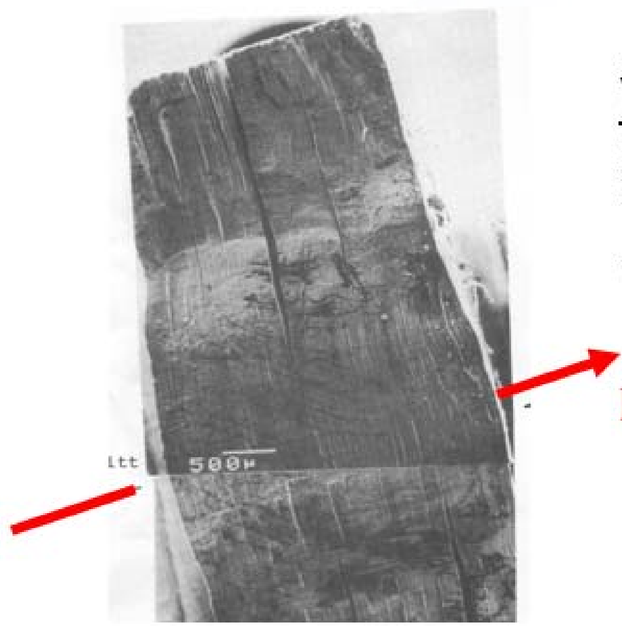
The cracks running through the plates develop at proton fluences above about 2×10^{25} P/m^2. Plates from targets irradiated to about 0.5 of this fluence show extensive delamination, but lack the macroscopic cracks across the a-b planes. These results indicate that pyrolytic graphite is very susceptible 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^… 10^22 p/cm2

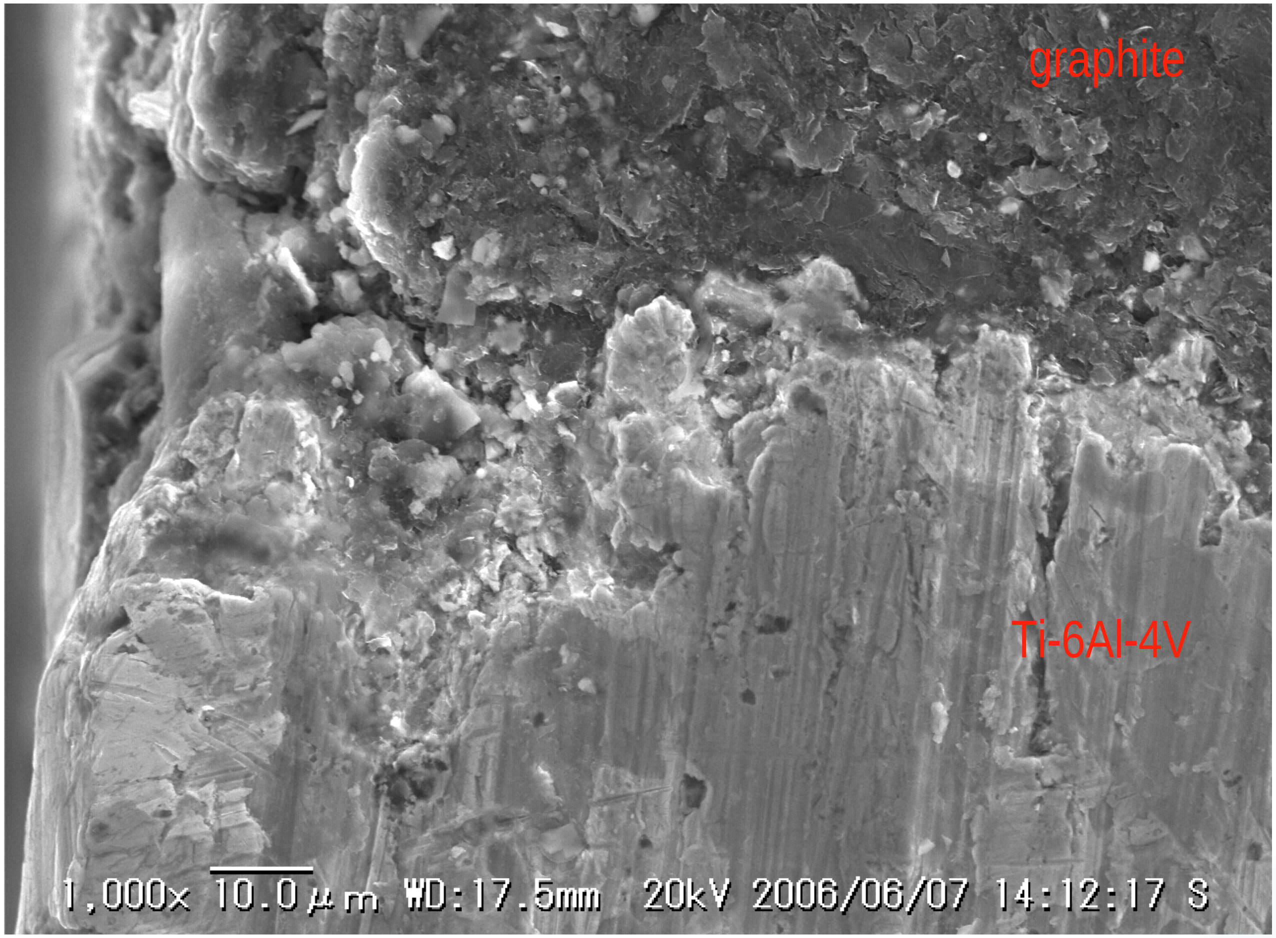


Swelling of the target after irradiation

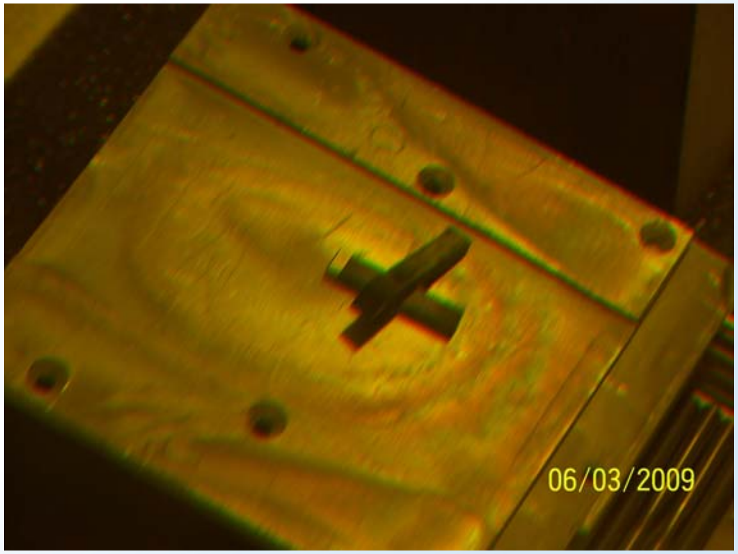
10^{22} p/cm2

radiation-cooled

High operating temp ~1100 C


graphite
Ti-6Al-4V
1,000x 10.0 µm WD:17.5mm 20kV 2006/06/07 14:12:17 S


06/03/2009


06/03/2009

Summary

A fluence threshold of ~ 10^21 p/cm2 has emerged that affects graphite and different carbon composite structures

Isotropic graphite (IG-430) appears to have more resilience (needs further study)

AlBeMet has experienced no structural damage due to radiation and environment

Proposed Studies

Address the effect of the environment on the physical/structural changes of graphite and carbon composites due to irradiation and identify limits

Explore isotropic graphite grades for irradiation damage that correspond to 2 MW beam

Horn material assessment for resistivity degradation under irradiation and corrosive environment (2 MW operation)

- Skin Effect and resistance
- physio-mechanical property changes
- Horn options with materials other than Al (Albemet) or nano-coatings

Horn inner conductor-Target integration tests and high-end simulations (current through horn, cooling schemes such as helium, monolithic conductor/target made of AlBeMet, etc)