OVERVIEW

Material Irradiation Damage Studies at BNL BLIP

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(BLIP = Brookhaven Linac Isotope Production Facility)

Study effects of:

Proton and/or neutron irradiation
on promising solid high-power TARGET materials
(*i.e.*, various graphite grades, carbon composites, low-*Z* composites such as AlBeMet, super-alloys)

- **mechanical properties**
- **thermal expansion**
- **thermal annealing**
- **thermal/electrical conductivity**
- **Oxidation** (high temp. furnaces and precision scales)
- **Photon-spectra (Ge detector)**

Also, take advantage of the primary proton beam as well as of the neutron field generated thru spallation with isotope targets to study:

- Nano-structured protective coatings and films (NuMI horn material, alumina and/or titania nano-coatings)
- Detector crystals (CZT or SiO_2 for LHC 0-degree calorimeter)
- Permanent Magnet demagnetization (Hall probe)

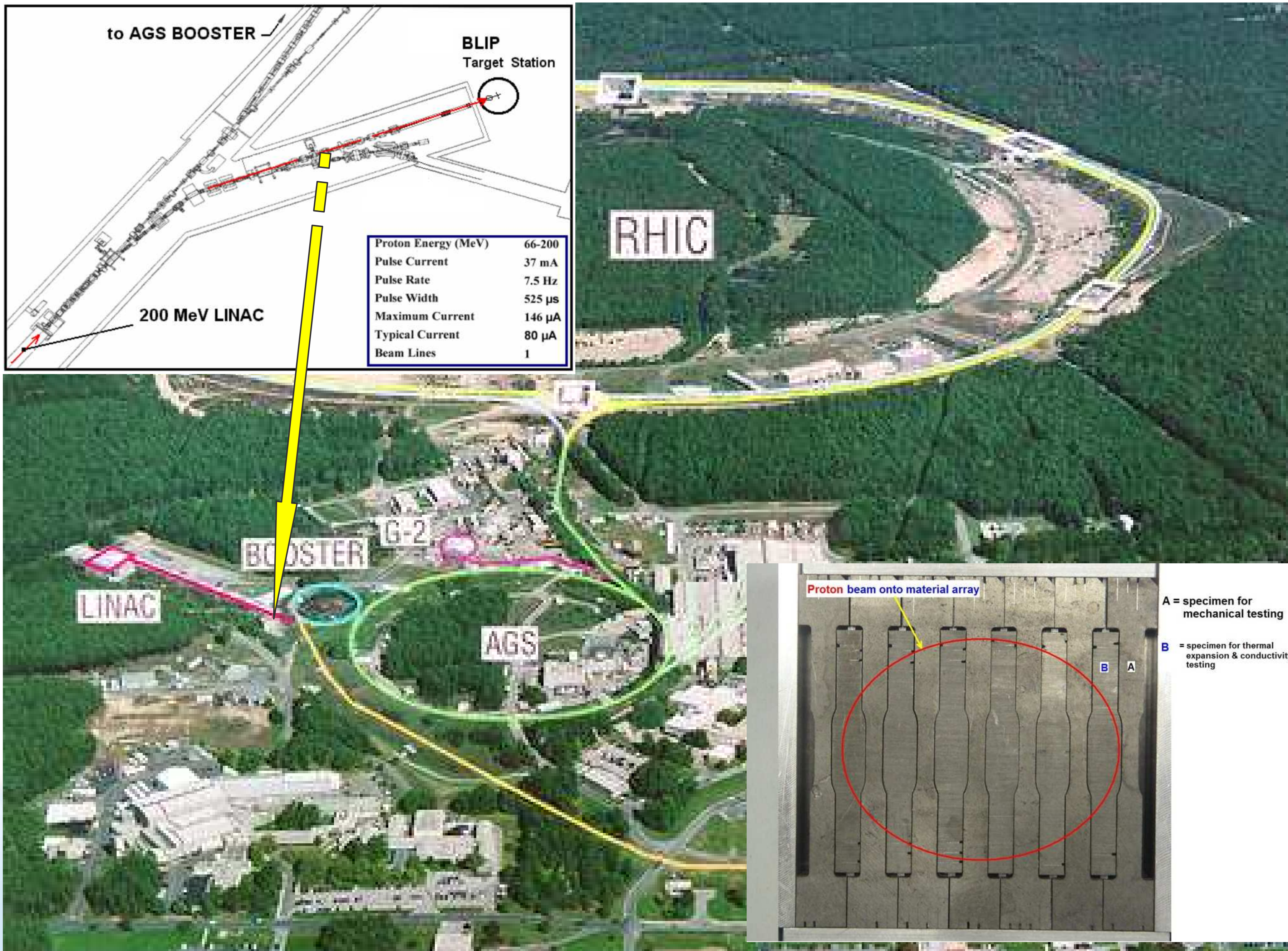
Use the BNL Linac proton beam to induce Radiation Damage by:

200 MeV or 112 MeV Protons from the BNL Linac

or by

Neutron irradiation from spallation (protons on isotope targets) upstream

(includes, other than the predominant neutrons, secondary protons, electrons and gammas)



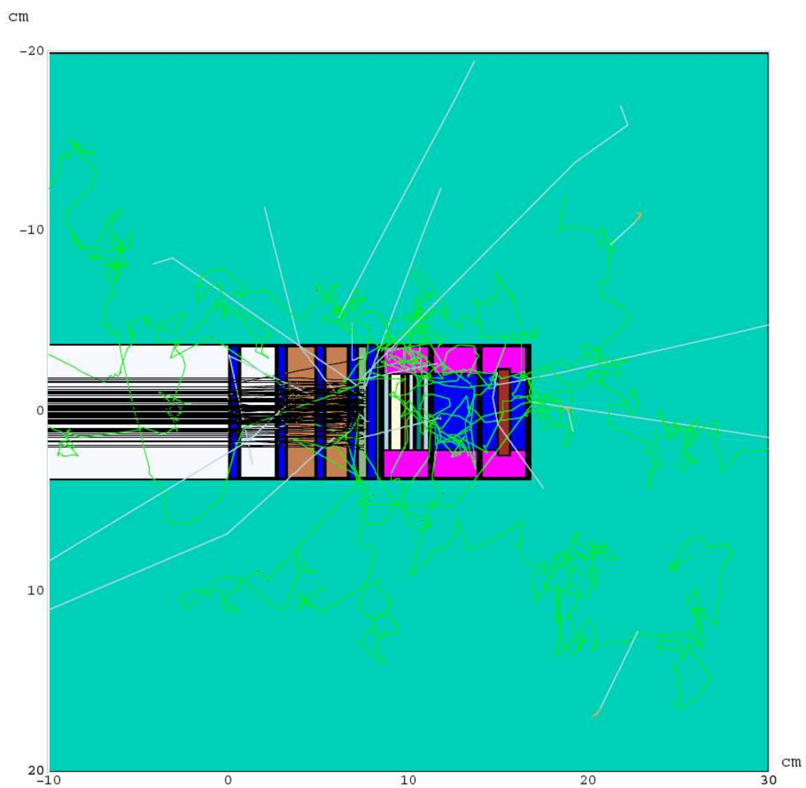
Proton Energy (MeV)	66-200
Pulse Current	37 mA
Pulse Rate	7.5 Hz
Pulse Width	525 µs
Maximum Current	146 µA
Typical Current	80 µA
Beam Lines	1

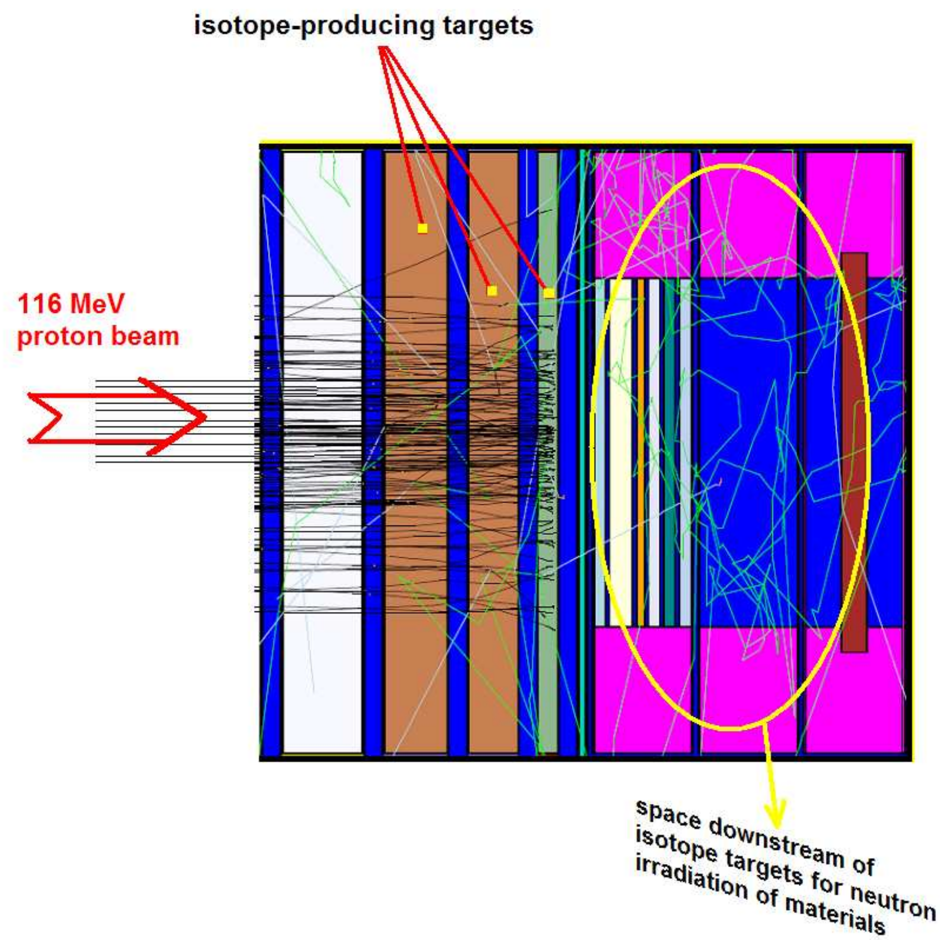
BLIP Parameters

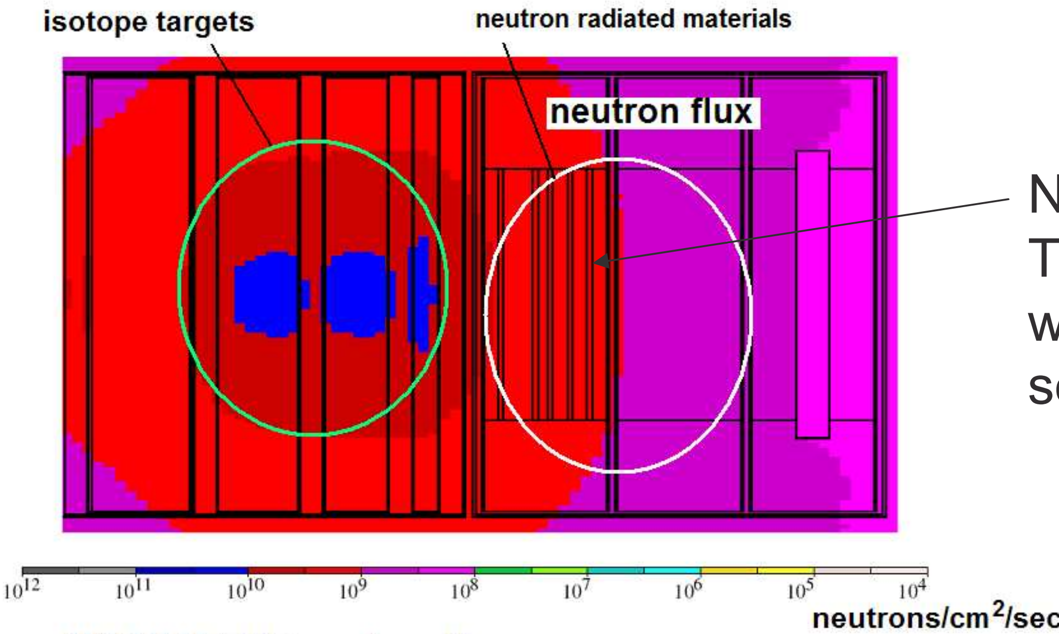
Rep Rate	=	6.67 Hz
Pulse Length	=	440 micro-secs
Micropulse length	=	5 ns
Micropulse structure	=	200.25 MHz
Average Current*	=	79-80 micro-A
6 sigma beam within	=	2-inch diameter
Beam Gaussian	==>	1 sigma = 4.233 mm

* Average current in previous RUNS averaged from 82 to 94 micro-Amps

BLIP Target Station Set-up for medical isotope production and target material irradiation

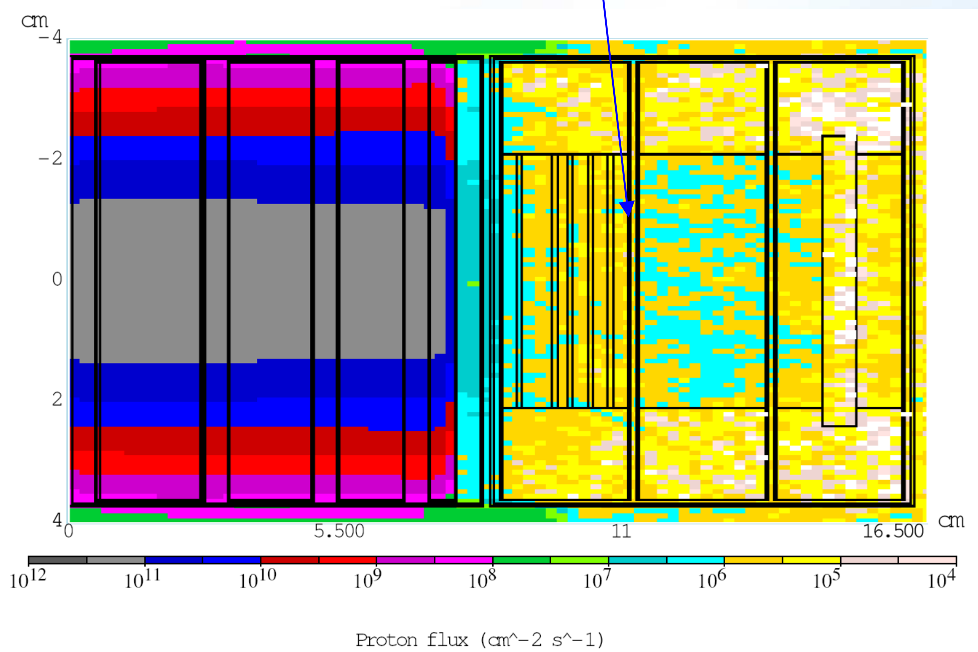




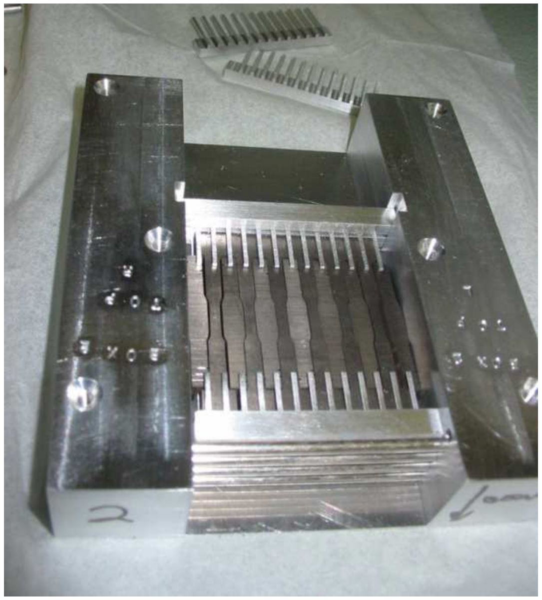


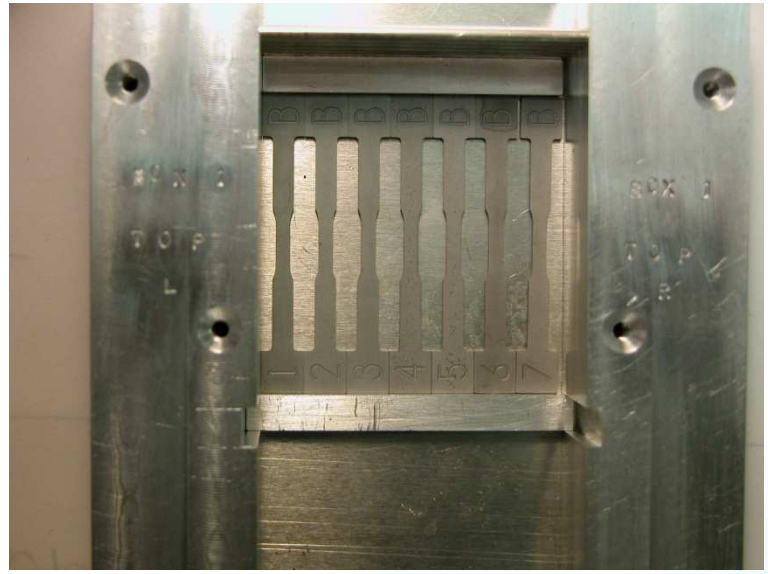
NORMALIZED neutron flux at BLIP target station (by N. Mokhov, FNAL)

Neutron and Proton Fluxes at Target Material space during when BLIP is used as "neutron source"

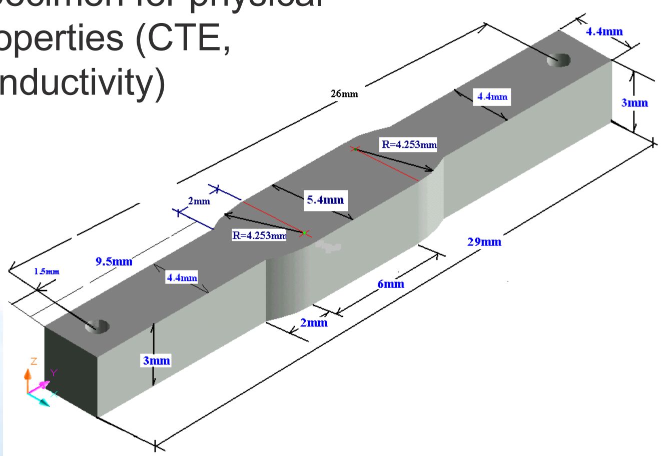


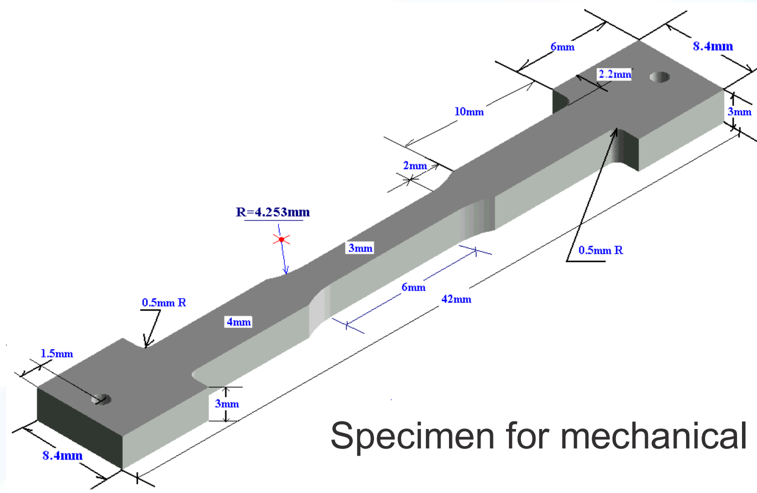
Typical assembly of target material irradiation specimens



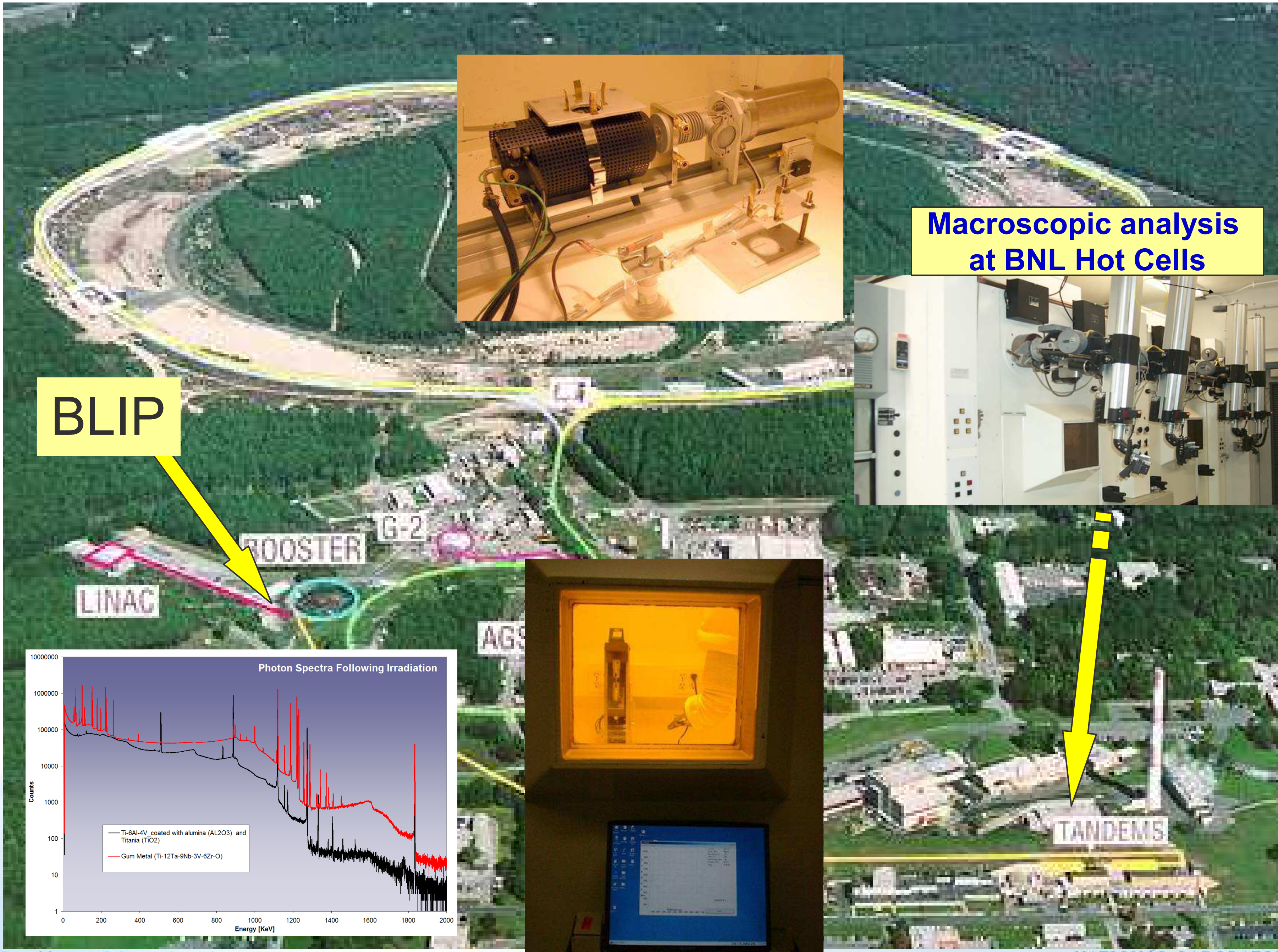


Specimen for physical properties (CTE, conductivity)





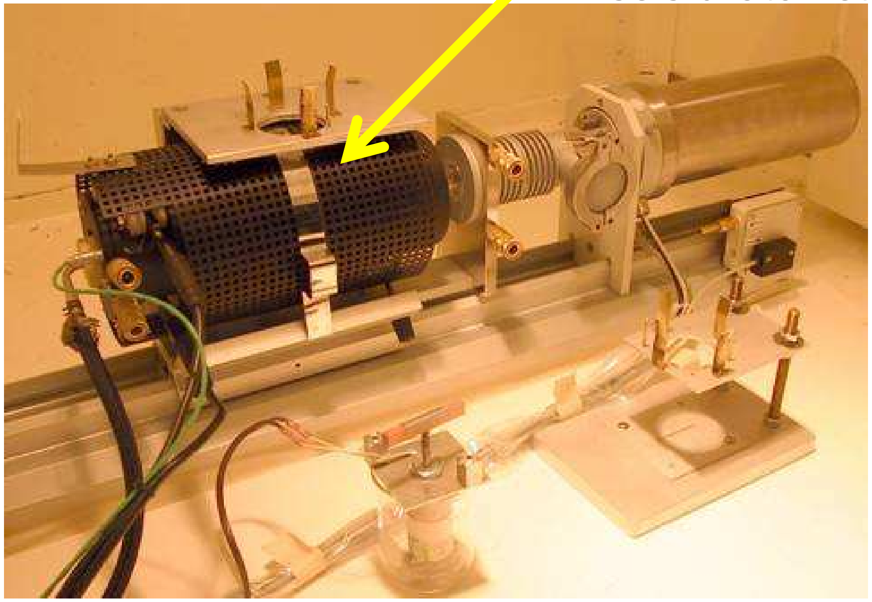
Specimen for mechanical properties

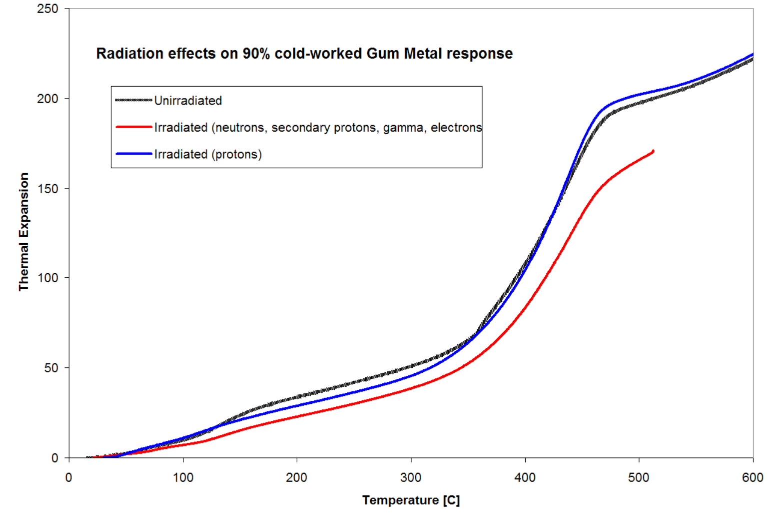

Macroscopic analysis at BNL Hot Cells
BLIP
BOOSTER
G-2
LINAC
AGS
TANDEMS
Photon Spectra Following Irradiation
Counts
Energy [KeV]
Ti-6Al-4V_coated with alumina (AL2O3) and Titania (TiO2)
Gum Metal (Ti-12Ta-9Nb-3V-6Zr-O)
10000000
1000000
100000
10000
1000
100
10
1
0
200
400
600
800
1000
1200
1400
1600
1800
2000

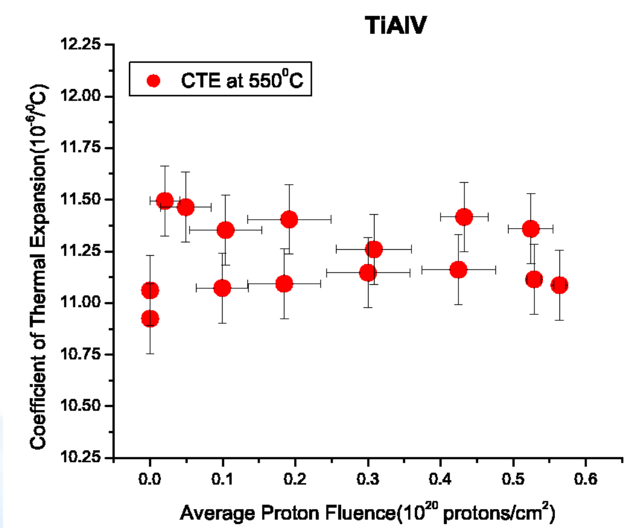
High-Sensitivity Measurements of Thermal Expansion (prior & after irradiation)

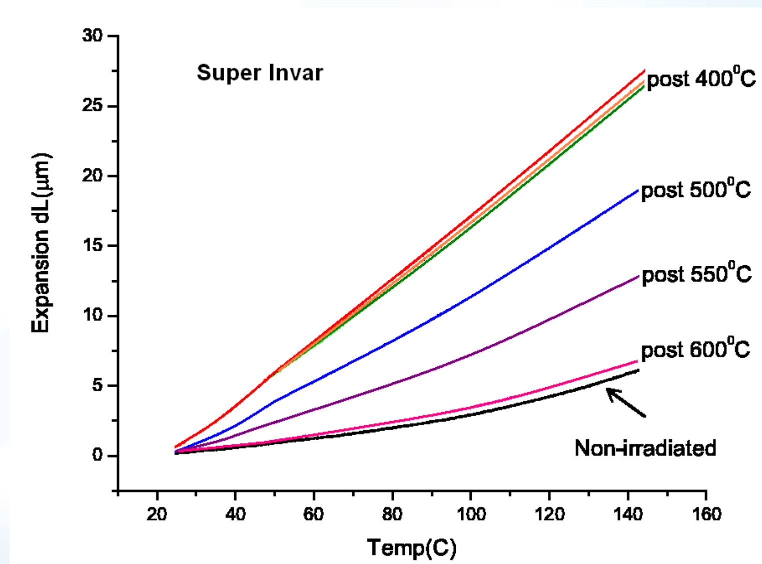
Controlled post-irradiation Annealing

Linseis dilatometer

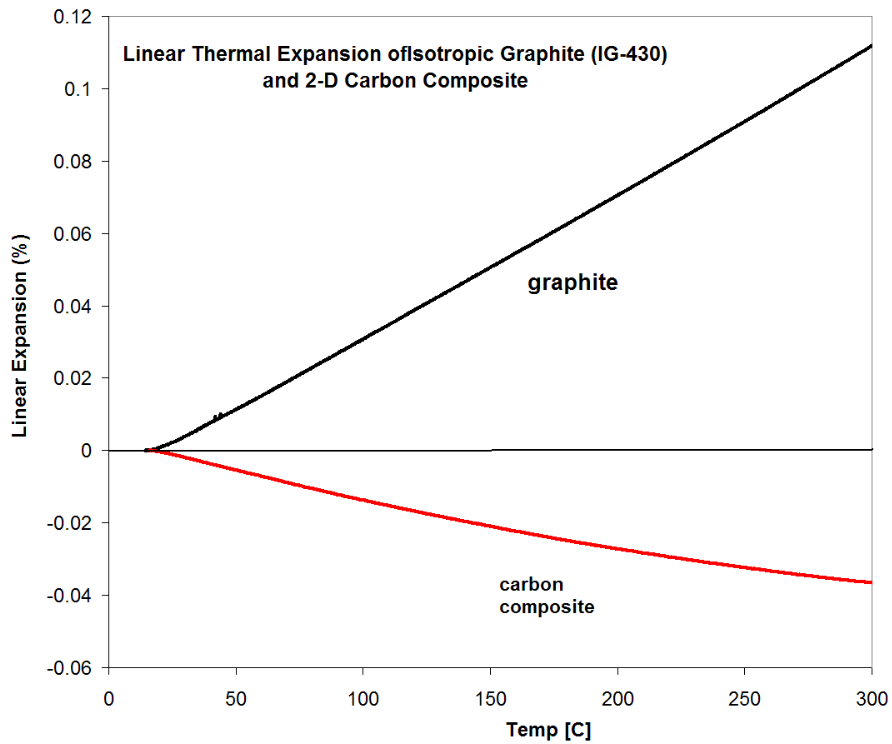


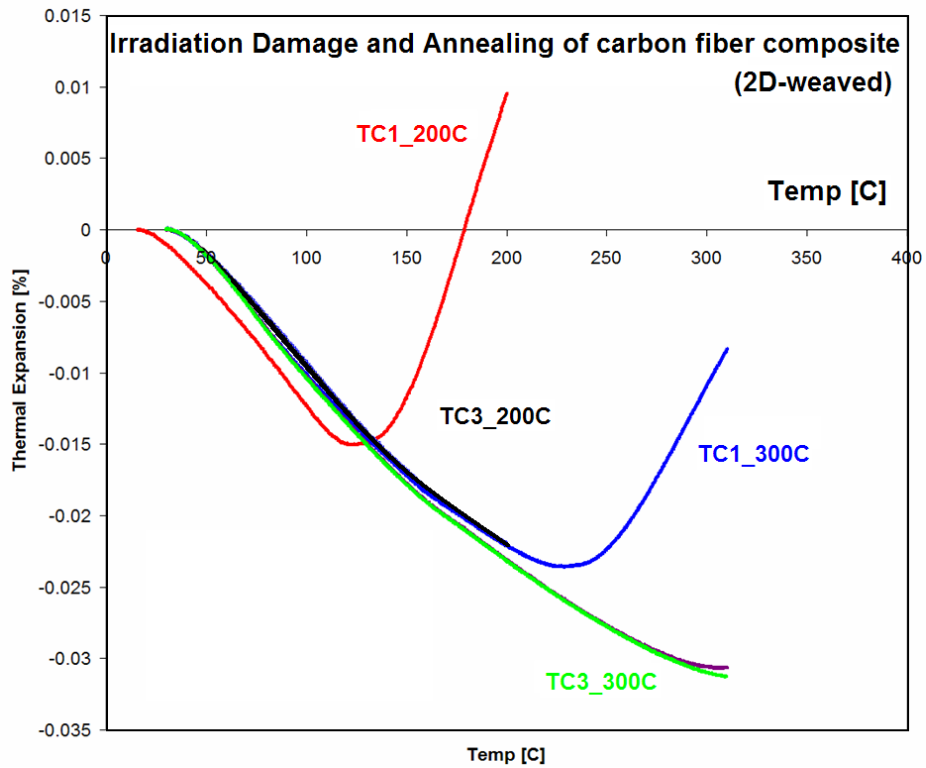






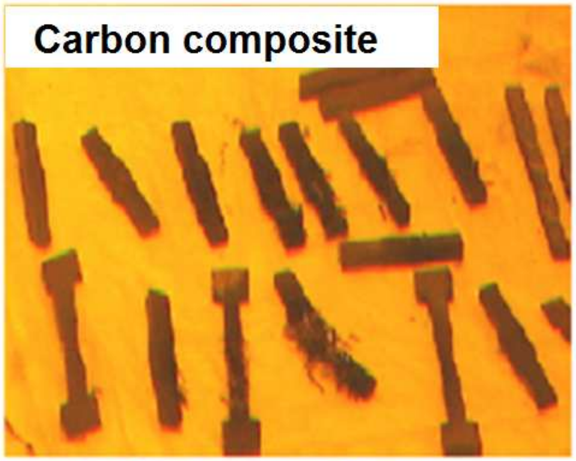
Studies of radiation damage reversal in graphite and carbon-carbon composite

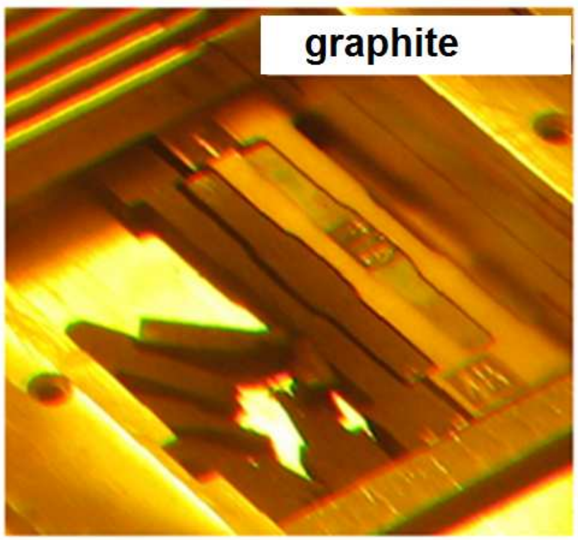


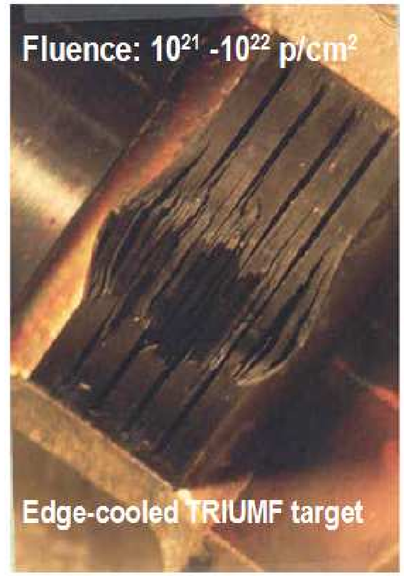


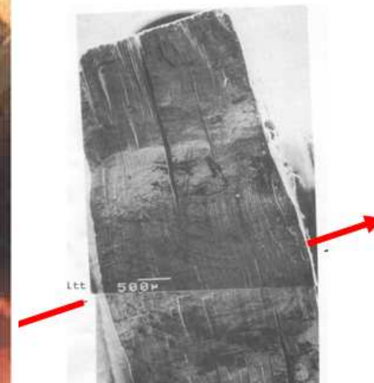
Damage Assessment of Graphite and Carbon Composite

IDENTIFICATION OF AN IMPORTANT FLUENCE THRESHOLD ~10^21 protons/cm2



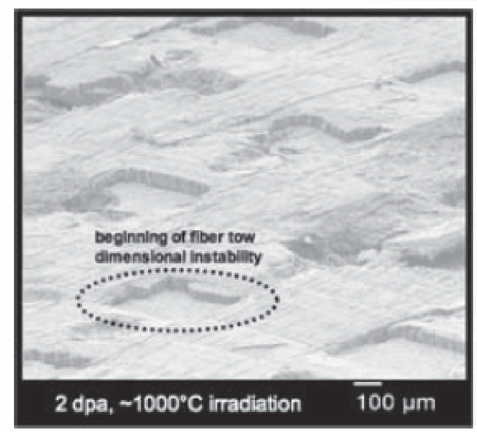






Swelling of the target after irradiation

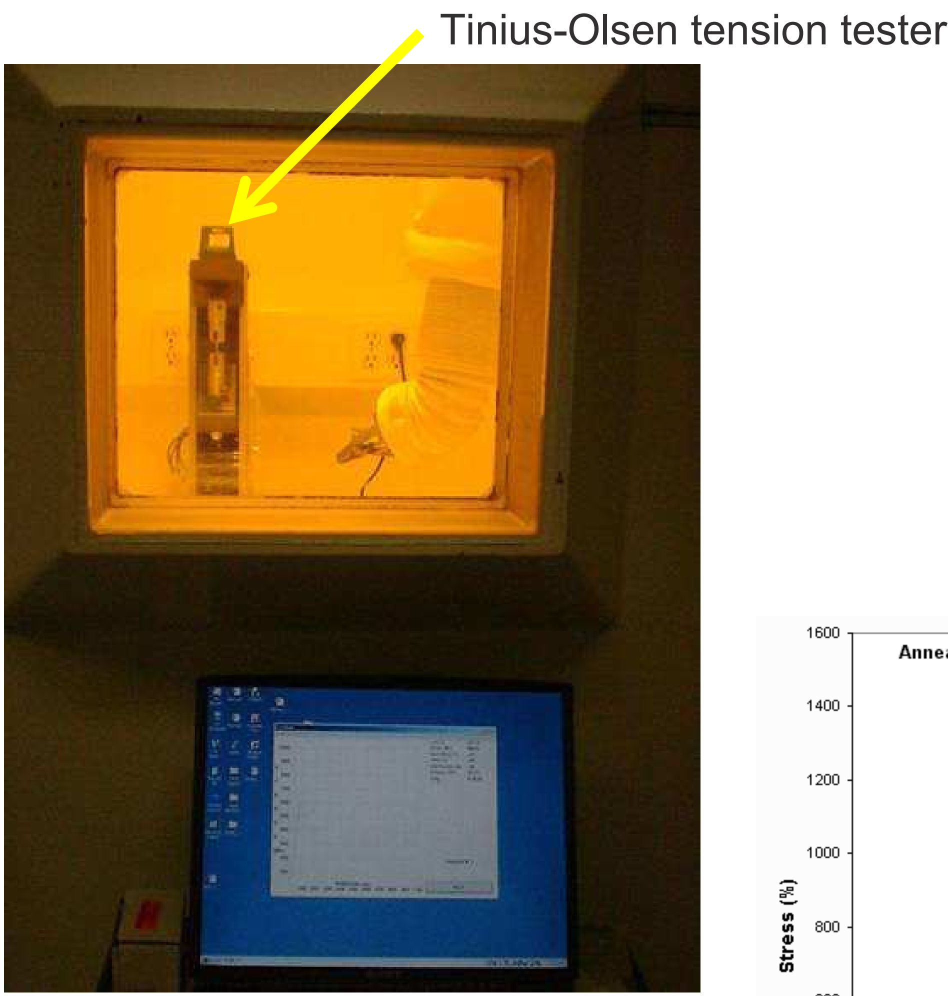
10^{22} p/cm2

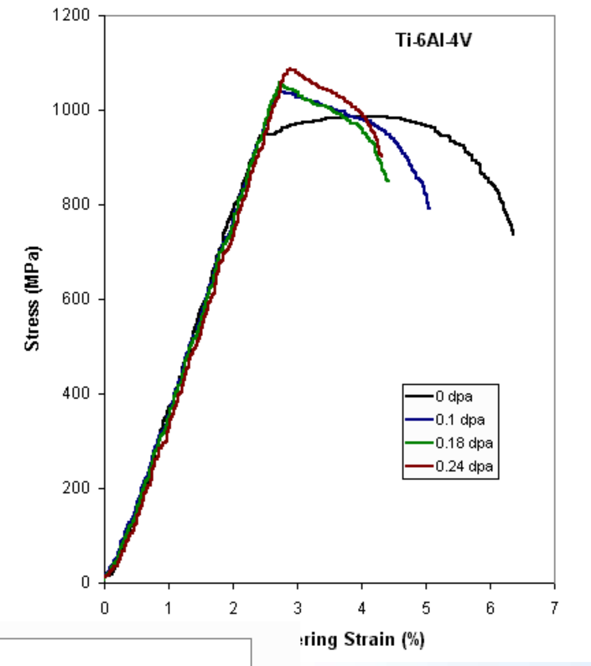


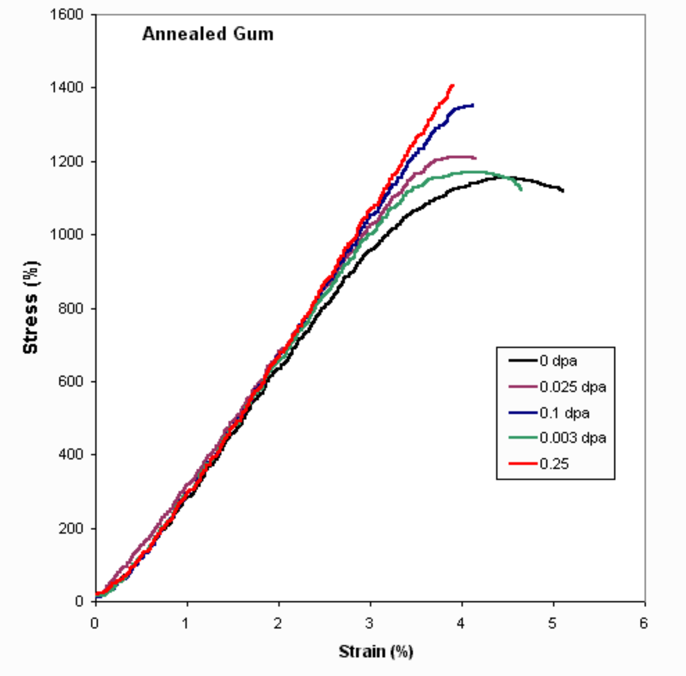
Confirmation by independent studies/observations

Multiple experimental verification of damage at BNL

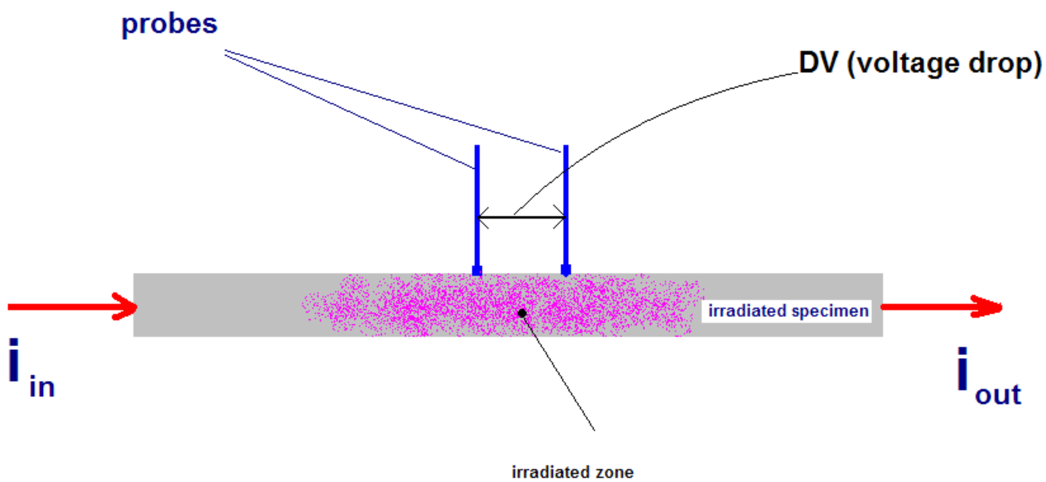
Effects of irradiation on stress-strain relations (strength, ductility loss, etc.)



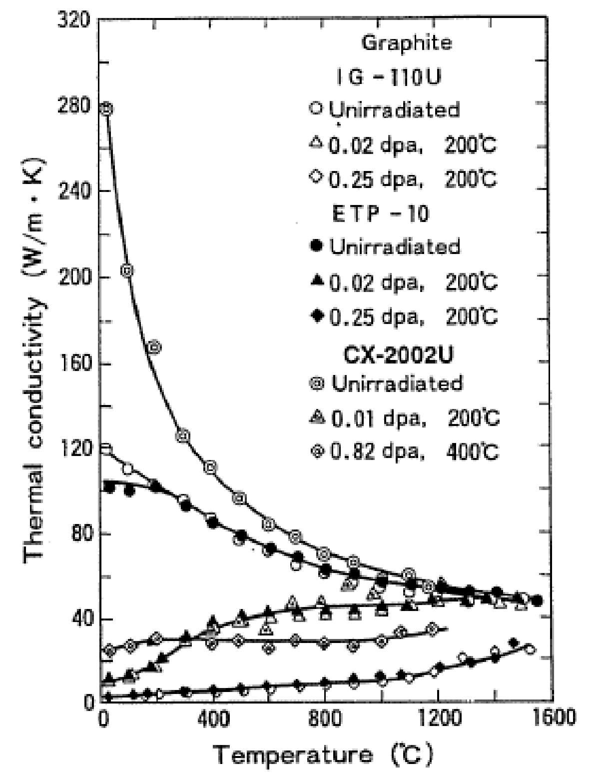




Experimental set-up for thermal conductivity degradation of irradiated target materials



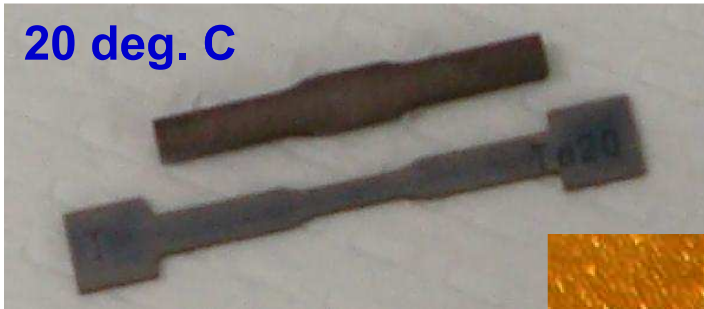
Thermal conductivity ~ electrical conductivity (Weidemann-Franz)



Thermal conductivity of neutron-irradiated graphites.

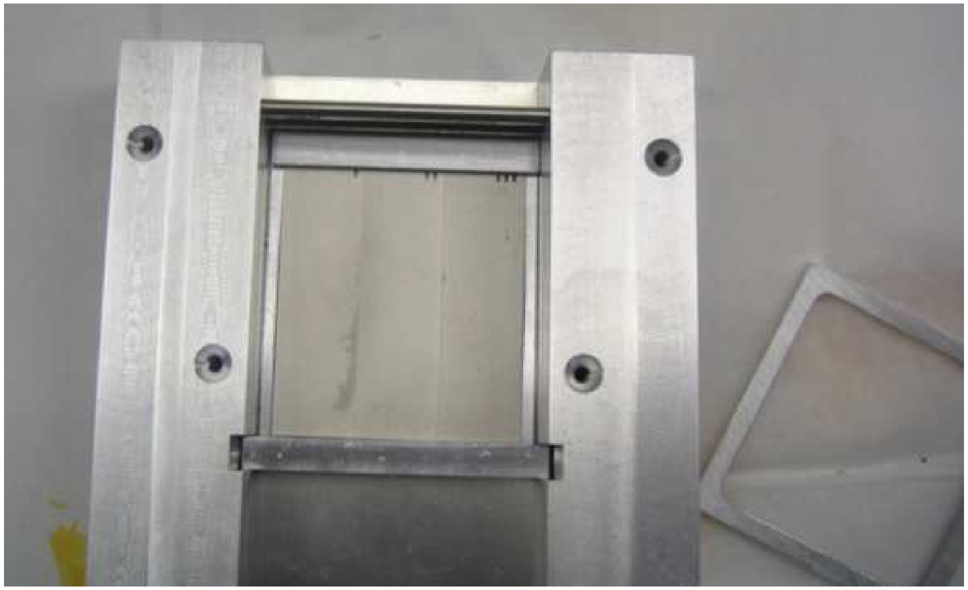
Figure depicts the accelerated loss of conductivity observed in graphite under modest neutron irradiation

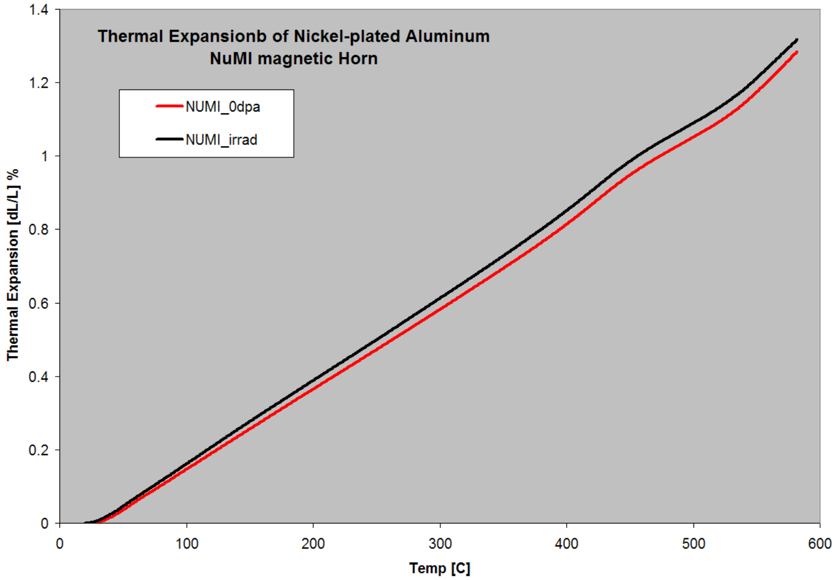
Experimental Set-Up addressing Oxidation/Volumetric Change (*i.e.*, **tantalum)**

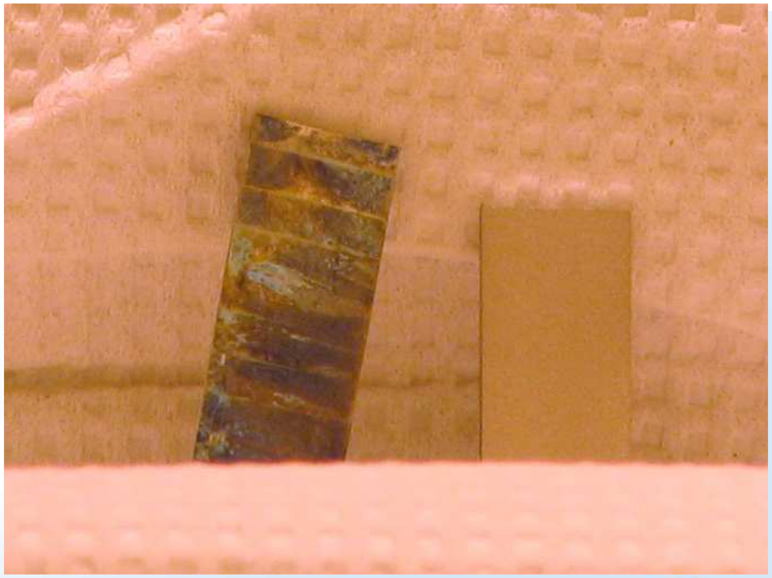


Accelerated Ta Oxidation:
Present of a third element
Radiation-induced oxidation acceleration ?

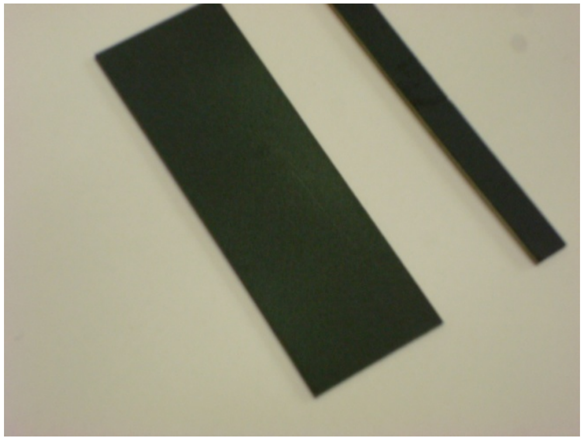
Irradiation, temperature and aggressively corrosive environment effect on Ni film with aluminum substrate (NuMI horn material)

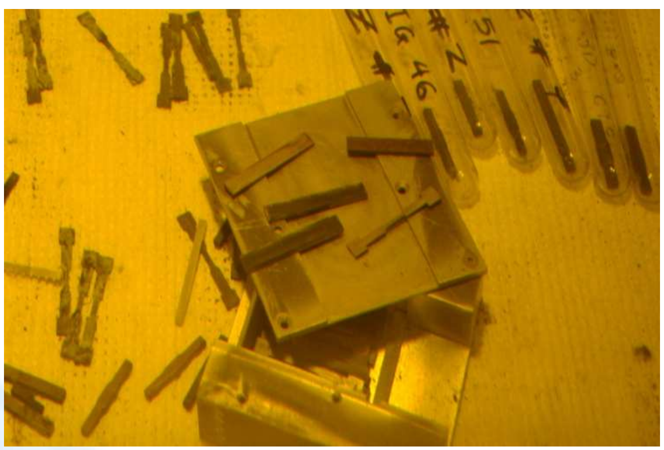




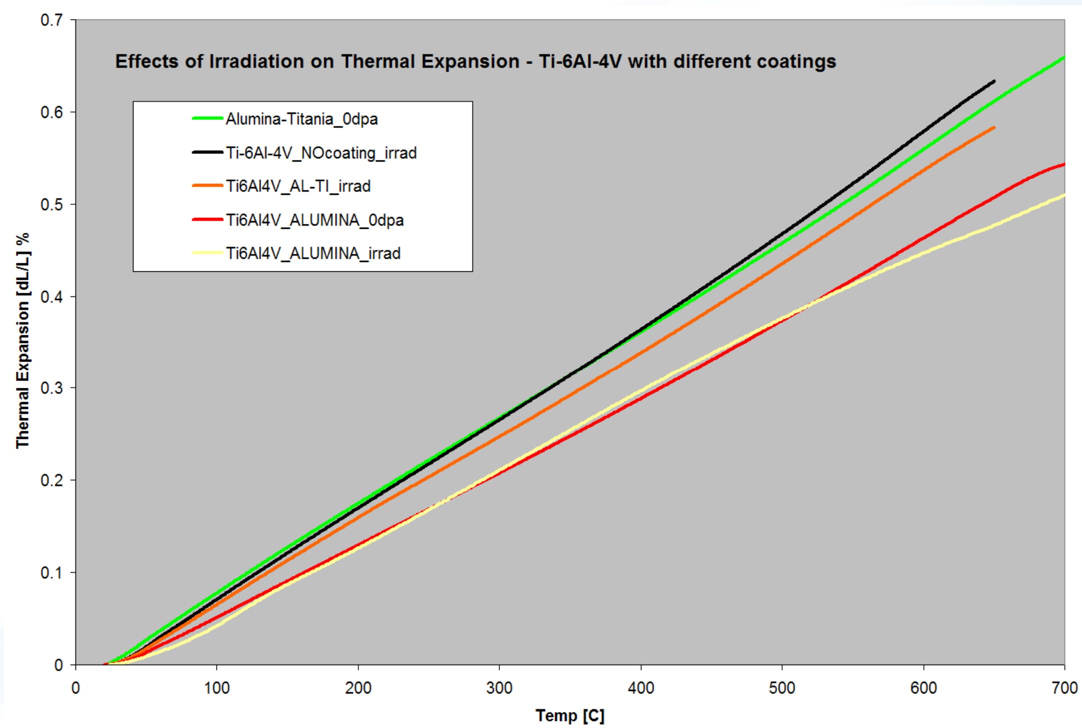


Irradiation and Temperature Effects on Nanostructured Coatings/Films

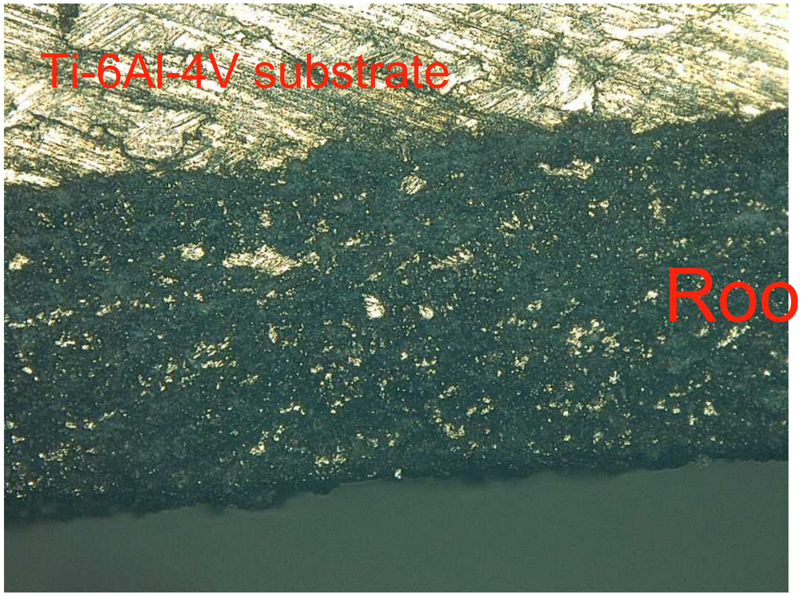


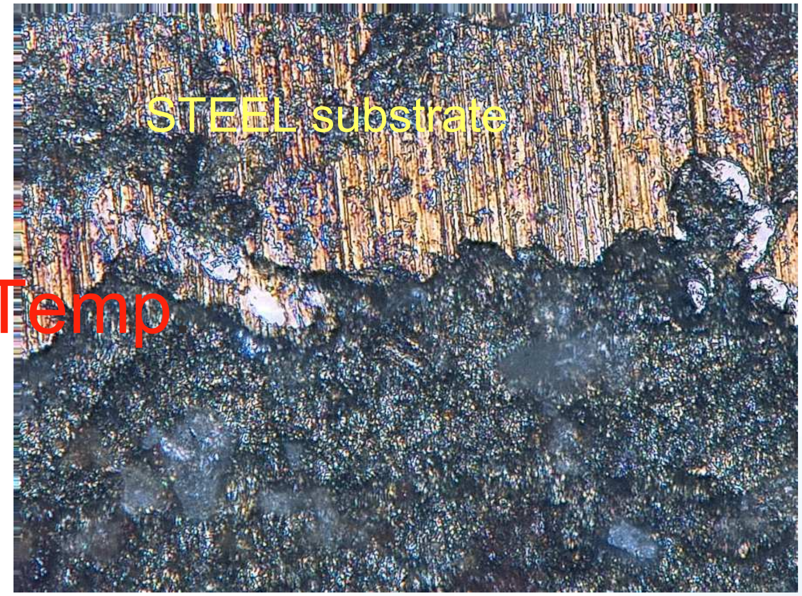


- ➔ **Ti-6Al-4V substrate with 200 μm-thick coating consisting of 87% Alumina and 13 % Titania [nanosize = 30 nanometers]**
- ➔ **Ti-6Al-4V substrate with ~600 μm-thick Al_2O_3 coating**
- ➔ **Alloy steel 4130 substrate with ~600 μm-thick Al_2O_3 coating**
- ➔ **4130 steel substrate with ~600 μm-thick with amorphous Fe coating**



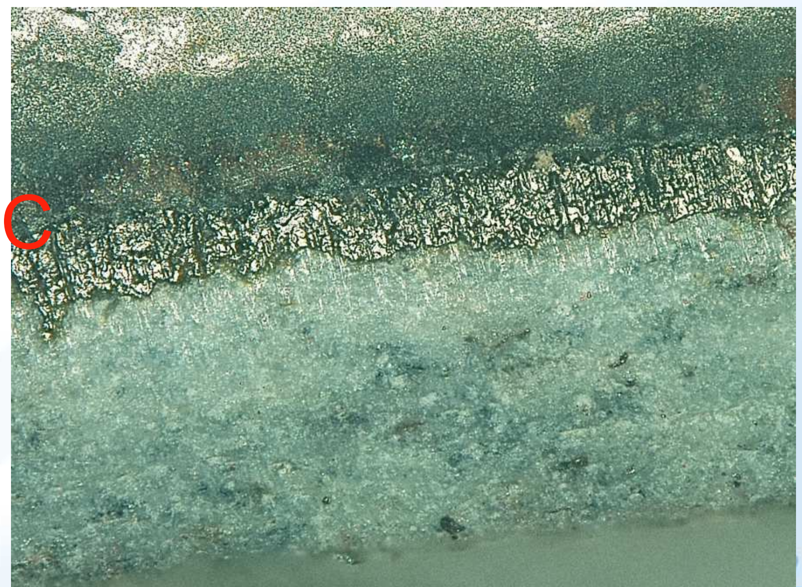
Temperature Effects at coating/substrate interfaces



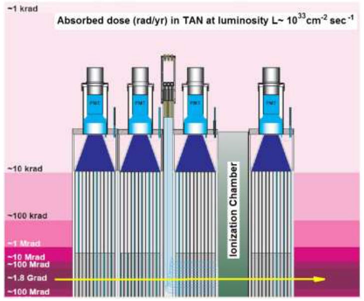


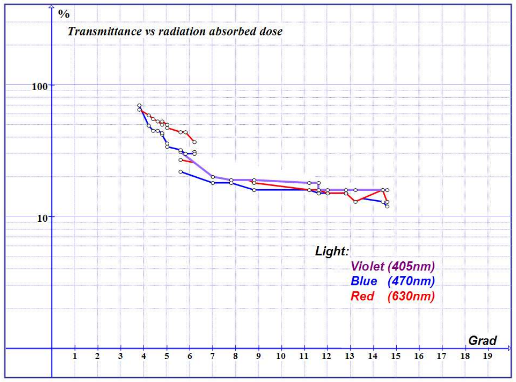
Room Temp

900 C



SiO_2 Irradiation (LHC 0-degree Calor.)

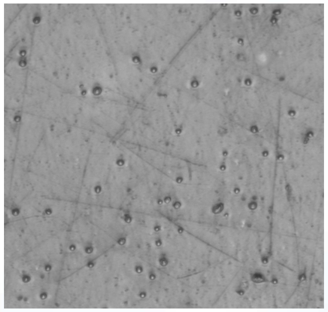


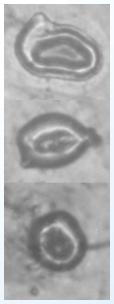


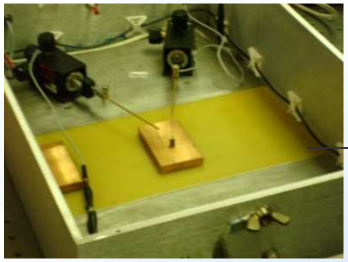
Grad level exposure and serious degradation of photo-transmission

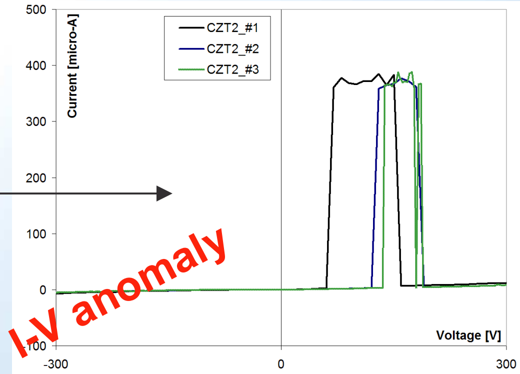
CZT Crystal Irradiation

Observed damage:

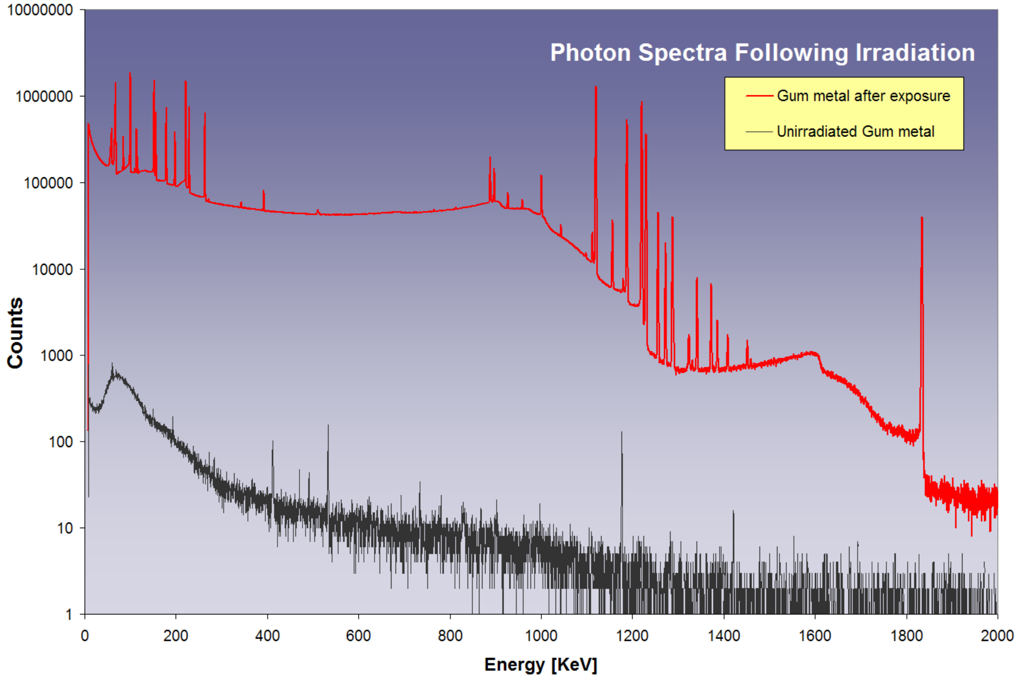


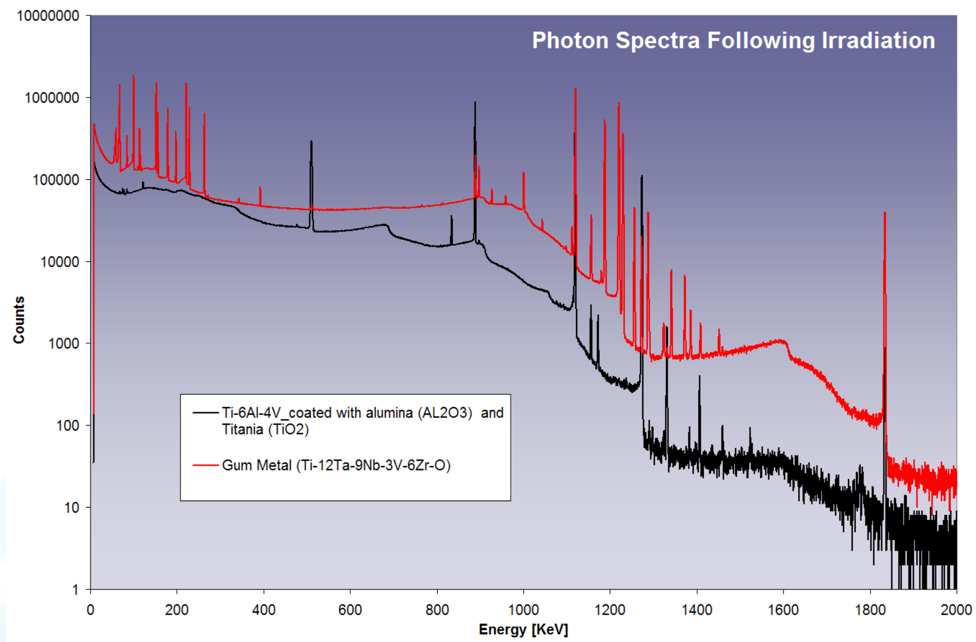






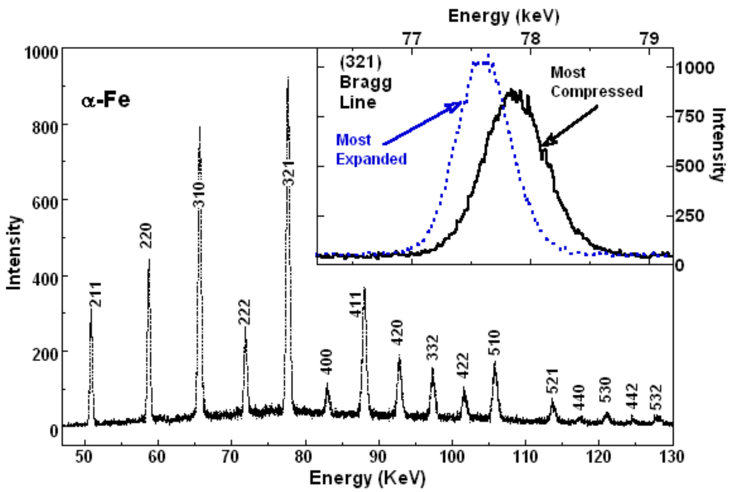
Gamma Spectra Following Irradiation of "gum metal" titanium alloy using High-Sensitivity Ge Detector





In Planning ➔

at the BNL
National Synchrotron Light Source

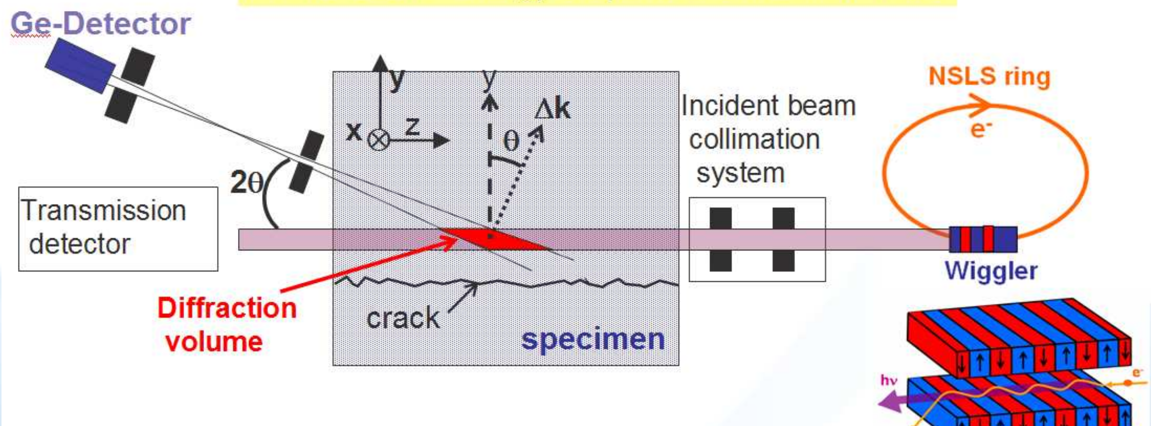


Powder diffraction experiments up to 2000 C at NSLS (X-ray Powder Diffraction and Pair Distribution Functions)

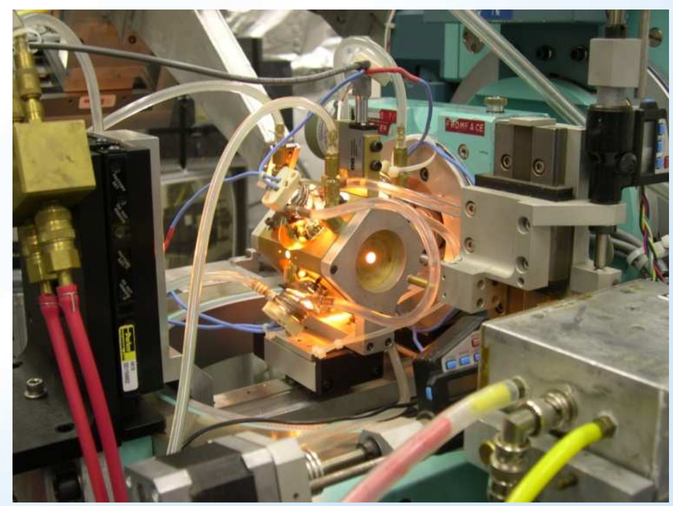
Use high-temperature diffraction data to characterize micro- and nano-defect structure following irradiation.

Cross-correlate PDF and Strain/Phase Mapping techniques at BNL Light Source (NSLS)

"White Beam" Energy Dispersive Diffraction Mode



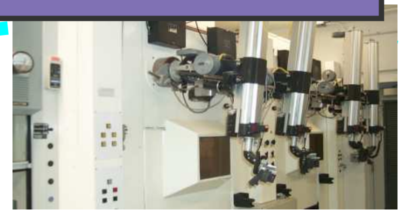
T. Tsakalakos, M. Croft, et al.



Characterization of Advanced Materials Under
Extreme Environments for the Next Generation Energy Systems

http://www.bnl.gov/camworkshop/

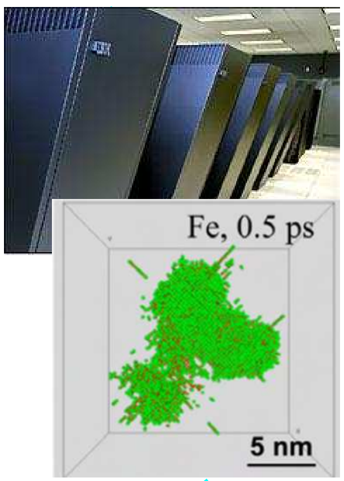
Irradiation & macroscopic assessment



Visualization of damage
(X-ray probing/strain mapping)
Light Source

Re-engineering of
nano- /micro-structure at CFN

- **Molecular Dynamics**
- **Monte-Carlo analysis**



Synergistic Model at BNL addressing materials under extreme radiation fluxes, temperatures and corrosive environments

Link damage, x-ray characterization, nano-structuring of resistant lattices and simulation