STUDIES OF MATERIAL PROPERTIES UNDER IRRADIATION AT BNL LINEAR ISOTOPE PRODUCER (BLIP)

N. Simos, H. Kirk, H. Ludewig; BNL

N. Mokhov, P. Hurh, J. Hylen, J. Misek, Fermilab

Overview – Materials & High Power Accelerators

Materials Limitations ➔ Shock and radiation damage

Targets & collimators are in same class

Extensive data banks on materials at extreme radiation levels but generated from reactor thermal neutron interaction with matter

As accelerator power has "graduated" from kW to MW so did the concern about functionality of materials as we know them

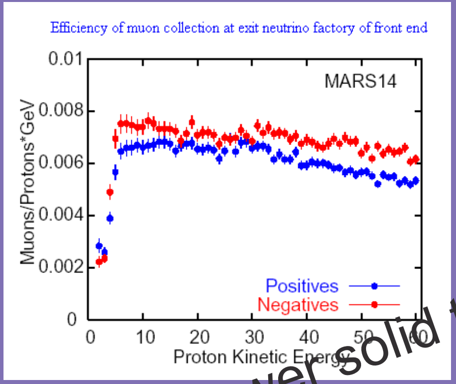
Q1: How about new generation materials and composites?
Q2: Can we, by playing with damage cross sections and energies, recreate effects anticipated at the MW levels?

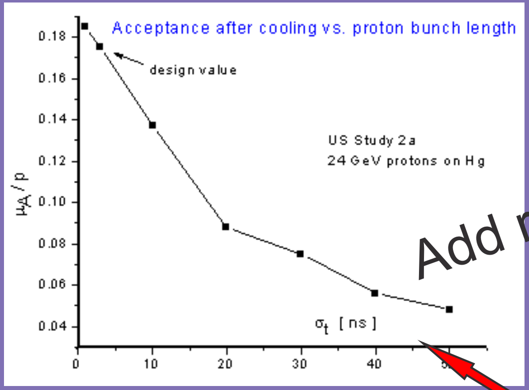
Parameter Space

Protons per pulse required for 4 MW

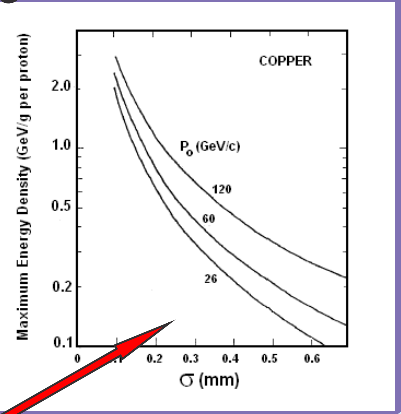
$$\overline{P}_{arc}(w) = E[eV] \times N \times e \times f_{rep}\,[Hz]$$

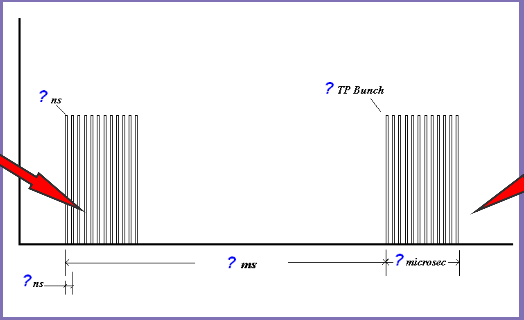
	10 Hz	25 Hz	50 Hz
10 GeV	250×10^{12}	100×10^{12}	50×10^{12}
20 GeV	125×10^{12}	50×10^{12}	25×10^{12}





Add radiation damage for high power solid targets



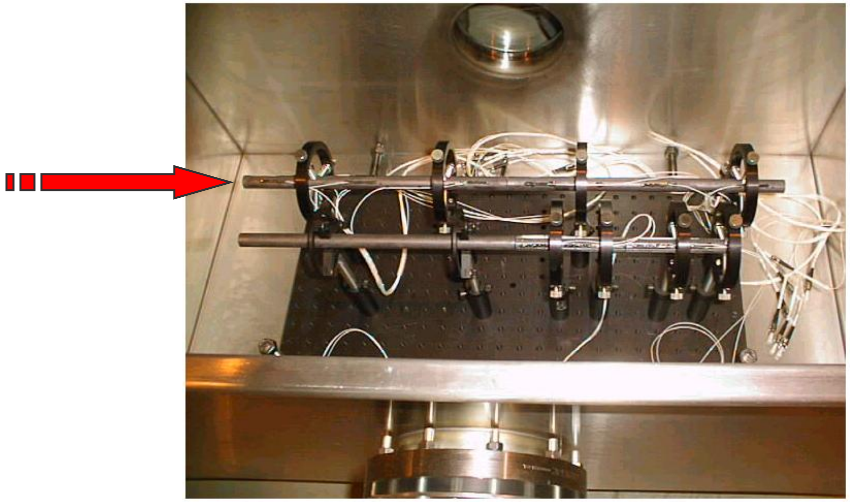


Driven by the high power demand (~order of magnitude above current accelerators and their targets) we have been searching for materials which:

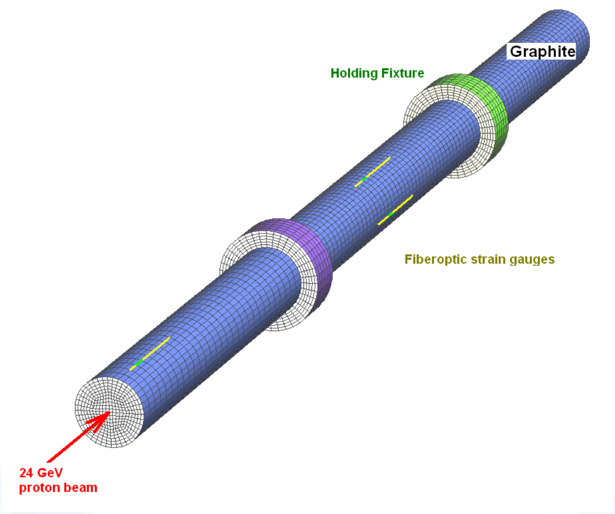
Respond well to shock (low thermal expansion, low E, large c_v)

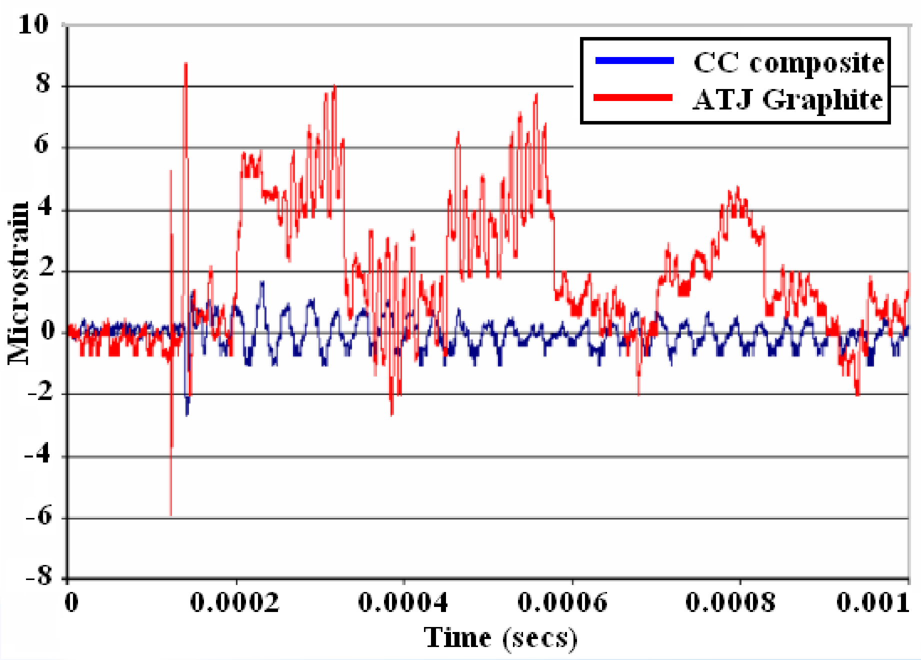
Have either inherent resistance against proton irradiation OR ability to self-heal at higher operating temperatures

Explored materials, super alloys & composites from low- to high-Z
from graphite to tungsten

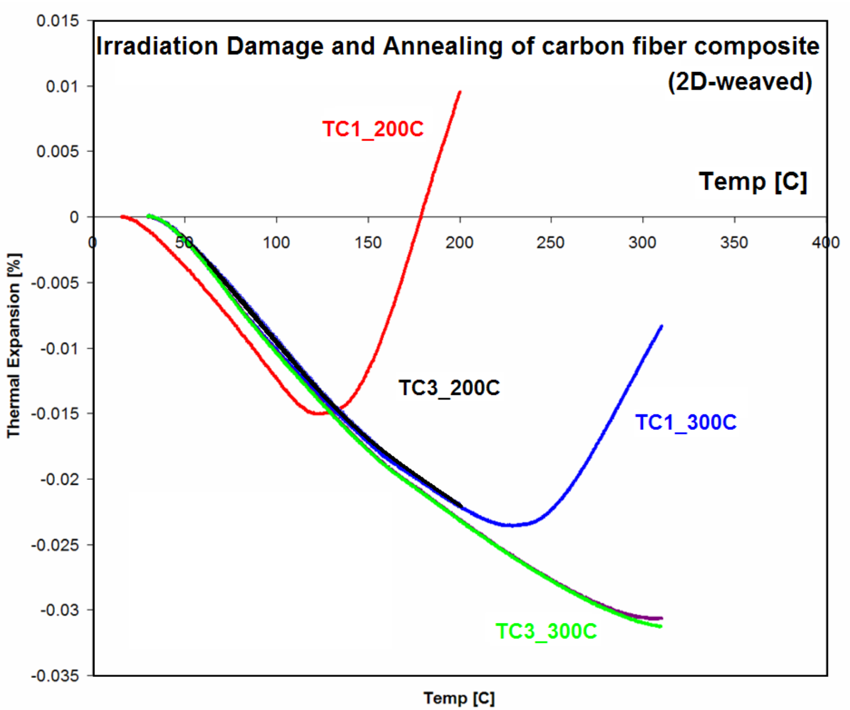


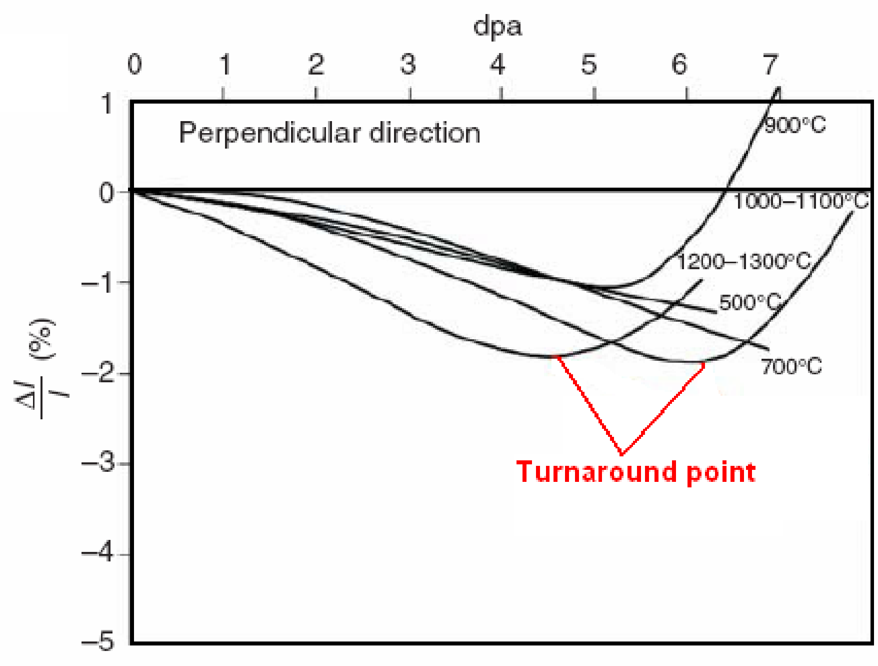
BNL AGS Experiment on beam shock
Graphite vs. Carbon composite



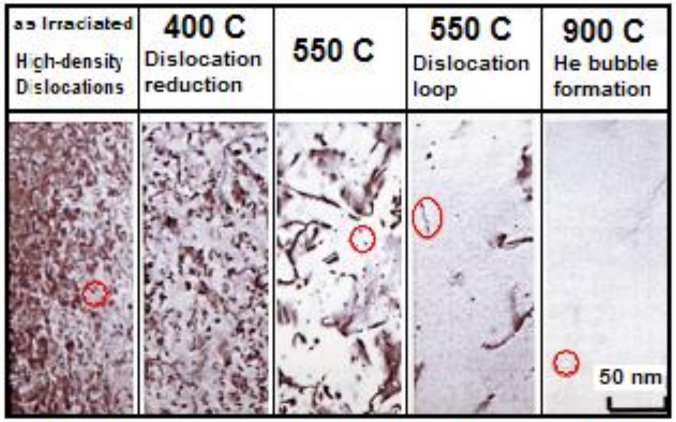


Irradiation & Temperature Effects on C-C composite

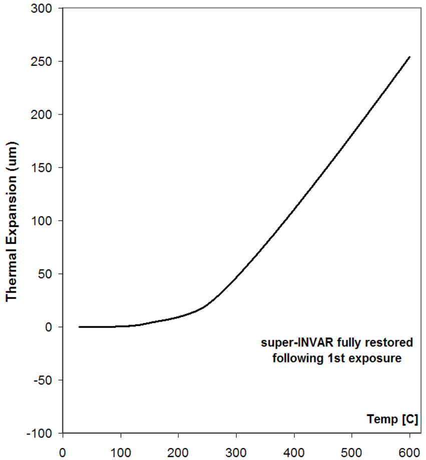


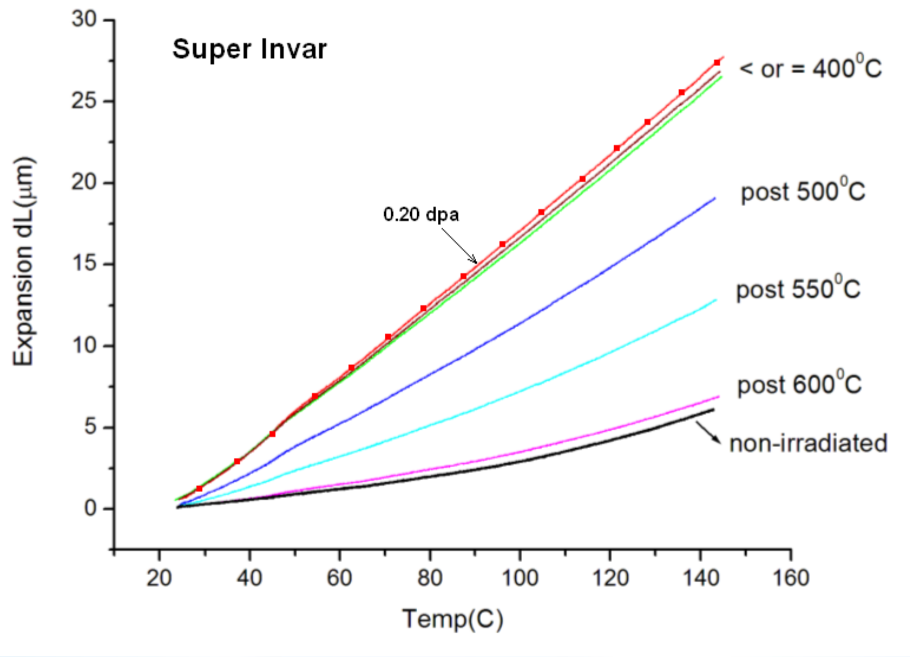


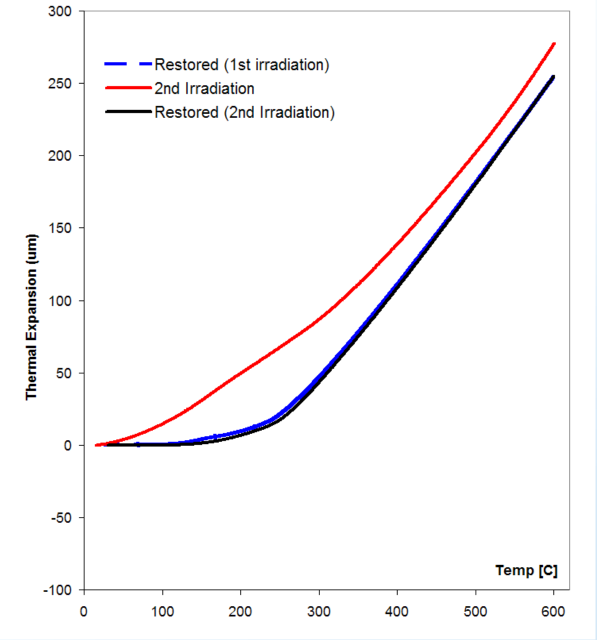
High Power Accelerator Targets & High Temperature Operation (1)



Y. Ishiyama et al., J. Nucl. Mtrl. 239, 1996







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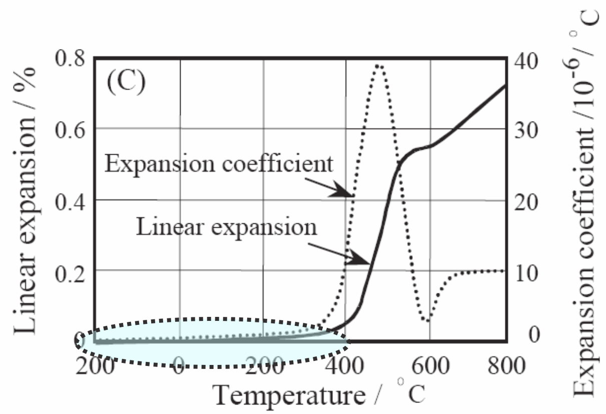
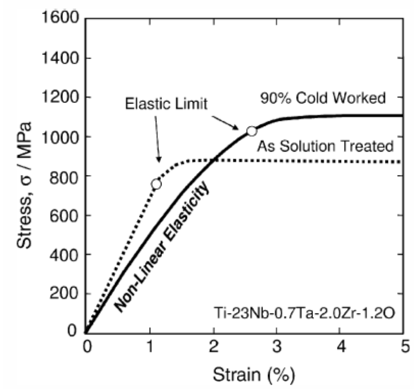
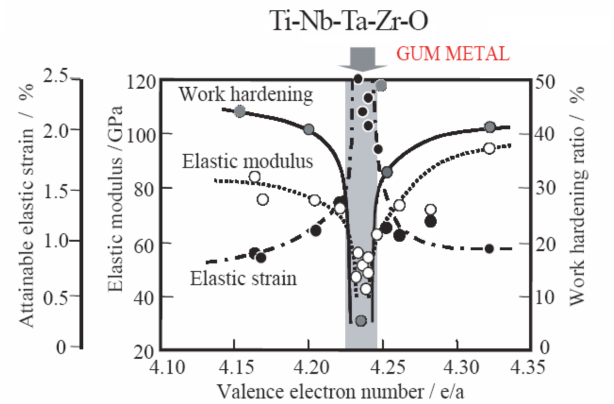
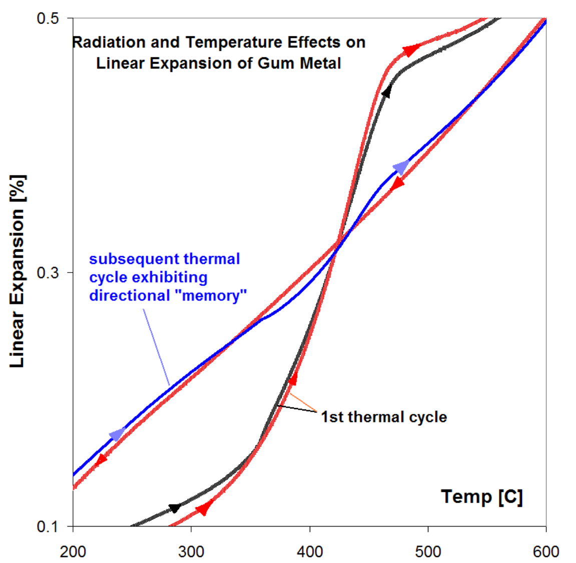
High Power Accelerator Targets & High Temperature Operation (2)

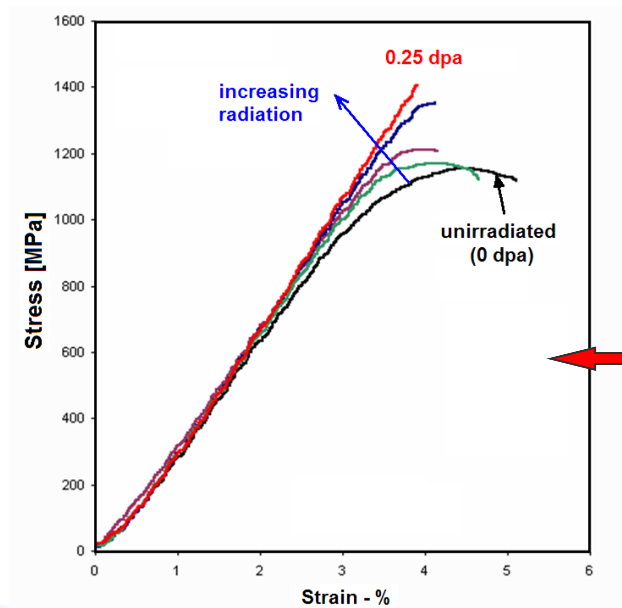


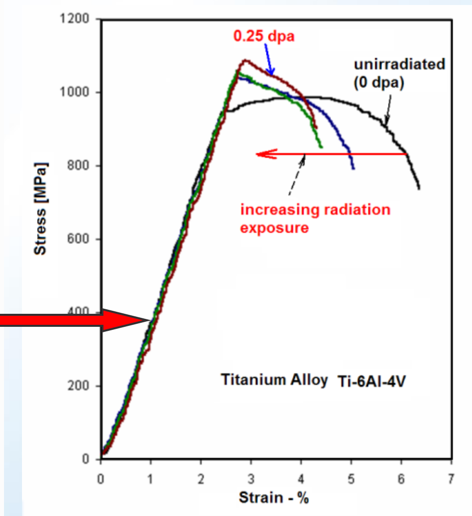




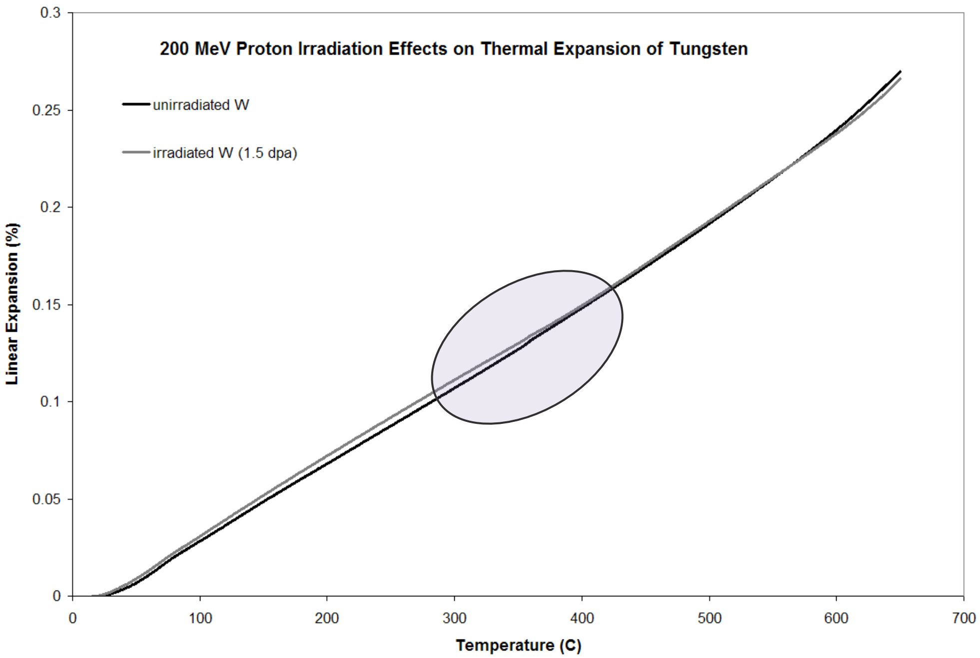
T. Saito, et al., Multifunctional Alloys Obtained via a Dislocation-Free Plastic Deformation Mechanism, Science, 300 (2003) 464

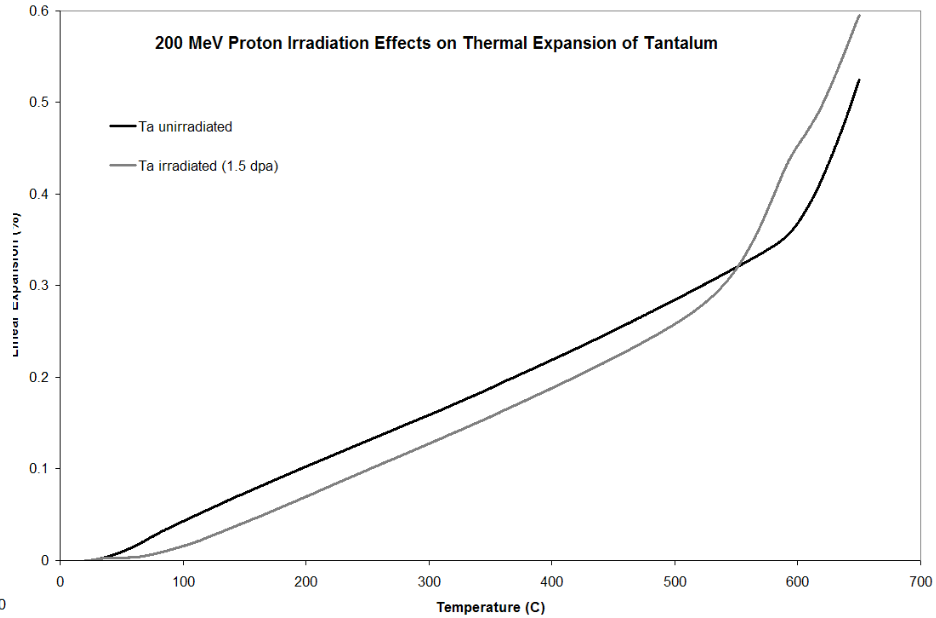


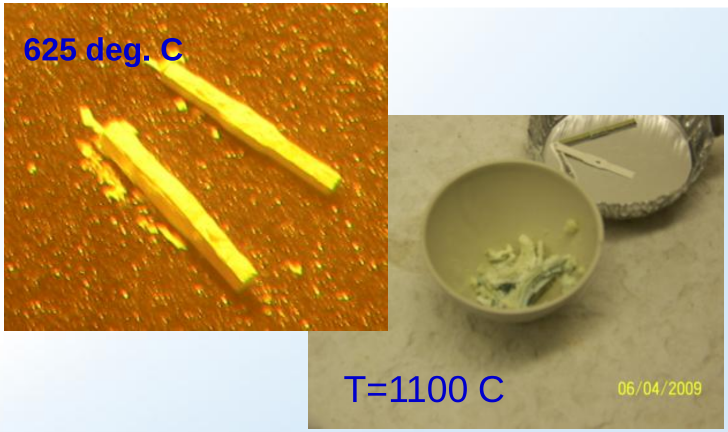




Materials & High Power Accelerators (3)







Long Baseline Neutrino Experiment and Target Studies

Driver behind the LBNE Study:

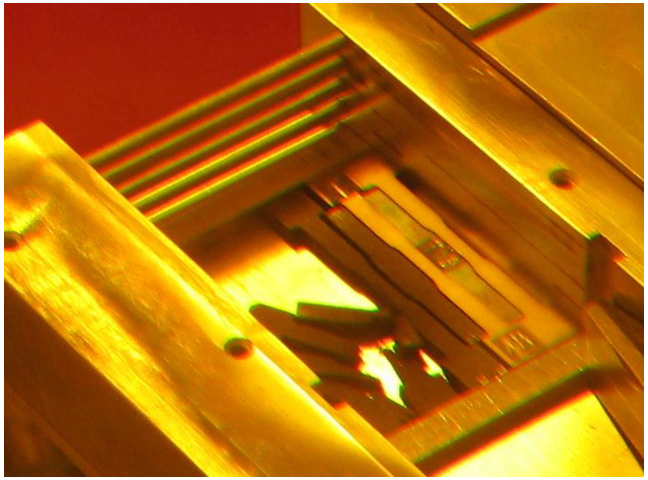
Operate at 700 kW while eying 2 MW with low-Z target materials

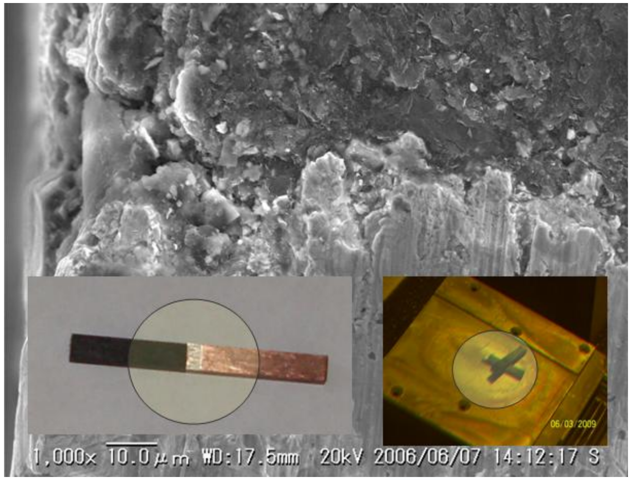
Evidence of NuMI target yield performance degradation attributed to radiation damage operating at 400 kW (peak)

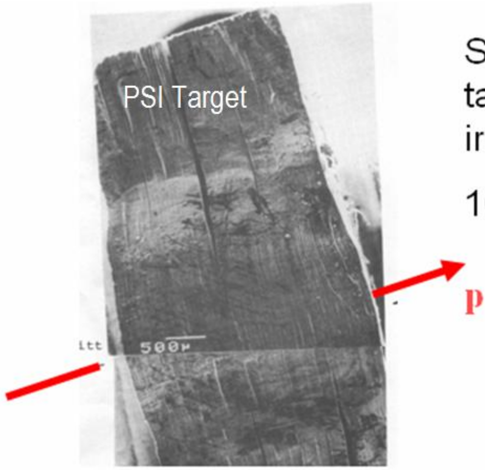
Evidence from BNL studies of susceptibility of carbon-based targets under proton irradiation at high fluences and certain ambient environments

Supporting operating target experience on graphite limited by proton fluence while reactor experience said otherwise

Recent BNL studies at BNL-BLIP (LHC collimators and Neutrino Factory targets) revealed a surprising proton fluence threshold **(~0.5 x 10^21 p/cm2)** for graphite and carbon composites and for proton energies between 120-200 MeV

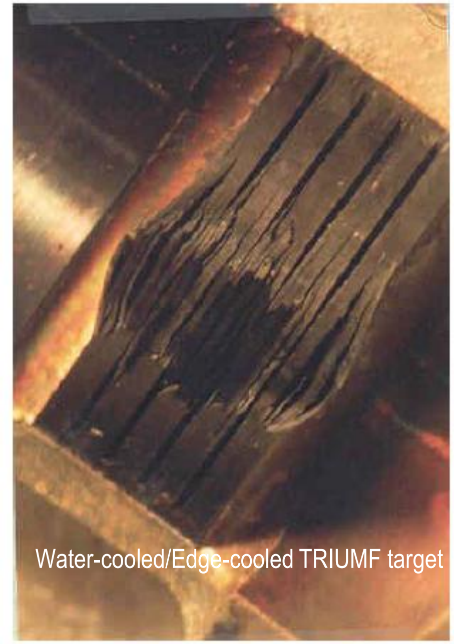






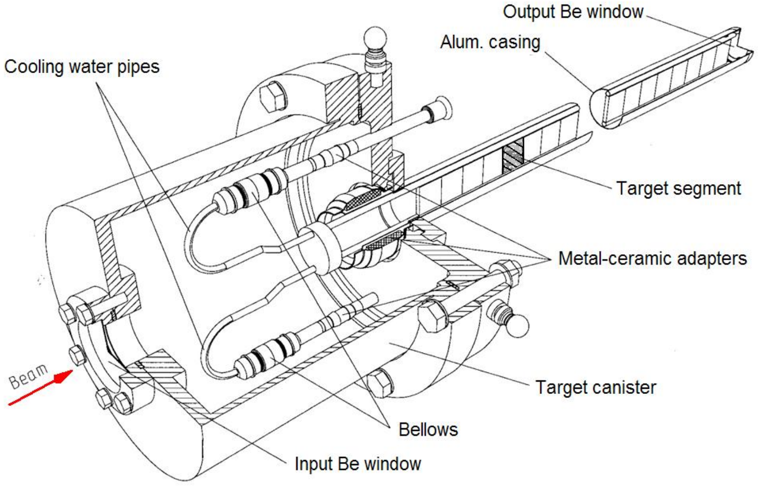
Swelling of the target after irradiation

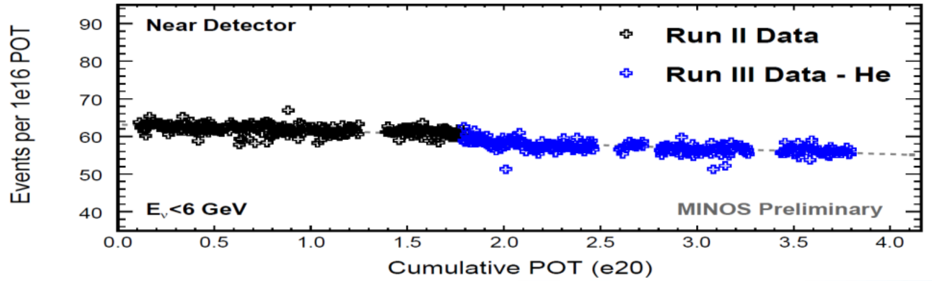
10^{22} p/cm2

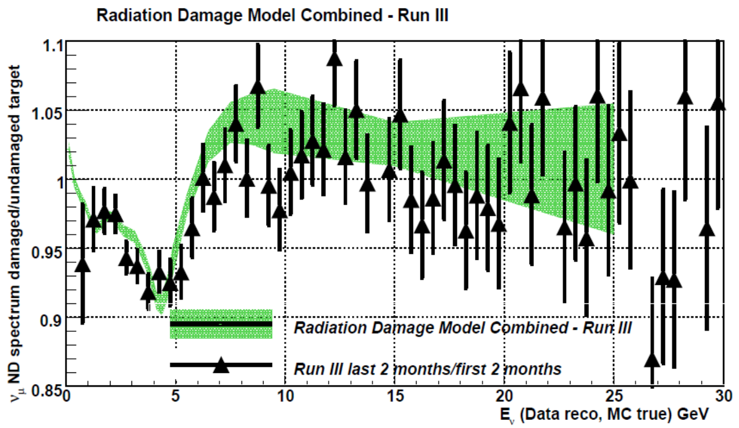


NuMI Target

Connecting performance to radiation damage

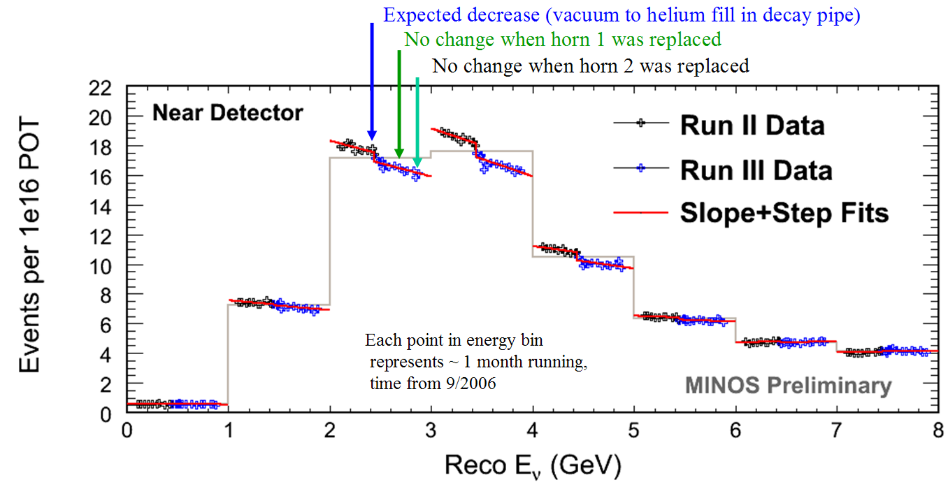






NUMI Target (ZXF-5Q amorphous graphite) Experience

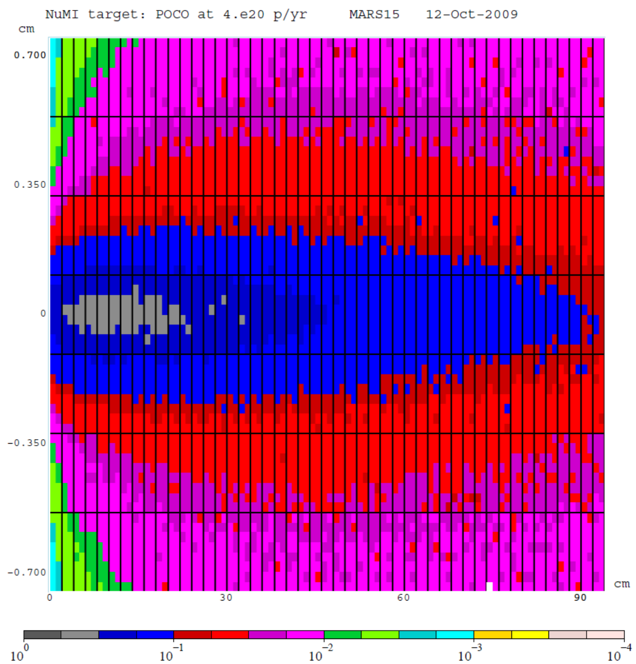
Gradual neutrino rate decrease attributed to target radiation damage



MARS15 Simulations CONFIRMED the accelerated damage at lower beam energies (<200 MeV vs. 120 GeV)

Such confirmation tends to also explain why damage from thermal neutrons is not at same rate as energetic (but not too energetic) protons.

NuMI

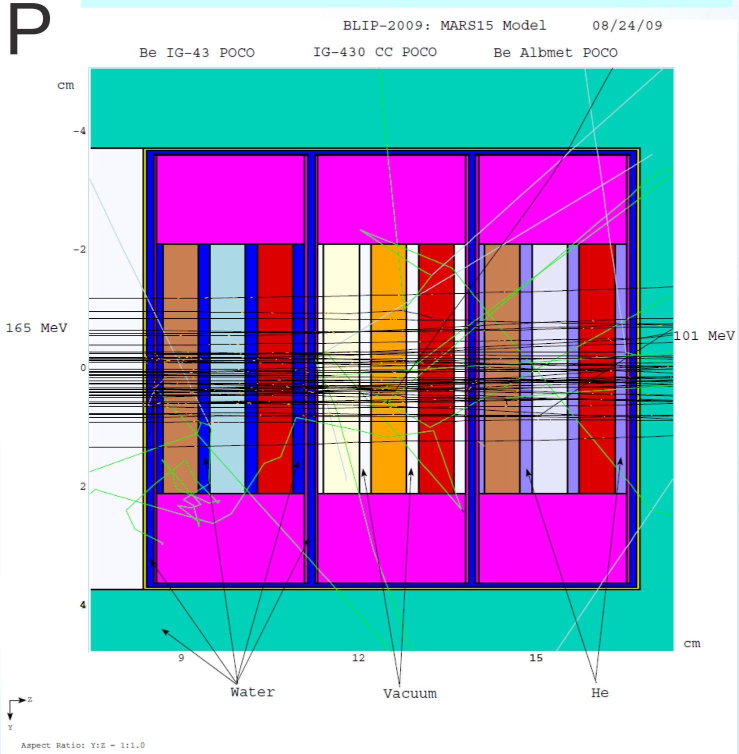


120-GeV proton beam
$\sigma_x = \sigma_y = 1.1$ mm
2e13 p/s × 2e7 s/yr = 4e20 p/yr

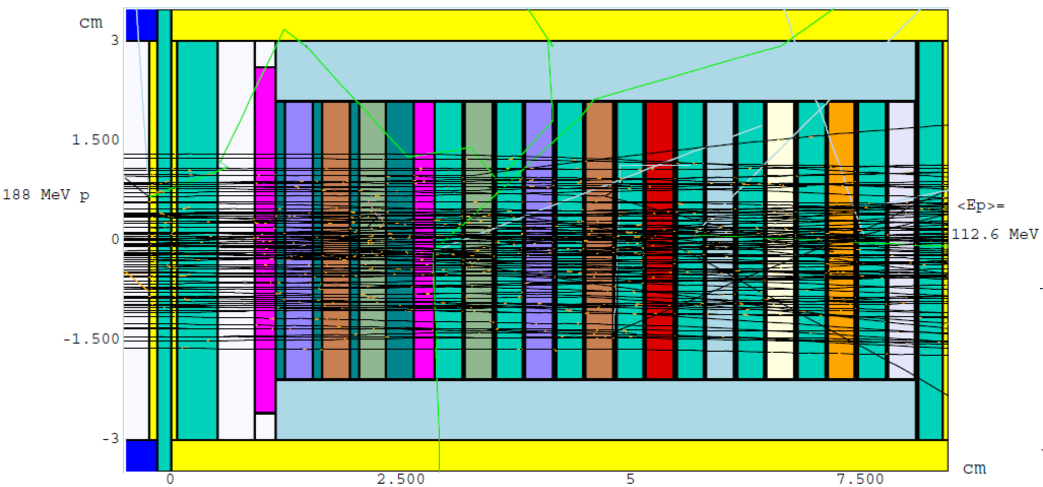
Target: POCO Graphite, 1.78 gcc
47 × (15 × 6.4 × 20 mm)

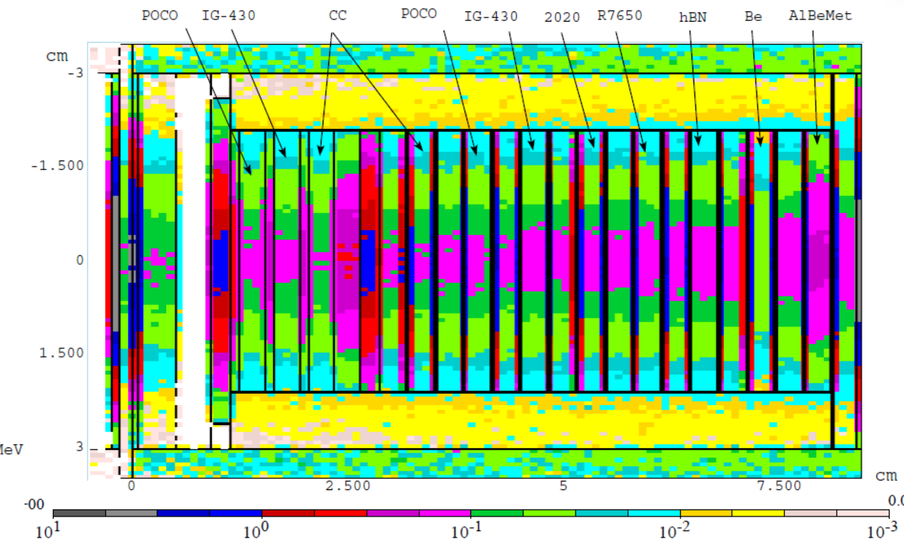
BLIP

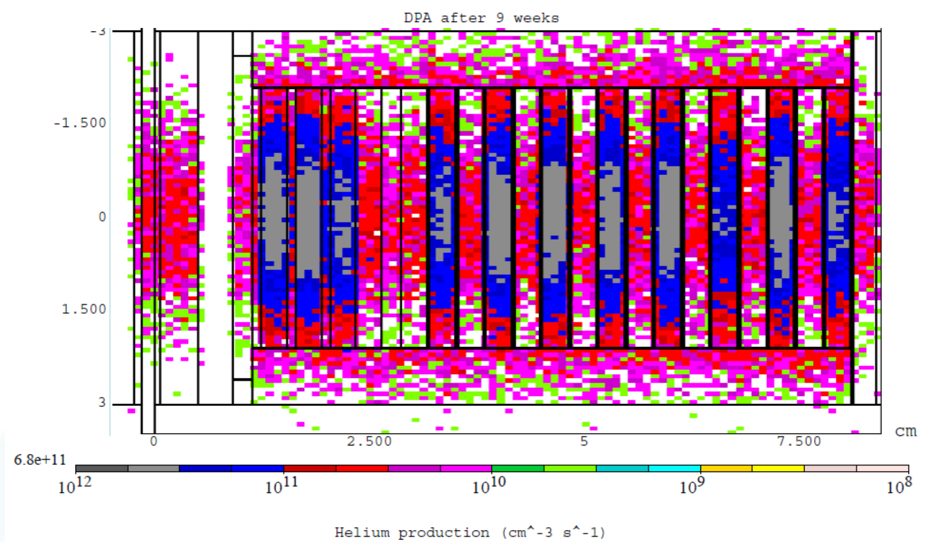
165-MeV proton beam
to get 101 MeV downstream
$\sigma_x = \sigma_y = 4.233$ mm
90μA: 5.62e14 p/s × 2e7 s/yr = 1.124e22 p/yr



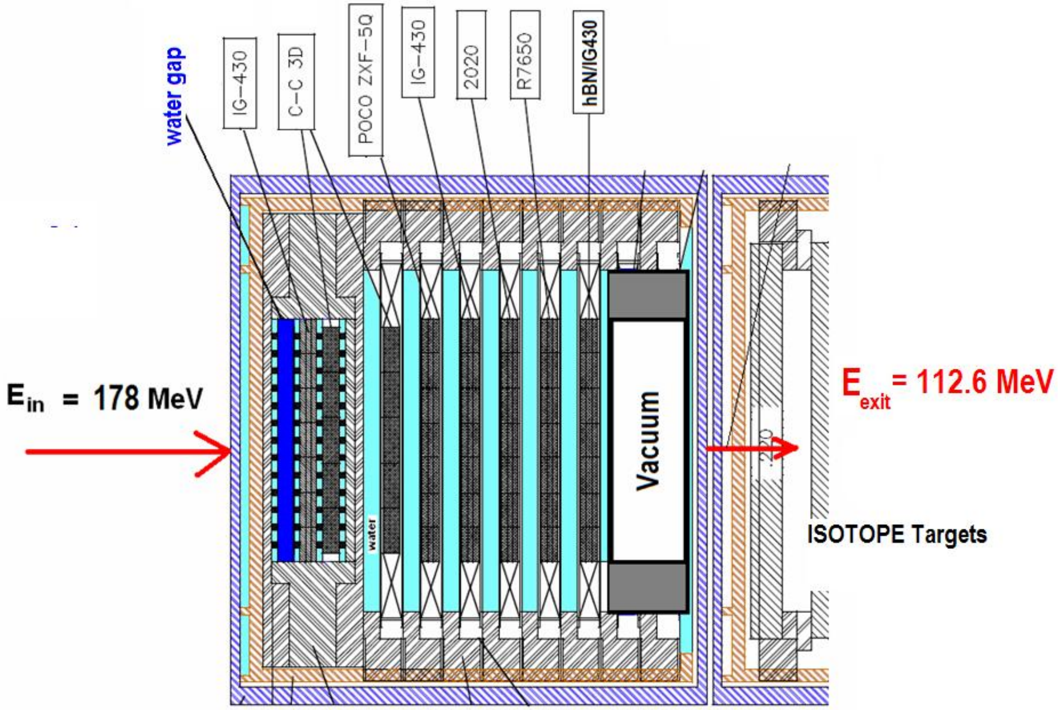
MARS15 Simulation of LBNE Target Array at BLIP (guidance on irradiation duration for 1-year LBNE operation equivalence)

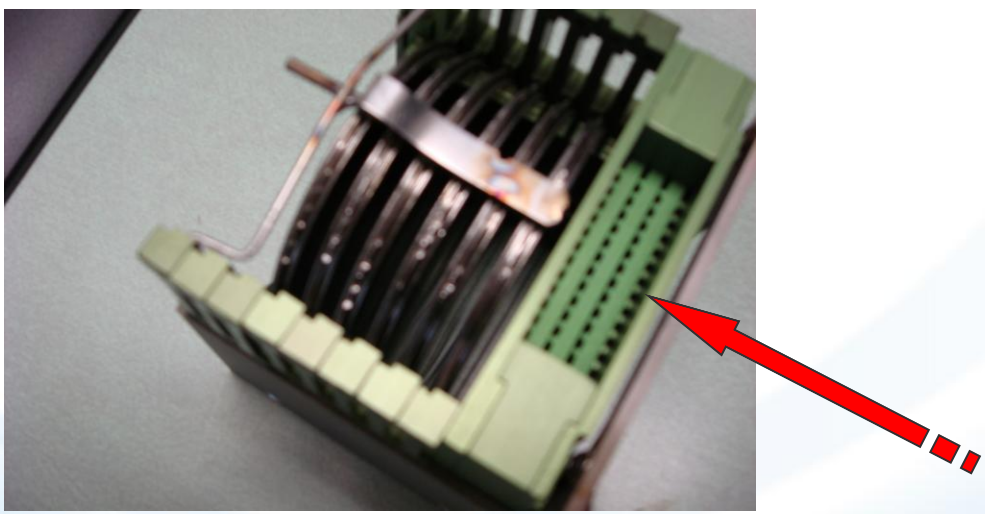


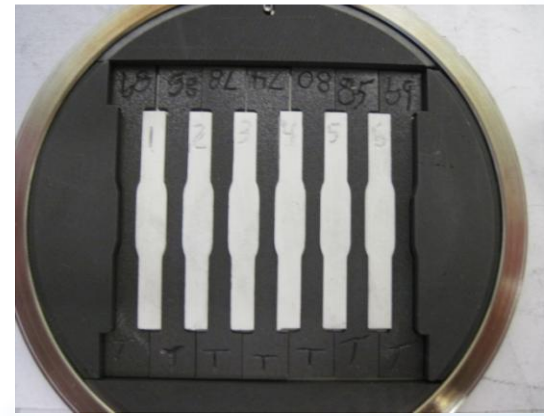




Target	E_p (GeV)	Beam σ (mm)	N_p (1/yr)	DPA (1/yr)
NuMI/LBNE	120	1.1	4.0e20	0.45
BLIP	0.165	4.23	1.124e22	1.5


water gap
IG-430
C-C 3D
POCO ZXF-5Q
IG-430
2020
R7650
hBN/IG430
E in = 178 MeV
Vacuum
water
E exit = 112.6 MeV
ISOTOPE Targets



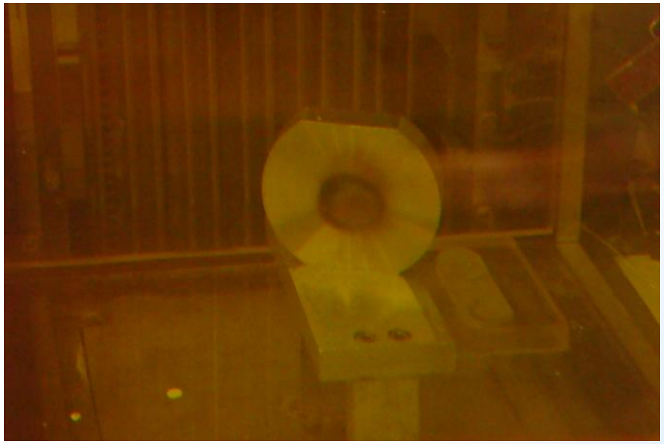


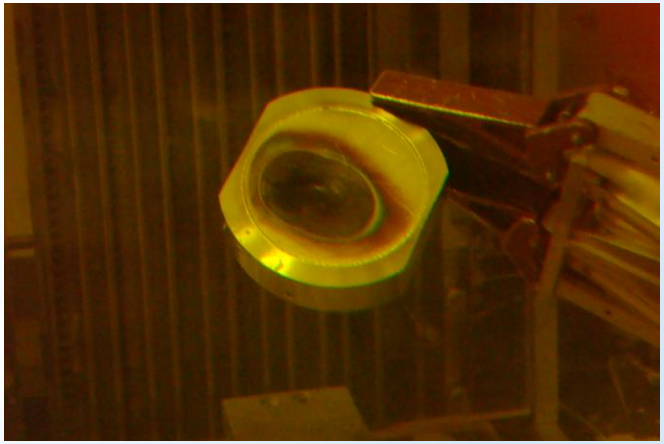
Some “interesting” things happened on the way to the LBNE study

Short-lived isotope production increase due to beam/water interaction

Be Window SHOCK Failure (beam current to a half, Energy 45 MeV and tight beam spot (σ = 4.23 mm)

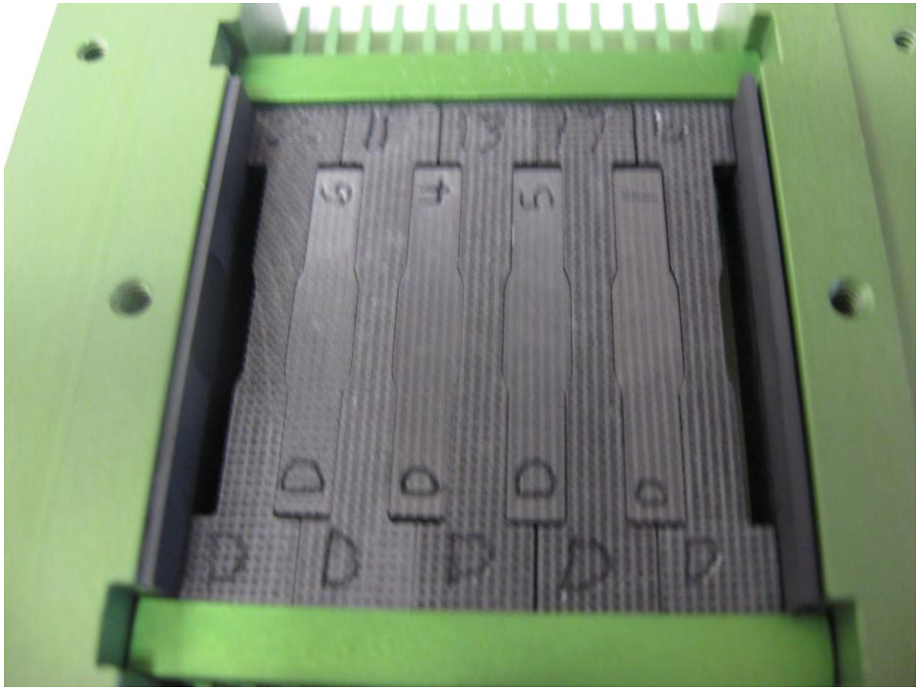
Vacuum “degrader” window failure

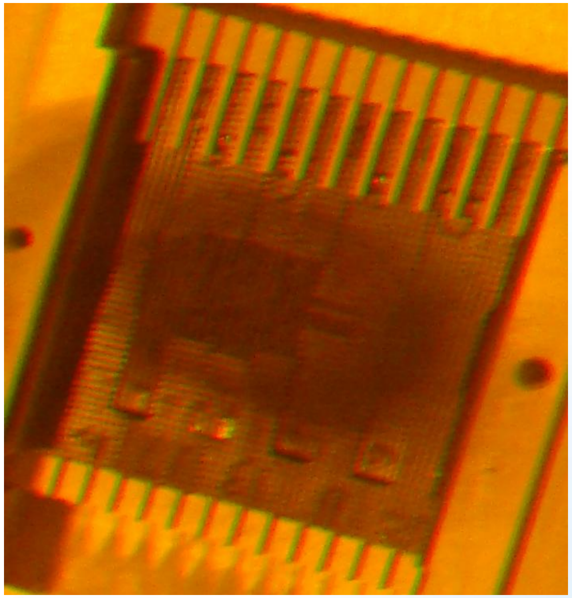


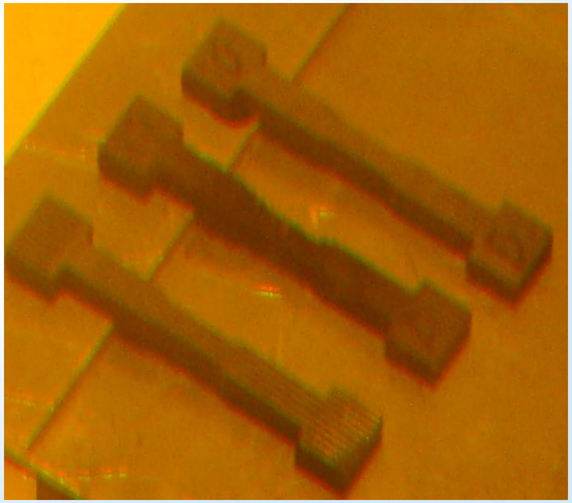


However, the run managed to complete 9 weeks in the beam which was the intended target

LBNE Target R&D Preliminary Assessment





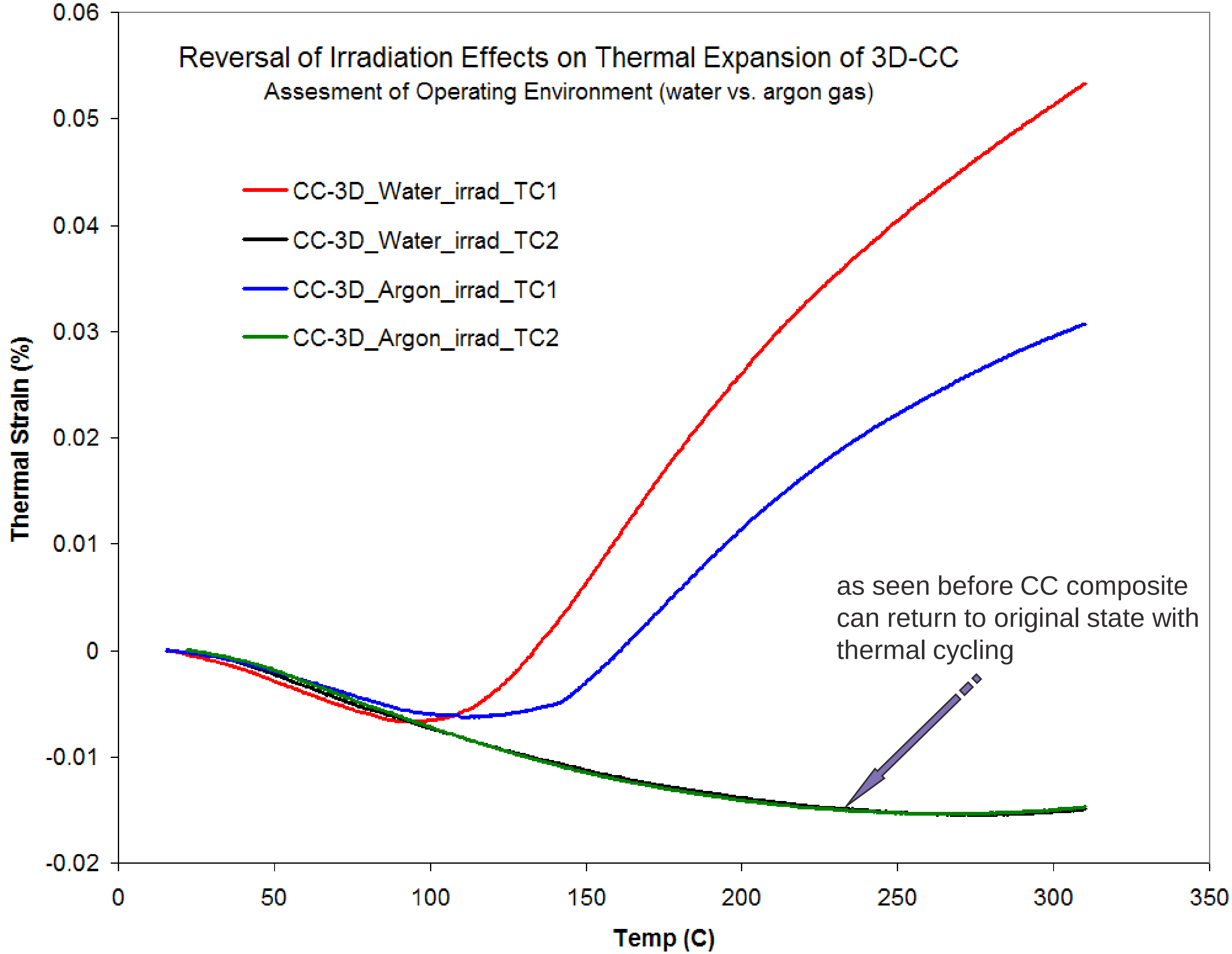


Confirmation of FLUENCE Threshold

achieved >0.5x10^{21} p/cm^2

oxidation should not be the trigger (T_{irrad} << 300^{o}C)

LBNE Target R&D Preliminary Assessment



LBNE Study - Preliminary Assessment

Clearly demonstrated that the operating ambient has a significant effect on CC composites and their ability to withstand intense beam irradiation

Inert gas cooling (fluid originally considered for the neutrino superbeam and eventually used in the T2K target system) should, as the LBNE-BLIP experiment showed increase the operating life of such target material

The fluence "threshold" of ~0.5×10^{21} p/cm^2 was shown to be true in water environment

Where the threshold is exactly in inert gas environment (10^{22} p/cm^2 ?) not established yet

Preliminary analysis shows that "damage" reversal is not affected by environment

Graphite (in all grades) crossed the same threshold without the appearance of damage

h-BN "appears" to sublimate under irradiation