POST-IRRADIATION PROPERTIES OF CANDIDATE MATERIALS FOR HIGH POWER TARGETS

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ABSTRACT

Intense muon and neutrino beams require high-performance targets intercepting energetic, several MW power proton beams. To achieve that one must push the envelope of the current knowledge regarding materials behavior and endurance for both short and long exposure. The limitations of most materials in playing such pivotal role have led to an extensive search and experimentation with new alloys and composites that, at first glance, seem to have the right combination of material properties. Through this study, a number of these new and "smart" materials are evaluated for their resilience to radiation damage and their potential use in the various target schemes. This paper presents preliminary results of on-going experimental studies at BNL irradiation facilities.

SEARCHING FOR SMART MATERIALS TO ACHIEVE >1 MW POWER

Motivation

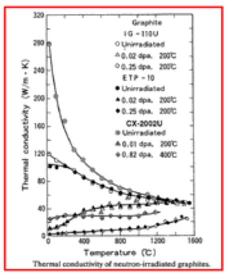
Often dramatic change of key properties with irradiation (Figure below tells the story !)
Extrapolation from other materials is invalid

FOCUS OF EXPERIMENTAL ASSESSMENT ON:

Mechanical Properties
- Strength
- Ductility
- Fracture Toughness

Physical Properties
- Thermal Diffusivity
- Resistivity
- Thermal Expansion (CTE)

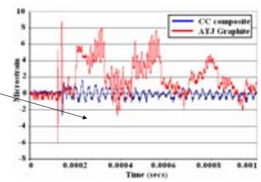
Integrated Effects
- Shock absorption

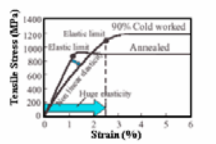


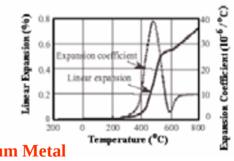
Thermal conductivity of neutron-irradiated graphites.

Is Carbon-Carbon the answer?
How about the super alloy "gum" metal?

Response to intense, focused 24 GeV proton beam expressed in measured strain







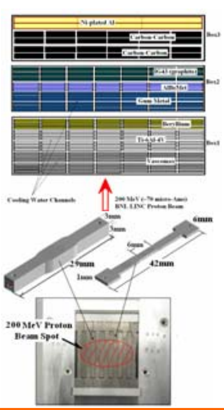
Gum Metal

Material Test Matrix

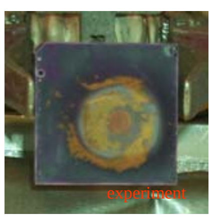
Carbon-Carbon composite: Low-Z, low CTE composite that may potentially minimize thermal shock and survive high intensity pulses.
Graphite (IG43): Different graphite grades respond differently to irradiation
Titanium Ti-6Al-4V alloy: Irradiation effects on fracture toughness of alloy combining good strength and relatively low CTE are sought
Toyota's "Gum Metal": "Super" alloy exhibiting ultra-low elastic modulus, high strength , super-elastic like nature and near-zero linear expansion coefficient for the temperature range -200 C to +250 C
Vascomax: High-strength, high-Z alloy. Irradiation effects on CTE, fracture toughness and ductility loss are sought.
Beryllium: Known material examined closer for irradiation damage
AlBeMet: Low-Z composite combining good properties of Be and Aluminum.
Nickel-plated Aluminum (NUMI horn): Assess how bonding between the layer and the substrate survive irradiation in the presence of water
Super-Invar: Re-examination of previously tested material for effects of temperature induced annealing

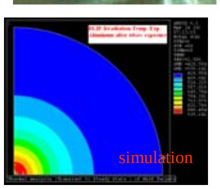
IRRADIATION PHASE AT THE BNL FACILITIES

Material Matrix Irradiation Assembly

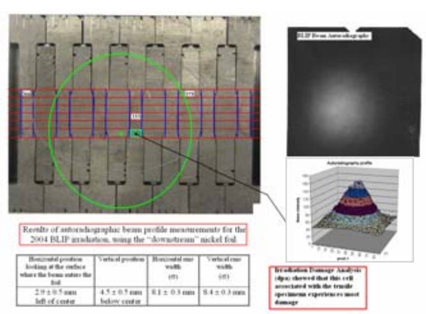


Irradiation Temperature Assessment with Thermal Sensitive Paint (TSP) and exact irradiation beam conditions at BNL BLIP

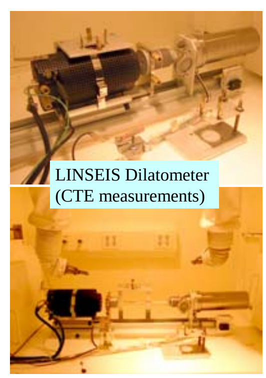




Radiographic Beam Analysis and irradiation damage (dpa) assessment based on MCNPX transport code



POST-irradiation Testing Set-up At the BNL Hot Cell Facility

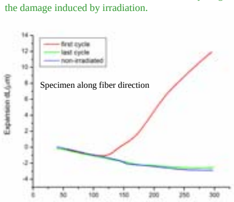


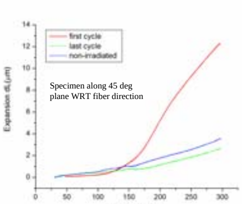
Remotely operating Tensile Testing apparatus (Stress-strain relation)

POST-IRRADIATION ASSESSMENT

C-C Composite

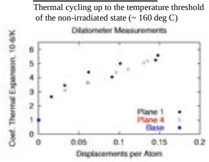
Composite behaves differently along different planes:
Along fibers it initially shrinks with increasing temperature while expands along planes at an angle with fiber direction.
In all cases, however, as seen below, thermal cycling "anneals" the damage induced by irradiation.



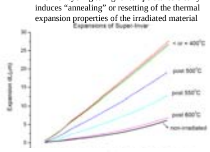


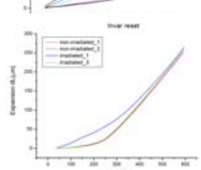
Super INVAR

PHASE I Irradiation Assessment
Thermal cycling up to the temperature threshold of the non-irradiated state (~ 160 deg C)

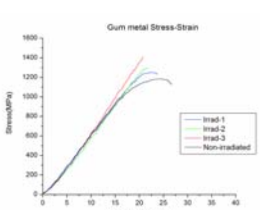


PHASE II Irradiation Assessment
Thermal cycling to higher temperatures clearly induces "annealing" or resetting of the thermal expansion properties of the irradiated material



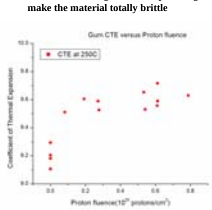


Gum Metal

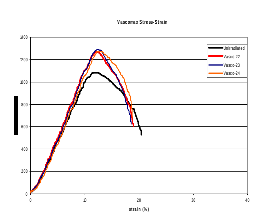


Gum metal strengthens with irradiation but clearly looses the "super-ductility" property

Irradiation damage of ~0.25 dpa enough to make the material totally brittle



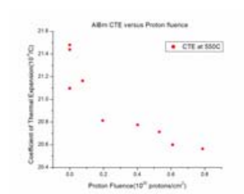
Vascomax



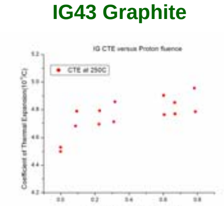
Vasomax is a very interesting Material

- Strengthens with irradiation without turning brittle
- CTE is not affected by irradiation

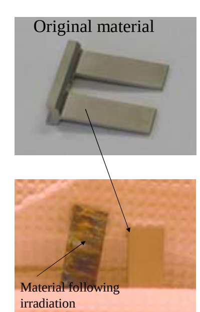
AlBeMet



IG43 Graphite



Ni-plated Aluminium



Preliminary Assessment:

Irradiation combined with water environment (oxidation) clearly affects the state of the plating layer. Further examinations planned.