Radiation Damage Study of Graphite and Carbon-Carbon Composite Target Materials

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Motivation
- Future high intensity proton beams for neutrino production (LBNE) will push target materials to their limit
- Need to better understand the radiation damage effect due to high energy proton beam on the thermal and structural material properties
- NuMI target experienced neutrino yield degradation due to target irradiation damage
- Experimental and operational observations prompted further study to investigate target material limitations

Objective: evaluate irradiation-induced changes in thermal and mechanical properties of low-Z target materials at varying DPA levels

Irradiation Experiment
- BNL Linac proton energy: 66 – 200 MeV
- Irradiation experiment performed in tandem with isotope production
- Upstream target array optimized and configured to meet stringent isotope production requirements downstream

MARS-15 Monte Carlo Simulations
- Target damage comparison between BLIP and LBNE beam parameters

<table>
<thead>
<tr>
<th>NuMI/LBNE</th>
<th>BLIP</th>
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<tr>
<td>E_p (GeV)</td>
<td>120</td>
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<tr>
<td>Beam ø (mm)</td>
<td>1.10</td>
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<tr>
<td>N_d (1/yr)</td>
<td>4.0e20</td>
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<tr>
<td>DPA (1/yr)</td>
<td>0.45</td>
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- 9 weeks of irradiation at BLIP is equivalent to 1 year of accumulated damage of LBNE POCO graphite target, operating at 120 GeV/700 kW
- After cool down period, target array transported to hot cell facility for post-irradiation examination

Future tests
- Flexural tests of 3D C/C composite specimens
- Possible second irradiation at BLIP for higher DPA
- Comparison to samples irradiated with fast neutrons at BLIP

Results

Thermal stability and damage annealing
- Radiation damage to graphite lattice structure:
  - production of interstitial atoms, mobile at lower temperatures
  - production of vacancies, mobile at T > ~1000 K
- For partial damage annealing, T_anneal > T_irradiation
- Irradiation temperature range during experiment: 140 – 200 °C

Thermal cycling of specimens using dilatometer
- Graphite partially anneals after thermal cycling
- Irradiation temperature can be inferred at point from which irradiated curve diverges from un-irradiated curve

Mechanical tests
- Radiation damage effects on elastic modulus and tensile strength

Specimens
- Graphite grades: POCO, IG-430, SGL R7650, C-2020
- 3D C/C composite orthogonal weave
- Peak DPA = 0.095

- Summary plot of all graphite tested showing CTE increase of ~10% after thermal cycling

Ultrasonic tests
- CC6 not previously annealed
- CC12 annealed to 310 °C
- Results show annealing-induced restoration of the elastic modulus