Horn/Target Material Studies at BNL
Towards multi-MW Beam

Nick Simos, Ph.D., P.E.
Energy Sciences & Technology Departments
National Synchrotron Light Source II
Superbeam Target-Horn Concept (from BNL Study)
Superbeam Target-Horn Concept
BNL Graphite and Carbon Composite Target SHOCK Test

![Image of test setup and graph showing microstrain over time for CC composite and ATJ Graphite.]
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)
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

Ni on aluminum: Magnetic Horn of the NuMI Experiment

After irradiation

Before irradiation
Thermal Expansion of Nickel-plated Aluminum NuMI magnetic Horn

- NUMI_0dpa
- NUMI_irrad

Thermal Expansion [dL/L] %

Temp [°C]
# AlBeMet® Property Comparison

<table>
<thead>
<tr>
<th>Property</th>
<th>Beryllium S200F/AMS7906</th>
<th>AlBeMet AM16H/AMS7911</th>
<th>E-Material E-60</th>
<th>Magnesium AZ30A T6</th>
<th>Aluminum 6061 T6</th>
<th>Stainless Steel 304</th>
<th>Copper H04</th>
<th>Titanium Grade 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density lbs/ cuin (g/cc)</td>
<td>0.067 (1.55)</td>
<td>0.076 (2.10)</td>
<td>0.091 (2.51)</td>
<td>0.065 (1.50)</td>
<td>0.098 (2.70)</td>
<td>0.29 (8.0)</td>
<td>0.32 (8.9)</td>
<td>0.163 (4.6)</td>
</tr>
<tr>
<td>Modulus MSI (Gpa)</td>
<td>44 (303)</td>
<td>28 (193)</td>
<td>48 (331)</td>
<td>6.6 (45)</td>
<td>10 (69)</td>
<td>30 (205)</td>
<td>16.7 (115)</td>
<td>16.2 (106)</td>
</tr>
<tr>
<td>UTS KSI (Gpa)</td>
<td>47 (324)</td>
<td>38 (262)</td>
<td>39.3 (273)</td>
<td>49 (340)</td>
<td>46 (310)</td>
<td>75 (515)</td>
<td>46 (310)</td>
<td>96.7 (660)</td>
</tr>
<tr>
<td>YS KSI (Gpa)</td>
<td>35 (241)</td>
<td>28 (193)</td>
<td>N/A</td>
<td>36 (250)</td>
<td>40 (276)</td>
<td>30 (205)</td>
<td>40 (276)</td>
<td>85.6 (690)</td>
</tr>
<tr>
<td>Elongation %</td>
<td>2</td>
<td>2</td>
<td>&lt; .05</td>
<td>6</td>
<td>12</td>
<td>40</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Fatigue Strength KSI (Gpa)</td>
<td>37.9 (261)</td>
<td>14 (97)</td>
<td>N/A</td>
<td>14.5 (100)</td>
<td>14 (95)</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Thermal Conductivity btu/hr/ft/F (W/m-K)</td>
<td>125 (216)</td>
<td>121 (210)</td>
<td>121 (210)</td>
<td>44 (76)</td>
<td>104 (180)</td>
<td>9.4 (16)</td>
<td>226 (391)</td>
<td>9.75 (16.9)</td>
</tr>
<tr>
<td>Heat Capacity btu/lb-F (Jig-C)</td>
<td>.46 (1.96)</td>
<td>.373 (1.56)</td>
<td>.310 (1.26)</td>
<td>.261 (1.05)</td>
<td>.214 (.896)</td>
<td>.12 (.5)</td>
<td>.092 (.385)</td>
<td>.129 (.64)</td>
</tr>
<tr>
<td>CTE ppm/F (ppm/C)</td>
<td>6.3 (11.3)</td>
<td>7.7 (13.9)</td>
<td>3.4 (6.1)</td>
<td>14.4 (26)</td>
<td>13 (24)</td>
<td>9.6 (17.3)</td>
<td>9.4 (17)</td>
<td>4.8 (8.6)</td>
</tr>
<tr>
<td>Electrical Resistivity ohm-cm</td>
<td>4.2 E-06</td>
<td>3.5 E-06</td>
<td>N/A</td>
<td>14.5 E-06</td>
<td>4 E-06</td>
<td>72 E-06</td>
<td>1.71 E-06</td>
<td>60 E-06</td>
</tr>
</tbody>
</table>
The AlBeMet Choice

![Graph showing the Coefficient of Thermal Expansion vs. Average Proton Fluence for AlBeMet](image)

- **CTE at 550°C**

![Graph showing the Stress vs. Strain for AlBeMet with various fluences](image)

- **0 dpa**
- **0.0037 dpa**
- **0.0018 dpa**
- **7.0e-05 dpa**
- **3.8e-04 dpa**

Brookhaven Science Associates
LBNE Science Collaboration
Meeting - FNAL July 15, 2009
Radiation Damage of Ti-6Al-4V Substrate

![Graph showing Coefficient of Thermal Expansion vs. Average Proton Fluence](image)

![Graph showing Stress vs. Engineering Strain](image)
Resistivity-Conductivity Degradation
Thermal Conductivity and Radiation of Target
Electrical resistivity ➔ Thermal conductivity
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 (~1 dpa) ➞ ~ 10% reduction
Glidcop ➞ ~ 40% reduction
AlBeMet (~0.4 dpa) ➞ within 10%
Graphite and carbon-carbon composites

Linear Thermal Expansion of Isotropic Graphite (IG-430) and 2-D Carbon Composite

Thermal Expansion [%] vs. Linear Expansion (%) vs. Temp [°C]

- Graphite
- Carbon Composite
While things seemed promising with carbon fiber composites, a threshold proton fluence of ~$10^{21}$ protons/cm$^2$ has emerged.


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

Reactor experience (dominated by thermal neutron flux) has shown that graphite can withstand tens of dpa of damage. Premature degradation result of:

- Radiation rate?
- Thermal neutrons vs. energetic protons?
Threshold $\sim 10^{21}$ p/cm$^2$
Graphite-CC experience

Accelerator Experience:

TRIUMF Target; LANL Target; PSI Target

Water-cooled/Edge-cooled TRIUMF target

Fluence: somewhere 10^21 - 10^22 p/cm²

Swelling of the target after irradiation

10^{22} p/cm²

Radiation-cooled
High operating temp ~1100°C
Summary

A fluence threshold of $\sim 10^{21}$ p/cm$^2$ 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.)