REPORT ON X-RAY MEASUREMENT ON LHC COLLIMATOR MATERIALS AT BNL

E. Quaranta

...with many thanks to:

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Outline

- Motivation
- BNL irradiation facility
- Material irradiation at BLIP and TANDEM
- X-Ray diffraction at the NSLS
- Summary of the tests
- Conclusion and Outlook
Motivation

LHC collimators are exposed to high radiation dose level during the normal operation of the machine. It may lead to DRAMATIC CHANGES in the material properties (reduction in thermal conductivity, increase in electrical resistivity and Young’s modulus, volume deformation, etc.)

Radiation hardness is a key requirement

Choice of new materials must take into account the behaviour under heavy radiation loads to:

MINIMIZE the WORSENING of physical/mechanical properties due to radiation-induced effects

Where do we are in terms of radiation-induced damage in present and novel collimator materials?

Answer will be based on:
- Investigation of material behaviour in highly irradiation environment.
- Complementary studies in several research center (Kurchatov Institute, GSI, BNL) with different irradiation conditions and setup.
BNL irradiation facilities

BLIP: irradiation up to 200 MeV proton or spallation neutrons from 112 MeV protons

Tandem van de Graaff: Irradiation with 28 MeV proton for very localized damage
Material irradiation at BLIP

200 MeV proton irradiation (8 weeks):
- Glidcop AL-15 (SCM Metals, USA)
- Molybdenum (Plansee, Austria)
- MoGr (Brevetti Bizz, Italy)
- CuCD (RHP Tech., Austria)

Note: 200 MeV proton irradiation performed at BLIP also on CFC and Glidcop in 2012 (US-LARP collaboration).

Setup for 200 MeV proton irradiation

Spallation neutrons from 112 MeV protons:
- CuCD (RHP Tech., Austria)
- Graphite (also interesting for collimators)
...and at TANDEM

- Tightly focused 28 MeV proton beam (1.5 x 1.75 mm beam core + tail)
- Primary beam intercepted by Mo sample (high-Z material) to maximize secondary particle spectrum
- Spallation neutron field produced by primary protons used to irradiate MoGr, CuCD and Glidcop (2x2x42 mm)
**NSLS: National Synchrotron Light Source**

X-ray beam from NSLS used for **phase and strain mapping** of cold and irradiated collimator material samples.
2 runs: April and September 2014 (“last light” before NSLS shutdown).
The new beamlines in NSLS II will start the operations in mid-2015.

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**LINAC (up to 120 MeV)**
**e-gun (100 keV)**
**Booster (up to 750 MeV)**
**X-Ray ring (up to 3 GeV)**
**UV/IR ring (up to 825 MeV)**
Constructive interference when:

\[ n\lambda = 2d \sin\theta \]

Bragg’s law

Single crystal diffracts in discrete directions

Polycrystalline material creates series of diffraction cones

A two dimensional (2D) XRD system is a diffraction system with the capability of simultaneously collecting and analyzing the X-ray diffraction pattern in 2D.

Main advantages compare with 1D:

- No sample orientation dependence
- Crystalline percentage measurement more accurate
2D XRD at X17A beamline

- **Monochromatic** X-Ray beam
- Energy = 60-70 keV
- Beam spot size: 0.5 x 0.5 mm

- Discretized scan along the length of each sample
- Data will be used as **benchmark** with similar measurements foreseen to be performed at NSLS II

CuCD sample irradiated at TANDEM
Energy Dispersive X-Ray Diffraction at X17B1 beamline

- Continuous *white* radiation
- Energy *up to 200 keV* (bulk analysis)
- **Fixed angle** $2\theta$ (good for in-situ measurements)
- **Energy distribution** of scattered photons analyzed by a semiconductor detector
- Multichannel analyzer to determine pulse height
EDXRD at X17B1 for simultaneous phase and strain mapping

Load on sample placed in 4-points bending fixture

Discretized scan along sample thickness
beam spot = 20 μm x 1 mm
20 μm step

Discretized scan along sample length
beam spot = 20 μm x 0.5 mm
0.5 mm step
# Summary of the tests

<table>
<thead>
<tr>
<th>Material</th>
<th>Irradiation</th>
<th>Activity and dose evaluation (at IEF)</th>
<th>X-Ray diffraction at X17A (NSLS)</th>
<th>Phase and strain map at X17B1 (NSLS)</th>
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<tbody>
<tr>
<td>Mo</td>
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<td>✓</td>
<td>✓**</td>
</tr>
</tbody>
</table>

* = waiting for the radioactive samples to cool down in hot cells  
** = measurement performed with pure bending load applied to the sample  
*** = sample exposed at only 2h of proton irradiation at BLIP
## Summary of the tests (cont’d)

<table>
<thead>
<tr>
<th>CuCD</th>
<th>Irradiation</th>
<th>Activity and dose evaluation (at IEF)</th>
<th>X-Ray diffraction at X17A (NSLS)</th>
<th>Phase and strain map at X17B1 (NSLS)</th>
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<td>✓</td>
<td>✓</td>
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</tr>
</tbody>
</table>

* = waiting for the radioactive samples to cool down in hot cells
Status and Outlook

**BLIP**
- 200 MeV proton irradiation (8 weeks): COMPLETED
- Neutron irradiation from 112 MeV protons (several months not continuously): COMPLETED
- Cooling of highly radioactive samples in Hot Cell Lab 66: ON-GOING

**TANDEM VAN DER GRAAF**
- 28 MeV proton irradiation + sample cooling: COMPLETED

**NSLS (National Synchrotron Light Source)**
- X-Ray diffraction studies for phase and strain mapping of some cold and irradiated samples: COMPLETED (to be continued in NSLS II in late 2015)
- Data analysis: ON-GOING

**CFN (BNL Center of Functional Nanomaterials)**
- Annealing and Electron Microscopy analysis: NOT STARTED (foreseen for beginning 2015)

**IEF (BNL Isotope Extraction Facility)**
- Activity and dose measurements per sample: COMPLETED
- γ-spectra for selected samples: PARTIALLY COMPLETED
Status and Outlook (cont’d)

IEF (BNL Isotope Extraction Facility)
- Macroscopic analysis: NOT STARTED (foreseen for 2015)

Physical and mechanical properties to be measured on both reference and irradiated samples are:
- Stress-strain behaviour up to failure (tensile tests on metals, flexural tests on composites)
- Thermal conductivity
- Coefficient of Thermal Expansion (CTE)
- Swelling
- Electrical resistivity
- Damage recover after annealing

The instrumentation now available in BNL laboratories are:
- Tinius-Olsen mechanical tester + CERN fixture for flexural test
- LINSEIS dilatometer (annealing up to 1000 °C for dimensional stability recovery, electrical resistivity and thermal conductivity)
- 4-point electrical resistance apparatus
- Panametrics Ultrasound system
- Ortec Ge Detector - photon spectra analysis
- High precision scales – density measurements
Thank you for your attention

The “fantastic 5” at NSLS X17B1 beamline!