Irradiation requirements of Nb3Sn based SC magnets electrical insulation developed within the EuCARD

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Outline

- Motivation of launching EuCARD irradiation task
- Nb3Sn SC magnet coils electrical insulation candidates
- EuCARD insulators certification conditions
- Post irradiation tests
- Tests sample irradiation
- Conclusions
Motivations

- Magnets in accelerators like the upgraded LHC and neutrino factories will be subjected to very high radiation doses.

- The electrical insulation employed on the coils must be resistant to this radiation.

- Degradation of electrical, mechanical and thermal properties of irradiated insulation need to be investigated.

- A dedicated certification program for the radiation resistance of the insulation material has been launched within the European Coordination for Accelerator Research and Development (EuCARD) sub-task WP7.2.1.
Radiation map for the Interaction Region Quadrupoles for LHC upgrade phase I

Peak fluence in 10 years: $2.5 \times 10^{17}$ neutrons/cm$^2$
Radiation spectrum at Q2a: 35m from Collision Point

<table>
<thead>
<tr>
<th>Radiation type</th>
<th>Contents, %</th>
<th>Influence on magnet coil materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutrons</td>
<td>4.82</td>
<td>SC and Cu</td>
</tr>
<tr>
<td>Protons</td>
<td>0.14</td>
<td>SC and Cu</td>
</tr>
<tr>
<td>Photons (γ)</td>
<td>88.93</td>
<td>Insulation</td>
</tr>
<tr>
<td>Electrons</td>
<td>4.31</td>
<td>small effect</td>
</tr>
<tr>
<td>Positrons</td>
<td>2.23</td>
<td>small effect</td>
</tr>
<tr>
<td>Pions +</td>
<td>0.19</td>
<td>probably small effect</td>
</tr>
<tr>
<td>Pions -</td>
<td>0.26</td>
<td>probably small effect</td>
</tr>
</tbody>
</table>
Photon spectrum on the inner coil of Q2a at the peak location - FLUKA simulation

e$^+$/e$^-$ annihilation peak

Dose - min. 50MGy
Insulation candidates

- RAL mix 71 - DGEBA epoxy + D400 hardener
- LARP insulation; CTD1202 + filler ceramic
- Cyanate Ester AroCy L10 40% + DGEBA epoxy 60%
Radiation literature review

- The materials were irradiated mostly with fast neutrons.
- The other radiation sources were characterized by the doses at least order of magnitude lower than predicted for new accelerators.
- Irradiations were mostly performed in non cryogenic conditions.
- Post-irradiation tests were mostly performed in non-cryogenic conditions.
- Long delay time between irradiation and testing - material warm-up effects and aging not taken into account.
- Post irradiation tests - mostly mechanical.
EuCARD insulators certification conditions

- Radiation type: photon, $E > 1$ MeV
- Integrated radiation dose - 50 MGy
- Irradiation temperature - 77 K
- Warm-up between the irradiation and certification tests:
  - mechanical/electrical test - short time only
  - thermal - yes, contact with atmospheric air should be limited
- Certification tests temperature:
  - mechanical/electrical tests - 77K
  - thermal - 1.6 - 2.0 K and 4.2 - 300K
Photons spectra from electron linac

Photons spectra for electron collision with target made of 1mm thick tungsten and 0.2mm thick gold
EuCARD insulators certification conditions

- Radiation type: photon beam, $E > 1$ MeV
- Integrated radiation dose - 50 MGy
- Irradiation temperature - 77 K
- Warm-up between the irradiation and certification tests:
  - mechanical/electrical test - short time only
  - thermal - yes, contact with atmospheric air should be limited

- Certification tests temperature:
  - mechanical/electrical tests - 77K
  - thermal - 1.6 - 2.0 K
Irradiation requirements and limitations

• 50 MGy integrated dose
  - electrons source with high dose rate is required
  - irradiation of a few specimens at once would be a good idea

• Electron beam diameter
  - appropriate post-irradiation certification method need to be applied

• Electrons energy
  - limited penetration of material by electron beam

• Certification test specimen dimensions preferences:
  - small thickness
  - small irradiation area - up to beam diameter
### Selection of the electron source available at NCBJ, Świerk, Poland

<table>
<thead>
<tr>
<th>Structure</th>
<th>6 MeV</th>
<th>12 MeV</th>
<th>15 MeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Real electron energy</td>
<td>MeV</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Depth of water penetration (range 80-100% of dose)</td>
<td>mm</td>
<td>10</td>
<td>26</td>
</tr>
<tr>
<td>Beam diameter (90-100% of intensity)</td>
<td>mm</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>Depth of insulation penetration</td>
<td>mm</td>
<td>5.6</td>
<td>14.4</td>
</tr>
<tr>
<td>Nbrs of samples radiated at once*</td>
<td></td>
<td>11.1</td>
<td>28.9</td>
</tr>
<tr>
<td>Max recorded dose rate</td>
<td>Gy/min</td>
<td>2200</td>
<td>12</td>
</tr>
<tr>
<td>Repetition frequency</td>
<td>Hz</td>
<td>76.4</td>
<td>5</td>
</tr>
<tr>
<td>Expected dose @f=300Hz</td>
<td>Gy/min</td>
<td>8639</td>
<td>720</td>
</tr>
<tr>
<td>Irradiation time for 50 MGy</td>
<td>Working days</td>
<td>12.1</td>
<td>144.7</td>
</tr>
<tr>
<td>Irradiated samples</td>
<td>Work. days/sample</td>
<td>1.1</td>
<td>5.0</td>
</tr>
</tbody>
</table>

* For 0.5 mm thick sample
Electrical certification tests

- Test standard - EN 60243-1: “Methods of test for electric strength of solid insulating materials. Tests at power frequencies”

- Specimens dimension:
  - thickness - 0.5mm
  - length x width - min. 50x50 mm

- Required irradiation area - 5mm diameter circle (spot)
Thermal certification method

1.6 – 2.1K - Drum method:
• allows determination of thermal conductivity and Kapitza resistance at superfluid helium conditions
• Specimens dimension:
  - min. 3 different thicknesses from 0.1 - 0.5 mm range
  - length x with - 100x100 mm
• Required irradiation area - 80 mm diameter circle

4.2 – 300 K - standard thermal conductivity set-up based on cryocooler
• Specimens dimension requirements: stripe of 0.5mm thick material
• Required irradiation area - full area of stripe
Mechanical certification tests 1/2

Typical tests methods:

_Determination of apparent interlaminar shear strength by short-beam method - EN ISO 14130_

- Specimens dimension requirements:
  - thickness - min. 2mm
  - length x width - min 20 x 6 mm/mm
- Required irradiation area - full area of the specimen

_Determination of mode I interlaminar fracture toughness - ISO EN 15024 standard_

- Specimens dimension requirements:
  - thickness - min. 5 mm
  - length x width - min 125 x 20 mm/mm
- Required irradiation area - full area of the specimen
Mechanical certification tests 2/2

Plastics - Determination of tensile properties - EN ISO 527-1

- Specimens dimension requirements:
  - thickness - 0.5 mm is acceptable
  - (test part) length x width - 60x8 mm x mm

- Required irradiation area - full area of the test part
Electron beam intensity - 2.5 cm from accelerator window

Sławomir Wronka, NCBJ 2012.01.15
Electron beam intensity - 2.5 cm from accelerator window

Sławomir Wronka, NCBJ 2012.01.15
Conceptual design of the irradiation cryostat
Distance between spots $d=22.5\text{mm}$
Thermal specimens irradiation pattern

d=10mm

d=12.5mm

d=15mm

d=17.5mm

d=20mm

d=22.5mm
Thermal specimens irradiation pattern

Dose distribution in marked cross section

D = 24 mm

D = 15 mm

Dose from 1 spot

Total dose

Distance from centre, mm

-20 -15 -10 -5 0 5 10 15 20

-30 -20 -10 0 10 20 30

0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9

Wrocław University of Technology
Thermal certification method

1.6 - 2.1K - Drum method:
- allows determination of thermal conductivity and Kapitza resistance at superfluid helium conditions
- Specimens dimension:
  - min. 3 different thicknesses from range 0.1 - 0.5mm
  - length x with - 100x100 mm
- Required irradiation area - 80 mm diameter circle - circle of 25 mm diameter can be applied

4.2 - 300 K - standard thermal conductivity set-up based on cryocooler
- Specimens dimension requirements: stripe of 0.5 thick material
- Required irradiation area - full area of stripe - stripe can be extracted from drum samples
Mechanical specimens irradiation pattern, d=17mm, 5 spots
Mechanical certification tests

*Plastics - Determination of tensile properties - EN ISO 527-1*

- Specimens dimension requirements:
  - thickness - 0.5mm is acceptable
  - (test part) length x width - 60x8 mm x mm
- Required irradiation area - full area of the test part - can be realized
Conclusions

- Irradiation type for radiation resistance certification of the electrical insulation for accelerator, Nb3Sn based SC SC magnet coils has been specified.

- Irradiation conditions, certification nominal integrated dose of irradiation as well as post-irradiation handling conditions of the material specimens have been defended.

- The mechanical, electrical and thermal certification standards/methods have been selected.

- The irradiation patterns for mechanical and thermal specimens have been determined.