Irradiation of insulators for EuCARD

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Outline

- Motivation of launching EUCARD irradiation task
- Irradiation methodology
- Post irradiation tests
  - Electrical
  - Thermal
  - Mechanical
- Irradiation cryostat
- 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.

• A dedicated certification program for the radiation resistance of the insulation material has been launched within the EuCARD sub-task WP7.2.1, in parallel to the modeling of future magnets.
Radiation map for the Interaction Region Quadrupoles for LHC upgrade phase I [1]

(Q1 120 10^{15} barn^{-1} total luminosity per year - 90mm full coll aperture - 220 \mu rad vertical crossing angle)

Peak fluence in 10 years: 2.5 \times 10^{17} neutrons/cm^2
## Radiation spectrum at Q2a: 35m from Collision Point [1,2]

<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 ($\gamma$)</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 [2]
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 one 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: electron beam, E>1MeV
- 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
Photon spectrum on the inner coil of Q2a at the peak location - FLUKA simulation [2]

Fig. 3 Comparison of the required and available (shadowed) photon beam energies
Beam energy required for the sample irradiation

Depth of beam penetration in water for various beam energy value

\[ \rho_{H2O} = 1.0 \, \text{g/cm}^3 \]
\[ \rho_{PMMA} = 1.2 \, \text{g/cm}^3 \]
\[ \rho_{G10} = 1.8 \, \text{g/cm}^3 \]

Scaling to G10 with density, For 2 cm long mechanical sample irradiation the beam energy as 10 – 11 MeV is necessary

Courtesy S. Wronka

WAMSDO – 14.11.2011 CERN
Experimental confirmation of the beam energy for 12 MeV structure

„12 MeV” Accelerator Structure: PMMA irradiation

Confirmed energy - 7÷8 MeV

Fig. 3 Measured depth-dose curve of „12 MeV” structure.
Technical limitations for higher doses

- The maximum dose rate limits come from existing in Soltan Institute accelerator technology – standing wave electron linac working at 3 GHz, gun current 300mA/pulse, transmission factor ~30%, i.e. beam current 100mA/pulse at the end of accelerating structure, pulse length typical 4.5-5us, PRF (Pulse Repetition Frequency) up to 300Hz.

- However in this application there is another limit. In all typical high power electron machines for industrial irradiations the beam on exit window is not point-like, but magnetically swept to avoid high current density (the window can be “burned”), this is called “scan horn window”.

- Therefore even the increasing of a linac current power will not decrease the irradiation time for each sample.
Electrical certification tests

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

- Required electrical resistance of insulation > 5kV/mm

Photo – CTD, Inc.
Mechanical certification tests

- **Typical tests methods**
  - *Determination of apparent interlaminar shear strength by short-beam method* - EN ISO 14130
  - *Determination of mode I interlaminar fracture toughness* - ISO EN 15024 standard

- Due to necessity of micro specimen applying of other mechanical test method is investigating
Mechanical tests - microsamples

• Tensile tests on microsamples with dimensions specified in the figure.

• Micro-bendig tests – sample’s dimensions: 8 mm x 3-4 mm x thickness
• Microtomography
• Thermal analysis (DSC, TGA, DMA)
Thermal certification method

Drum method:

- allows determination of thermal conductivity and Kapitza resistance at superfluid helium conditions
- temperature range: 1.6 - 2.1 K
PWR Hell cryostat status

Top view of the cryostat with wiring

Instrumentation and DAQ electronic

Insert

Measurement vessel
PWR Hell cryostat status

Measurement vessel

Top cover of measurement vessel
PWR Hell cryostat status

4 sample holders in the measurement vessel
PWR Hell cryostat status

- Instrumentation is installed
- Connection of instrumentation to DAQ system is done
- LabView program for cryostat operation is done
- 4 thickness of unirradiated 71 Mix samples are ready for thermal test
- During the first cool down with LHe some technical problems occurred
  - The manual shut-off valve need to be exchanged
  - Restart of measurement in expected till Dec. 2011
Irradiation cryostat - principle of irradiation process

Accelerator gun
Accelerator gun possitoner
Electron beam
LN₂ film
Sample holder
Samples package
LN₂
LN₂
LN₂
Heater
LN₂ Vapour
LN₂ level meter
Irradiation cryostat – commissioning test at manufacturer site
Irradiation cryostat installation at NCBJ
Conclusions

• The methodology of the insulation has been specified and a dedicated test stand commissioned.
• Thermal test – cryostat under commissioning
• Electrical tests – cryostat under production
• Mechanical tests – will be based on microprobes