Wrocław University of Technology

Radiation-Induced Degradation of Nb3Sn Based Electrical Insulation

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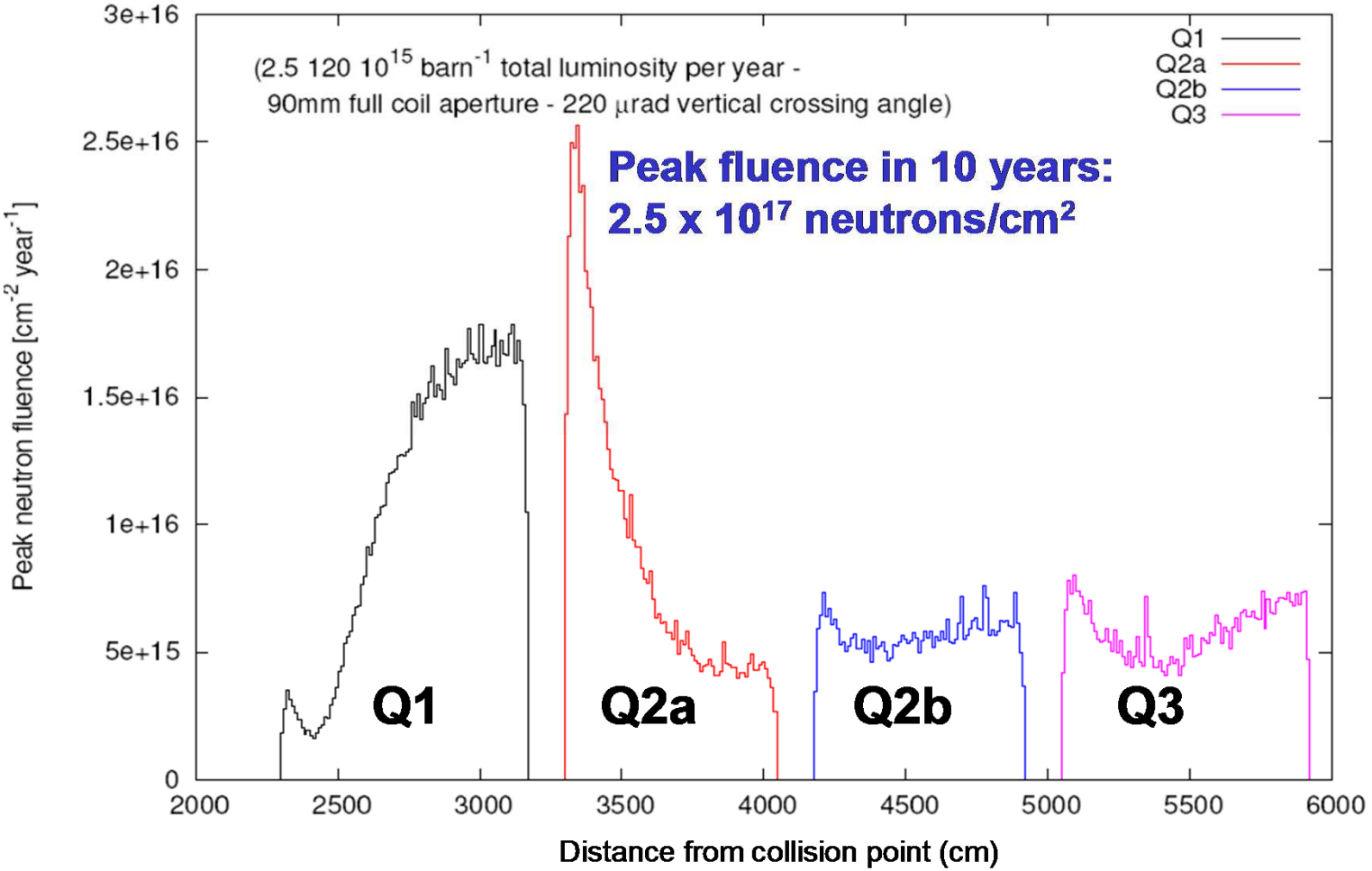
Motivations for cold irradiation and tests

- Increase of energy of future accelerator like the HL- LHC, HE-LHC and neutrino factories requires use of Nb_3Sn SC technology based magnets
- Such magnets will be subjected to very high radiation doses
- Due to necessity of the Nb_3Sn magnet coils heat treatment @650^{o}C the Kapton polyimide can't be applied for Nb_3Sn coil electrical insulation
- The new type of radiation resistant electrical insulation need to be found/developed
- A dedicated certification programme for radiation resistance of the insulation materials was launched within the European Coordination for Accelerator Research and Development (EuCARD) sub-task WP7.2.1.

Radiation map for the Interaction Region Quadrupoles for HL-LHC



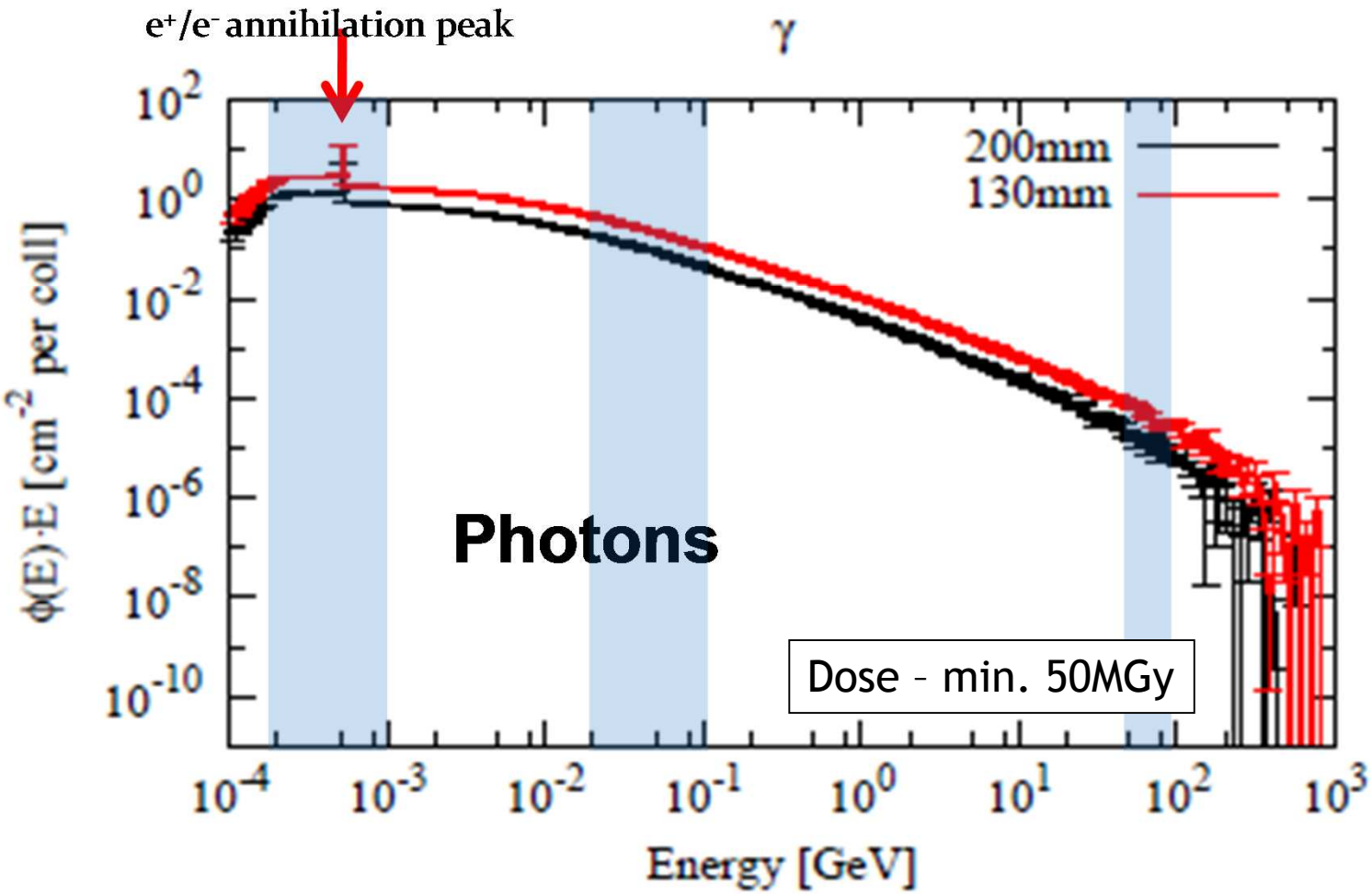
Courtesy R. Flukiger at al..

Radiation spectrum at maximum fluence for the Interaction Region Quadrupole

Radiation type	Contents, %	Influence on magnet coil materials
Neutrons	4.82	SC and Cu
Protons	0.14	SC and Cu
Photons (γ)	88.93	Insulation
Electrons	4.31	small effect
Positrons	2.23	small effect
Pions +	0.19	probably small effect
Pions -	0.26	probably small effect

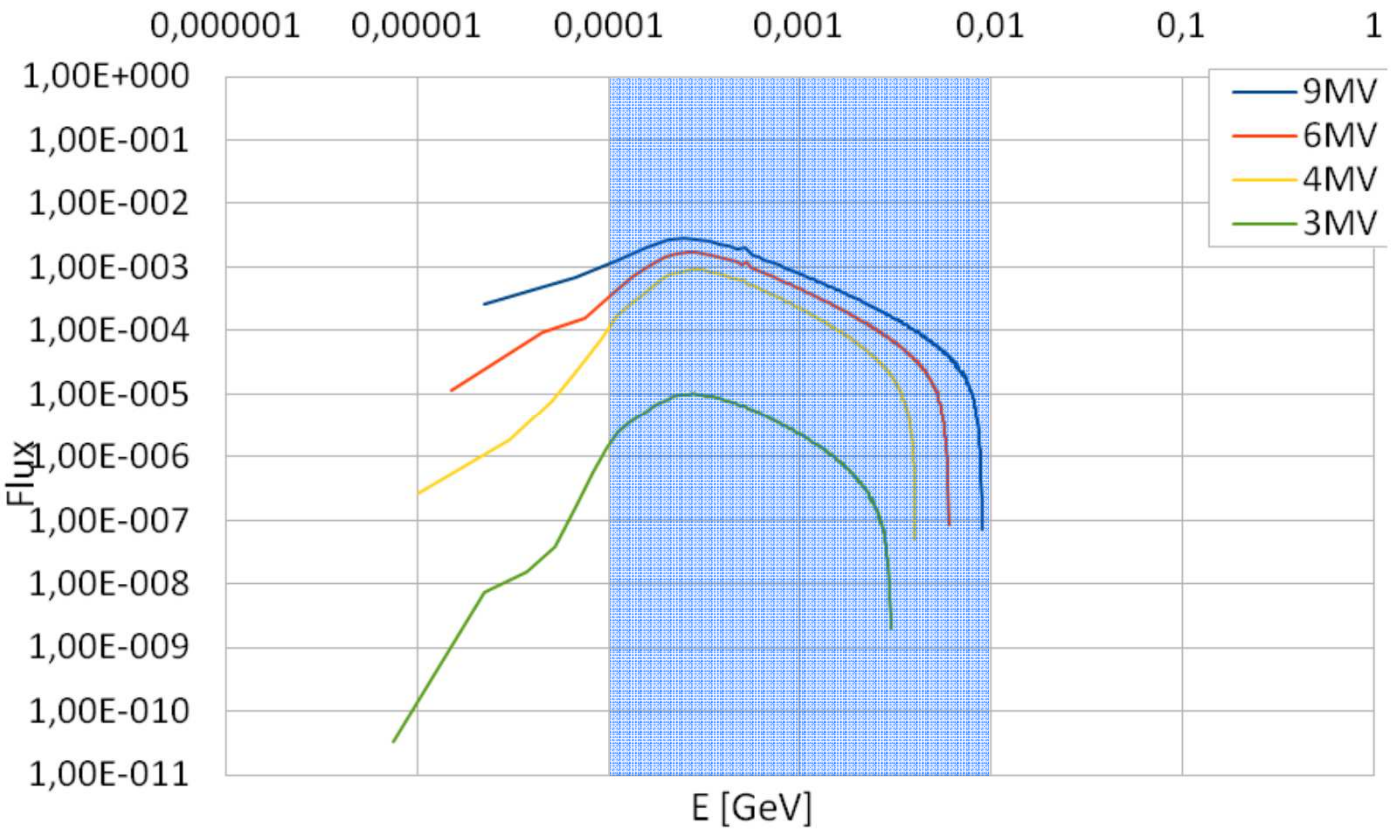
Courtesy R. Flukiger at al..

Photon spectrum on the inner coil of Q2a at the peak location - FLUKA simulation



Courtesy R. Flukiger at al..

Photons spectra from electron linac - after electrons collisions with target

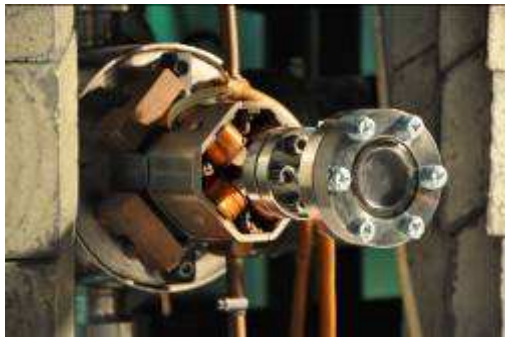


Photons spectra for electron collision with target made of 1mm thick tungsten and 0.2mm thick gold

Courtesy S.Wronka

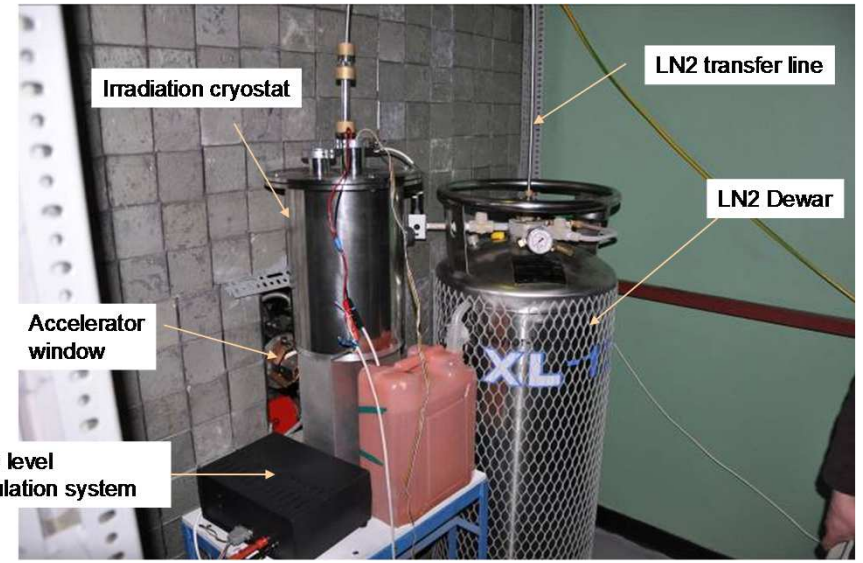
Irradiation process

- 4MeV electron beam
- Total dose 50MGy
- Samples in liquid nitrogen bath (77K) during irradiation and storage
- Beam diameter 6mm (90 - 100% intensity), dose 11kGy/min



Accelerator 0.2 mm thick Ti window

Irradiation set-up



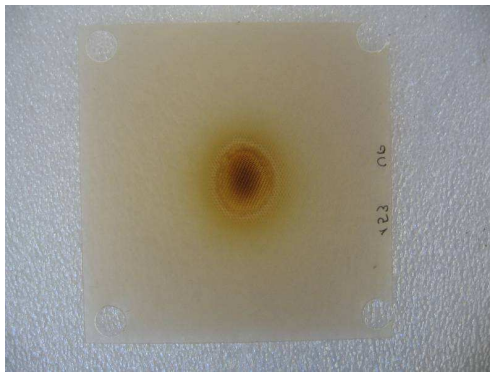
Insulation candidates

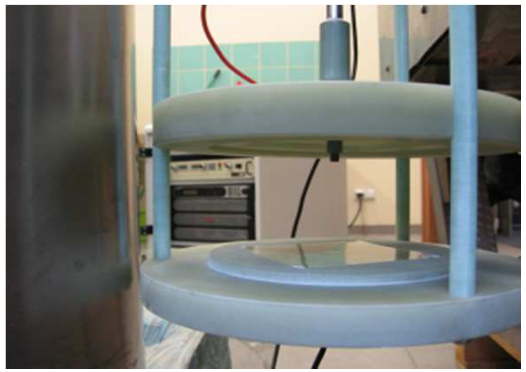
S-Glass +:

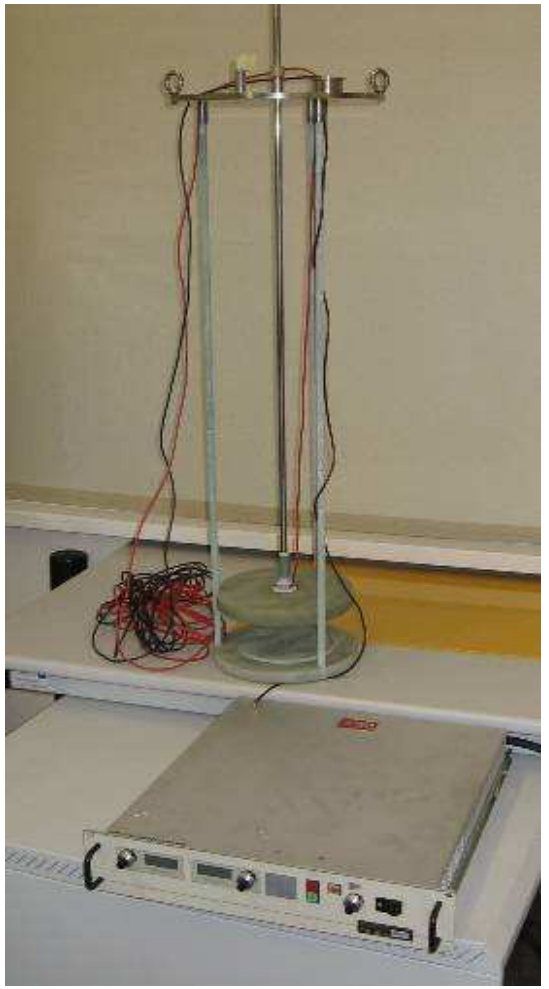
- RAL mix 71 – DGEBA epoxy + D400 hardener
- RAL mix 237 – Epoxy TGPAP-DETD(2002)
- LARP insulation; CTD1202 + filler ceramic
- Cyanate Ester AroCy L10 40% + DGEBA epoxy 60%

Radiation certification electrical tests

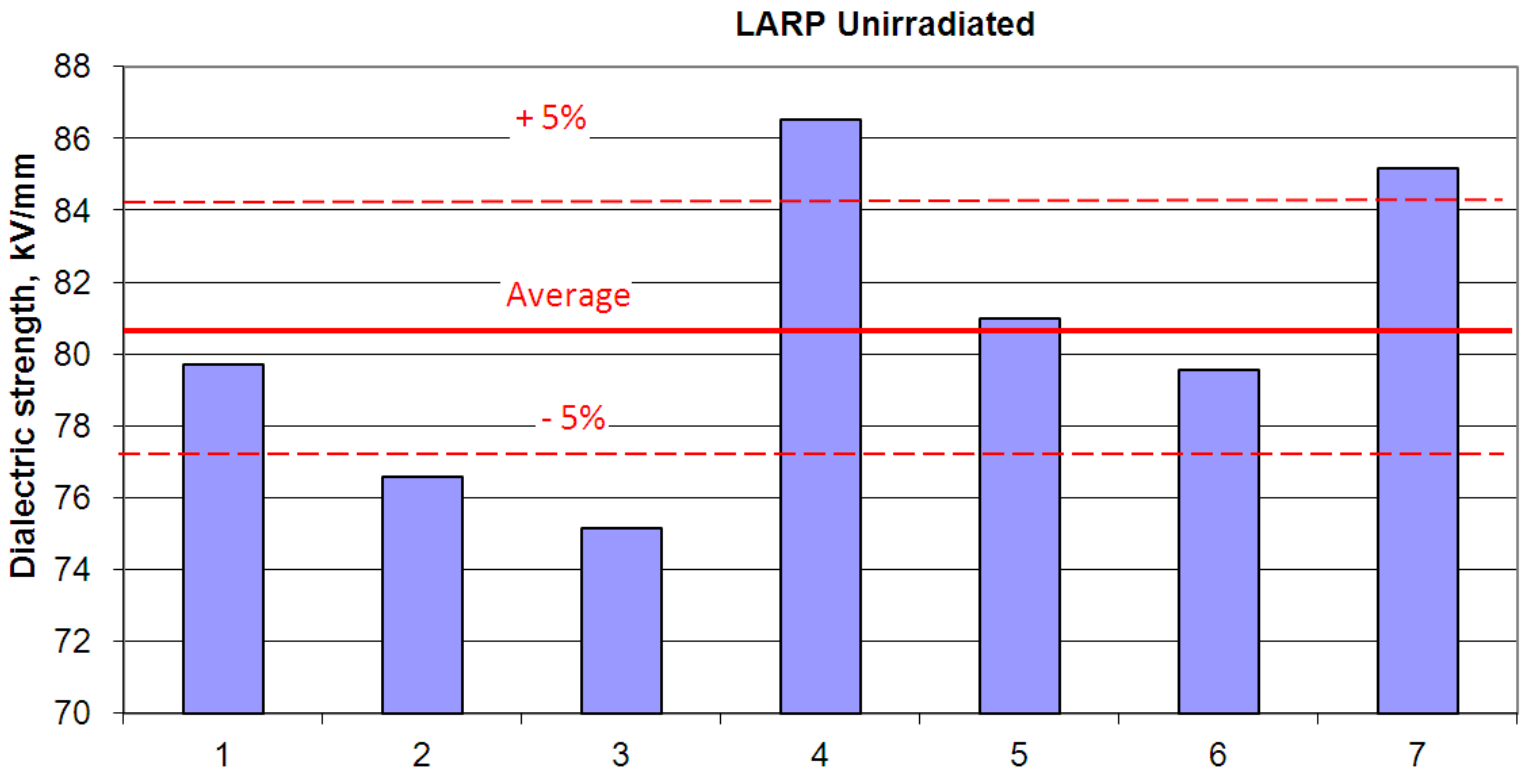
- Test environment – LN2
- Method – in accordance with ASTM D-149 standard, voltage increase rate – 1 kV/min, DC instead of AC voltage
- Specimens' dimensions:
  - thickness – 0.5 mm
  - length x width – min. 100x100 mmxmm
- Required irradiation area – 5mm diameter circle (spot)



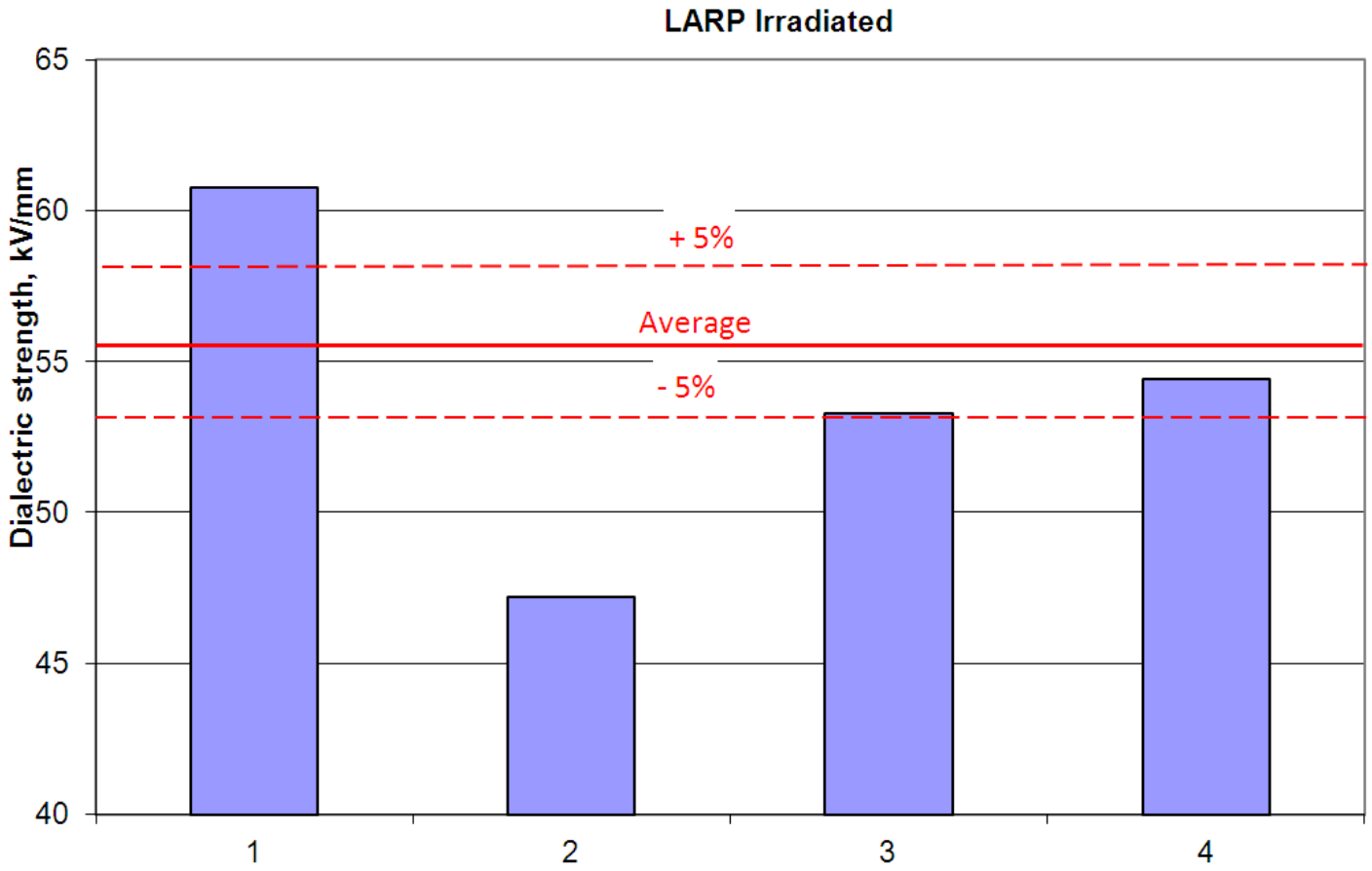




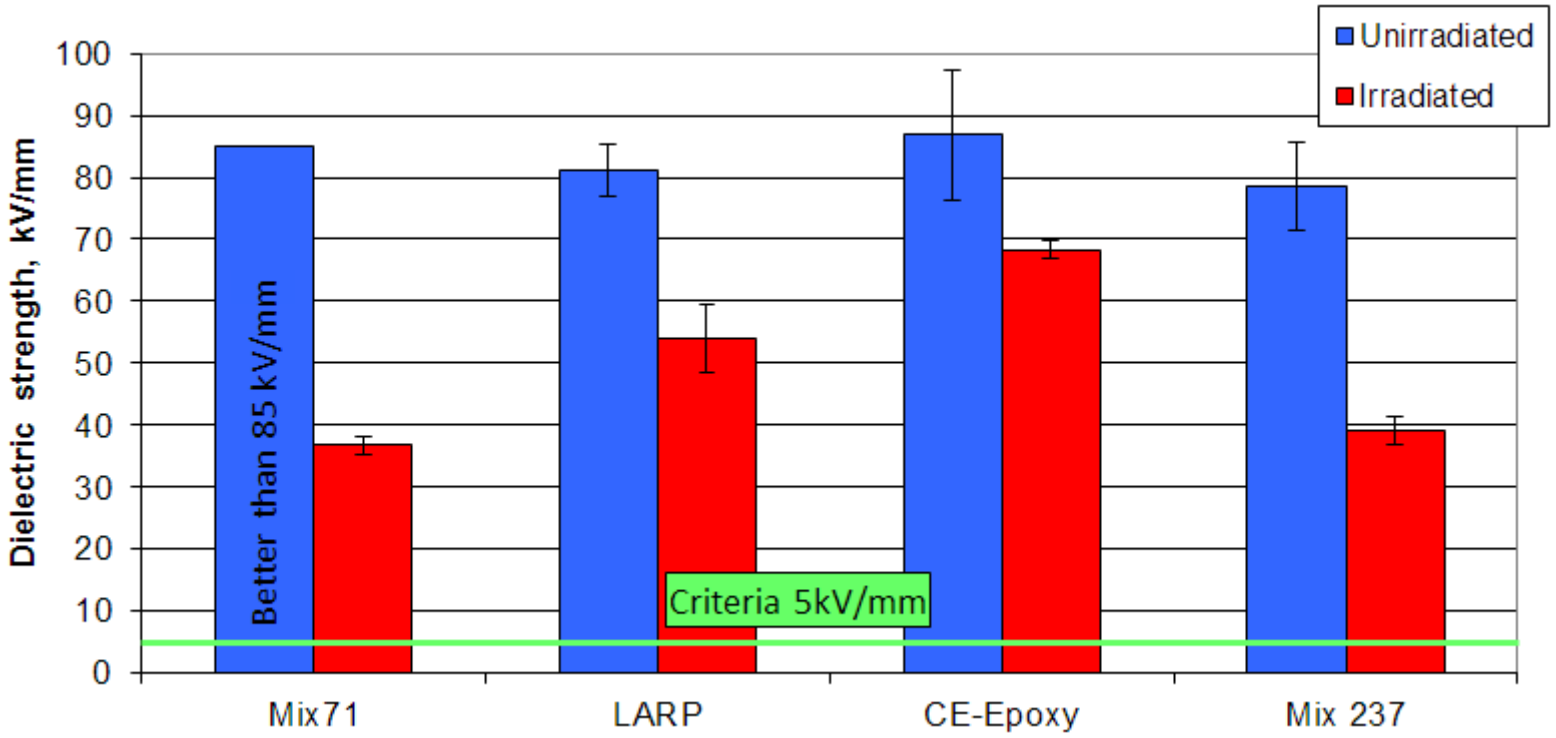
Radiation certification electrical tests LARP insulation



Radiation certification electrical tests LARP insulation

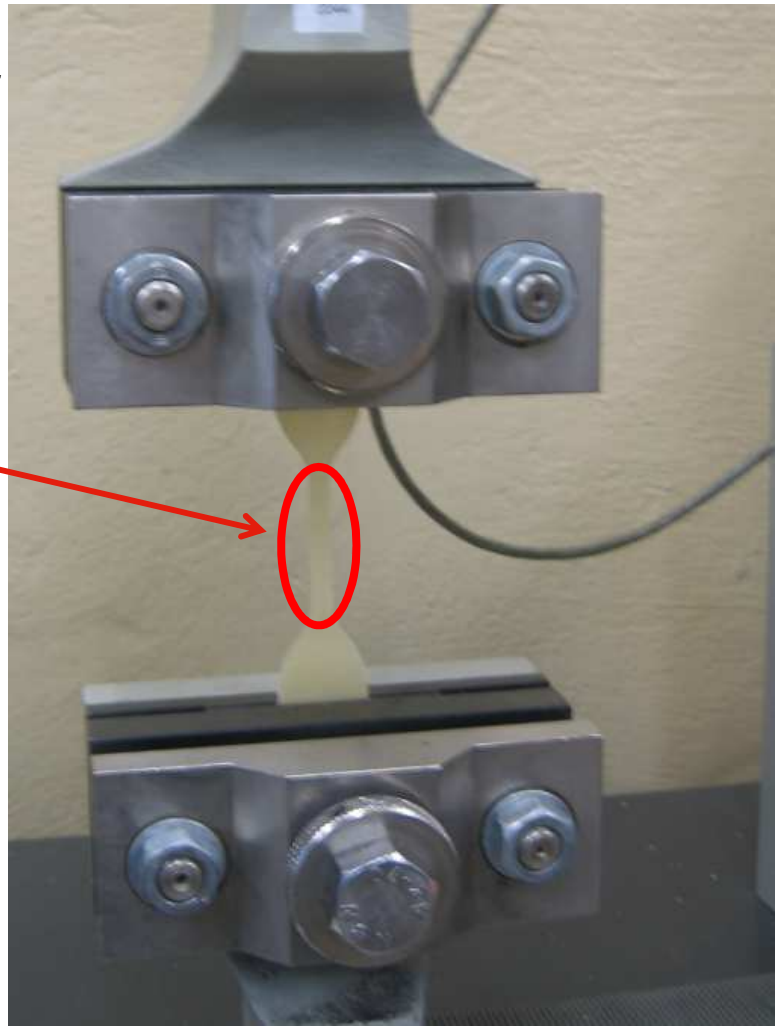


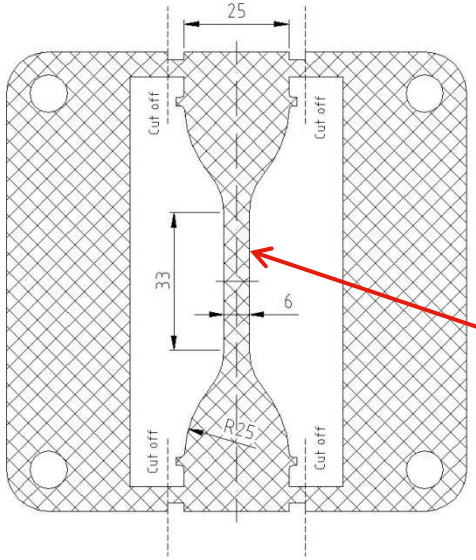
Radiation certification electrical tests summary



Mechanical certification tests

- ISO 37:2005 standard: "*Rubber, vulcanized or thermoplastic - Determination of tensile stress - strain properties*"
- Requirements for specimens' dimensions:
  - thickness – 0.5 mm is acceptable
  - (test part) length x width – 33x6 mm^2
- Required irradiation area – full area of the test part





- Shape is cut with water jet technology from 110x100x0,5 mmxmmxmm sheet
- Fibers orientation – 45dec. to the force direction

Mechanical certification tests parameters

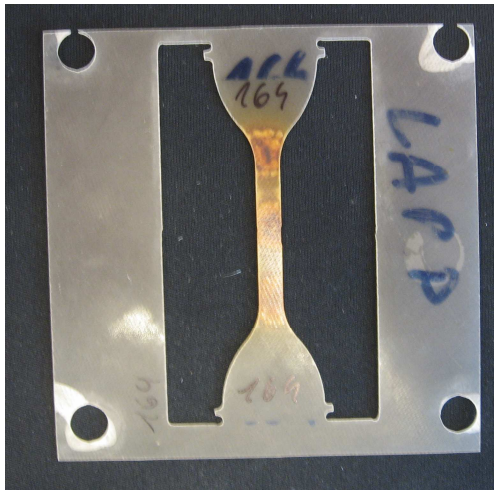
Temperature – 77K

Elongation speed – 1mm/min

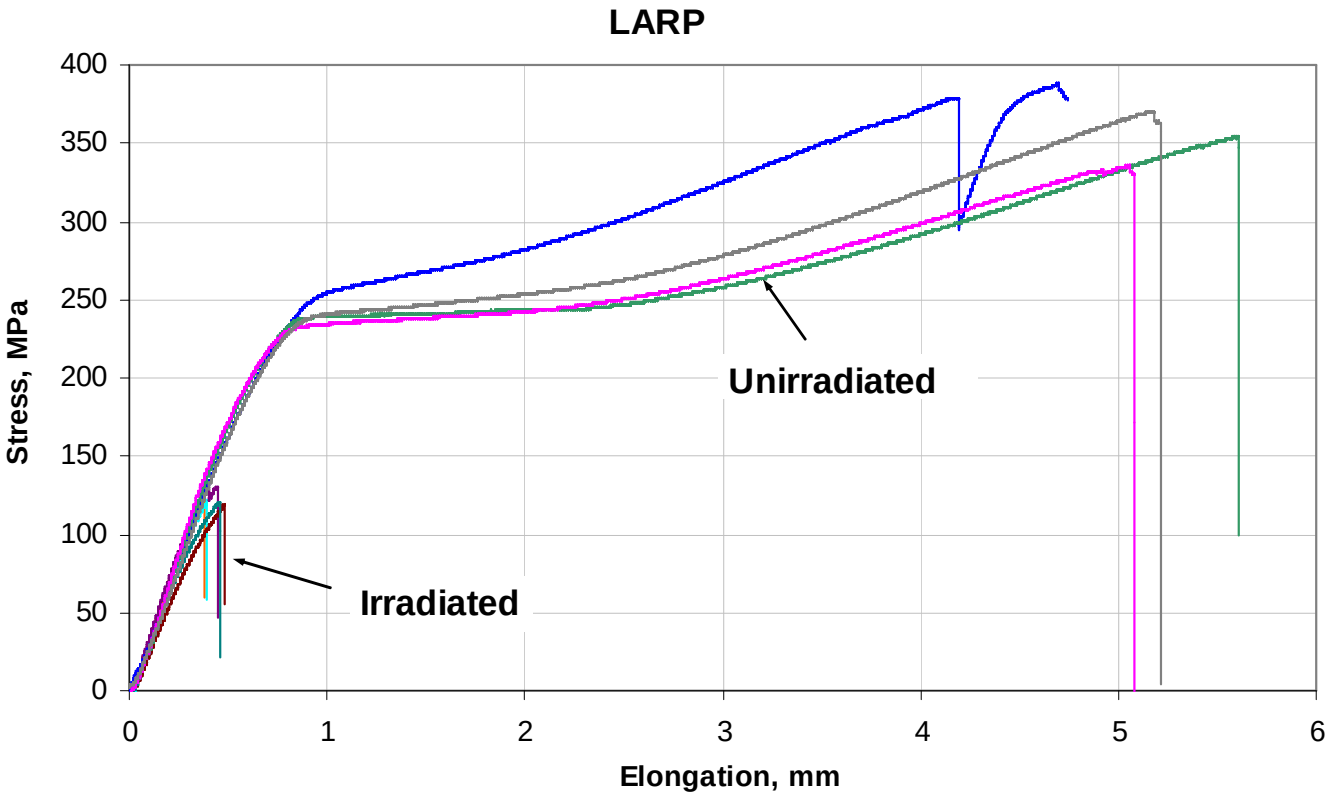
Force range – 0 ÷ 1 kN

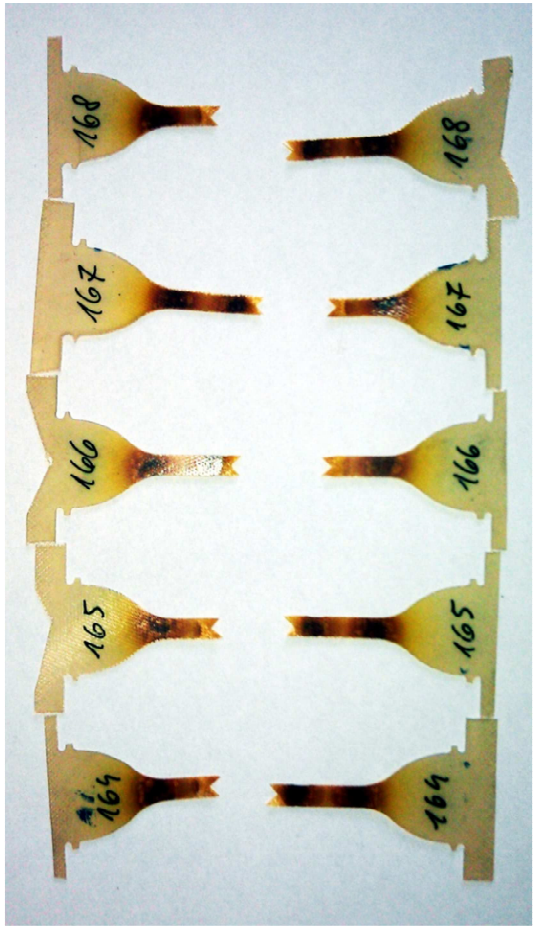
Stress range – 0 ÷ 500MPa

Number of material specimens: 3 ÷ 5

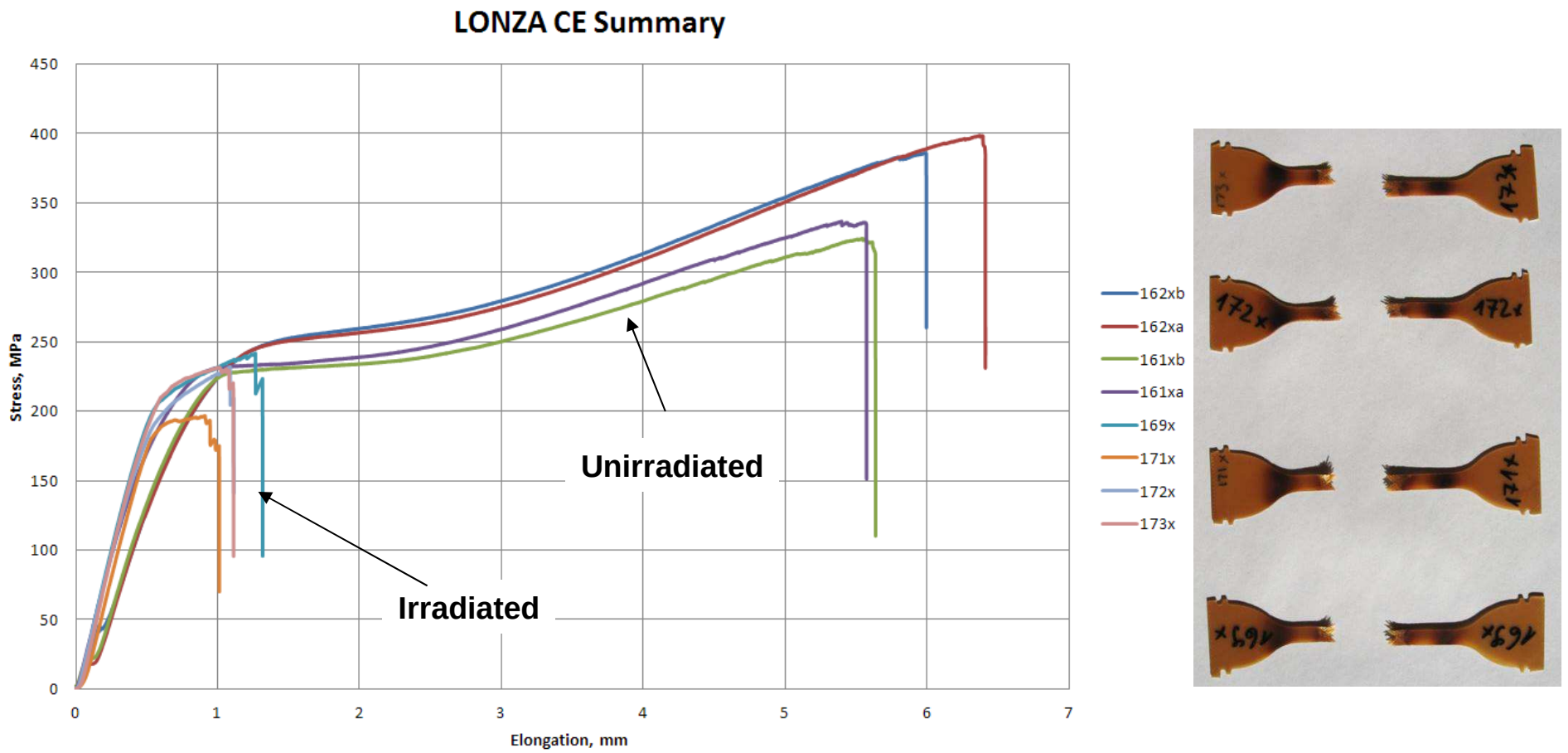


Mechanical certification test LARP insulation

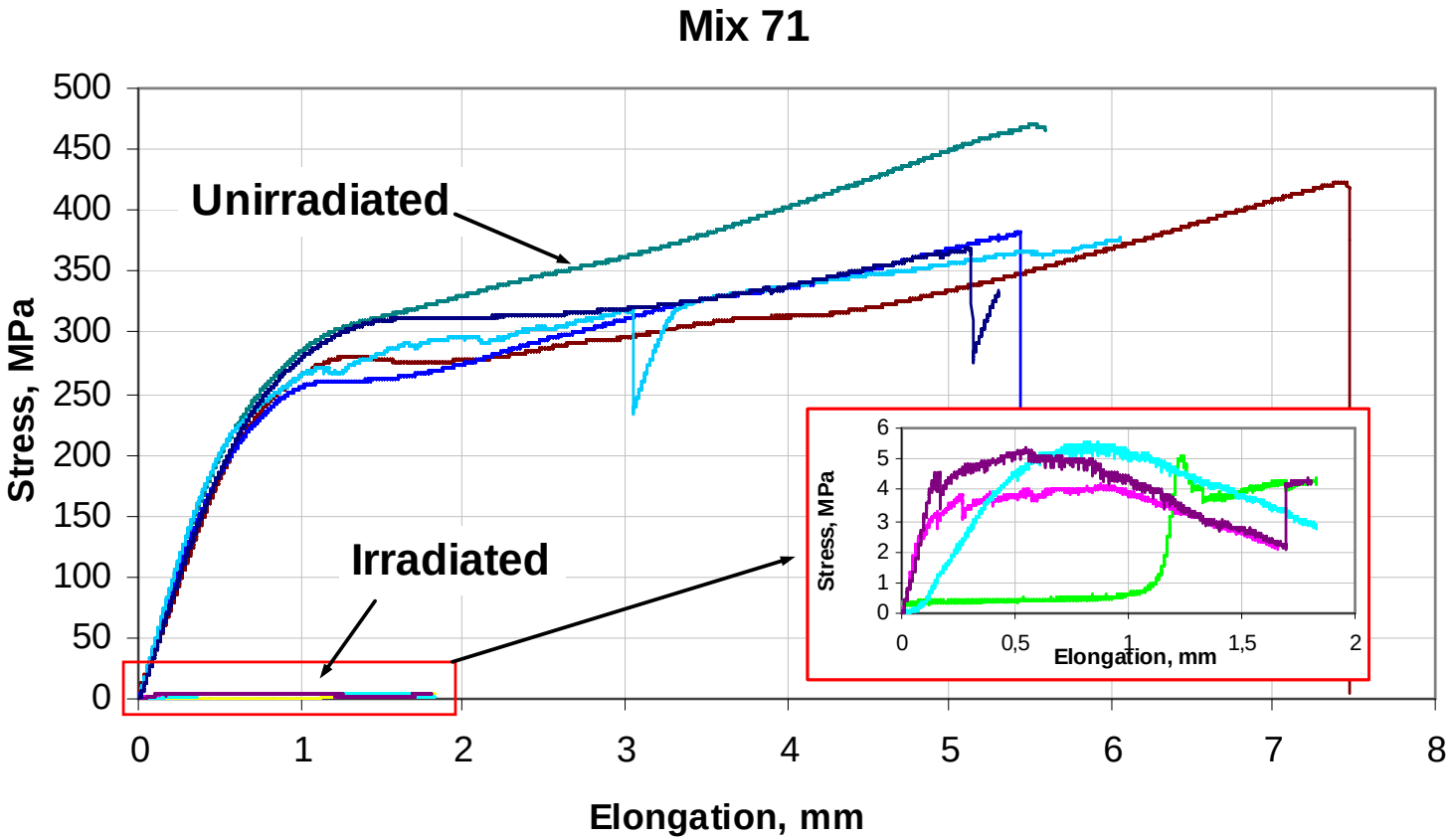


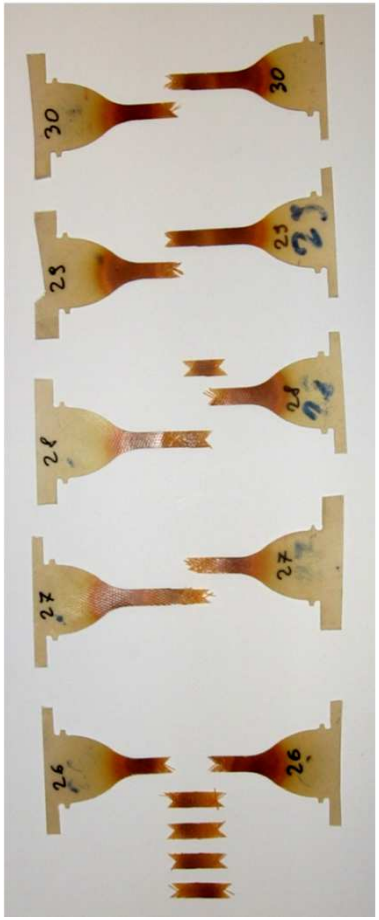


Mechanical certification test LONZA insulation

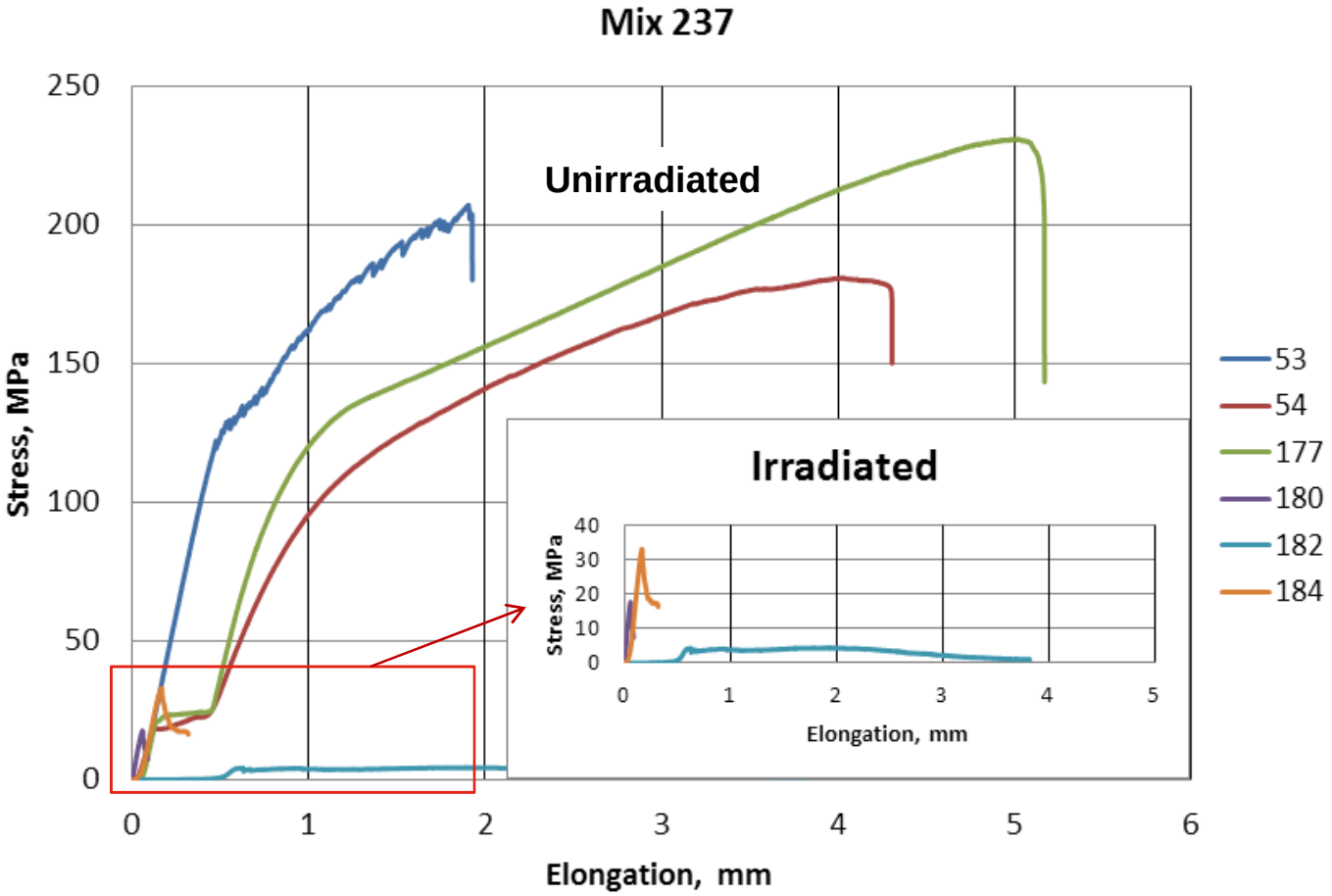


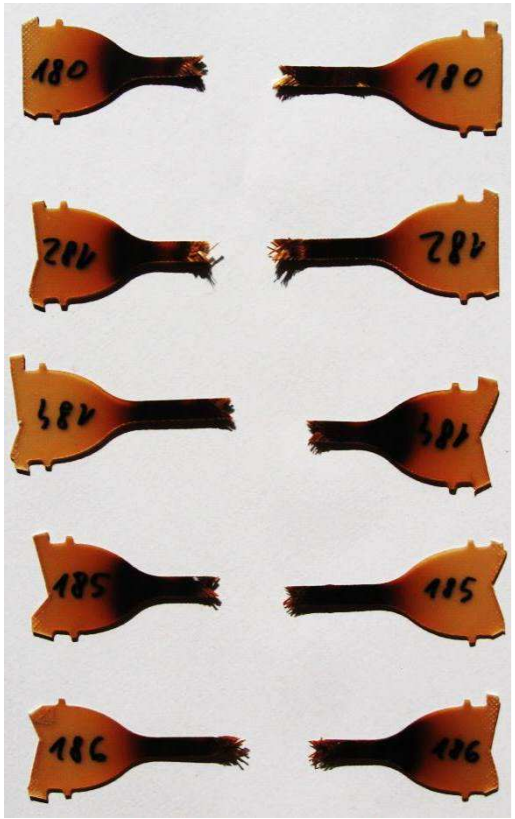
Mechanical certification test Mix71 insulation



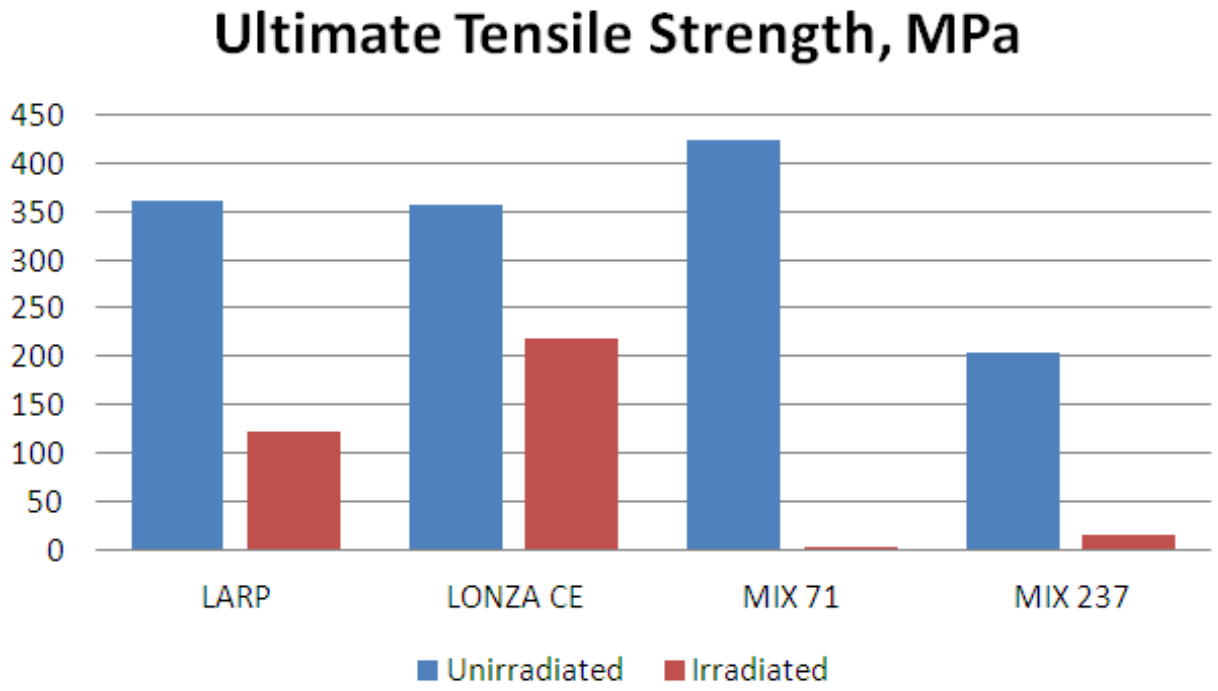


Mechanical certification test Mix237 insulation

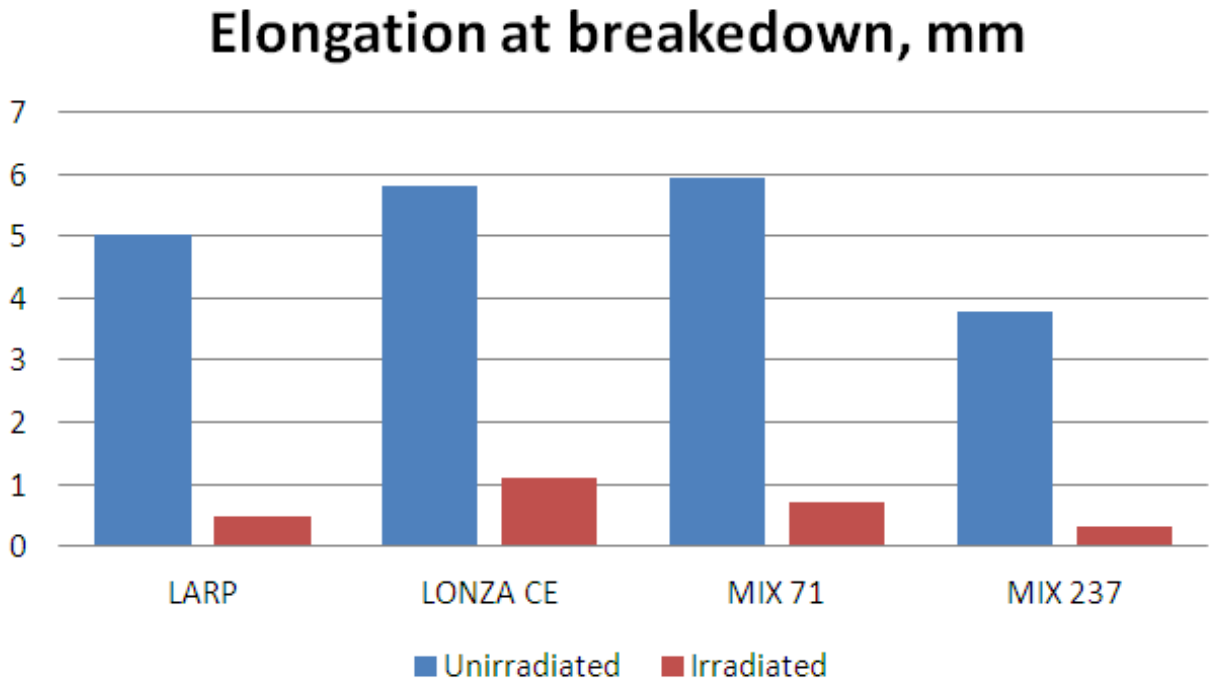




Radiation certification mechanical tests summary (1/2)



Radiation certification mechanical tests summary (2/2)



Conclusions

- The mechanical and electrical samples of measured insulation materials were successfully irradiated in cryogenic conditions (77 K) with electron beam up to 50 MGy dose
- High degradation of materials electric strength due to irradiation can be observed, but the irradiated materials' strength remained at the level a few time higher than required 5kV/mm
- Unirradiated and irradiated samples have been broken in the middle of the test part, what proves correctness of sample preparation methodology as well as sample irradiation uniformity obtained with the proper irradiation pattern
- Elongation at breakdown was quite low for all materials, but still acceptable
- Mechanical strength of the LARP material is reduced by 60% due to irradiation and LONZA CE to 40%
- Irradiation has completely destroyed Mix 71 and Mix 237 material, therefore these materials should be no longer considered electrical insulation of the superconducting circular accelerator magnet coils