Wrocław University of Technology

Irradiation Imposed Degradation of The Electrical and Mechanical Properties of Electrical Insulation for Future Accelerator Magnets

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Contents

- Motivation of launching EuCARD irradiation task
- Nb_3Sn SC magnet coils electrical insulation candidates
- EuCARD insulators certification conditions
- Certification tests
  - Electrical tests
  - Mechanical tests
- Conclusions

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, radiation resistance electrical insulation need to be found/developed
- A dedicated certification program for the radiation resistance of the insulation materials was launched within the European Coordination for Accelerator Research and Development (EuCARD) sub-task WP7.2.1.

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Insulation candidates

- Fiber glass tape
  - S-glass Type
    - a boron free glass fibers – not activated under irradiation
    - ease to weave
    - easily marked available

- Matrix materials:

  - RAL mix 71
    - DGEBA epoxy + D400 hardener
    - benchmark material due to long history of successful use in superconducting magnets
    - not expected to be very radiation tolerant because the hardener is structured as a long chain molecule

  - „LARP" insulation
    - CTD1202 + filler ceramic
    - low viscosity and very long pot life
    - widely used for magnets, both at room and cryogenic temperature

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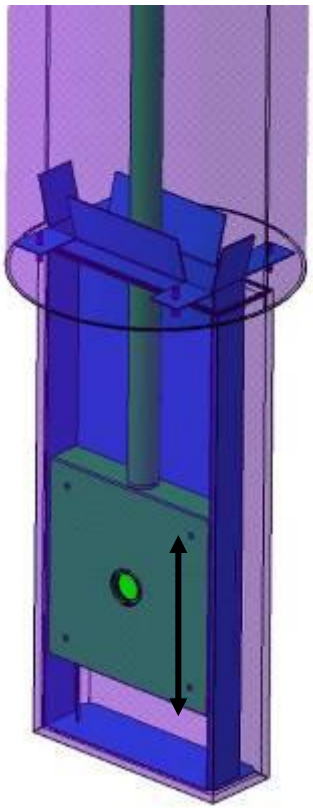
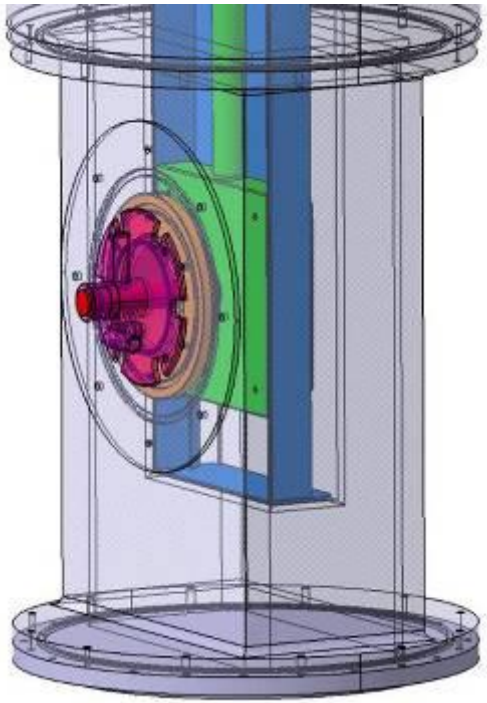
EuCARD insulators certification conditions

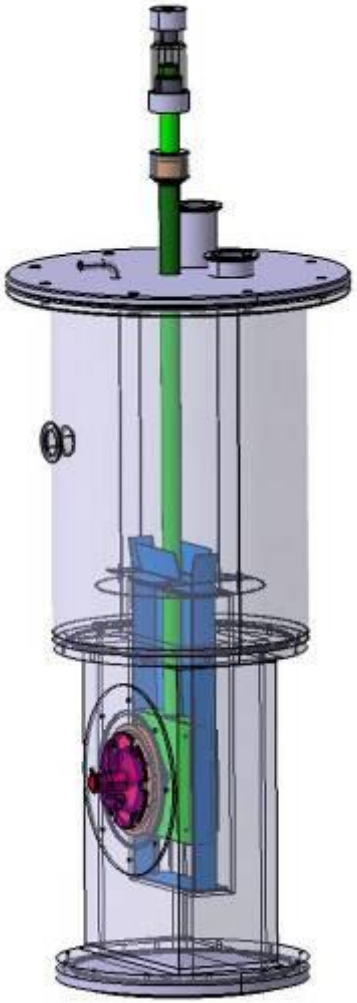
- Radiation type: photon beam, E>1MeV
- Integrated radiation dose – 50 MGy
- Irradiation temperature – 77 K
- Warm-up between the irradiation and certification tests:
  - mechanical/electrical test – short time only
  - thermal – yes, contact with atmospheric air should be limited
- Certification tests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

See detail irradiation methodology description in: *Certification of radiation resistance of Nb_3Sn based magnet coil electrical insulation materials*, Proceeding of the ICEC24, Fukuoka, Japan, May 2012

Conceptual design of the irradiation cryostat



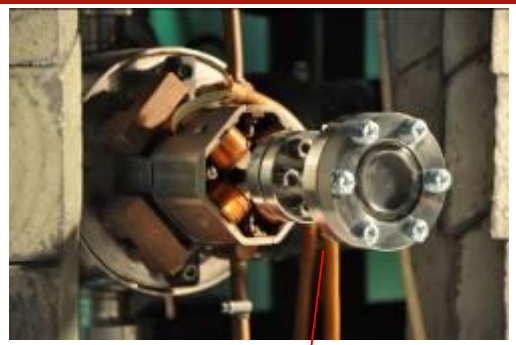




Designed, fabricated and commissioned at Wroclaw Univ. Tech.

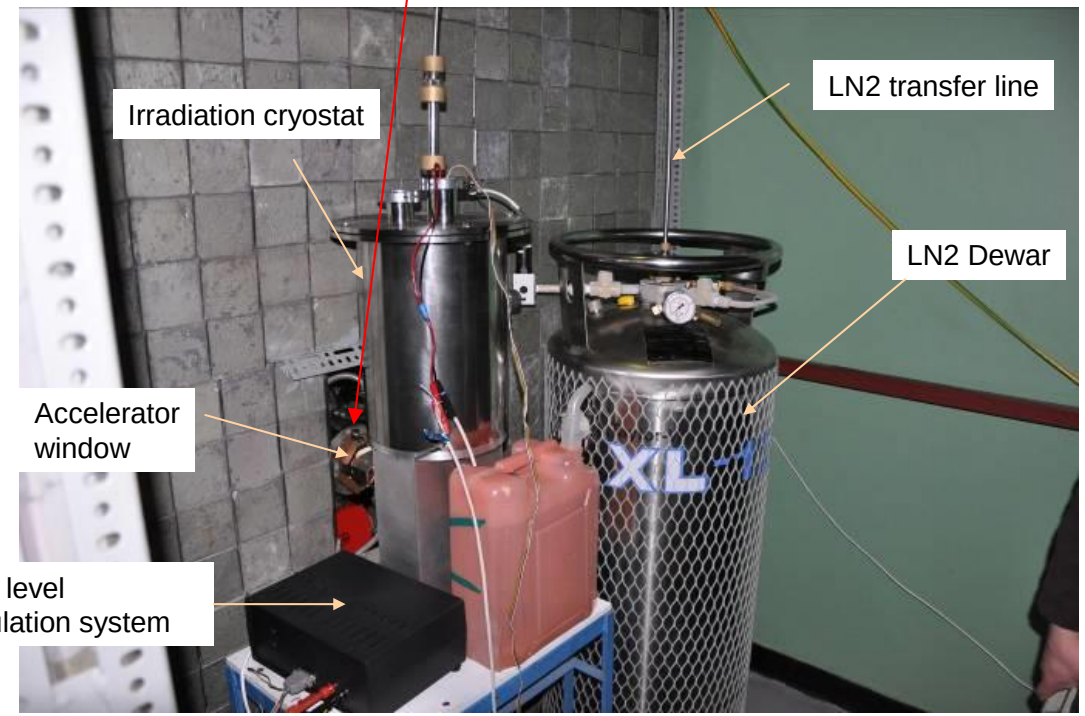
Irradiation set-up designed and commissioned at Wroclaw Univ. of Tech. and transferred to NCBJ, Swierk

Irradiation cryostat operation tests



Accelerator 0.2 mm thick Ti window

Irradiation set-up



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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 – 0.5 mm
  - length x width – min. 100x100 mmxmm
- Required irradiation area – 5mm diameter circle (spot)

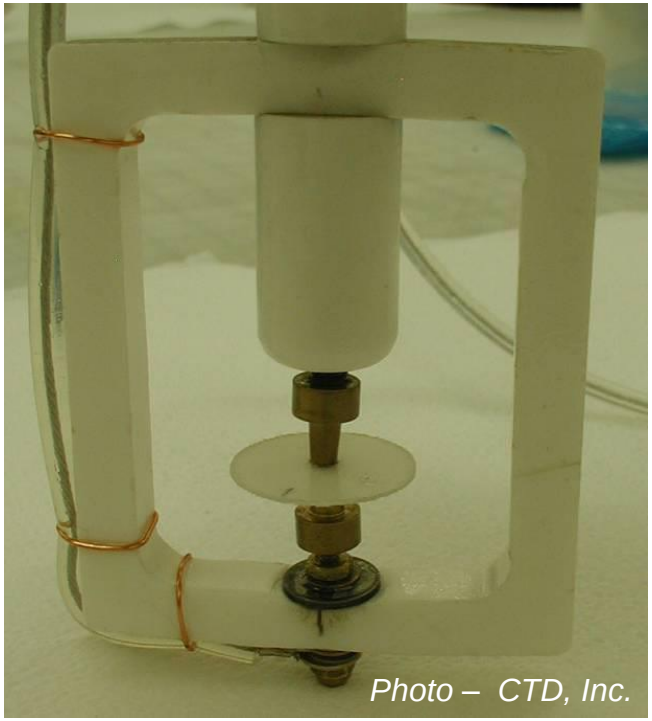
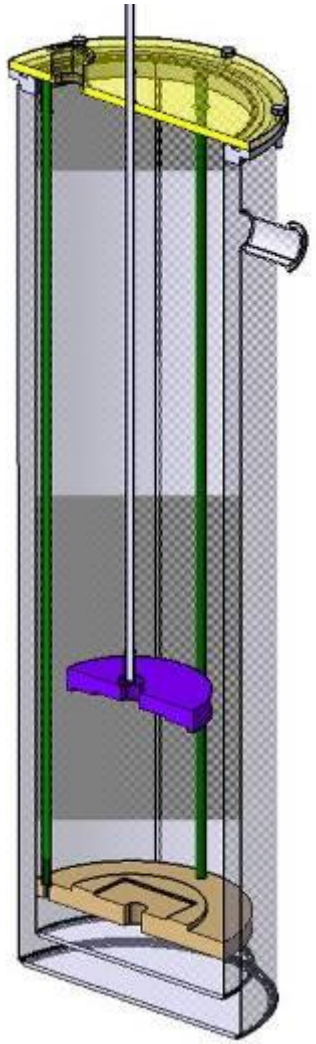
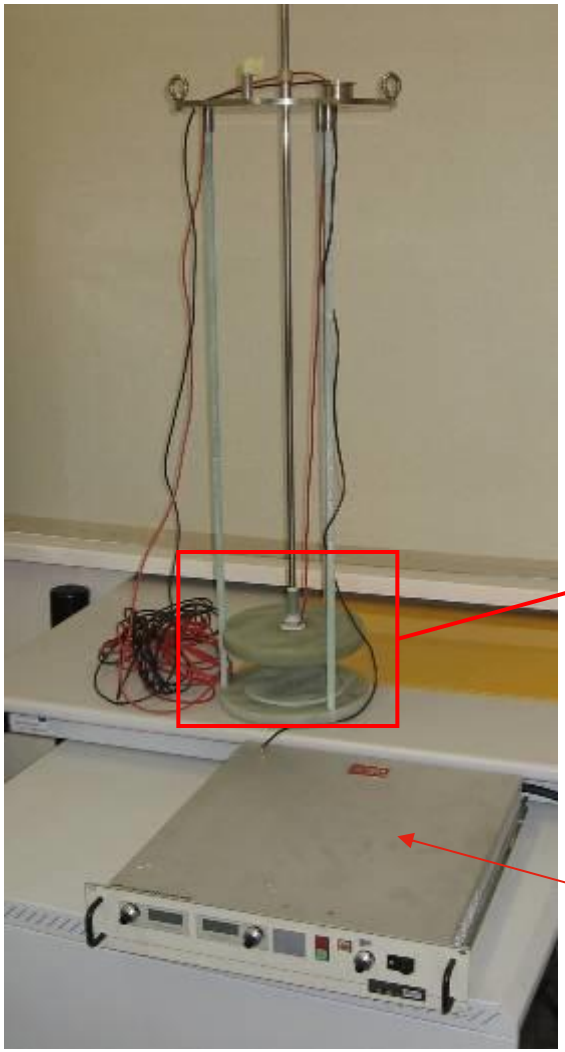


Photo – CTD, Inc.

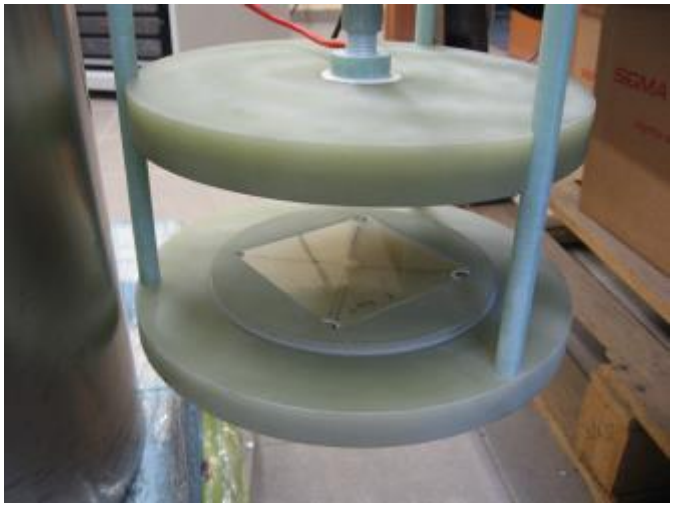
Electrical certification test cryostat at Wroclaw University of Technology

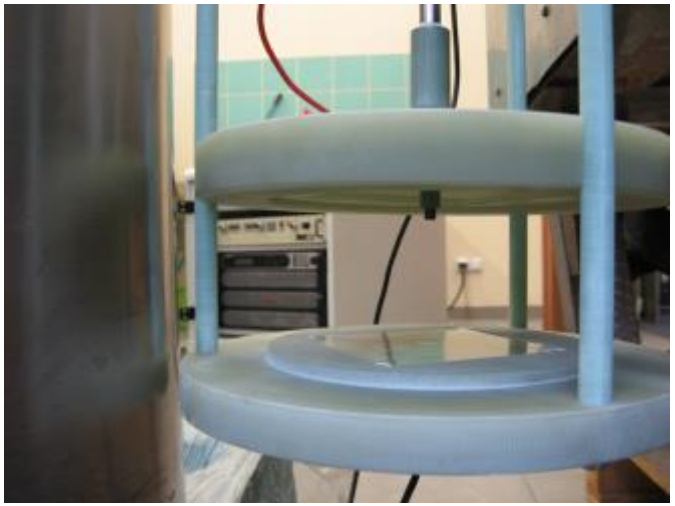




Voltage source – up to 60kV

Electrical certification test cryostat at Wroclaw University of Technology

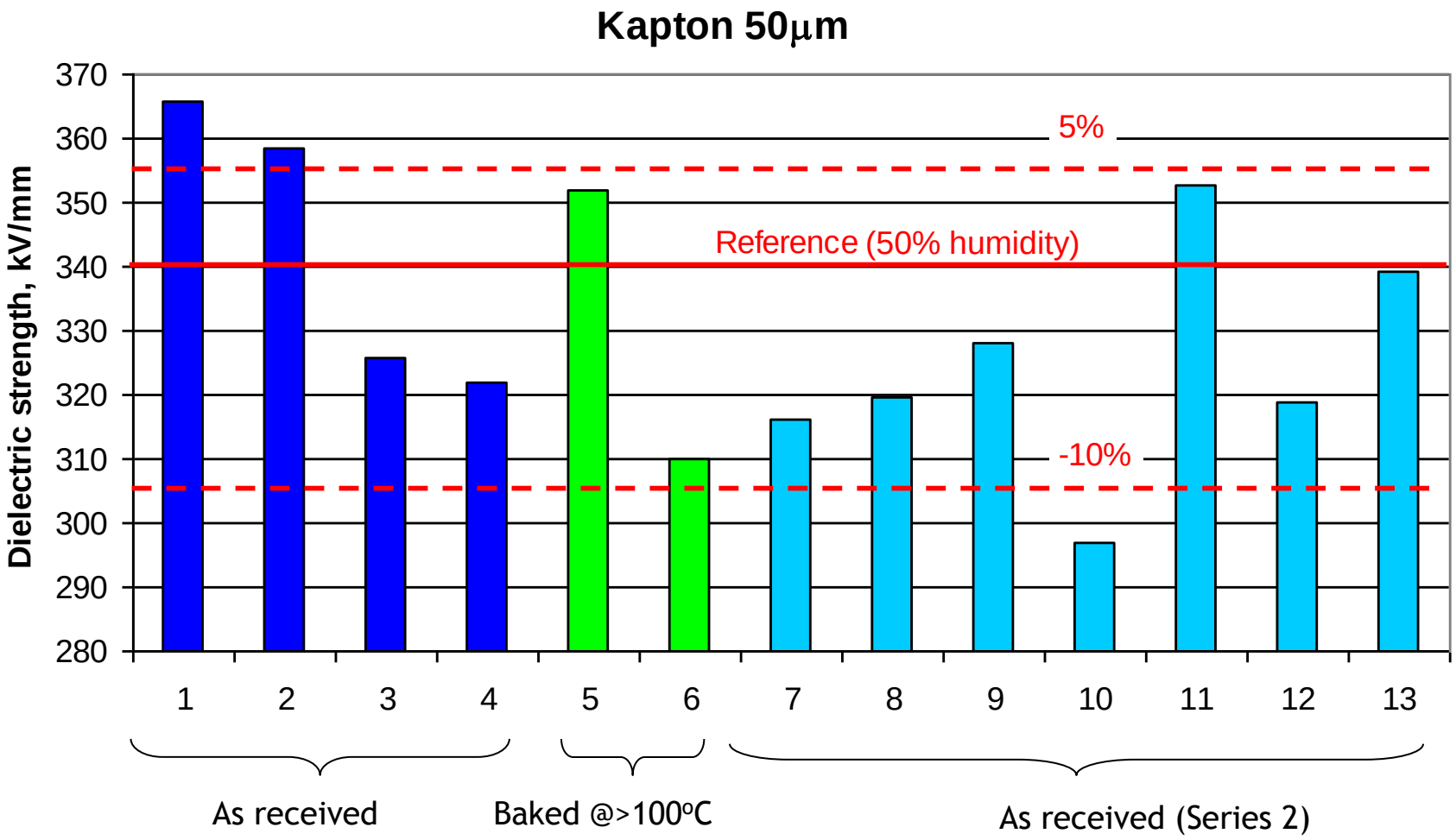




Electrical test of the reference materials

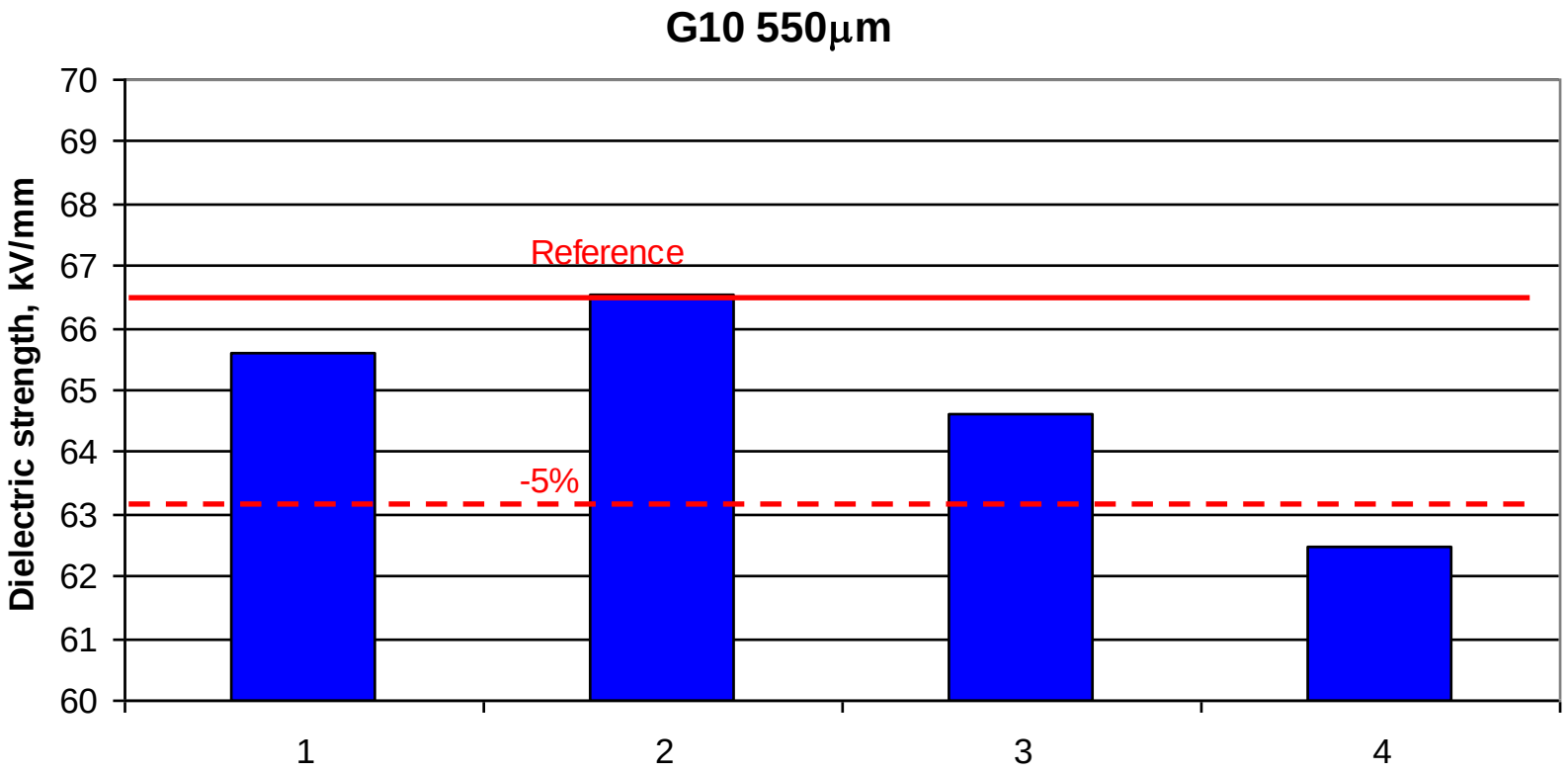
- Two materials have been tested:
  - Kapton®, 50 μm
  - G10 , 550 μm
- Method – in accordance with ASTM D-149 standard Short-Time-Test (of about 200V/s), DC instead of AC voltage
- ASTM D-149 standard method
  - 60Hz AC voltage
  - root-mean-square (rms) value $\sqrt{2}$
- Dielectric strength for DC test = rms*

Reference materials electrical test results Kapton®



Reference:DuPont, *Summary of Properties for Kapton® Polyimide Films* , www2.dupont.com

Reference materials electrical test results G10

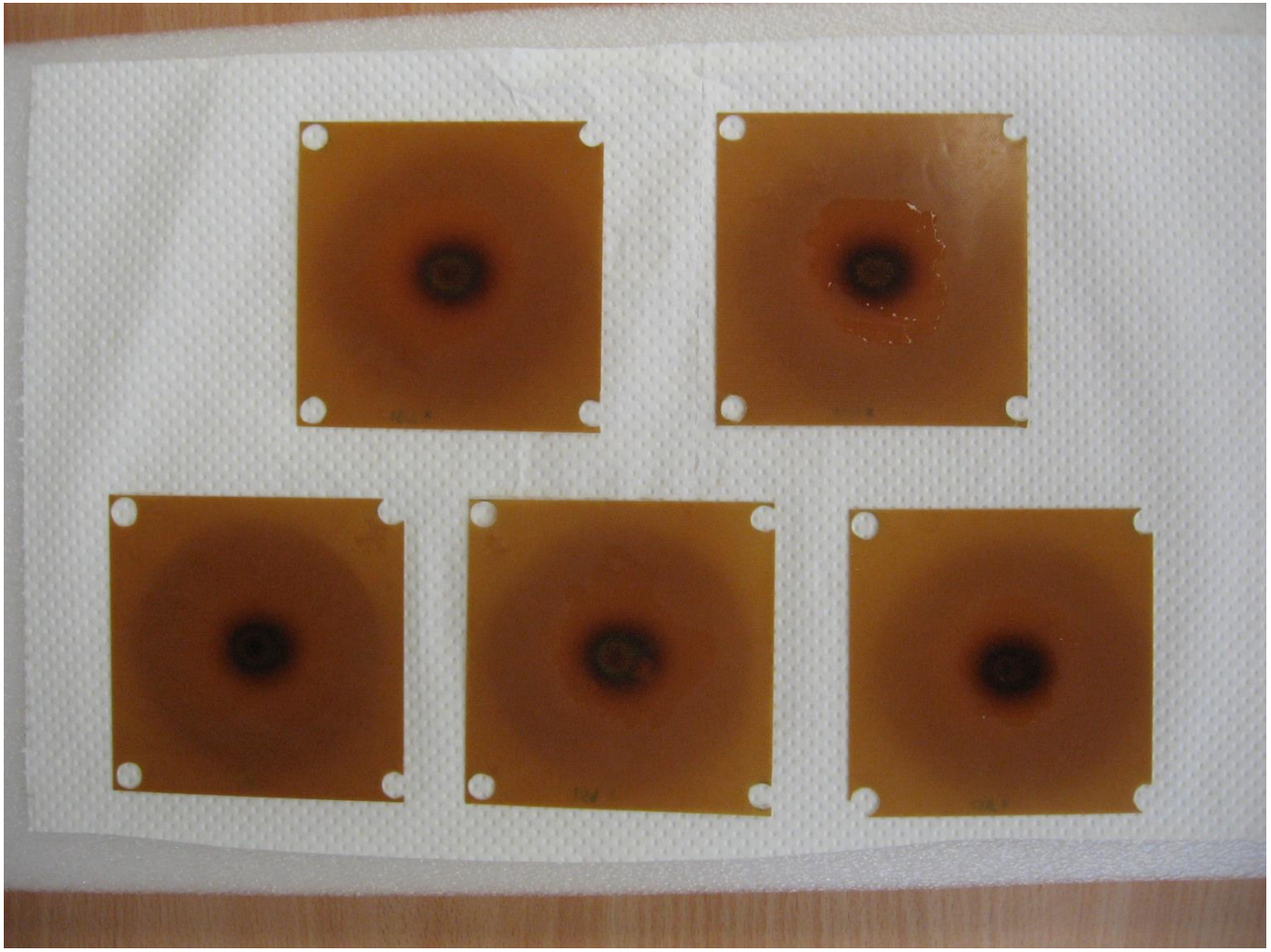


Reference: E. Tuncer, I. Sauers, , D.R. James , A.R. Ellis, *Electrical Insulation Characteristics of Glass Fiber Reinforced Resins*, IEEE Transactions on Applied Superconductivity, Vol. 19, No. 3, June 2009

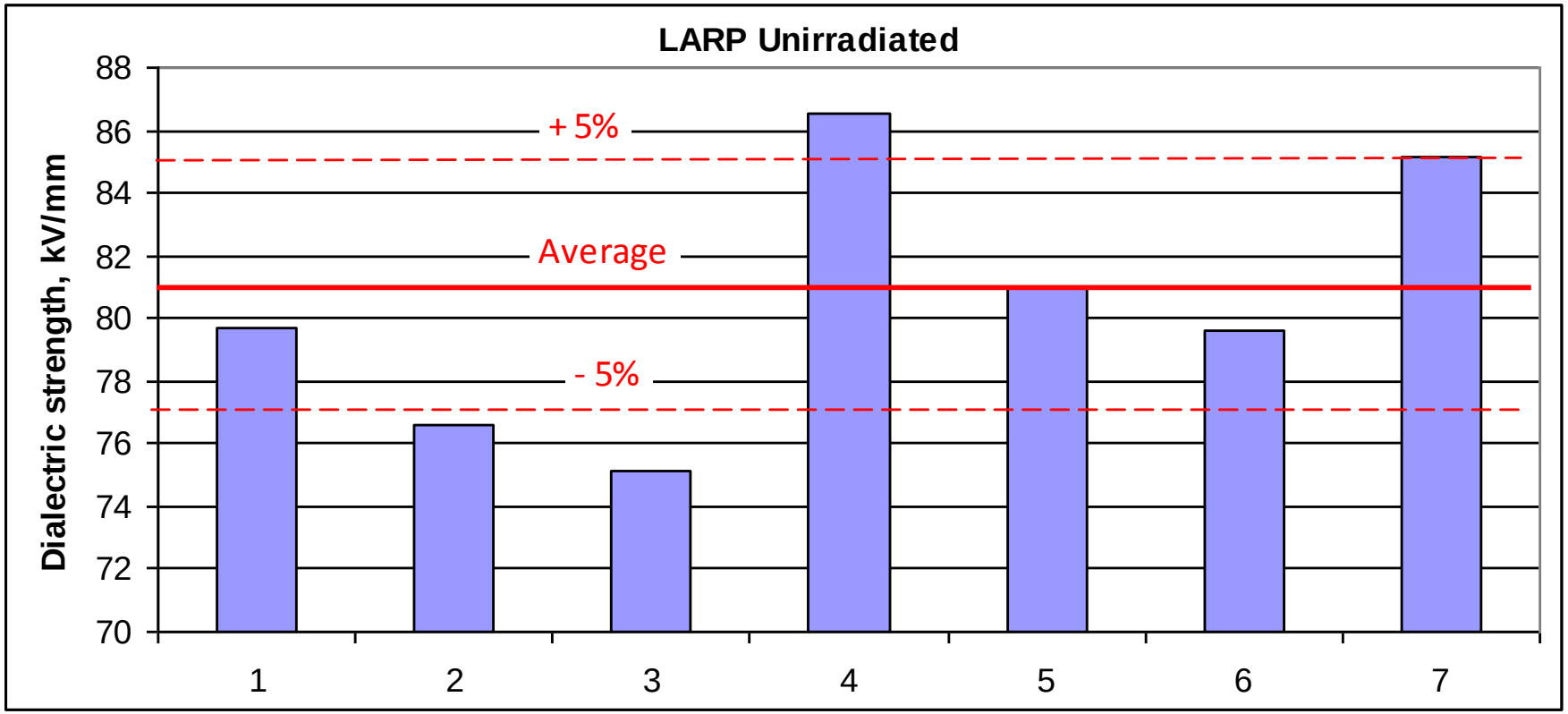
Radiation certification electrical tests

- Materials:
  - Mix 71, 0.7 mm
  - LARP, 0.5 mm
- Test environment – LN2
- Method – in accordance with ASTM D-149 standard, voltage increase rate – 1 kV/min, DC instead of AC voltage
- Sample thickness has been measured in each test point separately

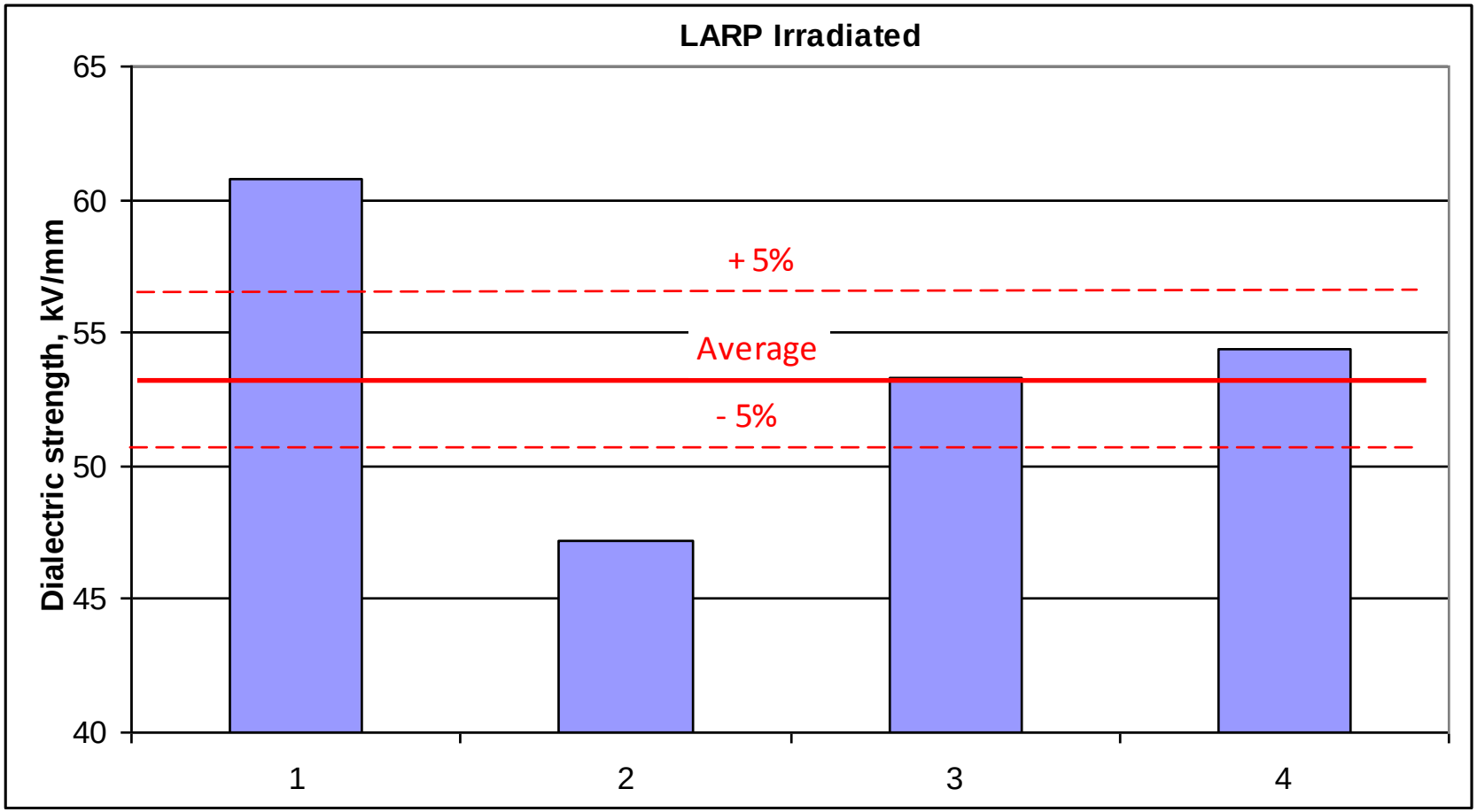
LARP electrical sample after irradiation



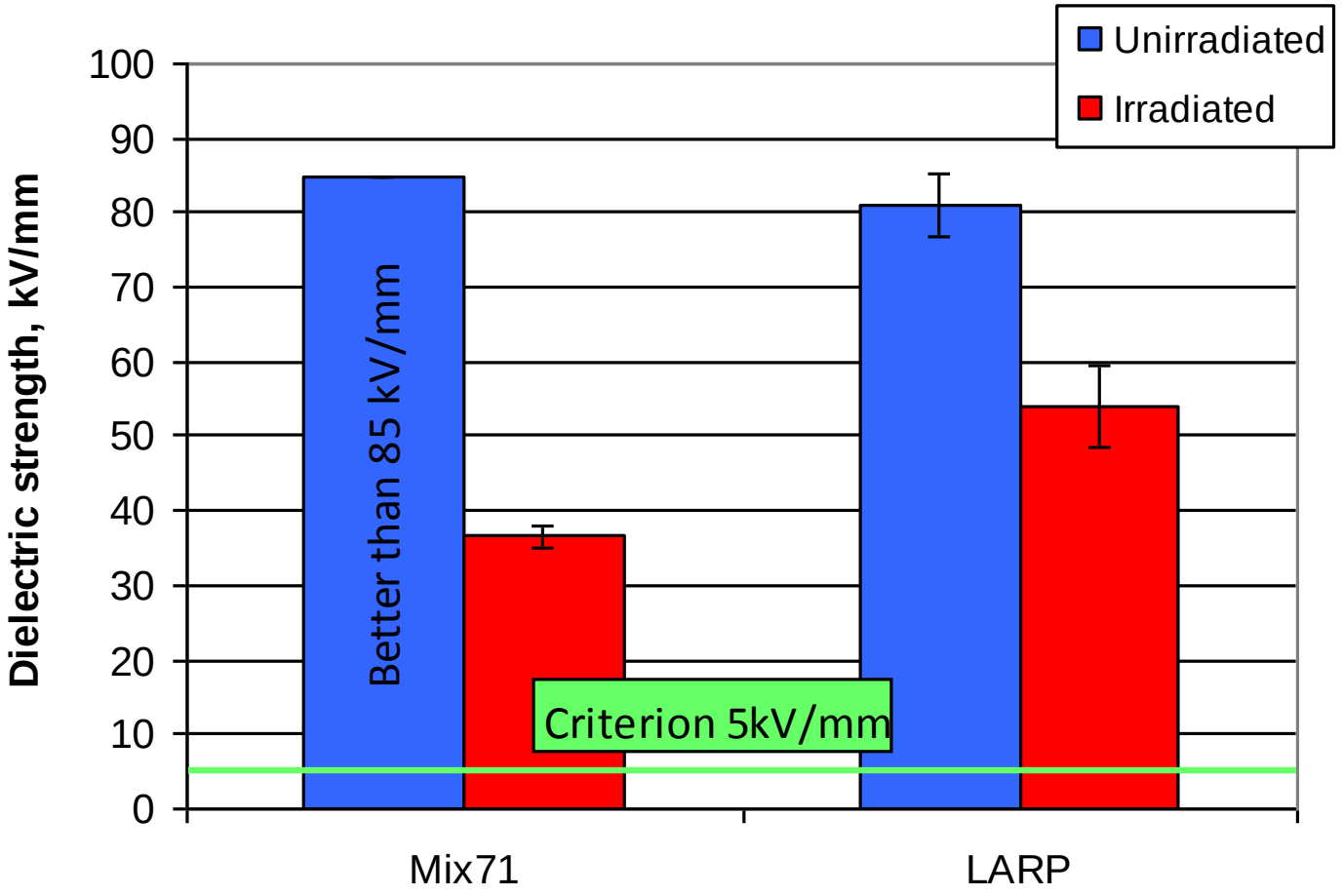
Radiation certification electrical tests - exemplary results



Radiation certification electrical tests - exemplary results



Radiation certification electrical tests summary



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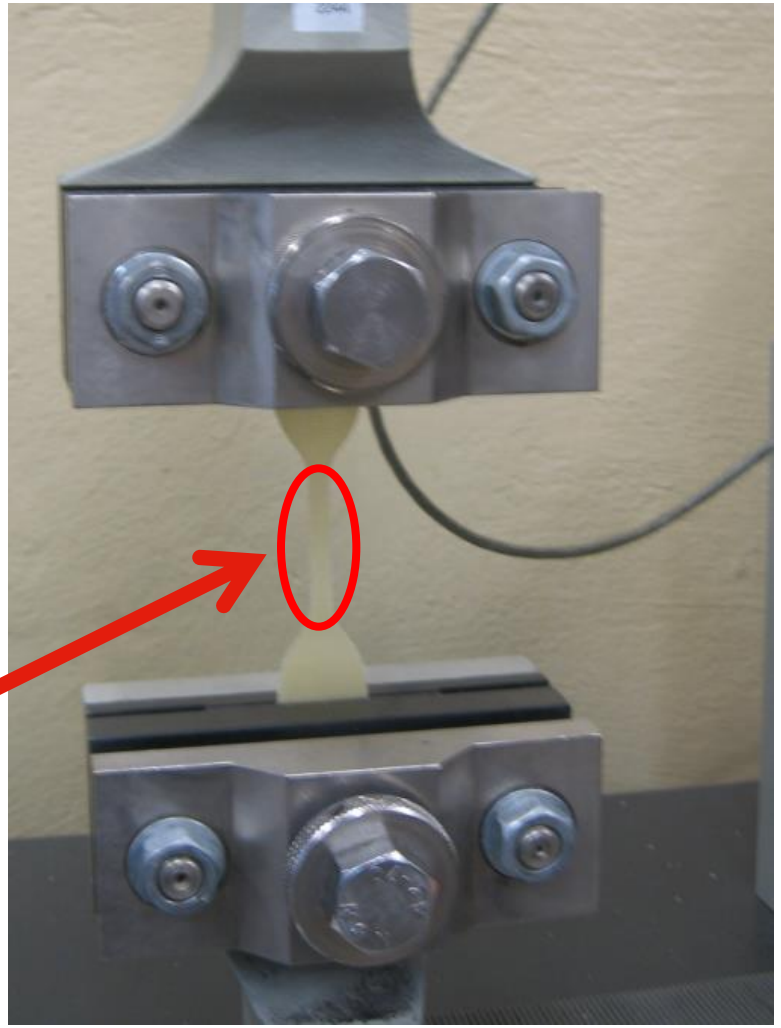
Mechanical certification tests

- ISO 37:2005 standard: "*Rubber, vulcanized or thermoplastic – Determination of tensile stress - strain properties*"

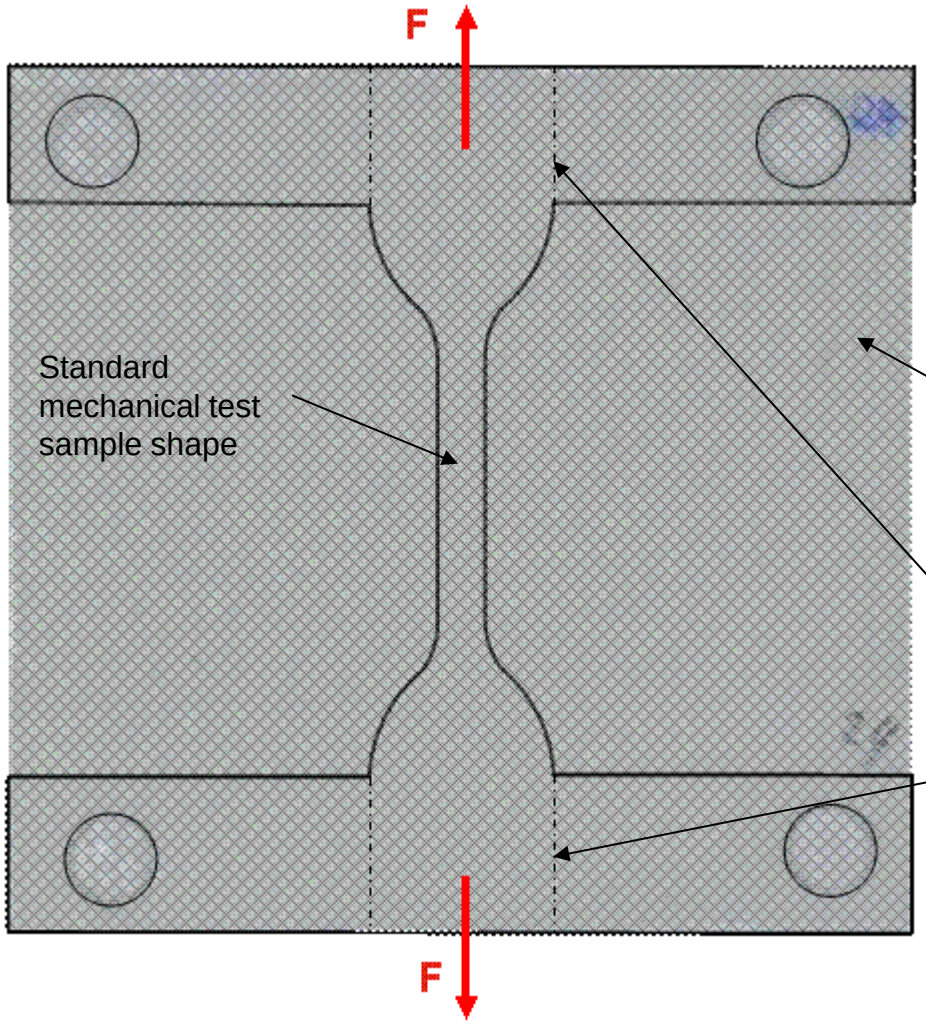
- Specimens dimension requirements:
  - thickness – 0.5 mm is acceptable
  - (test part) length x width – 33x6 mmxmm
- Required irradiation area – full area of the test part



Mechanical certification cryogenic test stand at Wroclaw University of Technology

TIRAtest Table Unit 2705 and its upgrade with LN2 vessel

Mechanical sample design



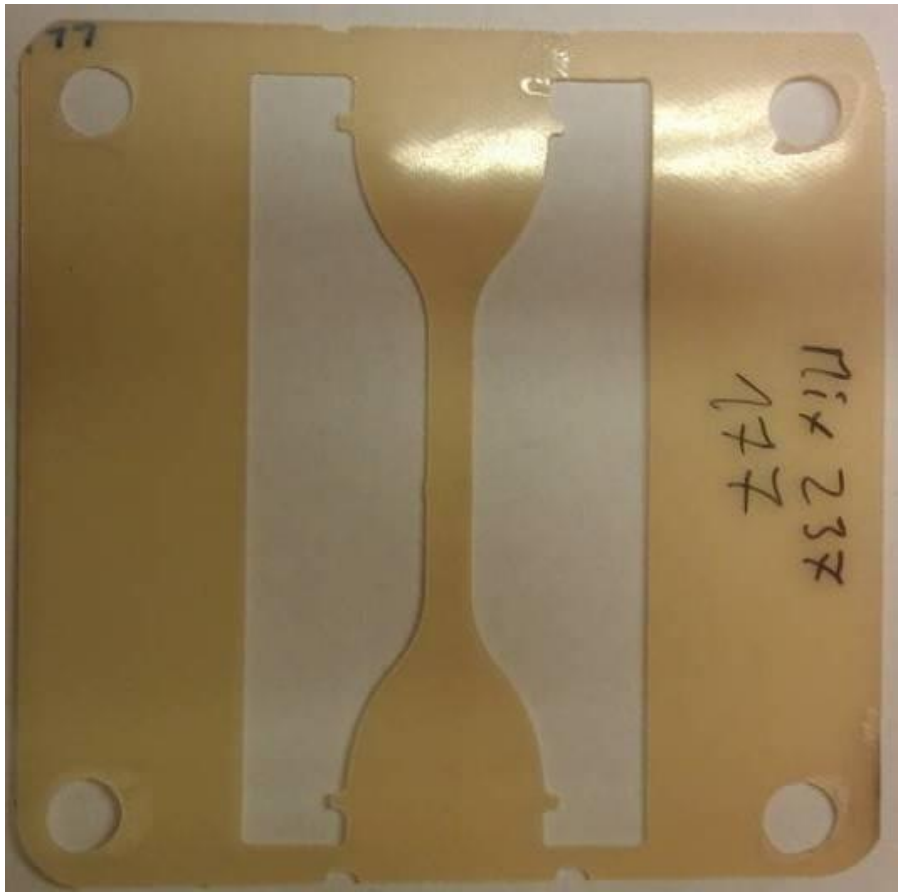
Shape is cut with water jet technology from 110x100x0,5 mmxmmxmm sheet

Fibers orientation – 45dec. to the force direction

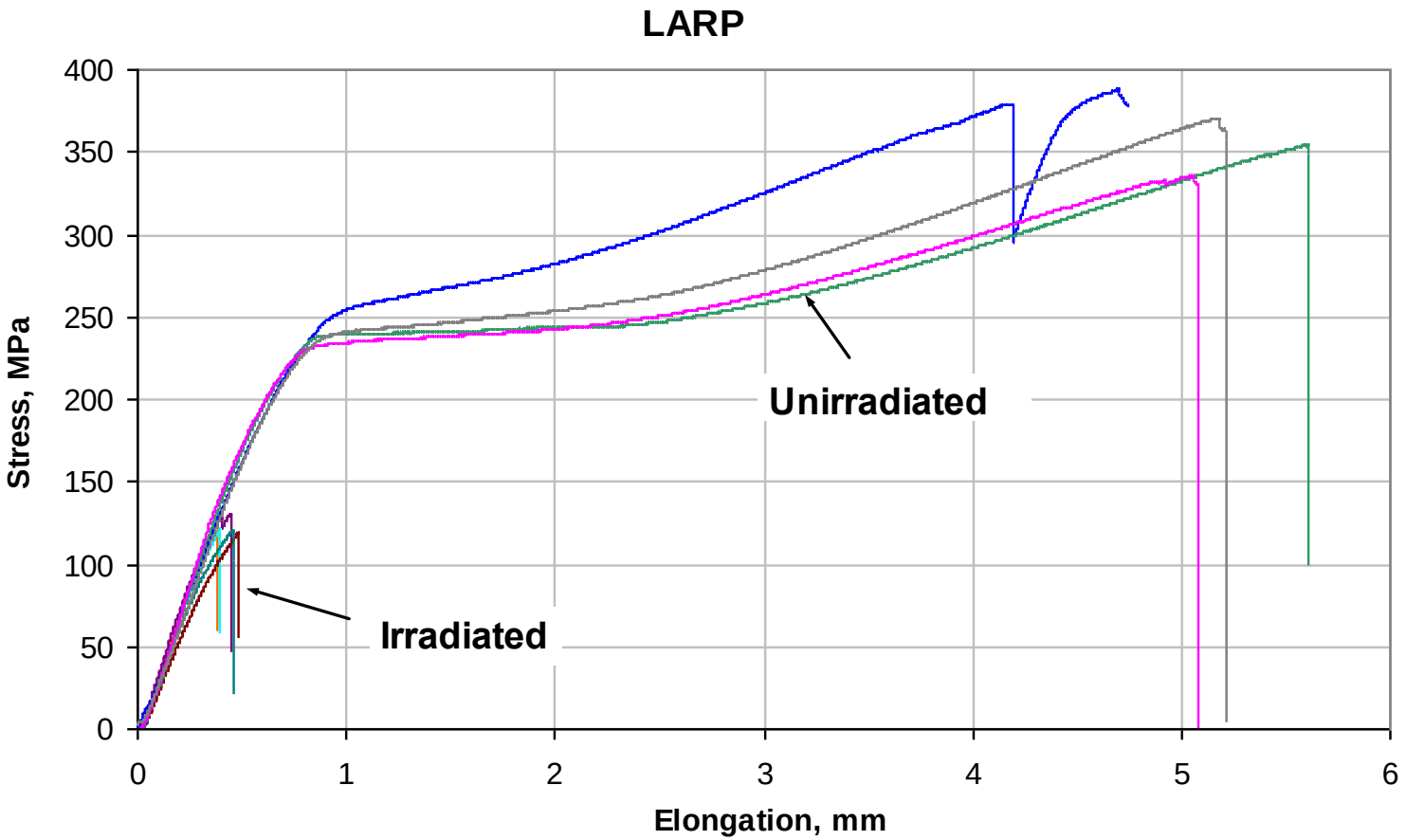
To be cut off after irradiation

Notice the fiber orientation: 45^{o}

Mechanical sample design

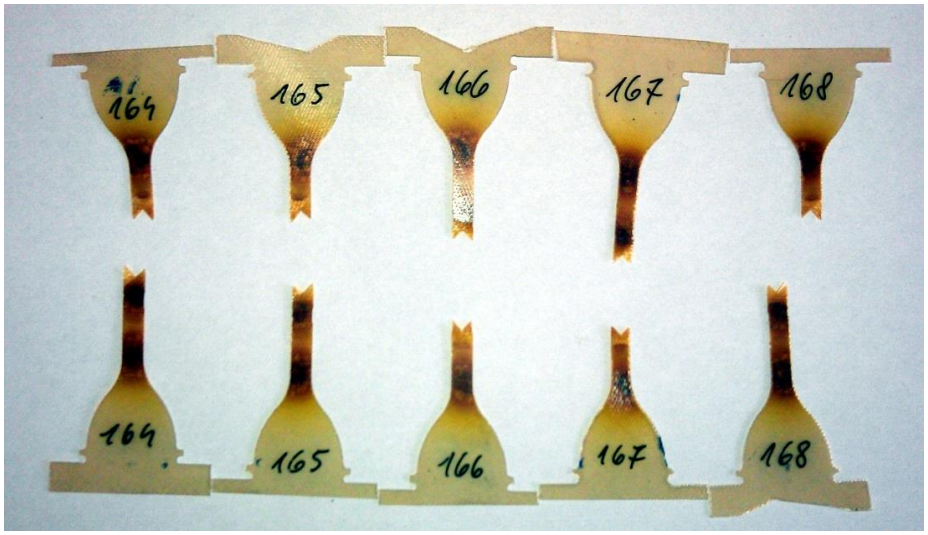


Mechanical certification test LARP insulation



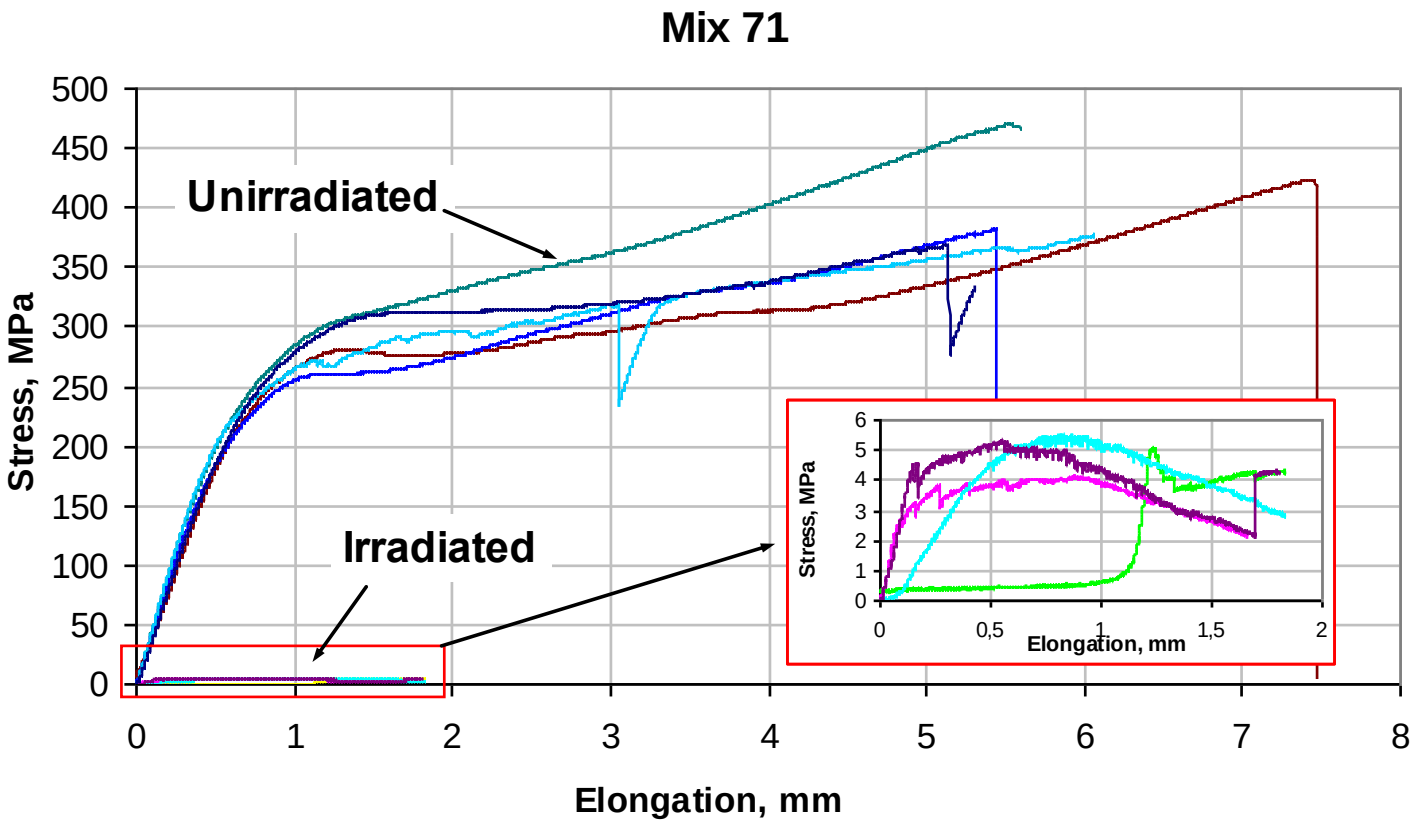
LARP insulation mechanical samples view

Unirradiated



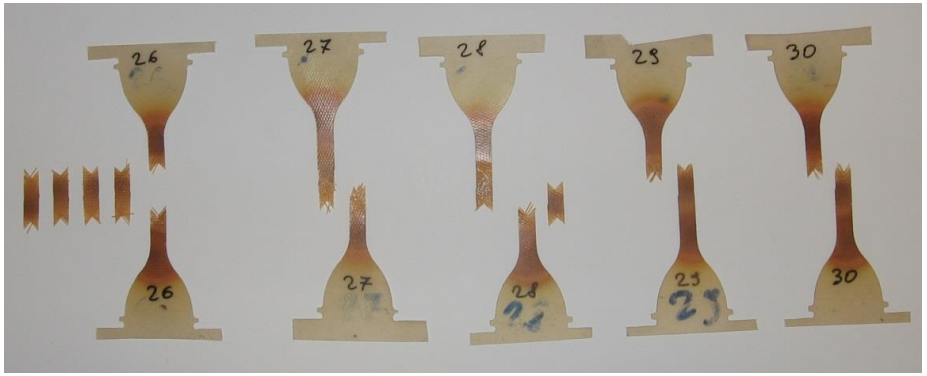
Irradiated

Mechanical certification test Mix71 insulation



Mix71 insulation mechanical samples view

Unirradiated



Irradiated

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Conclusions

- The mechanical and electrical samples of Mix71 and LARP insulation materials were successfully irradiated in cryogenic conditions (77 K) with electron beam up to 50 MGy dose
- The electrical and mechanical test of the materials have been done in 77K temperature conditions
- The high degradation of both 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
- Mechanical strength of the LARP material is reduced by 50% due to irradiation
- Irradiation has completely destroyed the Mix 71 material, therefore this material should be not longer considered as electrical insulation of the superconducting accelerator magnet coils