Wrocław University of Technology

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

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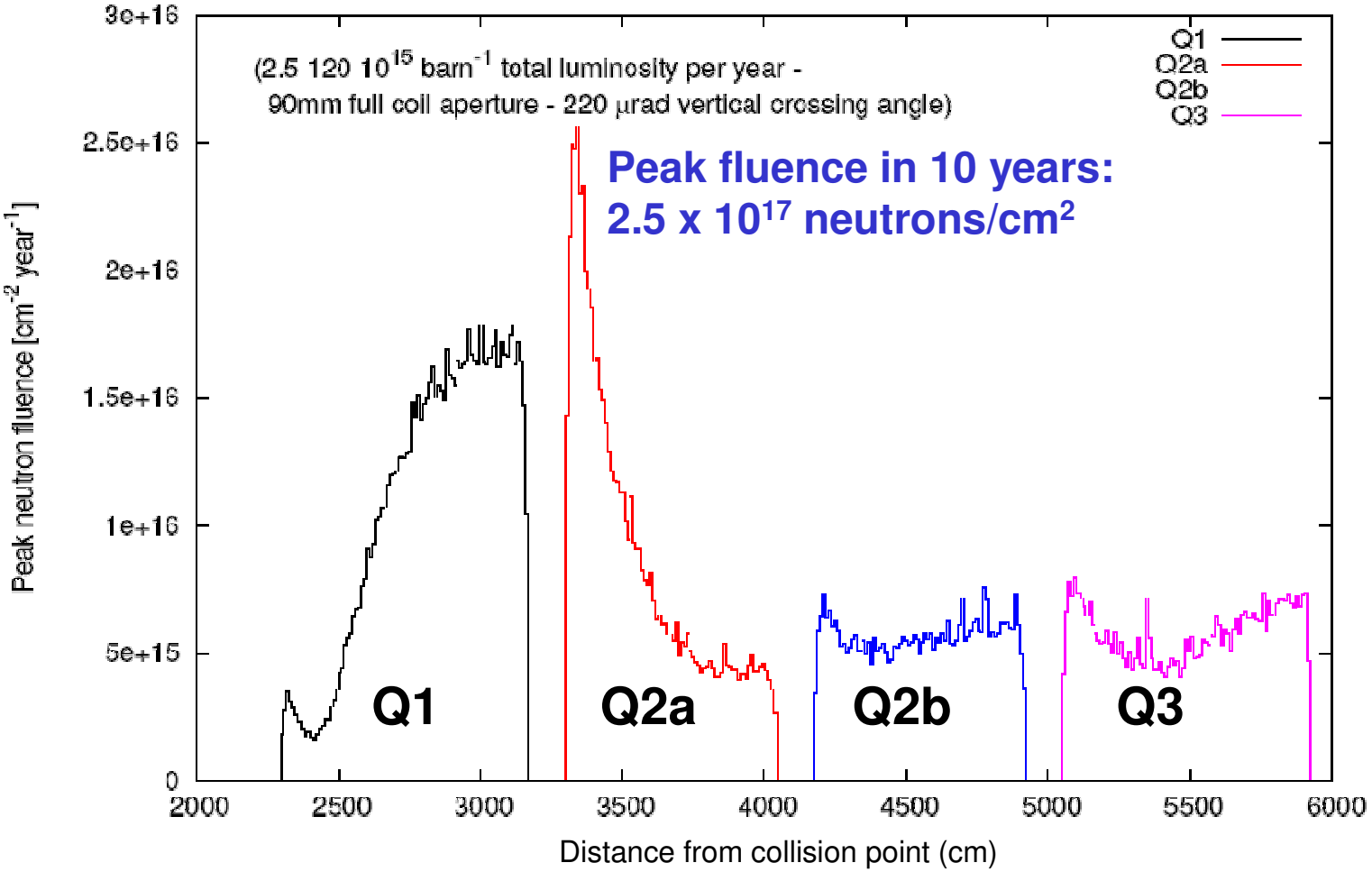
Outline

- 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.

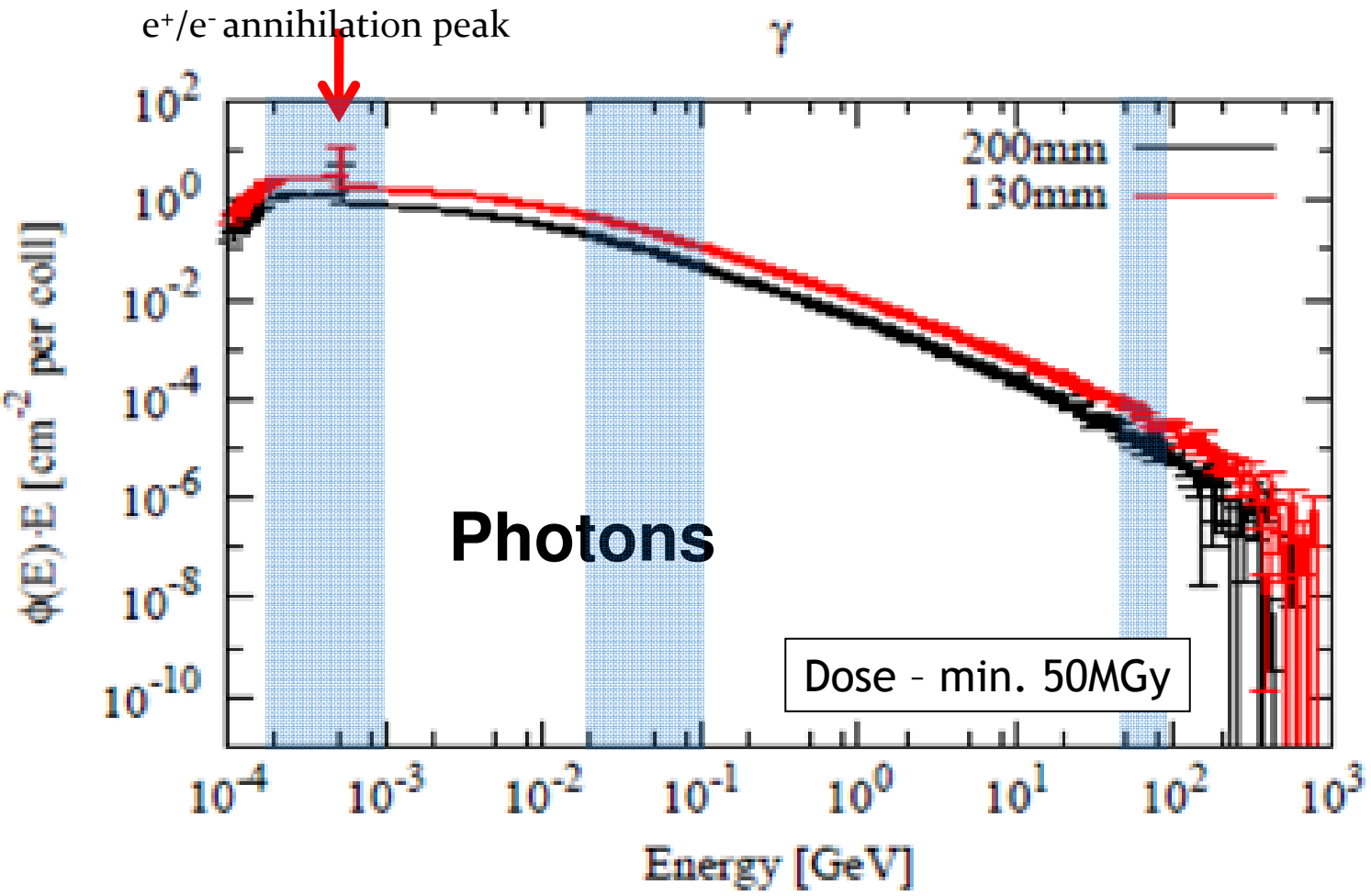
Radiation map for the Interaction Region Quadrupoles for LHC upgrade phase I



Radiation spectrum at Q2a: 35m from Collision Point

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

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



Insulation candidates

- 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%

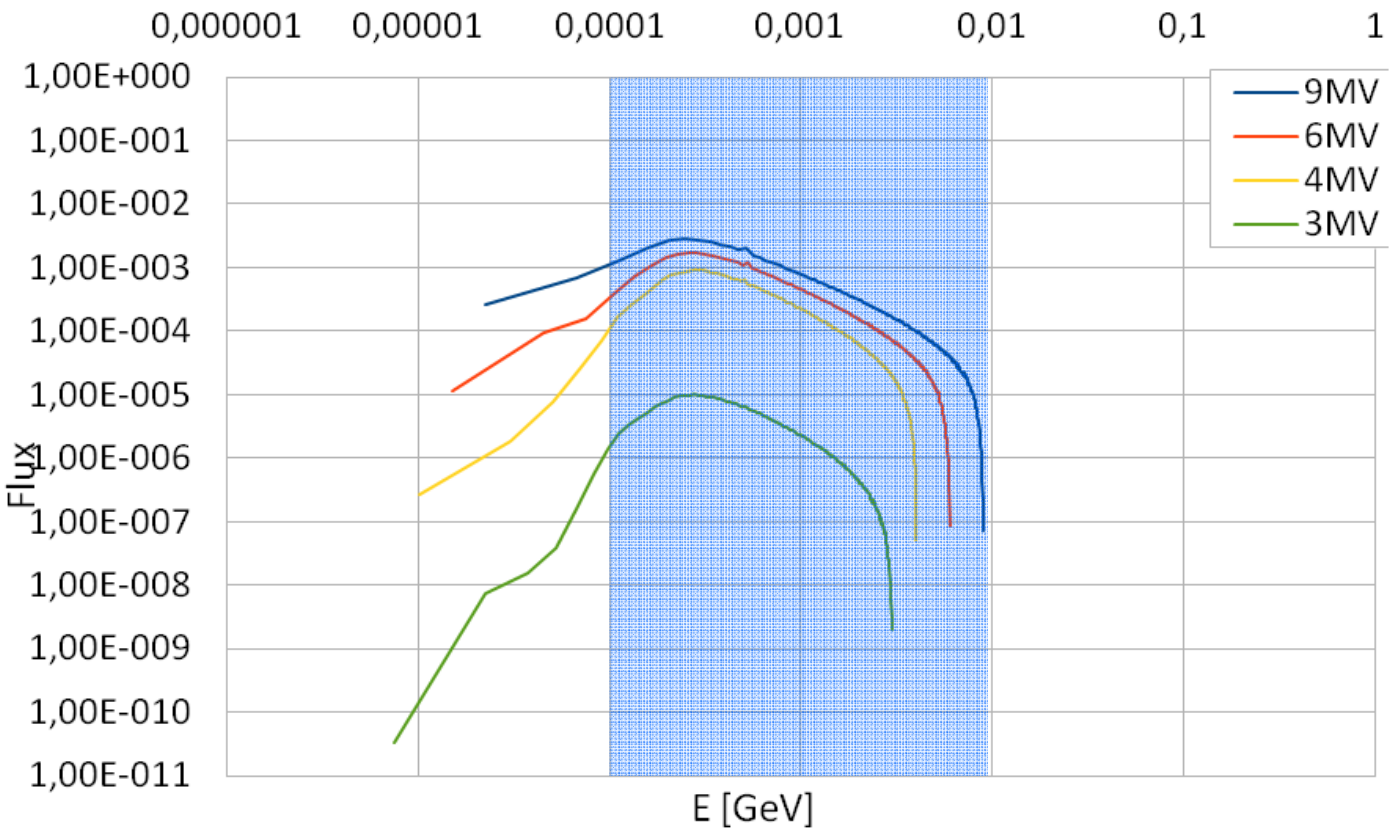
Radiation literature review

- 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>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 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~~ 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

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

Structure		6 MeV	12 MeV	15 MeV
Real electron energy	MeV	4	8	11
Depth of water penetration (range 80-100% of dose)	mm	10	26	38
Beam diameter (90-100% of intensity)	mm	**8**	2	2
Depth of insulation penetration	mm	5,6	14,4	21,1
Nbrs of samples radiated at once*		11,1	28,9	42,2
Max recorded dose rate	Gy/min	2200	12	12
Repetition frequency	Hz	76,4	5	5
Expected dose @f=300Hz	Gy/min	**8639**	720	720
Irradiation time for 50 MGy	Working days	12,1	144,7	144,7
Irradiated samples	Work. days/sample	1,1	5,0	3,4

* 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 mmxmm
- Required irradiation area – 5mm diameter circle (spot)

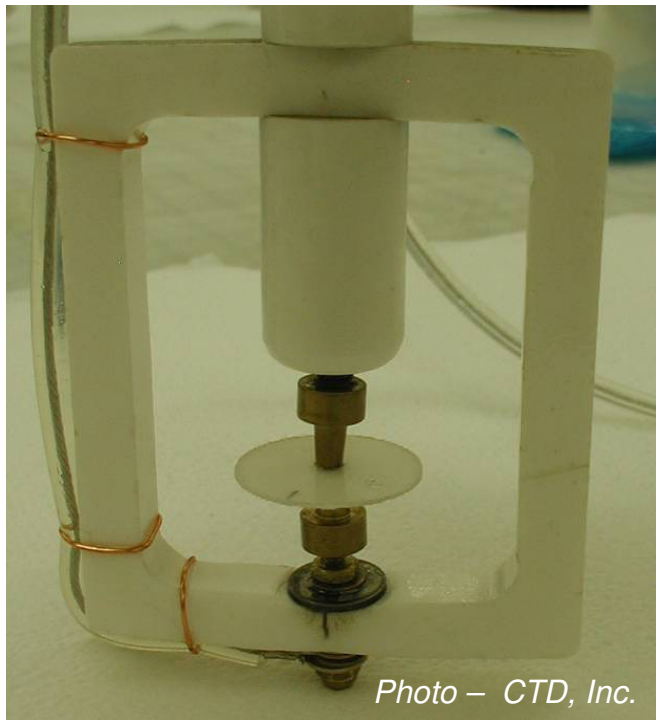
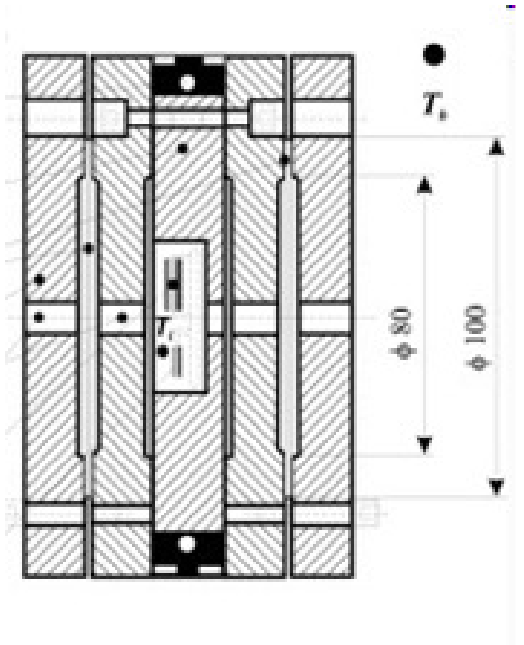


Photo – CTD, Inc.

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 mmxmm
- Required irradiation area – 80 mm diameter circle



4.2 – 300 K – standard thermal conductivity set-up based on cryocooler

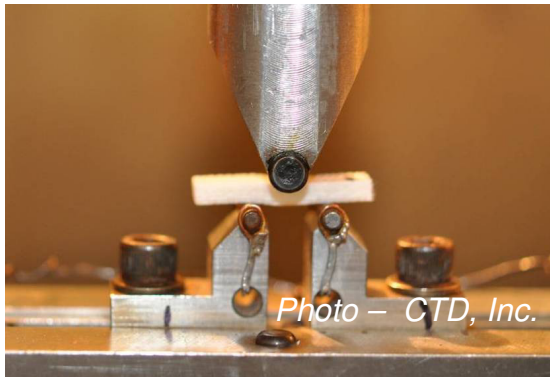
- Specimens dimension requirements: stripe of 0.5mm thick material
- Required irradiation area – full area of stripe

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 mmxmm
- Required irradiation area – full area of the specimen



Interlaminar shear strength test

Determination of mode I interlaminar fracture toughness - ISO EN 15024 standard

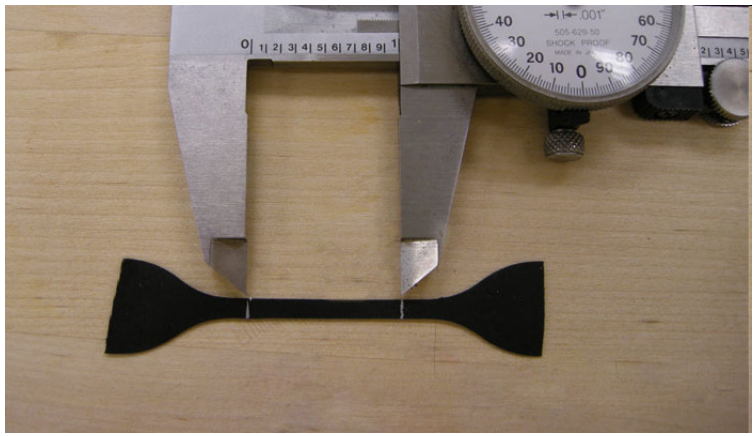
- Specimens dimension requirements:
  - thickness – min. 5 mm
  - length x width – min 125 x 20 mmxmm
- Required irradiation area – full area of the specimen

Interlaminar fracture toughness test

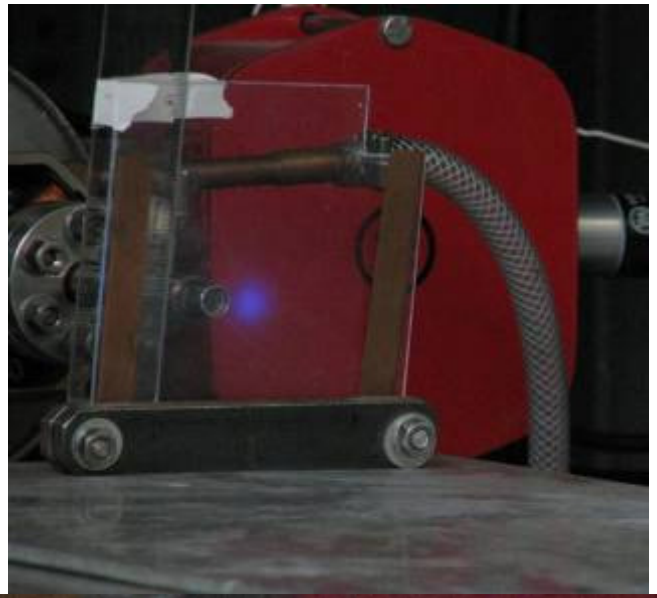
Mechanical certification tests 2/2

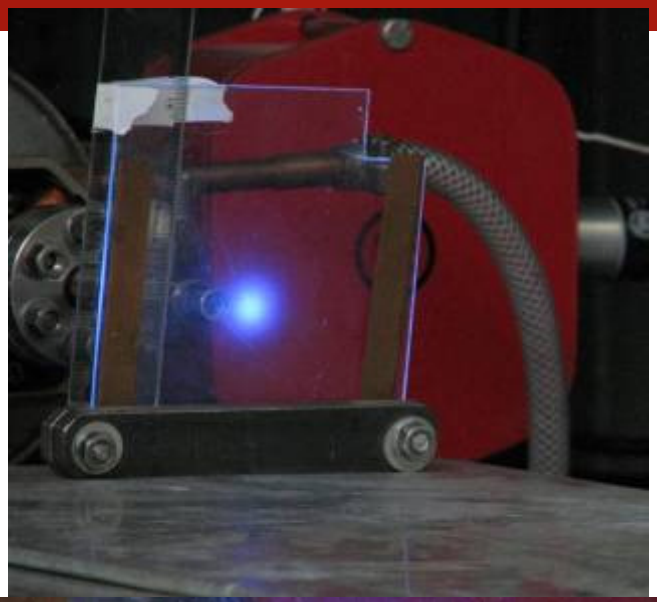
Plastics - Determination of tensile properties - EN ISO 527-1

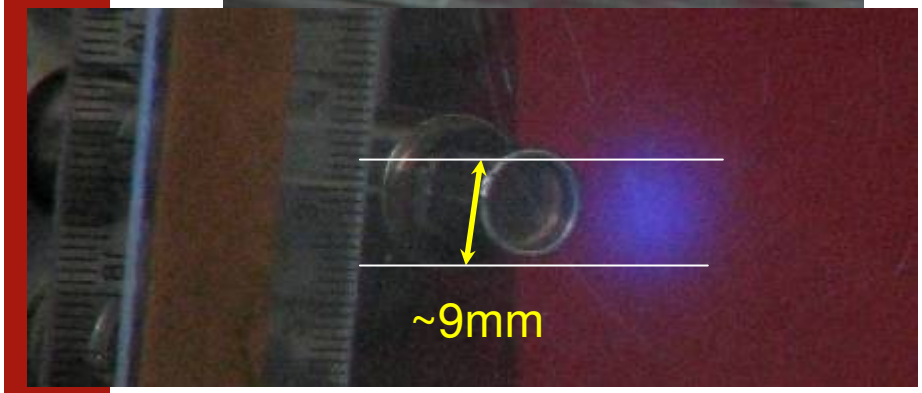
- Specimens dimension requirements:
  - thickness – 0.5 mm is acceptable
  - (test part) length x width – 60x8 mmxmm
- Required irradiation area – full area of the test part

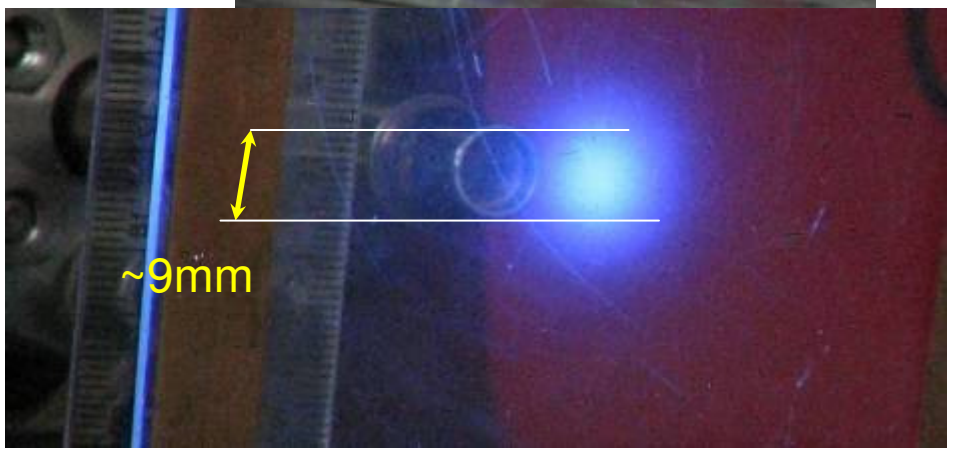


Electron beam intensity - 2.5 cm from accelerator window









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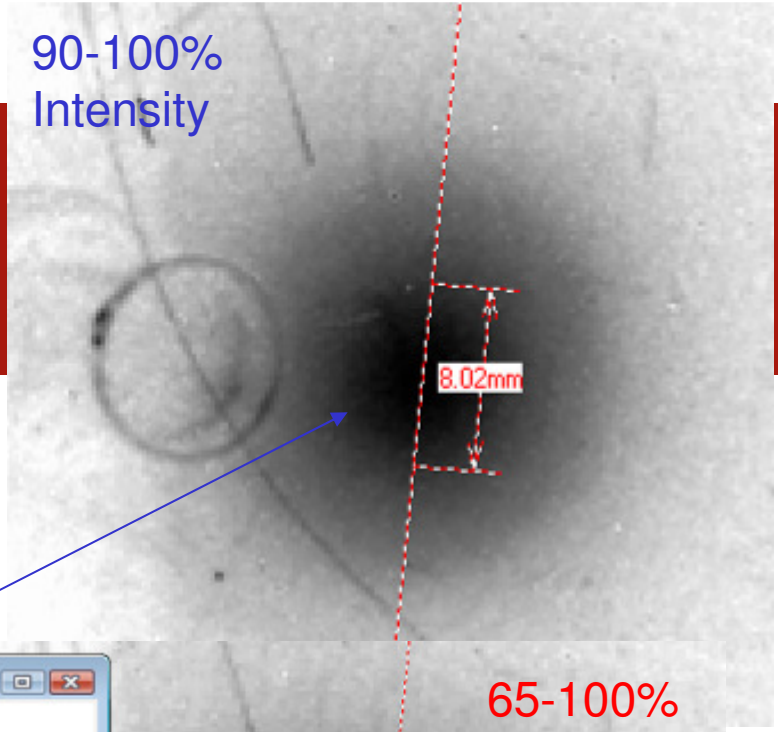
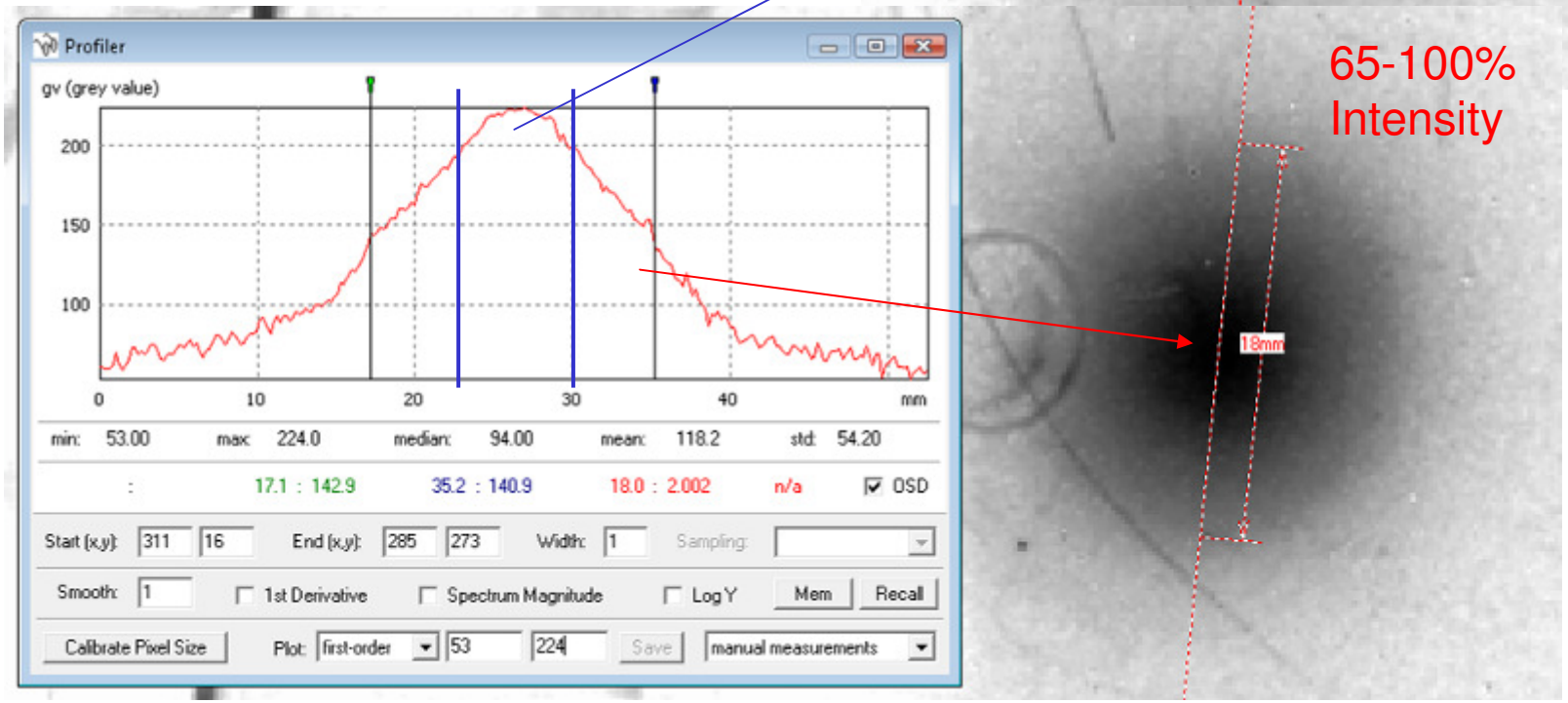
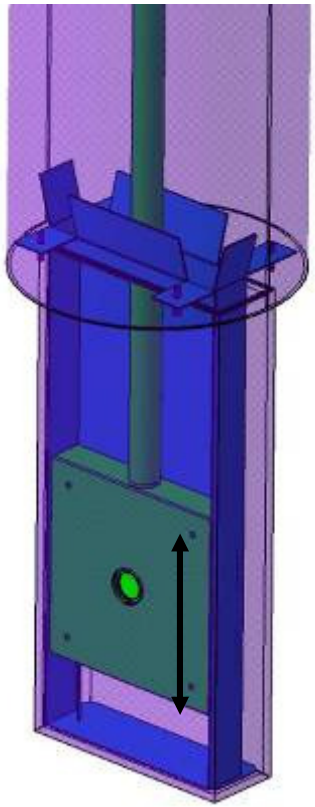
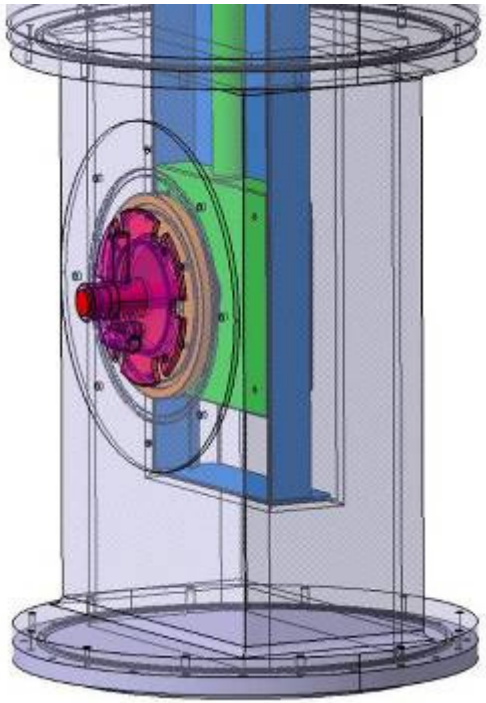
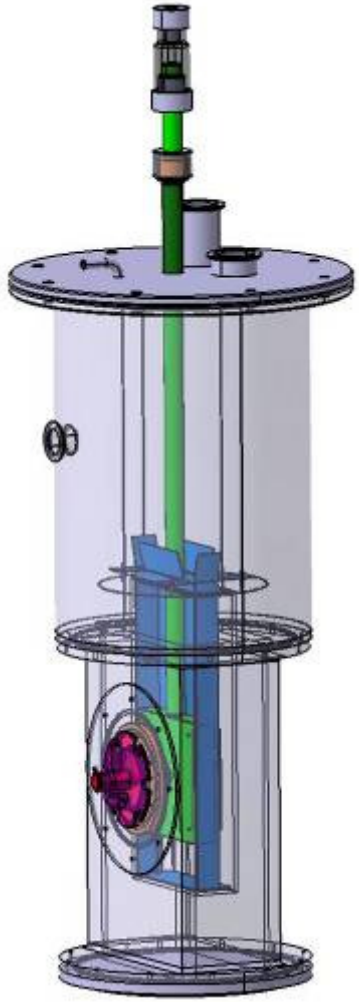




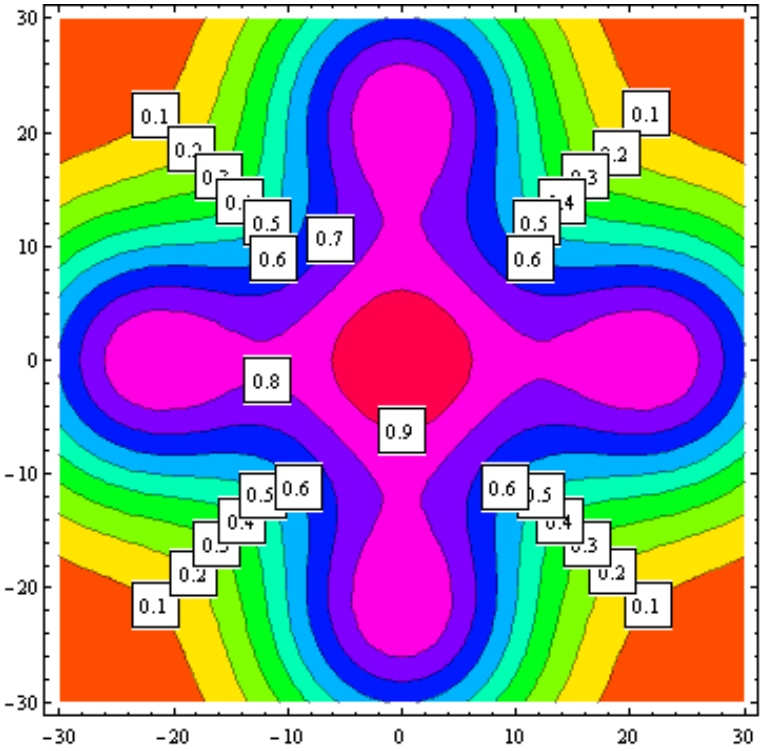
Conceptual design of the irradiation cryostat

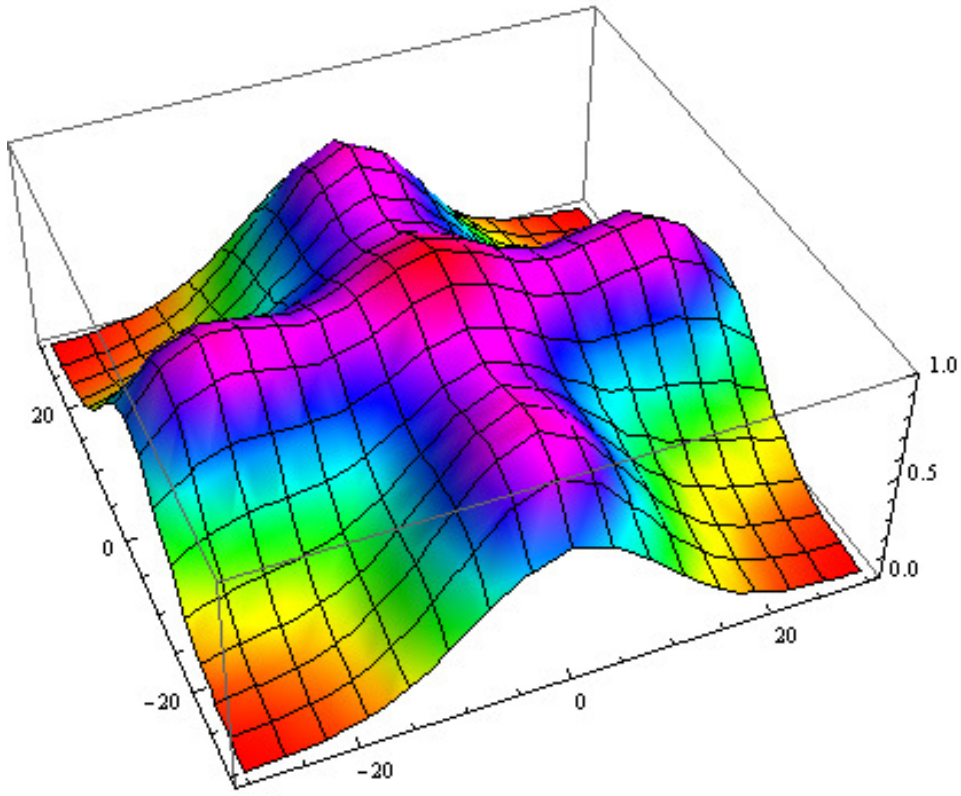






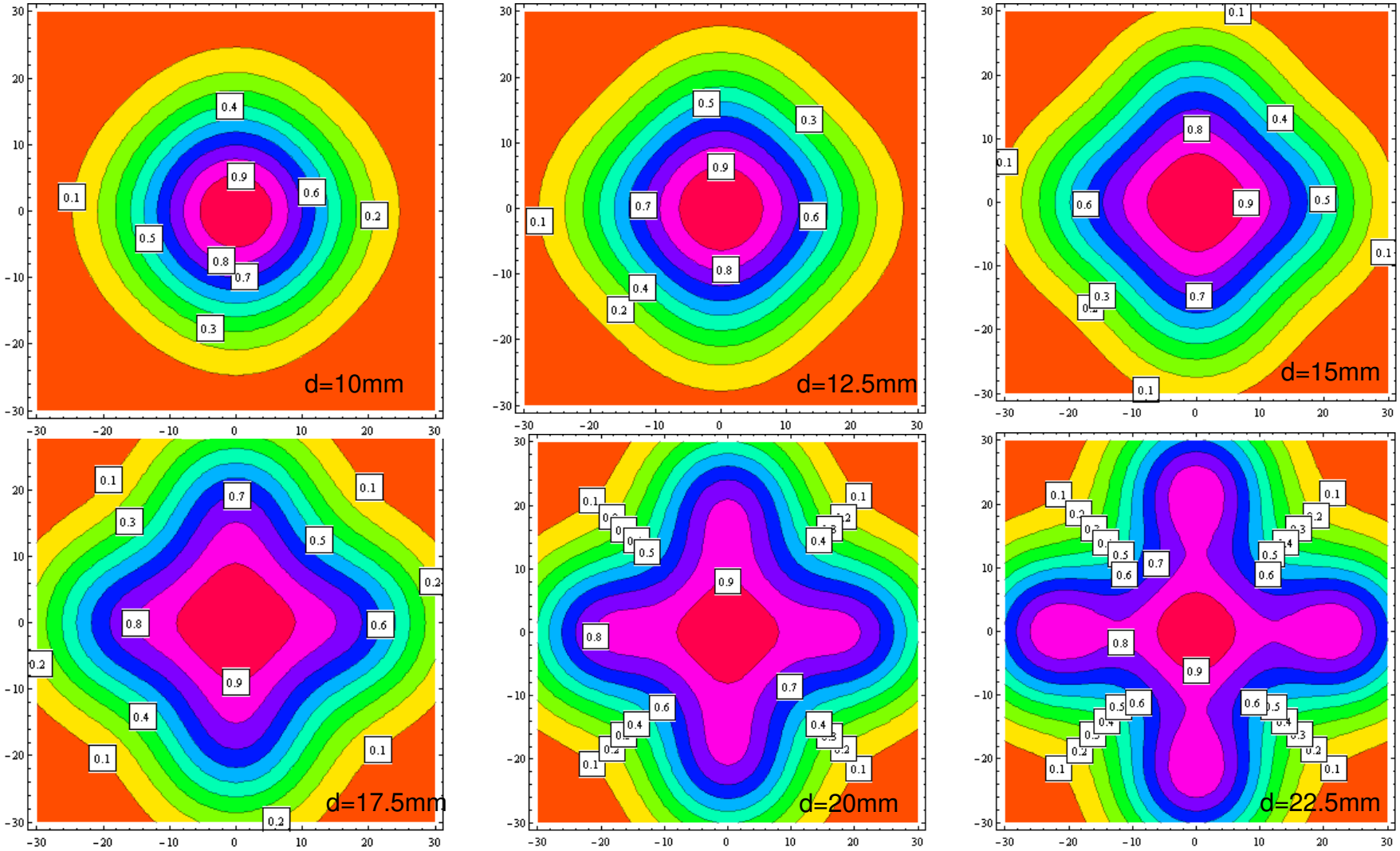
Thermal specimens irradiation pattern



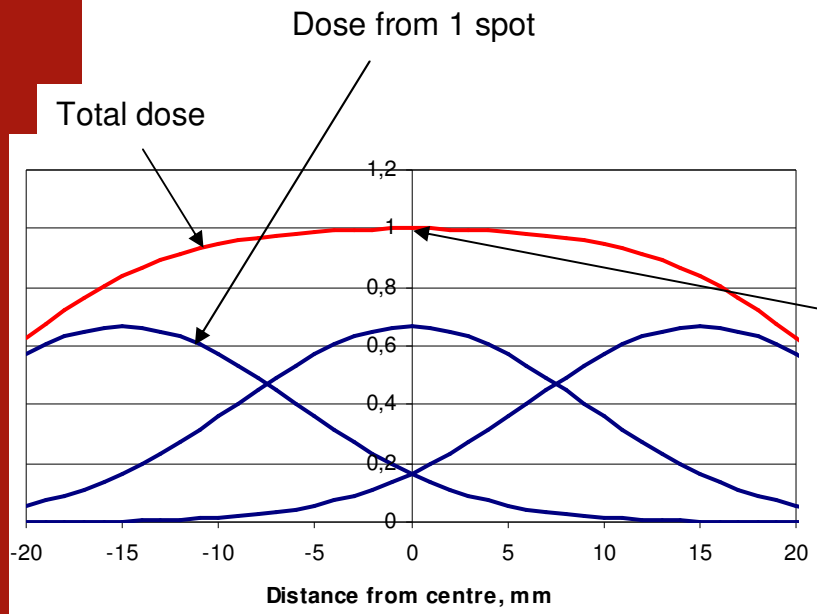


Distance between spots d=22.5mm

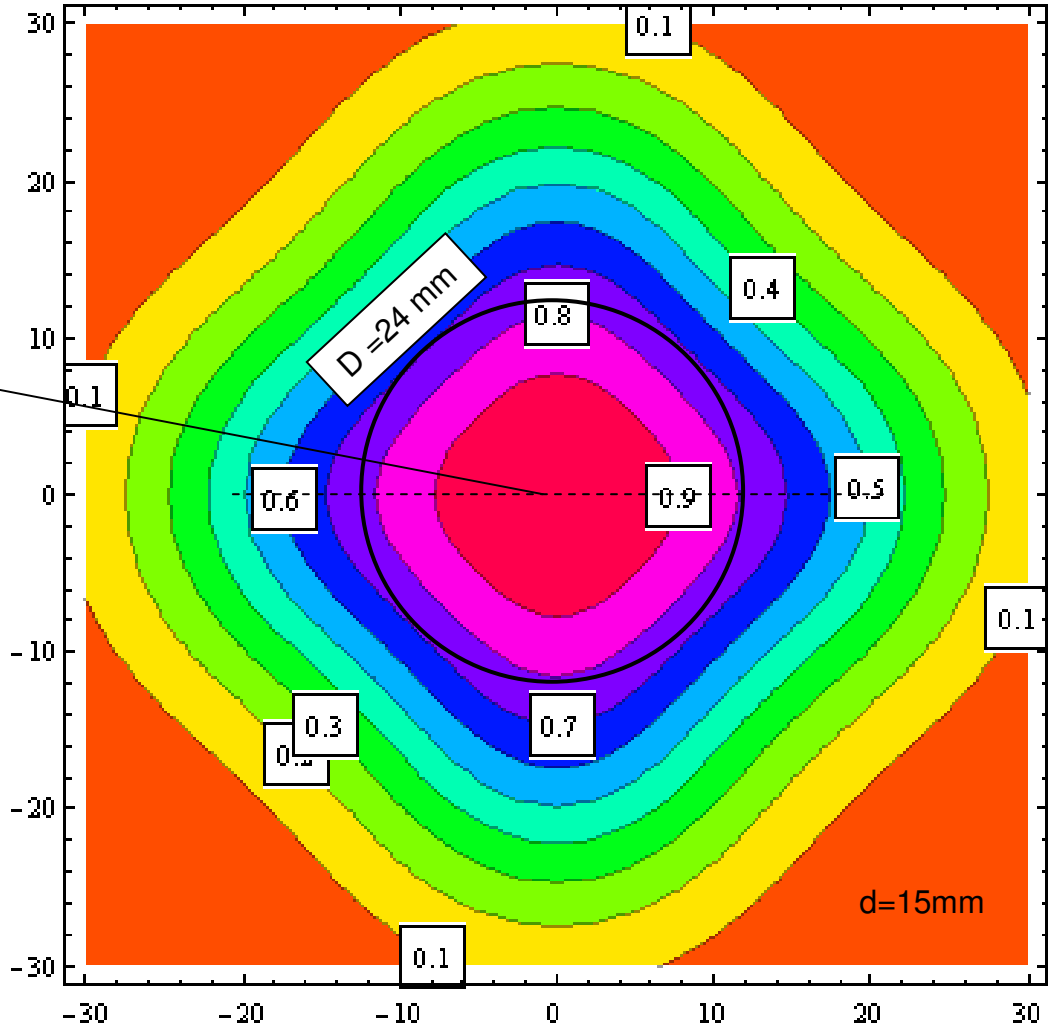
Thermal specimens irradiation pattern



Thermal specimens irradiation pattern



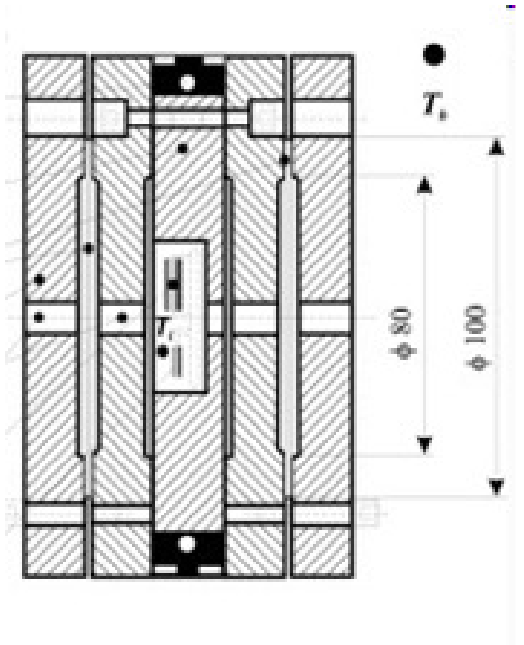
Dose distribution in marked cross section



Thermal certification method

1.6 – 2.1K - Drum method:

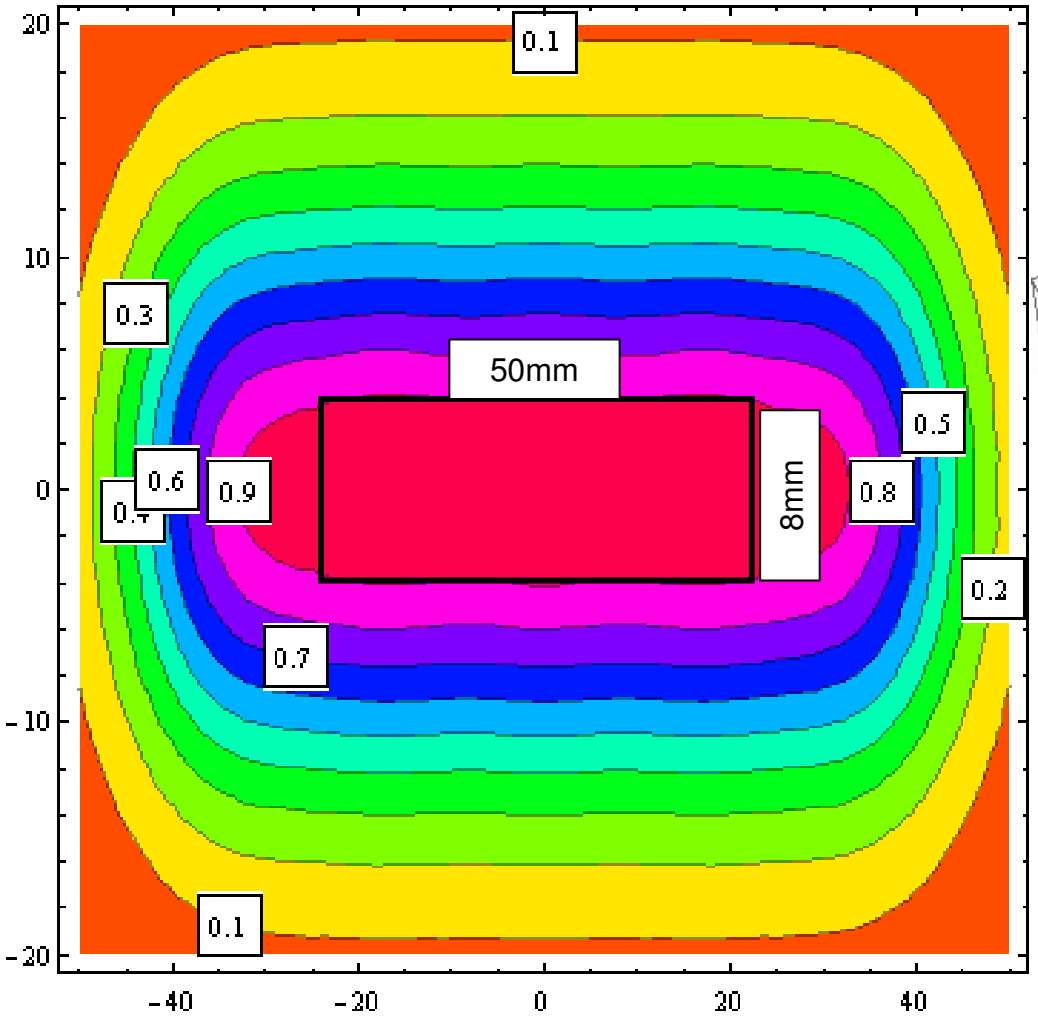
- allows determination of thermal conductivity and Kapitza resistance at superfluid helium conditions
- Specimens dimension :
  - min. 3 different thicknesses from range 0.1 – 0.5mm
  - length x with – 100x100 mmxmm
- Required irradiation area – ~~80~~ mm diameter circle – circle of 25 mm diameter can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

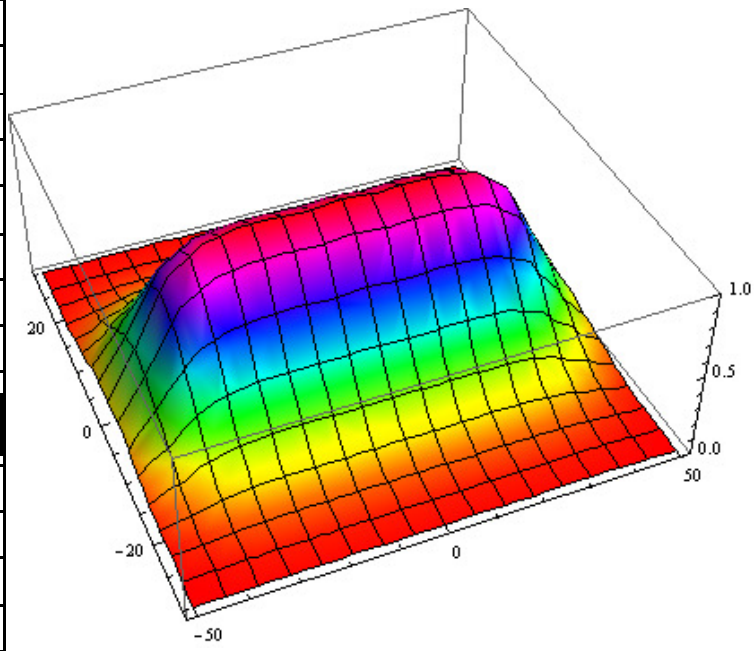


4.2 – 300 K – standard thermal conductivity set-up based on cryocooler

- 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

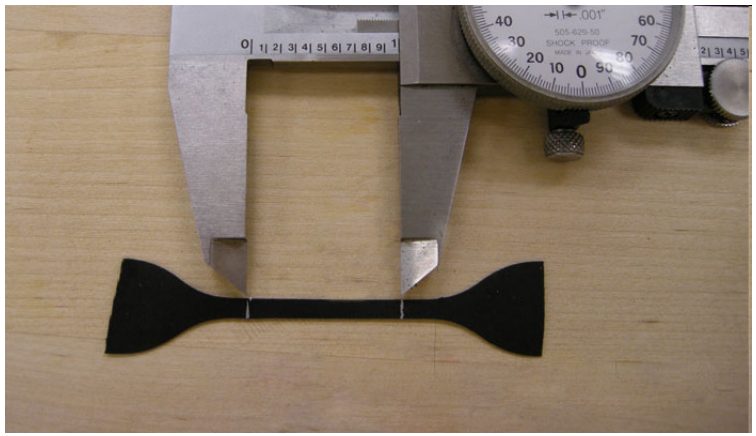




Mechanical certification tests

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

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