Russian Research Center “ Kurchatov Institute”

Studies of Radiation Damage in Irradiated Graphite Collimator Materials for LHC

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CERN, 19 February, 2007

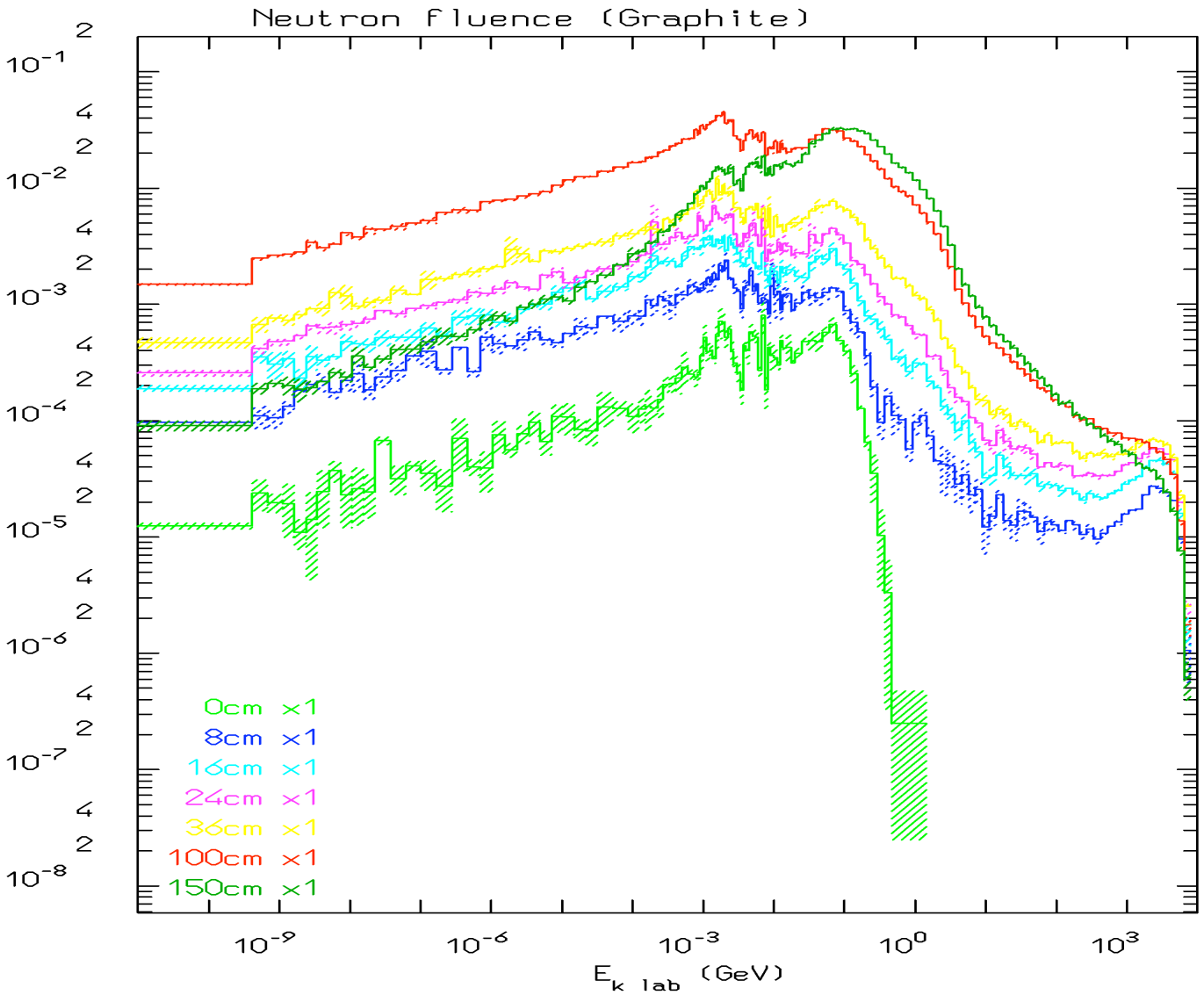
Task: Irradiation Damage Assessment of LHC Graphite Collimator Materials

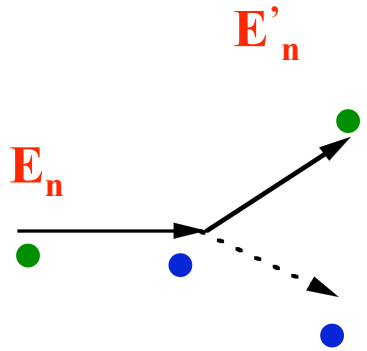
- ***Main aim of studies*** **– to measure the effect of irradiation on physical-mechanical material properties: thermal conductivity, thermal expansion, mechanical properties, electrical resistivity, microstructure change**

Objective:

- **Determine the effect of PKA carbon atoms energy spectrum near 7 TeV proton beam on physical - mechanical properties of graphite collimator materials for LHC – irradiation of graphite by carbon ions with the different energies**

Neutron energy spectrum per one 7 TeV proton in graphite on the several penetration depths of proton.





$$< E_C >= 2\frac{m_n}{m_C} E_n$$

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Investigated Graphite Collimator Materials for LHC

- C-C Composite Graphite REC
- C-C Composite Graphite Material AC
- High Density Graphite Material R4SSO

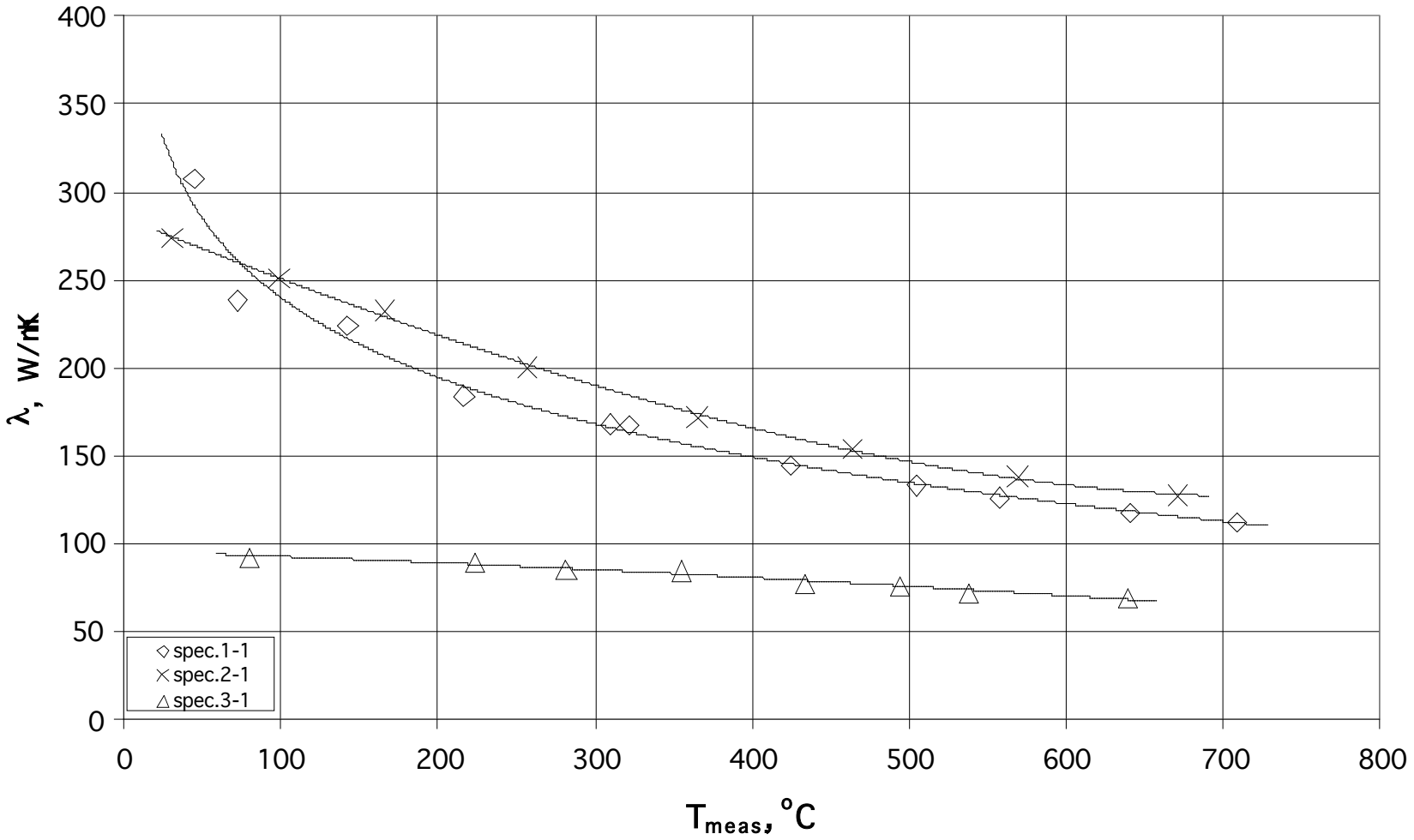
Measured values

- *d* - density
- λ - thermal conductivity coefficient (at T < 700°C)
- ρ - electrical resistivity (at T < 700°C)
- α - thermal expansion coefficient (at T < 700°C)
- σ - compression ultimate tensile stress
- E_d - dynamic elastic module
- E_s - static elastic module
- *a, c* - lattice constants (X-ray method)

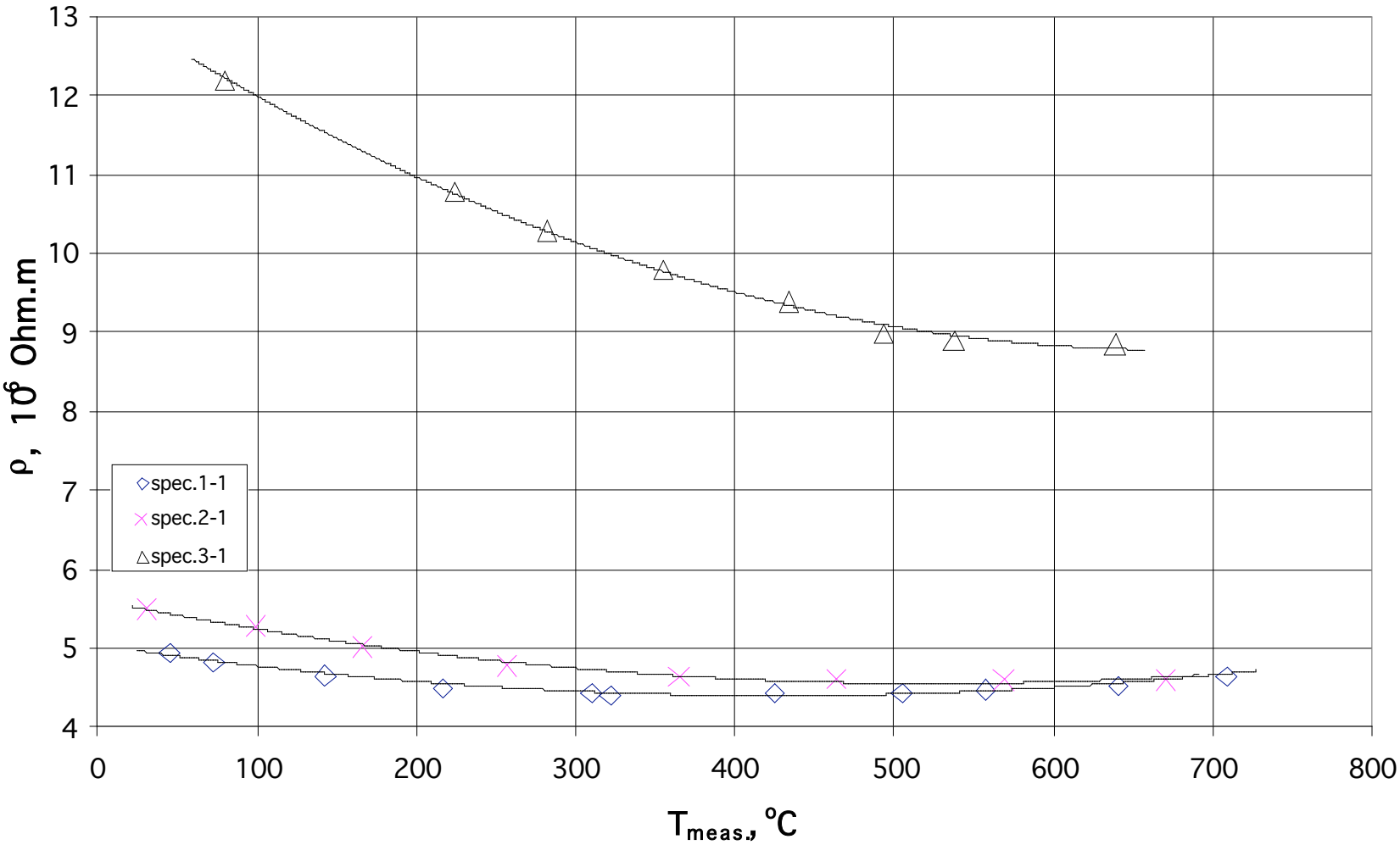
Measurements of Initial Properties of C-C Materials

Материал	№	$d_к$, г/см^3	$E_{дин}$, ГПа	r, 10^{-6} ОМ.м	l, W/m·K 20ºC	l, W/m·K 400ºC	a_{400}, 10^{-6} K-1	$s_{сж}$, GPa	$E_{стат}$, ГПа	a, Å	c, Å
REC (CFC)	1_1	1.77	32.33	4.94	350	150	0.9	76,7		2.463	6.734
REC (CFC)	1_2	1.80	34.25	4.72			0.9	78,5		2.463	6.738
REC (CFC)	1_3	1.74	33.56	5.04			0.9	70,5		2.463	6.742
Среднее		**1.77**	**33.38**	**4.9**			**0.9**	**75,2**	**12± 0,17**	**2.463**	**6.738**
AC150 (CFC)	2_1	1.77	32.87	5.48	280	170	0.2	71,5		2.463	6.742
AC150 (CFC)	2_2	1.73	33.39	5.91			0.2	63,8		2.463	6.734
AC150 (CFC)	2_3	1.77	31.12	5.62			0.2	65,2		2.463	6.738
Среднее		**1.76**	**32,46**	**5.67**			**0.2**	**66,8**	**15,3±0, 34**	**2.463**	**6.738**
R4SSO SLG	3_1	1.81	12.9	13.43	95	80	5.3	135,4		2.463	6.761
R4SSO SLG	3_2	1.81	13.1	13.20			4.9	138,5		2.462	6.761
R4SSO SLG	3_3	1.81	12.68	13.40			5	128,3		2.463	6.761
Среднее		**1.81**	**12.9**	**13.34**			**5.1**	**134,4**	**6,92±0, 53**	**2.463**	**6.761**

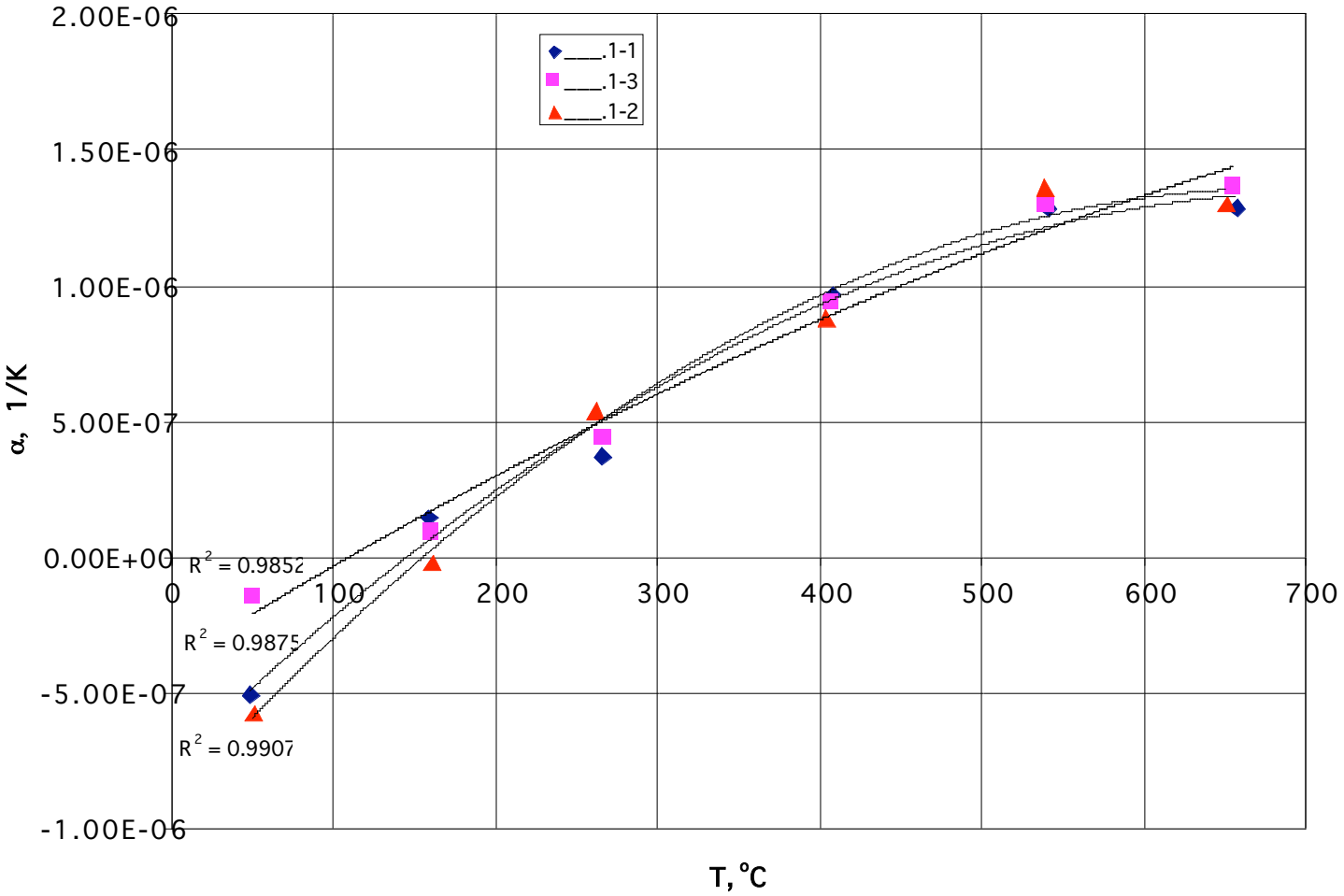
Temperature dependence of thermal conductivity coefficient **(1 – REC, 2 – AC150, 3 – R4SSO).**



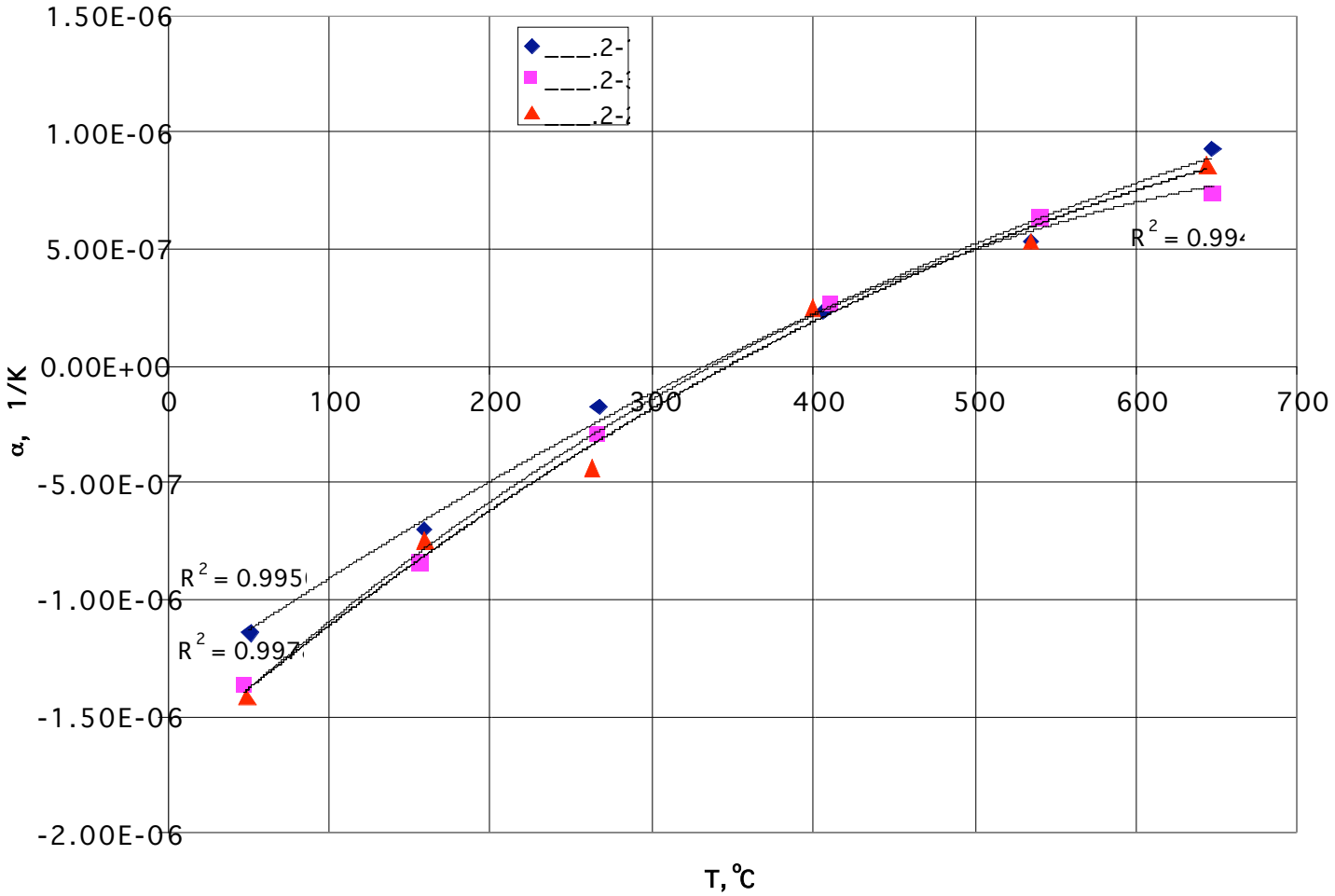
Temperature dependence of electrical resistivity (1 – REC, 2 – AC150, 3 – R4SSO).



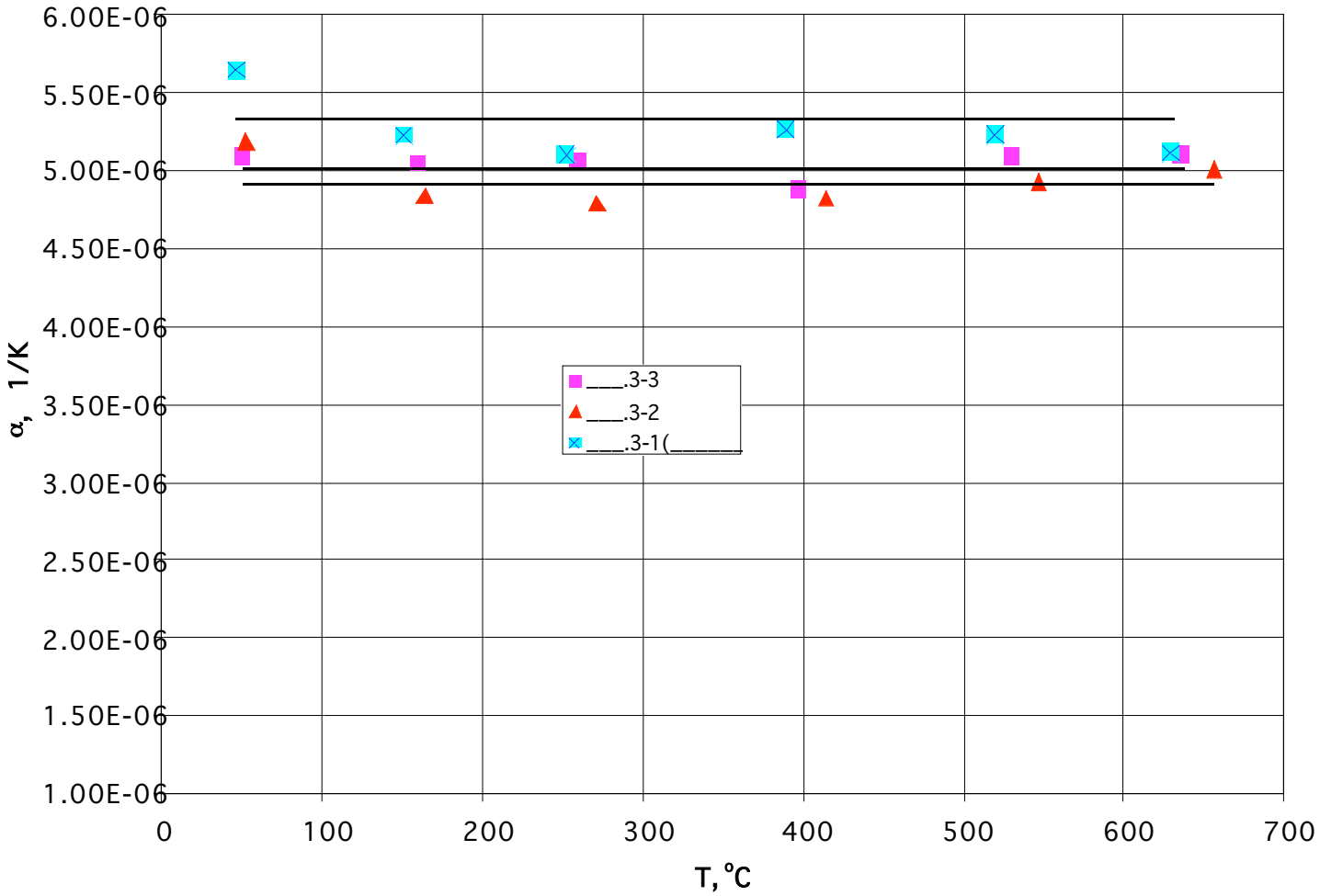
Temperature dependence of thermal expansion coefficient **of REC.**



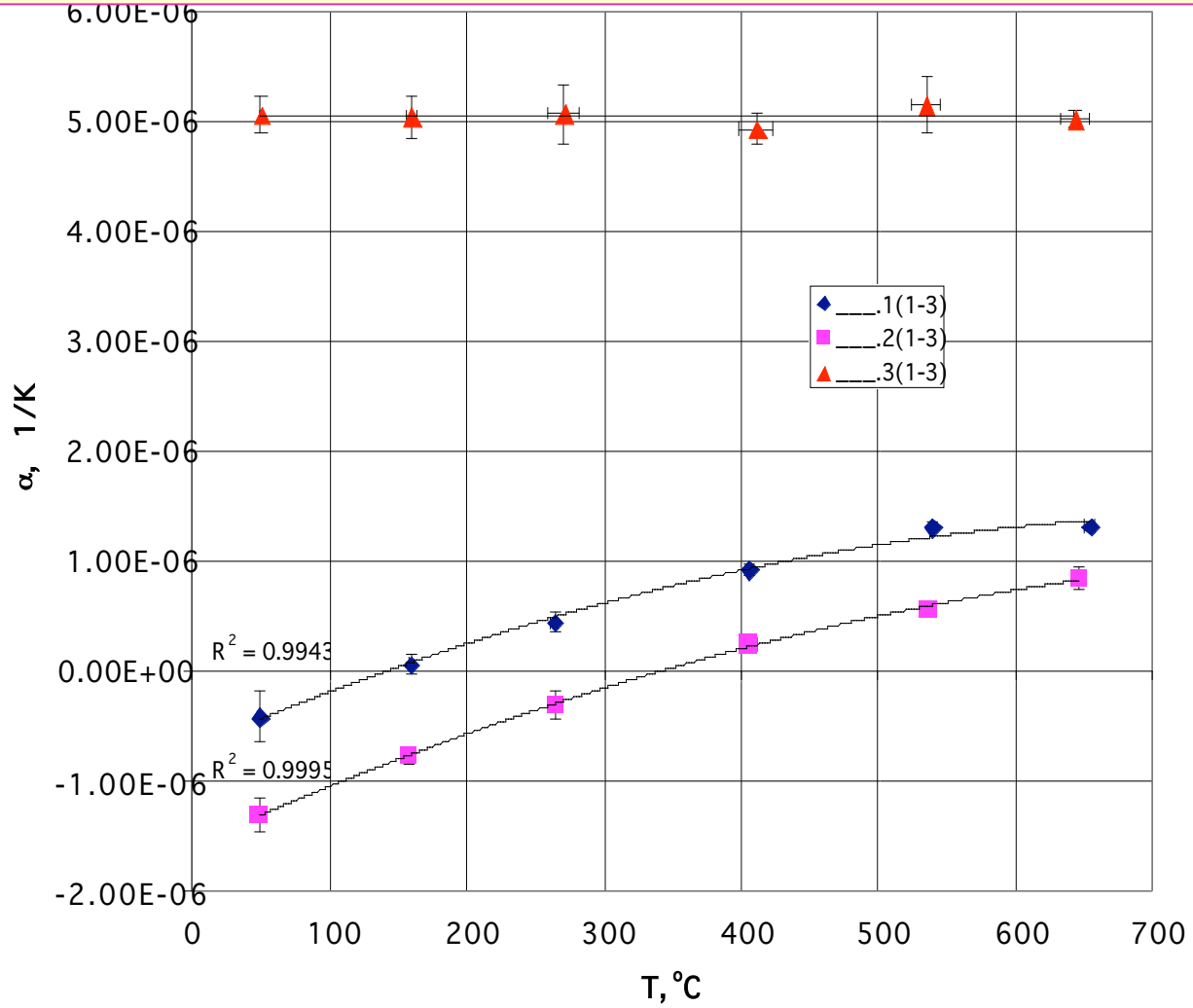
Temperature dependence of thermal expansion coefficient **of AC 150.**



Temperature dependence of thermal expansion coefficient **of R4SSO.**



Temperature dependence of thermal expansion coefficients **(1 – REC, 2 – AC150, 3 – R4SSO).**



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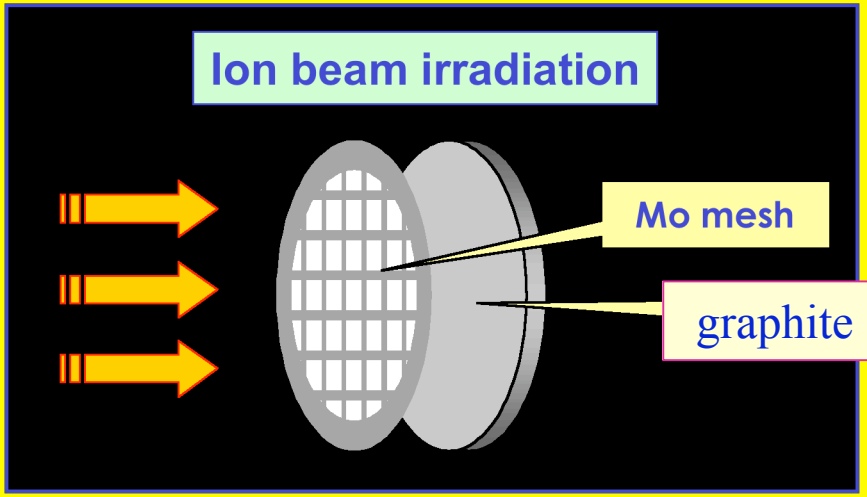
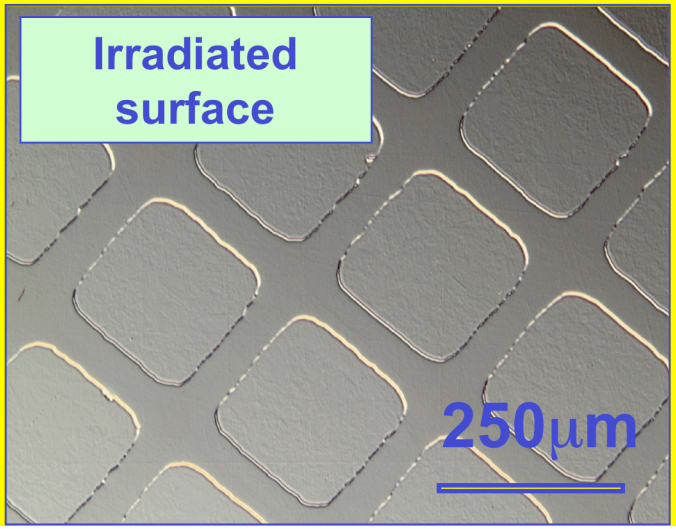
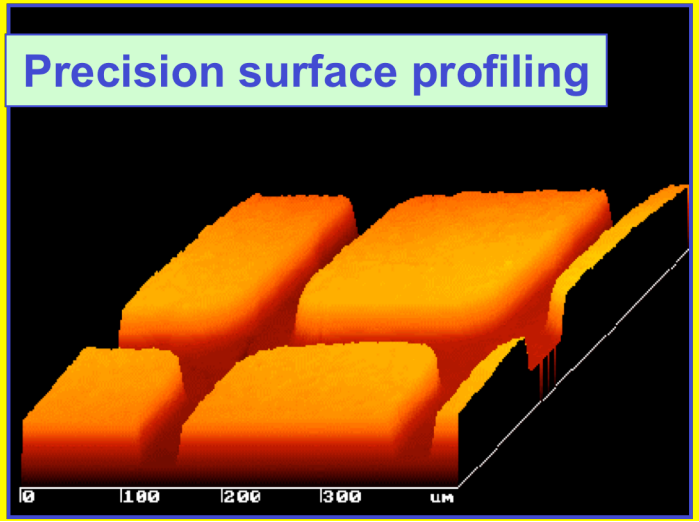
Investigation of Radiation Induced Deformation

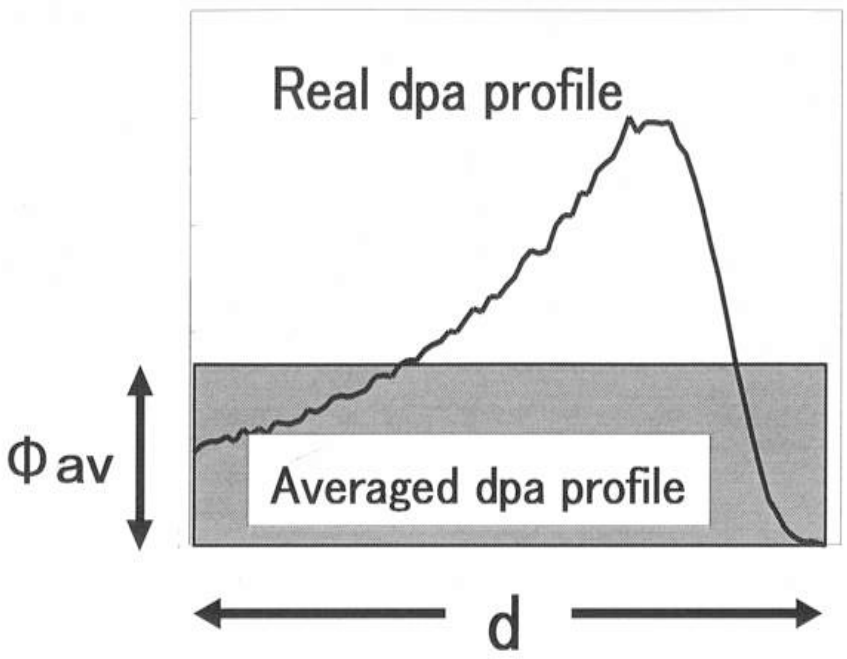
Ion beam irradiation and Surface profile characterization

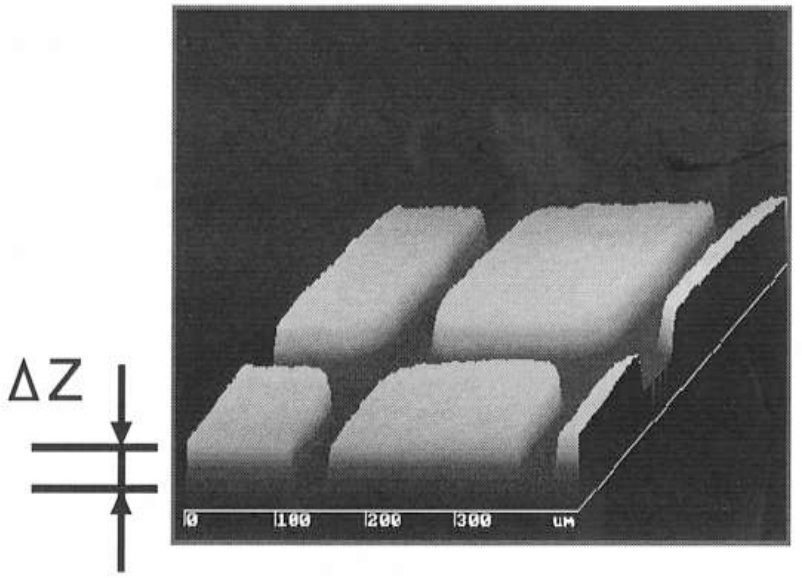






Experimental Measurement of Radiation Induced Deformation





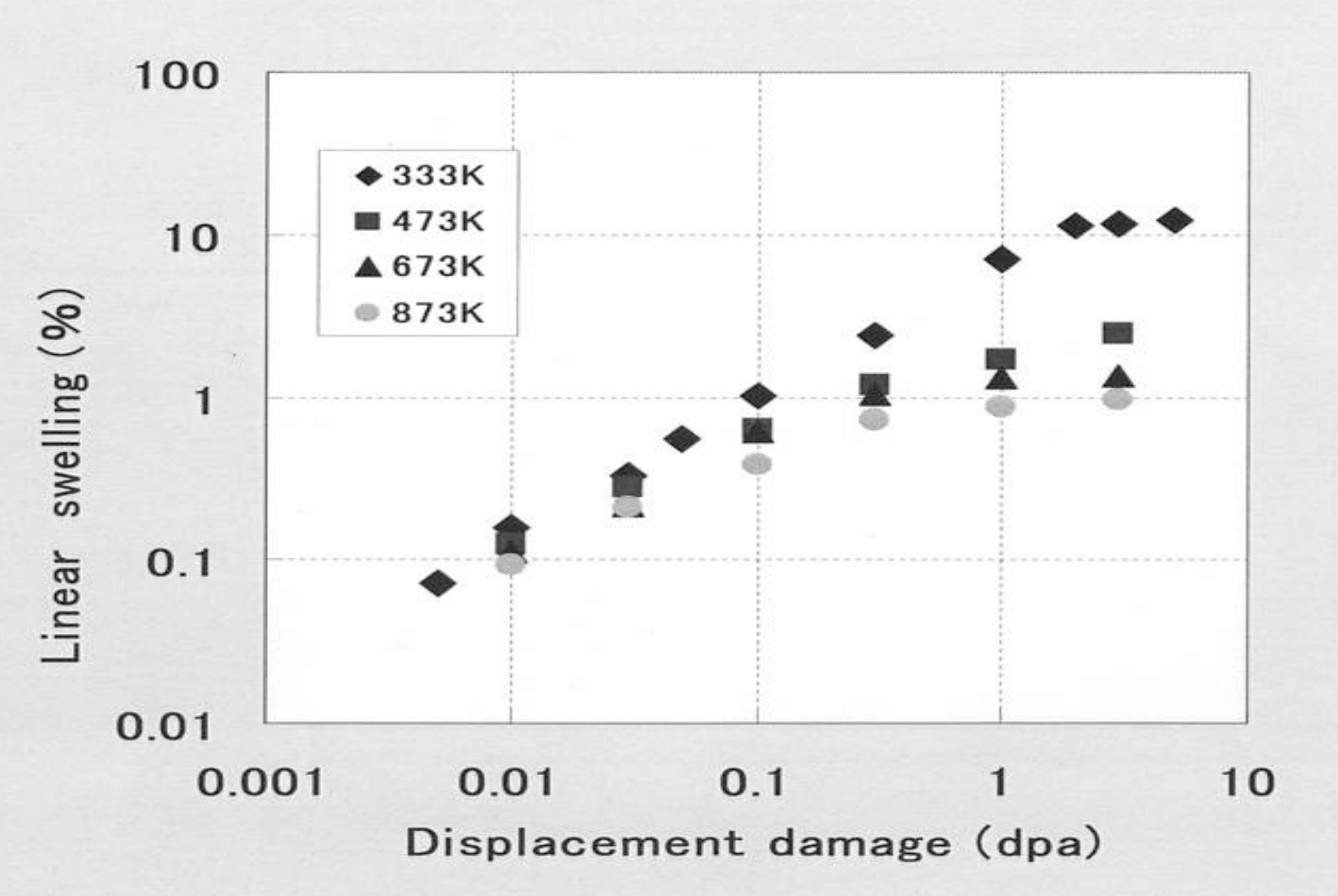
$$\Delta V / V (\Phi_{av}) \cong \Delta Z / d$$

Φ_{av} – Averaged dpa profile,

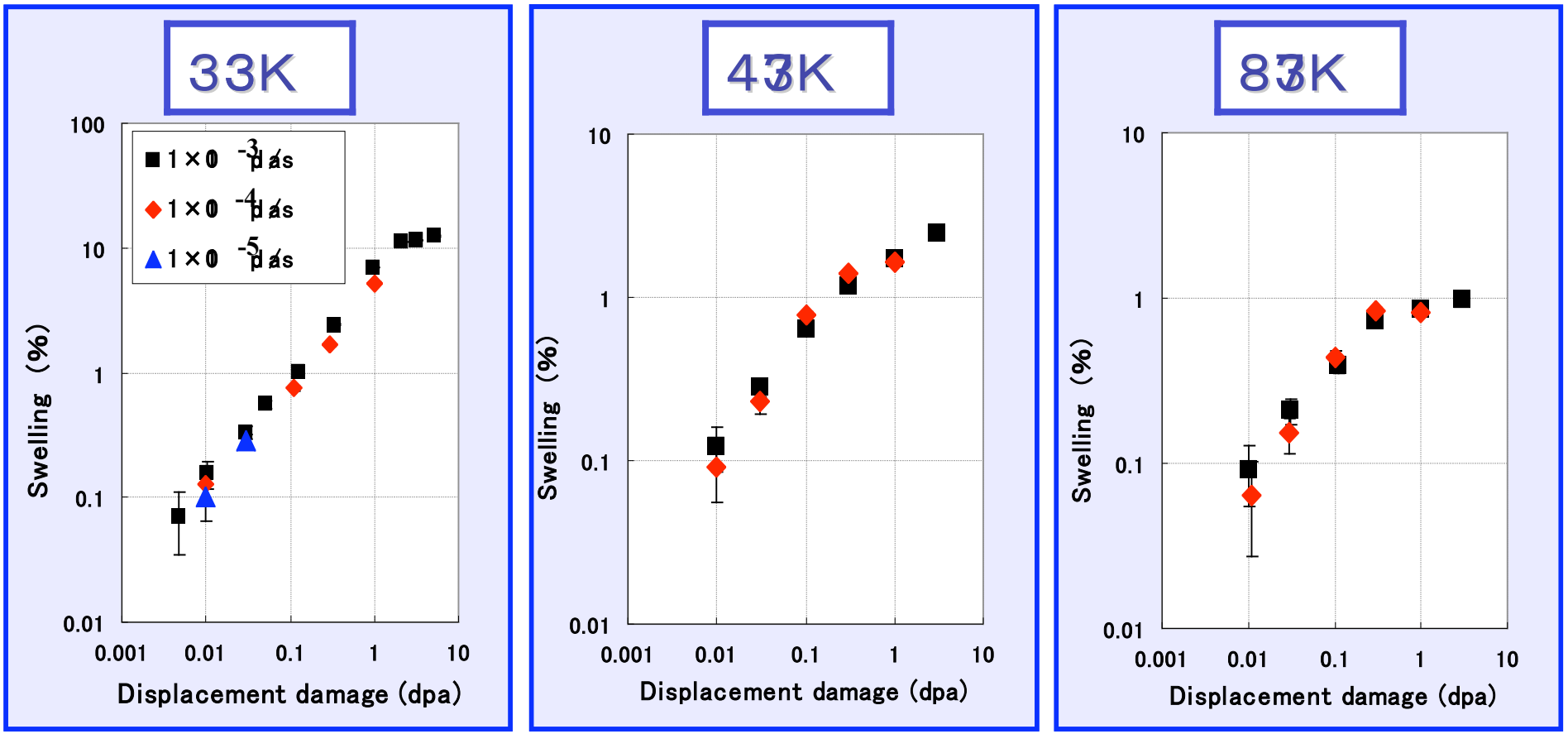
ΔZ - Height of step between irradiated and no irradiated area,

d - Penetration depth of irradiated sample.

Dose dependence of radiation swelling in SiC



Dose rate dependence of Ion-induced swelling in CVD-SiC



The displacement damage rates were 1×10^{-4} and 1×10^{-3} dpa/s at 333K-873K and 1×10^{-5} dpa/s at 333K with single-beam irradiation. The error bars represent the 96% confidence limits for the Gaussian distribution.

Accelerators of Charge Particles of Russian Research Center "Kurchatov Institute"

- **Cyclotron of RRC KI:**

  protons with energy < 35 MeV, current J < 30 mkA

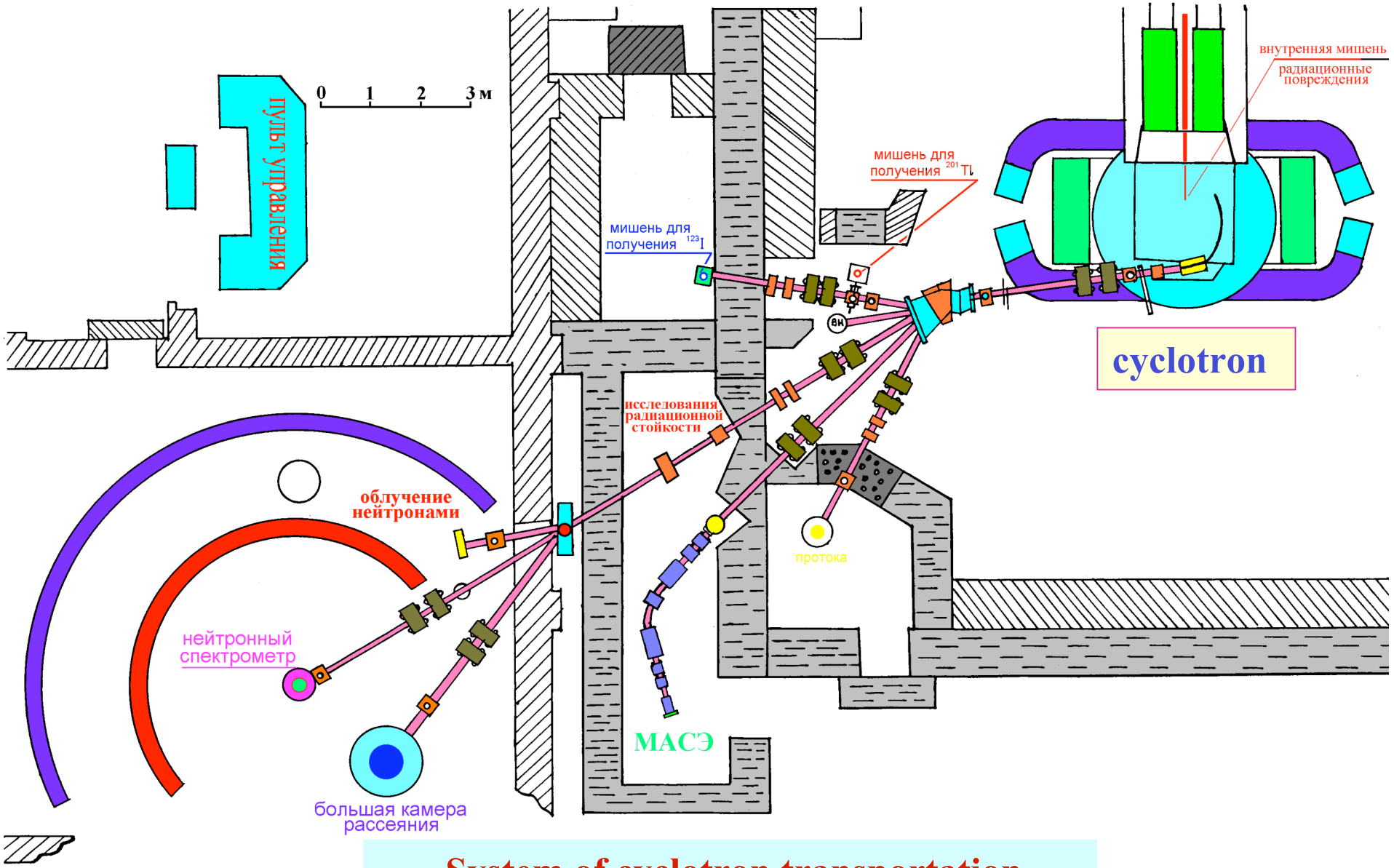
  helium ions He^4 with energy < 60 MeV, current J < 20 mkA

  ions O^{16} with energy < 120 MeV , current J < 5 mkA

  ions C^{12} with energy < 80 MeV, current J < 5 mkA

- **Van de Graaf Accelerator:**

  protons with energy < 3 MeV, current J < 25 mkA



System of cyclotron transportation

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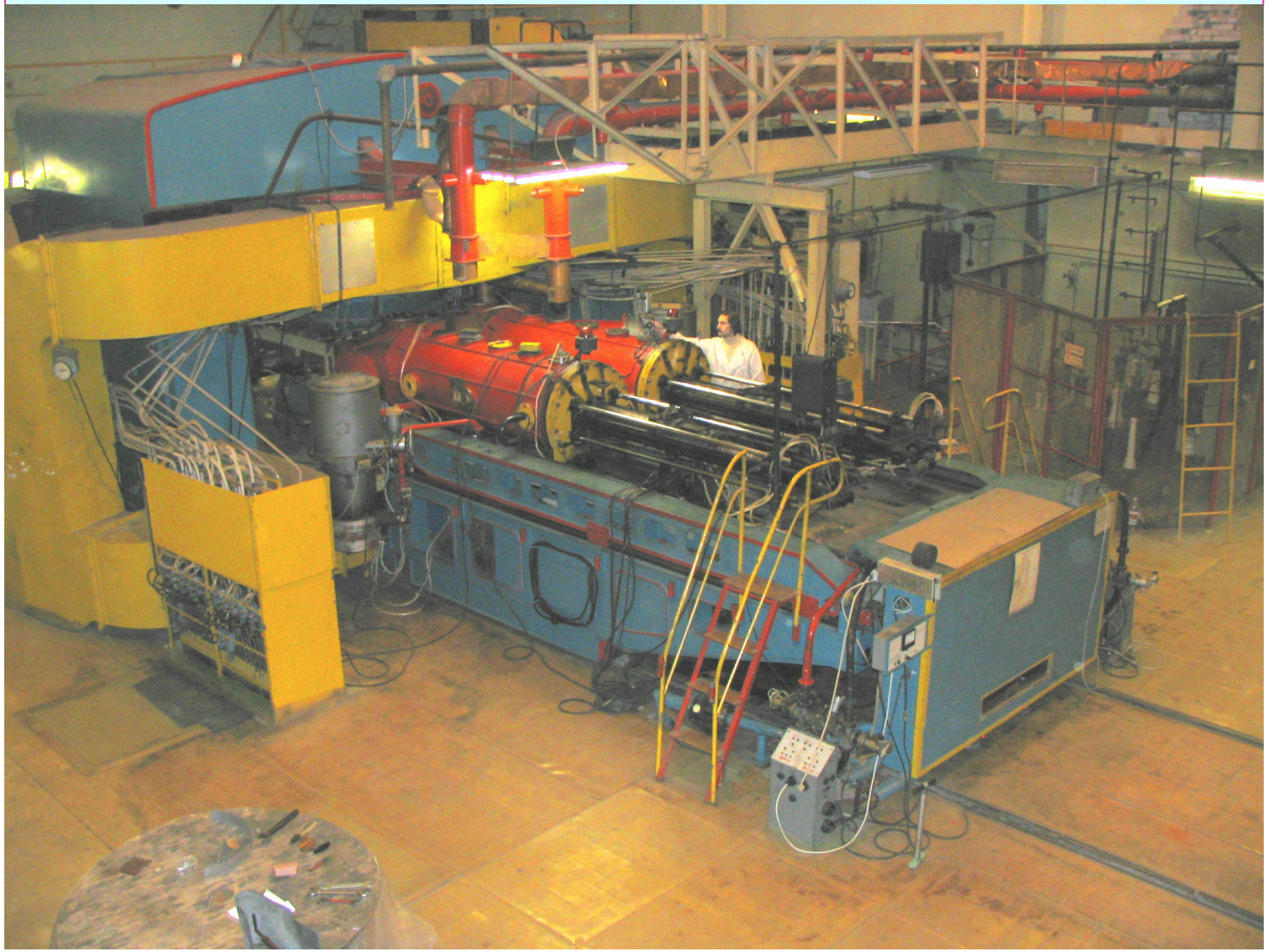
Cyclotron of RRC “Kurchatov Institute”



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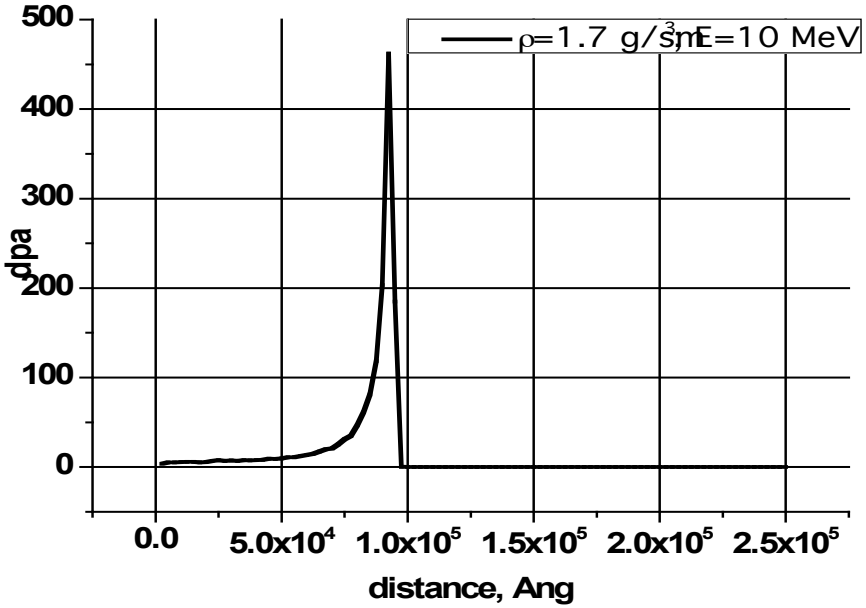
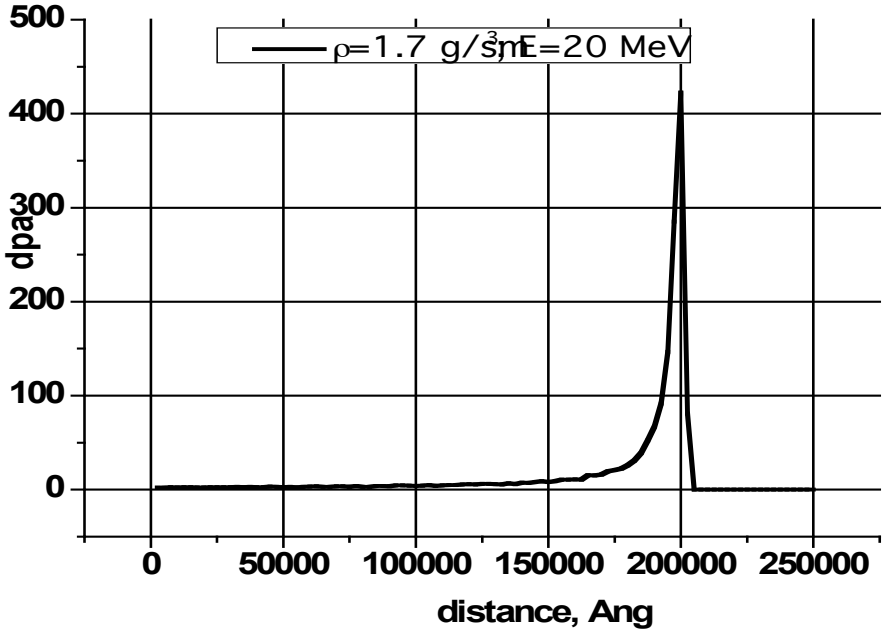
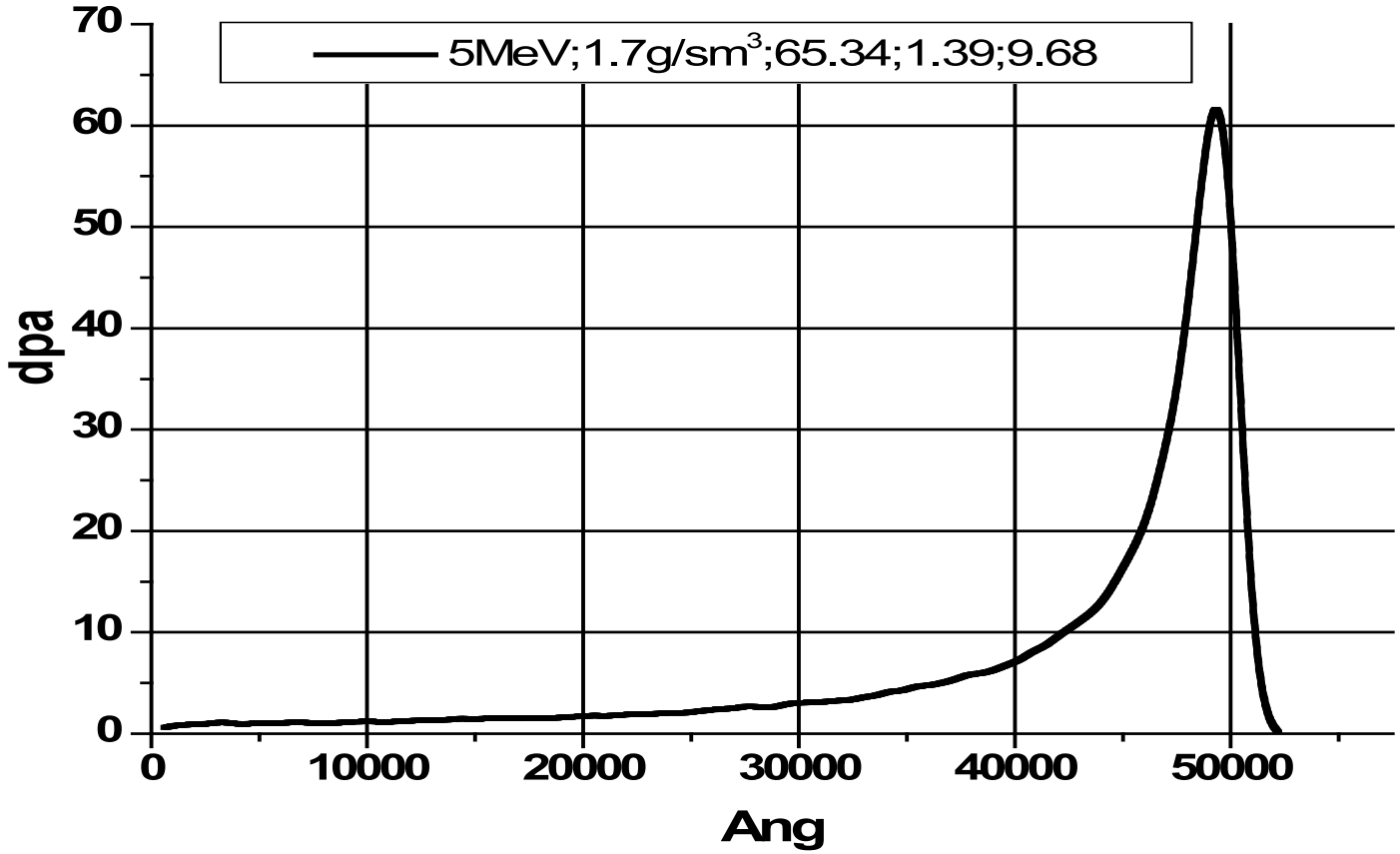
Generation Rate of Point Defects under Irradiation of Graphite by 10 MeV and 20 MeV Carbon Ions at Dose of Irradiation 4.10E18cm2

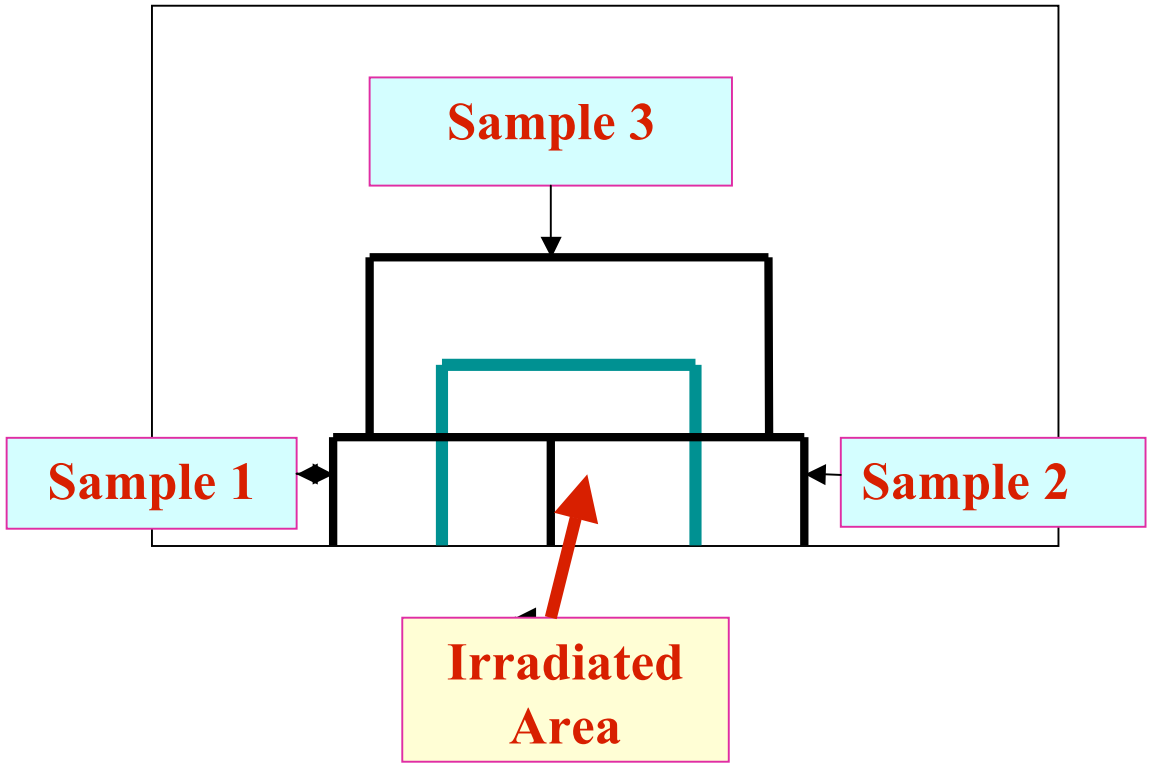




Generation Rate of Point Defects under Irradiation of Graphite by 5 MeV Carbon Ions at Irradiation Dose 5.10E17cm2



Scheme of Irradiation of Graphite Samples



Picture of Irradiated and Unirradiated Sample Area, Measurement of Radiation Swelling