Studies of graphite properties, assessment of technical conditions and projections of remaining life of RBMK reactors graphite structural components

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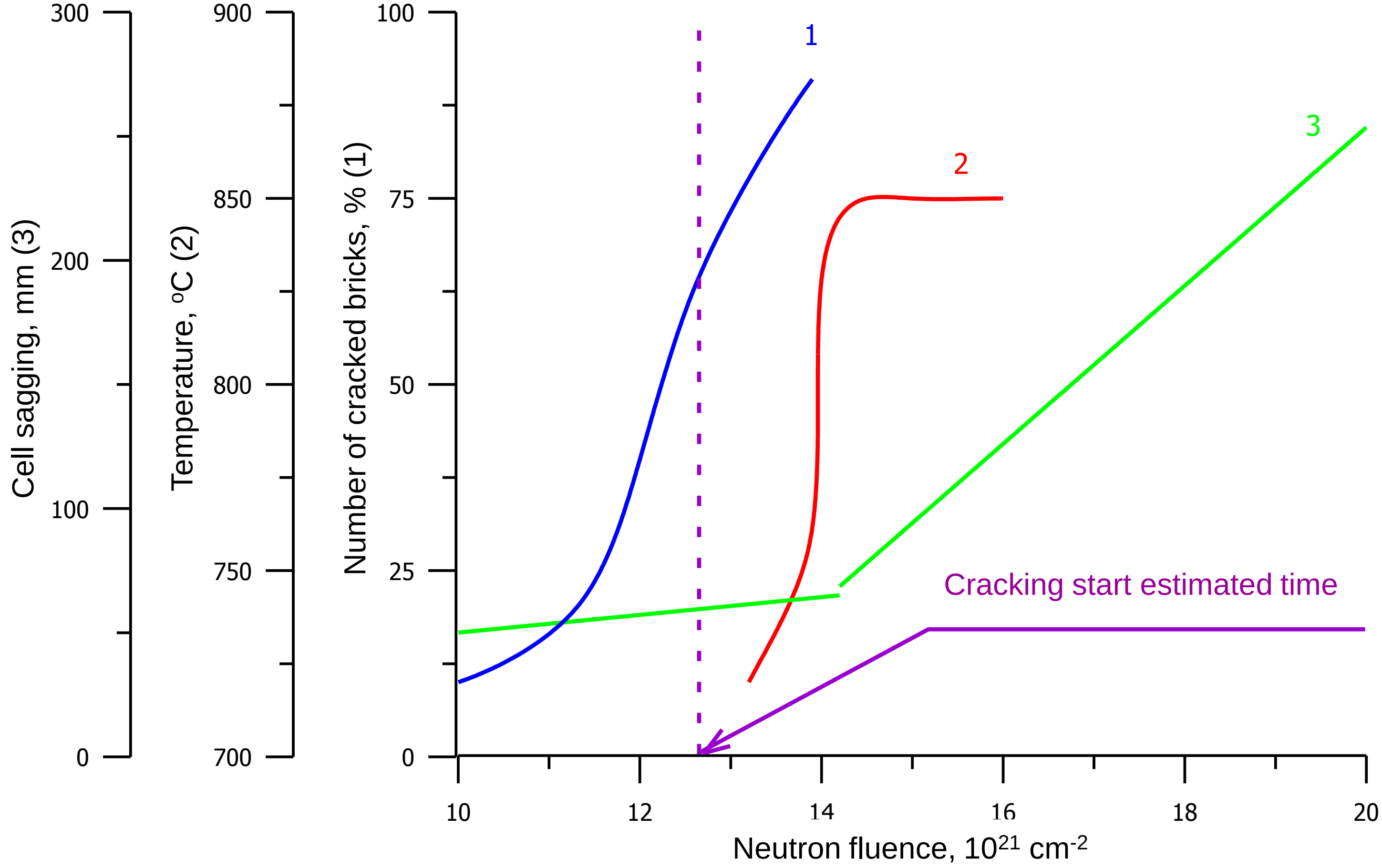
Performance history of production reactors

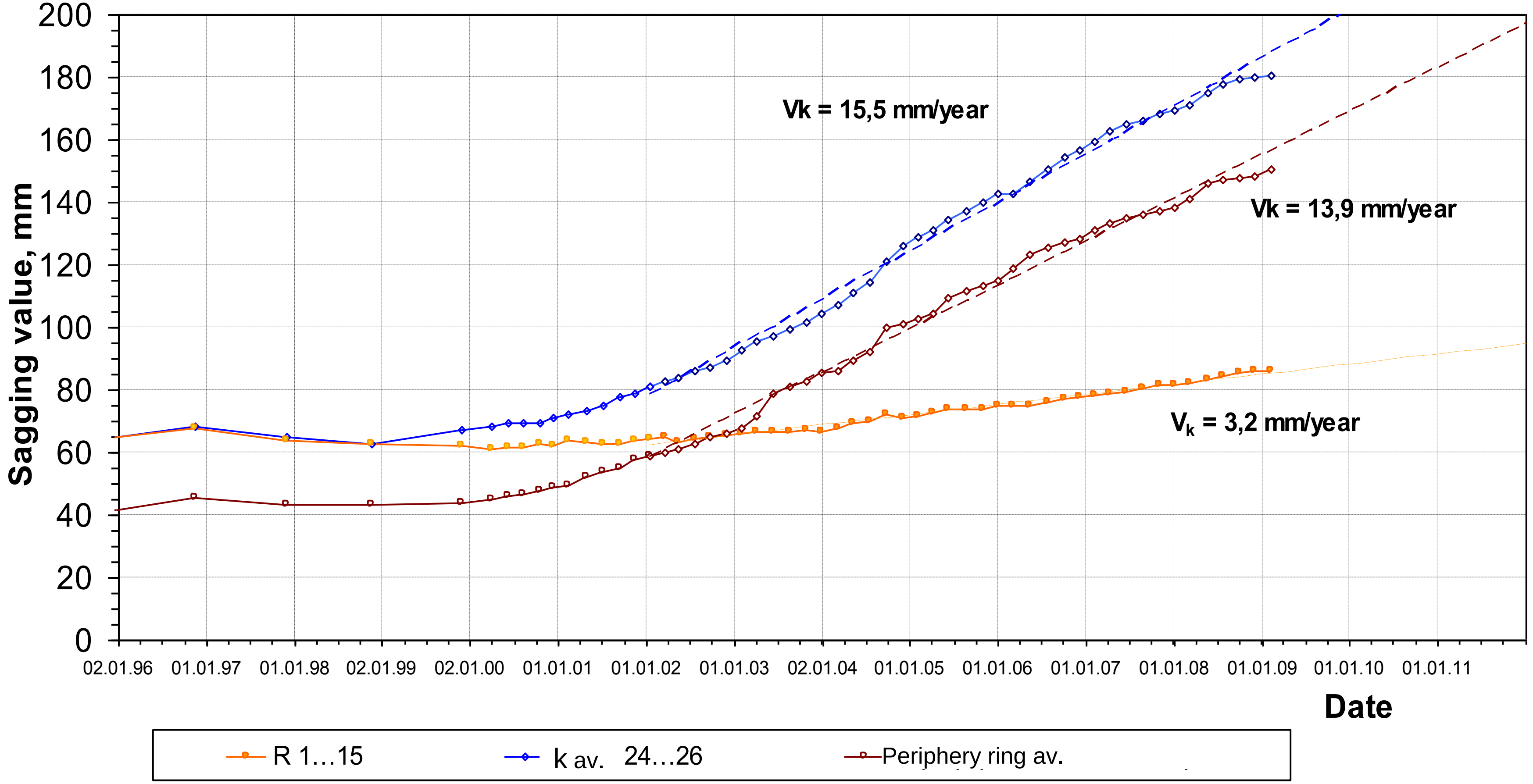
Degrading of AB-3 graphite stack



1 – Cracked bricks accumulation curve
2 – Graphite stack temperature curve
3 – Graphite column distortion rate (increase in sagging of periphery cells)

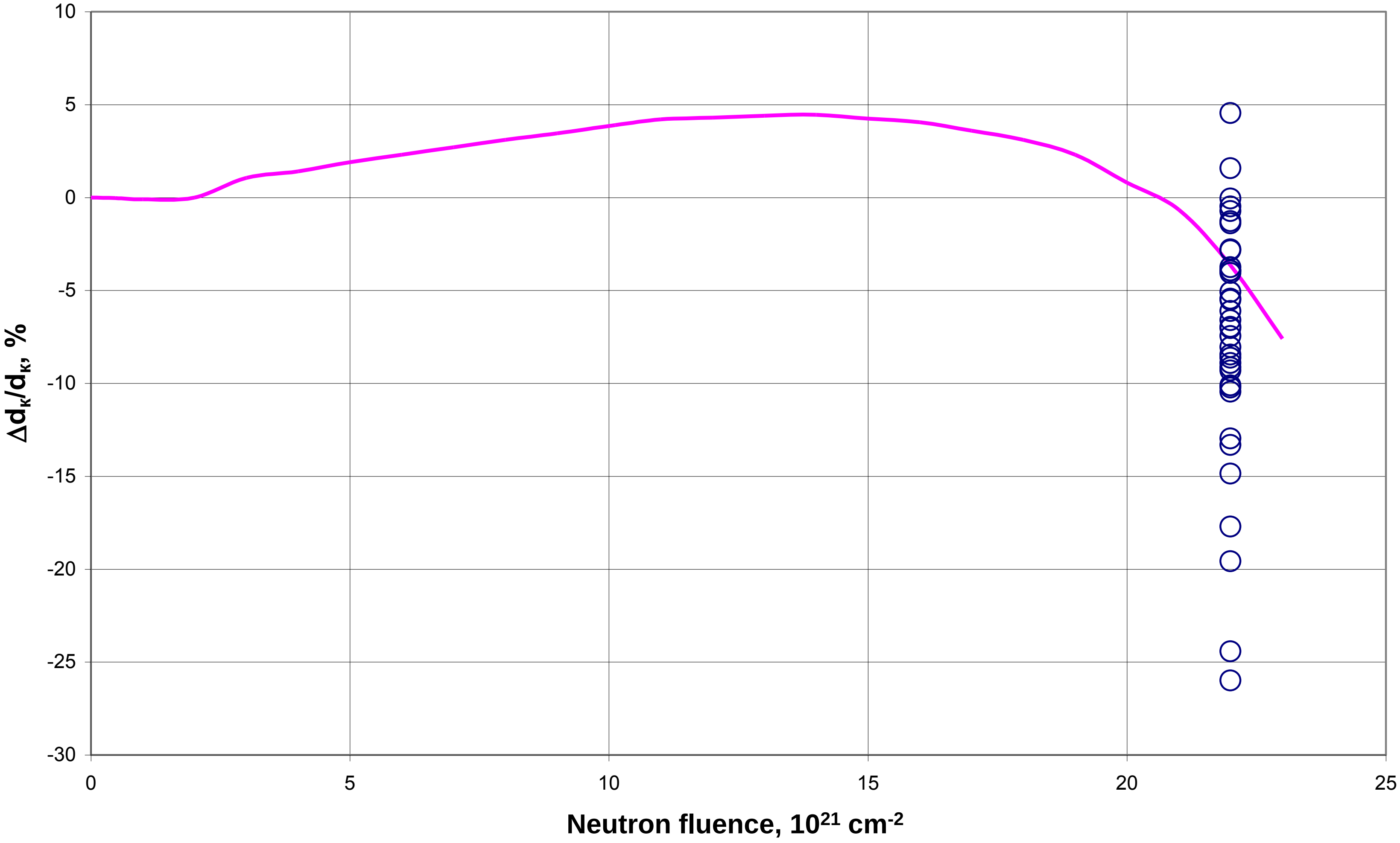
Average sagging of graphite columns for cells of typical graphite stack groups of ADE-2 reactor

(V_k – averaged deflection rate, mm/year)



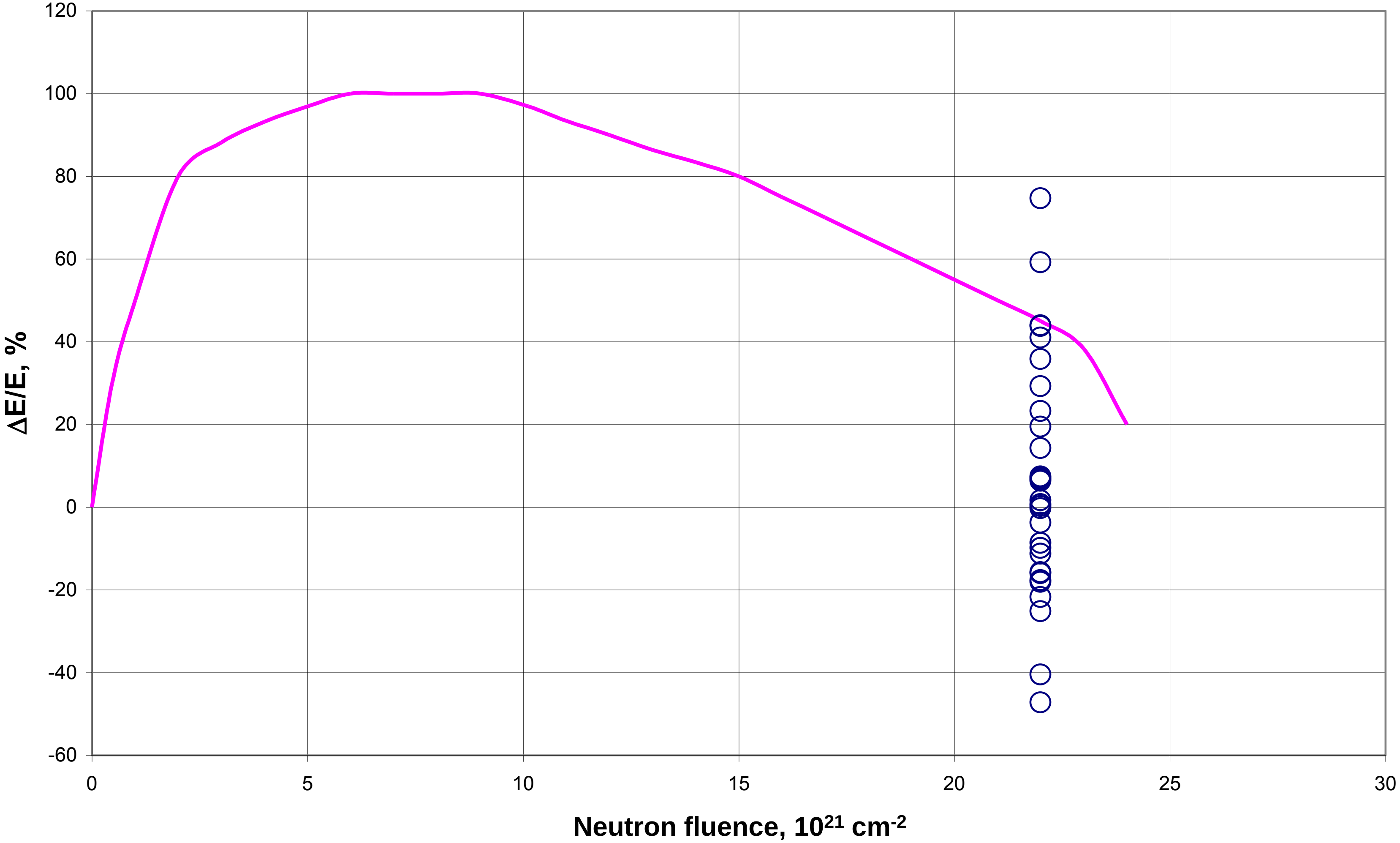
Relative change in graphite density of kernels taken from ADE-2 stack in 2004

Solid line – change in GR-280 graphite density under similar irradiation conditions



Relative change in graphite modulus of elasticity of kernels taken from stack of ADE-2 in 2004

Solid line – change in GR-280 graphite modulus of elasticity under similar irradiation conditions



Result

The production reactors demonstrated the possibility of safe operation of stacks in conditions where the graphite bricks retained their load-bearing capacity even with longitudinal through cracks and distortion of columns.

Operation of RBMK graphite stacks during their design service life

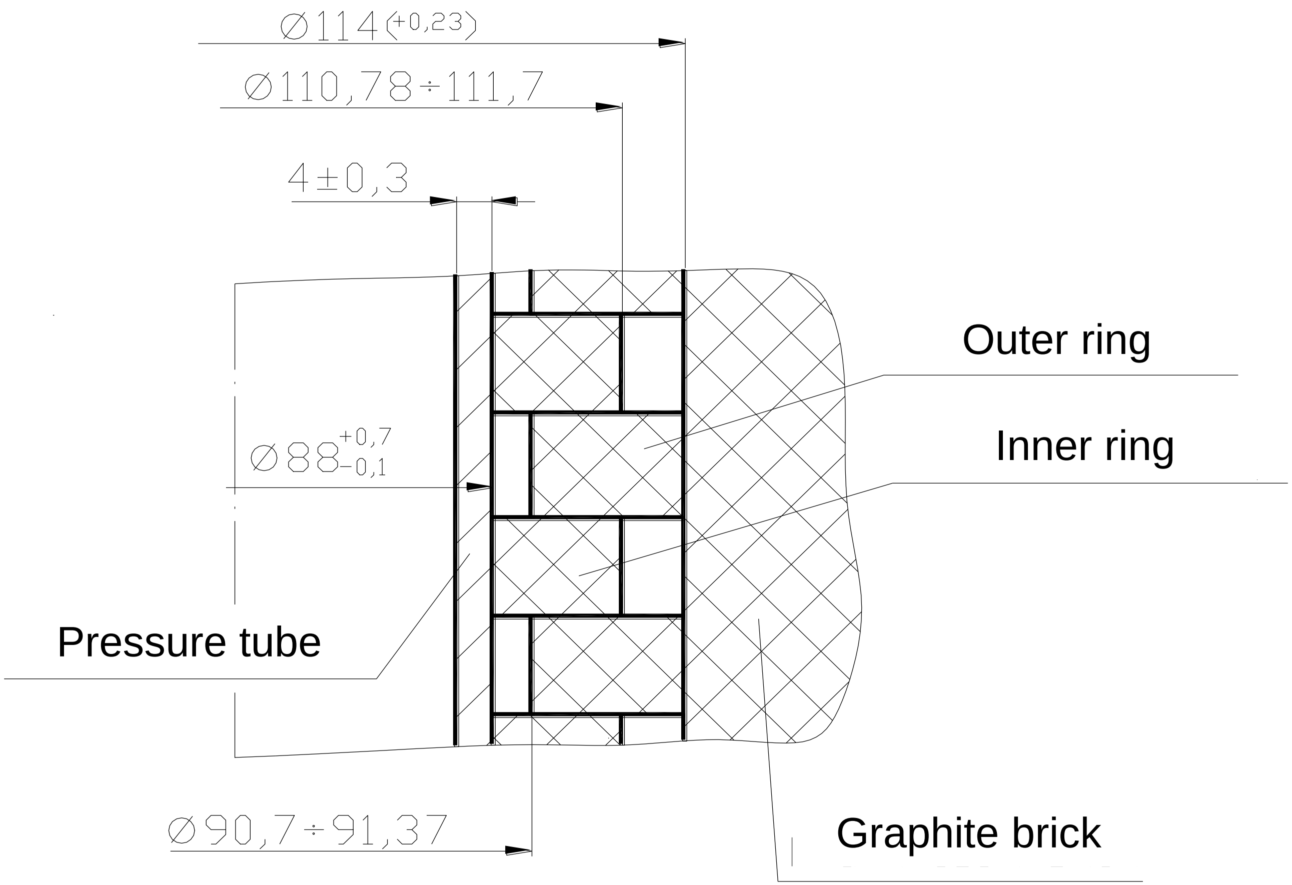
Operation criteria of RBMK graphite stacks

- Absence of force interaction between pressure tube and graphite brick – gas gap (GG) take-up;
- Integrity of graphite bricks – **absence of longitudinal through cracks;**
- Vertical shrinkage of columns – **performance of telescopic joint (TCT).**

Strength calculation standards for graphite units and parts

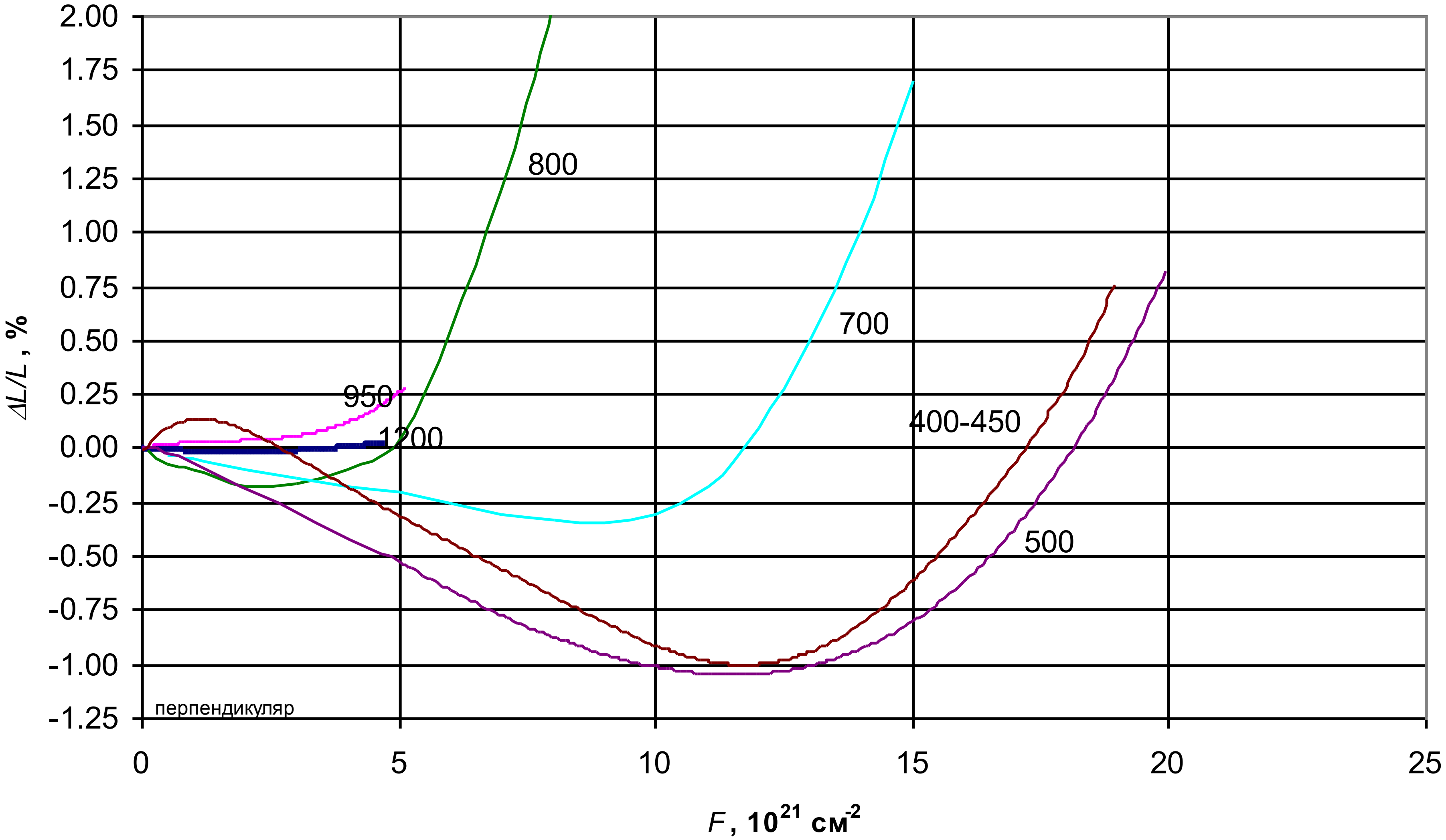
In 1990 the work was completed to produce the third revision of Strength Calculation Standards for type graphite units and parts of uranium-graphite channel-type reactors (NGR-01-90). The standards were produced by NIKIET, RRC Kurchatov Institute and NIIGRAFIT.

PT-stack system fragment

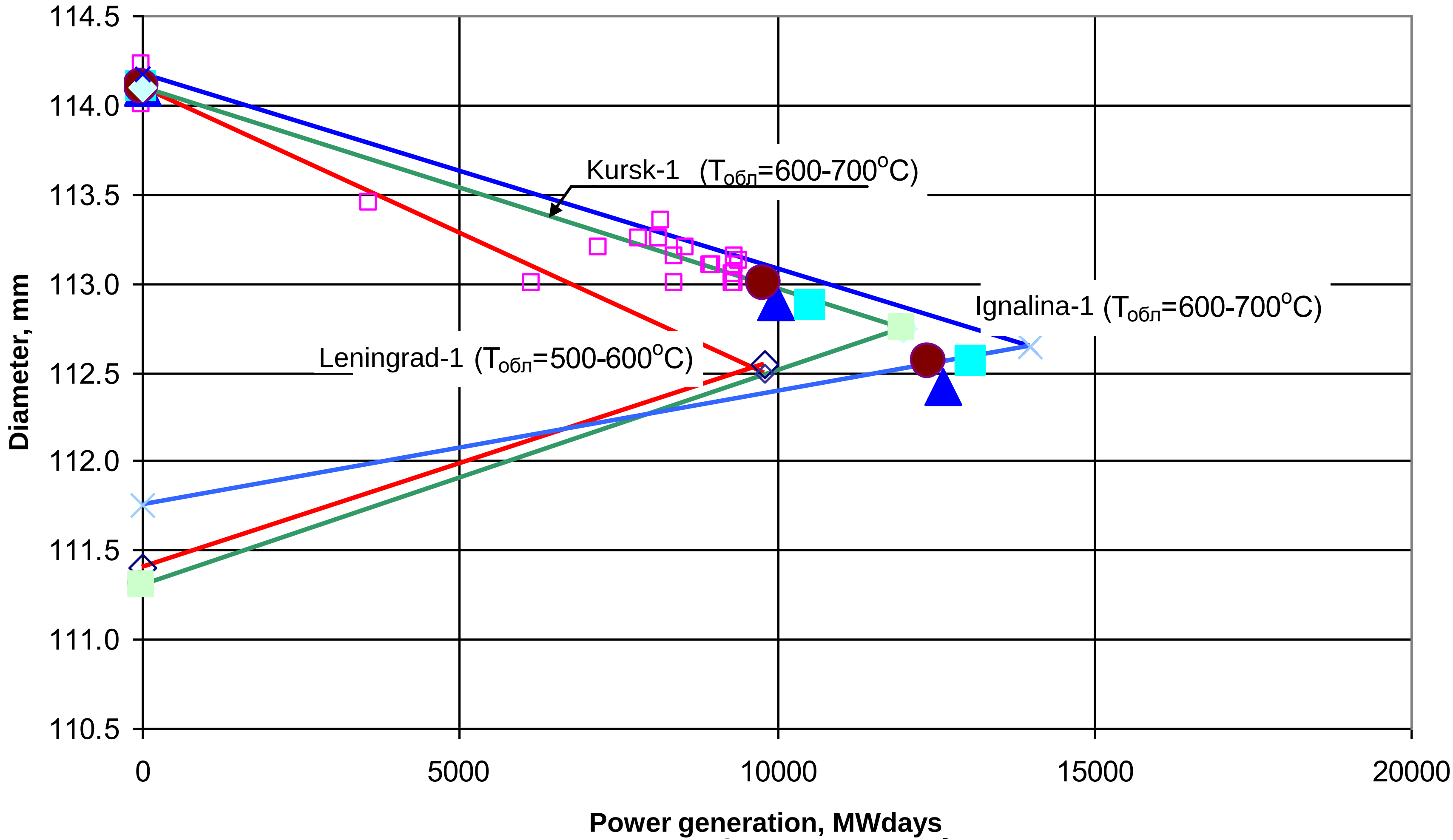


Gas gap (GG) take-up criterion

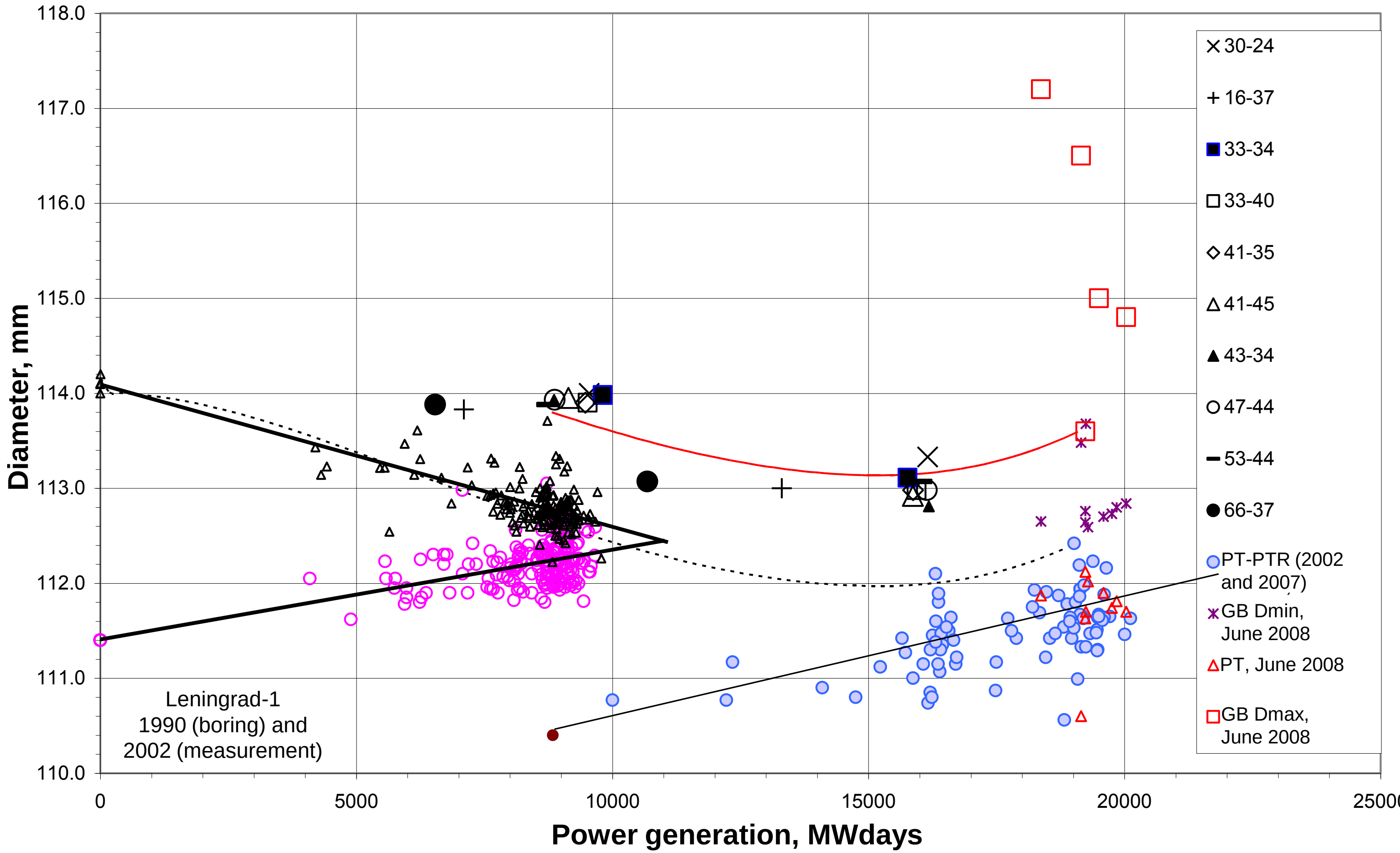
Graphite form change under irradiation



Rate of graphite bricks shrinkage and change in gas gap of different NPPs



Dependence of gas gap change during reactor operation (growth of power generation per cell), given GB hole diameter change due to a longitudinal through crack



Conclusions and results

The study of kinetics of the gas gap take-up has shown that it can be taken up before the assigned service life of the reactor (30 years).

This conditioned repairs of the graphite stack involving hole boring of the graphite bricks and replacement of pressure tubes.

Operation of RBMK graphite stacks during the extended life period (ELP)

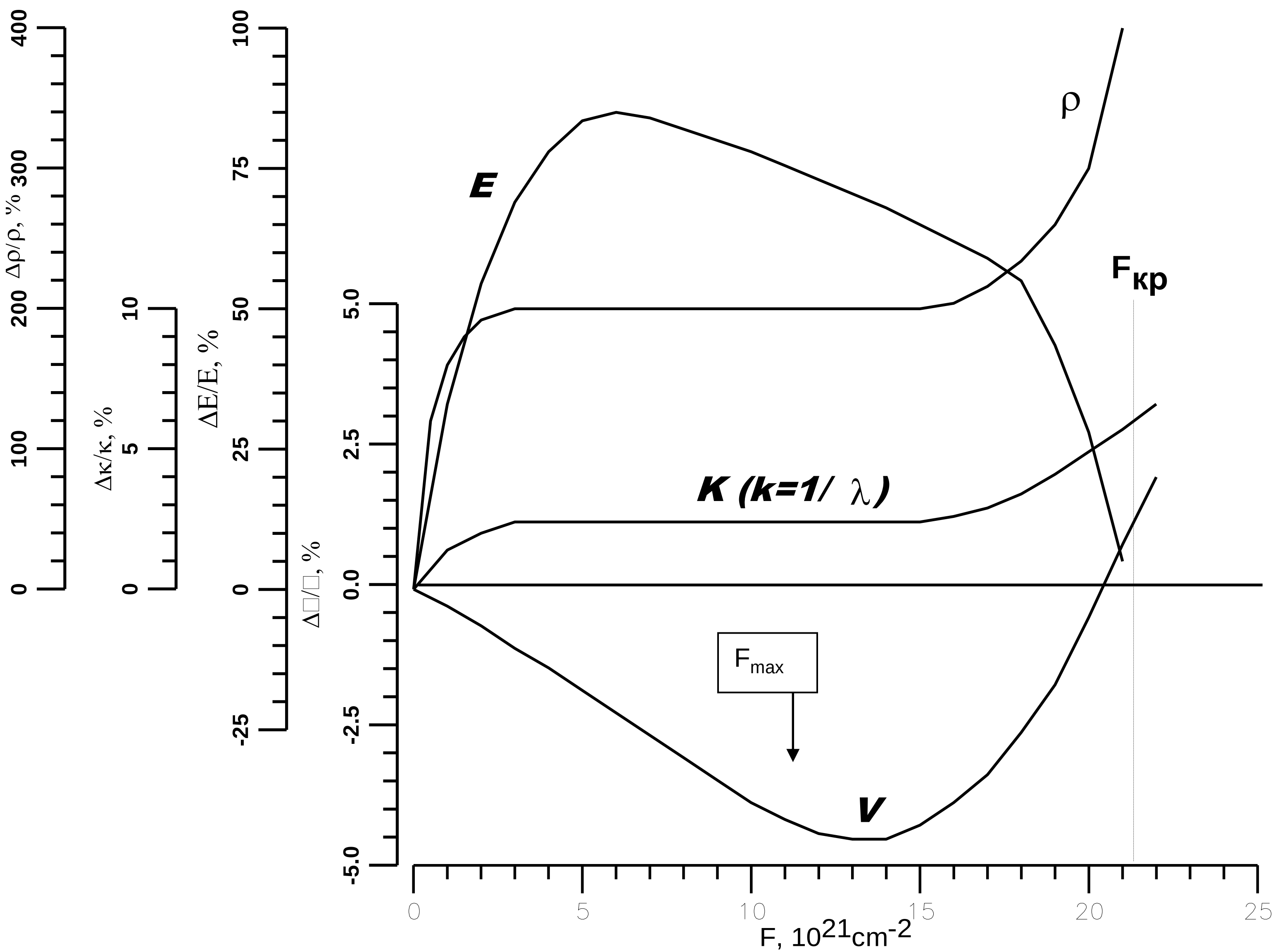
Carried out in accordance with the Methodology for assessment of RBMK-1000 graphite stack residual life (RD EO 362-0265) produced by NIKIET and NRC Kurchatov Institute and approved by Rosenergoatom in 2005.

Performance assessment criteria of RBMK-1000 graphite stack

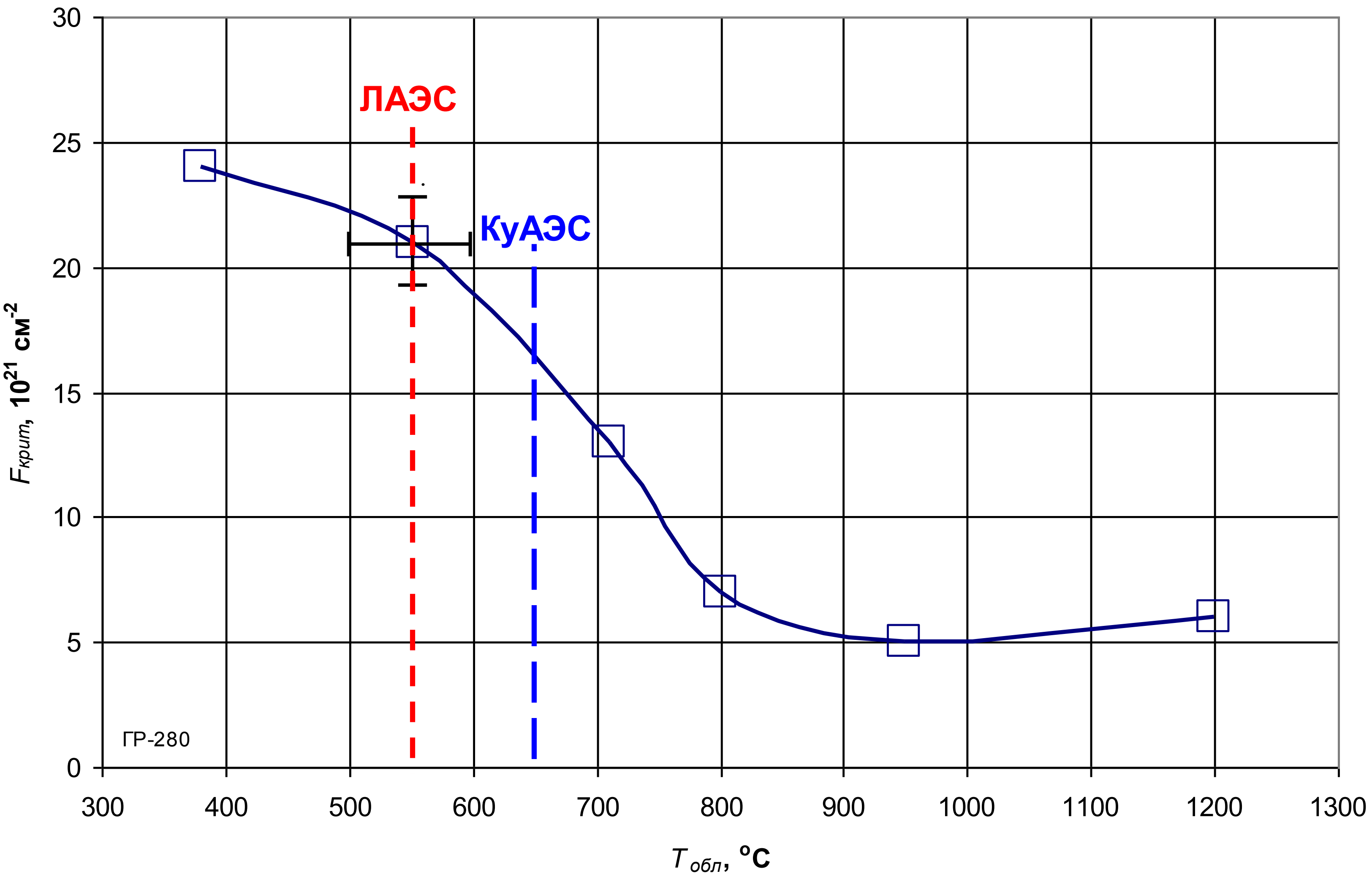
- Degradation of graphite as a structural material (**$F_n < F_{cr}$** – damaging neutrons fluence doesn't exceed critical fluence value) **– graphite retains strength.**
- Cracking of graphite bricks and distortion of graphite columns – **maximum sagging of columns**

Neutron critical fluence run-up criterion (Fcr)
(deterioration of strength and thermal physics properties of graphite)

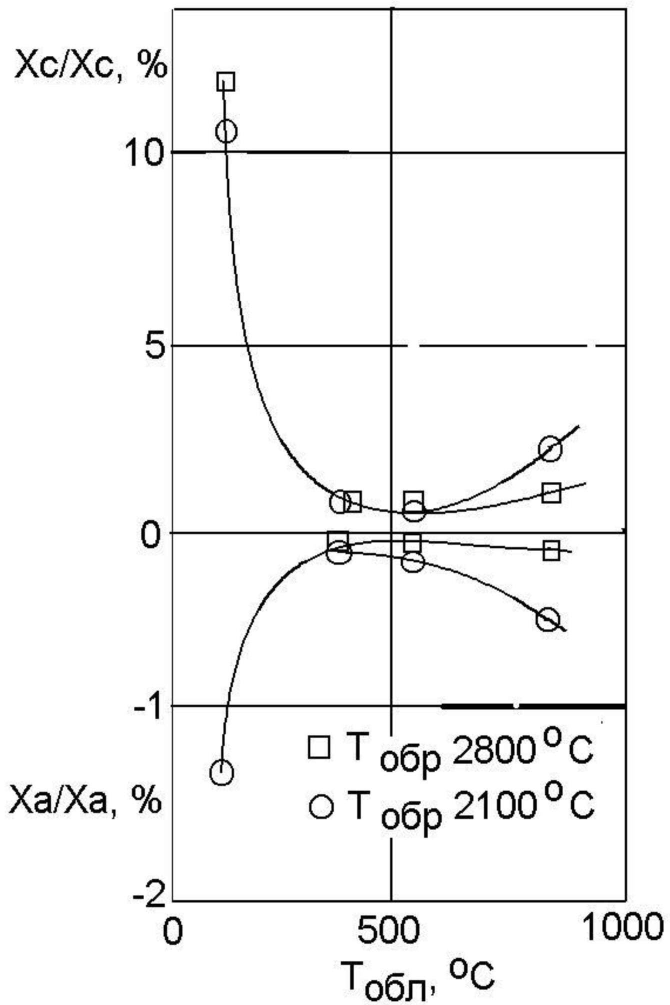
Critical neutron fluence



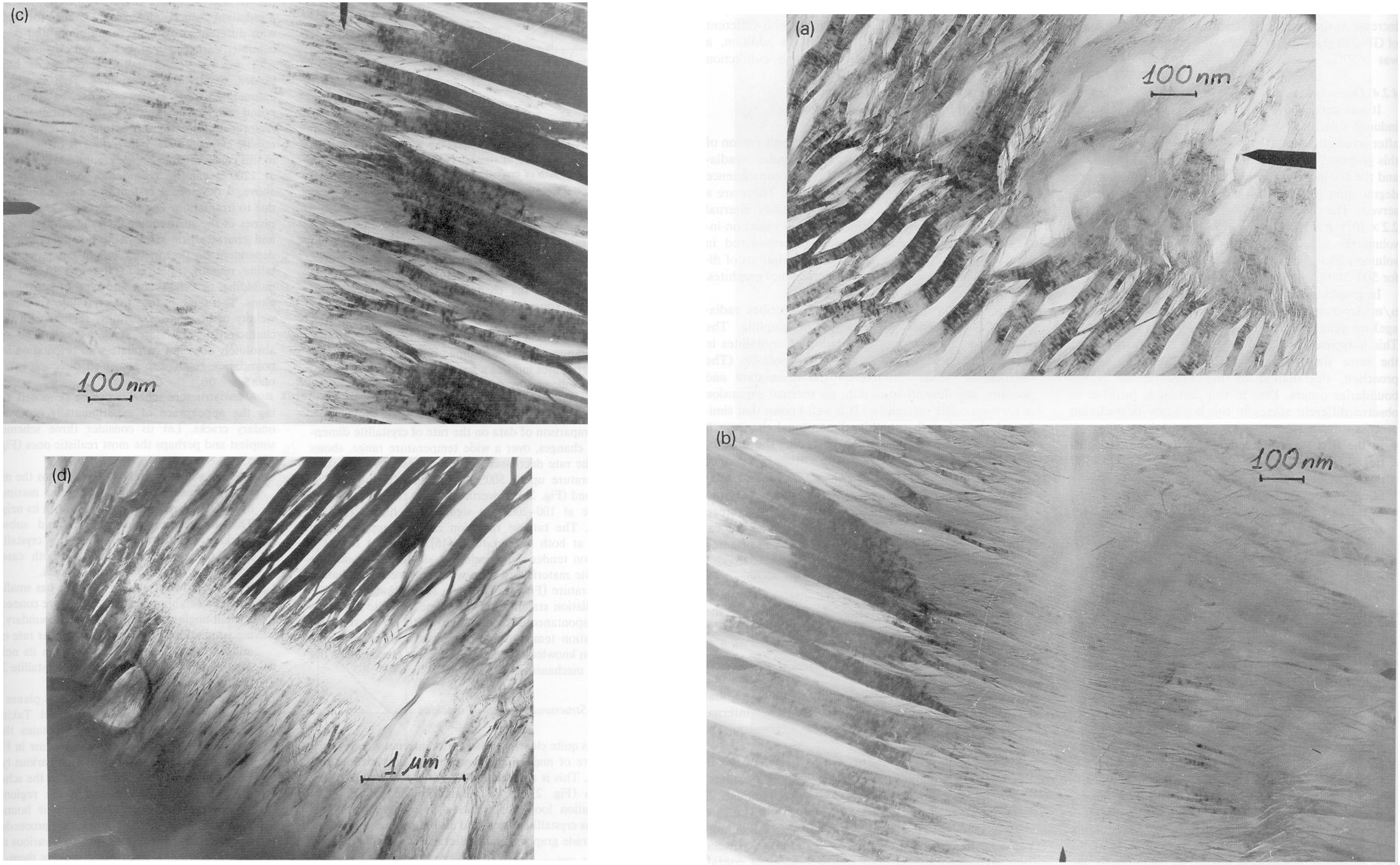
Temperature dependence of critical neutron fluence value F_{cr}



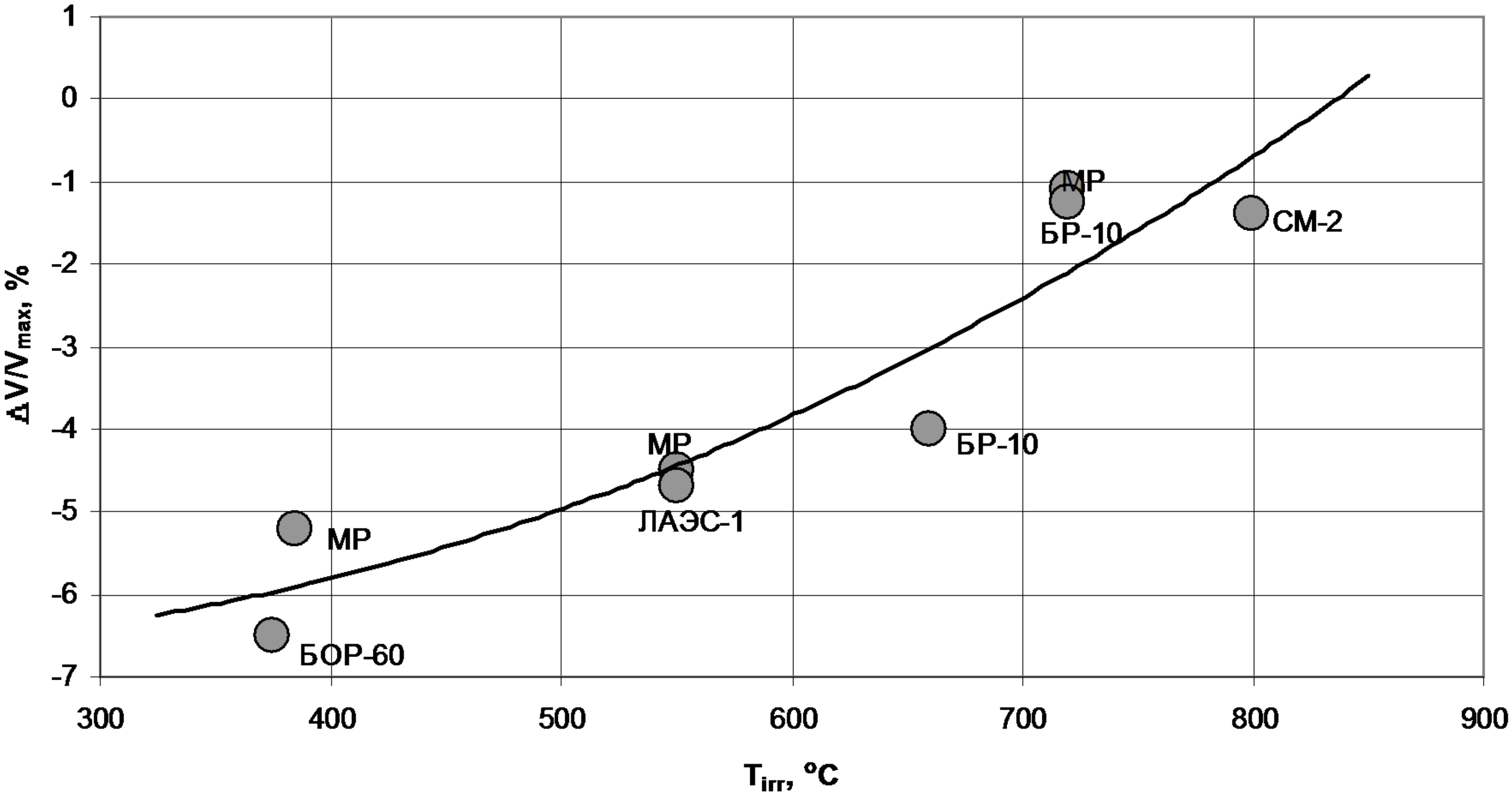
Relative form change of differently heat treated pyrographite samples depending on irradiation temperature



GR-280 graphite degradation kinetics under irradiation



Dependence of GR-280 graphite volumetric changes on irradiation temperature

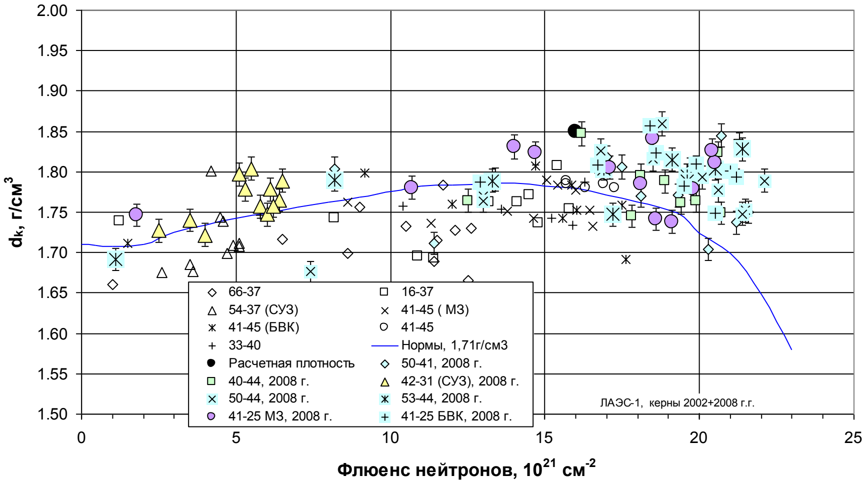


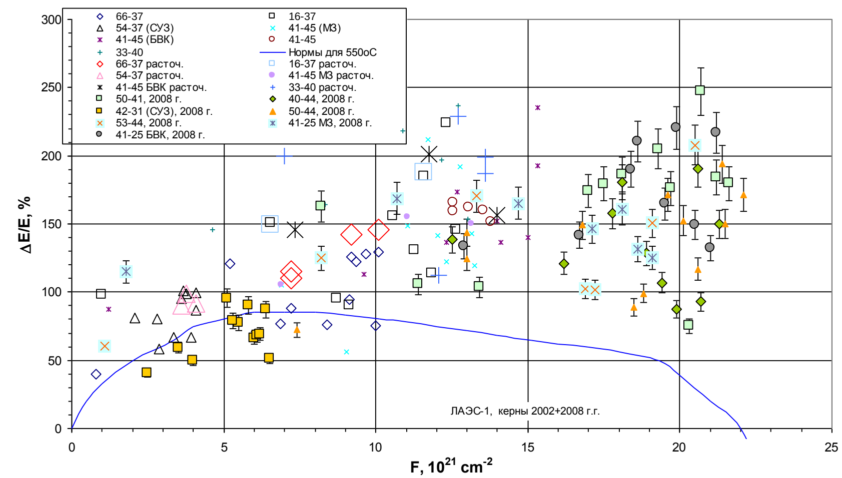
Maximum graphite shrinkage F_{max} to F_{cr} ratio

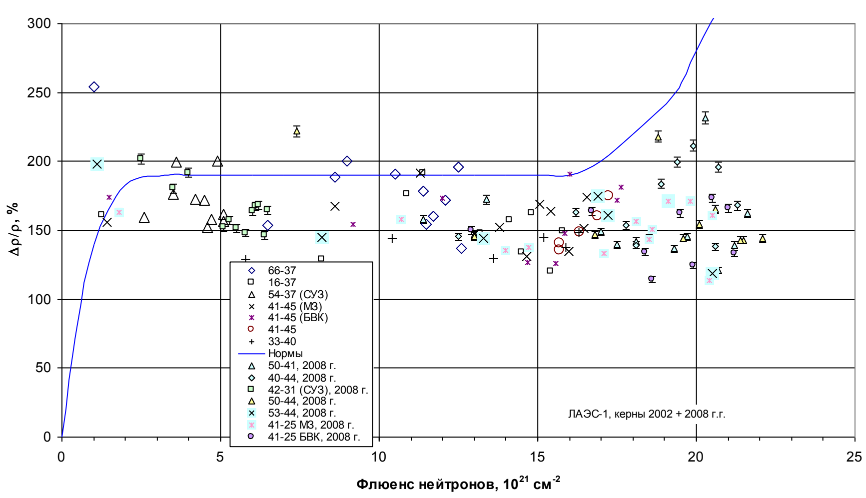
Reactor	T_{reg}, °C	$\frac{F_{кр}(\Delta V/V=0)}{F(\Delta V/V_{max})}$	Neutron flux density, φ, neutron/cm²·s
MR	550	1.5	10^{14}
BR-10	720	1.5	10^{15}
SM-2	800	1.7	2.10^{14}

Average = 1.55

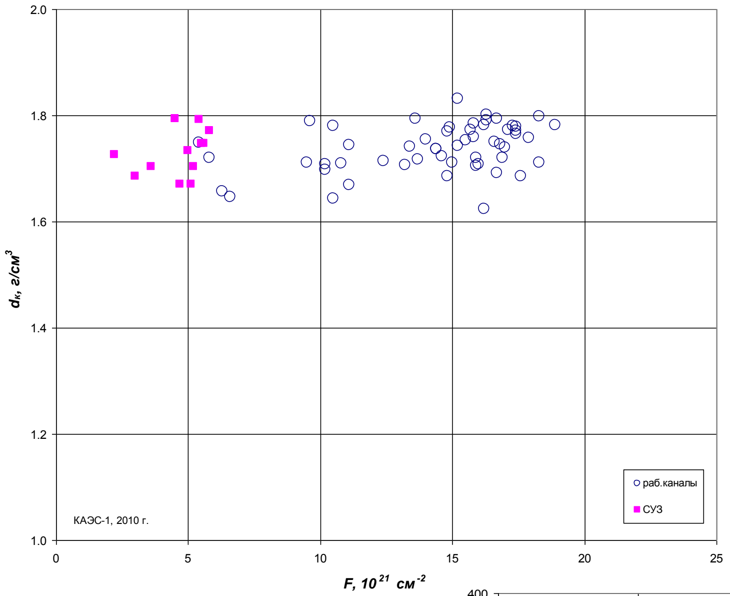
Change in properties of Leningrad-1 graphite kernels

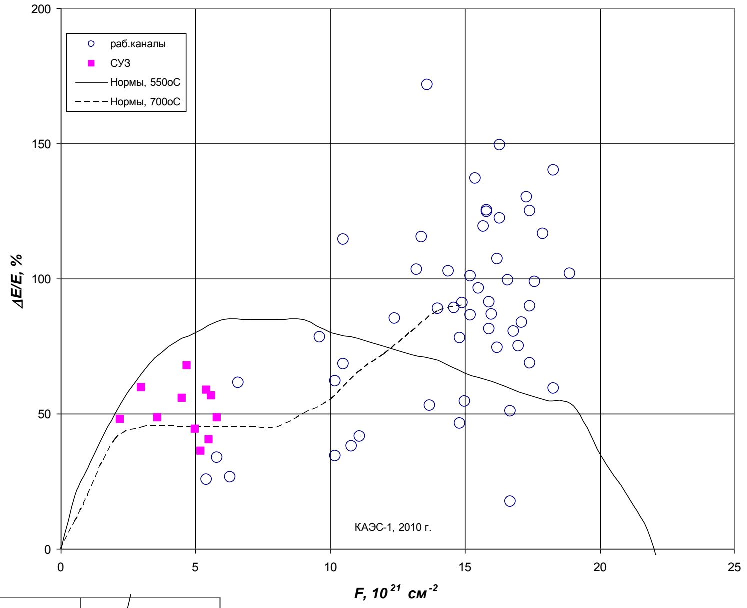


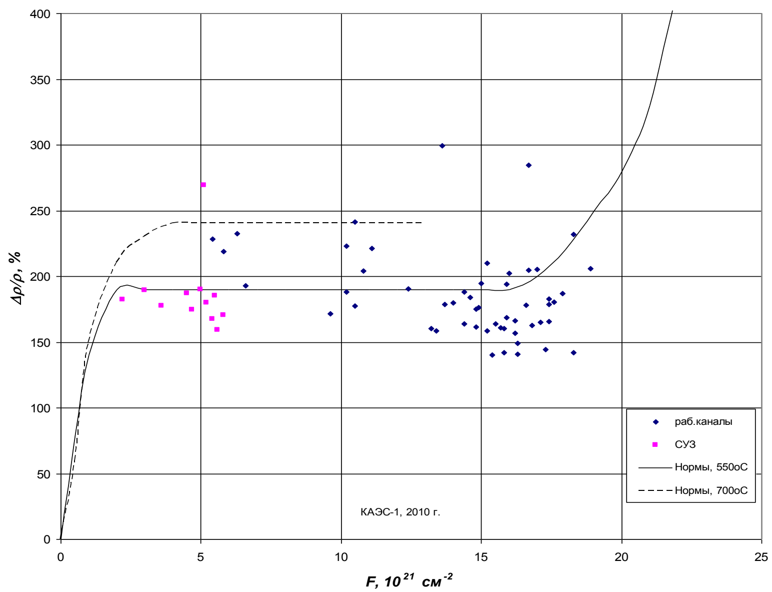




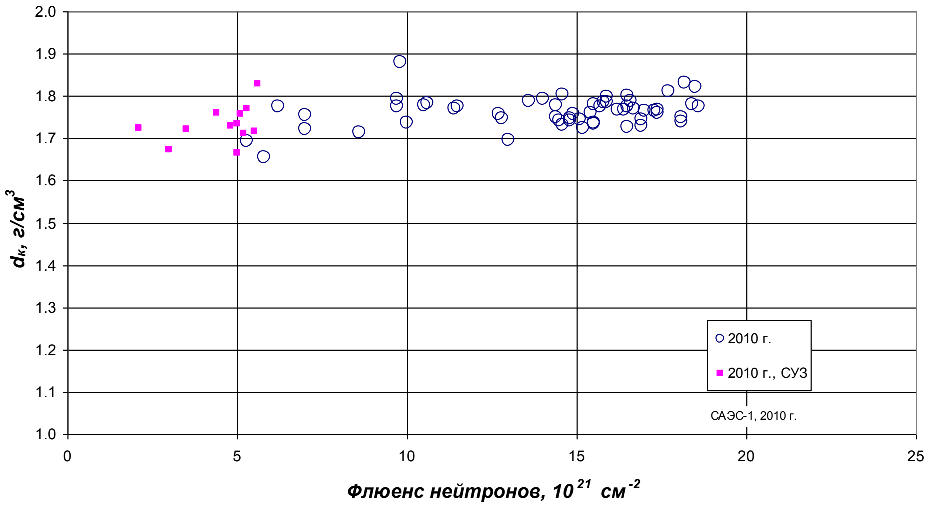
Change in properties of Kursk-1 graphite kernels

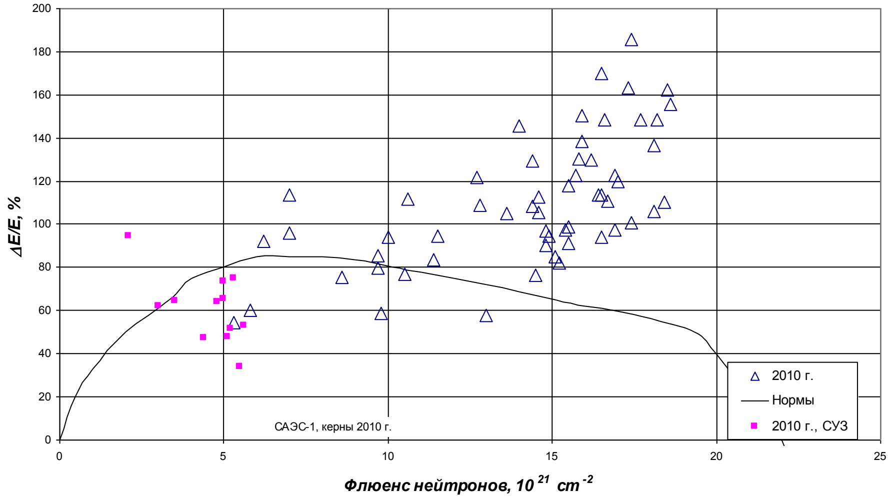


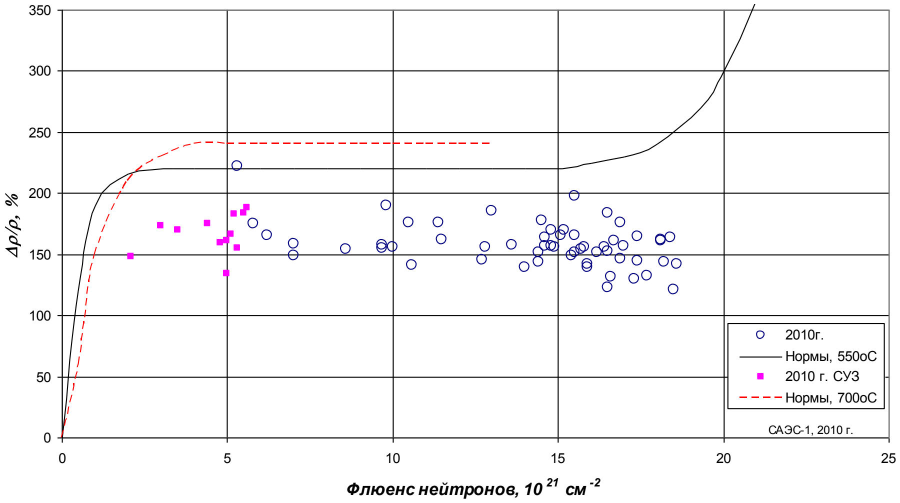


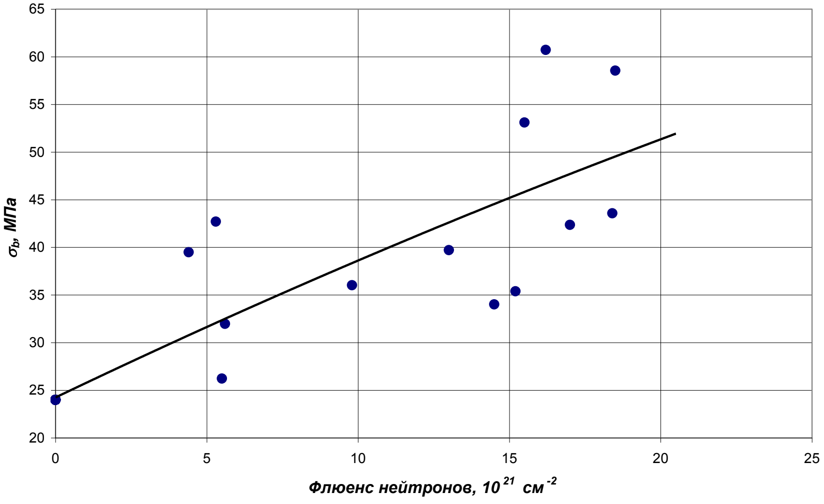


Change in properties of Smolensk-1 graphite kernels









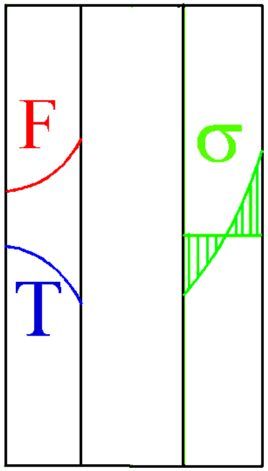
Conclusions and recommendations

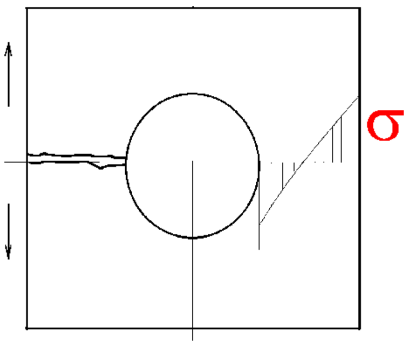
The study of properties of kernels taken from stacks of different reactors has allowed justifying the increase in F_{cr} value (which turned out to be substantially greater than the F_{cr} value obtained at samples) that, in turn, allowed justifying the safe operation of the reactors during the extended life period.

The analysis of operating conditions of the graphite stacks of different reactors has necessitated the power unit-tailored life extension measures.

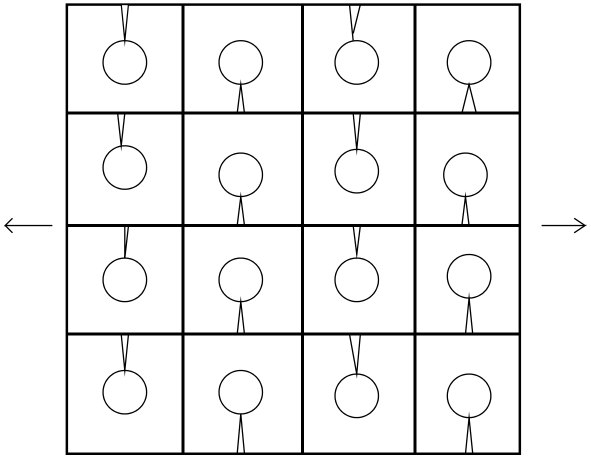
Criterion of graphite brick cracking and graphite column distortion

Distribution of temperature and neutron fluence in a graphite brick. Stresses and opening of longitudinal crack

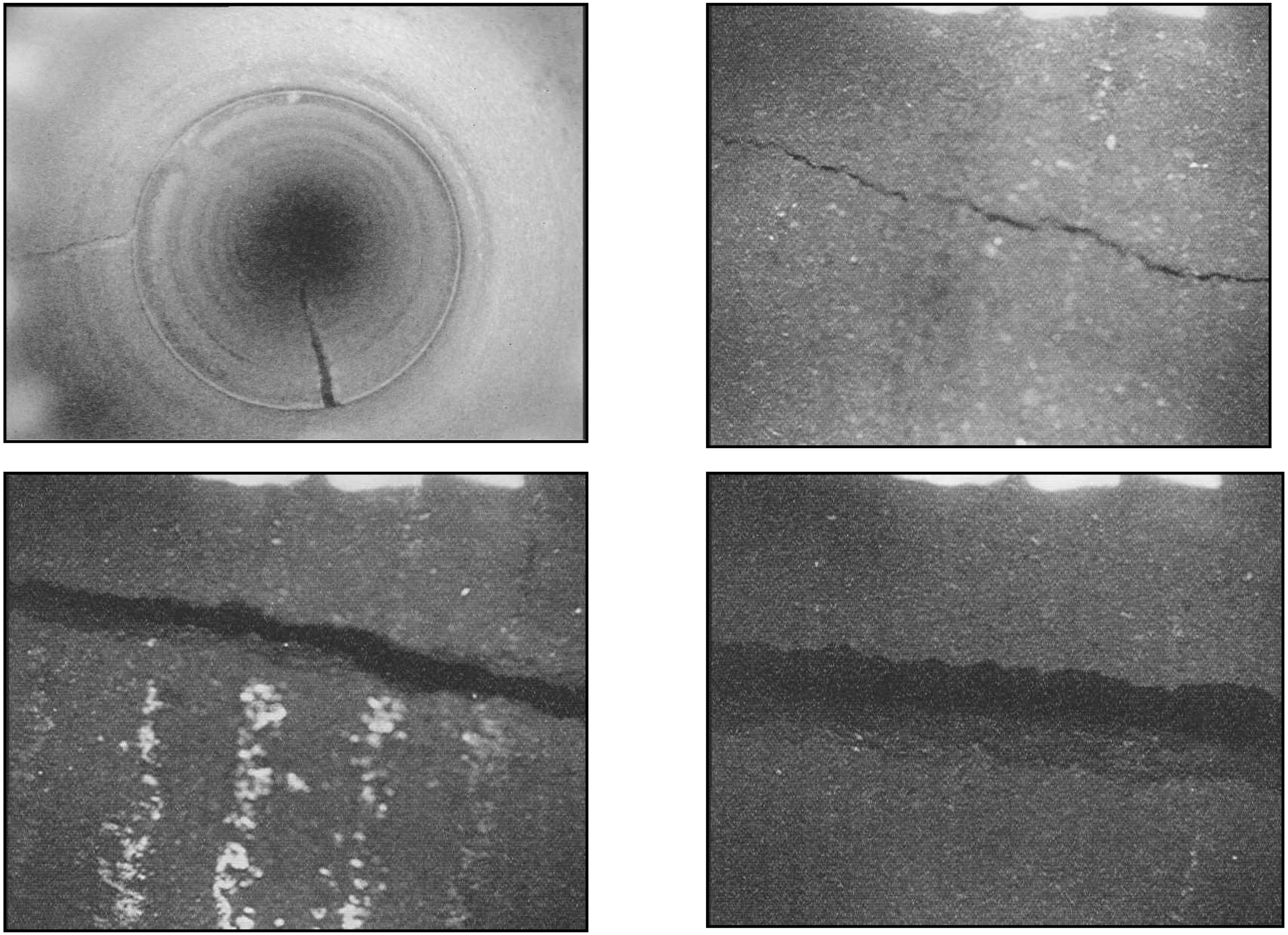




Graphite stack deformation due to crack opening

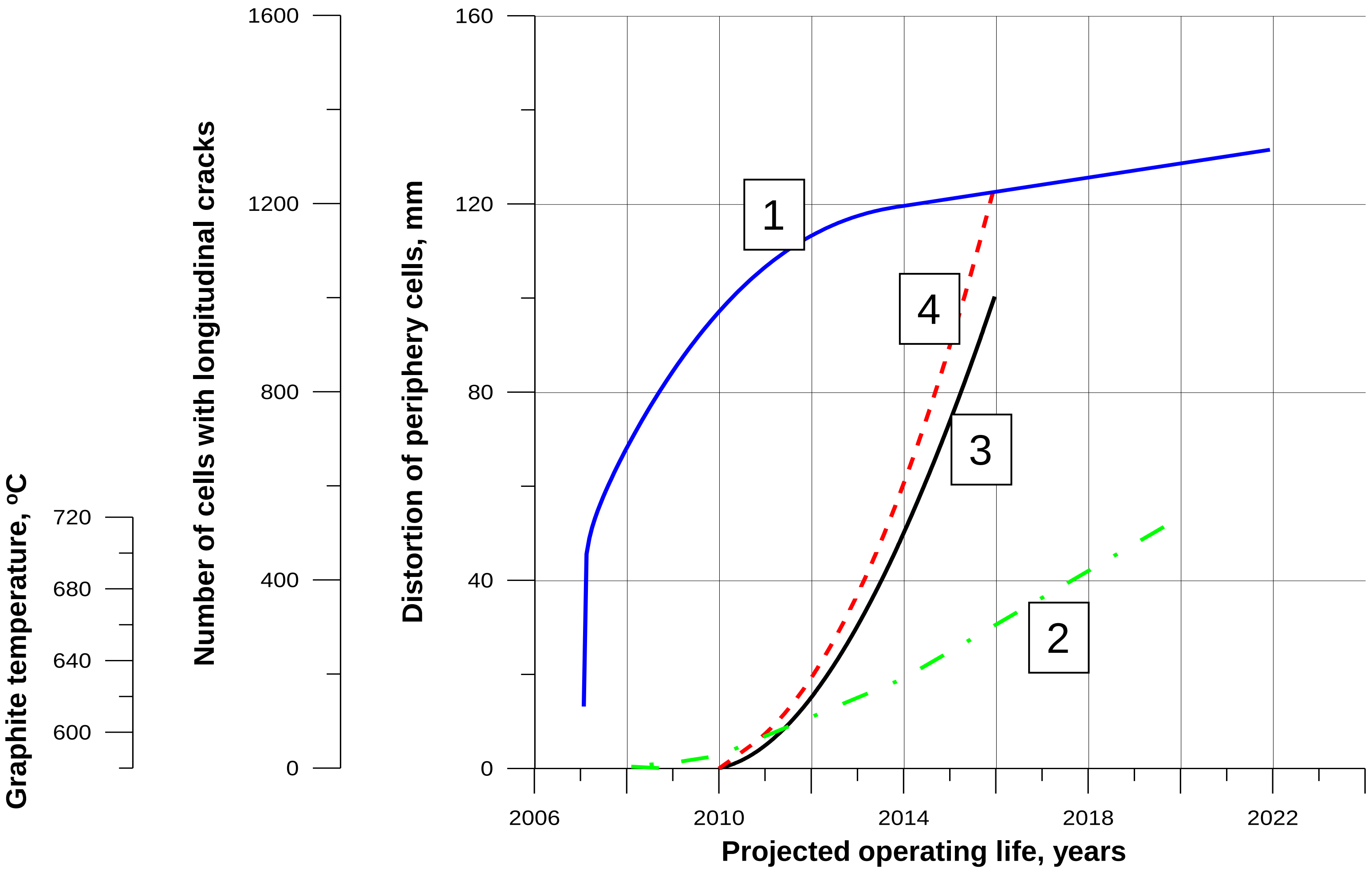


Cracks in graphite bricks. Visual examination at Leningrad-1 in 2008



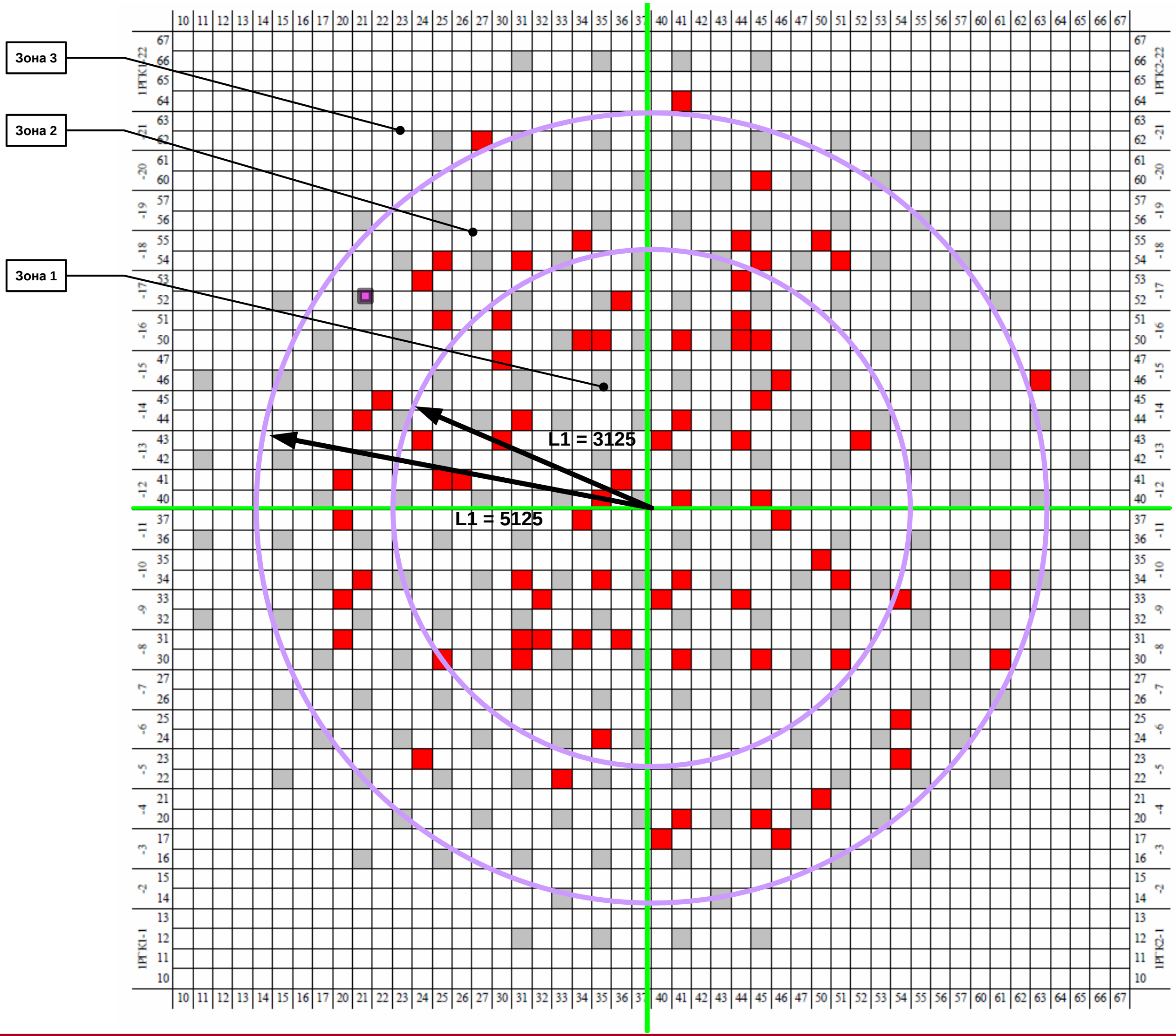
Cracking projection for Leningrad-1 stack

(power increment ~ 600 MW*day/year)



1-Cracking; 2-Temperature; 3-Sagging; 4-Sagging (given temperature growth)

Location of distortion zones of Leningrad-1 graphite columns; stack examination in 2011.



Conclusions

The possibility of stack operation under the accelerated form change has been confirmed, provided there is a continuous monitoring of the stack geometry and graphite sampling (kernels).

To reduce the graphite column distortion rate (which is the main criterion that limits the stack operation life under massive graphite brick cracking), it is necessary to:

- further verify calculation methodologies aiming at removing conservatism of the calculations;
- determine conditions of optimal operation of bricks (to be done by Rosenergoatom together with the Chief Designer and Scientific Supervisor.