Joint Institute for Nuclear Research
Frank Laboratory of Neutron Physics

Some problems on the dynamics of the IBR-2M reactor

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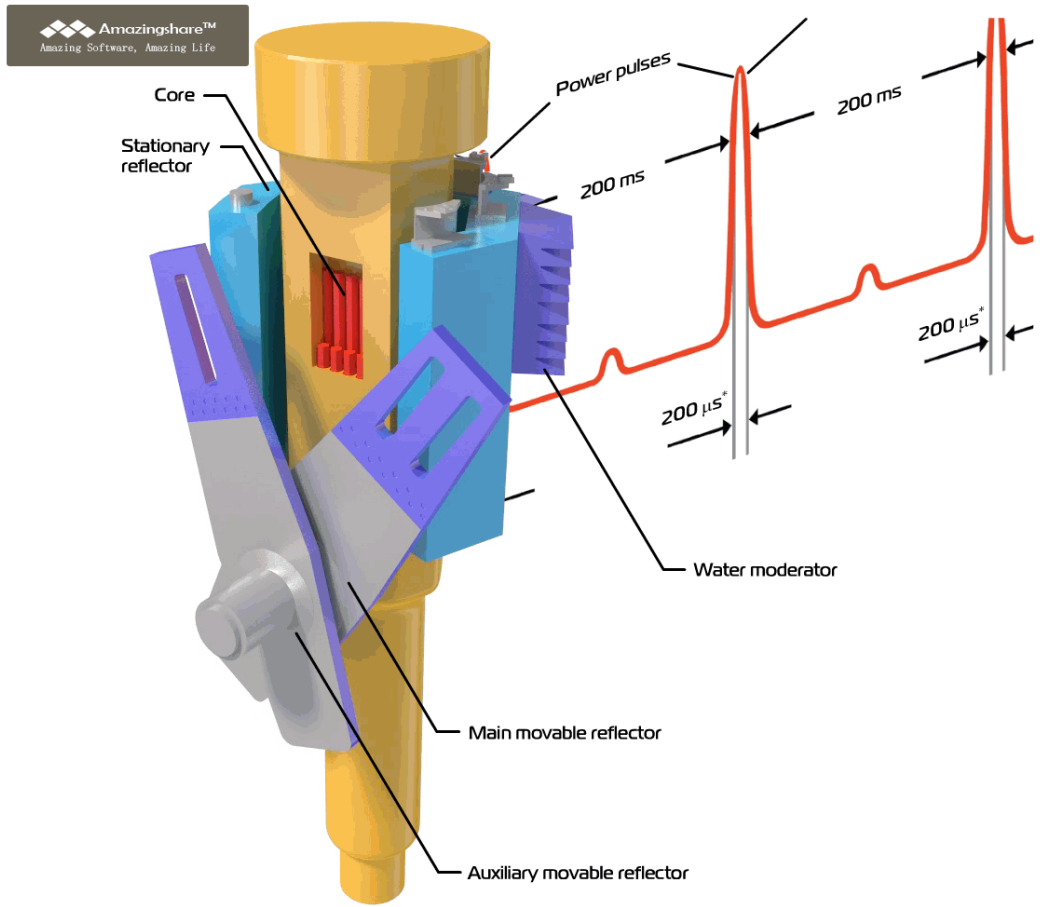
Brief description of the IBR-2M reactor

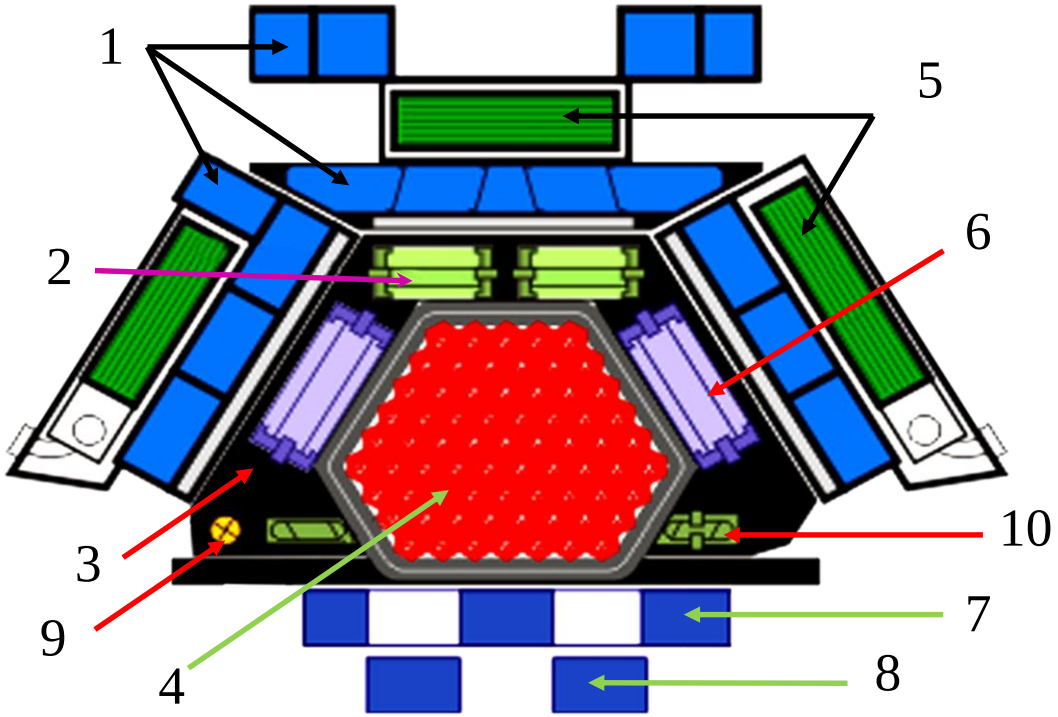


http://flnph.jinr.ru/en/facilities/ibr-2

IBR-2M REACTOR PARAMETERS

Average power, MW	2
Fuel	PuO_2
Number of fuel assemblies	69
Pulse repetition rate, Hz	5
Pulse half-width, μs:	
fast neutrons	200
thermal neutrons	340
Rotation rate, rev/min:	
main reflector	600
auxiliary reflector	300
MMR and AMR material	nickel + steel
Thermal neutron flux density from moderator surface:	
- time average	~ 10^{13} n/cm^2·s
- burst maximum	~ 10^{16} n/cm^2·s

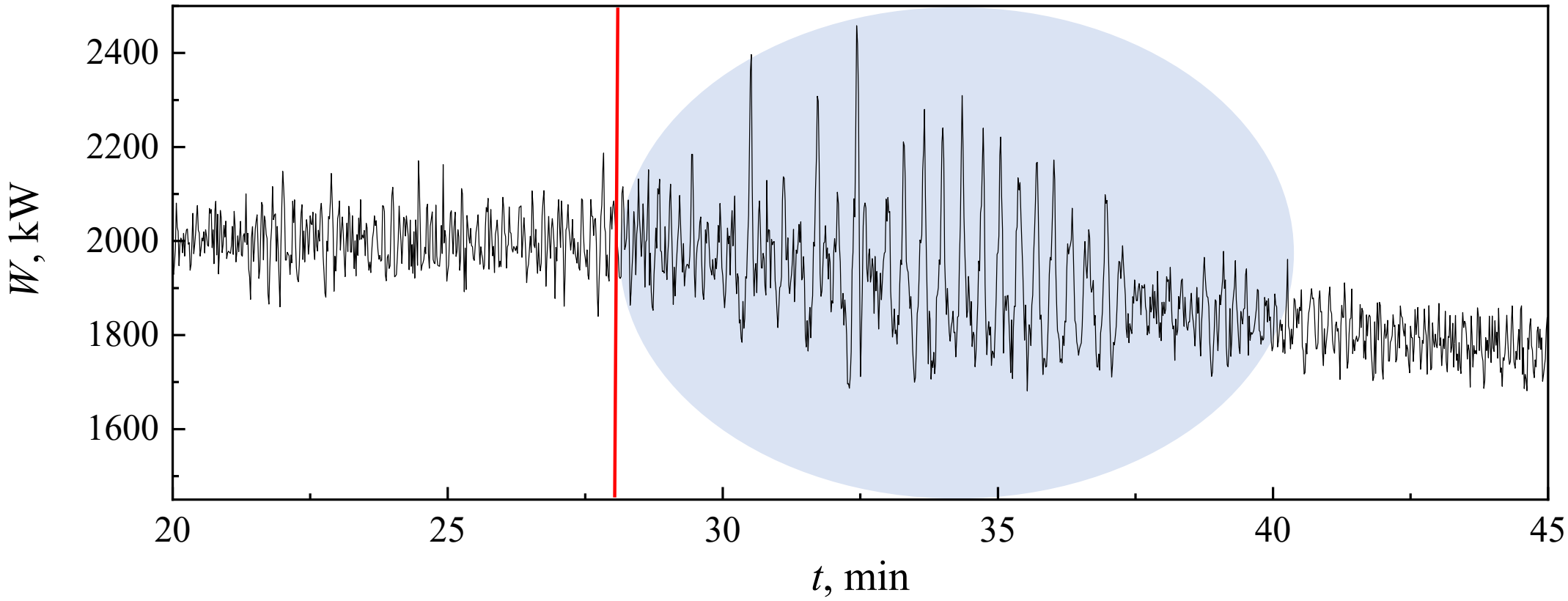
Brief description of the IBR-2M reactor



Cross-sectional view of the
IBR-2M reactor core

1 – grooved water moderators,
2 – emergency protection rods,
3 – stationary reflector,
4 – fuel,
5 – cold moderator,
6 – compensation rods,
7 – main movable reflector,
8 – auxiliary movable reflector,
9 – automatic regulator,
10 – hand operated regulator

Power fluctuation

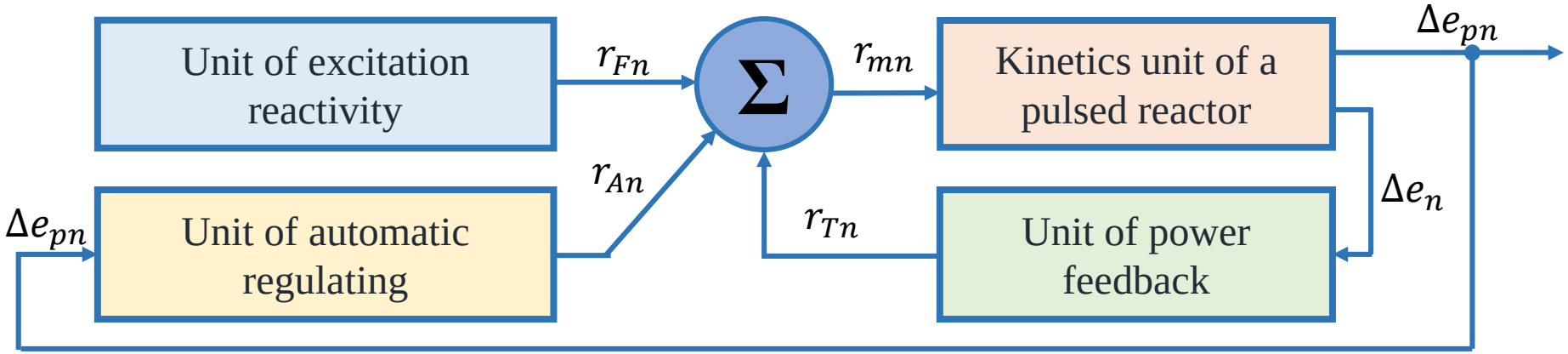


Power fluctuation when the average power of the reactor decreases from 2 MW to 1.7 MW

Purpose of the work

The aim of this work is to study power feedback and its influence on the stability of the IBR-2M reactor by modeling and experimentally

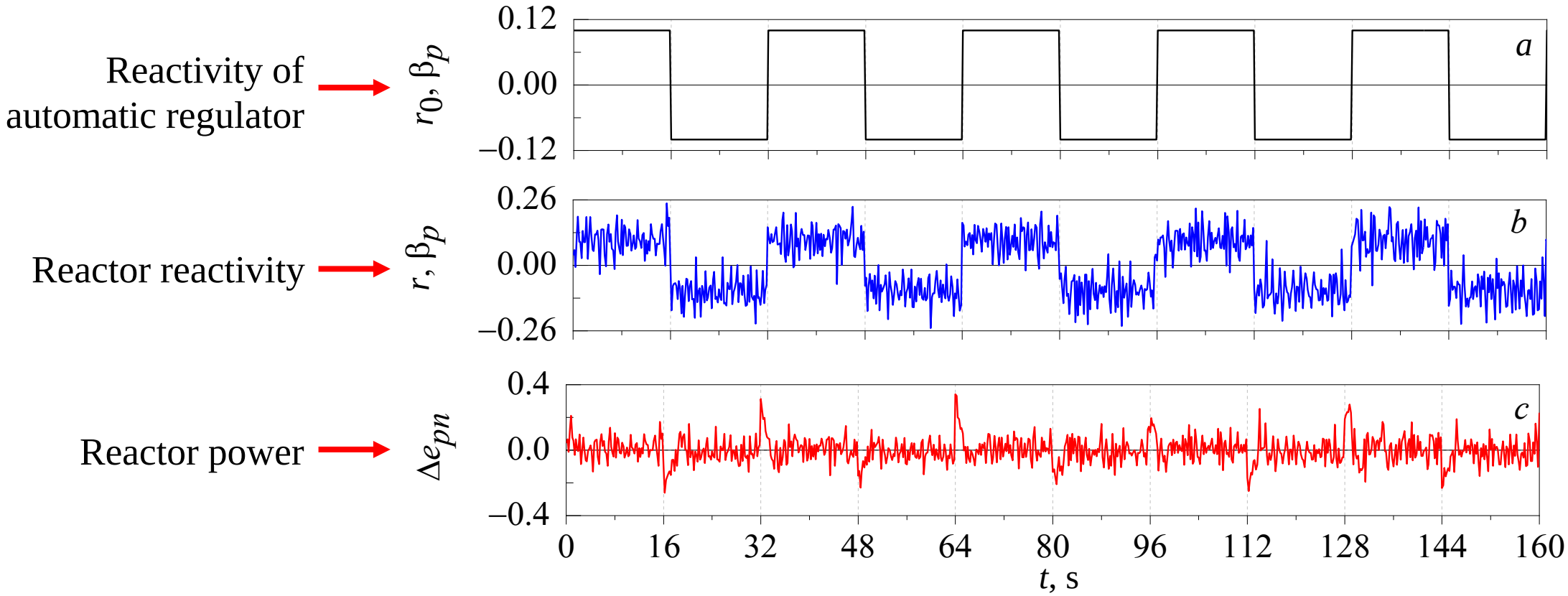
Model Dynamics of the IBR-2M



Block-scheme of the IBR-2M reactor with automatic regulating

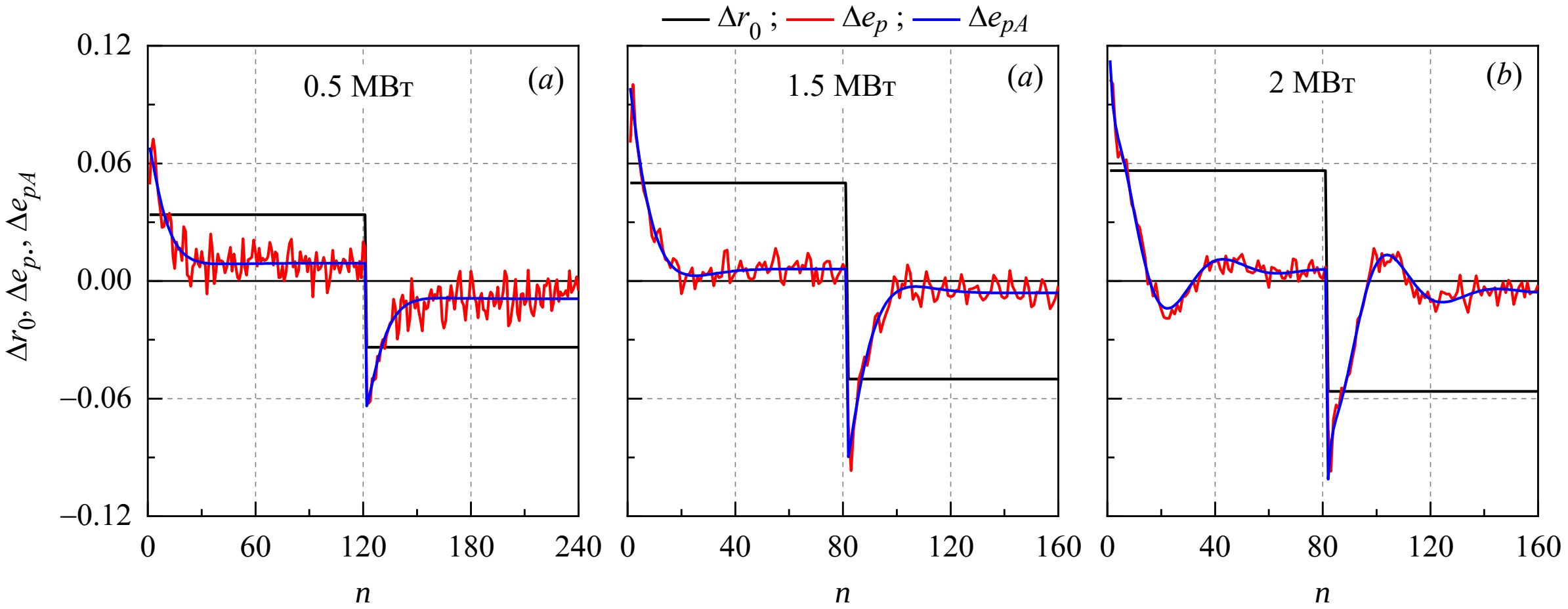
r_{mn}	the total reactivity of reactor ($r_{mn} = r_{Fn} + r_{Tn} + r_{An}$),
r_{Fn}	the external reactivity,
r_{Tn}	the power feedback reactivity,
r_{An}	the automatic regulating reactivity,
Δe_{pn}	the deviations of energy power pulses from its basic value,
Δe_n	the deviation of total energy of a period pulses from its basic value.

Square oscillation of the reactivity for estimation of power feedback



Reactivity AR r_0 as a square wave with amplitude $0.1\beta_p$ and period 32 s (a), total reactivity with noise r (b) and relative deviation of the power pulse energy Δe_{pn} (c)

Model approximation of power transient processes

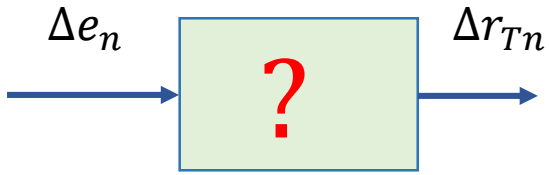


Transient processes caused by square oscillation reactivity Δr_0 (*1*) of the IBR-2M reactor at average power of 0.5 MW (*a*), 1.5 MW (*b*) and 2 MW (*c*). Δe_p – the deviation of the energy power pulse and n – number of power pulses

Estimation of PFB structure of the IBR-2M

A good approximation of the calculated transients to those recorded for the entire range of average powers from 0.5 to 2 MW gives the PBF model, presented in the form of three linear aperiodic links.

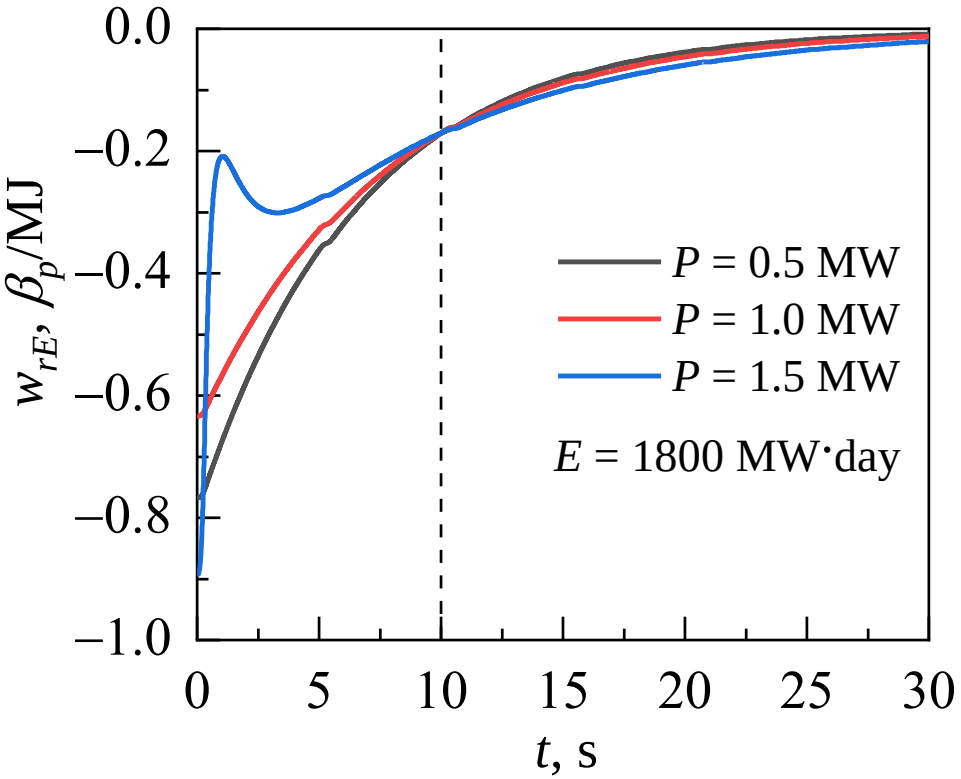
$$\Delta r_{Tn} = \sum_{j=1}^{3} \Delta r_{Tjn} = \sum_{j=1}^{3} \left[\Delta r_{Tjn-1} + \frac{k_{Tj}}{T_{Tj}} \Delta E_{n-1} \right] \exp\left(-\frac{T_p}{T_{Tj}} \right)$$



Unit of a power feedback of the IBR-2M

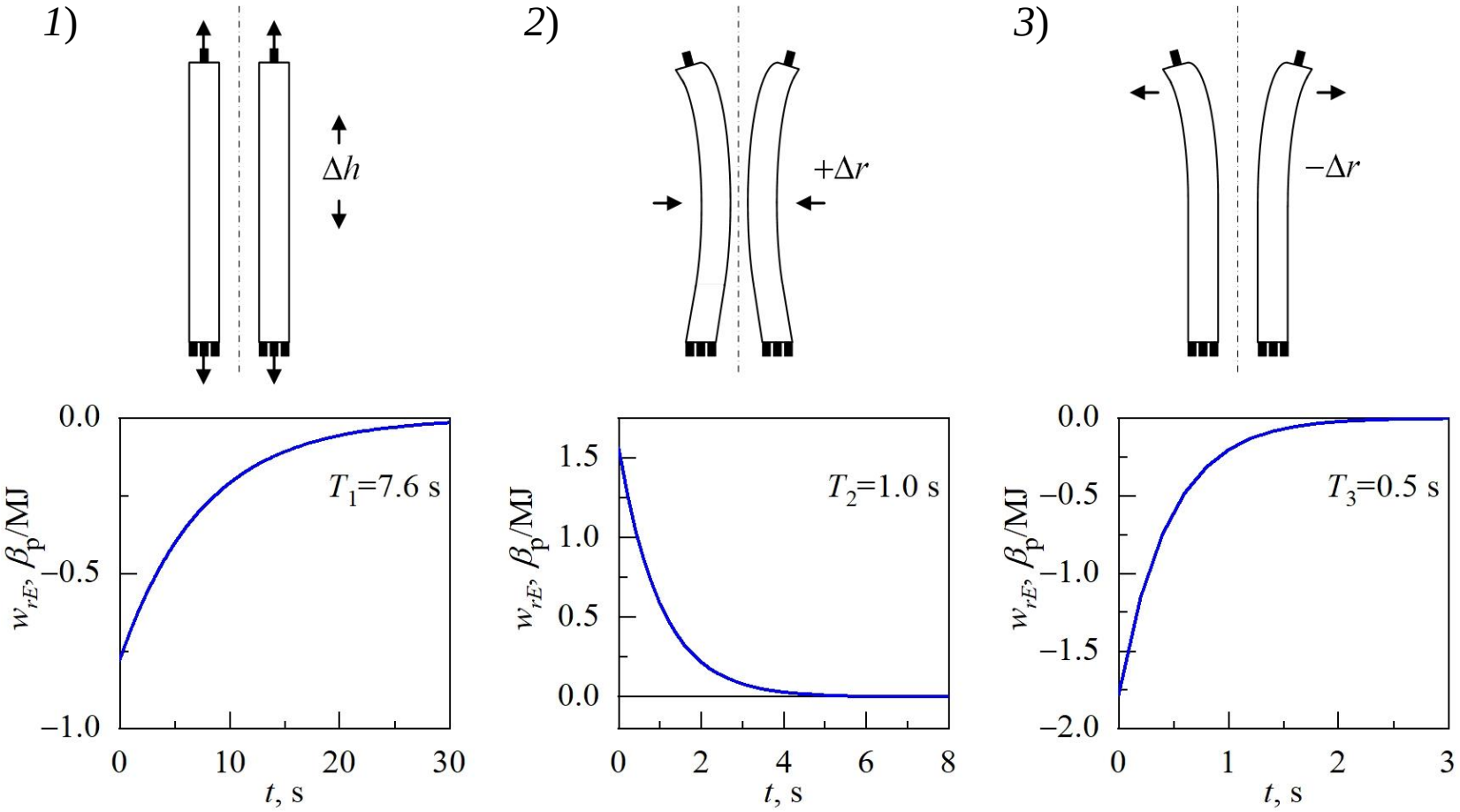
Δr_T	the PFB reactivity,
k_{Tj}	the transfer coefficient of j-th link of the PFB,
T_{Tj}	the time constant of j-th link of the PFB,
ΔE	the total energy of power pulse,
T_p	the period of power pulses (T_p =0.2 s),
j	the number of PFB link (j =1, 2, 3)

Impulse response of a power feedback of the IBR-2M



Impulse response of a power feedback of the IBR-2M reactor with energy production of 1800 MW·day (2021) at various average power (0.5, 1.0 and 1.5 MW) and a coolant flow rate of 100 m^3/h

Impulse response of a power feedback of the IBR-2M



An example of the effect of individual components of the IBR-2M power feedback:

1 – the axial fuel expansion,

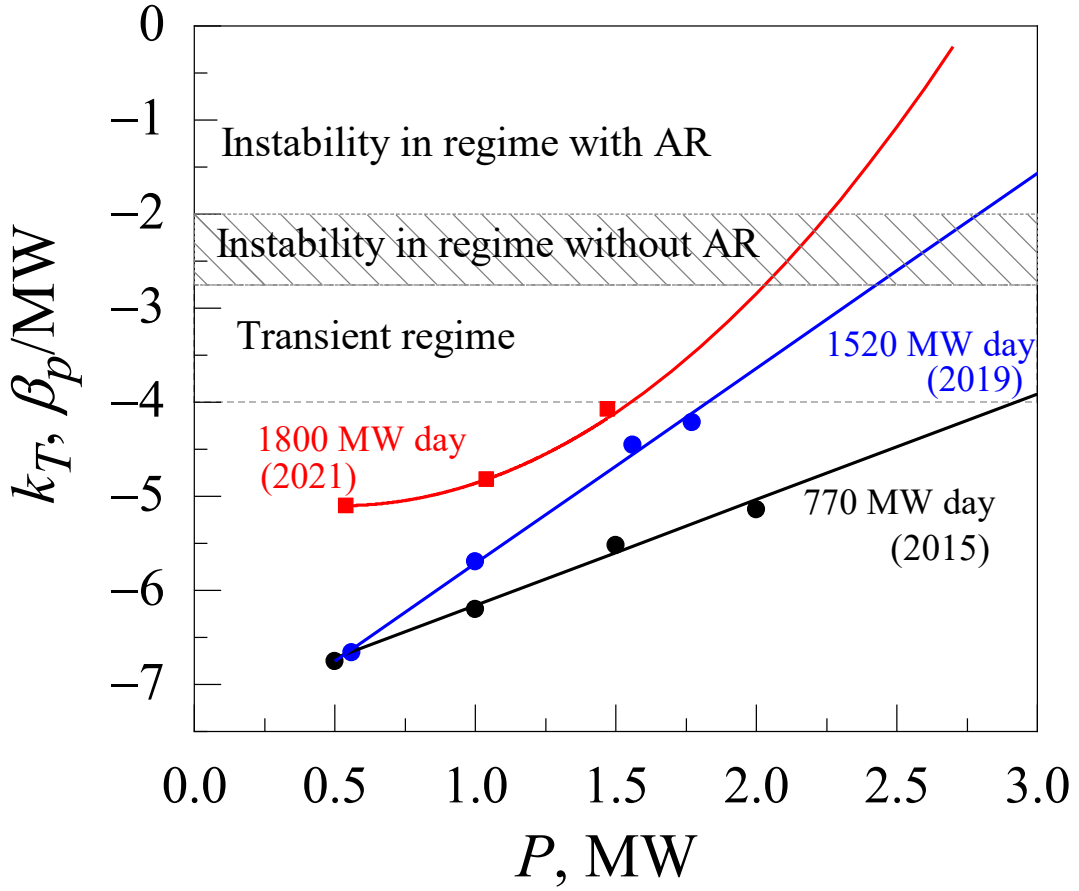
2 – the bending of fuel assemblies towards the center of the core,

3 – the bending of fuel assembly's periphery of the core.

Below – the corresponding impulse responses of the power feedback components with time constants

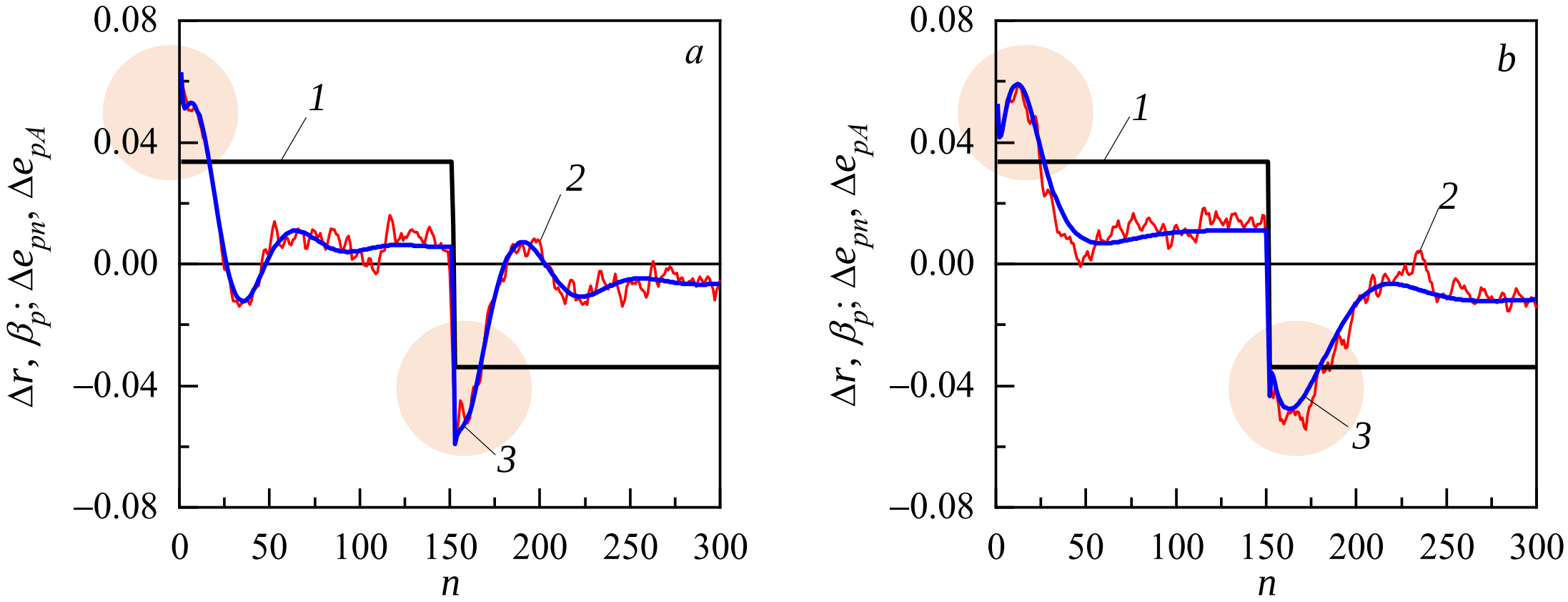
Total transfer coefficient of the power feedback

$$k_T = \sum_{j=1}^{3} k_{Tj}$$



Stability boundary for the IBR-2M depending on the reactor average power and total energy output.

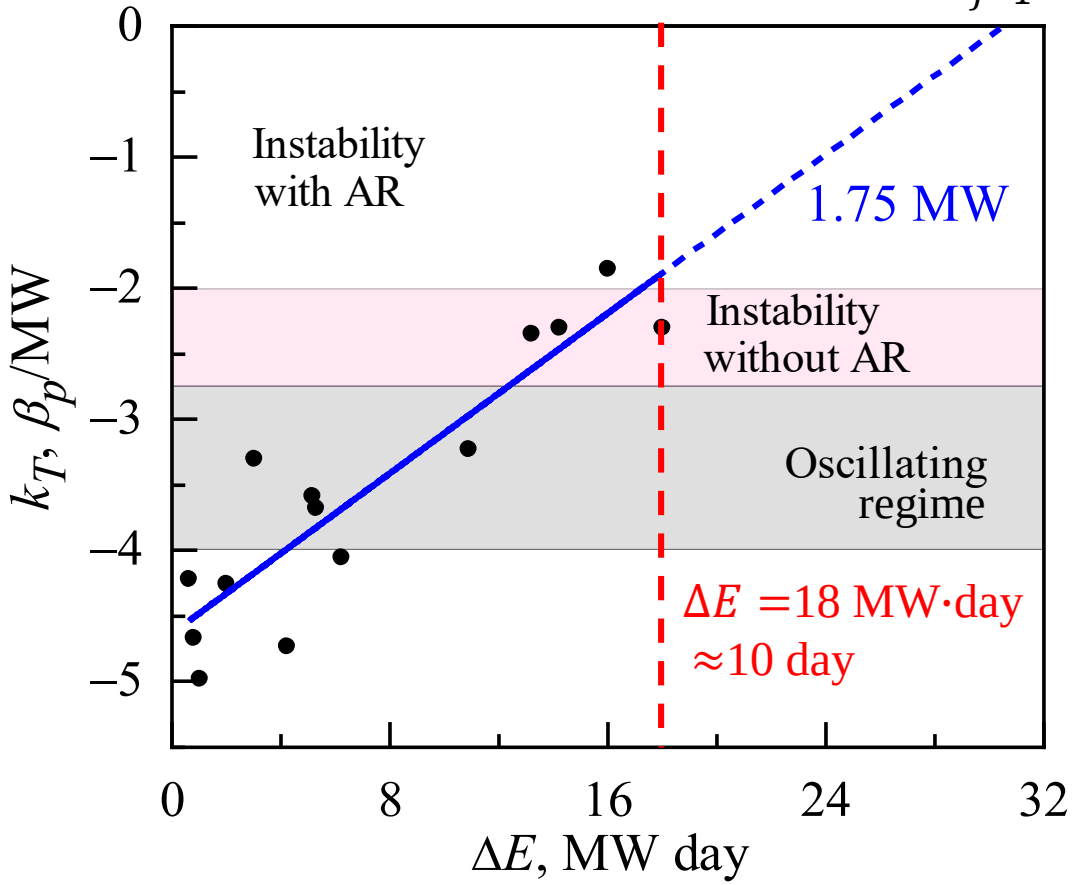
Model approximation of transient processes in a reactor cycle



Transient processes caused by square oscillation reactivity Δr_0 (*1*) of the IBR-2M reactor at average power of 1.75 MW corresponding to start (*a*) and end (*b*) of cycle.
Δe_p – the deviation of the energy power pulse (*2* – experimental, *3* – modeling), n – number of power pulses

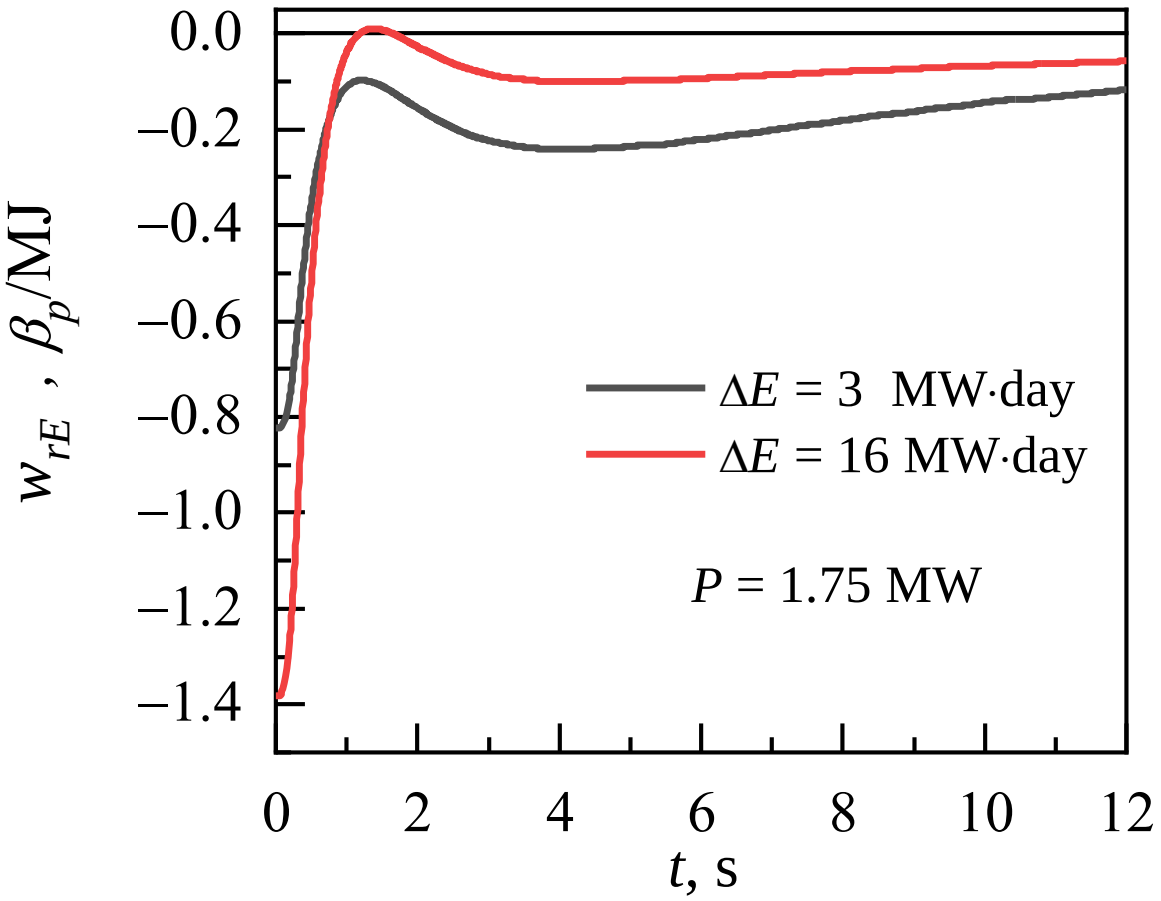
Total transfer coefficient of the power feedback during a reactor cycle

The transfer coefficient of the PFB $k_T = \sum_{j=1}^{3} k_{Tj}$



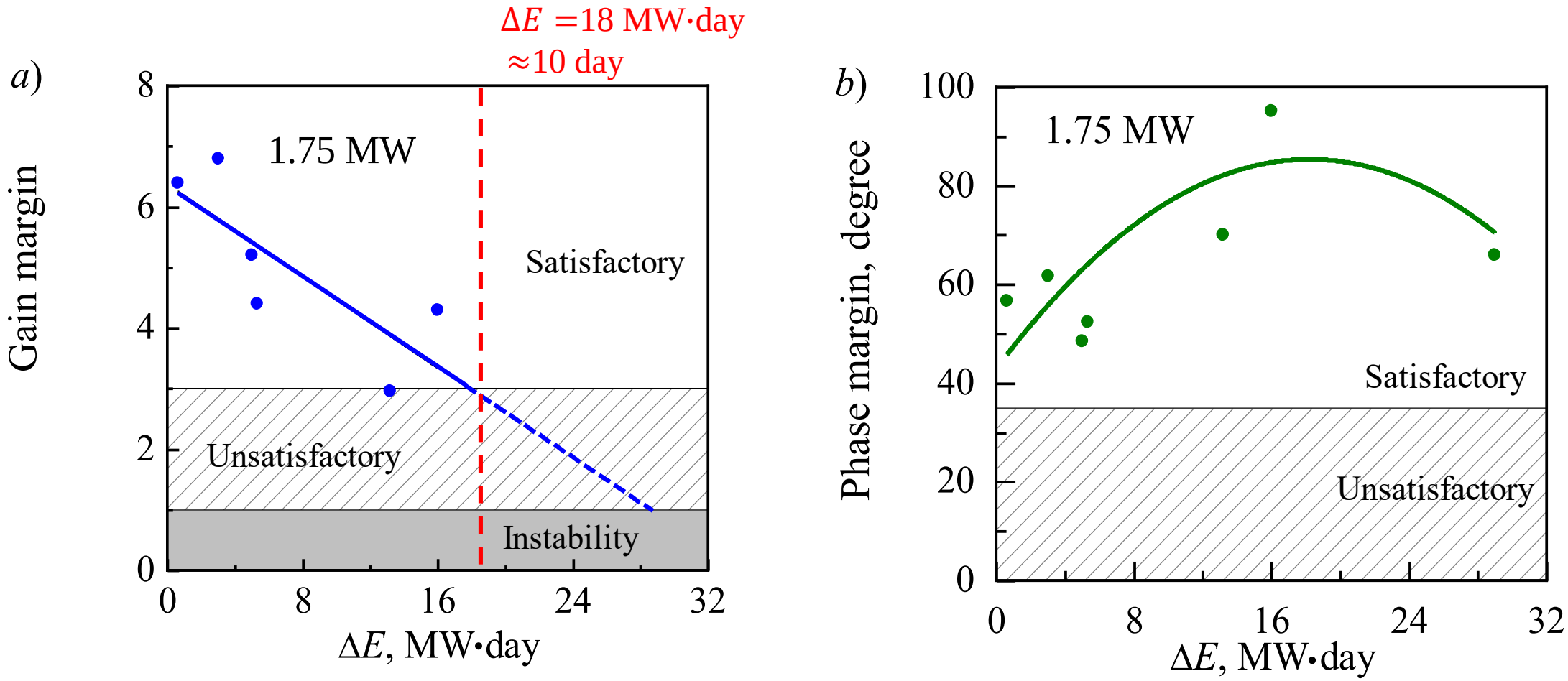
Stability boundary of IBR-2M reactor at average power of 1.75 MW dependence on energy output during the cycle

Impulse response of a power feedback of the IBR-2M in a reactor cycle



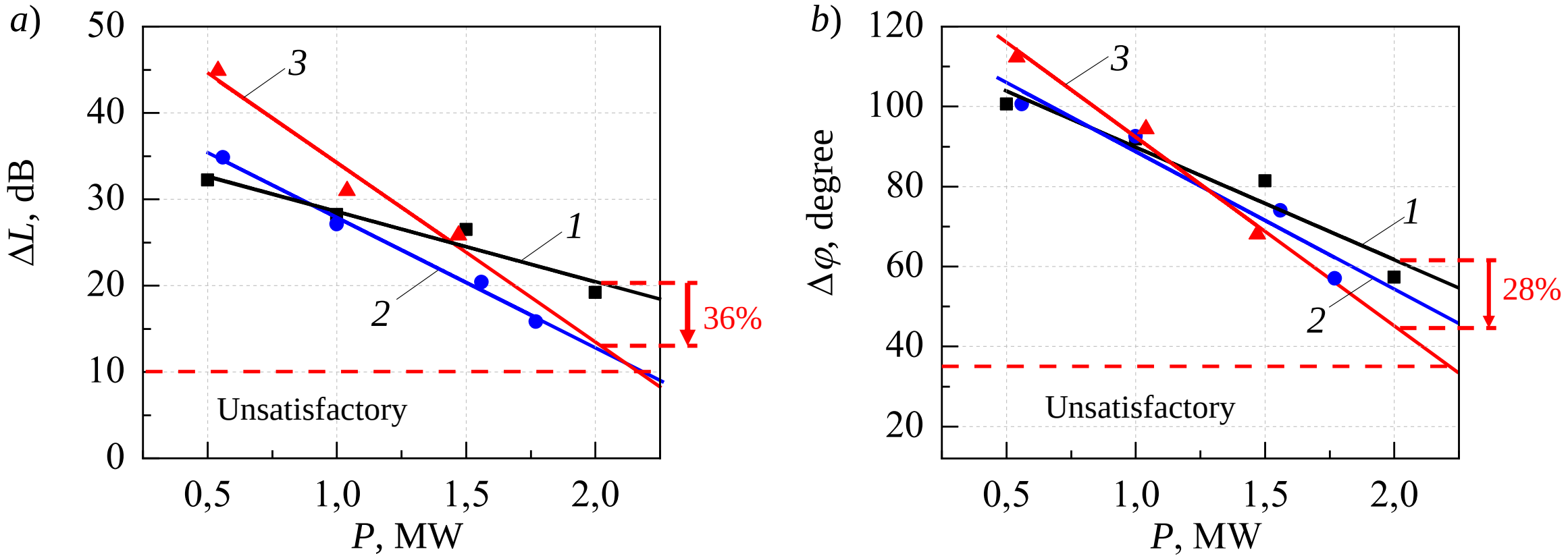
Impulse response of a power feedback of the IBR-2M reactor at an average power of 1.75 MW and a coolant flow rate of 100 m^3/h during the cycle №3 (2019).

Stability margins of the IBR-2M reactor at self-regulating regime



Stability margins of gain (*a*) and phase (*b*) dependence on the energy output of the IBR-2M reactor in the cycle.

Stability analysis of the IBR-2M in a self-regulating regime



Stability margins (gain - *a* and phase *b*) dependence on the average power and energy output (***1* – 770**, ***2* – 1520** and ***3* – 1800 MW·day**) of the IBR-2M during the reactor operation.

Conclusions

- On the basis of experimental and modeling studies carried out in the IBR-2M reactor, it is shown that this reactor has limitations on stability.
- Degradation changes in the core lead to a **strong weakening of the fast power feedback**, which causes a deterioration in the reactor dynamics.
- In the IBR-2M there are **cyclic changes in the dynamics** during the reactor cycle (12 days operation).
- The given data allow us to choose the operating modes of the reactor.
- These measures increase the safety and reliability of the reactor.

Acknowledgements

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Thank you for your attention!