ANALYSIS OF NEUTRON BURSTS IN REACTOR WWR-M BY MEANS OF PHASE TRAJECTORIES

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Certain nuclear reactor quality providing its inner selfsecurity is investigated in this work. Influence of negative temperature effects on free rise-up of a pile in point model approximation for linear reactivity increasing is considered. The applicability of this model for small multiplying sistems (WWR-M and PIK types for example) is well found with restrictions to positive reactivity value $\rho_+ < 4\beta_{ef}$ and steady rate reactivity increasing:

$$\frac{d\rho_+}{dt} = \gamma > \beta_{ef}\lambda_{ef} = 3.23\cdot 10^{-3}\, s^{-1}$$

for WWR-M.

The model for investigation is described by the following equations:

$$\frac{dn}{dt} = \frac{\rho(t)-\beta}{l} + \frac{\beta}{l}\, n_0;\ \frac{d\rho}{dt} = \gamma - \Gamma\cdot (MC_p)^{-1}\cdot (n - n_0);\ n(0) = n_0;\ \rho(0) = 0. \tag{1}$$

The analisys of this model was reduced to study of phase trajectories in the appropriate manner in the chosen phase space. The power n is represented in the form of $n = n_0 \exp F(\tau)$, and as phase variables were taken: $dF/d\tau = v$, and $dv/d\tau$, then (1) is transformed into:

$$\frac{dF}{d\tau} = v;\ \frac{dv}{d\tau} = \frac{1}{\varepsilon}\,[\,(1+\delta) - \delta\exp F - v\beta\exp(-F)\,];\ \varepsilon = \gamma l;\ \delta = \Gamma n_0/\gamma MC_p. \tag{2}$$

Here ε, δ — are dementionless key-parameters of the sistem. Owing to automodel character of the sistem (2) its phase trajectory is described by a single equation;

$$\frac{dv}{dF} = \frac{1}{\varepsilon}\left[\frac{1+\delta-\delta\exp F}{v} - \beta\exp(-F)\right];\quad \left.\frac{dv}{dF}\right|_{\substack{F=0\\ v=0}} = \infty. \tag{3}$$

It was investigated by the methods of isoclines [1].

It is found, that:

1. There exists $\lim\limits_{t\to\infty} n(t) = n_\infty$ stipulated by equillibrium between the introduced positive reactivity γt and negative temperature effects:

$$n_\infty = n_0 + MC_p\cdot\gamma\Gamma^{-1}. \tag{4}$$

It is shown by the particular single point of the phase portrait, namely stable focus $F_0 = \ln(1+\delta)/\delta$; $v = 0$.

2. The instantaneous power undergoes aperiodic falling oscillations and besides in the maximum of the first flach it is expressed as a solution x_m of the transcedental equation:

$$\frac{1+\delta}{\delta}\cdot x = e^x - 1. \tag{5}$$

The solution exists only when $\delta > 0$.

3. Exact relationship between the energy E_b and longitude t_b of the first burst is found to be:

$$E_b = n_0\cdot\frac{1+\delta}{\delta}\cdot t_b.$$

Therefore the mean power of the first burst is simply:

$$\bar{n} = n_0\cdot\frac{1+\delta}{\delta} = n_0 + MC_p\cdot\gamma\Gamma^{-1} = n_\infty. \tag{7}$$

But this equality is nontrivial and it cannot be obtaned by numerical methods.

4. Fasility is subcritical to the burst finishing and what's more for the first one;

$$\rho(t_b) = -\sqrt{2\gamma l_{ef} x_m}\cdot (2 - x_m^{-1}\cdot\ln 4\, x_m/\delta) \approx -\rho_+(t_b) = -\gamma t_b. \tag{8}$$

5. The expressions of E_b and n_{max} somewhat differ from the same in the Nordheim-Fucses model:

$$E_b = \frac{2MC_p}{\Gamma} \frac{|\rho(t_b)|}{2 - (1/x_m)\ln 4\, x_m/\delta}; \quad n_{max} = \frac{MC_p}{\Gamma l} \cdot \frac{|\rho(t_b)|^2}{[2 - (1/x_m)\ln 4\, x_m/\delta]^2}. \tag{9}$$

6. The longitude of neutron burst is determined by means of reactivity increasing velocity γ and effective time of neutron life l_{ef}, but not by thermal parameters Γ and MC_p:

$$t_b \approx \sqrt{\frac{2\, l_{ef}}{\gamma\, x_m}} \cdot \ln 4\, x_m/\delta \tag{10}$$

7. The comparison of our results with numerical ones from [2] and standard sample [3] is given in tables 1—3.

Table1

$\rho_0 = 0.8\%$; $n_\infty = 6.9\ MW$

	N—F	[2]	our
N_{max}, MW	37.8	33	60.4
E_b, MJ	4.2	7	5.3
T, K	55	90	69

Table 2

$\rho_0 = 1.5\%$; $n_\infty = 109.4\ MW$

	N—F	[2]	our
N_{max}, MW	1014	1200	1288
E_b, MJ	20.1	24	22.5
T, K	261	250	293

N—F — calculation by Nordheim-Fuchses model

The accordance with definitions [3] and ours:.

$$V_1 = \frac{\delta}{1+\delta} \cdot \exp x_m; \quad P_x = \sqrt{\gamma(1+\delta)/l}\ t_b; \quad \nu_0 = \frac{\delta}{1+\delta}.$$

Table 3

Comparison n_m and t_b with the same from standard sample [3].

$V(0)$	V_1	$\frac{\delta}{1+\delta}\cdot \exp x_m$	P_x	$\sqrt{\gamma\,(1+\delta)/l}\cdot t_b$
0.5	1.756	2.237	6.385	6.837
0.1	3.715	3.833	7.031	7.680
0.05	4.564	4.623	7.376	7.998
$9\cdot10^{-3}$	6.608	6.618	8.281	8.824
$1\cdot10^{-3}$	9.119	9.120	9.308	9.844
$1\cdot10^{-4}$	11.67	11.67	10.31	10.81
$5\cdot10^{-5}$	12.42	12.42	10.59	11.08
$1\cdot10^{-5}$	14.16	14.16	11.22	11.69

References

1. Gostev V.V. "Neutron bursts and analysis of selected possible accidents for reactor WWR-M". Report LNPI, ER-162. 1990.
2. Dik G.R., Petrov V.V., Shoustov V.A. "Inside security of the reactor WWR-M under falling fuel assembly into the core". Report LNPI, ER-134, 1988.
3. Froelich R., Johnson S.R. //Nukleonika. 1969. V.12. P.93.