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TESTS OF DIGITAL REACTIMETER WITH 15 GROUPS OF DELAYED NEUTRONS IN EXPERIMENTS ON ZPR

Yu.V. Volkov, T.G. Petrosov, D.A. Klinov, V.F. Ukraintsev, Y.V. Slekenitchs, M. Moniri

В статье описана математическая модель реактиметра для тяжеловодного реактора малой мощности с использованием 15 групп запаздывающих нейтронов. Описана также ее реализация на персональном компьютере в on-line режиме. Приведены результаты испытаний реактиметра и усовершенствования режимов его работы с помощью фильтрации сигналов и использования разных данных для запаздывающих нейтронов.

DIGITAL REACTIMETER

The digital reactimeter has been designed for the heavy water reactor [1] and was tested in operation on critical facility HWZPR. In starting option, the reactimeter treated signal, being proportional to neutron power, with 15 groups constant set [2], which are followed:

Algorithm of reactivity calculation is based on the Solution of Conversed Equations (SCE). The SCE, for six groups of delayed neutrons and nine groups of photoneutrons, is written as:

$$\rho = 1 + \frac{\Lambda}{\beta_{eff}} \frac{1}{n(t)} \frac{dn}{dt} - \frac{\sum_{i=1}^{6} \lambda_i \alpha_i \int_{-\infty}^{t} e^{-\lambda_i (t-t')} n(t')dt' + \sum_{j=1}^{9} \lambda_j \alpha_j \int_{-\infty}^{t} e^{-\lambda_j (t-t')} n(t')dt'}{n(t)}. \quad (1)$$

Using computers in online regime permits us to realize digital reactimeter, which, every time (with some delay), gives reactivity value of a reactor in β_{eff} units, by the following algorithm:

$$\rho_k = 1 + \frac{\Lambda}{\beta_{eff}} \alpha_k - \frac{\sum_{j=1}^{15} \lambda_j V_{jk}}{n_k}, \quad (2)$$

where

$$V_{jk} = V_{jk-1} e^{-\lambda_j \Delta t} + \frac{a_j}{\lambda_j + \alpha_j} (n_k - n_{k-1} e^{-\lambda_j \Delta t}). \quad (3)$$

DESCRIPTION OF ZPR

Critical facility HWZPR (Heavy Water Zero Power Reactor) is a critical heavy water reactor of zero power (nominal power ≤ 50 Wt) with heavy water as a moderator. To

Table 1

Set of constants β_{eff} = 0.0075 ; Λ = 10^{-4} sec ;

Group	1	2	3	4	5	6
λ_i, 1/sec	1.24E-2	3.05E-2	1.11E-1	3.01E-1	1.14	3.01
β_{effi}	2.13E-4	1.42E-3	1.27E-3	2.57E-3	7.47E-4	2.73E-4

Group	7	8	9	10	11	12	13	14	15
λ_i, 1/sec	6.26E-7	3.63E-6	4.37E-5	1.17E-4	4.28E-4	1.50E-3	4.81E-3	1.69E-2	2.77E-1
β_{effi}	4.91E-7	1.01E-6	3.23E-6	2.34E-5	2.07E-5	3.36E-5	6.99E-5	2.04E-4	6.50E-4

reach critical state the reactor tank is flooded by heavy water. There are three current fission chambers in an outlying area, which enable us to measure neutron flux. There are two control rods (CR) with total weight being equal to – 0.5β_{eff}.

There are two possibilities to shut down the reactor in emergency:

- to dump heavy water off the tank;
- to drop Scram rods (two rods weight is equal to - 5 β_{eff}).

The PC code complex, which is installed on the board computer, enables operator to carry out the following operations:

- start up the reactor;
- monitor of chambers current;
- monitor of radiation situation by outlying detectors;
- calculate doubling period of reactor power runaway by accumulated data of neutron flux;
- calculate the reactivity with using the equation of inverse hours.

In item 5 of the code, 15 groups of delayed neutrons are taken into consideration.

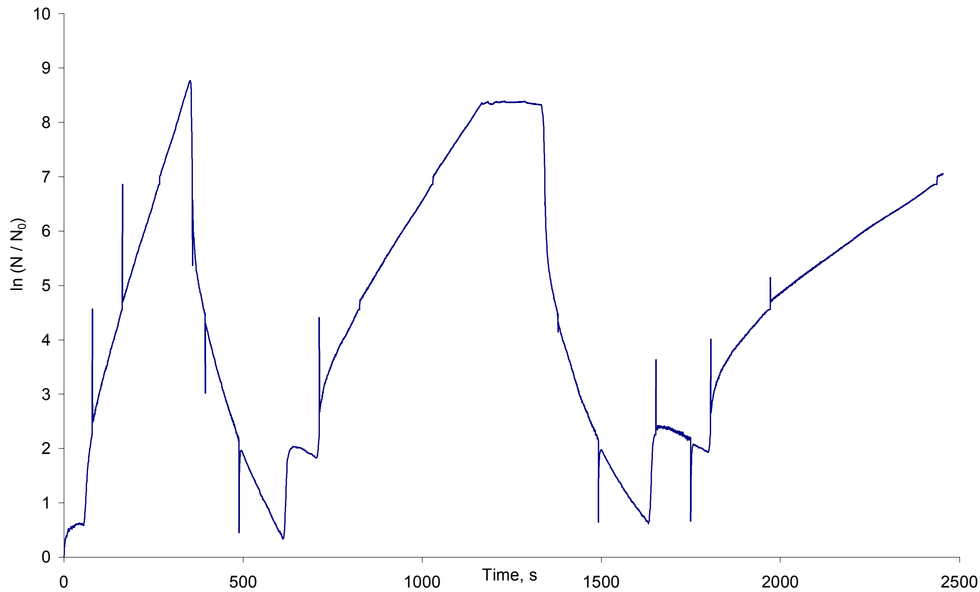
The reactor start up is carried out by a curve of inverse multiplication while flooding the reactor tank with heavy water.

EXPERIMENTS DESCRIPTION

Two dynamic experiments, with recording of neutron power, were carried out on HWZPR facility. The experiments order included reaching to critical state, sequential runaways with periods being equal about 30, 60, 150 sec, moreover, every runaway of the reactor was finished with fast power decrease by Scram rods drop, and insertion of control rods with maximum speed.

After the reactor had been at first gone to minimum critical level, the reactimeter was started up. The signal from the neutron detectors through the current power meter came to the board computer inlet and was at the same time the input signal for the reactimeter. The current range of detectors while changing of neutron power is from 10^{-11} till 10^{-6} A.

Further, runaways with constant periods were carried. To reach the required period, every runaway began from changing the heavy water level in the tank with the Control rods being on the bottom position. Since, the experiment includes three runaways with increasing period, the highest level of heavy water was achieved for the first reactor runaway, and it was necessary to pour heavy water off the tank for the following runaways. Such sequence of runaways is the most safe. From the deep undercritical state, the reactor was gone to the subcritical by the next way: Scram rods were taken out from the core to the top point, while this the reactor was keeping in undercritical state by control rods only. Extraction the control rods results to reactivity release corresponding to required period of runaway (pic.1).



Pic.1. Neutron power during the experiment

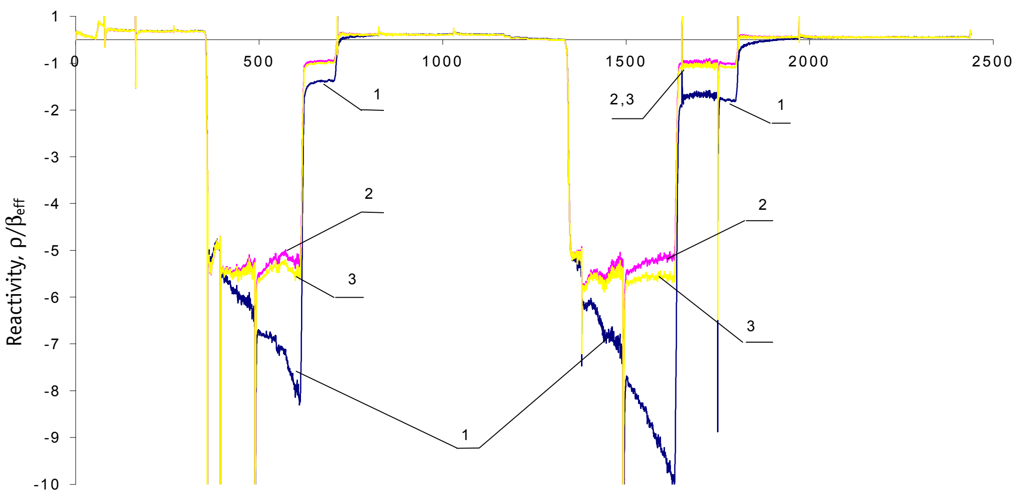
REACTIMETER TEST RESULTS

As a result of reactimeter operation (pic. $2_{(1)}$), one can immediately make a series of conclusions by its reading:

- reactivity estimations by the reactimeter during the reactor runaways with the constant period are close to reactivity estimations under the periods;
- reactimeter, after Scram rods drop, shows the linear abatement of the reactivity instead of its constant value, which should be equal to the Scram rods weight.

To verify accuracy of reactimeter operation, and, also, to reveal sources of mistaken reactivity calculations in undercritical state, the recorded neutron power data of both experiments were subjected to process, which includes analysis of reactivity behaviour with variation of delayed neutrons constants (Table 2-3)

The periods of runaways have been measured during every experiment by power



Pic. 2. Reactimeter reading with different fractions of delayed neutron groups: 1 - OINPE constants; 2 - ENTC constants; 3 - the last constants

doubling with stop-watch. Then, the recorded data of power changing were processed by the Least Square Method (LSM) within time intervals, which correspond to the runaway. It turns out, the both approaches of period estimation give close results. (Table 2-3) These power data were processed by the reactimeter with 15 groups of delayed neutrons. Tests were carried out with two options of constants:

1) with β_{eff} = 0.75% (OINPE);
2) with β_{eff} = 0.665% (ENTC).

The reactivity evaluations, in both cases, were approximately equal within limit of uncertainties. To make sure that consideration of addition photoneutron groups is necessary, it was taken six groups constant set with β_{eff} = 0.65%. In this case, the reactimeter reading was lower than the true reactivity value of the reactor.

The accuracy of the reactimeter reading was tested by a board table of dependency T_2 versus ρ, calculated just for this reactor. Here, the reactivity was presented as $\rho=\Delta k/k$ (%). In our case, for possibilities of comparing, it was required to transform them in β_{eff} units, that is to say, it is necessary to divide reactivity, found from the Table, to referred β_{eff} value (β_{eff} = 0.75% or β_{eff} = 0.665%). The maximum fitness of calculated reactivity value with the period of reactimeter reading was reached with β_{eff} = 0.665%.

The current signals of power had a big fluctuation, and, also, had short jumps at the moment of switching of ranges (pic.3).

These jumps led to short jumps of reactivity (up to 10 sec) with following return to the true reading.

Fluctuations of the power signal resulted to the fluctuations of reactivity near the true value.

Calculated coefficients of variation ($\sigma=\sqrt{Dx}/Mx$) of the power data and the reactivity data, corresponding to them, at the moments of runaways shows, that reactivity fluctuations is ten times higher, as minimum, than the power fluctuations.

Moreover, coefficients of variation were calculated by high evaluation, since it was taken $Mx=N_{min}$ into consideration (where N_{min} is the first power value at time intervals, corresponding to the runaway).

By the results of carried out comparative analysis, one can make following conclusions:

- in spite of the fluctuations of power signal, the reactimeter reading agreed, in average, with the table of dependency of power doubling period T_2 versus reactivity r during the reactor runaway with the constant periods (Table 2-3);
- the reactimeter starting up, carried out on the computer with supplying the recorded power data to the input, shows, that insignificant discrepancies in β_{eff} and, accordingly, in nine photoneutron groups doesn’t affect the reactimeter reading during the reactor runaway.

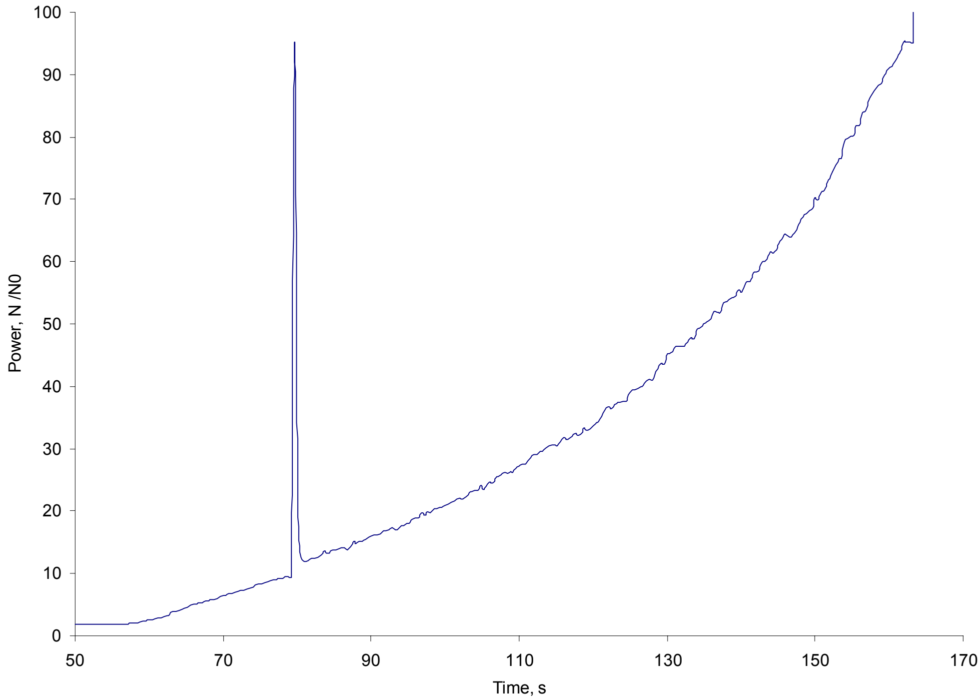
The both conclusions demonstrate acceptability of reactimeter operation with accuracy being achieved by constant set selection (pic. 4).

Mistaken reactimeter calculations of negative reactivity, after Scram rods drop, made us to analyze the influence of nine photoneutron groups and outside source on the reactivity reading in the case of considering of

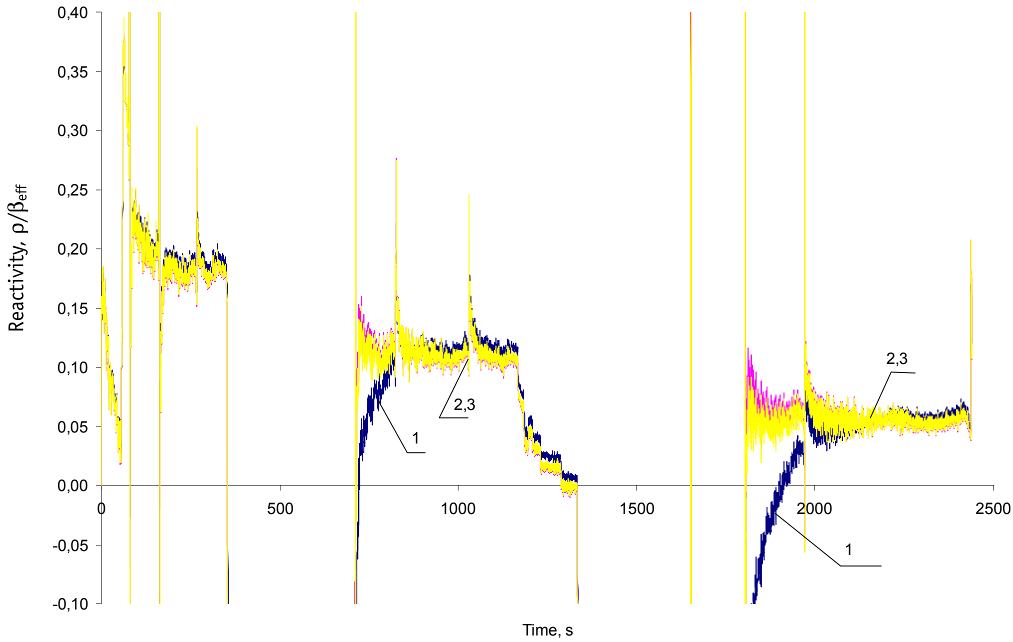
Table 4

Coefficients of variation of the power and reactivity data

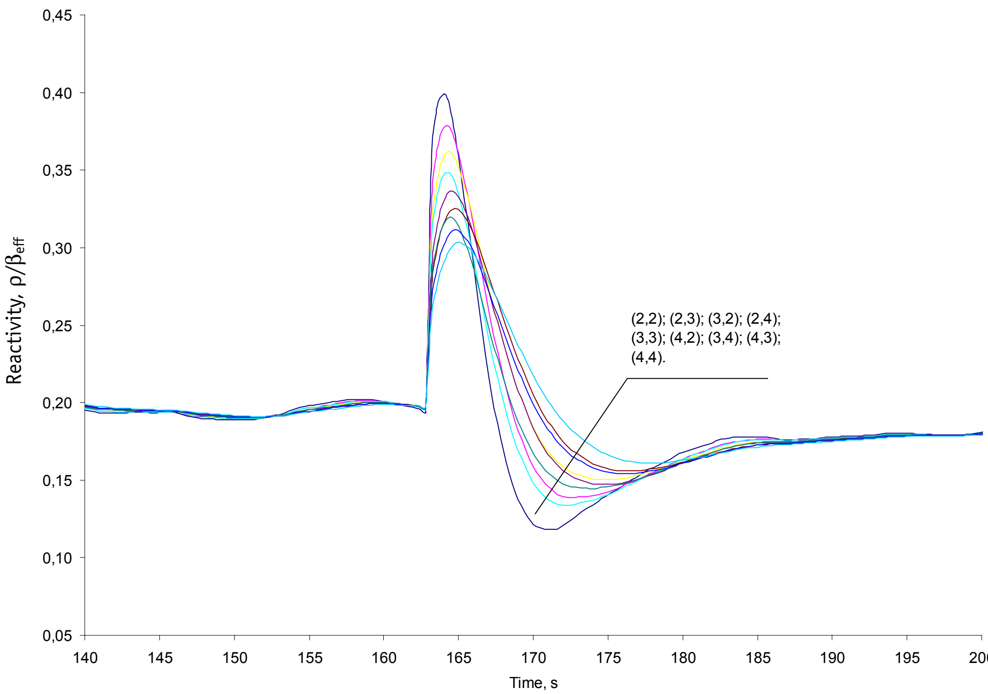
Runaways	σ_N	σ_ρ	
		β_{eff}=0.75%	β_{eff}=0.665%
1	1.964E-4	1.465E-3	1.917E-3
2	1.647E-4	1.530E-3	2.168E-3
3	1.724E-4	3.676E-3	3.460E-3



Pic. 3. Current power meter reading



Pic. 4 Reactimeter reading at the moment of reactor runaway with constant period.
(with different fractions of delayed neutron groups, see Pic. 2)



Pic. 5 Filter of the first order with different constant time combination : (TN,Tp)

undercritical state of the reactor.

The only distinctive feature of constants from Table 1 and constants from the permanent ZPR PC code complex was an essential difference in fractions of nine photoneutron groups. For ZPR they were three times lower than ones from Table 1. The comparative analysis of reactimeter reading, carried out with using of both sets of constants, enabled to make a conclusion, that the reducing of fractions of nine photoneutron groups signifi-cantly improves the result. This fact is explained by behaviour of recurrent correlation (3) in the reactivity calculation algo-rithm. Further investigations enabled to obtain more accu-racy constants set (Table 5), that gave the possibility to eliminate linear decreasing of reactivity reading in the case of undercritical state with constant reactivity (pic.2).

In this way, the final option of the digital reactimeter is designed with constant set of Table 5.

Outside neutron source can play an essential role for the reactor of zero power in undercritical state. ZPR – reactor is not exception, and it's necessary to estimate the source influence.

SCE, with outside neutron source, is written as:

Table 5

Relative portions of delayed neutrons
The last constants: β_{eff} = 0.00671; Λ= 8.84·10^{-4} sec;

Group	1	2	3	4	5	6
a_i	3.12E-2	2.07E-1	1.86E-1	3.74E-1	1.088E-1	3.976E-2

Group	7	8	9	10	11	12	13	14	15
a_i	2.17E-5	5.45E-5	1.72E-4	1.24E-3	1.097E-3	1.786E-3	3.711E-3	1.084E-2	3.448E-2

$$\rho = 1 + \frac{\Lambda}{\beta_{eff}} \frac{1}{n(t)} \frac{dn}{dt} - \frac{\sum_{i=1}^{6} \lambda_i \alpha_i \int_{-\infty}^{t} e^{-\lambda_i (t-t')} n(t') dt' + \sum_{j=1}^{9} \lambda_j \alpha_j \int_{-\infty}^{t} e^{-\lambda_j (t-t')} n(t') dt'}{n(t)} - \frac{Q}{\beta_{eff} \cdot n(t)}, \quad (4)$$

where Q is the source power.

Estimation of the source value was carried out by the following procedure:

Reactivity was calculated by the recurrent correlation, which differs from (2) only by the contribution of $-Q/\beta_{eff} \cdot n(t)$. The recorded neutron power data of the first experiment (pic.1) served as input signal for the reactimeter. During the data processing the value Q was varied from 10^{-6} till 10^{-2}. It turns out, that the influence of outside neutron source may be perceptible for $Q \geq 10^{-3}$. By the result of Q variations it is taken into consideration, that its most acceptable value, which ensures the steadiness of reactimeter reading after Scram rods drop, is: $Q = 2 \cdot 10^{-3}$. Since, relative power (chamber current) data are supplied to the reactimeter input, the influence of outside source into chamber current may be estimated as 0.2% of chamber current I_0 in starting critical state (I_0 = 1.08E-11 A).

So, the influence of the outside source on the reactimeter reading is insignificant. Consequently, the outside source may not be taken into consideration in the reactimeter for ZPR.

Short reactivity jumps, at the moment of switching current chamber ranges, have the following explanations. The reactimeter calculates the current jump as power jump due to prompt neutrons because of prompt reactivity insertion. Accordingly, the value of reactivity jump is proportional to the value of a gap in power reading. But, since, apparatus interference arises during the switching of ranges, the reactivity has a jump and returns to the starting state. The amplitudes of jumps depend on selecting of time discreteness interval for reading power data in Online regime. This discreteness was Δt = 0.4 sec.

In [1] it is cited results of carried out investigations of dependence of reactimeter reading uncertainty versus Δt in transient process caused by spasmodic introduction of negative reactivity. The uncertainty of reactivity estimations is about 10% for discreteness interval Δt = 0.4 sec. The most acceptable intervals are: Δt = 0.05-0.1 sec. During the digital reactimeter was installed on ZPR board computer, the selection of Δt was influenced by frequency of the computer operations. This interval is summed by the following time intervals: reading time + processing time + calculating time + graphic output time.

Reactivity fluctuations near the true value, caused by power fluctuations, reduce reactimeter effectiveness and require an applying of special filters for processing of power data. The recorded neutron power data were processed by a filter of high frequency of first order. Three ways of data processing were investigated:

1) filtration of input signal;
2) filtration of output signal;
3) filtration of both signals.

Besides, an influence of constant time filter T to the reactivity behaviour was investigated as well (pic.5).

It can be seen from the obtained data, that the most acceptable way of filtration is the processing of both input and output signals. Input filtration enables to smooth the fluctuating signal of neutron power and to adjust reactimeter reading. And filtration of reactivity solves the problem of jumps at the moment of switching ranges by reducing their amplitude.

Thus, as a result of comparative analysis, it was found the optimal combination of filtration of the both channels with constants times: T_N =2 sec and T_ρ = 2 sec.

CONCLUSION

As a result of the carried out investigations, the digital reactimeter, which takes photoneutrons into consideration, was elaborated and tested in the experiments on the ZPR-reactor.

By the results of tests, the reactimeter parameters were made more accurate, that permits to supply its acceptable accuracy during the operating both in sub- and under-critical state of the reactor.

List of Reference

1. *VolkovYu.V.,Petrosov T.G., Moniri M.* Evaluating effects of (γ,n) & (n,2n) reactions on criticality and kinetics of heavy water reactor. Obninsk, 1999.

2. *RobertKeepinG.* Phisics of nuclear kinetics, Addison-Wesley Publishing Company, INC, 1965.

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and Superphenix design concept fuelled with UN-PuN. These results can be useful for the design of new generation of nuclear reactors.

УДК 621.039.514.4
Tests of Digital Reactimeter with 15 Groups of Delayed Neutrons in Experiments on ZPR \ Yu.V. Volkov, T.G. Petrosov, D.A. Klinov, V.F. Ukraintsev, Ya.V. Slekenitchs, M.Moniri; Editorial board of journal "Izvestia visshikh uchebnikh zavedeniy. Yadernaya energetica" (Communications of Higher Schools. Nuclear Power Engineering) – Obninsk, 1999. – 10 pages, 5 illustrations, 5 tables. – References, 2 titles.

The mathematical model of the reactimeter for low power heavy water reactor with using of 15 groups of delayed neutrons is described. Realization of this model on the personal computer in the on-line option is also described. Results of the reactimeter testing and improving its operating regimes by using a signals filter and different delayed neutron data sets are presented.

УДК 536.248: 532.5: 621.039.52
Hydrodynamics and Heat Generation in a Liquid Vertical Eutectic Jet as a Target for the Intense Neutron Source \ E.F.Avdeev, S.L.Dorokhovitch; Editorial board of journal "Izvestia visshikh uchebnikh zavedeniy. Yadernaya energetica" (Communications of Higher Schools. Nuclear Power Engineering) – Obninsk, 1999. – 7 pages, 4 illustrations. – References, 8 titles.

As the target of high-power spallation neutron source the vertical jet of melted lead-bismuth eutectics directed towards to the beam of protons is considered. Locking up vacuum chamber of the accelerator is offered to be realized using the supersonic jet of an inert gas. The computational estimations of gas leakage to the vacuum chamber are given. The analytical solution of a magnetohydrodynamic task and the determination of jet borders using approximation of flow is given. The thermal power of the target, distribution of temperature along the height of the jet and the neutron yield for choosed parameters of protons beam are calculated.

УДК 536.242
On the Basic Regularities of Crisis of Heat Exchange in Water Cooled Channels \ V.P. Bobkov; Editorial board of journal "Izvestia visshikh uchebnikh zavedeniy. Yadernaya energetica" (Communications of Higher Schools. Nuclear Power Engineering) – Obninsk, 1999. – 6 pages. – References, 14 titles.

The regularities for critical heat flows in channels cooled with boiling water are discribed. Accent is put on the solution of a problem of influence of various factors on crisis in complex channels. The developed semiempirical model for treating critical heat flows in channels is used. The detected obtained have allowed to receive new approaches to prediction of critical heat fluxes in channels.

УДК: 621. 039. 534.63
Some results of Experimental Studies of Evaporation-cooled Reactor Fuel Rod Operation Modes in Single-rod Three-circuit Model \ V.N. Bogomolov, V.N. Lopatinsky, V.N. Zamiussky, V.M. Ryaby; Editorial board of journal "Izvestia visshikh uchebnikh zavedeniy. Yadernaya energetica" (Communications of Higher Schools. Nuclear Power Engineering) – Obninsk, 1999. – 6 pages, 3 illustrations. – References, 6 titles.

Some results of experimental studies on fuel rod heat removal obtained on physical three-circuit single-rod model which simulated evaporation-cooled reactor cooling system with sodium as a coolant are presented in this work. They give new insight into the problems of designing of sodium reactor installations with evaporation cooling.

УДК 546.718:621.039.7:539.174
Ruthenium as a 99Tc Transmutation Product: Necessary Separation Factor for Use \ A.A. Kozar, V.F. Peretroukhin; Editorial board of journal "Izvestia visshikh uchebnikh zavedeniy. Yadernaya energetica" (Communications of Higher Schools. Nuclear Power Engineering) – Obninsk, 1999. – 10 pages, 3 illustrations. – References, 26 titles.

The process of preparation of stable ruthenium as platinum group metal by 99Tc transmutation is considered. On the basis of the analysis of parasitic capture of neutrons in targets it is shown