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CONSTRUCTION OF THE SOFTWARE AND TECHNICAL COMPLEX OF CONTROL BASIC PARAMETERS OF REACTOR INSTALLATION

The main problem associated with the operation of nuclear power plants is the problem of correct and timely diagnosis of failure or violation. The mistakes of technologists can lead to severe damage to nuclear power plants, or simply to a reduction in the utilization rate of installed capacity. The personnel make the main mistakes in the conditions of time shortage and being in a stressful situation during the development of an accident, when assessing changes in emergency parameters is not always possible, which leads to incorrect diagnosis of initial events (IE). Any IE leads to the deviation of the monitored parameters from normal values (values that are inherent to normal operation). The operator-technologist needs as soon as possible to determine the parameter (or parameters) for which the change occurs and, by performing a certain sequence of actions, bring their values to the norm. For information support of the operator-technologist is the information computing system (ICS). In the ICS, it is possible to control all parameters affecting the safe operation of the equipment, for each of which there are certain values, the deviation from which may lead to an accident. The paper considers the issues of the need to separate the measured parameters of NPP into separate groups that uniquely characterize the state of the critical security features. In particular, the necessity of consideration as the most important mass parameter of the primary coolant is shown. The issues of level measurement problems in the pressure compensator are discussed as the most important from the point of view of determining the mass of the primary coolant. Methods are proposed for determining the operability of sensors, the method of calculating a reliable level in the volume compensator. Estimates of the computational efficiency of the proposed methods are given.

Key words: nuclear power plants, coolant mass, installed capacity utilization factor, initial events, operator-technologist, information and computing system.

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ПОБУДОВА ПРОГРАМНО-ТЕХНІЧНОГО КОМПЛЕКСУ КОНТРОЛЮ ОСНОВНИХ ПАРАМЕТРІВ РЕАКТОРНОЇ УСТАНОВКИ

Основною проблемою, пов’язаною з експлуатацією АЕС, є проблема правильного і своєчасного діагностування відмови або порушення. Помилки операторів-технологів можуть призводити, як до важких пошкоджень ядерних енергетичних установок (ЯЕУ), так і просто до зниження коефіцієнта використання встановленої потужності (КВВП). Основні помилки персонал здійснює в умовах дефіциту часу і перебуваючи в стресовій ситуації під час розвитку аварії, коли оцінити зміни аварійних параметрів не завжди можливо, що тягне за собою неправильне діагностування вихідних подій (ВП). Будь-які ВП призводять до відхилення контрольованих параметрів від нормальних значень (значень, які властиві для нормальної експлуатації). Оператору-технологу необхідно в найкоротші терміни визначити параметр (або параметри), за якими відбувається зміна і шляхом виконання певної послідовності дій привести їх значення до норми. Для інформаційної підтримки оператора-технолога служить інформаційно обчислювальна система (ІОС). В ІОС є можливість контролю всіх впливаючих на безпечну роботу устаткування параметрів, для кожного з яких є певні значення, відхилення від яких, може привести до аварії. В роботі розглянуті питання необхідності виділення вимірювальних параметрів ЯЕУ в окремі групи, які однозначно характеризують стан критичних функцій безпеки (КФБ). Зокрема показано необхідність розгляду, як найбільш важливого параметра, маси теплоносія першого контуру. Порушені питання проблем вимірювання рівня в компенсаторі тиску, як найбільш важливих з точки зору визначення маси теплоносія першого контуру. Запропоновано методи визначення працездатності датчиків, методику розрахунку достовірного рівня в компенсаторі об'єму. Дано оцінку обчислювальної ефективності запропонованих методів.

Ключові слова: ядерні енергетичні установки, маса теплоносія, коефіцієнт використання встановленої потужності, вихідні події, оператор-технолог, інформаційно обчислювальна система.

Introduction

With the purpose of the reliable economically reasonable use of NPP in the field of production of electric energy it is necessary to increase security of nuclear power plants (NPP). That does actual the questions of increase of safety and operating reliability of NPP.

The basic problem related to exploitation of NPP is a problem of the correct and timely diagnosticating of refuse or violation. The errors of operators-technologists can result both in the damages of nuclear power installations (NPI) and simply to the decline of the coefficient use of installed capacity. Basic errors a personnel accomplishes in the conditions of deficit of time and being in a stress situation during development of accident, when to estimate the changes of emergency parameters not always it is possible that entails the wrong diagnosticating of initial events (IE).

Any initial event leads to a deviation of the controlled parameters from normal values (values that is inherent for normal exploitation). The operator-technologist must in the earliest possible dates define a parameter (or parameters), on that there is a change and by implementation of some sequence of executions to bring their values over to the norm. For information support of the operator-technologist is the information computing system. There is a checking of all influencing to safe work of equipment parameters feature in the information computing system, for each of that there are the defined values, deviation from that, can lead to an accident.

Concordantly [1] for every block of NPP the checking and management systems are foreseen. These systems must conform to the requirements set in a project on reliability, metrology descriptions and others. Similarly on the stage planning must optimally the questions of co-operation will decide a «man – machine». In accordance with [1] control and management of NPI and other systems NPP (to both normal exploitation and by the systems of safety) are conducted from a sectional control panel.

A project in composition the checking and management of block NPP system is foresee the systems of informative support of operator, including system of operative presentation of the generalized information about current status of safety of the reactor setting and block of the NPP on the whole [1]. To the systems of grant of the generalized information, it is possible to take the system of security parameter presentation system. In addition, in the complement of information computing system the row of fragments enter with the generalized state of the systems reactor and turbine separations.

To the operator, even with the use of information computing system, not always is possible to define parameters that change, and on their rejection simply to identify the emergency state. Operating of operator-technologist under authentication and reacting in most cases begin from the moment of wearing-out of the technological signaling or defence. It is related to imperfection of information computing system, and plenty of the controlled technological parameters. Prime to that example – to flow the first contour by 1–3 м^3/hour. As calculations and design show, a level at such flow in the pressure compensator (H_{PC}) does not go down below 8600 mm. The light or voice signaling will not be to the moment of decline of level in the deaerator feed (H_{DF}) to 640 mm (only discoloration on a monitor) or blowing off the pumps feed of the first contour, that aggravates an accident.

At existing now development of science and technique, there is possibility to watch the critical group of parameters, determine speeds of their changes and forecast the tendencies of these changes.

A problem of choice of critical group of parameters is very important. For every project of NPP, these groups of parameters will be different. They must simply characterize the state of critical functions of safety, beforehand to forecast violation of critical functions of safety. That is the set of these parameters, their automatic analysis and presentation to the totechnologist, must allow diagnosing events on the early stage.

The aim of the work

The aim of the work is construction of the software and technical complex of control basic parameters of reactor installation. Develop a methodology of reacting at deviations from normal exploitation, that will help, both to improve the technical and economic indexes of NPP and improve safety.

1 Statement of the research problem

In accordance with [1] a project of NPP is foresee facilities and methods of finding out the flow of coolant-moderator of the first contour, exceeding the size and on possibility places of her being set by a project. However, on this stage the questions of automatic search of flow of the first contour are not realized. In addition, as shown higher, flows of the first contour to a 3 м^3/hour quickly to find out difficult enough, although in [2–10] the stop of NPI is foreseen at flows > 2 м^3/hour with the known location of the flow and > 0,7 м^3/hour with the unknown location of the flow.

The authors of this article are not known, now, any thoughtful pieces of work on a selection in the separate group of critical parameters and ground of these groups. Although, being base on normatively technical documentation [5–11], it is possible to draw conclusion that such groups exist. There can one of such critical parameters be mass of coolant-moderator of the first contour (this parameter can not be measured directly, and requires a calculation to that some technical difficulties are related). It is possible to take advantage of next formula:

$$M = \mathrm{const} + \Delta M\,; \qquad (1)$$

$$\Delta M = 4.2\Delta H_{PC} + 6.9\left(\Delta H_{TK} + \Delta H_{TY}\right) + \\ + 16\Delta H_{BB} - 0.65\Delta \overline{T}_{1K}\,, \qquad (2)$$

where ΔM is an increase of mass of coolant-moderator in the first contour м^3/hour;

ΔH is a change of level in the pressure compensator, deaerator feed, tank of organized leakage, bubbling tank according to a m/hour;

ΔT is a middle temperature of coolant-moderator of the first contour ºC/hour.

The use of this formula, seemed, decides the great number of questions, but, firstly, her application limitedly, secondly, mass of coolant-moderator does not give an answer for a question about the state of all critical functions of safety.

However using dependence for ΔM, it is possible to find the volume of loss of coolant-moderator, define her speed, that not insignificantly for flows with an expense 1–60 м^3/hour. The early diagnosticating will allow both to decrease the volume of exit of radioactive waters for the borders of contour of circulation and prevent violation in-process by facilities of normal exploitation NPP, that is priority [1].

We will mark that an analysis of parameters for a formula (2) is analogical for blocks with the reactors of type of WWER.

Analysing value $\Delta H_{TK,\ TY,\ BB}$ can be narrowed circle of search of flow, that considerably will facilitate a decision-making about the ways of liquidation of violation. It is necessary similarly to mark that for more detailed analysis it is needed to use the row of other parameters.

The all above-stated talks that it is necessary to distinguish the groups of critical parameters and their border values that would describe the state of any critical functions of safety. In a project of symptom-oriented emergency instructions the next critical functions of safety are accepted: «Subcriticism», «Cooling of active zone», «Heatsink», «Integrity of the first contour», «Hermetic shell», «Radioactivity». In addition, it is necessary to warn the operator-technologist of possibility of change of the state of critical functions of safety. Now we are not known formalization of critical functions of safety, in addition, the amount of functions is different in different sources.

A management process at liquidation of violations is begun with implementation by the operative personnel of complex of operating under diagnosticating of the block state. Most errors of personnel in case of violations of normal exploitation take place during authentication of event that is diagnosticians.

During diagnostics of event (initial stage) a personnel is in the stress state, that it contingently transient behavior and misunderstanding, in first moment, what be going on processes.

Diagnostics is conducted either on parameters or to the discrete signaling. The far enough of time is needed in first case, in the second errors are possible in authentication and, as a result of both cases, acceptance of the correct program of optimal renewal.

Presently a process of diagnosticating of the state of block is the prerogative of operative personnel of the station, that makes decision on the basis of the knowledge and experience. It is also necessary to notice that procedure of determination of type of accident occupies the certain interval of time, for that an accident can accept other transient state coming from that, other actions are required. A prime to that example is accidents with out-of-control expiration of steam on steam line, because the process of change of pressure from nominal to the zero flows in times of order of 10 sec, and evaporation of all liquid in times of 3,5 min.

The decision of problem of diagnosticating can be introduction on information computing systems, program that will watch the changes of parameters and give out to recommendation in relation to the state of block. It is possible to consider introduction of security parameter presentation system the attempt of development and introduction of such system, however this system not to a full degree describes the state of block during transients.

Coming from higher said it is possible to draw conclusion, that for the choice of optimal renewal it is necessary to conduct formalization of functions of safety. For this purpose it is necessary for every critical functions of safety to distinguish the group of parameters. To define the border values of parameters that determine the state of block simply. On the basis of diagnostics it is necessary to work out instructions on optimal renewal, that are simple sequences of executions.

Passing to dignities and defects, and also the fundamental differences of symptomatically and eventfully oriented instructions must mark:

- A SYMPTOM is a sign that an event begins or is in development (for example, a level goes down in the pressure compensator);
- An EVENT is this actual incident (for example, the feed-pumps of turbogenerator became disconnected).

Technological parameters are destroyed on unit control panel give an opportunity simply to define initial events [1]. It gives an opportunity to talk that by means of copula «man – machine» is possible authentication of all initial events. It is necessary in a copula a «man - machine» to minimize the vagueness brought in by a man, id est to eliminate a human factor even on the period of the stress state [10–15].

It is necessary similarly to mark that at correct diagnostics of events reaction on these events with the use of sequence of the executions described in eventful instructions for emergency response, is more exact and preferable. But on the other hand the spectrum of events is very wide and fully to define them in instructions for emergency response it is impossible. Thus for adequate actions the high enough level of qualification of operator-technologist is required. For eventful instructions for emergency response the amount of critical functions of safety is limited, that reduces the amount of eventful instructions, and also in connection with absence of the stage of diagnostics, as such, requirements go down to qualification of personnel, that simplifies his preparation. But, coming from a reaction on a symptom in symptom-oriented emergency instructions, efficiency of reaction goes down on initial events and, as a result, requires surplus of primary counter-measures. Symptom-oriented emergency instructions and accident management instruction is not intended for the improvement of technical and economic indexes of work of block.

According to foregoing it is necessary to work out methodology of reacting at deviations from normal exploitation, that will help, both to improve the technical and economic indexes of NPP and improve safety.

2 Research of the critical functions of safety

For the critical functions of safety, as be obvious from higher than said, the certain parameters of the state of the systems and elements of NPI are characteristic, the ground of these values of parameters is conducted, as a rule, on the stage of planning specified in the process of starting-up and adjustment works. These parameters are hardly regulated and controlled by an operator-technologist. For the grant of the generalized information on the state critical functions of safety it is necessary to conduct the analysis of eventual number of parameters.

The parameters controlled by an operator are both an analog and discrete. It is thus necessary to notice that the state of critical functions of safety in an equal degree depends both on the state of discrete and from the state of analog parameters.

State of discrete parameters and their influence it is easy to analyse on critical functions of safety, but verification of accordance of this discrete parameter to the real state of equipment is attended with some difficulties.

Conducting the analysis of analog parameters is difficult, although verification of rightness of testimonies of this analogue can be conducted on reserve measuring channels.

Concordantly [1] the next critical functions of safety are accepted: «Subcriticism», «Reliable heatsink from an active zone» (Heatsink), «Radioactivity». Although in a project these functions are extended and specified, we will make an effort formalize these functions.

State of critical functions of safety «Subcriticism» depends mainly on the amount of absorber in an active zone. Controlling being of reactor in the subcritical state is possible mainly according to the regulations of bars of regulators control and protection systems and concentrations of boric acid in the active zone of reactor.

A reliable heatsink from an active zone depends both on the volume of coolant-moderator of the first contour and from composition and capacity of equipment of first and second contours. However, in the first approaching at the accidents examined as credible, heatsink from an active zone it is possible to examine as some function from the volume of coolant-moderator of the first contour. Therefore, critical functions of safety «Heatsink» simply related to the volume of coolant-moderator of the first contour.

Critical functions of safety «Radioactivity» depends on the degree of damage of fuel, but it is more correctly necessary to examine her as a function of integrity of protective barriers concordantly [1]. The function of withholding of radionuclidess in the set borders we will express as a function from mass of the divided material:

$$A = \alpha_1 M_{DM} + \alpha_2(\alpha_1 M_{DM}) + \alpha_3(\alpha_2(\alpha_1 M_{DM})) + \\ + \alpha_4(\alpha_3(\alpha_2(\alpha_1 M_{DM}))), \qquad (3)$$

where M_{DM} is mass of the divided material;

α_n – coefficients depending on the state of protective barriers.

In case of accident with the exit of coolant-moderator of the first contour outside the contour of circulation and absence of damage of other protective barriers we can write:

$$\alpha_3(\alpha_2(\alpha_1 M_{DM})) \approx M_{T_{out}} A_T \delta_T, \qquad (4)$$

where $M_{T_{out}}$ is mass of coolant-moderator of going out outside the contour of circulation;

A_T is activity of coolant-moderator;

δ_T is a coefficient of exit of activating.

Consequently, critical functions of safety «Subcriticism» depends on the concentration of boric acid, and to mean is a function from the volume of coolant-moderator of the first contour. Critical functions of safety «Radio-activity» depends on the amount of radionuclidess going out outside protective barriers, that can be counted also by a function from the volume of coolant-moderator of the first contour. Connection of critical functions of safety «Heatsink» with the volume of coolant-moderator of a one contour was shown higher. That is, all three functions in one or another measure depend on the volume of coolant-moderator in the first contour.

Coming from importance of mass or volume of coolant-moderator being in the first contour, and also from that basic limitations on the change of volume of coolant-moderator are regulated as not function of mass or volume, but as functions of level in the pressure compensator, we will show, as a volume of a one contour depends from a level in pressure compensator. We will take advantage of function for the calculation ΔM as (2).

Using a formula (2) taking into account that $\Delta H_{TK,\,TY,\,BB} = 0$ we will get:

$$\Delta M = 4.2\Delta H_{PC} - 0.65\Delta\overline{T}_{1K}; \qquad (5)$$

$$\Delta H_{PC} = 0.158\Delta\overline{T}_{1K}. \qquad (6)$$

That is, in default of flow of coolant-moderator of the first contour the change of middle temperature of the first contour on one degree causes the change of level in the pressure compensator on 15,8 cm.

We will conduct a few calculations, that will be based on the numbers regulated in regulatory and technical documents. Middle temperature of the first contour $\overline{T}_{1K}$ = 304 °C work on nominal power, $\overline{T}_{1K}$ = 304 °C during work at minimum controlled level of power, $\overline{T}_{1K}$ = 260 °C before entering boron before cooling down. Putting in (4) we get, at a load-off from nominal power to the zero and absence of flow we get ΔH_{PC} = 3.792 m, at a load-off from nominal power to the zero absence of flow and chilldown of the first contour to 260 °C we get ΔH_{PC} = 6.952 m.

Taking into account that at nominal power a level is supported in the pressure compensator H_{PC} = 8.770 m, then at a load-off from nominal power to the zero and absence of flow – H_{PC} = 4.80 m, and at a load-off from nominal power to the zero and absence of flow and sharp chilldown of the first contour to 260 °C – H_{PC} = 1.820 m. Thus, we can explain work of regulator of level in the pressure compensator.

Higher we showed importance and necessity of knowledge of level in the volume compensator even in default of flows of the first contour. In addition, taking into account regulated in [2–5] the value of level can be talked about inconstancy of mass of coolant-moderator of the first contour during normal exploitation. Practical necessity of knowledge of mass of coolant-moderator of the first contour and current deviation from this value, needed both for the estimation of rightness of work of regulator of level in the pressure compensator and for the search of flow of the first contour.

We will define the error of calculation of mass of coolant-moderator of the first contour coming from the error of measuring of parameters included in a formula (5). A measuring channel for determination of level in the pressure compensator works with the error ΔH = 0,015 m, and middle temperature ΔT = 1 °C. We get $\sigma_{\Delta M}$, m^3:

$$\sigma_{\Delta M} = 4{,}2 \cdot 0{,}015 + 0{,}65 \cdot 1 = 0{,}713. \qquad (7)$$

Concordantly (7) error of calculation ΔM more than the value regulated in [2–5] for translation of the reactor setting in the cold state with normal speed. It talks about the necessity of diminishing of error of the applied methodology. Decreasing the error of calculation of change of mass is possible using statistical methods described in [12, 13].

3 Parameters and control methods

3.1 Problems, methods and methods of measuring of level in the volume compensator

It is necessary to analyse and offer basic models and methods for a construction programmatic of technical complex for the estimation of current level in the volume compensator, and estimation of capacity of sensors.

A list over of sensors of level in the volume compensator is brought in a table 1.

Table 1 – List of sensors by system of YP10

Stage number	Technological denotation	Scale of sensor	Place of setting of sensor	Note
1	2YP10L01B1	380–1527 cm	AK329/2	–
2	2YP10L02B1	0–1270 cm	AK329/2	–
3	2YP10L03B1	380–1270 cm	AK329/2	That correction
4	2YP10L04B1	380–1527 cm	AK329/2	–
5	2YP10L05B1	0–1010 cm	AK329/2	That correction
6	2YP10L06B1	380–1010 cm	AK329/2	That correction
7	2YP10L07B1	380–1010 cm	AK329/2	That correction
8	2YP10L08B1	0–1839 cm	AK329/2	–
9	2YP10L09B1	0–1839 cm	AK329/2	–
10	2YP10L10B1	0–1839 cm	AK329/2	–
11	2YP10L11B1	380–1527 cm	AK329/1	–
12	2YP10L12B1	380–1527 cm	AK329/1	–
13	2YP10L13B1	380–1527 cm	AK329/1	–
14	2YP10L14B1	0–1010 cm	AK329/3	That correction
15	2YP10L15B1	0–1839 cm	AK329/1	–
16	2YP10L16B1	0–1839 cm	AK329/1	–
17	2YP10L17B1	0–1839 cm	AK329/1	–
18	2YP10L18B1	0–1839 cm	AK329/3	–
19	2YP10L19B1	0–1839 cm	AK329/3	–
20	2YP10L20B1	0–1839 cm	AK329/3	–
21	2YP10L21B1	380–1527 cm	AK329/3	–
22	2YP10L22B1	380–1527 cm	AK329/3	–
23	2YP10L23B1	380–1527 cm	AK329/3	–

As be obvious from a table 1 there are 23 sensors of level in the volume compensator. From them on 8 we have testimonies on unit control panel, and on seventeen registration is conducted in information computing system of block. Some measuring channels have a temperature correction. All of it has to be kept in the head of the operator-technologist. That characteristically, an operator not always in primary moment can assuredly assert about the presence of some changes of level in the volume compensator.

As be obvious from the higher brought table over 1, a technologist has to watch a few parameters simultaneously. It entails impossibility to define the changes of level due to the flow of the first contour at the change of temperature, because for this purpose it is necessary to count parameters for the current value of temperature.

In addition, all sensors have a different base, that complicates supervisions. Fluctuations of the measured values can also bring in certain confusion. Sensors can fall out, and also entered in work after the removal of remarks. All of it must not influence on authenticity of testimonies of level and to work of operator.

It is necessary to work out models and methods of estimation of capacity of level gauges in the pressure compensatorand define a reliable level in the pressure compensator for all modes of operations of NPI.

For consideration of methods we will choose a base from 380 cm to 1010 cm where all level gauges of pressure compensatoris capable of working. In addition we will not originally break up level gauges on having and not having a temperature correction.

Authors hired consider that for normal exploitation it is necessary to check up the capacity of sensors more not often what one time in a minute. Although the labour intensiveness of this process allows it to do one time in 5 sec, and during setting of additional calculable powers and more often – up to the period of questioning of sensor (1 sec).

It is suggested for smoothing out of fluctuations in a measuring channel to conduct smoothing out of measurands on the interval of time equal to the interval of verification of the in good condition state of sensor.

3.2 Smoothing out of dynamic rows and short-term prognostication of values of level

One of effective receptions of exposure of tendencies, short-term prognostication and smoothing out of dynamic row with the purpose of screening-out of fluctuations taking into account the “obsolescence” of data is the use exponential middle [14] Q_i (smoothed out value of level of row) on a moment t_i, that looks like for a row $\{H_i\}_i$

$$Q_i = \alpha H_i + (1-\alpha)Q_{i-1}, \quad (8)$$

where α is a parameter of smoothing out, $0 < \alpha \le 1$ – sets weight of current supervision.

Exposing recurrent correlation (8), we will get

$$Q_i = \alpha \sum_{j=0}^{i-1} (1-\alpha)^j H_{i-j} + (1-\alpha)^i H_0, \quad (9)$$

where H_0 is a size characterizing initial conditions (first measuring for period of smoothing out).

From (9) evidently, that the middle Q_i has exponentially up-diffused weight; otherwise speaking, at moving away “in the past” from a moment t_i, weight decrease in geometrical progression and, in this sense, the value of parameter α determines the interval of smoothing out.

Substantially, that the expected values of sizes Q_i and H_i coincide, that is $M[Q_i] = M[H_i]$, and dispersion middle Q_i less dispersion of initial supervisions:

$$D[Q_i] = \frac{\alpha}{2-\alpha} D[L_i]. \quad (10)$$

Thus, the increase of coefficient α promotes speed of reaction on the change of process, and diminishing – assists “filtration” of small oscillations of function H_i. Experiments show [14], that practically effective range of values α it [0.1; 0.3], thus in most cases gives α = 0.1 good values.

Use exponential sliding middle (8) allows, accordingly (9), to ground the choice of volume of pre-history, k, for verification of hypothesis about the presence of trend in (21)–(26). In particular, at α = 0.1 meaningfulness H_{i-5} of supervision, relatively H_i, will make $(0.9)^5 \approx 0.6$, that can be considered not very much substantial at the poorly expressed trend.

The expounded method of smoothing out without changes can be applied to all sensors.

In default of meaningful variations of levels of row and absence of obvious tendency of row to the height or falling, the use gives a next prognosis exponential middle [14]

$$H_{i+1} = Q_i. \quad (11)$$

A confidence interval looks like for this point estimation

$$H_{i+1} = Q_i \pm t_p \sigma \sqrt{\frac{2}{2-p}}, \quad (12)$$

where t_p – a quantile t is distributions of Styudent with $\nu = n - 1$ the degree of freedom and level of significance p;

$\sigma = \sqrt{\frac{1}{n-1}\sum\left(H_i - \overline{H}\right)^2}$ – mean quadratic deviation for a selection.

It is further suggested to define the presence of trend in every sensor, for example with the use of method of Foster-Steward.

3.3 Verification of hypothesis about existence of trend

For verification of hypothesis about the presence of local (for a separate sensor) or global (for the reliable value of level) trend we will take advantage of method of Foster-Steward [14]. That, along with high calculable efficiency, gives more reliable results, than other methods of this type practically, and small sensible, on the structure, to deviation of law of distribution of the examined casual size from normal. In addition, he allows to find out a trend in the value of dispersion of levels, that it is important for the examined models. For simplification we will consider application of this method to one of sensors.

Foster and Steward suggested from data of the investigated row to determine sizes U_i and W_i, that are by successive comparison of levels:

$$U_i = \begin{cases} 1, & if \quad H_i > H_{i-1}, H_{i-2}, \ldots, H_1; \\ 0, & else. \end{cases} \quad (13)$$

$$W_i = \begin{cases} 1, & if \quad H_i > H_{i-1}, H_{i-2}, \ldots, H_1; \\ 0, & else. \end{cases} \quad (14)$$

On the basis of these sizes indexes are determined:

$$\sigma = \sum_{i=1}^{n} \left(U_i + W_i\right), \quad (15)$$

$$d = \sum_{i=1}^{n} \left(U_i - W_i\right). \quad (16)$$

that lie scope $\sigma \in [0; n-1]$, $d \in [-(n-1); n-1]$, asymptotically normal and have independent distributions. An index d is used for the exposure of trend in middle, and σ are dispersions. For this purpose on t – criterion of Styudent hypotheses are checked up about absence of trend in middle and dispersions. Thus the looked after values of criteria look like:

$$t_d = \frac{d-0}{\sigma_2}, \quad (17)$$

$$t_\sigma = \frac{\sigma - \mu}{\sigma_1}, \quad (18)$$

where μ is the expected value of size σ, certain for the casual location of levels in time;

σ_1, σ_2 are middle quadratic errors of sizes σ and d.

These parameters are tabbed [14], but values σ_1 and σ_2 can be got and on correlations

$$\sigma_1 = \left[2\sum_{i=2}^{n}\frac{1}{i} - 4\sum_{i=2}^{n}\frac{1}{i^2}\right]^{1/2} \approx \sqrt{\ln n - 3.4253}\,, \quad (19)$$

$$\sigma_2 = \left[2\sum_{i=2}^{n}\frac{1}{i}\right]^{1/2} \approx \sqrt{2\ln n - 0.8456}\,. \quad (20)$$

Clear, that if instead of values $\{H_i\}_{j=1,n}$ in (13), (14) to use the values of other sensors, we will get a statistical conclusion analogical character about the presence of trend on all sensors.

We will notice that in connection with the "obsolescence" of data of scan-out, in correlations (13), (14) it is expedient to use not everything n supervisions, and last $k < n$, thus smoothed out, with the purpose of filtration of casual fluctuations.

Then, if used k the last values, and at a calculation (13), (14) the maximal is memorized and minimum values, then, ignoring the account of a few comparisons in (13), (14), labour intensiveness of calculation (15)–(18) will make the sizes of order

$$\kappa_d \approx k + (k-1) + 2 \approx 2k \text{ (operations)}, \quad (21)$$

$$\kappa_\sigma = k + (k-1) + 1 = 2k \text{ (operations)}. \quad (22)$$

Otherwise speaking, labour intensiveness and expenses of memory for verification of hypothesis about the presence of trend for a size H_i on a next step make

$$\kappa_i \sim 4k \text{ (operations)}, \quad (23)$$

$$\Pi_i \sim k \text{ (numbers)}. \quad (24)$$

Corresponding calculable expenses on the analysis of trends in all sensors of N

$$\kappa_n \sim 4k\,N \text{ (operations)}, \quad (25)$$

$$\Pi_n \sim k\,N \text{ (numbers)}. \quad (26)$$

We will notice that although sizes (25), (26) arcwise depend on the number of sensors, thus with the small coefficient of proportion. In any case, however, estimations (23) are (26) show that for the offered model verification of hypothesis about the presence of trend both local and global, can come true real-time, as a size κ_n is comparable with the number of sensors.

In case of exposure of trend on one of sensors and absence of trends in other sensors a signal is given out about disparity of testimonies to the Nth sensor, a corresponding signal will be given out and in opposite case, that will demand the order of $N(N-1)$ of operations where N amount of sensors.

For determination of reliable level in a range 380–1010 cm it is suggested to take arithmetical mean all sensors testimonies that oriented to the identical environment of the first contour. Further, to bring values over of these testimonies to the value at a current temperature and to take arithmetical mean from testified, what will give the maximally reliable value of level.

The use the higher brought methodology over will allow to destroy us on the displays of sectional control panel one reliable value of level, and also to signal about measuring channels that broke ranks. That will result in the improvement of safety from diminishing of number of parameters that it is necessary to control and analyse to the technologist.

3.4 Middle temperature, exactness of calculation

The problems related to exactness of calculation of leakage of the first contour are constrained first of all, not only with exactness and authenticity of measuring of level in the pressure compensator, and also with exactness of determination of middle temperature of coolant-moderator.

As be obvious from (2) in the stationary modes determination of middle temperature of coolant-moderator of the first contour, as middle arithmetic between the temperature of hot and cold threads, satisfactorily to the search of debalance of coolant-moderator.

However at the non-stationary modes, and also in transient behaviors in the modes with a power-off main circulation pump, determination of middle temperature of the first contour, as middle arithmetic temperatures of hot and cold threads not acceptable. Therefore, there is a necessity of calculation of the real middle temperature of the first contour, that has acceptable exactness in all modes of normal exploitation and at violations of normal exploitation.

We will offer the method of calculation of middle temperature of the first contour on the basis of the use of measureable temperatures of the first contour and averaging on volumes with an identical temperature. A volume over of coolant-moderator of the first contour in an equipment is brought in a table 2. These descriptions can be specified and resulted as approximate values for the ground of methodology.

Table 2 – Geometrical descriptions of equipment of the first contour

Name of equipment and elements	Volume, m^3	Length of highway (height), m	Diameter (width), m	Minimum communicating section, м^2
Reactor including:	107,6	–	–	–
– entrance union coupling	0,4	0,63	0,85	0,567
– circular movable channel	20,0	7,08	0,263	2,15
– bottom chamber of mixing	12,4	1,76	–	1,7
– active zone	14,8	3,53	–	4,17
– overhead chamber of mixing	59,6	6,87	–	4,6
– output union coupling	0,4	0,63	0,85	0,567
Hot thread of loop	5,7	10,1	0,85	0,567
Cold thread of loop	15,1	26,6	0,85	0,567
Steam generator, including:				
– entrance collector	2,4	4	0,834	0,546
– tubing	16,2	11,1 (middle)	0,013 (one tube)	1,46
– output collector	2,4	4	0,834	0,546
Pressure compensator, including:				
– corps*	79 (55 water)	(11,2)	3,0	7,06
– respiratory pipeline	1,69	18	0,346	0,094
Passive part of emergency core cooling system, including:				
– capacity of emergency core cooling system*	60 (50 water)	(8,5)	3,00	7,06
– pipeline, connecting the capacity of emergency core cooling system with the bottom chamber of mixing	1,6	26,5	0,279	0,061
– pipeline, connecting the capacity of emergency core cooling system with the overhead chamber of mixing	1,8	29,3	0,279	0,061

* a size is a variable.

We will define the complete volume of the first contour, occupied by a coolant-moderator at nominal parameters, m^3:

$$V_{1K} = V_{Reactor} + V_{PC} + 4V_{HT} + 4V_{SG} + 4V_{CT} . \quad (27)$$

where $V_{Reactor}$ = 107.6 m^3, V_{PC} = 56.7 m^3, V_{HT} = 5.7 m^3, V_{SG} = 21 m^3, V_{CT} = 15.1 m^3. In addition it is necessary to take into account V_{MCP} = 2,5 m^3, as a volume of cold thread (CT) of main circulation pipeline.

$$V_{1K} = 107.6 + 56.7 + 4 \cdot 5.7 + \\ + 4 \cdot 21 + 4 \cdot 15.1 + 4 \cdot 2.5 = 341.5 . \quad (28)$$

We will write down a formula for determination of middle temperature of coolant-moderator of the first contour as a function of the measureable temperatures and volumes, occupied by these temperatures:

$$\overline{T}_{1K} = \frac{V_{Reactor}\overline{T}_{Reactor} + V_{PC}T_{PC} + \sum_{i=1}^{4}\left(T_{HTi}V_{HTi} + \overline{T}_{SGi}V_{SGi} + T_{CTi}V_{CTi}\right)}{V_{1K}} . \quad (29)$$

As necessary to notice, we examine the temperature of coolant-moderator on steam generator (SG) and reactor as a middle temperature. Middle temperature on SG we will examine as a simply middle temperature. For a reactor we will consider a few volumes:

$$V_{Reactor} = V_{\substack{Entrance\ to \\ the\ active\ zone}} + V_{\substack{Active \\ zone}} + V_{\substack{Active \\ zone\ out}} . \quad (30)$$

Then a temperature we will define, as:

$$\overline{T}_{Reactor} = \frac{V_{\substack{Entrance\ to \\ the\ AZ}} T_{\substack{Entrance\ to \\ the\ AZ}} + \overline{T}_{AZ}V_{AZ} + T_{AZ\ out}V_{AZ\ out}}{V_{Reactor}} . \quad (31)$$

where $$\overline{T}_{AZ} = \frac{T_{Entrance\ to\ the\ AZ} + T_{AZ\ out}}{2};$$

$V_{Entrance\ to\ the\ AZ}$ = 32.8 m^3, V_{AZ} = 14.8 m^3, $V_{AZ\ out}$ = 60.

We defined the middle temperature of the first contour as function, in that permanent sizes are the volumes occupied by a coolant-moderator, except for the volume of pressure compensator, that is a function from a temperature and set in [2, 3, 6, 7]. Temperatures participating in a formula can be measured. Volumes can be specified in the process of adaptation of method to concrete power unit.

It is necessary also to take into account for the calculation of middle temperature of the first contour, that a volume of coolant-moderator in the pressure compensatoris a function from the maximal value of overfall of temperatures on a loop. That is a volume of the first contour is function of temperature, that complicates methodology of calculation.

Coming from [2, 3] we will describe, as a curve of basic value of level is set in pressure compensator depending on the middle temperature of coolant-moderator of the first contour presented on a picture 1.

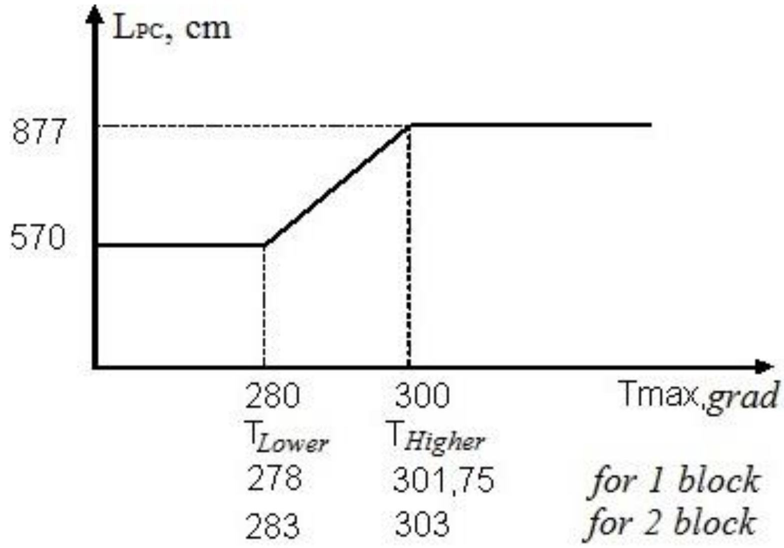

Fig. 1 – Change of level of pressure compensator:
T_{max} is the measured maximal temperature of middle temperatures of a first contour – YA10T24;
L_{PC} is the measured level of coolant-moderator in the pressure compensator – YP10L04B1I;
T_{Lower} is the bottom temperature set in a regulator – YPC02; T_{Higher} is the overhead temperature set in a regulator – YPC02; T_{Lower} and T_{Higher} – set at tuning of regulator of YPC02 for every block the personnel of laboratory

3.5 An existent algorithm of calculation of level in pressure compensator

A calculation is produced only at reliable entry parameters on a next algorithm: If $T_{Lower} \le T_{max} \le T_{Higher}$ the that regulation value of level in pressure compensator is determined on a formula, embedded in the regulator of YPC02:

$$L_{reg}(T_{max} - T_{Lower}) + 570; \qquad (32)$$

If $T_{max} > T_{Higher}$, then L_{reg} = 877;

If $T_{max} < T_{Lower}$, then L_{reg} = 570.

We will put in accordance to the regulation level in pressure compensator volume of coolant-moderator, m^3: If $T_{Lower} \le T_{max} \le T_{Higher}$ that

$$V_{reg} = L_{reg}S_{PC} + 33{,}3. \qquad (33)$$

We defined the volume of coolant-moderator for the modes of operations of NPI on power, and we can expect the change of mass of coolant-moderator of the first contour using the reliable values of level in pressure compensator. It is necessary only to bring in some changes in the constants used in formulas. As talked higher authenticity of this methodology in the interval of levels 380–1010 cm. We will bring sequence of calculations for the calculation of mass of coolant-moderator in the first contour.

$$V_{PC} = (H - 380)S_{PC} + 19{,}9. \qquad (34)$$

The volume of pressure compensator must be expected each time for the period of calculation of leakage of coolant-moderator of the first contour. The labour intensiveness of calculation is three operations.

$$V_{Reactor} = V_{Entrance\ to\ AZ} + V_{AZ} + V_{AZ\ out}. \qquad (35)$$

The volume of reactor can be expected one time, labour intensiveness three operations, and to keep in memory.

$$V_{1K} = V_{Reactor,\,PC,\,loops} + V_{PC}, \qquad (36)$$

where

$$V_{Reactor,\,PC,\,loops} = V_{Reactor} + 4V_{HT} + 4V_{SG} + 4V_{CT}, \qquad (37)$$

Volume of the first contour that settles accounts each time, one operation has labour intensiveness, because (18) settles accounts one time, with labour intensiveness six operations, and kept in memory.

$$\overline{T}_{AZ} = \frac{T_{Entrance\ \ to\ \ AZ} + T_{AZ\ \ out}}{2}; \qquad (38)$$

$$\overline{T}_{SGi} = \frac{T_{CTi} + T_{HTi}}{2}; \qquad (39)$$

Taking into account that $T_{Entrance\ to\ AZ} = (\Sigma T_{CTi})/4$, $T_{AZ\ out} = (\Sigma T_{HTi})/4$, the labour intensiveness of calculation of middle temperature for ELEMENT makes 12 operations, for every steam generator two operations. It should be noted that T_{CTi}, T_{HTi} we wake to examine as an arithmetical mean temperature-control sensors, it will not demand additional calculable expenses because these values settle accounts in systems of intra-reactor control and passed in information computing system.

$$\overline{T}_{Reactor} = \frac{V_{\substack{Entrance\\ to\ \ AZ}} T_{\substack{Entrance\\ to\ \ AZ}} + \overline{T}_{AZ} V_{AZ} + T_{AZ\ \ out} V_{AZ\ \ out}}{V_{Reactor}}; \qquad (40)$$

$$\overline{T}_{1K} = \frac{V_{Reactor}\overline{T}_{Reactor} + V_{SG}T_{SG} + \sum_{i=1}^{4}\left(T_{HTi}V_{HTi} + \overline{T}_{SGi}V_{SGi} + T_{CTi}V_{CTi}\right)}{V_{1K}}. \qquad (41)$$

for the temperature of reactor six operations are needed, and for the middle temperature of the first contour 17 operations are needed.

For the calculation of mass of coolant-moderator of the first contour it is necessary to find the closeness of coolant-moderator at nominal pressure where $\rho \Leftrightarrow \overline{T}_{1K}$. It is necessary to notice that a closeness in less degree depends on pressure of coolant-moderator, it is therefore possible a closeness constituent neglected.

$$M_{\text{const}} = \rho V_{1K}, \qquad (42)$$

where M_{const} is mass of coolant-moderator of the first contour in certain moment of time. ΔM can be expected as a difference between mass of coolant-moderator in present moment and by mass in preceding moment of time. Deviation of mass of coolant-moderator it is possible to expect from a regulation value, as a difference of the regulated mass for the current value of time and measured. ΔM can be also expected, using a formula (2) for deviation from a regulation value and for last period.

$$\Delta M = 4.2\Delta H_{PC} + 6.9\left(\Delta H_{TK} + \Delta H_{TY}\right) + 16\Delta H_{BB} - 0.65\Delta\overline{T}_{1K}.$$

The labour intensiveness of calculations for ΔM is not considerable. However, coefficient at ΔT certain experimentally, it is necessary to specify for this value of middle temperature. In general case this coefficient is a function from a temperature.

3.6 Analysis of parameters of reactor instalation for determination of volume of flow

Higher we defined the middle temperature of the first contour. Mass of coolant-moderator of the first contour was certain for the modes related to the change of middle temperature of the first contour at nominal pressure. At violations of normal exploitation maybe similarly and change of pressure of coolant-moderator of the first contour. On this stage there are methodologies and software products for the calculation of closeness of coolant-moderator (waters under constraint) with high calculable efficiency. In this connection we do not examine the questions of calculation of closeness, and we simply will determine her as $\rho(T, P)$ and to consider the known size.

We will consider the balancing network of the first contour. We see that four capacities are, the changes of level in that determine the change of mass of coolant-moderator of the first contour including the systems of signup of blowing out, organized leakage, protecting of the first contour from surplus pressure. There is level gauge in each of these capacities, and we can define the changes of mass for every capacity separately. We will define the change of mass of coolant-moderator as

$$\Delta M_{1Kgeneral} = \Delta M_{1K} + \Delta M_{TK} + \Delta M_{BB} + \Delta M_{TY}, \qquad (43)$$

where ΔM_{1K} is the change of mass of coolant-moderator of the first contour, expected as a difference (23) for the period of time;

ΔM_{TK} is a change of mass of coolant-moderator in the deaerator of blowing out;

ΔM_{BB} is a change of mass of coolant-moderator in a bubbling tank;

ΔM_{TY} is a change of mass of coolant-moderator in the tank of organized leakage.

We will define

$$\Delta M_{TK} = \rho_{TK} S_{TK} \Delta H_{TK}, \qquad (44)$$

$$\Delta M_{BB} = \rho_{BB} S_{BB} \Delta H_{BB}, \qquad (45)$$

$$\Delta M_{TY} = \rho_{TY} S_{TY} \Delta H_{TY}, \qquad (46)$$

where $\rho_{TK,\ BB,\ TY} = f(T, P)$ is a closeness of coolant-moderator;

$S_{TK,\ BB,\ TY}$ is an area of surface of liquid;

$\Delta H_{TK,\ BB,\ TY}$ is a change of level for this period of time.

Change of mass of coolant-moderator first we can present as a change of levels is in capacities. However, the change of level in the volume compensator can take place both due to the change of mass of coolant-moderator of the first contour and due to the change of middle temperature. In addition, on the changes of mass of coolant-moderator work of regulator of level influences in the pressure compensator. In general case ΔM_{1K} it is possible to present as a difference of preceding and current value of mass of coolant-moderator.

As shown higher, the change of mass of coolant-moderator of the first contour can not take place, although the generalized mass of coolant-moderator can will change, it is related to work of regulator of level of the first contour. In addition, the change of expense of leakage is possible in the tank of organized leakage, bubbling tank. From work of regulator of level in the volume compensator maybe redistributions of volume of coolant-moderator on capacities.

If $\Delta M_{1Kgeneral} = 0$ we will talk that a flow is absent. In case $\Delta M_{1Kgeneral}$ <>0 we will talk about unbalance coolant-moderator. Unbalance of coolant-moderator is possible both in connection with a flow and with a technological necessity (boric regulation, etc.).

For the analysis of balancing network it is necessary to define the ways of receipt and weathering of coolant-moderator. It is necessary both to fill up at different operating modes and diminish the volume of coolant-moderator. We will consider the variants of receipt and weathering of coolant-moderator from the limits of the first contour (table 3).

For the analysis of presence of flows of the first contour it is necessary to analyse debalance organized by a technological process. The deaerator of the boric adjusting can be not taken into account, because a distillate, in the total, undertakes from the volume of tanks of distillate, that is, there is a change of volume. The system of chemical reagents can be not taken into account, because small expense of reagents there is not possibility to take into account from the large error of method of calculation of mass of coolant-moderator.

We will write down correlation for the change of mass of the coolant-moderator, conditioned by technological processes.

$$\Delta M_{Tech} = \Delta M_{TB30} + \Delta M_{TB10} + \Delta M_{TB40}, \quad (47)$$

$$\Delta M_{Tech} = \rho_{TB30} S_{TB30} \Delta H_{TB30} + \rho_{TB10} S_{TB10} \Delta H_{TB10} + \rho_{TB40} S_{TB40} \Delta H_{TB40}, \quad (48)$$

where S_{TB30}, S_{TB10}, S_{TB40} – area of surface accordingly;

ρ_{TB30}, ρ_{TB10}, ρ_{TB40} – closeness of liquid accordingly;

ΔH_{TB30}, ΔH_{TB10}, ΔH_{TB40} – change of level in capacities accordingly.

The calculation ΔM_{Tech} is related to the large errors in connection with that the changes ΔH are not considerable, and S is great. In a table 4 the areas of capacities are certain the necessary for the calculation of change masses of coolant-moderator.

Table 3 – Technological connections of the first contour

Name of capacities for an environment	Connection with the first contour	
	arrival	drain
TB30	+	+
TB10	+	-
TB40	+	-
TK70	+	-
TB20	+	-

Table 4 – Areas of surface of capacities participating in the balancing network of the first contour

Name of capacity	Area of m^2
Deaerator of signup of TK10	7
Tank of organized leakage of TY	7
Bubbling tank of BB	14.5
Tank of boric concentrate of TB10	42
Tank of boron containing waters of TB30	58.4
Tank of distillate TB40	58.4

For diminishing of error of measuring of level it is possible to take advantage of the same methods, what for the volume compensator, with a that only difference, that there is only one level gauge in these capacities.

3.7 Algorithm of search of flow of the first contour

We will bring an algorithm over of search of flow of the first contour. For definiteness we will take the period of time in 10 minutes.

Algorithm:

1 Determination of necessary for a calculation measureable parameters.

2 Determination of reliable level is in the volume compensator.

3 Determination of middle temperature of the first contour.

4 Determination of current and regulation mass of coolant-moderator of the first contour.

5 Comparison of current mass and regulation

$\Delta M_{1K} = \Delta M_{1Kregul}$ then transition on 7.

ΔM_{1K} <> $\Delta M_{1Kregul}$ then 6.

6 Comparison of current mass and preceding value of mass $\Delta M_{1Ki} = \Delta M_{1K(i-1)}$ then rejection of level in the pressure compensator from regulation.

7 To define $\Delta M_{1Kgeneral}$ in obedience to (24).

8 Comparison $\Delta M_{1Kgeneral}$

$\Delta M_{1Kgeneral} = 0$ then 11.

$\Delta M_{1Kgeneral}$ <> 0 then 9.

9 We will define ΔM_{Tech}.

10 Comparable ΔM_{Tech} and $\Delta M_{1Kgeneral}$

$\Delta M_{Tech} = -\Delta M_{1Kgeneral}$ then 11.

ΔM_{Tech} <> $\Delta M_{1Kgeneral}$ then 12.

11 A flow is not present. End.

12 A flow is. End.

This algorithm gives an opportunity to define the presence of flow of the first contour with the high degree of exactness. For the location of flow this algorithm must be finalized.

Conclusions

1 The necessity of realization of works is shown for the area of man-machine co-operation for the improvement of safety of NPI.

2 The necessity of formalization of critical functions of safety is shown, an example of mass of coolant-moderator of the first contour is made as one of major functions.

3 Methodology is offered allowing to expect a reliable level in the volume compensator, to analyse the capacity of sensors of level.

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