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RELAP5 MODELING OF THE NPP VVER-1000 STEAM GENERATOR

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В статье обсуждается теплопередача от первого контура ко второму и моделирование процесса испарения в парогенераторе (ПГ) ВВЭР-1000 для АЭС. RELAP5/MOD3.2 используется для моделирования гидродинамических и тепловых параметров горизонтального ПГ с U-образными обогреваемыми трубками поверхности теплообмена. Результаты стационарного режима и режима естественной циркуляции и компьютерный анализ представлены и проведено сравнение с опубликованными данными о ПГ.

INTRODUCTION

Heat transfer calculation enters the reactor analysis for two reasons of indispensable significance. Firstly, the power generation capability of the core is confined by the thermal-hydraulic parameters, which have to remain within the designed ranges. Secondly, temperature and pressure of the coolant determined the coolant density that influence on neutron field properties.

The steam generator (SG) is one of the most important components of the VVER type reactor. Thus, the ability to simulate and predict the steady state and transient thermal-hydraulic behavior is important for removing the heat from primary circuit and production of a dry saturated steam. For safety analysis of a Nuclear power plant it is important to have reliable model of SG. For transient simulation of NPP it is necessary to have a model that can perform calculations for different modes of operation. Such modes for SG include forced convection at nominal mode and natural circulation in primary circuit at shut down mode.

The RELAP5 is a widely used computer code for steady state or transient calculations of thermal-hydraulic system. The task of reactor thermal-hydraulic is to assess safe, reliable and economical heat transfer systems. The RELAP5 code was already used for the calculation of vertical type SG [5].

This paper summarized the results of the RELAP5/MOD3.2 analysis related to the SG modeling, which aim at evaluation of cod's ability to predict the VVER-1000 SG behavior and to investigate the primary to secondary heat transfer.

RELAP5 CODE DESCRIPTION

The RELAP5 (Reactor Excursion and Leak Analysis Program) is best estimate code, developed for transient simulation of a light water reactor coolant system. It uses one dimensional, two fluid, non-equilibrium transient model of steam water mixture flow with the possibility to take into account the vapor phase containing a non-condensable

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component, and the liquid phase containing a non-volatile solutes, that are derived from the basic thermal-hydraulic laws.

The model consists of two-phase continuity equations, two-phase momentum equations, and two-phase energy equations. The system of six basic partial differential equations with non-constant coefficients is closed with semi-empirical correlations for interface drag, wall friction, mass and heat transfer between phases, fluid to wall heat transfer, and it has a number of special process models (e.g. radiation heat transfer and so on).

The solution of six basic equations for six primary independent variables and some other variables (pressure, internal energies, velocities, non-condensable gas and boron density) is determined by partially implicit numerical scheme. Thermal dynamic quantities are computed in the middle of each cell of the discretization scheme and volume averaged for each phase. Thus, the results may depend on the discretization scheme.

THE VVER-1000 STEAM GENERATOR AND ITS MODEL DESCRIPTION

The VVER-1000 SG is a horizontal U-tube type (Fig. l, 2 and 3) and is used as the heat sink of the primary circuit. The primary side collector is intended for coolant distribution along the horizontal heat exchanger tubes, coolant collection and removal.

Heat from primary circuit is transferred via tubes into the secondary circuit. The feed-water, which is normally introduced into the secondary side, removes heat from U-tube and warms up to saturation temperature, and finally evaporates in the multiple natural circulation loop formed by tube packets and gaps between this packets (see fig. 3). Further on a water-steam mixture flows upward through the U-tube packets to the moisture separator area. The separated liquid is moved by natural circulation through the down chamber and back to the packet inlet at the lower part of the tube. Dry steam, however, leaves the SG top through perforated plate and separator to steam collector. For detail description of circulation see [1,2].

A detailed nodalization and corresponding RELAP5/MOD 3.2 input model have been developed for the VVER-1000 SG (Fig. 4, 5). The actual physical dimensions are used to describe the flow areas, volumes, hydraulic diameters, elevations, heat transfer area and heat structure masses.

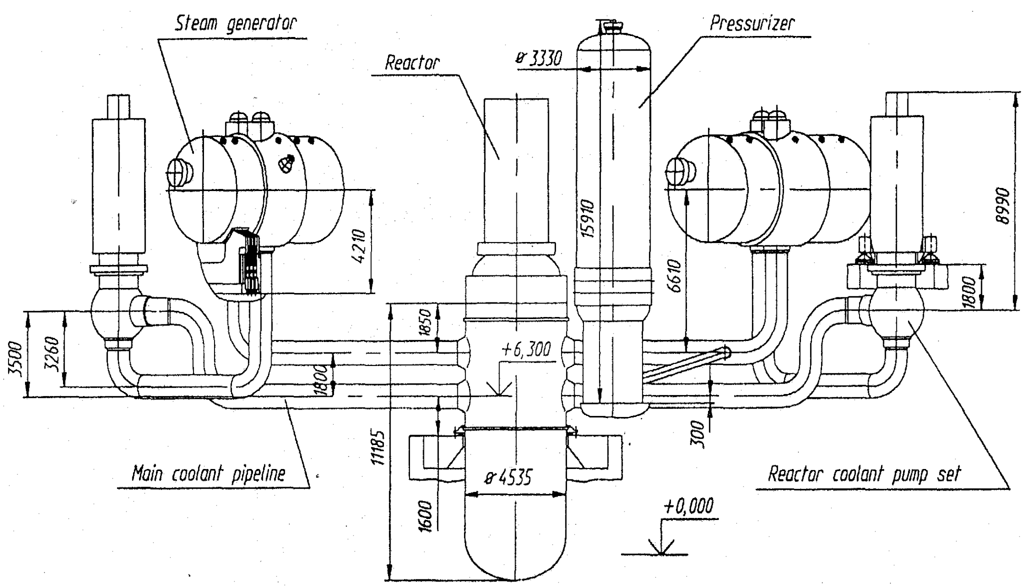

Fig.1. VVER-1000 - Scheme of primary side

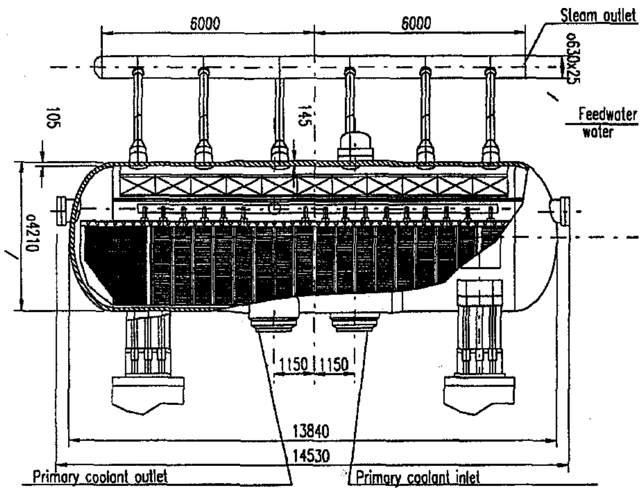

Fig.2. VVER-1000 - Steam Generator

The description of the nodalization scheme for one circulation loop of I and II circuits

1. The scheme of I circuit
1.1. Reactor (hydraulic volumes and fuel rod assembly).
1.2. Cold/Hot Leg pipe lines.
1.3. Reactor Coolant Pump (RCP) of I circuit.
1.4. Steam generator (steam generating tubes and collectors of I circuit)
1.5. Pressurizer.
1.6. Tank of emergency core cooling system (high-pressure safety injection system)
1.7. Pipeline of I circuit "Break" (leakage from the pressurizer)
1.8. System of valves for the introduction of the leakage scenario.
2. The scheme of II circuit
2.1. Feed water pump (inlet boundary condition).

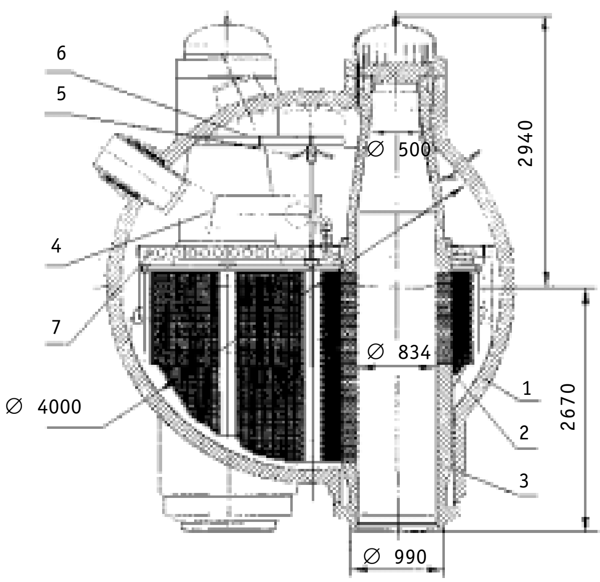

Fig. 3 VVER-1000 - Steam Generator of PGV-1000 type cross section: 1-vessel, 2-tube packet, 3 - collector, 4 - feedwater inlet, 5-separator plates, 7-perforated plates

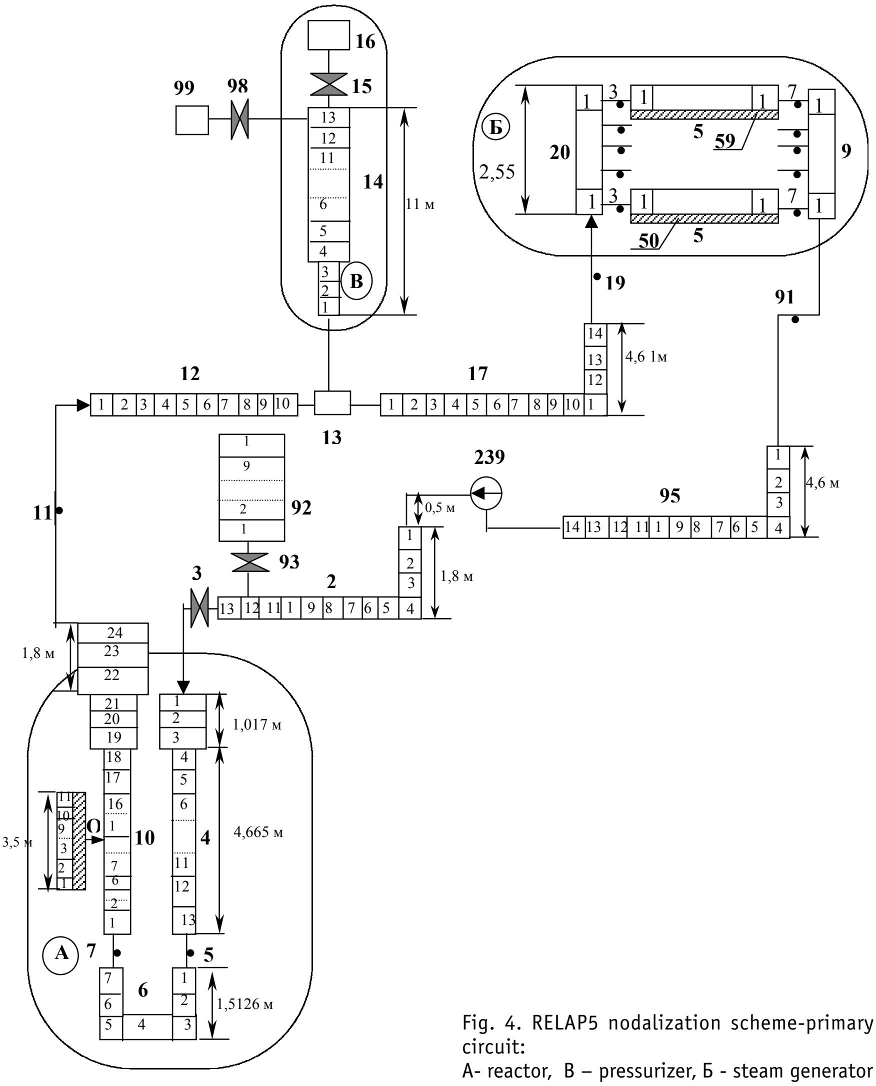

Fig. 4. RELAP5 nodalization scheme-primary circuit:
A- reactor, В – pressurizer, Б - steam generator

2.2. SG (hydraulic volumes of II circuits, separator).

2.3. Main steam lines volume (as outlet boundary condition).

The II circuit scheme is created as a linear one (without turbine, main condenser, high and low-pressure regenerative reheaters).

The fluid hydraulic of the reactor is presented as one fuel rod assembly of average power. Gap flow between fuel rod assemblies is not simulated.

The SG is presented as semi-two dimensional model. It is considered 10 groups of tubes along of SG altitude and 2 collectors in I circuit. The group of tubes describes 11000 U-tubes heat exchanger situated horizontally from hot to cold collector. The II circuit is considered as 10 segments with the natural circulation up-flow for volume between the tubes of steam generator shell. In summary, SG shell is simulated as the systems of vertical pipes and horizontal junctions (10x9 of connections are simulated for cross-flow). It includes only volumes arranged in tank between tubes with predominantly up-flow mode. Each segment is presented for heat transfer on 10 cells in accordance with subdivision of I circuit. Separator and bypass down-flow line close circuit of a multiple natural circulation in SG bulk of II circuits. Down-flow pipelines integrate volumes in central and side gaps between

Table 1

List abbreviation for Fig. 4

№ of element	Type of element in RELAP5	Designation
2,95	PIPE	"Cold" leg
239	PUMP	RCP
4	PIPE	Downcomer "annular gap"
6	PIPE	Lower Plenum
10	PIPE	Core
12,17	PIPE	"Hot" leg
13	BRANCH	Three way pipe
14	PIPE	Pressurizer(PRZ)
16	TMDPVOL	Boundary Condition for P in PRZ
20,90	PIPE	Inlet and Outlet SG Collector
50÷59	PIPE	Internal Space of SG tubes
92	PIPE	Vessel of HPSI
99	TMDPVOL	Boundary Condition for P in atmosphere
3,15,93,98	VALVE	Motor Operated Valves
101	HS	Fuel Rods of Core
501÷591	HS	SG Pipes
Other	SNGLJUN	Junctions

tube bundles with predominantly down-flow by flow of coolant and are simulated by pipe with decreasing area from top to bottom.

RESULTS OF SIMULATION

The following modes of operation were considered:

- Steady state on 100 % of power. Check of the hydraulic characteristics in I circuit at design values of nominal flow and pressure drop.
- Steady state on 10 % of power at natural circulation in I circuit with switch off RCP. The mode of an emergency heat removal through a steam generator was simulated (shutdown mode).

Table 3 shows the main parameters of VVER-1000 steam generator and calculation results after stabilization.

Pressure drop in the steam generator

The following correlations are especially important in the RELAP5 for predictions of SG heat transfer:

- Dittus-Boelter correlation for single-phase liquid convection;
- Two Chen correlations for subcooled and saturated nucleate boiling heat transfer.

The natural circulation into SG bulk has a non-regular character and is described in [1,2]. Inside SG shell there exists a mode of non-organized natural circulation, which is very complicated and difficult to predict.

There exist some methods of SG characteristic improvement. One of them is to insert baffle in the shell side. The baffles make natural circulation in the shell as organized one

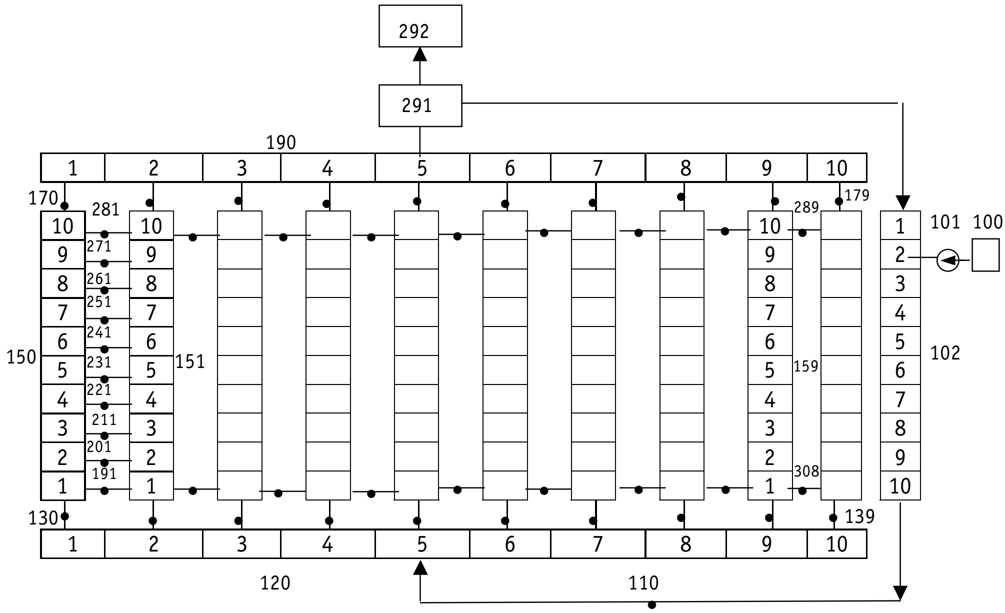

Fig. 5. RELAP5 nodalization scheme (secondary circuit- steam generator)

Table 2

List abbreviation for Fig. 5

№ of element	Type of element in RELAP5	Designation
120	PIPE	Lower Plenum
150÷159	PIPE	Shell space inside SG U-tube bundles
190	PIPE	Upper Plenum
102	PIPE	Shell space in gaps between U-tube bundles
191	SEPARATR	Shell Separator
192	TMDPVOL	Main Steam Line Boundary Condition(BC)
100	TMDPVOL	Feedwater BC
101	TMDPJUN	Feedwater Pump
130÷139, 170÷179	SNGLJUN	Shell Bottom/Top Junction
191÷289	SNGLJUN	Shell side 2D Cross flow Junction

and improve it, and moving force at baffles operation will be also increased. The results of 2 cases (non-organized and organized circulation with baffles that is without cross flow junctions) are compared for pressure and void fraction distribution in Fig. 6,7 and 8,9 respectively.

According to nodalization along x-axes there presented numbers of tube and after "-"number of cell in tube at simulation (see numbering in Fig. 4 for details). Hot collector is to the left and the cold one is to the right from the plot.

The results of pressure calculations in 10 sections of SG bulk from hot to cold collector are presented in Fig. 6. First 10 points go down due to decreasing of water-steam column.

Pressure distribution along the tube is presented in Fig. 11 and 12 for both sides. There exists horizontal almost constant distribution of pressure. Void fraction distributions

Table 3

Main design parameters of SG-1000

Parameter	Design value	Calculation
Thermal power, MW	750	750
Steam capacity (t/h)	1470	1466
Outlet steam pressure (MPa)	6.27	6.24
Primary coolant pressure at the SG inlet (MPa)	15.7	15.7
Primary coolant inlet temperature (°C)	321	326.7
Primary coolant outlet temperature (°C)	291	295
Feedwater temperature (°C)	220	220
Steam temperature (°C)	278.5	278.4
Steam humidity at the SG outlet, %	0.2	0.2

demonstrate presence of some vortexes in SG bulk. More accurate 3D-model data presented in Fig. 10 shows the same maximal values of void fraction.

Fig. 7 corresponds to organized natural circulation case with baffles. The results of calculations in 10 sections of SG bulk from hot to cold collector are presented in Fig. 7 for pressure. First 6 columns are similar to Fig. 6 but pressure drop from bottom to top is higher. Last 4 mixture columns in right bottom of Fig. 7 have 3 points with almost constant pressure due to steam column, rgh value is small at SG top near cold collector with down-flow (water goes down but steam goes up in this place). There is no horizontal constant distribution of pressure due to the influence of baffles. At the hot collector there exist up-flow movement and near cold collector there is down-flow

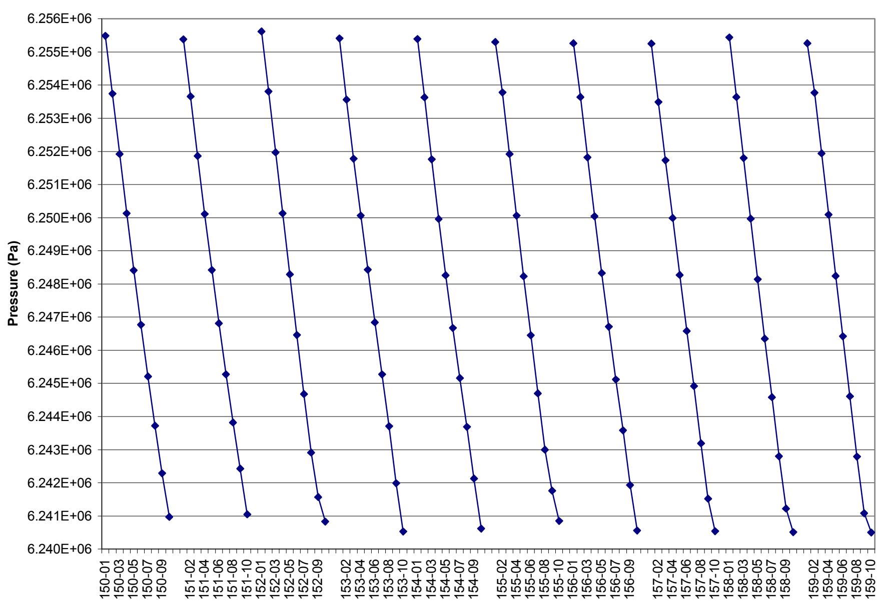

Fig. 6. Pressure distribution along the altitude of II side SG in up-flow 10 zones (for 2-dimentional case with horizontal junctions 191-289)

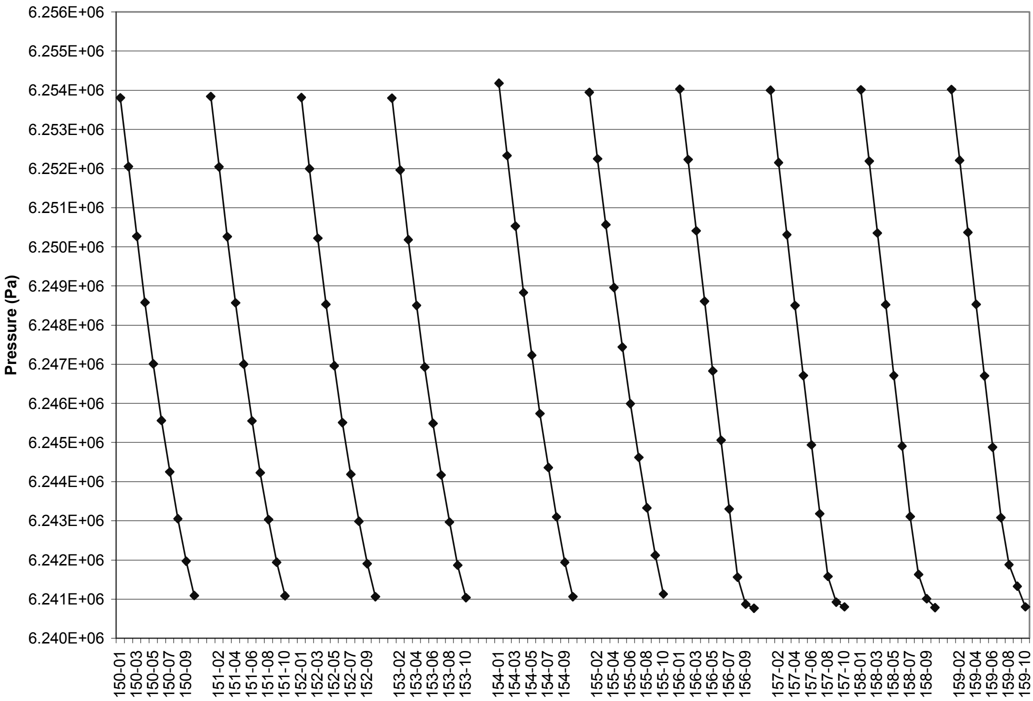

Fig. 7. Pressure distribution along the altitude of II side SG in up-flow 10 zones
(for 2-dimentional case without horizontal junctions, organized circulation)

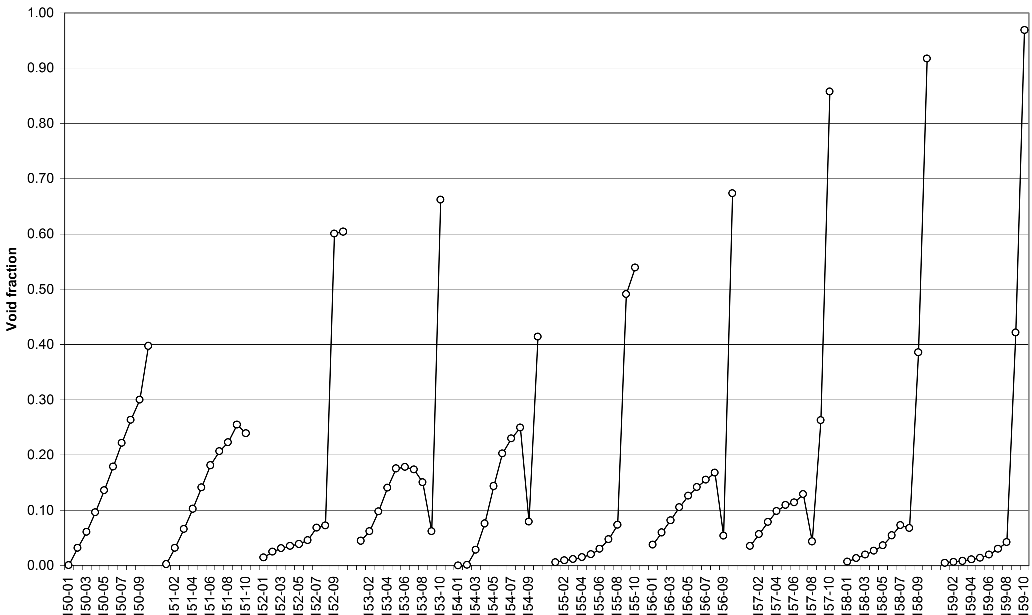

Fig. 8. Void fraction distribution along the altitude of II side SG in 10 zones
(for 2-dimentional case with horizontal junctions 191-289)

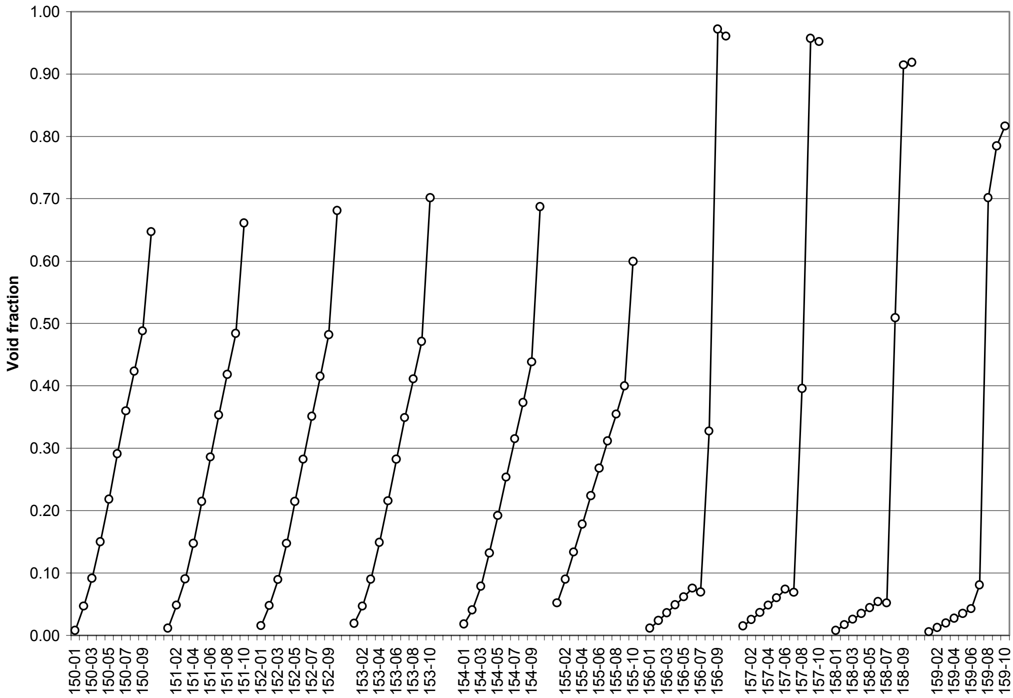

Fig. 9. Void fraction distribution along the altitude of II side SG in 10 zones
(for 2-dimentional case without horizontal junctions, organized circulation)

movement. Void fraction distribution demonstrates presence of only one organized vortex in all SG bulks instead of numerical vortexes for non-organized circulation case.

Natural circulation during shut-down mode

Paper [6] presents distribution of flow rate in steam generator in modes of its natural circulation is presented. Our calculation in this mode is presented in Fig 13. This figure shows the non-uniform velocity distribution due to the gravity force action along the altitude of SG. The results are coincide with data [6]. The results that the bottom tube group has negative velocity in comparison with nominal flow direction also coincide.

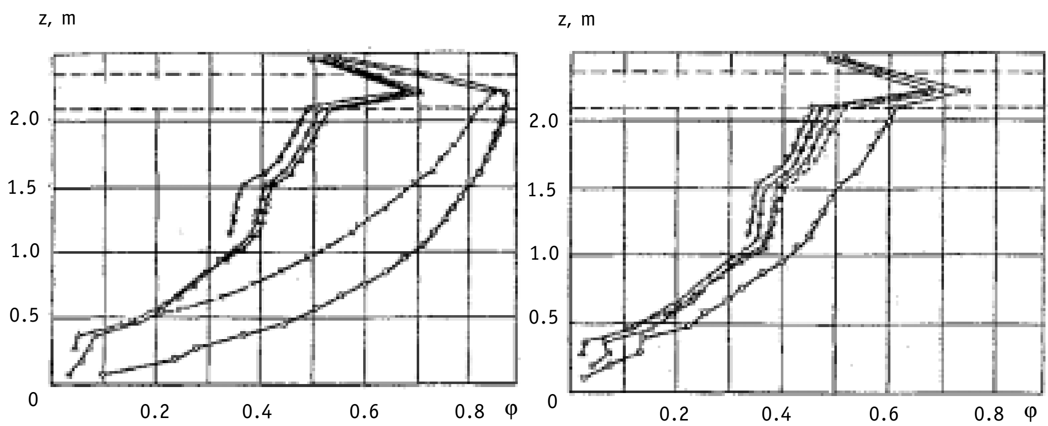

Fig. 10. Distribution of void fraction along altitude
(counting from the lower series of tubes of the main packet) from [1]

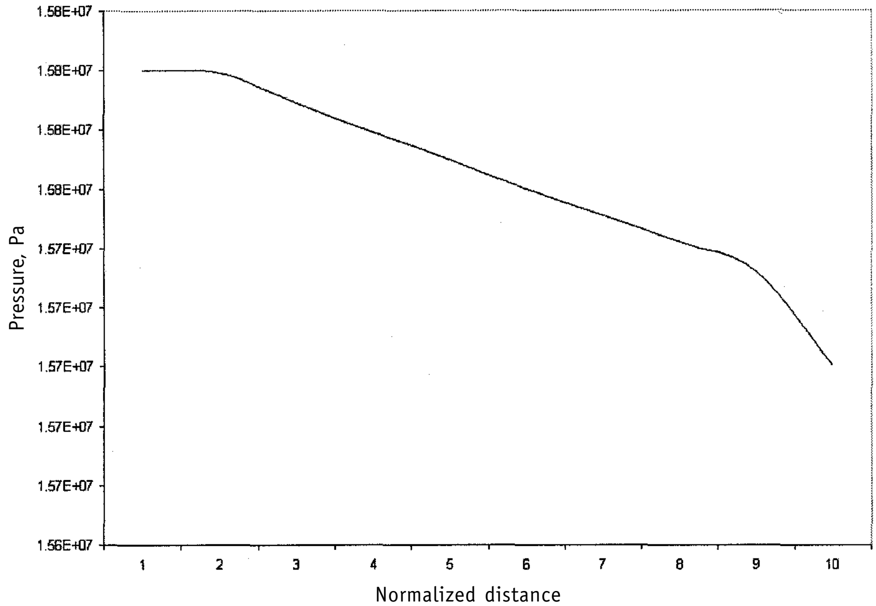

Fig. 11. Pressure distribution along the primary side SG

On the basis of schemes introduced in a Fig. 4,5 the file of INPUT data is prepared and debugged. It is valid for codes RELAP5/MOD3.1, RELAP5/MOD3.2. A volume of the INPUT file is near 120 kilobyte.

The problem was decided as non-steady, at first system came in a stable state during 200 seconds, then either the solution of a received steady-state problem was analyzed, or the emergency (leak) was simulated (due to limited volume of paper the results of leak scenario are not presented). The computer debugging of a problem was conducted in comparison to steady-state parameters with the design data from OKB "Hydropres" for nominal modes, and also matching with the data, published in the literature, on

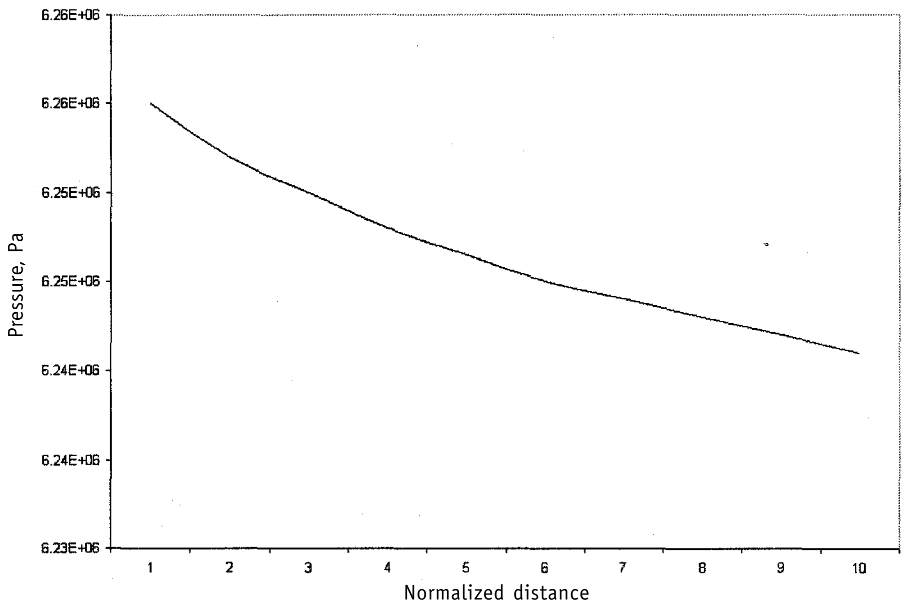

Fig. 12. Pressure distribution along the secondary side SG

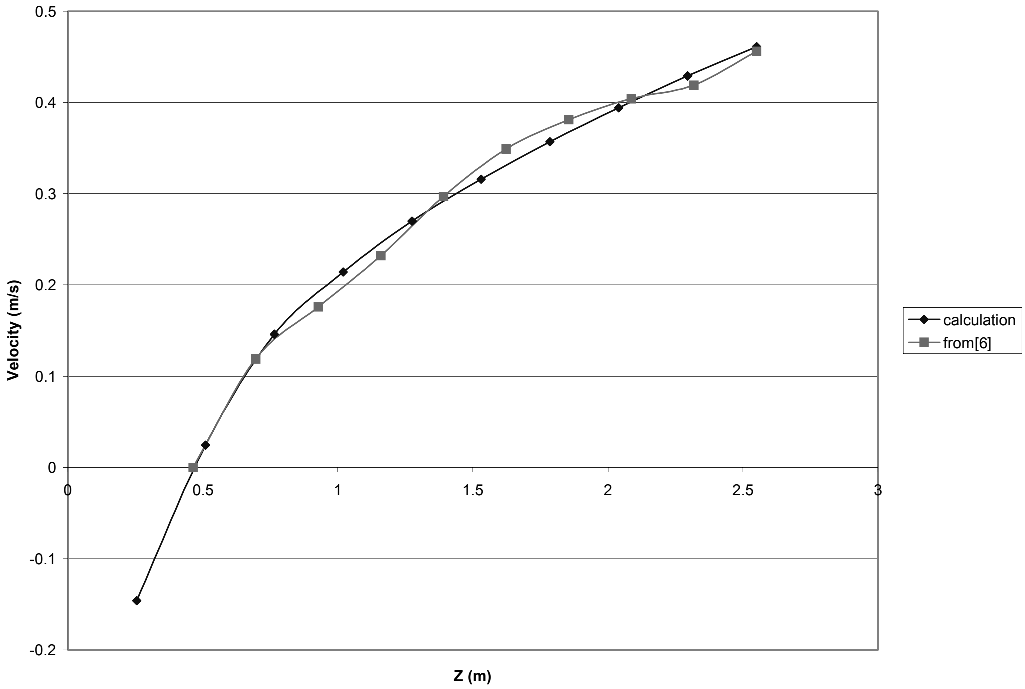

Fig. 13. Velocity distribution in the I circuit SG due to natural circulation

distributions of fields of speeds and void fraction.

The consumed computer time for problems described above is within the limits 30 minutes for one calculated variant at computer Pentium III 700 MHz.

ACKNOWLEDGMENTS

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metastable, 6 summed independent metastable plus ground, and 104 cumulative yields of radinuclide products. The experimental data were compared with theoretical yields predicted via 7 simulation codes: CEM95, CEM2k, LAHET, CASCADE, HETC, INUCL, YIELDX. Results are analyzed from a point of formation of secondary products that may be of large ecological and technological hazard.

УДК 621.039.51

Ballslayer as a core for the fast reactor\G.B. Usynin, S.G. Usynina; Editorial board of journal "Izvestia vissikh uchebnikh zavedeniy. Yadernaya energetica" (Communications of Higher School. Nuclear Power Engineering). - Obninsk, 2001. - 6 pages, 6 illustrations, 2 tableы. – References – 5 titles.

The analysis of pebbly bed conception for the fast reactor is carried out. Balls medley from plutonium oxide and depleted uranium carbide are considered. The neutronic and hydraulic characteristics of such core is given. The opportunities deep burnout of heavy nuclei are discussed in the paper.

УДК 502.3

Geoinformation System of Radioactive Contaminated Territories\B.I.Yatsalo I.A.Pichugina, G.V.Kozmin, O.A.Mirzeabassov, I.V.Okhrimenko, M.F.Kanevsky, E.A.Savelieva; Editorial board of journal "Izvestia vissikh uchebnikh zavedeniy. Yadernaya energetica" (Communications of Higher School. Nuclear Power Engineering). - Obninsk, 2001. - 5 pages, 2 illustrations, 1 table. – References – 8 titles.

Description of Geographic Information System as a part of the Decision Support System PRANA for rehabilitation of radioactive contaminated territory of Bryansk region is presented. Developed vector electronic maps and databases of attributive information are pointed out.

УДК 621.039.75

Immobilization of Radioactive Waste in Ceramet Materials by the Method of Self-propagating High Temperature Synthesis\E.N. Ilyin, I.Yu. Pashkeev, A.V. Senin; Editorial board of journal "Izvestia vissikh uchebnikh zavedeniy. Yadernaya energetica" (Communications of Higher School. Nuclear Power Engineering). - Obninsk, 2001. - 9 pages, 3 illustrations,2 tables. – References – 7 titles.

For the immobilization of solid high-level waste (HLW) to use self-propagating high temperature synthesis (SPHTS) is proposed, which allowing to raise the temperature of the reaction mixture from 1500 to 4000°C due to the heat-evolution of the chemical reactions. As a initial reaction mixture thermite mixture Fe_2O_3, Cr_2O_3, Al, SiO_2, CaO, Na_2O and CeO_2, which imitating composition of HLW is being considered. As a result of SPHTS, ceramet block is formed. Ceramet block consist of corrosion-proof iron-chromium metal matrix and ceramic matrix based on aluminates, silicates and alumosilicates. The estimation of chemical resistance of material-immobilizators, obtained by means of leaching in water has revealed their preference for the conventional borosilicate glass.

УДК 532.529

Analysis of the MAGICO and QUEOS experiments on the premixing of the clouds of particles with water with the VAPEX code \ M.V.Davydov, V.I.Melikhov, O.I.Melikhov, I.V.Parfenov; Editorial board of journal "Izvestia visshikih uchebnikh zavedeniy. Yadernaya energetica" (Communications of Higher Schools. Nuclear Power Engineering) – Obninsk, 2001. - 8 pages, 3 tables, 7 illustrations. – References, 4 titles.

The objective of the investigation was to simulate the MAGICO and QUEOS experiments devoted to the study of the melt-water premixing with the thermohydraulic code VAPEX developed at the EREC VNIIAES. The behavior of the melt drops cloud was simulated in the MAGICO and QUEOS experiments by the cloud of the metal spheres, mixing with the water under gravitational force. Both, the experiments with cold and hot particles were considered. The integral parameters, such as the velocity of the leading edge of the cloud, the mixture level dynamic, the rate of the vaporization and local values of the void fraction were compared with the experimental results. Generally, the calculation results are in a reasonable agreement with the experimental ones.

УДК 621.039.517

Relap5 Modeling of the NPP VVER-1000 Steam Generator\S.A.Rouhanifard, A.A. Kazantsev, V.V. Sergeev; Editorial board of journal "Izvestia vissikh uchebnikh zavedeniy. Yadernaya energetica" (Communications of Higher School. Nuclear Power Engineering). - Obninsk, 2001. - 11 pages, 13 illustrations,3 tableы. – References – 7 titles.

This paper deals with the application of primary to secondary heat transfer and secondary coolant vaporization process in the WWER-1000 Steam Generator for the Nuclear Power Plant. The RELAP5/MOD3.2 computer code is used for simulation of hydrodynamic and thermal parameters of the horizontal Steam Generator with U-tube heating surface. The results of steady state and natural circulation of computational analysis are presented and compared with known Steam Generator data.

УДК 543.52+615.849

Development of Technicomethodical Means for Radiometric Investigations and Dosimetric Design of Radioiodine Therapy \Yu.M. Bakun, A.S. Apyan, N.N. Lyannoy, E.S. Matusevich, N.G. Shishkanov, R.A. Roziev; Editorial board of journal "Izvestia vissikh uchebnikh zavedeniy. Yadernaya energetica" (Communications of Higher School. Nuclear Power Engineering). - Obninsk, 2001. - 7 pages, 5 illustrations, 1 table. – References – 6 titles.

The measuring tracer and treatment radionuclide (^{131}I) activities device and method to ensure reliable and high accuracy of measuring results of iodine activity in the thyroid in courses of tracer research and therapy is presented in this paper.