3D TRANSIENT CALCULATIONS OF PGV-1000 BASED ON TRAC

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ABSTRACT

3D transient simulation is one of best methods to understand comllex phenomena inside this horizontal steam generator. Such calculations are presented in report for PGV-1000M.

Main results of work was next:

1. There was shown by analysis the applicability of code TRAC (Los-Alamos laboratory) for thermal - hydraulic calculations of horizontal steam generator PGV-1000M. Spesial nodalization scheme was developed for this purposes.

2. Validation and selection of thermal-hydraulic correlations for provement of using the code at calculation PGV-1000M were performed. As result Labuntsov formula is recommended for horizontal SG.

3. Calculations of nominal mode operation of PGV-1000M for cross-verification with code STEG (EREC Russia) during its verification were performed. Solution by TRAC was obtained for transient problem after stabilization time.

4. Development of dynamic SG model as conjugate problem (thermal hydraulic of I and II circuits are calculated together) for research of the transient and acident processes stipulated by safety standards for NPP with VVER-1000 and VVER-1500.

5. Creating of calculation program complex on the basis of code TRAC for the purposes of the analysis and optimization of a design. Development graphic pre- and postprocessor for code TRAC.

6. The TRAC code allows to use correlation Zukauskas for friction factors in tube bundles through the initial data. Using postprocessing calculations and restart mode iterations allows to use Kolbasnikov's correlations for fliction factors for biphasic mode in tube bundles.

KEYWORDS

Horisontal Steam Generator, PGV-1000M, Code TRAC, Cross-verification, Pre- and Postprocessor, 3D transient calculation, bubble boiling.

1. INTRODUCTION

The Russian FSUE OKB "GIDROPRESS" is working regularly on correspondence to the international quality standards in the field of safety in nuclear power for steam generators. It is important in connection with participation on the international market of reactors VVER type. Cross-verification calculations can be presented in final volume of safety analysis report between the Russian code and also the code licensed abroad in the field of atomic engineering, such as code TRAC.

FSUE OKB "GIDROPRESS" is considered as one of basic Russian code for SG the code STEG (EREC Russia) (Trunov e.a. 2001, 2004).

Model for PGV-1000M (Sergeev and Kazantsev 2004) was developed on the basis of code TRAC for cross-verification calculations with code STEG. Code TRAC is the universal two - phase code (Spore e.a. 1990) specially created for the solving the problems, necessary for proving the safe operation of NPP with water coolant. At the same time the frame of code TRAC allows us to use the Russian correlations of friction factors, through the initial data being calculated according to them. In FSUE IPPE Russia the code TRAC was transferred from operation system UNIX on widely widespread system WINDOWS.

Developed mathematical model of PGV-1000 includes a conjugate thermal - hydrodynamic problem on I and to II circuits with the thermal connections through packages of tubes. Thus the primary circuit is considered in multi - channel 1D approach with hydraulic non-uniformity of flow rates between calculated groups of tubes having different lengths. The hydrodynamics of coolant in SG vessel is presented in 3D approach on the basis of model of an anisotropic porous body. Scope of simulation includes the packages of tubes, collectors of primary circuit, underwater porous sheet (UPS), spacer grids and supporting structures for tube and grids. External pipelines include systems of main steam collector, make - up water tubes and collector of feed water and SG blow down system pipes. Subdivision of calculation volume for the case in accepted Cartesian geometry is equal to X, Y, Z = 45, 32, 31 cells.

The calculations for nominal mode operation were performed by method of transient calculation up to steady conditions on the basis of the developed model. Also the calculation of transient accident mode connected to drop of SG level was carried out for accident with stop of feed water flow rate.

The solution of similar 3D problem demands using of graphic pre- and postprocessors. Developers of code TRAC did not deliver the postprocessor because of impossibility to make universal such development for all operation systems and recommend to users to do it by them. Postprocessor Fieldview for code TRAC, under OS WINDOWS, was written in Simulation System (SSL Russia, Obninsk) that has enabled to increase an overall performance and to receive a product at a level close to other modern codes. The postprocessor allows to receive fields of vector and more than 40 scalar components in graphic and as digital form, being calculated both in a code, and in the postprocessor, and these fields can be written down also in a tabulated digital kind in files.

Results of calculations were used in FSUE OKB GIDROPRESS for cross- verifications of Russian code STEG with code TRAC, with reference to the analysis of modernized project PGV-1000M.

Influence of thermal physic correlations on results of calculation was investigated

2. SPECIFIC FEATURES OF THERMAL HYDRAULIC IN HORIZONTAL SG

From the point of view of modeling the thermal hydraulic processes, essential features of horizontal SG, in comparison with vertical SG with natural circulation of coolant are the following.

1.Difference of lengths of heat exchange tubes results to essential non-uniformity of flow rates distribution on the primary circuit that generates change of heat-transfer coefficients, increasing a range of non-uniformity of local specific heat fluxes up to values $q_{max}/q_{min} \approx 10 \div 12$ (Trunov e.a. 2001).

2.Absence of organized natural circulation circuit on the second circuit results in an appreciable output of a steam from warmed packages in corridors. In addition there observed the effect of steam capture at downstream movement of a liquid in the bottom parts of corridors. It significantly complicates the analysis of a picture of circulation.

3.Models of slip between phases and wall friction have the principal importance for SG with natural circulation. As a rule, they are verified on tubes and fuel rod assemblies' simulators. Strictly speaking, it does not correspond to conditions of a transversal external flow for heat exchanger tubes for two-phase stream in volume of PG.

4.3D non-uniformity of hydrodynamics and heat exchange generate rather essential non-uniformity into void fraction in water volume of PG vessel.

The mentioned aspects put forward series of specific demands to thermal hydraulic codes used for calculation of processes for modeling in horizontal steam generators.

3. BRIEF REVIEW OF THERMAL HYDRAULIC CODES

In table 1. there is given the list of the calculation codes used for modeling of horizontal SG.

Code	Relap5/ Mod3.2	TRAC	STEG	BAGIRA	3D ANA	FLUENT 4.5/2
Developer	USA, Idaho	USA, Los-Alamos	Russia, EREC	Russia, VNIIAES	Germany	USA
References	(RELAP5/ MOD3 1995)	(Spore e.a. 1990)	(Trunov e.a. 2001, 2004)	(Kalinichenko, Kroshilin e.a. 2003)	(Stevanovic , Kiera e.a. 2002)	(Fifth International Seminar 2001)
Type of model	1D и semi-3D (cross-flow)	1D and 3D	3D	1D and 3D	3D	3D
Structure of phases	2 (water, steam, non condensable gases)	2	2 and impurity	2	2	Arbitrary (including streams of solid particles)
Models of slip between phases	Drift flow	Friction between phases	Friction between phases	1. drift flow 2. Friction between phases	Friction between phases	Friction between phases
Model of friction	Homogeneous model	Separate on phases and homogeneous model	Separate on phases and homogeneous model	1.Homogeneous model 2. Separate on phases	Separate on phases	Separate on phases
Model of heat transfer at bubble boiling	Chen formula	Chen formula	Not used directly	LabyntsovD.A. correlation	Labyntsov D.A. correlation	No data
Model of turbulence	no	no	no	I order	No	II order (k-ε)
Experience of application to PGV - 1000	RRC KIAE, IPPE Obninsk	IPPE Obninsk	EREC , OKB Gydro-press	VNIIAES Moskow	Germany, Fram-atome	Finland test problems

Table 1: Characteristics of thermal hydraulic codes

Remark. Abbreviations in Table 1 are explained in item Nomenclature below

.

From Table 1 it is visible that all 3D codes used for SG calculation at present have similar correlations and correspond to modern statte of arts. All codes use model friction betven phases instead of slip model of drift flow. As model of friction there is used separate on phases and homogeneous model. Now only STEG code use Kolbasnikov's correlations for fliction factors for biphasic mode in tube bundles. This correlation was based on special experiments in tube bundles similar to horizontal SG packets. Model of heat transfer at bubble boiling is presented by Chen formula and Labyntsov correlation (Russian). Comparison between them is presented below.

4. SYSTEM OF THE EQUATIONS IN CODE TRAC AND USED CORRELATIONS

System of the equations in used by us version of code TRAC-PF1/Mod.2 v. 5.4.15 are described in manual (Spore e.a. 1990). It is used non-stationary, three-dimensional, the non-equilibrium mathematical model of two -phase flows from 6 equations. Our model was homogeneous .

Used correlations during initial data preparations and existed in code TRAC are presented in the Table 2.

Correlation	Comment
Friction factors for tube bundles	Zhukauskas correlations (Petukhov e.a. 1987) for different type of flow in tube bundles
Interphase factors of friction	On the basis of calculation of interphase friction forces and map of flow modes at φ<0.5 –the model of friction of single bubble into flow with sub ranges according to void fraction φ; at φ;>0.75 – friction model stratified flow; 0.5<φ<0.75 - interpolation between models.
Bubble mode heat transfer	Chen formula
Forsed convection heat transfer in I circuit	Dittus - Boelter correlation

Table 2: Used correlations

5. DESCRIPTION OF MODEL PGV-1000M BASED ON CODE TRAC

The model of PGV-1000M, with reference to the purposes of cross - verifications on nominal mode operation, and also for the analysis of transient and emergency processes is developed on the basis of code TRAC taking into account the demands given in the first section.

The model of steam generator includes:

1. Conjugate problem of heat transfer and hydrodynamic on I circuit and II circuit with taking into account thermal inter - connections and as non steady state task.
2. 3D Model of hydrodynamics on II circuit on the basis of anisotropic - porous medium in the Cartesian system of coordinates.
3. 1D multi - channel model of hydrodynamics of tube bundle on I circuit with 3D collectors.
4. 1D transient model of heat conductivity for heat transfer through tube bundle steel.
5. For calculation of slip between phases the model of interphase friction of code TRAC is used with correspondent map of flow modes.
6. The homogeneous model was used on the basis of correlation Zhukauskas (Petukhov e.a. 1987) was used for calculation of wall friction into tube bundles for two phase mixture.
7. Calculations of heat transfer coefficients were carried out as on standard correlations of TRAC code (Chen and Dittus - Boelter), and in the modified variant under the Labuntsov formula.
8. The following design elements are modeled in the scheme for calculation: 4 packages of tubes with subdivision on 172 groups having various lengths, two 3D collector of I circuit, 21 space grid with supports, underwater porous plate (UPP) with one gap between wall and plate situated on a cold half of vessel (PGV-1000M), 15 separator plates in UPP part, systems of a feed water, main steam pipeline system header and blow down pipelines. The cylindrical form of the SG vessel was satisfied and described in the Cartesian coordinate system taking into account the elliptic form of end faces in 3D vessel.

Number of cells of 3 dimensional grids on II circuit makes 44640 items.

The calculation scheme is shown in the Fig. 1.

In figures 2, 3 it is presented the calculation scheme of steam generator on 2 circuit.

Subdivision of tube bundle surface on heat transfer cells is presented in Fig. 4

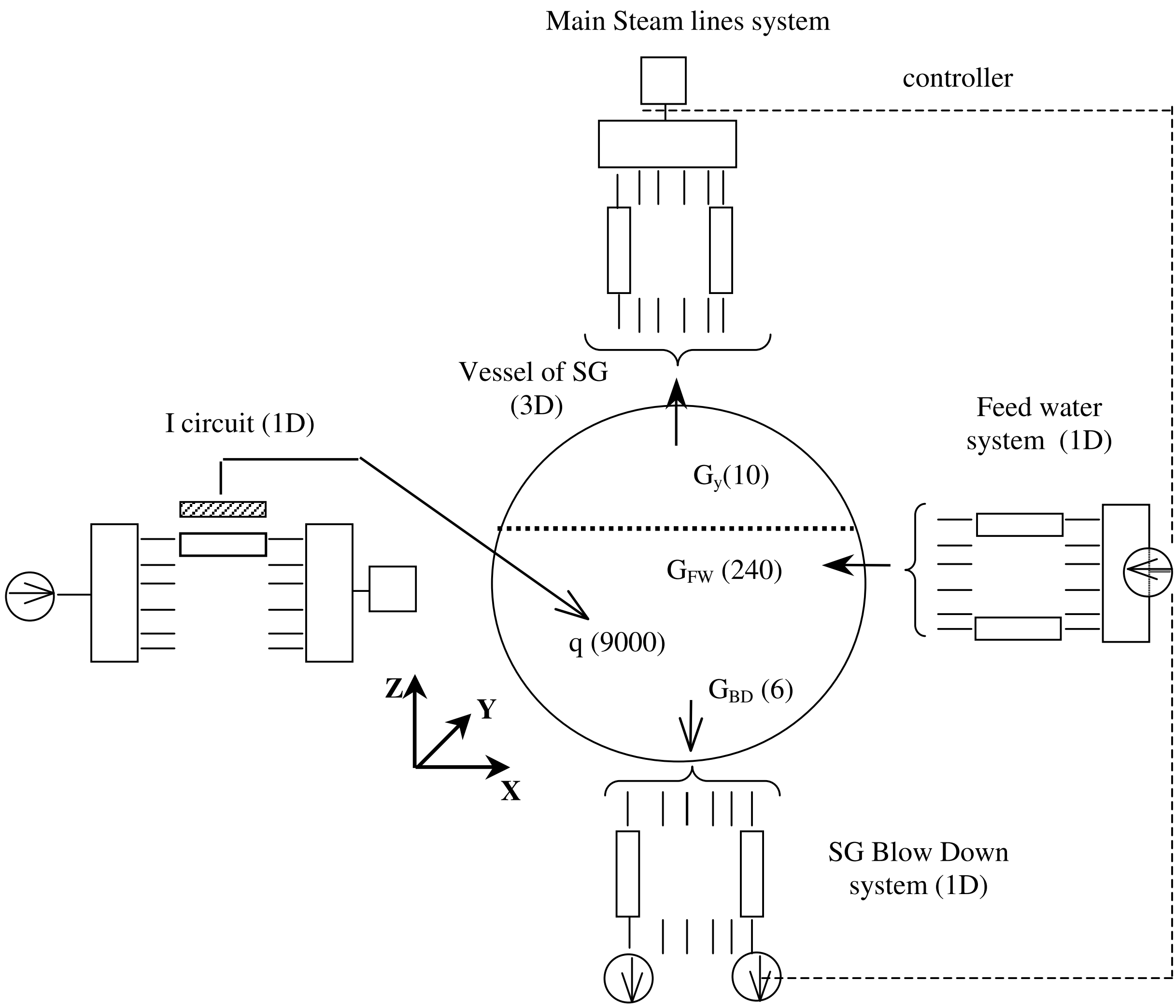

Figure 1: Calculation scheme of steam generator PGV-1000M.

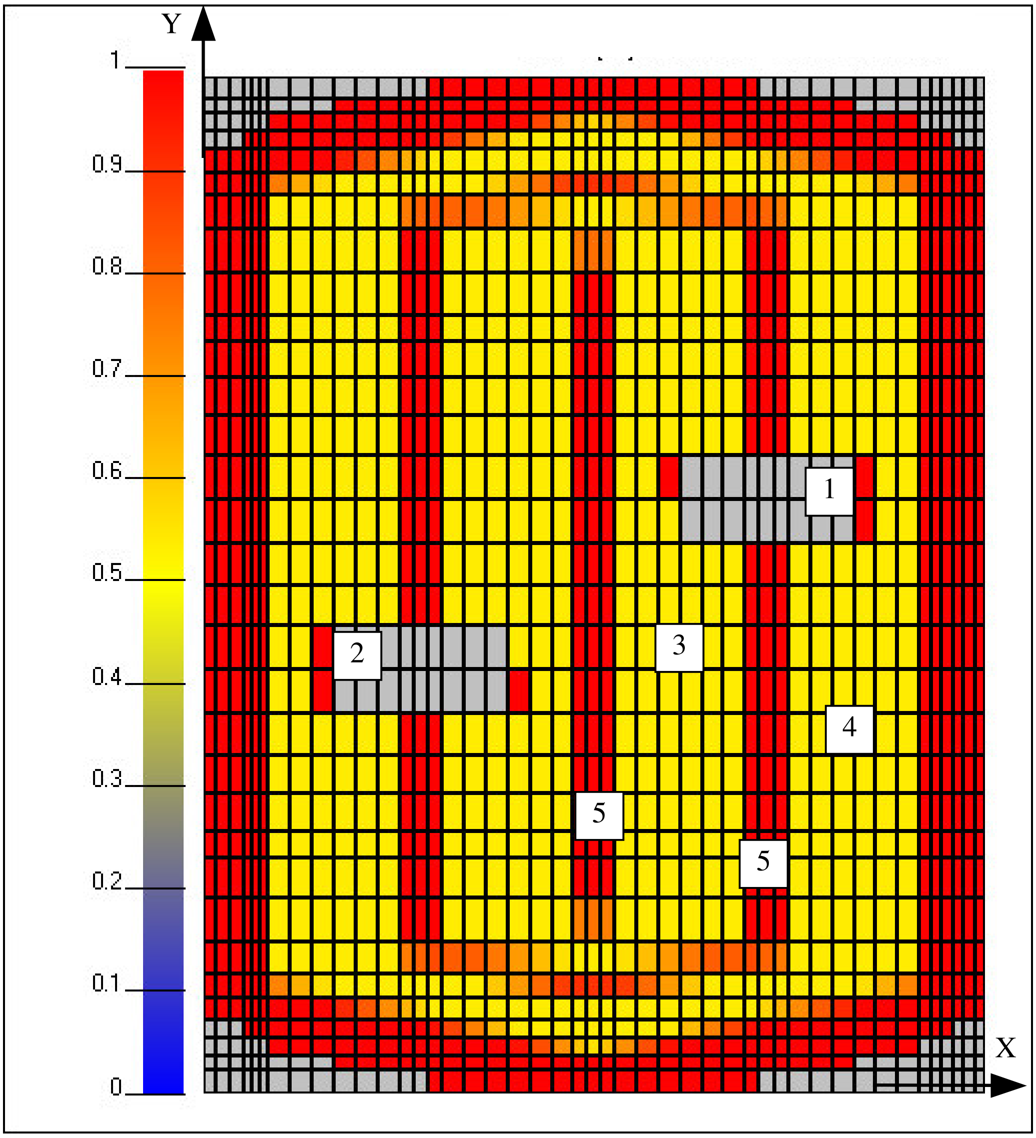

Figure 2: Calculation diagram of SG vessel in plane X-Y. Section at mark Z=2,19 m (section of top level of tube bundles). 1-Hot header. 2-Cold header. 3- Central packet. 4-Peripheral packet. 5-Corridors. Volumetric coefficient of porosity is shown by color.

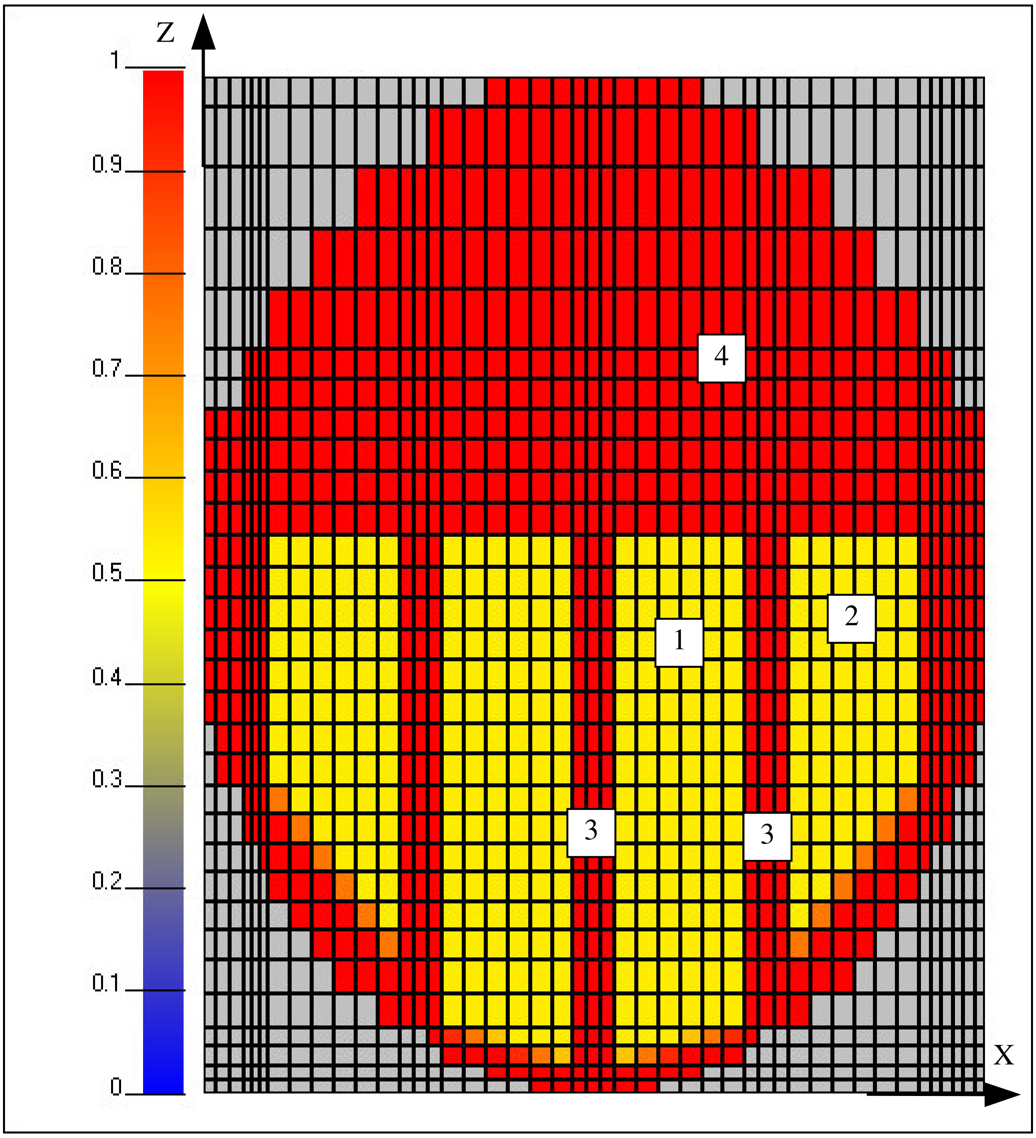

Figure 3: Calculation diagram of SG vessel in plane X-Z. Section Y=7,0 м (section between collectors). 1-Central packet. 2-Peripheral packet. 3-Corridors. 4- Gas volume. Volumetric coefficient of porosity is shown by color

	Y=1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	
45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	45
44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	44
43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	43
42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	42
41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	41
40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40
39	0	0	0	0	0	421	420	419	418	417	416	415	414	413	412	411	410	0	0	705	706	707	708	709	710	711	712	0	0	0	0	0	39
38	0	0	0	0	0	422	454	453	452	451	450	449	448	447	446	445	444	0	0	739	740	741	742	743	744	745	713	0	0	0	0	0	38
37	0	0	0	0	0	455	487	486	485	484	483	482	481	480	479	478	477	0	0	772	773	774	775	776	777	778	746	0	0	0	0	0	37
36	0	0	0	0	423	456	488	518	517	516	515	514	513	512	511	510	509	0	0	804	805	806	807	808	809	779	747	714	0	0	0	0	36
35	0	0	0	0	424	489	519	549	548	547	546	545	544	543	542	541	540	0	0	835	836	837	838	839	840	810	780	715	0	0	0	0	35
34	0	0	0	0	457	490	520	579	578	577	576	575	574	573	572	571	570	0	0	865	866	867	868	869	870	811	781	748	0	0	0	0	34
33	0	0	0	0	458	521	550	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	841	812	749	0	0	0	0	33
32	0	0	0	0	491	522	580	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	871	813	782	0	0	0	0	32
31	0	0	0	0	492	551	581	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	872	842	783	0	0	0	0	31
30	0	0	0	425	523	552	0	606	605	604	603	602	601	600	599	598	597	0	0	892	893	894	895	896	897	0	843	814	716	0	0	0	30
29	0	0	0	426	524	582	0	607	625	624	623	622	621	620	619	618	617	0	0	912	913	914	915	916	898	0	873	815	717	0	0	0	29
28	0	0	0	459	553	583	0	626	645	644	643	642	641	640	639	638	637	0	0	932	933	934	935	936	917	0	874	844	750	0	0	0	28
27	0	0	0	460	554	0	608	646	663	662	661	660	659	658	657	656	655	0	0	950	951	952	953	954	937	899	0	845	751	0	0	0	27
26	0	0	427	493	555	0	627	664	680	679	678	677	676	675	674	673	672	0	0	967	968	969	970	971	955	918	0	846	784	718	0	0	26
25	0	0	428	494	556	0	628	681	697	696	695	694	693	692	691	690	689	0	0	984	985	986	987	988	972	919	0	847	785	719	0	0	25
24	0	0	461	525	584	0	647	698	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	989	938	0	875	816	752	0	0	24
23	0	0	462	526	585	0	665	682	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	973	956	0	876	817	753	0	0	23
22	0	0	463	527	586	0	648	699	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	990	939	0	877	818	754	0	0	22
21	0	0	429	495	557	0	629	683	700	701	702	703	704	0	0	999	998	997	996	995	994	993	992	991	974	920	0	848	786	720	0	0	21
20	0	0	430	496	558	0	630	666	684	685	686	687	688	0	0	983	982	981	980	979	978	977	976	975	957	921	0	849	787	721	0	0	20
19	0	0	0	464	559	0	609	649	667	668	669	670	671	0	0	966	965	964	963	962	961	960	959	958	940	900	0	850	755	0	0	0	19
18	0	0	0	465	560	587	0	631	650	651	652	653	654	0	0	949	948	947	946	945	944	943	942	941	922	0	878	851	756	0	0	0	18
17	0	0	0	431	528	588	0	610	632	633	634	635	636	0	0	931	930	929	928	927	926	925	924	923	901	0	879	819	722	0	0	0	17
16	0	0	0	432	529	561	0	611	612	613	614	615	616	0	0	911	910	909	908	907	906	905	904	903	902	0	852	820	723	0	0	0	16
15	0	0	0	0	497	562	589	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	880	853	788	0	0	0	0	15
14	0	0	0	0	498	530	590	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	881	821	789	0	0	0	0	14
13	0	0	0	0	466	531	563	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	854	822	757	0	0	0	0	13
12	0	0	0	0	467	499	532	591	592	593	594	595	596	0	0	891	890	889	888	887	886	885	884	883	882	823	790	758	0	0	0	0	12
11	0	0	0	0	433	500	533	564	565	566	567	568	569	0	0	864	863	862	861	860	859	858	857	856	855	824	791	724	0	0	0	0	11
10	0	0	0	0	434	468	501	534	535	536	537	538	539	0	0	834	833	832	831	830	829	828	827	826	825	792	759	725	0	0	0	0	10
9	0	0	0	0	0	469	502	503	504	505	506	507	508	0	0	803	802	801	800	799	798	797	796	795	794	793	760	0	0	0	0	0	9
8	0	0	0	0	0	435	470	471	472	473	474	475	476	0	0	771	770	769	768	767	766	765	764	763	762	761	726	0	0	0	0	0	8
7	0	0	0	0	0	436	437	438	439	440	441	442	443	0	0	738	737	736	735	734	733	732	731	730	729	728	727	0	0	0	0	0	7
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
x=1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	x=1
	Y=1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	

Figure 4: Scheme of arrangement of cells for solution of conjugated (between I and II circuits) heat transfer problem. Top view from top level of tube bundles. Tube groups connected in primary circuit are shown by similar colors. "Hot" and "cold" collectors are situated in top and bottom of scheme correspondently.

6. DEVELOPMENT OF GRAPHIC PROGRAMM PACKET

There no any doubt in necessity of using the graphic methods of work (preprocessor and postprocessors) if one use the 3D code with cell number more than 10^4 calculation nodes.

Developers of TRAC code don't deliver the graphical programs for calculation result treatment. In SSL was performed development of special program packet Fieldview (it includes programs Fieldview, TracBin, PreVessel) designed for next purposes.

1. Program packet Fieldview performed output of fields 3D matrixes of initial data for preprocessor graphical treatment (typing error checking for 3D arrays of initial data such as porosity coefficients, hydraulic resistances, hydraulic diameters and so on).
2. Visual control of transient and convergence process on calculated fields vectors (6 component) and scalar (nearby 40 parameters) 3D fields.
3. Obtaining of results for local characteristics for multidimensional (2D and 3D) fields of vector and scalar values in graphical and digital forms.

Output information can has some forms:

a. Graphical file of results for interactively selected 2D cross-section in form of colored maps (in colored view or as arrows for velocity components for every of phases).
b. Output data in digital form for selected two-dimensional section with colored digits according to selected scale. Given method is suitable for next treatment by other codes and graphical applications.

In the list of processed parameters for I and II circuits were included: 3D arrays of velocity components of vapor and liquid or component of velocity multiplated on void fraction , void fraction, temperatures of liquid and gas phases, saturation temperature, pressure, saturation pressure, quality of steam, density of phases and mixture, slip factor, specific heat flux, distribution of heat transfer coefficients in every circuit values of specific heat fluxes to every phase and total heat flux and some other parameters.

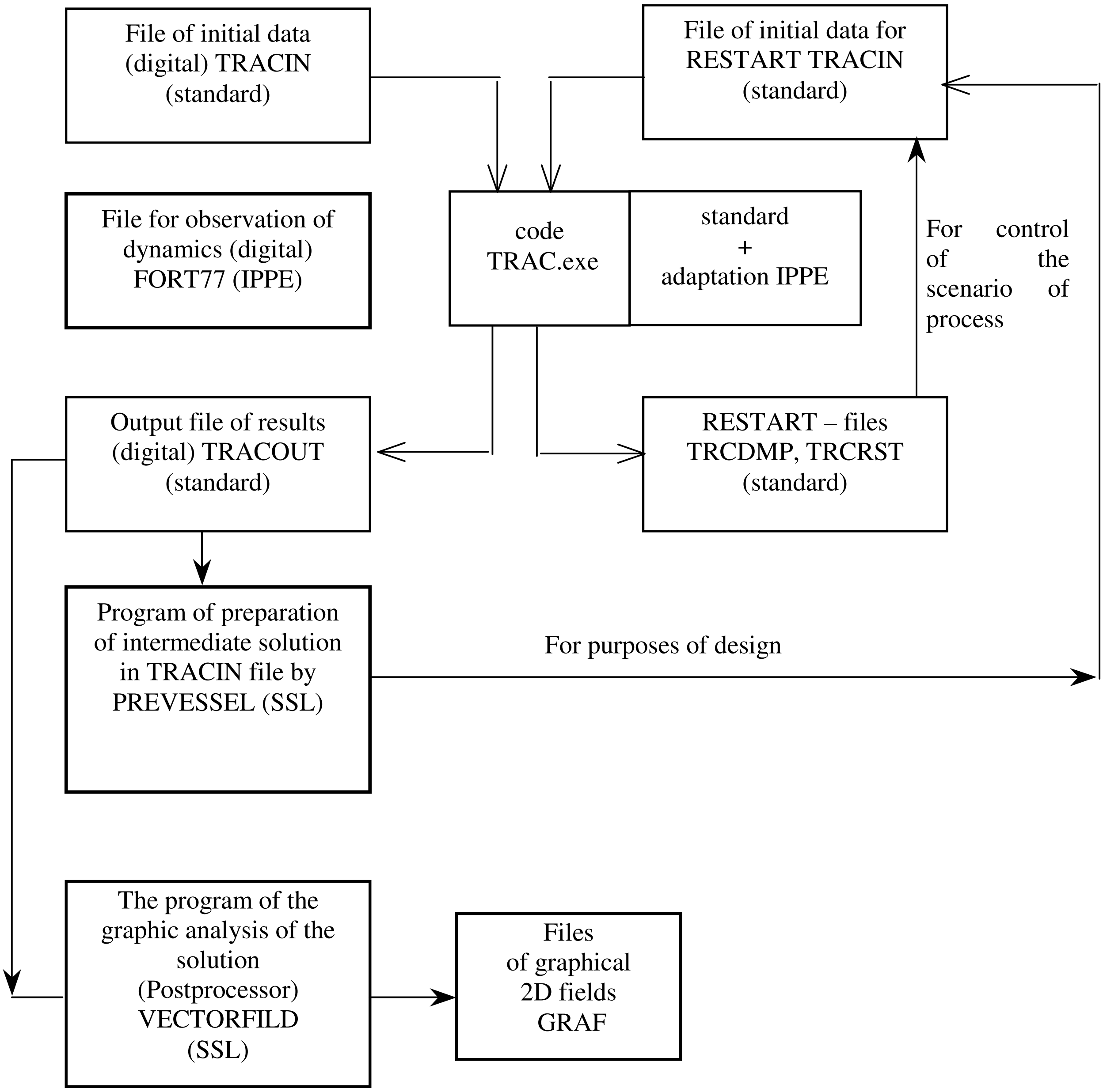

Figure 5: Block-diagram of the computer complex of programs

7. SOME RESULTS OF CALCULATIONS FOR DESIGN MODE OPERATION

Calculation of nominal mode operation of SG was carried out by the solving of transient conjugate problem by method of finding of steady state condition at the given nominal flow rates and temperature of the coolant in I circuit. Thus as the initial data parameters there were used data of project PGV-1000M.
results of calculations of local parameters of PGV-1000M are presented in Table 3.

Parameter	Place	Calculation by TRAC
Specific heat flux (on an external surface of steam generating tubes).	Integrated average	128 kW/m^2
	The central package in "hot collector" region	254,4 kW/m^2
	The peripheral package in "cold collector" region	23 kW/m^2
Heat transfer coefficient in primary circuit side.	The central package in "hot collector" region	31,6 kW/m^{2}K
	The peripheral package in "cold collector" region	26,2 kW/m^{2}K
Heat transfer coefficient in second circuit side.	The central package in "hot collector" region	42,2 kW/m^{2}K
	The peripheral package in "cold collector" region	9,30 kW/m^{2}K
Void fraction	The central package in "hot collector" region	0,76
	The peripheral package in "cold collector" region	0,19
Mixture mass flow rate	"Hot collector" region	240 (kg/m^{2}s)
	"Cold collector" region	118 (kg/m^{2}s)
Non uniformity of outlet temperature in I circuit	Exit from tubes to "cold collector"	8 K

Table 3: Calculated local parameters of PGV-1000M

The wide part of map flow is presented in natural circulation circuit inside vessel due to the wide range of void fraction change is observed in calculations as visible from given Table 3.
Results show, that practically at all volume of the vessel of below physical level there exist steam phase. In all packages the void fraction mainly grows with height increasing. Thus maximal void fraction equal to φ=0,76 is observed on an output from the central hot tube package in the central part of the vessel.

For corridors the maximum void fraction is on an output from the hot corridor in the central part of the vessel (φ=0,54).

Integral calculated parameters of PGV-1000M were close to design values. Calculated total mass flow rate of outlet steam equal to 410 kg/s was close to the design value of 408 kg/s. Calculated SG thermal power equal to 755 MW was close to design value of 750 MW.

On Fig 6, 7 there are presented the colored map of void fraction and arrows of liquid and gas velocity component in the SG middle section between "hot" and "cold" collectors. Velocity scale arrow is below write under map. The picture of circulating flow is shown on figures for section of middle of the vessel in plane X-Z section.

Results of calculations show, that natural circulation in PGV-1000M has complex character, thus circulation in tube packages is interconnected with circulation through underwater porous plate.

In tube packages there exists mainly upstream flow of steam-and-water mixture with appreciable value of slip coefficient between steam and liquid phases.

In corridors movement of mixture has complex both upstream and downstream character connected, on the one hand, with the phenomenon of an output of steam from tube packages in corridors and on the other hand, with capture of a steam by water at downstream flow. Besides in some parts of corridors the sign-variable (up - down) character of movement is observed.

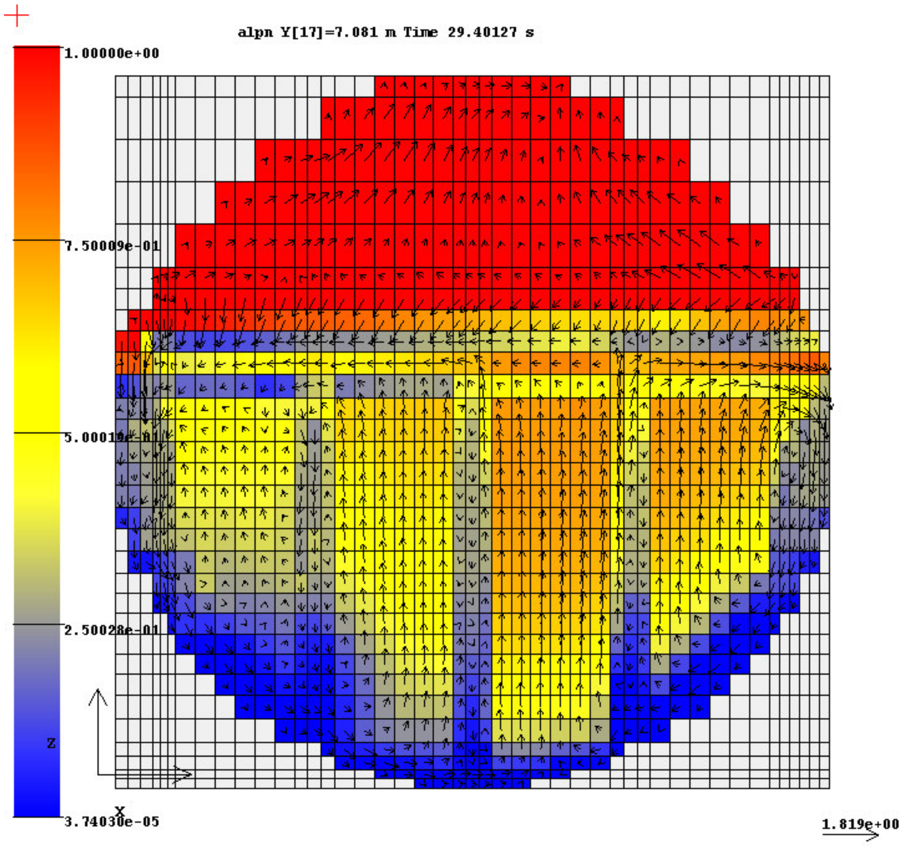

Figure 6: Colored map of void fraction and arrows of liquid velocity component is for the SG middle section between "hot" and "cold" collectors. Velocity scale in m/s arrow is below write under map.

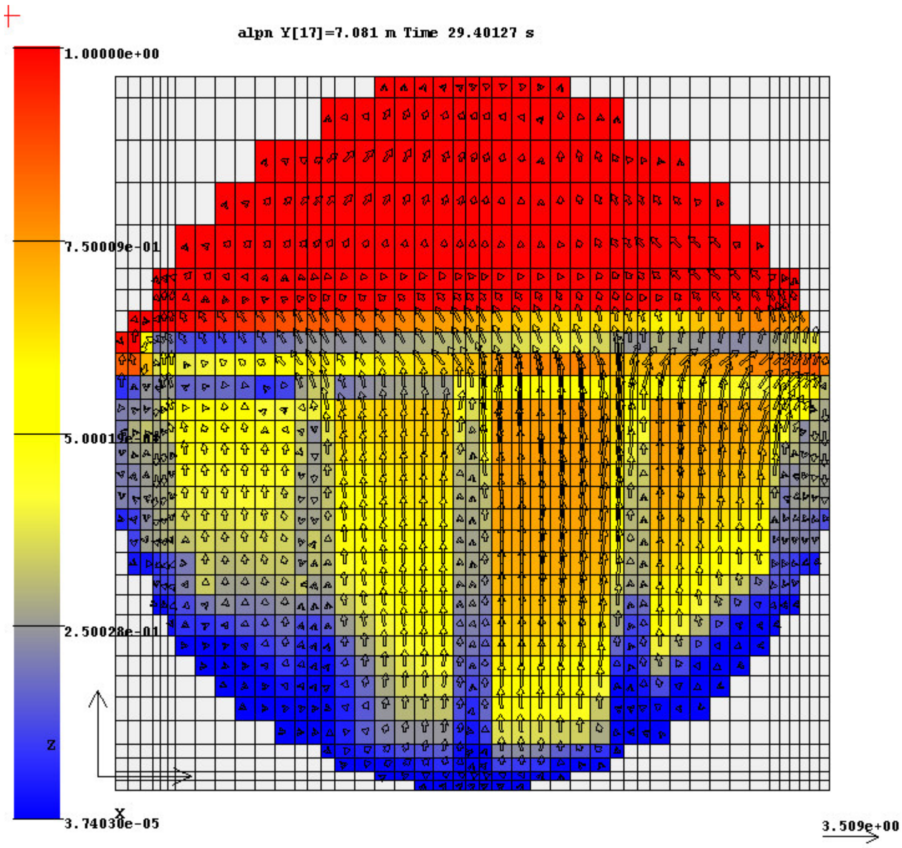

Figure 7: Colored map of void fraction and arrows of steam velocity component is for the SG middle section between "hot" and "cold" collectors. Velocity scale arrow in m/s is below write under map.

It is exist down flow current of liquid between vessel wall and edge of underwater porous plate. The feed water goes down to the vessel bottom and flows to bottom part of tube packages of a cold half and to the central hot package. Therefore water together with the steam rises up to underwater porous plate. By influence of this circulation circuit one can explain phenomena that in a peripheral cold package on the external side takes place down flow movement of a liquid inside a package in conditions of a small heat fluxes in this zone.

The peripheral hot package has an own circulating cycle of water around of itself as on the part of hot collector underwater porous plate touches the vessel wall. It results in an asymmetrical picture of flow. As result, on the external side of a peripheral hot package there is observed appreciable cross flow of liquid to wall of vessel.

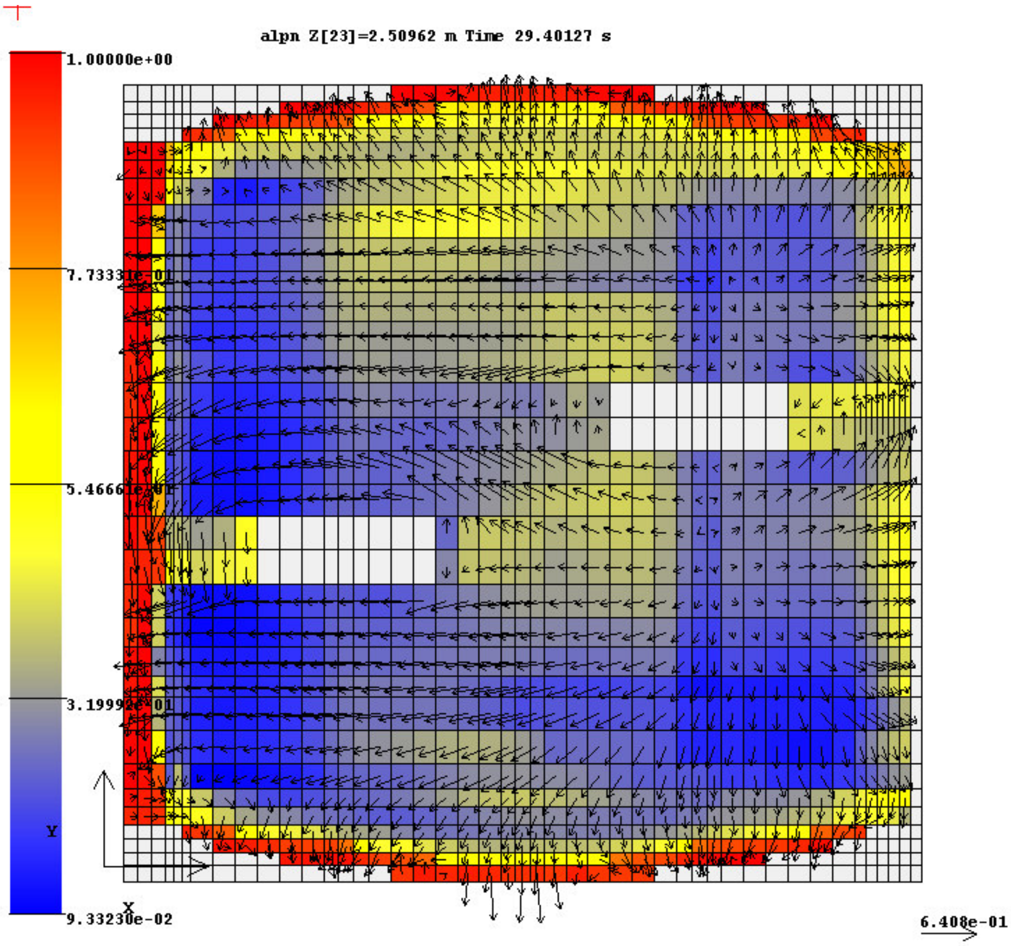

Figure 8: Color map of void fraction and arrows of liquid velocity component in m/s is shown for level of feed water distribution aboveнад underwater porous plate. It is section with feed water collector position. Scaling arrow for liquid velocity is shown in bottom right.

The picture of liquid flow above underwater porous plate in X-Y planes also is complex. It is shown in Fig. 8. Upstream steam is an obstacle for movement of a liquid downwards to packages of pipes. In a result water flows to edge of underwater porous plate, flows down in gaps between the vessel elliptic bottoms and underwater porous plate at "hot" and "cold" end faces.

There exist two circulating vortexes or cycles in Y-Z plane. Axial component of velocity of liquids is essential in region of end faces in a range of 3 meters from the cold and hot elliptical end faces.

Field of velocities the tube bundles, due to slip, repeats the field of velocities of a liquid, irregular on outlet from tube packages. Presence of underwater porous plate provides equalization of steam velocity on an output to physical level and improves requirements of a gravitational separation in vessel.

Thus, water circulation along SG vessel takes place in all three Cartesian coordinate planes. Thus in some zones the velocity values along all coordinate axes are competitive on value. All this creates three-dimensional character of water circulation and causes necessity of application the 3D computational codes.

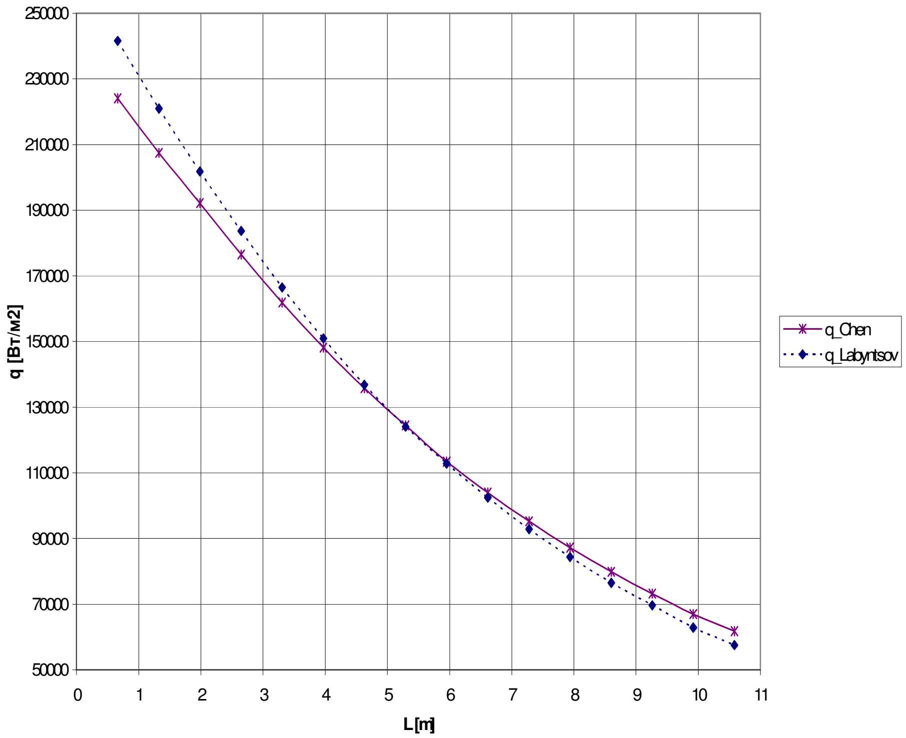

Figure 9: Comparison of calculation profiles of specific heat flux (on external surface of a tube) in function along length of tubes from "hot" to "cold" collectors for two versions.
Versions:
q_Chen- original (solid line) specific heat flux distribution
q_Labyntsov - correlation of Labyntsov for bubble boiling mode used (dotted line)

Comparison of calculation profiles of specific heat fluxes shows difference between Chen formula and Labyntsov Correlation is presented on Fig 9. This difference arise due to heat transfer coefficient according to Labuntsov correlation is higher on 58 % at region near "hot" collector. Nevertheless calculated thermal power of steam generator totally have difference less then 1% for this two versions.

Calculation investigation of influence nodalisation scheme on results was performed. Some version of meshes were compared. Steam generator in first nodalisation scheme has 48 cells on height (axis Z); 24 cells on cross - vessel axis X, and the the axis Y has 8 calculation cells along length of the vessel. Total cell number was equal to 9212. In fact half of vessel lehgth was simulated. Due to non symmetry conditions in real SG and symmetry boundary condition in the middle of Y direction there was performed modification of model.

Second full length version of model has number of calculation 3D grids on II circuit equal to 29000 cells and was similar in presented in report. Investigation of effect of nodalisation on the solution was performed. It was executed the increasing in two time the number of grid cells in tube packages and corridors. Results have shown essential influencing of subdivision on the solution in corridors and non essential influencing in tube packages. Finally for cross verification with STEG code number of calculation nodes was equal to 44640 cells.

Next model was developed for PGV-1500. There exist practically dry saturated steam for nominal mode operation due to influence of gravitational separation for this new progect of steam generator.

8. CONCLUSIONS

1. It was developed 3D model of the conjugate non-stationary thermal - hydraulic problem for steam generator PGV-1000M on the basis of code TRAC. The conjugate formulation of problem has shown both flexibility in capabilities of calculation for different mode of operation and good stability of a numerical solution.

2. It was designed graphic pre-and the postprocessors for code TRAC.

3. Thermal hydraulic calculations performed at present for PGV-1000M problem on the basis of code TRAC have shown, that in zones of arrangement of tube packages in the second circuit there exist generally upstream flow of steam-and-water mixture. Because of absence of specially organized by design the circuit of natural circulation, there observed the outlet of steam from tube packages to corridors in tops of packages. In corridors there are observed complex upstream and downstream flow of steam and water. Thus in some calculation meshes in corridors the counter flow of phases is observed.

4. Investigation of effect of nodalisation on the solution (the increasing in two time the number of grid cells in tube packages and corridors was executed). Results have shown essential influencing of subdivision on the solution in corridors and non essential influencing in tube packages.

5. Comparison of calculation formulas for heat transfer at bubble boiling was performed in condition of operation parameters of SG PGV-1000M. There was comparison between correlation of Chen in TRAC (USA standard) and formula Labuntsov D.A. (according to Russian standard) for bubble boiling mode.

6. The dynamic model allows to observe the pulsation regime of exit flow from tube packages in region of central "hot" collector and edge of underwater perforated plate.

7. Calculations of a dynamic problem on SG draining on II circuit in stop supplying of feed-water are performed. Results have shown good correspondence with cross-verification calculations performed for code KORSAR (NITI Russia – Science and research Technological Institute).

8. Calculation of the steam generator for new project PGV-1500 is performed on the basis of experience operation with PGV-1000M. Good gravitational separation inside top part of vessel was confirmed at adopted changes of SG design.

NOMENCLATURE

SG – steam generator.
RRC KIAE – Russian Research Center Kurchatov's Institute of Atomic Energy.
IPPE – Government research center Institute of Physics and Power Engineering
VNIIAES – All-Russian Research Institute of Nuclear Plant Safety
EREC - Electrogorsk Research and Engineering Center of All-Russian Research Institute of Nuclear Plant Safety
FSUE – Federal state Unitary Enterprize

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