THE USE OF BEST ESTIMATE CODES IN SOLVING THE PROBLEMS OF ANALYSIS OF REACTOR SAFETY

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ABSTRACT

System thermohydraulic codes are software systems, designed for the simulation parameters of the coolant throughout the reactor facility. The coolant in pressurized water reactors during normal modes is a single phase liquid. In emergencies the coolant boils, turning into a vapor-liquid mixture. In the coolant implemented various modes of flow and heat transfer. Correctly describe such processes can only simulating vapor-liquid mixture in the approximation of a separate phase flow. System codes in which the coolant is described in the approximation of a separate phase flow have been called best estimate codes. Number of modern best estimate codes is small: about a dozen families. Here, the "family code" is code and its modifications. The authors used a Mod2.2 (Cycle-A) version of the software package ATHLET [1]. The authors thank the GRS (Germany) for licensed code ATHLET/Mod2.2(Cycle A) and for providing data for computational experiments.
The results of numerical simulation of the blowdown scenarios at the BC V-213 test facility [2], which are models of the hermetic compartments of NPP confinement (VVER-440/213) with a full-scale fragment of bubble condenser, and all major equipment necessary for the test facility operation and testing, were presented in the report. It was shown how important in simulation of the experimental facility to take into consideration the fragments of the "clipped" devices, which are located up to closed valves and, therefore, are parts (even a dead end) of circuit.

I. INTRODUCTION

Thermal-hydraulic codes used for safety justification of the reactor facility are classified as four groups [3], one of which is system thermal-hydraulic codes.

System thermal-hydraulic codes are software systems designed to simulate the parameters of the coolant in the entire reactor facility. By simulating the behavior of the

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coolant in all elements of the plant in their interconnection communication system codes rather roughly interpret the structure the investigated equipment [4]. The coolant of the pressurized water reactor is the single-phase liquid during normal operation. In case of prospectived operational occurrences and a fortiori the emergency modes the phase composition of the coolant is changed. At accident conditions the coolant boils transforming into the vapor-liquid mixture. The different regimes of flow and heat transfer are realized in the coolant in depending on kind of the process evolution. Such processes can be correctly described if the vapor-liquid mixture is simulated by approximation of the two-phase flow [3].

System codes in which the coolant is described by the approximation of a separate phase flow [5, 6] are called best estimate codes. Number of the modern system thermal-hydraulic best estimate codes is about ten families. Here, the "family of code" means the code and its modifications. The authors use the system best estimate code ATHLET of the version ATHLET /Mod2.2 (Cycle-A) (developed in 2009). The developers of the code (GRS) are officially passed this version of the code to belarussian researchers. A brief characteristics of code ATHLET /Mod2.2 (Cycle-A) is given in the works [7, 8]. More detailed information is presented in the code manuals [1, 9–15].

II. MATHEMATICAL MODELS OF ATHLET/MOD2.2

The two mathematical models of hydrodynamics and heat transfer processes are realized in the ATHLET/Mod2.2. One of them is a model based on the approximation of the separate phase flow. This model is a main mathematical model available to user. The system of the governing equations of this model includes six equations. Therefore the authors of the code call this mathematical model of the 6-equation model [1, 9–15]. In earlier versions of the ATHLET code use a mathematical model based on the drift flux approximation. The system of the governing equations of this model includes five equations. Therefore the authors of the code call this mathematical model of the 5-equation model [1, 9–15]. In both models, the coolant is treated as a heterogeneous mixture of two phases, liquid (water) and the vapor (steam).

In this paper we consider a model based on the approximation of the separate phase flow. In this case the equations of conservation of the mass, momentum and energy are formulated for each phase [2, 5, 6]. These equations have the next form

$$\big[\alpha_p\,\bar\rho_p\big]_{,t} + \big[\alpha_p\,\bar\rho_p\,\tilde w_p^{\beta}\big]_{,\beta} = \Gamma_p \ , \tag{1}$$

$$\begin{aligned}\big[\alpha_p\,\bar\rho_p\,\tilde w_p^{\beta}\big]_{,t} + \big[\alpha_p\,\bar\rho_p\,\tilde w_p^{\beta}\,\tilde w_p^{\gamma}\big]_{,\gamma} = {} & -\big[\alpha_p\,\bar P_p\big]_{,\beta} + \big[\alpha_p\,\big(\bar\tau_p^{\beta\gamma} + T_{T\,p}^{\beta\gamma}\big)\big]_{,\gamma} \\ & + \alpha_p\,\bar\rho_p\,f_p^{\beta} + M_{k\,p}^{\beta} \ ,\end{aligned} \tag{2}$$

$$\begin{aligned}\big[\alpha_p\,\bar\rho_p\,\tilde h_p\big]_{,t} + \big[\alpha_p\,\bar\rho_p\,\tilde h_p\,\tilde w_p^{\gamma}\big]_{,\gamma} = {} & -\big[\alpha_p\,q_{tot\,p}^{\gamma}\big]_{,\gamma} + \big[\alpha_p\,\bar P_p\big]_{,t} + \big[\alpha_p\,\bar P_p\big]_{,\beta}\,\tilde w_p^{\beta} \\ & + \alpha_p\,\tau_{tot\,p}^{\gamma\beta}\,\tilde w_{p\,,\gamma}^{\beta} + \alpha_p\,\bar\rho_p\,Q_p + \Lambda_p \ .\end{aligned} \tag{3}$$

Here α_p is a void fraction of the p-phase; $\bar\rho_p$ is a density of the p-phase, kg/m^3; $\tilde w_p^{\beta}$ is a flow velocity (weight-average) of the p-phase, m/s; Γ_p is a volumetric generation rate of the p-phase due to of interphase exchange, $kg/(m^3 s)$; $\bar{P}$ is a pressure of the p-phase, Pa; $\bar{\tau}_p^{\beta\gamma}$ is a additional stress tensor of the p-phase, Pa; $T_{T\,p}^{\beta\gamma}$ is a turbulent stress tensor of the p-phase, Pa; f_p^{β} is a acceleration of mass forces of the p-phase, m/s^2; $M_{k\,p}^{\beta}$ is a total generation rate of momentum of p-phase due to of interphase exchange, $kg/(m^2 s^2)$; $\tilde{h}_p$ is a specific virtual enthalpy (weight-average) of the p-phase, J/kg; $\tau_{tot\,p}^{\beta\gamma}$ is a total stress tensor of the p-phase, Pa; Q_{Ipf} is a specific rate of heat generation in p-phase, W/kg; Λ_p is a total volumetric rate of heat generation in p-phase due to of interphase exchange, W/m^3.

Terms in the equations (1) - (8) are determined as

$$T_T^{\alpha\beta} \equiv -\overline{\rho\, w'^{\alpha}\, w'^{\beta}} \quad , \tag{4}$$

$$\tau_{tot\,p}^{\beta\gamma} \equiv \bar{\tau}_{,}^{\beta\gamma} p + \tau_{T\,p}^{\beta\gamma} \quad ; \tag{5}$$

$$M_{k\,p}^{\beta} \equiv M_{\Gamma\,p}^{\beta} + \bar{P}_p^{(I)}\,\alpha_{p\,,\,\beta} - \tau_{tot\,p}^{\beta\,\gamma\,(I)}\,\alpha_{p\,,\,\gamma} \quad , \tag{6}$$

$$M_{\Gamma\,p}^{\beta} \equiv \Gamma_p\,\tilde{w}_p^{\beta\,(I)} \quad ; \tag{7}$$

$$\Lambda_p \equiv \Lambda_{c\,p} + \frac{1}{2}\Gamma_p\,\tilde{w}_p^{\beta}\,\tilde{w}_p^{\beta} - M_{k\,p}^{\beta}\,\tilde{w}_p^{\beta} \quad , \tag{8}$$

$$\Lambda_{c\,p} \equiv H_p + Q_{I\,p} + E_{c\,p} \quad , \tag{9}$$

$$H_p \equiv \Gamma_p\,h_p^{(I)} \quad ; \tag{10}$$

$$h \equiv \iota + \varepsilon_T \quad , \tag{11}$$

$$\varepsilon_T \equiv \frac{\overline{\frac{1}{2}\rho\, w'^{\alpha}\, w'^{\alpha}}}{\bar{\rho}} \quad . \tag{12}$$

Here Q_{Ipf} is a volumetric rate heat transfer due to thermal conductivity from phase p to phase f at the interface, W/m^3; H_p is a volumetric rate heat transfer due to mass transfer from phase p to phase f at the interface, W/m^3; ι is a specific enthalpy, J/kg; ε_T is a specific kinetic energy of turbulence, J/kg.

Coolant is a set of two phases: vapor (steam) and liquid (water). Variable characterizing the vapor phase is marked by subscript v. Variable characterizing the liquid phase is marked by subscript l. Obviously that the following relations are valid.

$$\left[\alpha_v\,\bar{\rho}_v\right]_{,\,t} + \left[\alpha_v\,\bar{\rho}_v\,\tilde{w}_v^{\beta}\right]_{,\,\beta} \;=\; \Gamma_v \quad , \tag{13}$$

$$\left[\alpha_l\,\bar{\rho}_l\right]_{,\,t} + \left[\alpha_l\,\bar{\rho}_l\,\tilde{w}_l^{\beta}\right]_{,\,\beta} \;=\; \Gamma_l \quad . \tag{14}$$

$$\Gamma_v + \Gamma_l \equiv 0 \;\Rightarrow\; \Gamma_l = -\Gamma_v \Rightarrow \Big|\text{ if }\;\Gamma \equiv \Gamma_v\Big| \Rightarrow\; \Gamma_l = -\Gamma \quad , \tag{15}$$

$$\alpha_v + \alpha_l \equiv 1 \;\Rightarrow\; \alpha_l = 1 - \alpha_v \Rightarrow \Big|\text{ if }\;\varphi \equiv \alpha_v\Big| \Rightarrow\; \alpha_l = 1 - \varphi \quad . \tag{16}$$

$$\left[\varphi\,\bar{\rho}_v\right]_{,\,t} + \left[\varphi\,\bar{\rho}_v\,\tilde{w}_v^{\beta}\right]_{,\,\beta} \;=\; \Gamma \quad , \tag{17}$$

$$\left[(1-\varphi)\,\bar{\rho}_l\right]_{,\,t} + \left[(1-\varphi)\,\bar{\rho}_l\,\tilde{w}_l^{\beta}\right]_{,\,\beta} \;=\; -\Gamma \quad . \tag{18}$$

$$f_v^{\beta} \;\equiv\; g^{\beta} \;+\; f_{pump\,v}^{\beta} \quad , \tag{19}$$

$$f_l^{\beta} \;\equiv\; g^{\beta} \;+\; f_{pump\,l}^{\beta} \quad . \tag{20}$$

$$\bar{P}_p^{(I)} \;\cong\; \bar{P}_p \quad , \tag{21}$$

$$\tilde{w}_p^{\beta\,(I)} \;\cong\; \tilde{w}_p^{\beta} \quad , \tag{22}$$

$$\tau_{tot\,p}^{\beta\gamma\,(I)} \;\cong\; \tau_{tot\,p}^{\beta\gamma} \quad . \tag{23}$$

$$M_{k\,p}^{\beta} \;\cong\; M_{\Gamma\,p}^{\beta} \;+\; \bar{P}_p\,\alpha_{p\,,\,\beta} \;-\; \tau_{tot\,p}^{\beta\,\gamma}\,\alpha_{p\,,\,\gamma} \quad , \tag{24}$$

$$M_{\Gamma\,p}^{\beta} \;\cong\; \Gamma_p\,\tilde{w}_p^{\beta} \quad . \tag{25}$$

$$\left[\varphi\,\bar{\rho}_v\,\tilde{w}_v^{\beta}\right]_{,t}+\left[\varphi\,\bar{\rho}_v\,\tilde{w}_v^{\beta}\,\tilde{w}_v^{\gamma}\right]_{,\gamma} \;=\; -\left[\varphi\,\bar{P}_v\right]_{,\beta}\;+\;\left[\varphi\left(\bar{\tau}_v^{\beta\gamma}\;+\;T_{T\,v}^{\beta\gamma}\right)\right]_{,\gamma}\;+\;\varphi\,\bar{\rho}_v\,g^{\beta}$$

$$+\;\varphi\,\bar{\rho}_v\,f_{pump\,v}^{\beta}\;+\;M_{k\,v}^{\beta}\quad. \tag{26}$$

$$M_{k\,v}^{\beta}\;\equiv\;M_{\Gamma\,v}^{\beta}\;+\;\bar{P}_v\,\varphi_{,\,\beta}\;-\;\tau_{tot\,v}^{\beta\,\gamma}\,\varphi_{,\,\gamma}\quad, \tag{27}$$

$$M_{\Gamma\,v}^{\beta}\;\equiv\;\Gamma\tilde{w}_v^{\beta}\quad. \tag{28}$$

$$\left[\left(1-\varphi\right)\bar{\rho}_l\,\tilde{w}_l^{\beta}\right]_{,t}+\left[\left(1-\varphi\right)\bar{\rho}_l\,\tilde{w}_l^{\beta}\,\tilde{w}_l^{\gamma}\right]_{,\gamma}=-\left[\left(1-\varphi\right)\bar{P}_l\right]_{,\beta}$$

$$+\;\left[\left(1-\varphi\right)\left(\bar{\tau}_l^{\beta\gamma}\;+\;T_{T\,l}^{\beta\gamma}\right)\right]_{,\gamma}+\;\left(1-\varphi\right)\bar{\rho}_l\,g^{\beta}\;+\;\left(1-\varphi\right)\bar{\rho}\,f_{pump\,l}^{\beta}+\;M_{k\,l}^{\beta}\quad. \tag{29}$$

$$M_{k\,l}^{\beta}\;\equiv\;M_{\Gamma\,l}^{\beta}\;-\;\bar{P}_l\,\varphi_{,\,\beta}\;+\;\tau_{tot\,l}^{\beta\,\gamma}\,\varphi_{,\,\gamma}\quad, \tag{30}$$

$$M_{\Gamma\,l}^{\beta}\;\equiv\;-\,\Gamma\tilde{w}_l^{\beta}\quad. \tag{31}$$

$$\left[\varphi\,\bar{\rho}_v\,\tilde{w}_v^{\beta}\right]_{,t}+\left[\varphi\,\bar{\rho}_v\,\tilde{w}_v^{\beta}\,\tilde{w}_v^{\gamma}\right]_{,\gamma} \;=\; -\varphi\,\bar{P}_{v\,,\,\beta}\;+\;\varphi\left[\bar{\tau}_v^{\beta\gamma}\;+\;T_{T\,v}^{\beta\gamma}\right]_{,\gamma}\;+\;\varphi\,\bar{\rho}_v\,g^{\beta}$$

$$+\;\varphi\,\bar{\rho}_v\,f_{pump\,v}^{\beta}\;+\;\Gamma w_v^{\beta}\quad, \tag{32}$$

$$\left[\left(1-\varphi\right)\bar{\rho}_l\,\tilde{w}_l^{\beta}\right]_{,t}+\left[\left(1-\varphi\right)\bar{\rho}_l\,\tilde{w}_l^{\beta}\,\tilde{w}_l^{\gamma}\right]_{,\gamma}=-\left(1-\varphi\right)\bar{P}_{l\,,\,\beta}$$

$$+\;\left(1-\varphi\right)\left(\bar{\tau}_l^{\beta\gamma}\;+\;T_{T\,l}^{\beta\gamma}\right)_{,\gamma}+\;\left(1-\varphi\right)\bar{\rho}_l\,g^{\beta}\;+\;\left(1-\varphi\right)\bar{\rho}\,f_{pump\,l}^{\beta}-\;\Gamma\,w_l^{\beta}\quad. \tag{33}$$

$$\left[\alpha_v\,\bar{\rho}_v\,\tilde{h}_v\right]_{,t}\;+\;\left[\alpha_v\,\bar{\rho}_v\,\tilde{h}_v\,\tilde{w}_v^{\gamma}\right]_{,\gamma}\;=\;-\left[\alpha_v\,q_{tot\,v}^{\gamma}\right]_{,\gamma}\;+\;\left[\alpha_v\,\bar{P}_v\right]_{,t}+\left[\alpha_v\,\bar{P}_v\right]_{,\beta}\tilde{w}_v^{\beta}$$

$$+\;\alpha_v\,\tau_{tot\,v}^{\gamma\,\beta}\,\tilde{w}_{v\,,\,\gamma}^{\beta}\;+\;\alpha_v\,\bar{\rho}_v\,Q_v\;+\;\Lambda_v\quad. \tag{34}$$

$$\left[\alpha_l\,\bar{\rho}_l\,\tilde{h}_l\right]_{,t}\;+\;\left[\alpha_l\,\bar{\rho}_l\,\tilde{h}_l\,\tilde{w}_l^{\gamma}\right]_{,\gamma}\;=\;-\left[\alpha_l\,q_{tot\,l}^{\gamma}\right]_{,\gamma}\;+\;\left[\alpha_l\,\bar{P}_l\right]_{,t}\;+\;\left[\alpha_l\,\bar{P}_l\right]_{,\beta}\tilde{w}_l^{\beta}$$

$$+\;\alpha_l\,\tau_{tot\,l}^{\gamma\,\beta}\,\tilde{w}_{l\,,\,\gamma}^{\beta}+\;\alpha_l\,\bar{\rho}_l\,Q_l\;+\;\Lambda_l\quad. \tag{35}$$

From the mathematical expressions (13, 14, 24, 29, 34 and 35) the following equations can be obtained.

$$\boxed{\boldsymbol{\frac{dx_m}{dt}=\frac{M_l\,\dfrac{dM_v}{dt}\;-\;M_v\,\dfrac{dM_l}{dt}}{\left(M_l+M_v\right)^2}}}\quad, \tag{36}$$

$$x_m \equiv \frac{M_v}{M_v + M_l} \equiv \frac{M_v}{M} \quad , \tag{37}$$

$$M_v = M_{cvl}\, x_m \quad , \tag{38}$$

$$M_l = M_{cvl}\big(1 - x_m\big) \quad , \tag{39}$$

$$M_{cvl} = \frac{V}{x_m v_v + \big(1 - x_m\big) v_l} \quad , \tag{40}$$

$$\boxed{\boldsymbol{\frac{dT_v}{dt} = \frac{1}{c_{P,v}}\,\frac{E_v}{M_v} + \frac{1}{c_{P,v}}\left(w_v - \frac{\partial\,\iota_v}{\partial\,P}\bigg|_{T_v}\right)\frac{dP}{dt}}} \quad \boldsymbol{,} \tag{41}$$

$$\boxed{\boldsymbol{\frac{dT_l}{dt} = \frac{1}{c_{P,l}}\,\frac{E_l}{M_l} + \frac{1}{c_{P,l}}\left(w_l - \frac{\partial\,\iota_l}{\partial\,P}\bigg|_{T_l}\right)\frac{dP}{dt}}} \quad \boldsymbol{,} \tag{42}$$

$$E_v = \left[G_v\left(\iota_v + \frac{w_v^2}{2}\right)\right]_{in} - \left[G_v\left(\iota_v + \frac{w_v^2}{2}\right)\right]_{out} - \frac{dM_v}{dt}\left(\iota_v + \frac{w_i^2}{2}\right) - M_v w_i \frac{dw_i}{dt} + R_{Ev} \quad , \tag{43}$$

$$E_l = \left[G_l\left(\iota_l + \frac{w_l^2}{2}\right)\right]_{in} - \left[G_l\left(\iota_l + \frac{w_l^2}{2}\right)\right]_{out} - \frac{dM_l}{dt}\left(\iota_l + \frac{w_i^2}{2}\right) - M_l w_i \frac{dw_i}{dt} + R_{El} \quad , \tag{44}$$

$$R_{Ev} = Q_{Ev} + Q_{I_v} \quad , \tag{45}$$

$$R_{El} = -Q_{EI} + Q_{I_l} \quad , \tag{46}$$

$$w_i = \frac{1}{S_i \rho_m}\frac{G_{in} + G_{out}}{2} \quad , \tag{47}$$

$$\frac{dw_i}{dt} = \frac{1}{2 S_i \rho_m}\left[\frac{dG_{in}}{dt} + \frac{dG_{out}}{dt} - \frac{G_{in} + G_{out}}{M_v + M_l}\left(\frac{dM_v}{dt} + \frac{dM_l}{dt}\right)\right] \quad , \tag{48}$$

$$\boxed{\boldsymbol{\frac{dP}{dt} = -\frac{Z_1}{Z_2}}} \;, \tag{49}$$

$$Z_1 = \frac{dM_v}{dt} v_v + \left.\frac{\partial v_v}{\partial T_v}\right|_P \frac{E_v}{c_{p,v}} + \frac{dM_l}{dt} v_l + \left.\frac{\partial v_l}{\partial T_l}\right|_P \frac{E_l}{c_{p,l}} \;, \tag{50}$$

$$\begin{aligned} Z_2 = M_v &\left[\left.\frac{\partial v_v}{\partial P}\right|_{T_v} + \frac{1}{c_{p,v}} \left.\frac{\partial v_v}{\partial T_v}\right|_P \left(v_v - \left.\frac{\partial h_v}{\partial P}\right|_{T_v} \right) \right] + \\ + M_l &\left[\left.\frac{\partial v_l}{\partial P}\right|_{T_l} + \frac{1}{c_{p,l}} \left.\frac{\partial v_l}{\partial T_l}\right|_P \left(v_l - \left.\frac{\partial h_l}{\partial P}\right|_{T_l} \right) \right] \;, \end{aligned} \tag{51}$$

$$\boxed{\boldsymbol{\begin{aligned} \frac{d\overline{(w_v S)}}{dt} = \frac{1}{\int\limits_x \frac{\rho_v}{S} dx} \Bigg[& - \int\limits_x \frac{\rho_v}{S} dx + \Delta P_{pump,v} - g \int\limits_x \rho_v \sin\gamma \, dx - \\ & - (1-\varphi)(\rho_l - \rho_v)\, g \int\limits_x F\left(\frac{\partial \varphi}{\partial x}, D \right) dx - \\ & - \int\limits_x f_{wall,v}\, dx - \frac{1}{2} \int\limits_x \rho_v \frac{\partial w_v^2}{\partial x} dx - \\ & - \int\limits_x \frac{1}{\varphi} \tau \, dx + \int\limits_x \frac{\Psi w_\Gamma}{\varphi} dx - \int\limits_x \frac{\Psi w_v}{\varphi} dx \Bigg] \end{aligned}}} \;, \tag{52}$$

$$\boxed{\boldsymbol{\begin{aligned} \frac{d\overline{(w_l S)}}{dt} = \frac{1}{\int\limits_x \frac{\rho_l}{S} dx} \Bigg[& - \int\limits_x \frac{\rho_v}{S} dx + \Delta P_{pump,l} - g \int\limits_x \rho_l \sin\gamma \, dx - \\ & + \varphi(\rho_l - \rho_v)\, g \int\limits_x F\left(\frac{\partial \varphi}{\partial x}, D \right) dx - \\ & - \int\limits_x f_{wall,l}\, dx - \frac{1}{2} \int\limits_x \rho_l \frac{\partial w_l^2}{\partial x} dx - \\ & - \int\limits_x \frac{1}{1-\varphi} \tau \, dx - \int\limits_x \frac{\Psi w_\Gamma}{1-\varphi} dx + \int\limits_x \frac{\Psi w_l}{1-\varphi} dx \Bigg] \end{aligned}}} \;, \tag{53}$$

$$\boxed{\frac{dG}{dt} = \frac{1}{\int\limits_x \frac{1}{S}dx}\left(\Delta P_S + \Delta P_{MF} + \Delta P_{WR} + \Delta P_{grav} + \Delta P_{fric} + \Delta P_{\rho} + \Delta P_I\right)}, \tag{54}$$

Here φ is a void fraction; S is a flow section area, m^2; G is a mass flow the coolant, kg/s.

Equations (36, 41, 42, 49, 52, 53) are a governing equation system of the 6-equation model. Equations (36, 41, 42, 49, 54) are a governing equation system of the 5-equation model.

III. DISCUSSION OF THE RESULTS

One of the bubble-condenser (BC) accident scenarios are playable on test bench BC-213 [2, 16–18]. The general view of the test bench is shown in figure 1.

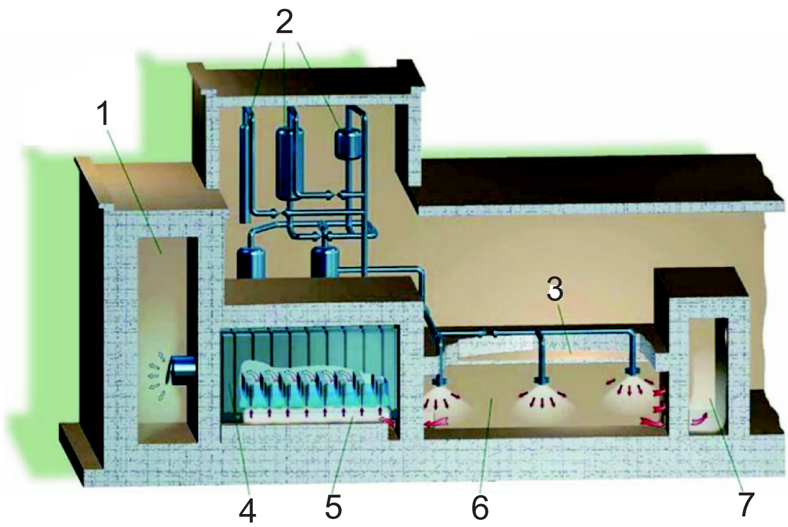

Figure 1: General view of test bench: 1 – Air trip, 2 – Pressure vessels, 3 – Boxes of reactor compartments No.2, 4 – Bubble Condenser (BC), 5 – BC shaft, 3 – Boxes of reactor compartments No.1, 7 – Dead box.

The BC V-213 test facility is a large-scale integrated facility modeling the vacuum pressure suppression pool of the accident localization system and the leak-tight compartments of the NPP with VVER -440/V-213 reactors. The volumetric scaling factor of the facility is 1:100. BC V-213 is designed for the conduct of thermo-hydraulic experiments to investigate operability and reliability of the vacuum pressure bubbler condenser of the NPP with VVER-440/V-213 reactors under the conditions of ultimate design basis accidents, small primary and secondary LOCA and secondary steam pipeline breaks [2, 17].

To provide require initial conditions of the coolant discharging in the boxes, the high-pressure system is used, which consists of five vessels (Vv1, Vv2, Vv3, Vv4 and Vv5). The volumes of the vessels are chosed to provide discharge of steam-water mixture under various accident conditions (LB LOCA, SB LOCA, MSLB). The flow diagram of the high-pressure system are presented in figure 2.

The water treatment installation system is designed for preparing coolant with specified parameters. The coolant with specified parameters can be prepared with the aid of steam

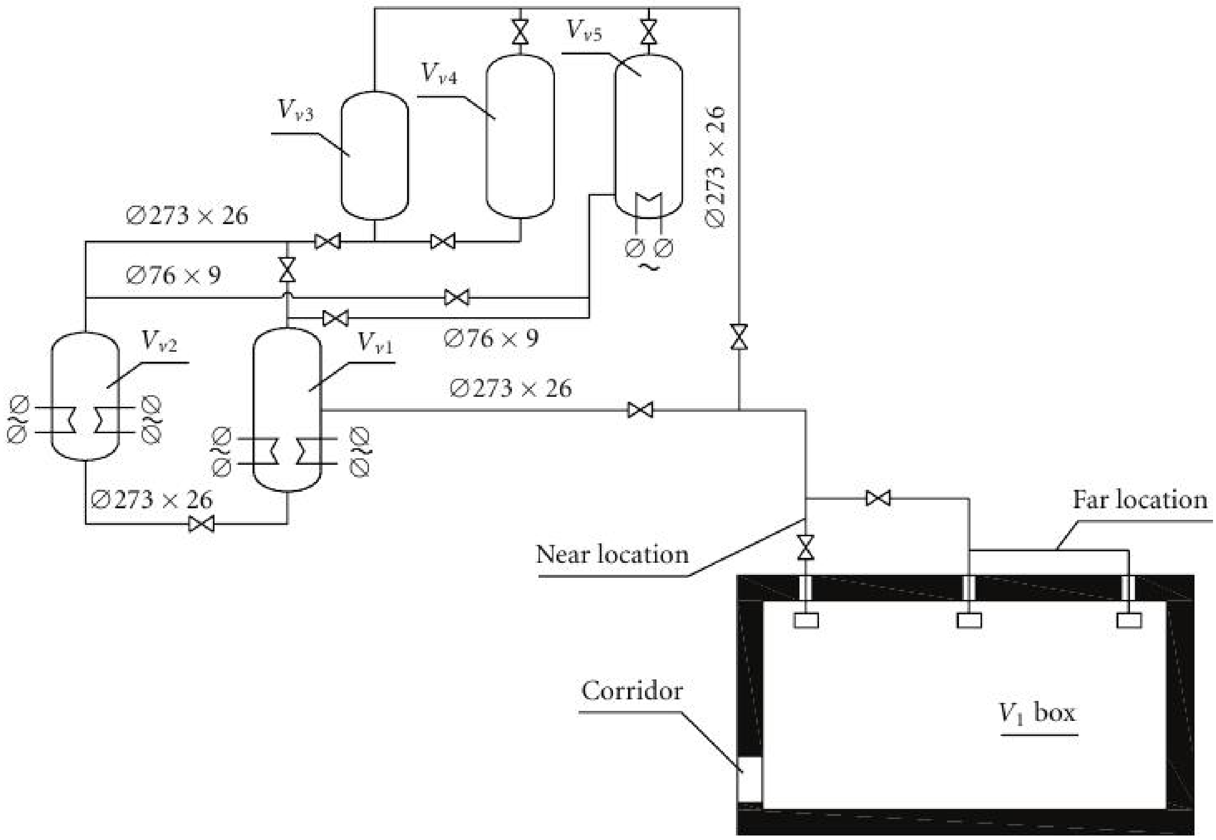

Figure 2: High-pressure system.

supplied to vessel Vv1, water heated in the heat exchangers before its supply to the vessels and heaters installed in vessels Vv1, Vv2 and Vv5. There are two heaters installed in each of vessels Vv1 and Vv2, Vv5 has one. The power of each heater is 90 kW. The vessels are equipped with safety valves and pipe connections to install pressure and temperature transducers and level gages.

Arrangement of the blowdown lines is presented in figure 2. There are three positions of the coolant discharge in the V1 box:

1. Near the corridor to simulate air-steam mixture with maximum concentration of the steam ("Near location" in figure 2);

2. Far from the corridor to simulate air-steam mixture with maximum concentration of the air ("Far location" in figure 2);

3. Middle position.

A flange is located at the end of each blowdown line for installation of the nozzle. The rupture disc is used for simulation of pipe break.

Nodalization scheme used in calculations is shown in figure 3.

Information on the simulated experiments is in [18]. Simulated process lasted 3500 s. The outflow occurs through the nozzles. On the 800th second there is a leak from the vessel BOCHKA1 (Vv1). Up to 1200 seconds mass flow leak is 0.44 kg/s. Beginning from 1200th second and up to end of the experiment (3500 seconds) it is equal to 0.2 kg/s.

Results of computational experiments are presented in figures 4-7.

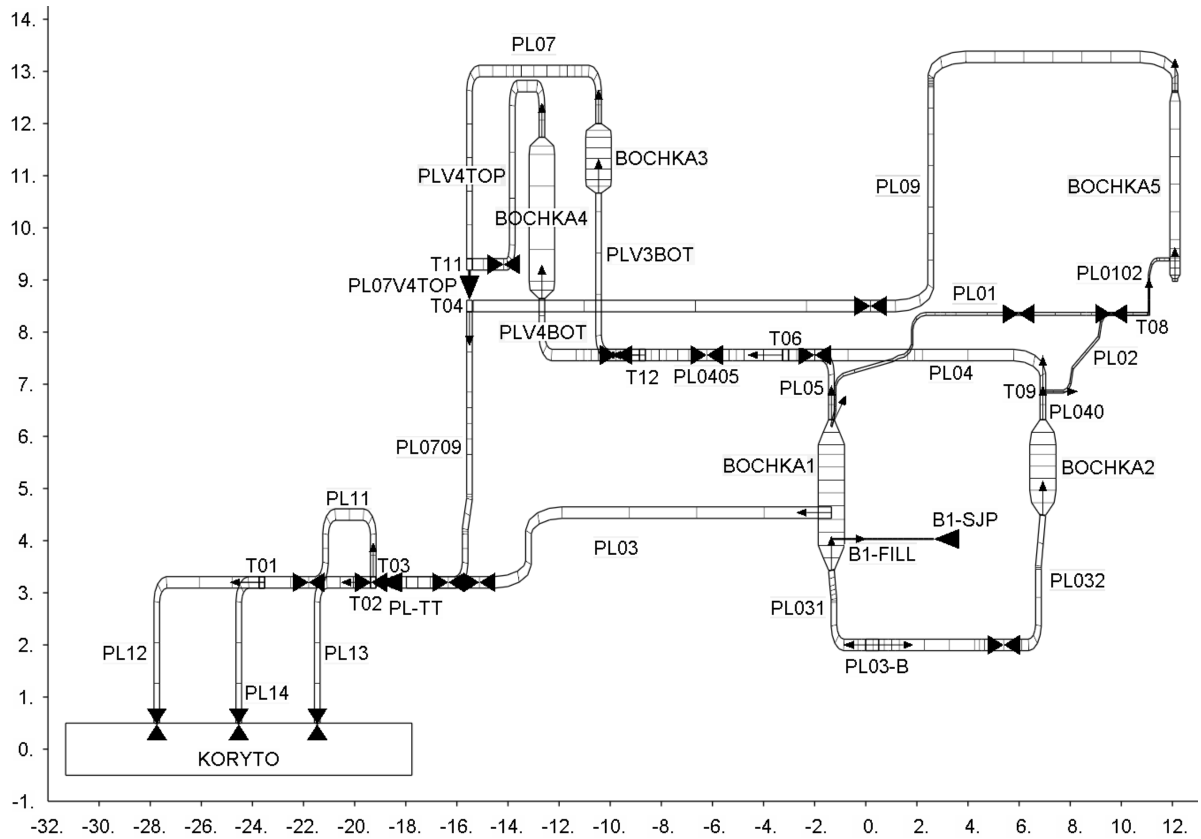

Figure 3: Nodalization scheme of the high-pressure system.

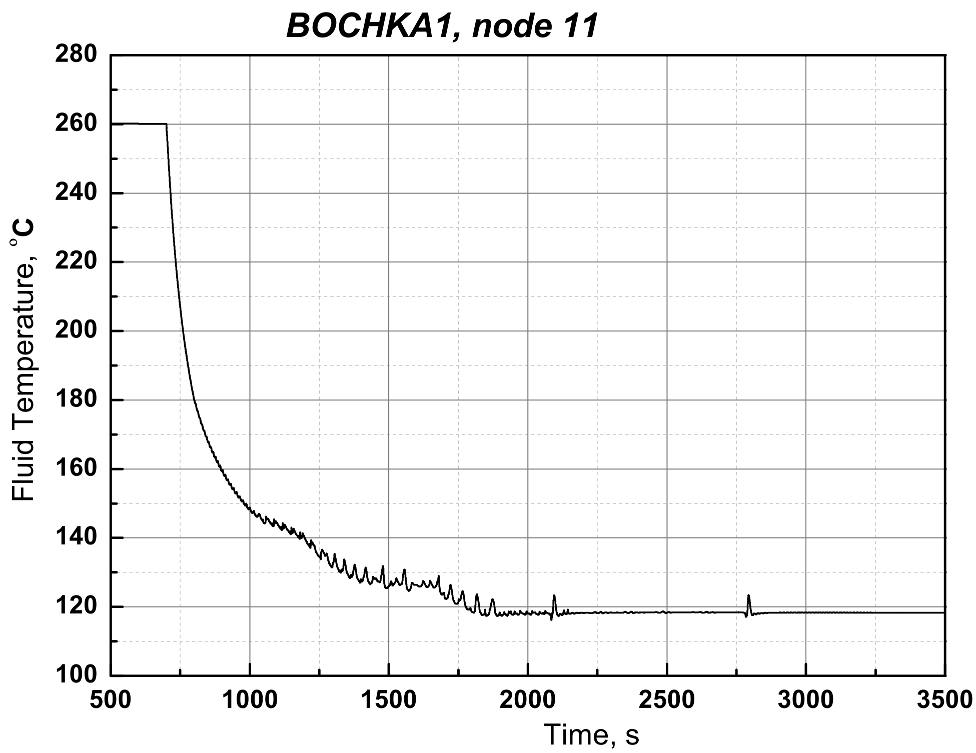

Figure 4: Fluid temperature.

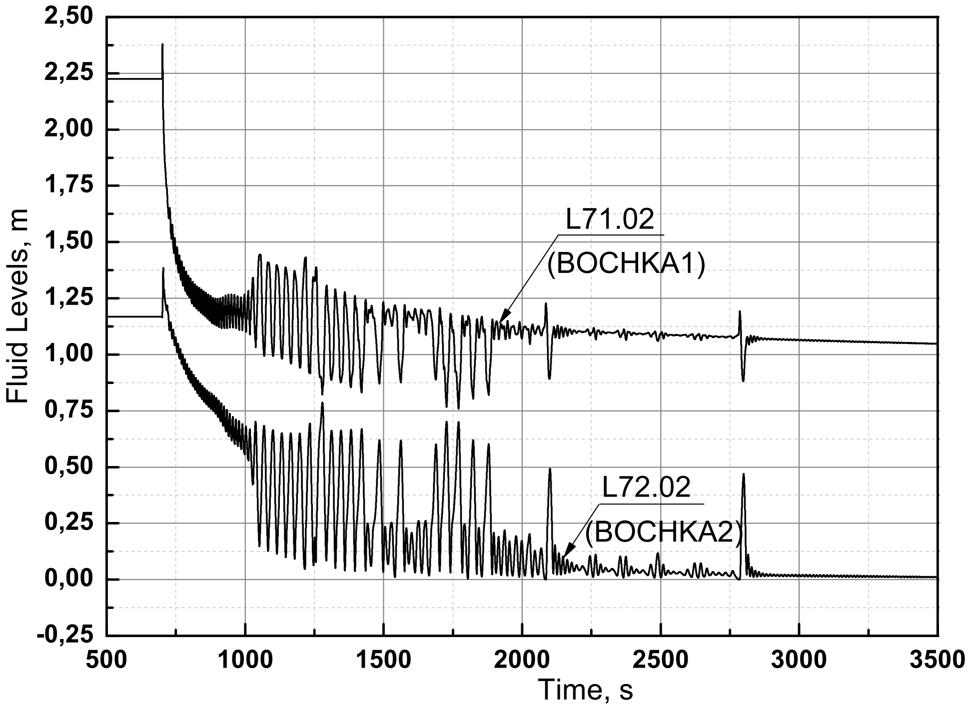

Figure 5: Fluid levels.

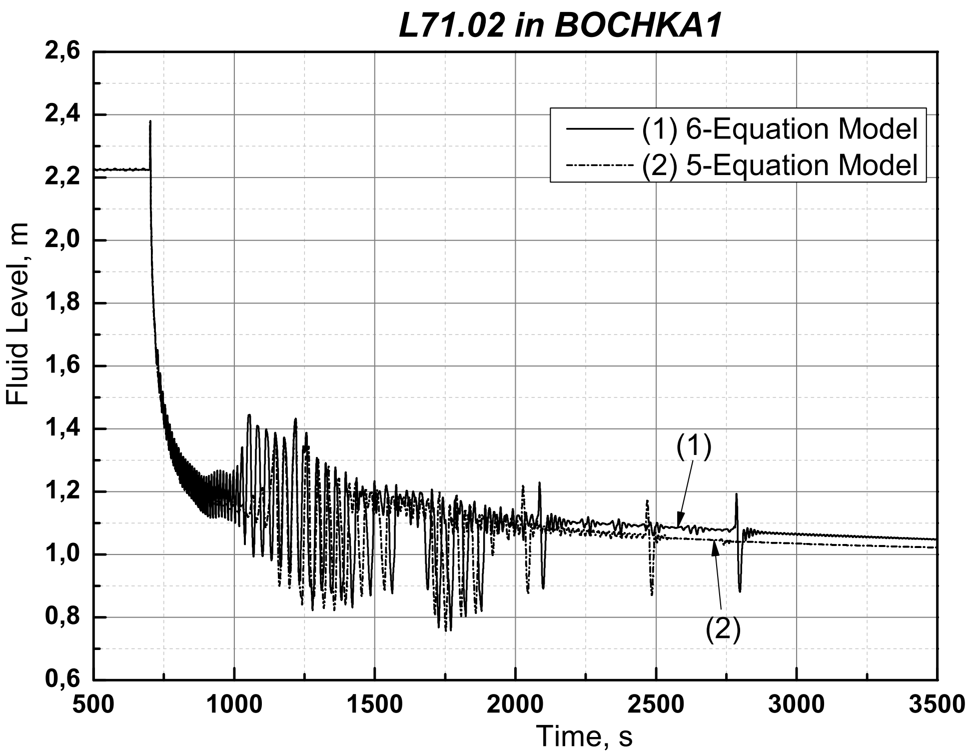

Figure 6: Fluid level L71.02 for the high pressure system: (1) – 6-Equation Model, (2) – 5-Equation Model.

As Figure 6 shows the notable differences between the results of the use of the 5-Equation and 6-Equation models begin to appear approximately from the middle of the transition process.

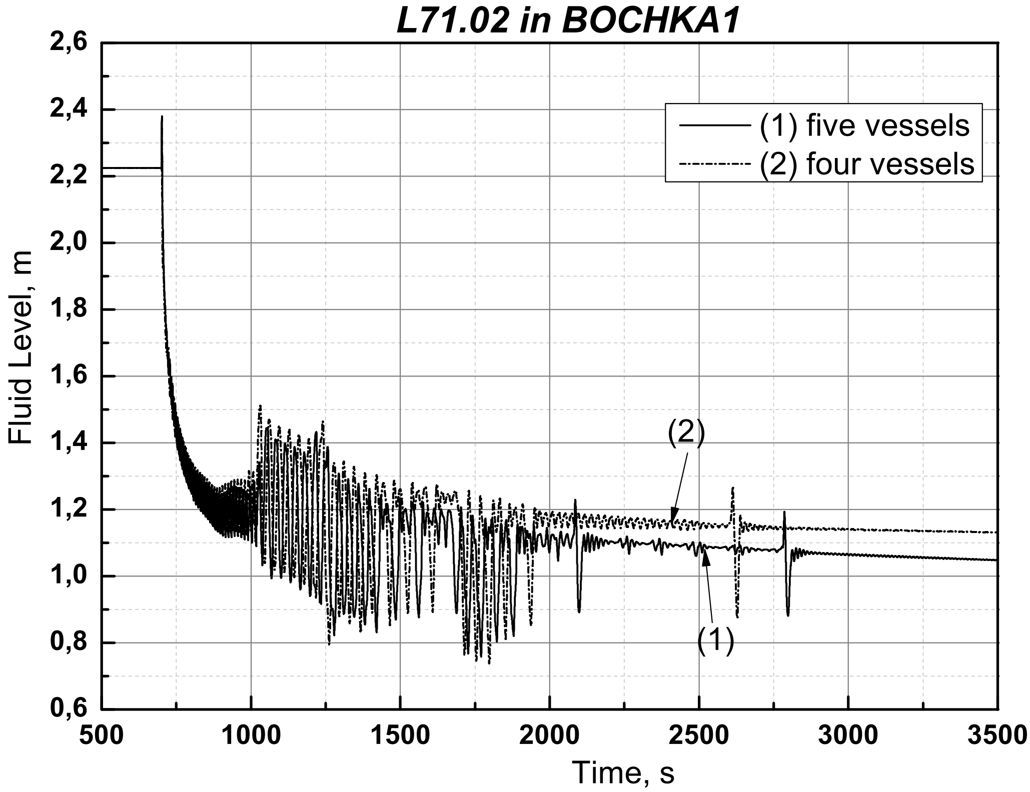

Figure 7: Fluid level L71.02 for the high pressure system: (1) – five vessels, (2) – four vessels.

In figure 7 numerical results of the fluid level in BOCHKA1(Vv1) is presented for system with consideration total equipments (5 vessels) and for system "four vessels" without the fragments of the "clipped" devices, which are located up to closed valves. Obviously at the same initial conditions numerical results of the "5 vessels"-system simulation lie more close to the experimental results. It indicates the importance taking into account "appendix" circuit.

IV. CONCLUSION

The mathematical model (governing equation system) of hydrodynamic and heat transfer processes, used in the thermohydraulic system best estimate code ATHLET/Mod2.2, were represented in the article. Equations of the thermohydrodynamic multiphase heat transfer, from which the governing equation system obtained, were given here.

The results of numerical simulation of the blowdown scenarios at the BC V-213 test facility [4], which are models of the hermetic compartments of NPP confinement (VVER-440/213) with a full-scale fragment of bubble condenser, and all major equipment necessary for the test facility operation and testing, were presented in the article.

It was shown how important in simulation of the experimental facility (the topology calculation area) to take into consideration the fragments of the "clipped" devices, which are located up to closed valves and, therefore, are parts (even a dead end) of circuit. Neglect of this kind of "appendix" circuit can leads to significant errors in the simulation results (Figure 7).

Therefore it is necessary be very attentive to such seemingly irrelevant from the point view of the coolant dynamics in the fragments of the "clipped" devices.

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