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Preliminary Results of LOCA (DN250) Analyses with ATHLET for a Generic VVER-1200 Plant

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The present paper describes the analyses of the ATHLET simulations of the next loss-of-coolant accident (LOCA) sequence, utilizing a generic VVER-1200 input deck:

1. Beyond design basis accident (BDBA): LOCA in the cold leg (close to the RPV nozzle), diameter 250 mm with failure of LPI and HPI systems.

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1. Introduction

In the investigation of violations of the expected normal operation and design basis accident (DBA) should use relevant computer codes for thermohydraulics. In many cases the safety parameters such as the temperature of the fuel and cladding and peak linear heat capacity cannot be measured directly and their values cannot be represented by the reactor operator. Therefore it should be estimated of the reactor core states by special computer codes in order to set the values of the parameters in the operating procedures.

Owing to the absence complete empirical basis possible analysis of nonstationary normal and accident processes in the reactor facility is a calculation analysis which has a theoretical prediction character and is not the generalization of empirical data.

Thermohydrodynamic (thermohydraulic) codes are one of the groups of computer programs that are required for justification of a nuclear facility safety analysis and include subgroup "system thermohydraulic codes". Programs of this subgroup are usually divided into codes of the conservative and realistic estimates. The second type of code called best estimate codes. This type does not contain specific models of individual plant elements and processes occurring in them, based on empirical data. Therefore best estimate codes are sufficiently accurate and universal, they are applicable to the whole class research facilities.

System thermohydraulic codes are software systems, designed to simulate the parameters of the coolant throughout the nuclear power plant. In case of abnormal mode initiation and especially of emergency modes the coolant phase composition changes. As in the coolant can be realized various flow regimes and heat transfer for the correct description of such processes to be modeled vapor-liquid mixture in the approximation separate phase flow. System codes in which the coolant is described in the mentioned approximation, were scalled realistic or best estimate codes.

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One of the representatives of this type of codes is a software package ATHLET which is based on modern deterministic models.

The thermal-hydraulic computer code ATHLET (Analysis of the THermal-hydraulics of LEaks and Transients) is being developed by the Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) for the analysis of anticipated and abnormal plant transients, small and intermediate leaks as well as large breaks in light water reactors. ATHLET can be applied for all types of design base and beyond design base incidents and accidents without core damage in light water reactors, like PWR, BWR, VVER, and RBMK.

2. Beyond design basis accident (BDBA)

The loss-of-coolant accident (LOCA) starts at time 0 s, when the leakage of DN 250 mm is opened (Figure 2.1). Simultaneously, the level of the coolant in the pressurizer begins to drop (Figure 2.2). Rapid reduction of pressure in the primary circuit of the reactor installation (Figure 2.3) begins and after about 0.5 s the pressure above the reactor core falls below 14.2 MPa, which is a condition for the actuation of the SCRAM signal.

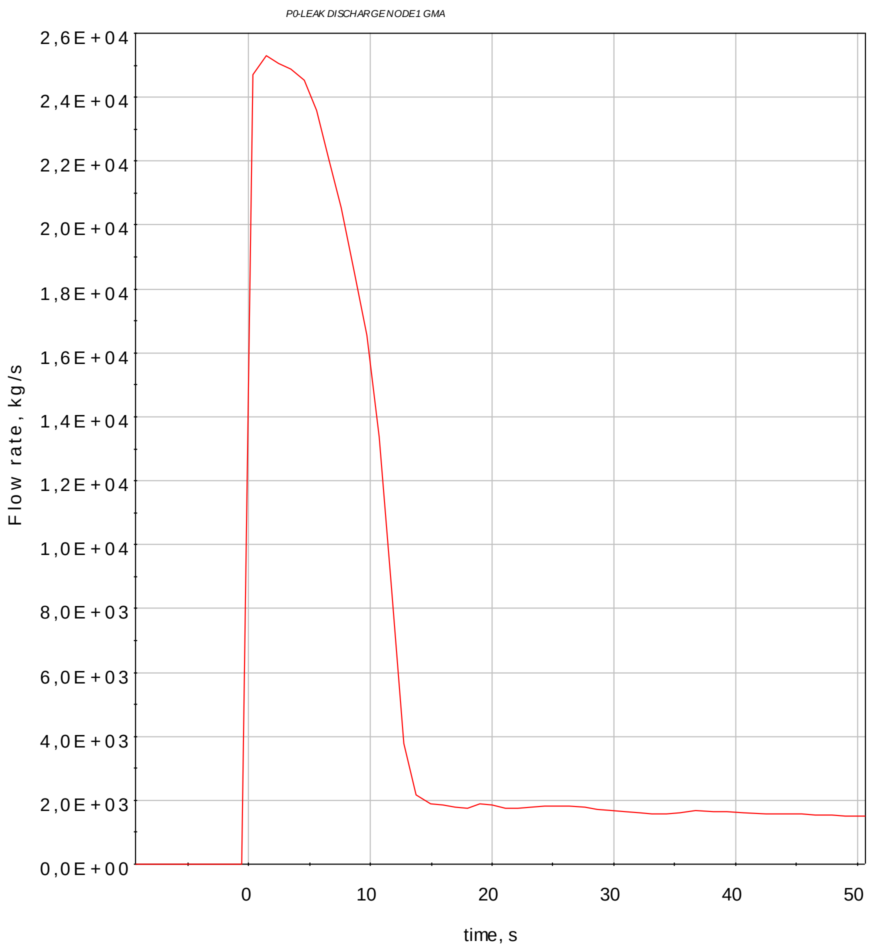

Figure 2.1 Leak opening

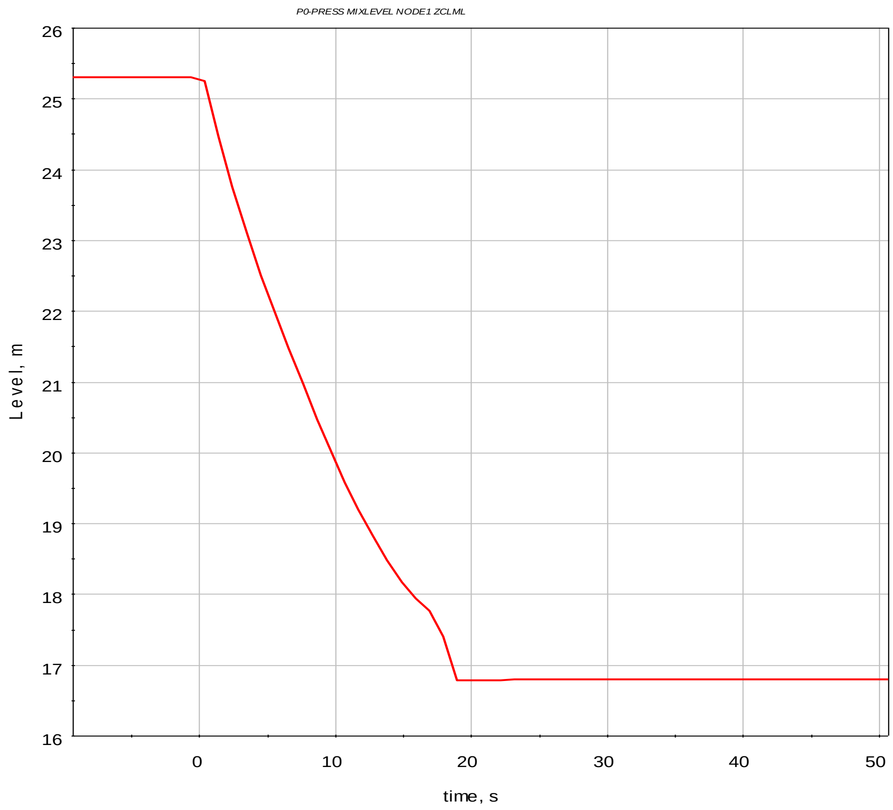

Figure 2.2 Coolant level in Pressurizer

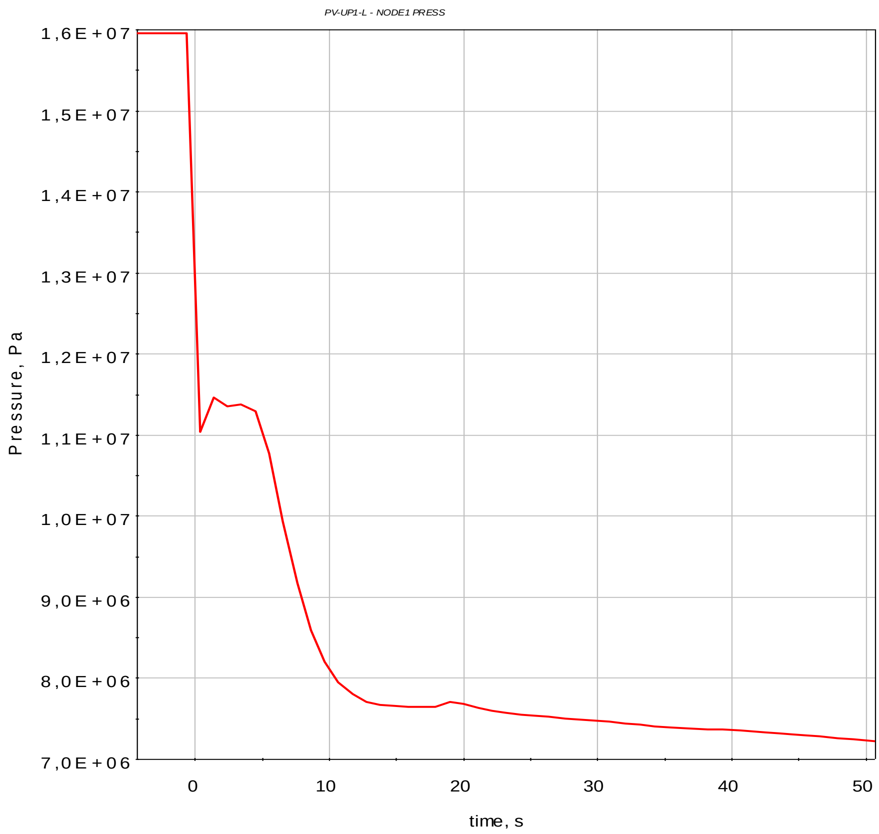

Figure 2.3 Pressure above the core

When the SCRAM is activated, the control rods are immediately inserted into the active zone (the time of fall of the rods is 1.5 to 4 s) and the main circulation pumps are disconnected (Figure 2.4). Further procedures which would be performed in a real VVER-1200 plant are not included in this simulation. The neutron power of the reactor starts to decrease rapidly (Figure 2.5). With a delay of 4 seconds, after the full introduction of the control rods into the active zone, the turbine trip signal is given and the turbine mass flow coasts down linearly within 10 s (Figure 2.6) – this behavior was specified in the ATHLET input deck.

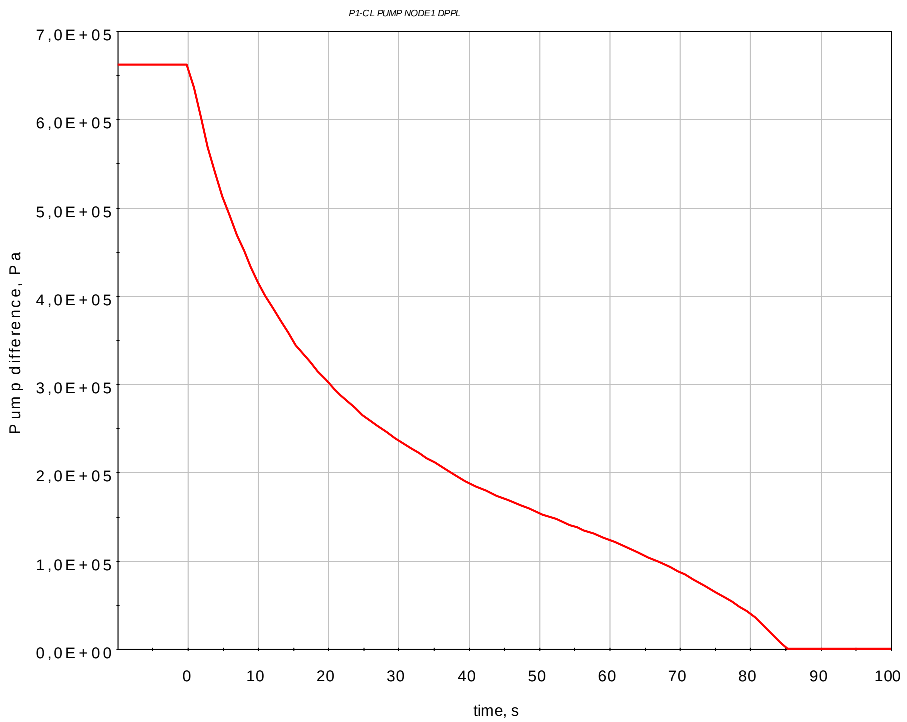

Figure 2.4 Main circulation pump head

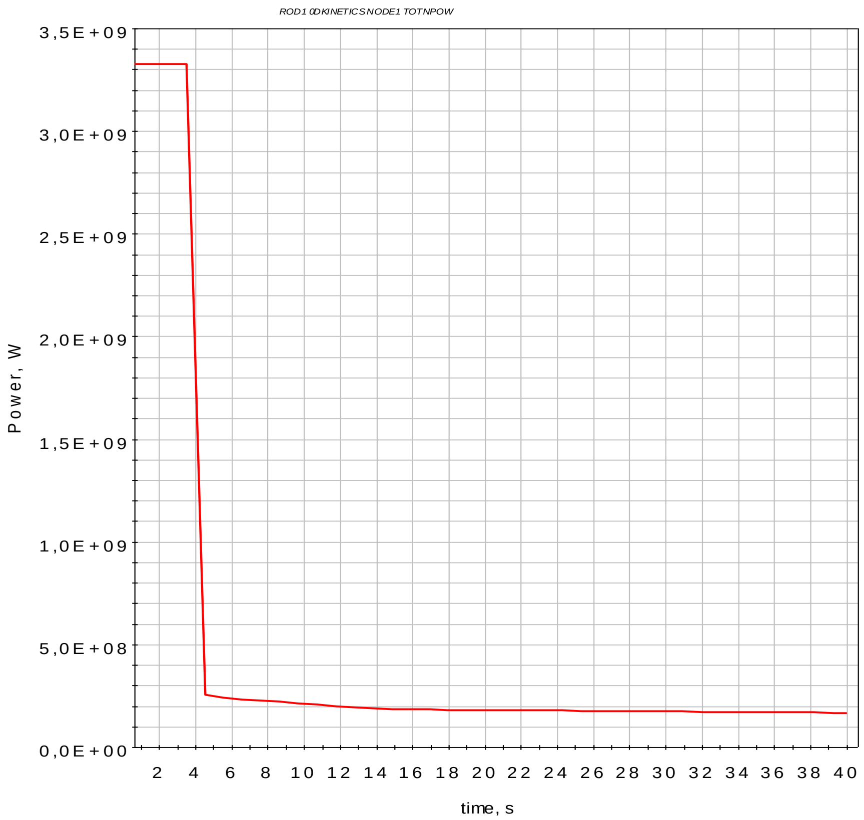

Figure 2.5 Total power of the core

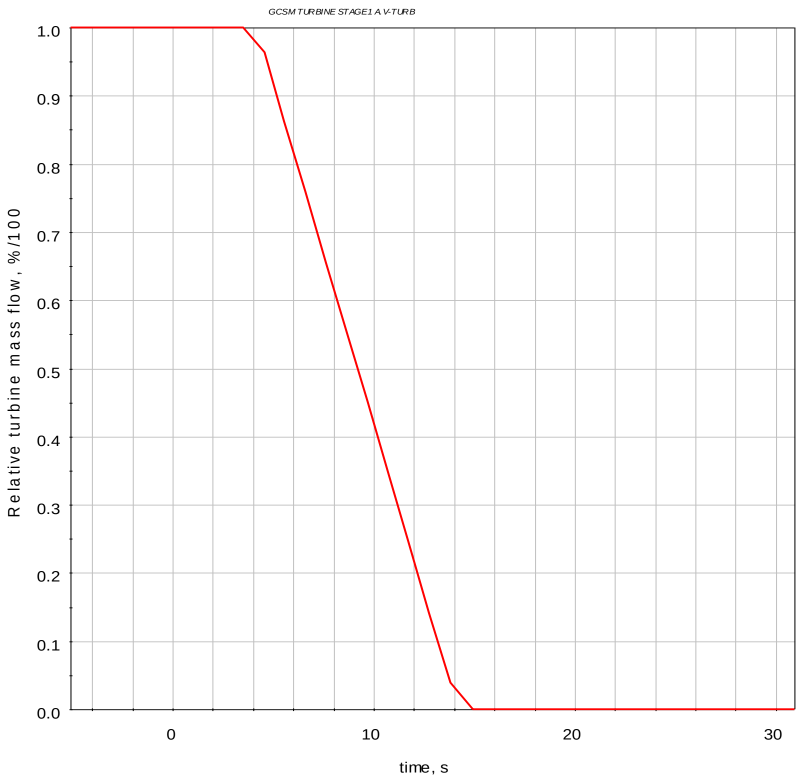

Figure 2.6 Turbine shutdown

As the main steam valve of the turbine closes, steam pressure in the steam generators begins to increase (Figure 2.7). Since the signal "fast turbine unloading" is active, the BRU-K valve opens when a pressure of 7.4 MPa is reached, dumping surpluses of the produced steam into the turbine condenser (Figure 2.8). The valve opens at 553 second and closes at 557 seconds when the pressure sinks below 6.92 MPa. As can be seen in Figure 2.8, the mass flow through the BRU-K valve is controlled around a maximum discharge rate of 50 kg/s per valve and remains sub-critical during the discharge period. Due to the fact that the pressure in the steam generators does not reach the value of 7.8 MPa (the maximum pressure in Figure 2.8 is 7.38 MPa), the BRU-A valve does not open.

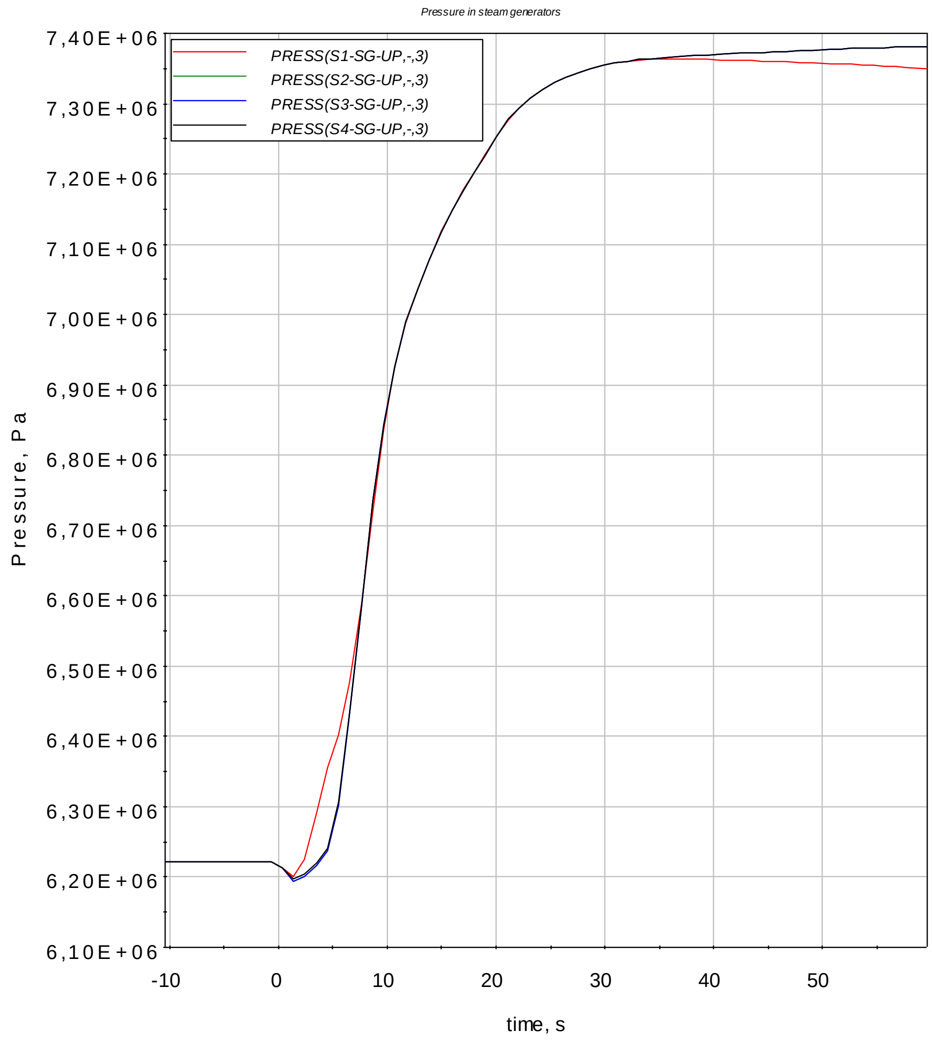

Figure 2.7 Pressure in steam generators

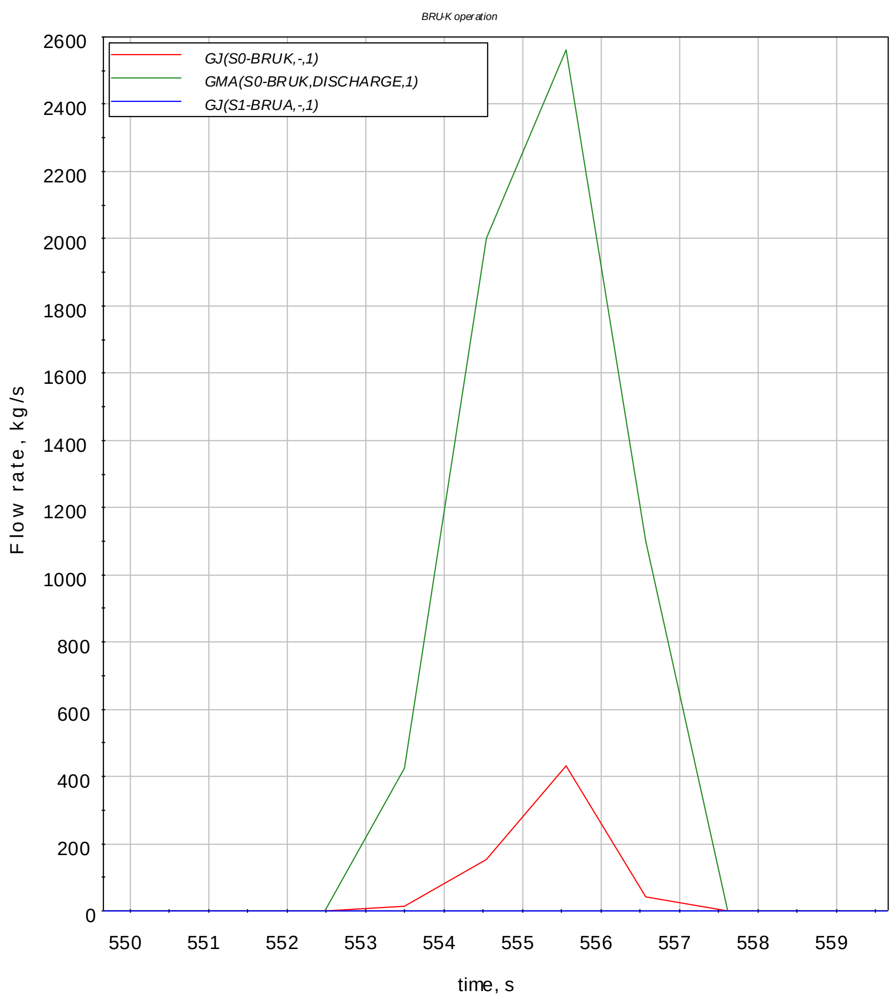

Figure 2.8 BRU-A and BRU-K operation

red curve: BRU-K mass flow rate

blue curve: BRU-A mass flow rate
green curve: critical discharge rate of BRU-K (= maximum possible mass flow through the valve)

The coolant from the pressurizer is drained in less than 20 seconds (cf. Figure 2.2). When the pressure at connection points of the hydro-accumulator pipelines falls below 5.88 MPa, the boric acid solution starts to flow from the hydro-accumulators (Figure 2.9 and Figure 2.10; note that the present ATHLET input deck contains neutron kinetics, but an effect of the boron acid on the power generation is not observed here). The process of the reactor filling by the coolant starts at the 99th second and ends approximately at the 179th second when the valves in the hydro-accumulator injection lines close as the levels in the accumulators drop to 0.578 m, measured from the bottom of each vessel (Figure 2.10; the red and the green curves coincide because of the same bottom elevations of the accumulators). Due to the fact that under the assumed BDBA conditions the active part of the emergency core cooling system

(ECCS) does not work, the process of core overheating and boiling-out of the coolant from the reactor begins.

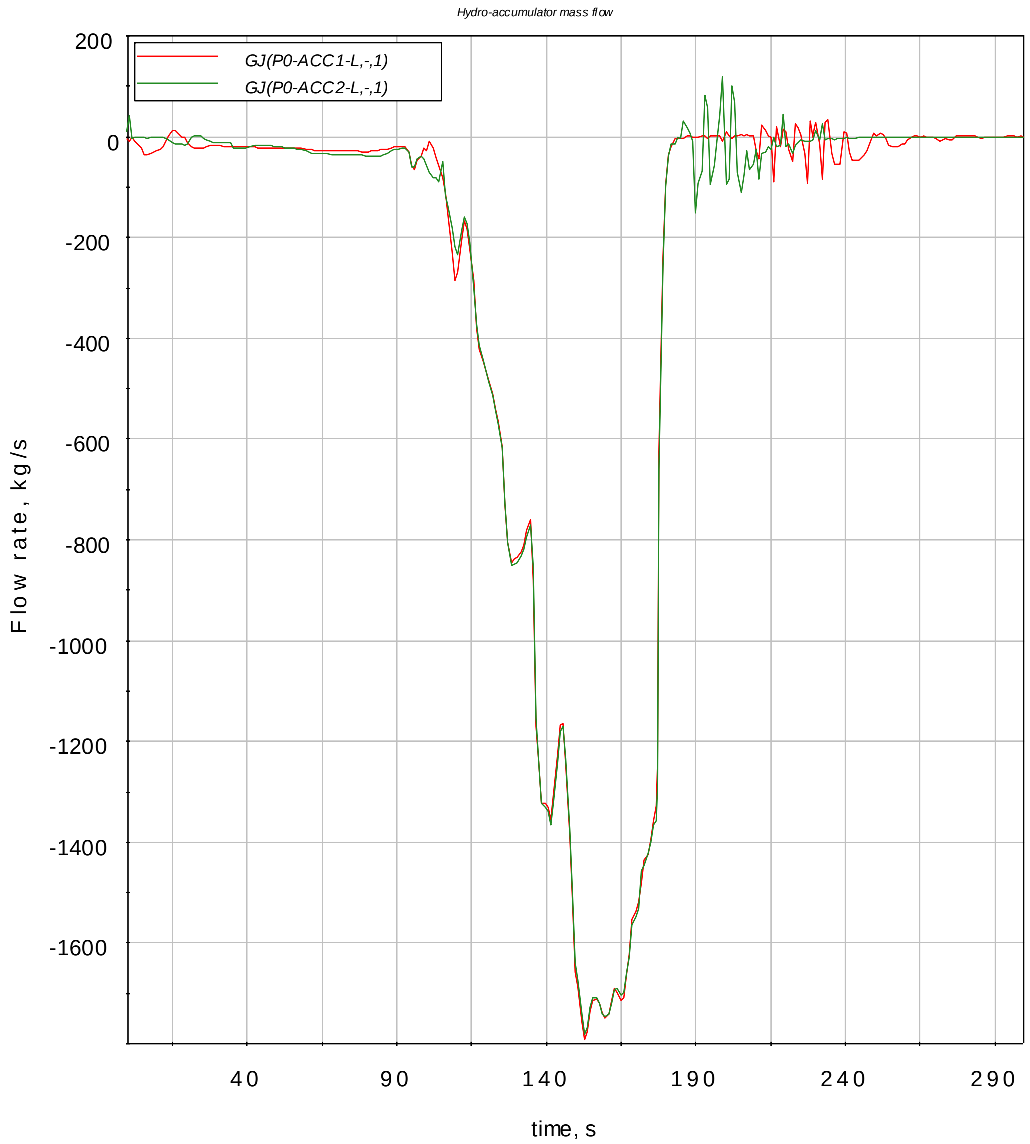

Figure 2.9 Hydro-accumulator mass flow

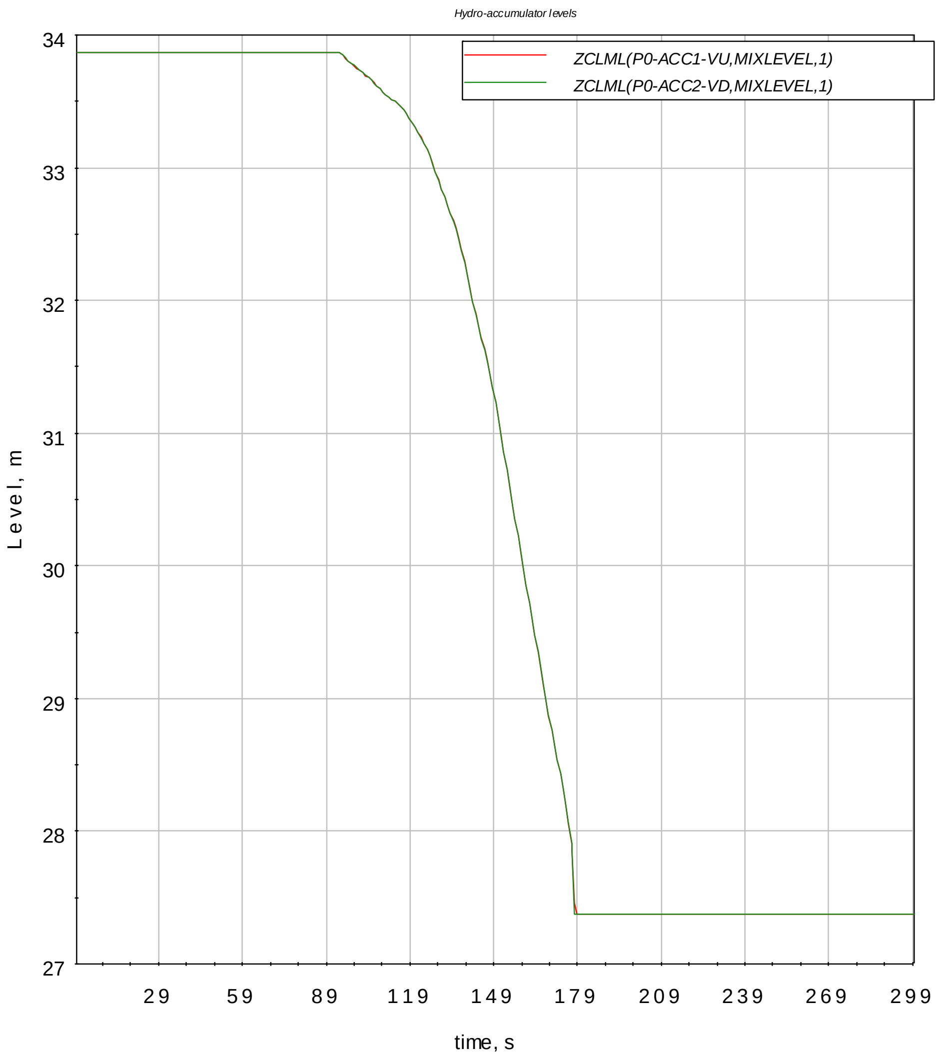

Figure 2.10 Hydro-accumulator levels (absolute height values)

After the MCPs are stopped, the reactor core is cooled by natural circulation, which almost completely stops after draining the U-tubes of the steam generator. Almost immediately after the formation of the leak, a short-term boiling of the coolant in the core occurs, then stops for a few seconds and starts again at 12 seconds (Figure 2.11). After the end of operating of the ECCS passive part (179 s), the mass fraction of steam in the coolant flow begins to increase. In Figure 2.12 and Figure 2.13, you can see that by the 850th second the u-tubes of the steam generator completely dry out.

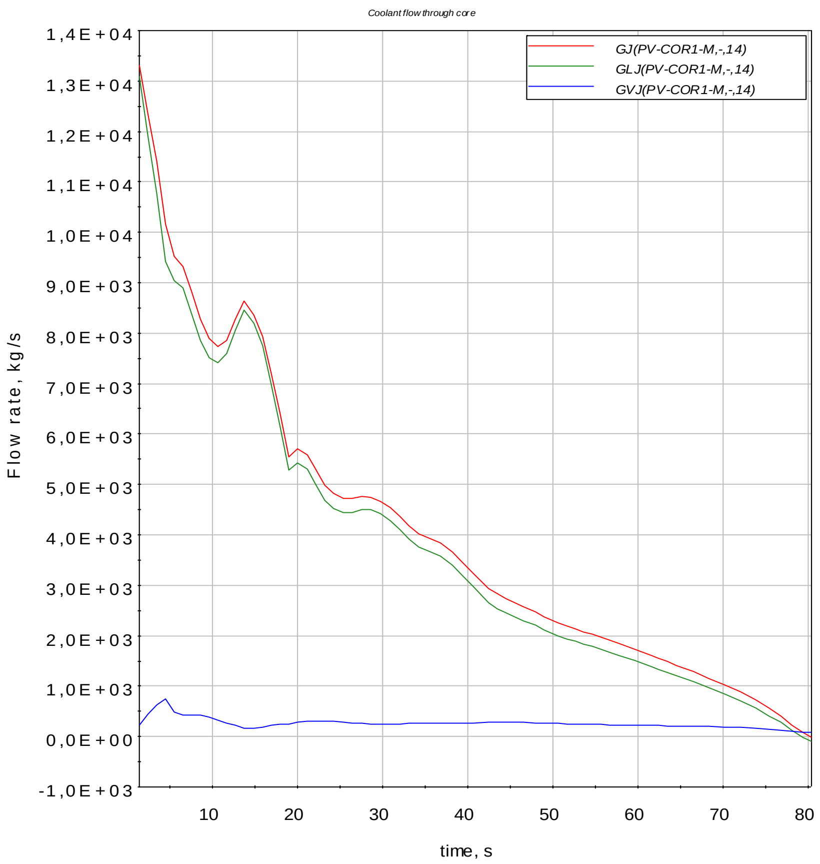

Figure 2.11 Coolant flow through core

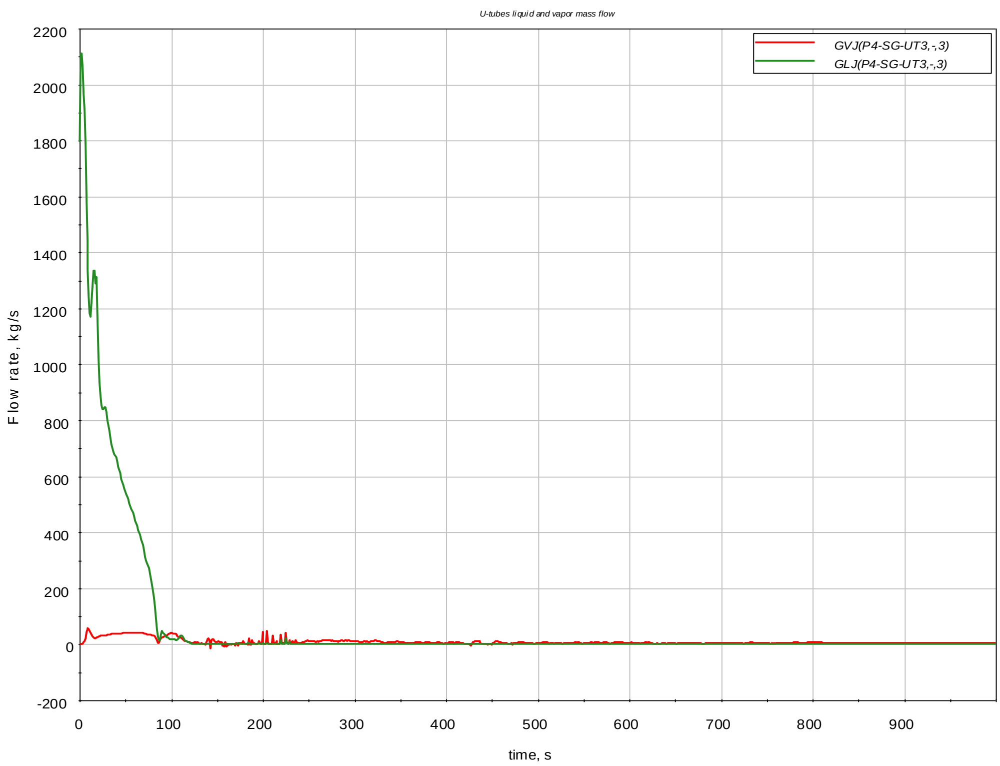

Figure 2.12 U-tubes liquid (green) and vapor (red) mass flow

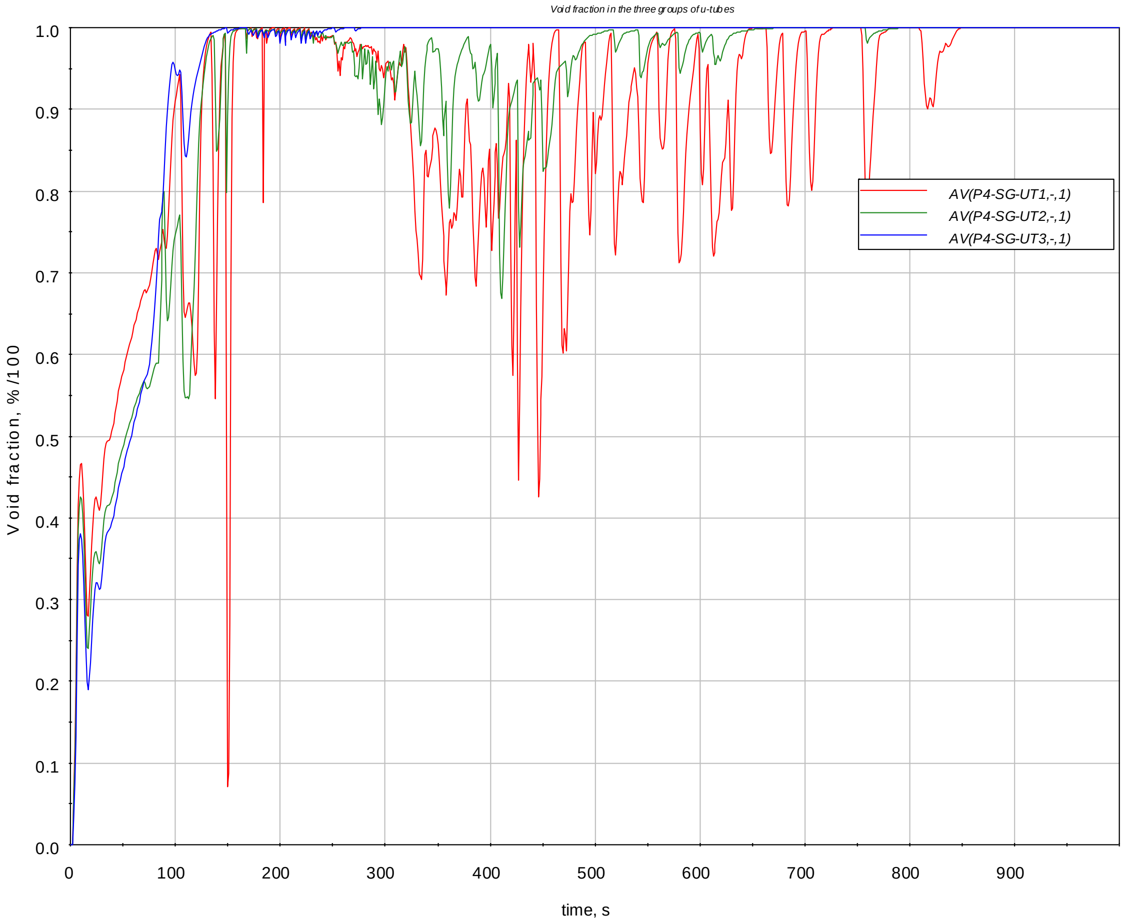

Figure 2.13 Void fraction in the three groups of u-tubes

Figure 2.14 shows that the liquid mass flow in the upper part of the core from the 1150th second is 0 kg/s, which indicates the beginning of the core dehumidification process; the temperature of the steam begins to increase sharply (Figure 2.15). This process will inevitably lead to the occurrence of a steam-zirconium reaction and then melting of fuel rods.

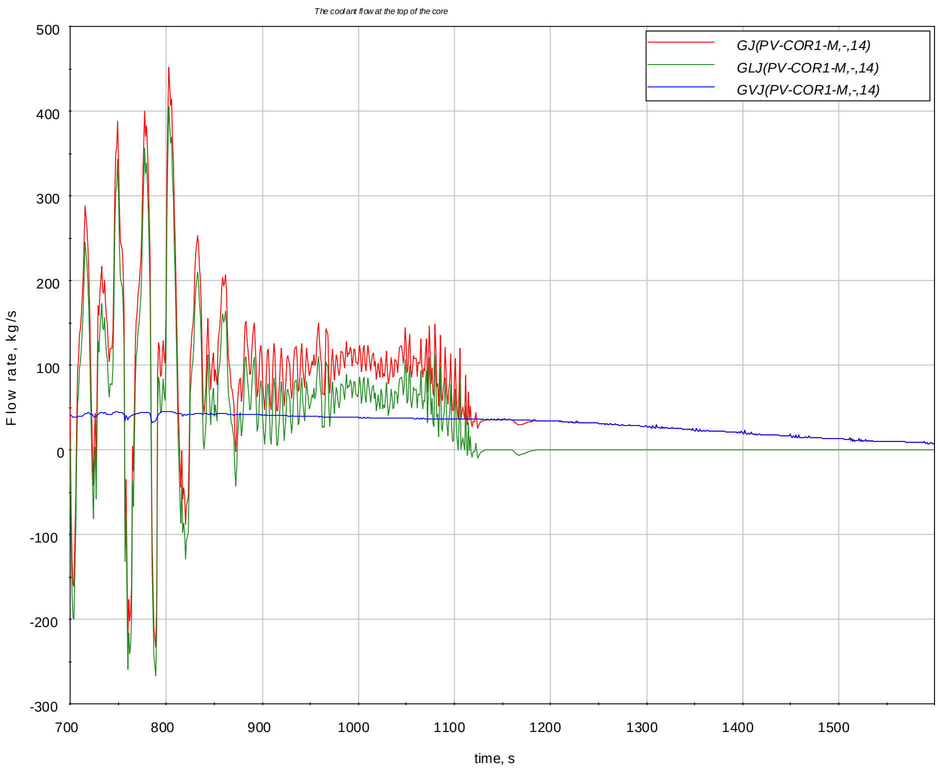

Figure 2.14 The coolant flow at the top of the core

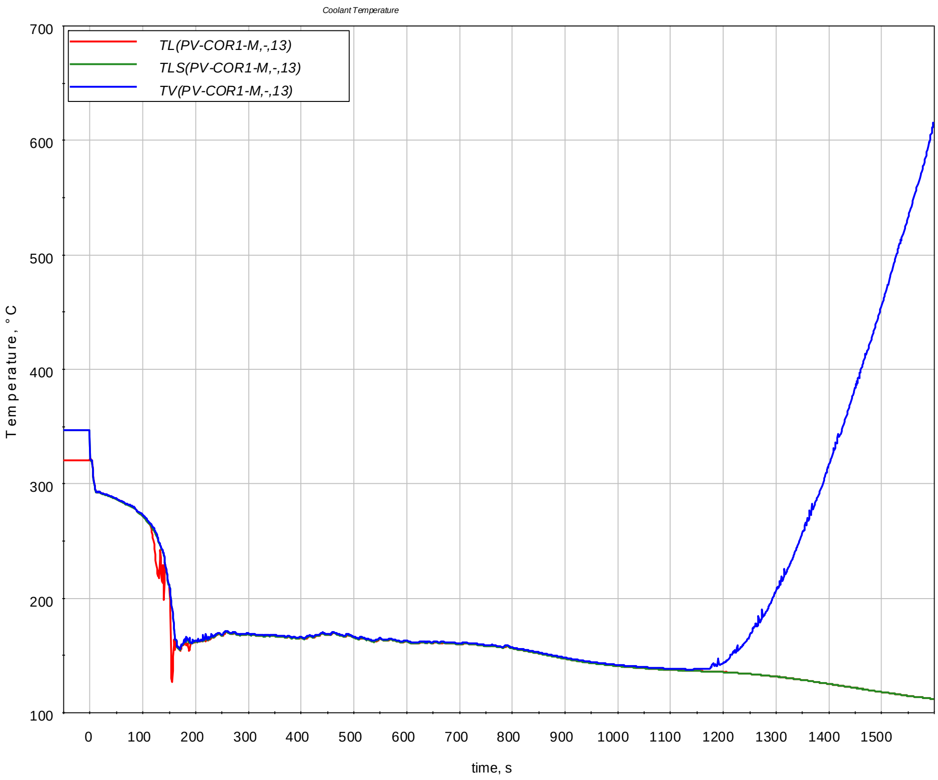

Figure 2.15 The coolant temperature at the top of the core

3. Conclusion

The analyse and description of the ATHLET simulation beyond design basis accident (BDBA) of a LOCA in the cold leg (close to the RPV nozzle), diameter 250 mm with failure of LPI and HPI systems was presented.

In the formation of the initial data set, the stationary initial state of the VVER-1200 with increased initial power (104%) was used. To create this state, the design parameters of the operation of individual systems integrated into the general model of the power unit were set, and the stationary mode was calculated to stabilize the parameters. After establishing a stable stationary state, this state was fixed and used as the initial one for calculations of the transient processes.

It was shown that

- In the case of BDBA, the core draining starts and the steam temperature rises. Accordingly, the temperature of the fuel begins to increase rapidly at a certain time in the BDBA case (which will lead to its destruction).
- The region slightly above average in the heated part of the core is the hottest.
- The melting point of the cladding of a fuel rod is reached at 1850 seconds since the start of the accident.

The input deck created during the execution of this project is sufficient to complete the assigned task. But the analysis of other accidents requires its modernization and greater detailing of the simulated equipment. This will be possible in the course of other projects by people with sufficient experience working with ATHLET code.

Acknowledgments

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