THERMO-HYDRAULIC BEHAVIOUR OF COOLANT IN NUCLEAR REACTOR VVER-440 DURING OUTAGE

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1. Introduction

Thermo-hydraulic conditions in nuclear reactors are important not only in operation mode but also under refuelling and outage conditions. During outage several components of nuclear reactor system (NR) are flooded by coolant [1]. These interconnected components are reactor vessel (RV), reactor pool (RP) and spent fuel storage pool (SFSP). Values of pressure and temperature are significantly lower than in operation mode, because the system is operated under atmospheric pressure conditions. For thermal behaviour only residual heat of fuel assemblies is considered. But the thermo-hydraulic conditions are important also for outage conditions, because:

- reactor vessel is interconnected with reactor pool and spent fuel storage pool (flooded by coolant)
- fuel assemblies with their residual heat are situated in the reactor vessel and in the spent fuel storage pool
- thermal and hydraulic influence between reactor vessel and pools occurs
- transfer of impurities may occurs

The paper presents thermo-hydraulic conditions calculated using Computational Fluid Dynamics - CFD code [2] ANSYS CFX in nuclear reactor VVER-440 during outage conditions where the above mentioned phenomena are discussed.

2. CFD Analysis

The CFD analysis was performed considering the geometric model, Fig. 1, that represents volume of coolant in the system during outage conditions.

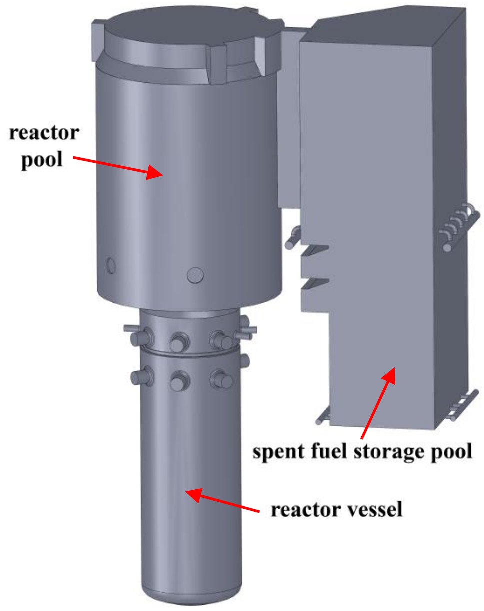

Fig.1: *Geometric model of the system during outage conditions.*

The fuel assemblies with their residual heat were situated in RV (residual heat from fuel assemblies that were in operation right before the outage) and in SFSP (residual heat from fuel assemblies stored there since previous campaigns and outages). Residual heat in RV had value of approx. 4.4 MWt in sum. Cooling of the RV was provided by natural convection using loop through steam generator (over 40 kg/s of coolant flow). Forced convection was considered only in SFSP represented by two inlets and two outlets, which mass flow was approx. 100 kg/s in sum and inlet temperature was 35 °C, Fig. 2. Residual heat in fuel assemblies in SFSP had value of approx. 0.25 MWt in sum. These parts of the system with fuel assemblies (RV and SFSP) were not modelled in detail but they were modelled as two components with porous properties. This approach was necessary because of the complexity of the computational intensive model.

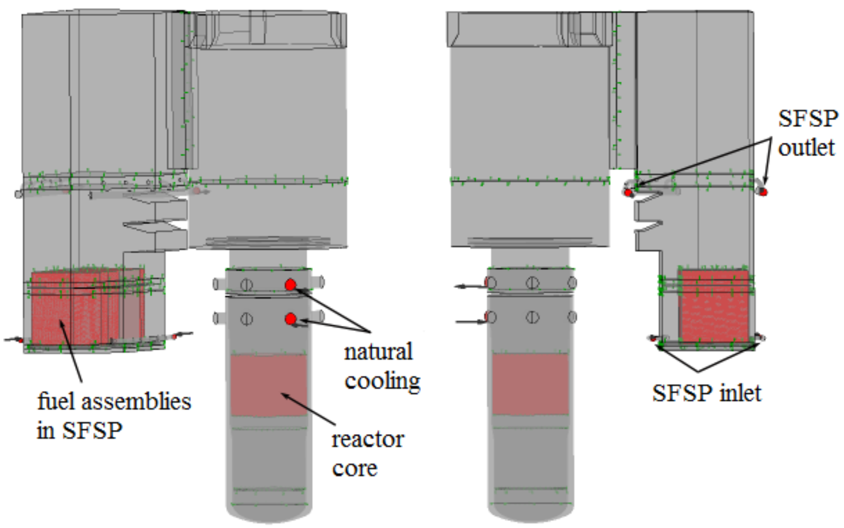

Fig.2: *Boundary conditions of the model.*

The model was discretized to approx. 2.1 mil. elements, Fig. 3.

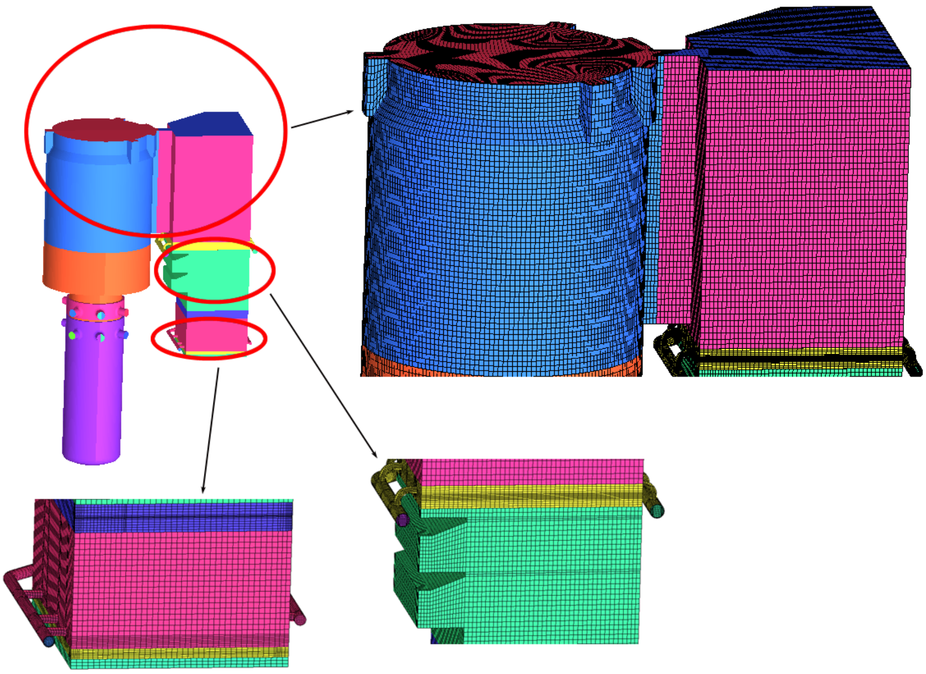

Fig.3: *Model mesh.*

The parameters of the simulations were:

- steady-state analysis
- shear stress transport turbulent model [3]
- 1 second physical timescale for fluid
- convergence control by value 1×10^{-4} residual RMS

The analysis was calculated using iterative method where thousands of iterations were necessary to achieve convergent solution. Obtained results are show in Fig. 4, 5 and 6. Fig. 4 shows the temperature distribution at the longitudinal cross-section of the model. Fig. 5 shows temperature distribution at the chosen lateral cross-sections of the model. Fig. 6 shows the velocity distribution.

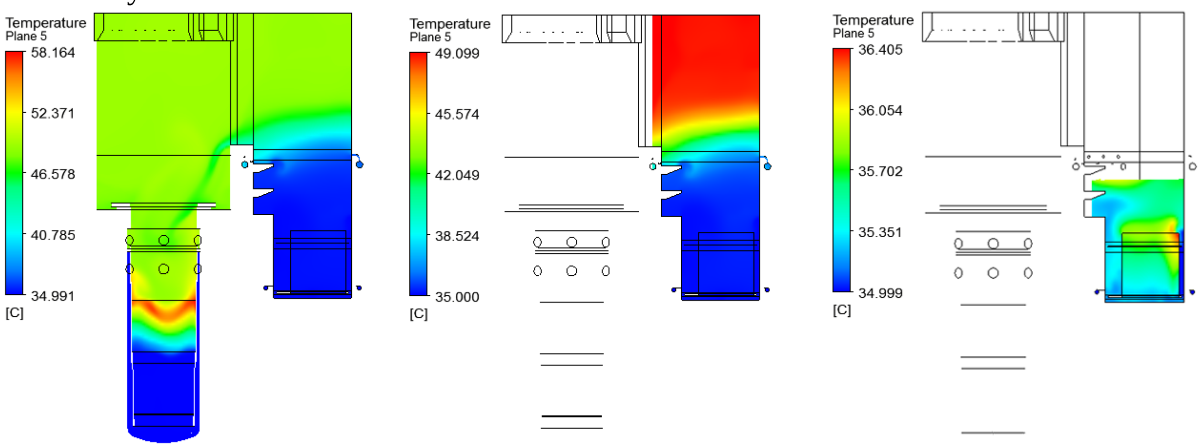

Fig.4: *Temperature distribution at longitudinal cross-section.*

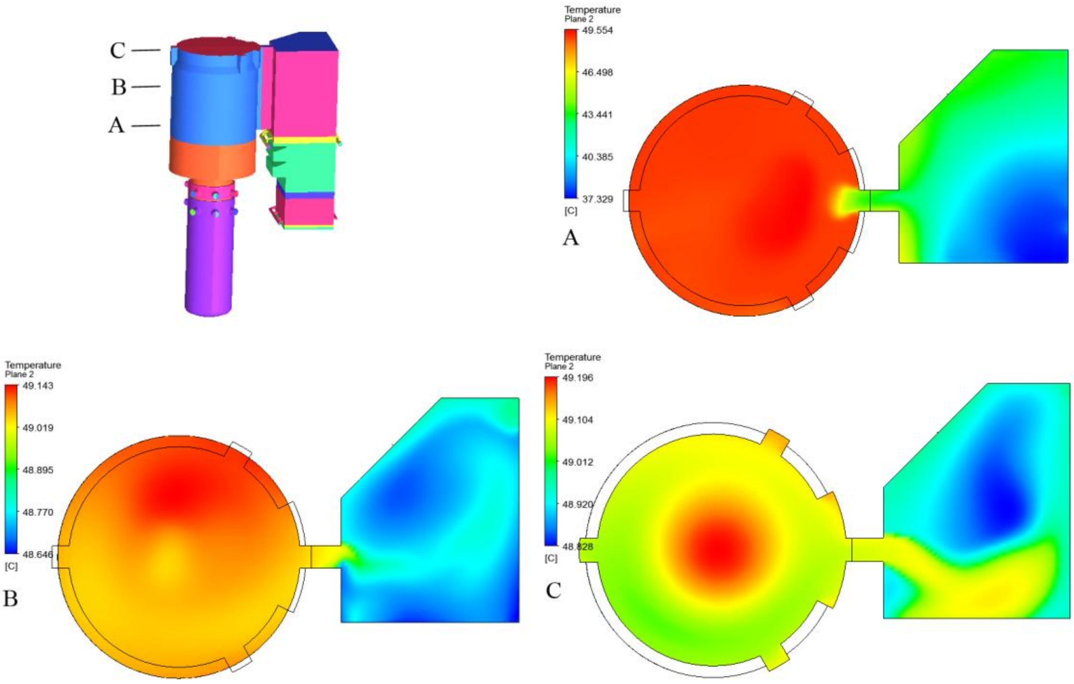

Fig.5: *Temperature distribution at chosen lateral cross-sections.*

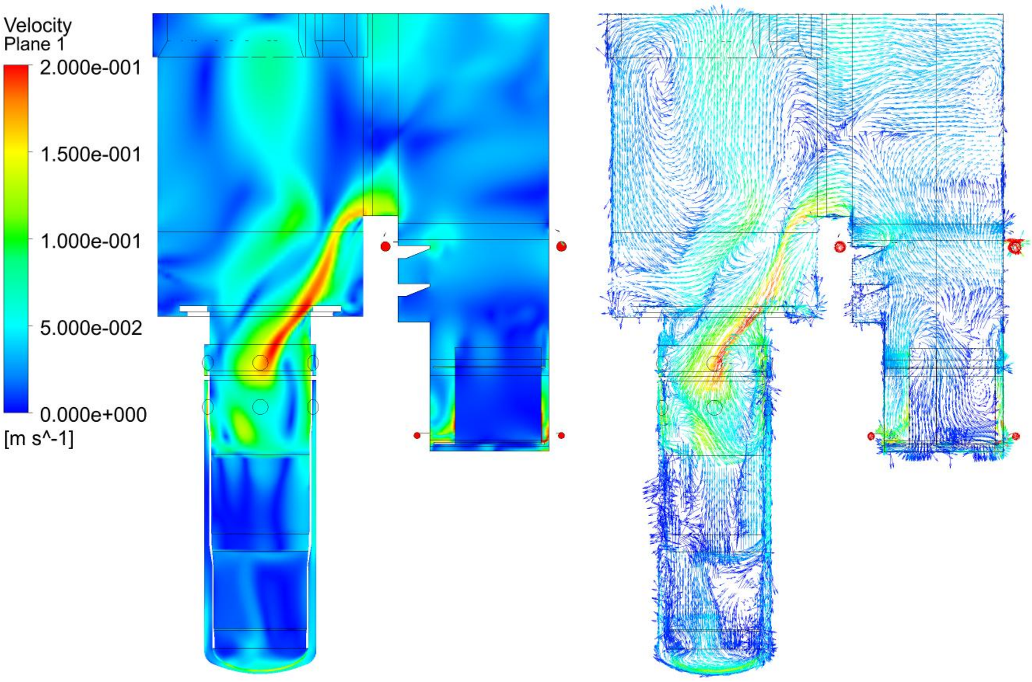

Fig.6: *Velocity distribution at cross-section.*

As it can be seen from these results the flow of coolant is relatively slow and mixing of coolant between SFSP, RP and RV is gentle. Heat-up of the coolant is approx. 23°C. Dominant thermal effect is caused by reactor core, the influence of SFSP is low.

3. Discussion of results

The results show that mutual influence between RV, RP and SFSP is evident especially in coolant temperature distribution, but the flow of coolant is relatively slow across the whole system.

4. Conclusions

The paper presented computational analysis of the thermo-hydraulic conditions of coolant during outage. The results show that flow of coolant under these conditions is relatively slow and mixing of coolant between the individual components of the interconnected system is not significant.

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