Transient Flow Simulation for VVER-1000 Using MCNP6/ANSYS Codes

R. M. Refeat, S. H. Abdel-Latif and A. M. Refaey
Atomic Energy Authority (EAEA), Cairo 11787, Egypt

Abstract: Investigating the time-dependent behavior of nuclear reactors during loss of flow accidents is necessary for safety assessment. Coupled neutronic/thermal-hydraulic codes are used to simulate a full three-dimensional model and predict the essential safety parameters. MCNP6/ANSYS-FLUENT17.2 coupled scheme is used in the present study to simulate a three-dimensional model for VVER-1000 assembly and analyze its behavior during a LOFA (loss of flow accident). Three LOFA scenarios are proposed to represent the failure of one, two or three of the coolant pumps. The influence of the accident on the reactivity and axial power distribution of the assembly is determined considering thermal-hydraulic feedbacks. Then the data obtained are provided to the thermal-hydraulic code to calculate the actual temperature values. The results of the study showed that the developed coupling scheme granted an actual and precise description of the axial behavior of the assembly during LOFA. The output data obtained from both neutronic and thermal-hydraulic calculations have a strong feedback effect; this demonstrated the effect of data exchange between codes to predict accurate values for the main safety parameters. Moreover, it revealed the importance of studying the detailed axial distribution of the safety parameters for the reactor assessment during accidents rather than taking average values in calculations.

Key words: Coupling Codes, MCNP6, ANSYS FLUENT, LOFA.

1. Introduction

LOFA (loss of flow accident) is classified as transients resulting from the failure of power plant equipment and perturbing the coolant flow rate through the reactor core. During LOFA, the fuel and coolant temperatures vary causing changes in reactivity, radial and axial power distribution of the reactor core. These changes must be estimated to ensure the safe control of reactors. For accurate computation, coupled neutronic and thermal-hydraulic codes are used to simulate full three-dimensional models of the reactor. The thermal-hydraulic code computes the fuel temperatures, coolant temperatures and density, which are provided as feedback parameters for the neutronic code to compute the power distribution and the reactivity coefficients. The calculations are executed separately by each code and the data are transferred between the codes during calculations. Coupling codes allow for a best-estimate calculation of safety parameters.

Several coupling schemes were used during transient analysis of VVER reactors. For instance, two different coupling modules were developed to analyze transients due to control rod drop or ejection in Bushehr VVER-1000 reactor. In the first module, WIMSD4, CITATION and RELAP5/3.2 codes were linked together in one package called IRTRAN [1]. The second one is the integrated module (Core Modular Simulator) which contains a neutronic module based on the point kinetic equations and a thermal-hydraulic module based on the time-dependent single heated channel approximation [2]. In another study, ATHLET-BIPR8KN coupled codes were used to simulate a transient in VVER at low power level. The studied case is a simultaneous isolation of one steam generator from the steam line and the feed water supply [3]. In case of LOFA in VVER due to pump failure, the coupled code systems DYN3D-ATHLET, DYN3D-RELAP5, Serpent 2-HEXTRAN-SMABRE...
and PARCS v2.7-COBRA-EN-WIMSD-5B were developed to analyze transient due to one coolant pump failure [4-7].

In the present study, the coupling time-dependent scheme (MCNP6/ANSYS-FLUENT17.2) is used to investigate the safety performance of VVER-1000 assembly during a LOFA. Three scenarios are assumed based on the number of RCP (reactor coolant pump) tripping. Each scenario represents failure of one, two or three pumps causing decrease of flow rate which in turn increase the fuel, clad and coolant temperatures. Hence, the effect of these variations on the neutronic safety parameters is estimated for each scenario. The investigated parameters are changes in reactivity and axial power distribution within fuel assembly. The fuel and moderator coefficients are computed to represent the reactivity changes. The results obtained are used as feedback to ANSYS code to calculate the actual values for fuel, clad and coolant temperatures. The neutronic and thermal-hydraulic safety parameters are evaluated for each scenario to investigate whether these parameters exceed their design limits or not.

The main aspect in the present study is the investigation of the detailed axial behavior of the neutronic and thermal-hydraulic safety parameters during LOFA. The fuel assembly is divided to 9 axial layers and the actual power value for each layer is determined by MCNP6 at every time step, then it is provided to ANSYS to calculate the variation of the actual temperature values with time for each layer. This allows the precise simulation for the assembly and estimation of its behavior during LOFA. The results are compared to those obtained by MCNP6 and ANSYS codes individually without coupling whereas the input values of temperatures and power taken along the fuel rod height are assumed to be constant (average values).

MCNP6 code [8] is used for neutronic calculations and ANSYS-FLUENT17.2 code [9] is used for thermal-hydraulic calculations. This coupling scheme was validated in steady-state calculations for VVER-1000 assembly in a previous study [10] and the results obtained demonstrated the accuracy of the suggested coupling scheme.

2. Model Description and Methodology

MCNP6/ANSYS-FLUENT17.2 coupling scheme is used to simulate a VVER-1000 fuel assembly. The VVER-1000 is a 4-loop pressurized water-reactor. It has a reactor coolant pump and a horizontal steam generator on each loop. The nominal thermal power of the reactor is 3,000 MW and the inlet pressure in the assembly is 16.2 MPa. The fuel assembly includes 312 UO$_2$ fuel rods with Zircaloy clad and 18 guide channels. The active length of the fuel rod is 370 cm. The assembly is divided into 11 axial zones (9 in the fuel active part and 2 in the inlet and outlet coolant parts). Fig. 1 shows a horizontal view for the simulated assembly model and axial view for the fuel rod.

Three LOFA scenarios are proposed assuming the tripping of one, two or three of the RCPs at 100% reactor power. In consequence, this leads to loss of forced flow through the fuel channels. Initial conditions for each scenario were determined in a previous study for steady-state calculations for the VVER-1000 assembly with the developed coupling scheme (MCNP6/ANSYS17.2) [10]. The transient study is performed during the first 80 s following the pumps tripping without scram.

2.1 Scenario-1 (S1)

In this scenario, it is assumed that three main coolant pumps are working and one pump is switched-off. In a nuclear reactor, the analysis of coast down pump flow is important for the safety analysis. In such event, the core cooling depends on the inertia (coast down period) of the primary pumps. As shown in Fig. 2, the primary mass flow rate at 40 s decreased to 75% from the nominal mass flow rates and at the end of simulation time (80 s) the primary mass flow rate decreased to 60%.
2.2 Scenario-2 (S2)

In this scenario two of the four main circulation pumps are tripped. As shown in Fig. 2 the primary mass flow rate decreased to 50% from the nominal mass flow rates at 40 s, then it decreased to 40% at 60 s. Finally, the primary mass flow rate decreased to 27% at the end of simulation time.

2.3 Scenario-3 (S3)

In this scenario, three of the four main RCPs are tripped. This causes a sharp decrease in the mass flow rate as observed in Fig. 2. The primary mass flow rate decreased to 60% at 20 s. At 40 s it is lower than 40%, while at 60 s it decreases to 20%. At the end of simulation time the coolant mass flow rate reached 13.5% from the nominal mass flow rates.

For each scenario, the thermal-hydraulic ANSYS-FLUENT code provides sets of temperature values for the fuel, clad and coolant. These values are obtained for each of the nine axial layers and at different time steps (10-80 s). The produced data together with the coolant densities are provided to MCNP6 code to calculate the reactivity, radial and axial power...
distribution. The Doppler and moderator coefficients are calculated to determine the response to temperature changes.

A total of 10,000 neutrons in 2,000 active cycles are used in MCNP6 calculations and the cross-section data are taken from the ENDF/B-VII [11] nuclear data library. A large number of temperature values are produced by ANSYS code in the calculations and the nuclear data libraries associated with MCNP6 do not cover these values, so the Makxsf code [12] is used to build the needed cross section libraries.

The results obtained from MCNP code are provided as a feedback to ANSYS code to calculate the actual fuel temperatures. The flow chart for the external coupling process used in the present study is shown in Fig. 3.

3. Results and Discussion

Three LOFA scenarios for VVER-1000 assembly are simulated at 100% reactor power. In all scenarios the transient is initiated at time zero due to hypothetical pump coast-down, the flow decreases exponentially with time until 80 s as shown in Fig. 2. Calculations are carried out using MCNP6/ANSYS17.2 coupling scheme at different time steps (10-80 s). Two sets of results are obtained, first variation of fuel, clad and coolant temperatures with time is determined by ANSYS-FLUENT code without coupling with MCNP6. In the second set, the temperature results are calculated using the actual power values provided by MCNP6.

3.1 Results of Scenario-1 (S1)

3.1.1 The Transient Response without Coupling

In this scenario, one of the four main circulation pumps is tripped and the primary mass flow rate decreased slowly as time increased. The thermal-hydraulic parameters are determined by means of ANSYS-FLUENT code using the steady state power calculated in Ref. [10]. Fig. 4 shows the variation of the relative power (steady state power), the mass flow rate and the ratio between relative power and mass flow rate.
Fig. 4  The variation of normalized relative flow rate and power during S1 (without coupling).

Fig. 5  The variation of maximum fuel, clad and coolant temperatures during S1 (without coupling).

Fig. 4 shows that as time increases, the relative power is assumed to be constant while the flow rate decreases. The power-flow ratio increases with time till it reaches its maximum value at 80 s that is 1.75 times the rated power-flow ratio.

From ANSYS calculations, it is found that the maximum fuel temperature is obtained at the sixth layer while the maximum clad and coolant temperatures are found in the seventh and ninth layers (outlet channel) respectively. The variation of the maximum fuel, clad and coolant temperatures during scenario-1 is presented in Fig. 5.

From Fig. 5, the variation of fuel temperature with time seems to be constant and reaches 1,175 K at the end of simulation time; this is because the power is assumed to be constant. The temperatures of clad and coolant increase slightly with time due to the increase in the relative power-flow ratio (as shown in Fig. 4). This increase in temperatures is insignificant and within the required limits [13].
3.1.2 The Transient Response with Coupling

In the previous section the power is assumed to be constant as time increases but this is not true as the power changes with time. To determine the actual power distribution profiles, the different temperature values obtained by ANSYS code at different time steps are provided to MCNP6 code. The reactivity variation with time is shown in Fig. 6 and the axial relative power profiles at steady state, 40 s and 80 s are presented in Fig. 7.

Figs. 6 and 7 show that the changes in reactivity and axial power distribution with time are not significant. The PPF (power peaking factor) did not exceed 1.4 which is acceptable and maintains the safety limits for the reactor operation [14].

The results obtained in case of one pump failure showed that the variation in thermal-hydraulic parameters is insignificant and consequently has no impact on the neutronic parameters and the safety margins.
3.2 Results of Scenario-2 (S2)

3.2.1 The Transient Response without Coupling

In this scenario, the calculated transient starts with the failure of two pumps. The thermal hydraulic ANSYS-FLUENT code used the steady state power to calculate the thermal-hydraulic parameters. The power is assumed to remain constant as the mass flow rate decreases due to the coast down of the two pumps. The total mass flow reached 27.8% from the nominal value at the end of simulation time and the power-flow ratio increased to 3.592 times at 80 s.

The thermal-hydraulic parameters: fuel, clad and coolant temperatures are determined; the variation of maximum temperatures with time is presented in Fig. 8. The maximum fuel temperature increases with time; at the end of simulation time (80 s) its value is 1,381 K with 21% increase from the normal operation. The increase in clad temperature reached 44% at 80 s where the clad temperature is 894 K. The coolant temperature also follows the increase in power-flow ratio; the coolant temperature reached 671.0 K with 12.96% increase.

3.2.2 The Transient Response with Coupling

To demonstrate the effect of coupling in case of two pumps failure, the temperature data derived from ANSYS are provided to MCNP6 to calculate the main neutronic parameters.

During thermal-hydraulic calculations for S2, it is found that the axial distribution of the coolant density in the assembly varies as time increases (as shown in Fig. 9). There is a slight change in coolant density for layers (1-4), but for layers (5-9) the coolant density remains constant for some time then starts to decrease with time. For instance the coolant density for the eighth and ninth layers is constant (~600 kg/m$^3$) during the first 40 s then it starts to decrease. This is due to the change of the coolant phase from liquid to steam.

The results obtained for the variation of reactivity with time are presented in Fig. 10; they are typical to those in Fig. 9. The values of reactivity are constant for the first 40 s then start to decrease at time 50 s.

According to the results obtained in Figs. 9 and 10, the axial power profiles for the first 40 s are not significant where there is no change in the power values. So the axial power profiles presented in Fig. 11 started at 40 s and they are compared to those obtained for the steady state.

![Fig. 8 The variation of maximum fuel, clad and coolant temperatures during S2 (without coupling).](image-url)
Fig. 9  The variation of the axial coolant density with time during S2 (Without coupling).

Fig. 10  The variation of reactivity during S2.

Fig. 11 shows that it is very important to study the axial behavior of neutronic and thermal-hydraulic parameters during accident. As the temperature increases the coolant changes its phase gradually with time from liquid to steam across the axial layers (Fig. 9). The formation of steam in the upper layers causes no moderation at the top of the assembly while more moderation occurs in the lower layers (inlet) due to the presence of the coolant in liquid phase. This has an effect on the microscopic cross sections and the axial power distribution, which decreased in the upper layers of the fuel assembly and increased in the lower layers. At 80 s, the PPF is almost zero in the upper layers and 2.64 in the lower layers, this exceeds the safety limit.

To demonstrate the capability to control the system during accident, the fuel and moderator coefficients are computed during the last 40 s and presented in Table 1.

The results of the reactivity coefficients are kept negative in spite of the temperatures and power increase and this guaranteed the reactor’s control during accident.
Transient Flow Simulation for VVER-1000 Using MCNP6/ANSYS Codes

To calculate the actual temperatures and determine whether it satisfies the safety limits or not, the power data obtained from MCNP6 are provided to ANSYS code to calculate the actual temperatures. Figs. 12-14 present the temperature results for fuel, clad and coolant compared to those obtained from ANSYS without coupling with MCNP6.

Fig. 12 demonstrates the comparison of the time variation of axial fuel temperature with and without coupling. In the case of no coupling, the axial fuel temperature increases with time in all axial layers. The maximum fuel temperature occurred at layer 7; it increased from 1,205 K at 50 s to 1,381 K at 80 s. After coupling, the lower layers (layers 1 to 4) have higher temperature values than the upper ones, the maximum fuel temperature occurred at layer 2; it increased from 1,243 K at 50 s to 1,933 K at 80 s.

Similarly, the clad temperature increases with time in the case of no coupling as shown in Fig. 13; it follows the increase in power-flow ratio where the maximum clad temperature reached 894 K at layer 8 at 80 s. In the case of coupling, the clad temperature at the same layer (8) decreased to 660 K as the power decreased in the upper layers. In the lower layers, the clad temperatures reached the maximum value 803 K at layer 3 and 80 s as shown in Fig. 13.

Fig. 14 presents a comparison for the coolant temperatures obtained without and with coupling. At 80 s, the outlet coolant temperature decreased from 708 K in the case of no coupling to 655 K in the case of coupling.

The results obtained for S2 showed that in the case of two pumps failure, the PPF till 70 s did not exceed 2.5 which is acceptable safety limit for power [14] but at 80 s it reached 2.64 in the lower layers exceeding the safety limit while it is almost zero at the upper layers. The thermal-hydraulic safety parameters obtained in both cases (with and without coupling) are within acceptable safety limits. This means that the increase in power of the lower layers has not violated the thermal-hydraulic safety limits and that it can be controlled by the operators. The results obtained for the Doppler and moderator coefficients confirmed the results.
Fig. 12  Variation of the axial fuel temperatures during S2 (with and without coupling).

Fig. 13  Variation of the axial clad temperatures during S2 (with and without coupling).

Fig. 14  Variation of the axial coolant temperatures during S2 (with and without coupling).
3.3 Results of Scenario-3 (S3)

3.3.1 The Transient Response without Coupling

The transient started by tripping three RCPs causing a sharp decrease in the mass flow rate. It reached 50% of the nominal value at 30 s and 20% before 60 s. At the end of simulation time (80 s) the flow rate decreased to 13.5% of the nominal flow. Assuming the power remains constant as the flow rate decreases the power-flow rate ratio increases with time.

Fig. 15 shows the maximum fuel, clad and coolant temperatures, which are found in layers 7, 8 and 9 respectively. As the power-flow rate ratio increases, the temperatures of fuel, clad and coolant increase with time.

3.3.2 The Transient Response with Coupling

The sharp decrease in the coolant flow rate and increase in coolant temperature caused a sharp decrease in the coolant density at the upper layers of the coolant channel, as shown in Fig. 16. Layer 9 is the first layer where the coolant after 20 s starts to change its phase from liquid to steam followed by the rest of the layers in sequence with time. The coolant phase starts to change in layer 8 at 25 s and in layers 7 to 3 at times from 30 to 80 s respectively.

![Fig. 15](image1.png) The variation of the maximum fuel, clad and coolant temperatures during S3 (without coupling).

![Fig. 16](image2.png) The variation of the axial coolant density with time during S3 (without coupling).
The decrease in coolant density has a strong effect on the reactivity and axial power distribution within the fuel assembly; this is demonstrated in Figs. 17 and 18. Fig. 17 shows that the reactivity is constant during the first 20 s then it decreases with time.

From Fig. 18, the relative power increased with time especially at the lower layers (from 1-3). The PPF at 25 s is 1.87 and increases at 30 and 40 s but it is still less than 2.5. Starting from 50 s, the PPF starts to exceed the safety limits and it reaches to 5 at 80 s exceeding the safety limits. On the other hand, it decreases to be less than 1.0 in the upper layers.

The fuel and moderator coefficients are calculated to assess the capability to control the power increase. The results are presented in Table 2.

<table>
<thead>
<tr>
<th>Doppler coefficient (1/K)</th>
<th>Moderator coefficient (1/K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-4.83E-06</td>
<td>-1.66E-04</td>
</tr>
<tr>
<td>-6.63E-06</td>
<td>-1.72E-04</td>
</tr>
<tr>
<td>-5.26E-06</td>
<td>-2.15E-04</td>
</tr>
<tr>
<td>-3.86E-06</td>
<td>-2.83E-04</td>
</tr>
<tr>
<td>-3.96E-06</td>
<td>-2.12E-04</td>
</tr>
<tr>
<td>-2.34E-06</td>
<td>-3.38E-04</td>
</tr>
<tr>
<td>-4.83E-06</td>
<td>-1.66E-04</td>
</tr>
</tbody>
</table>
Table 2 shows that both the fuel and moderator coefficients have negative values which maintain the system control during the accident.

To evaluate the effect of the obtained power values on the thermal-hydraulic performance of the VVER fuel assembly during S3, the variation of axial fuel, clad and coolant temperatures obtained using coupling codes is compared to those obtained without coupling. The results are presented in Figs. 19-21.

As shown in Fig. 19, there is a slight change in the axial fuel temperature distribution obtained without coupling, because the input power (steady state power) for each axial layer is assumed to be constant [10]. The maximum temperature which occurred in layer 7 at 80 s, is 1,747 K. The fuel temperature increases with time due to decrease in coolant flow rate. After coupling the fuel temperature increased in the lower layers following the increase in power distribution. At 20 s the maximum fuel temperature reached 1,486 K at layer 3 and at 80 s the maximum fuel temperature
reached 2,434 K at the first layer. The fuel temperatures for layers 4-9 decreased at all time of simulation due to the reduction in power.

Similarly, the clad temperature increased with time due to the increase in power-flow ratio in case of calculations without coupling (Fig. 20). The maximum clad temperature at 40 s is 787 K and reaches to 1,311 K at 80 s which occurred at layer 8; this exceeds the critical clad temperature 1,200 K. With coupling the axial clad temperatures decreased with the height of the fuel assembly following the axial power distribution obtained from MCNP6. The maximum clad temperature 1,160 K occurred in the first layer at 80 s and decreased rapidly to reach 731 K at layer 9 as shown in Fig. 20. This is due to the consideration of the actual values of power which are affected by the coolant phase change.

Fig. 21 depicts the comparison for the variation of the axial coolant temperatures during S3 with and without coupling. In the case of no coupling, as the relative power-flow ratio increases the coolant temperature increases with time and layers. The temperature of the last layer reached 941 K at 80 s. In the case of coupling, the coolant temperature increased from layer 1 to layer 5 (563-745 K) and decreased slightly from layer 6 to layer 9 to reach 738 K.

The results obtained in the case of three pumps failure (S3) showed that, the PPF in the lower layers is less than 2.5 during the first 40 s which is considered to be within safety limits but at 50 s it starts to exceed the safety limits and reaches 5. Despite this, the clad and coolant temperatures obtained in case of coupling are within acceptable safety limits. On the contrary, their values exceed safety limits in the case of no coupling. This expresses the effect of using the actual power values.

3.4 Comparison between Coupling Scheme Results and Individual Code Results

The coolant temperature varies along the height of the assembly; so considering the average temperature in calculations does not represent the actual situation. The coolant average temperature \( T_{\text{ave}} \) is higher than the temperatures of the lower layers and hence the corresponding coolant density is lower than the actual value. On the other hand, \( T_{\text{ave}} \) is lower than the temperatures of the upper layers and the coolant density is higher.

This section demonstrates the importance of determining the actual values for power and temperatures to be used as feedback between the coupled codes MCNP6 and ANSYS. This is achieved...
by comparing the results obtained after coupling for axial power distribution and temperatures with those calculated by each code individually (without coupling). The comparison is performed for scenario-3 which is considered to be the worst scenario.

The effect of coupling on the axial power distribution is demonstrated in Figs. 22 and 23. In Fig. 22 the axial power values obtained from MCNP6 code separately for the steady state (at $t = 0$ s) are compared to those obtained after coupling with ANSYS code, whereas Fig. 23 presents the comparison for axial power values at the end of simulation time (at $t = 80$ s).

The power before coupling is denoted by 1 and after coupling by 2. In the case of no coupling, MCNP6 calculated the axial power profiles at each time step using a constant value for temperature (average temperature) specified for all radial and axial zones within the assembly. While in the case of codes coupling, the axial power profiles are calculated by providing the actual axial temperature values obtained by ANSYS to MCNP6.

Fig. 22 shows that at steady state the power profile obtained in both cases has the cosine shape, but the PPF obtained in the case of codes coupling (1.39) is lower than in the case of no coupling (1.46). At the end of simulation (Fig. 23) the power profile ($P$) preserves the cosine shape in case of individual code.
Fig. 24  Variation of average fuel, clad and coolant temperatures for S3.

calculations (without coupling) and the PPF has decreased to 1.44. On the other hand the power profile in case of coupling increased in the lower layers and the PPF reached 5 while it is almost zero in the upper layers. This is due to considering the actual values of fuel and coolant temperatures in each zone and at every time step.

The effect of coupling on the temperature distributions is demonstrated by comparing the time variation of the average temperature values obtained by coupling ANSYS and MCNP6 with those obtained by ANSYS individually using constant power value for all the axial layers of the assembly. This value is equal to the average power value obtained from the steady state calculations [10]. Fig. 24 depicts the variation of temperatures with time. TF, TC and Tcool stand for the fuel, clad and coolant temperatures respectively. The temperature before coupling is denoted by 1 and after coupling is denoted by 2.

It is found that the temperatures increased rapidly with time from (1,004-1,450 K) for fuel, (606-1,091 K) for clad and (578-715 K) for coolant in the case of no coupling. On the other hand, with coupling all the temperatures are lower than those obtained without coupling, the maximum values for fuel, clad and coolant temperatures are (1,176 K), (842 K) and (692 K) respectively.

4. Conclusion

The coupling scheme MCNP6/ANSYS-FLUENT17.2 is used to investigate the transient behavior of VVER-1000 assembly during LOFA. Three LOFA scenarios were proposed; in each scenario a hypothetical failure of a number of coolant pumps is assumed causing a decrease in the nominal steady-state conditions and the coolant flow rate to a suggested percentage of the nominal VVER-1000 flow rate. ANSYS-FLUENT17.2 is used to calculate the thermal safety parameters including axial temperature distribution for fuel, clad and coolant. Meanwhile, MCNP6 code is used to calculate the neutronic safety parameters including neutron multiplication factor (reactivity), axial power distribution and reactivity coefficients. The axial power profiles were generated at defined points in time during the accident and provided once more to ANSYS to calculate the actual temperatures. The main neutronic and thermal hydraulic safety parameters obtained during calculations are evaluated to investigate whether these parameters exceed their design limits and the reactor is sufficiently safe. The specified time of simulation is the first 80 s after pumps trip.

The results obtained showed that in the case of one pump failure, the increase in the temperatures is
Transient Flow Simulation for VVER-1000 Using MCNP6/ANSYS Codes

insignificant and has no impact on the neutronic parameters and the assembly safety margins. In the case of two pumps failure, the PPF till 70 s did not exceed the safety limit for power but at 80 s it exceeded the safety limit in the lower layers while it is almost zero at the upper layers. Even though, the thermal-hydraulic safety parameters obtained are within acceptable safety limits. In the case of three pumps failure the PPF in the lower layers is less than 2.5 during the first 40 s which is considered to be within safety limits but at 50 s it starts to exceed the safety limits. Despite this, the clad and coolant temperatures obtained in the case of coupling are within acceptable safety limits.

The present study investigated that the MCNP6/ANSYS-FLUENT17.2 coupling scheme can be used in the analysis of loss of flow accidents providing a precise and actual simulation of the studied cases. It is shown that the neutronic parameters are strongly influenced by the heat transfer behavior and vice versa. So considering the detailed neutronic and thermal-hydraulic axial behavior at each spatial location and within each time step, is crucial in safety assessment and allows for more accurate analysis than using average values.

References


