EXPERIMENTAL SUPPORT OF THE BLEED AND FEED ACCIDENT
MANAGEMENT MEASURES FOR VVER-440/213 TYPE REACTORS

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ABSTRACT

In the original design of the VVER-440/213 type nuclear power plants event oriented emergency operating procedures (EOP) were implemented. In the last years, however, new symptom based procedures of Westinghouse-type have been developed and partly implemented for the plants in Central Europe including the Paks Nuclear Power Plant. Paper gives a short review of the experiments performed in the PMK-2 facility to study the effectiveness of the bleed and feed strategies and to get experimental data bases for the validation of thermohydraulic system codes like RELAP5, ATHLET and CATHARE.

1 INTRODUCTION

Results of the AGNES project performed for safety reassessment of the Paks Nuclear Power Plant in the time interval of 1991 to 1994 [1] show that among the factors determining the core damage, the effect of eventual human failures is the most significant. Because of the importance of the human factor it was concluded that one of the items of primary importance in increasing the safety level of the plant is the introduction of new, e.g. symptom oriented Emergency Operating Procedures (EOP), which replaces the original event-oriented procedures.

Since 1997 new EOPs have been developed for the Paks NPP and the introduction is under preparation [2]. The EOPs are based on the Westinghouse type Optimal Recovery Guidelines (ORGs) and Safety Function Restoration Guidelines (FRGs). In the EOPs there are procedures where the bleed and feed (B&F) operator actions are applied to decrease the pressure and cool down the plant. These are as follows: loss of all AC power, response to degraded core cooling, response to inadequate core cooling and response to loss of secondary heat sink.

Several experiments have been performed in the PMK-2 facility to support the development of EOPs or to assess the effectiveness of the procedures developed. Based on the experiments the effectiveness of EOPs can be evaluated and computer codes can be validated.

Paper deals with the experiments performed and discussion and conclusions will be given. Short notes are also given about the computer code validation.

2 THERMOHYDRAULIC RESEARCH SUPPORTING THE EOPS

2.1 Experiments Performed

Experiments performed cover the types of accidents where, in the EOPs, the bleed and feed operator actions are applied. These are as follows:
2.2 The PMK-2 Experimental Facility [3]

Figure 1 shows the scheme of the PMK-2 facility. The main circulating pump of the facility serves to simulate the flow coast down following pump trip. After the pump trip the pump is valved off by valves PV11 and MV12 and opening of MV11. From the emergency core cooling systems (ECCS) the four SITs (Hydroaccumulators) of the Paks NPP are modeled by two vessels and they are connected to the downcomer and upper plenum. The HPIS (High Pressure Injection System) and LPIS (Low Pressure Injection System) are modeled by the use of piston pumps. Figure shows locations of measured parameters, e.g., PR21, TE15, LE11, LV21, etc. and the elevations. The reference level of 0.00 m, levels of the main components and LV sensors are also shown in Fig. 1.

![Scheme of PMK-2 facility](image-url)
The nominal parameters of the loop corresponding to the nominal operating parameters of the reference plant are as follows: primary pressure: 12.3 MPa; coolant temperature at core inlet: 540 K; core power: 664 kW; mass flow rate: 4.5 kg/s; secondary pressure: 4.6 MPa; feedwater temperature: 493 K; steam mass flow rate: 0.36 kg/s.

Measurement locations are presented in circles as follows: TE – temperature; PR – pressure; LE – (coolant) level; LV – local void. The local void is measured by needle shaped conductivity probes. Each probe consists of a thin electrode wire. When the liquid phase is covering the tip of the probe, electric current is flowing from the tip to the counter electrode. If any gas bubble contacts the probe, the current is interrupted. The accuracy is less than ±10%. The measurement errors of parameters are given in Table 1.

Table 1: Measurement errors

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Unit</th>
<th>K</th>
<th>Δ(±)</th>
<th>σ(±)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TE63</td>
<td>K</td>
<td>3.0</td>
<td>1.67</td>
<td>1.16</td>
</tr>
<tr>
<td>TE22</td>
<td>K</td>
<td>2.2</td>
<td>1.67</td>
<td>1.16</td>
</tr>
<tr>
<td>TE15</td>
<td>K</td>
<td>-0.2</td>
<td>1.96</td>
<td>1.30</td>
</tr>
<tr>
<td>PF21</td>
<td>MPa</td>
<td>0.01</td>
<td>0.005</td>
<td>0.004</td>
</tr>
<tr>
<td>PR71</td>
<td>MPa</td>
<td>0.01</td>
<td>0.005</td>
<td>0.004</td>
</tr>
<tr>
<td>PR81</td>
<td>MPa</td>
<td>0.01</td>
<td>0.032</td>
<td>0.028</td>
</tr>
<tr>
<td>LE11</td>
<td>kPa</td>
<td>88.6</td>
<td>0.563</td>
<td>0.458</td>
</tr>
<tr>
<td>LE31</td>
<td>kPa</td>
<td>12.5</td>
<td>0.051</td>
<td>0.045</td>
</tr>
<tr>
<td>LE45</td>
<td>kPa</td>
<td>35.7</td>
<td>0.352</td>
<td>0.286</td>
</tr>
<tr>
<td>LE71</td>
<td>kPa</td>
<td>20.8</td>
<td>0.141</td>
<td>0.114</td>
</tr>
</tbody>
</table>

where K is an additional constant (for absolute and differential pressures it is the hydraulic head, for temperatures it is the calibration constant); Δ is the maximum error obtained from calibration; σ is the standard deviation.

2.3 Selected Results of Experiments

From the experiments performed the results of 2.1.a, 2.1.b and 2.1.e are presented in the report to study the effectiveness of bleed and feed actions.

2.3.1 1% cold leg break with primary bleed and feed [4,5]

The experiment is started from the nominal operating parameters of the plant with 1% cold leg break and loss of secondary heat removal, with 1 HPIS in action, but without SITs. To cool down the system primary side bleed and feed is applied using the pressuriser safety valve for bleed and the HPIS for feed. The valve opening corresponds to a 1% break size. An other experiment was also performed to facilitate the understanding of the effect of the primary bleed. A comparison between the two experiments for two parameters is presented in Figs. 2 and 3.

Figures show the time variations of the primary pressure (PR21) and the coolant collapsed level in the reactor model (LE11). The primary bleed is initiated at 580 s resulting in the earlier opening of the hot and cold legs. With B&F the hot and cold leg loop seals open at 620 s and 1520 s, while without bleed at 750 s and 1820 s, respectively. As shown in Fig. 2, the primary pressure continuously drops. The early opening of the seals results in a coolant level of 4.5 m in the reactor model, higher than the level of the core outlet section of 3.5 m, therefore, in contrast with the case without B&F boiling crisis does not occur. The coolant loss can be compensated by 1 HPIS and there was no need for secondary feed.
2.3.2 2% cold leg break with secondary bleed [6]

The experiment is started from the nominal operating parameters of the plant with 2% cold leg break and from the ECCSs 2 SITs are active, but HPIS is not available. Figure 4 shows the primary (PR21) and the secondary (PR81) pressures. Fuel rod surface temperatures at the outlet of the core (TE18 and TE19) are presented in Fig. 5. Because the SITs are active only, the question is whether the primary pressure will drop to the setpoint pressure of the LPIS which can provide the long term cooling of the system.

It can be seen that after the subcooled blowdown the primary pressure is near to the setpoint pressure of SIT, which practically results in the stop of the injection from SITs. As a consequence of the loss of coolant through the break, crisis occurs three times in the core as
shown in Fig. 5. However, as a consequence of the cold leg loop seal clearing and significant flow oscillations the core is reflooded. When the crisis occurs third time at 1410 s, the operator opens the BRU-A valve model initiating the secondary bleed at 1504 s, when the fuel surface temperature is 730 K. This operator action activates the injection from the SITs again and the core is reflooded, however, the primary pressure does not drop to the 7 bar setpoint pressure of the LPIS until the end of the measured transient time. As shown, the secondary bleed is effective, however, the operator should make arrangements to reach the setpoint pressure providing the long term cooling of the core.

2.3.3 Total loss of feedwater [7]

The experiment is started from the nominal operating parameters of the plant with the initiating event “total loss of feedwater”. The scram is initiated at 12 s after the turbine trip of 10 s in the plant. Figures 6 and 7 present the key parameters of the transient.

![Figure 6: Primary (PR21) and secondary (PR81) pressures, coolant level (LE71) in the pressuriser](image1)

![Figure 7: Coolant temperature at the core inlet (TE63), outlet (TE22) and the integrated value of the valve flow (MA01)](image2)

To cool down the system secondary bleed and primary bleed and feed are applied. The BRU-A valve model opens at 127 s and left open by the operator for secondary bleed. As a consequence of the drop of the coolant temperature the primary feed by 1 HPIS is initiated when the coolant level in the pressuriser is the nominal minus 1 m at 513 s. The primary bleed is initiated at 1522 s, by opening of the pressuriser safety valve when the coolant level in the pressuriser is nominal again, resulting in a fast drop of primary pressure as it can be seen in Fig. 6. When the pressuriser completely fills up at about 4000 s the drop of pressure is slowing down, even increasing and at the end of the measured time it is 25 bar, far from the 7 bar setpoint pressure of the LPIS. The integrated value of valve flow is 160 kg. The coolant loss is compensated by 1 HPIS. In the secondary side there was no need for feed.

3 BRIEFLY ABOUT THE CODE VALIDATION

Results of the experiments support the development/assessment of EOPs with the evaluation of the effectiveness of the operator actions. However, the experimental results cannot be applied directly to the EOPs, only the results of code calculations validated by the experimental results. Test results selected for this report have been applied to the validation of
RELAP5/MOD3 which was used for the EOPs of the Paks NPP. A few results of validation are presented below for the three experiments, without the aspects of computer code modelling.

The results of validation for two parameters in case of 1% cold leg break are presented in Figs. 3.1 and 3.2 [4].

Figure 3.1: Pressure in upper plenum (PR21)

Figure 3.2: Steam generator inlet temperature

Figure 3.1 presents the measured and calculated primary pressure. Results of calculation follow the results of experiment. It means that the effect of operator action, i.e. the diminishing of the unfavourable effect of the hot leg loop seal, is well calculated by the code. The time variation of the steam generator inlet temperature shows the same effect as it can be seen in Fig. 3.2.

Results of validation for two parameters of the 2% cold leg break are presented in Figs. 3.3 and 3.4. The average deviation is less than ±1%.

Figure 3.3: Primary pressure

Figure 3.4: Hydroaccumulator level
Figure 3.3 shows the time variation of the PR21 primary pressure. All the three main characteristic parts of the transient process, as the subcooled blowdown, the stagnation of pressure until the bleed and the continuous drop after it, are well calculated. Similar statement is true for the prediction of the coolant level in the hydroaccumulator as it can be seen in Fig. 3.4.

Results of validation for the total loss of feedwater are presented in Figs. 3.5 and 3.6 [7].

![Figure 3.5: Measured and calculated pressuriser levels](image1)

![Figure 3.6: Comparison of measured and calculated core inlet temperatures](image2)

The right prediction of the time variation of the pressuriser level when the pressuriser safety valve is used for primary bleed is important. Figure 3.5 shows that the drop of the level in consequence of the drop of coolant temperature, the fill up procedure by the HPIS injection and the filled up phases are well calculated. The core inlet temperature is also fairly well predicted.

**4 DISCUSSION AND CONCLUSIONS**

4.1 A number of experiments have been performed to study the effectiveness of the bleed and feed operator actions and to create data bases for computer code validation. The experiments cover the types of accidents in which cases the EOPs for the plant contain bleed and feed strategies, like loss of all AC power, response to degraded core cooling, response to inadequate core cooling and response to loss of secondary heat sink.

4.2 Results of experiment of 1% cold leg break with the loss of secondary side heat removal show the effectiveness of the primary side bleed and feed. The bleed is initiated, when the formation of the hot leg loop seal is started which is evaluated from the temporary increase of the primary pressure. The result of the bleed is the continuous drop of the primary pressure with lower values than without bleed resulting in lower value of coolant loss and, therefore, crisis does not occur.

4.3 In case of 2% cold leg break experiment SITs are active only. The question is whether the primary pressure will drop to the setpoint pressure of LPIS without the availability of HPIS. As a result of the break size the primary pressure practically
stagnates at about the setpoint pressure of the SITs, therefore, the injection from SITs is practically terminating and the significant loss of coolant without feeding results in boiling crisis. After the initiating of the secondary bleed the injection from the SITs is reinitiated and the cooling down is continued. However, the operator should make arrangement to reach the LPIS setpoint pressure.

4.4 Secondary and primary bleed and feed is applied to the experiment with initiating event “total loss of feedwater”. The operator actions practically follow the actions prescribed in the EOPs for the plant. The cooling down of the system is provided even at the end of the transient time, the system pressure is far from the setpoint pressure of the LPIS.

4.5 Results of the code validation show that the transient process and the key events of the accident management are well predicted by the RELAP5/MOD3. The quality of the prediction is significantly upgraded in the evaluation of the effectiveness of the secondary and primary bleed and feed. The related procedures in the plant apply similar actions and therefore, experiments – through the code predictions – mean significant assessment activity of the EOPs. The computer code modelling aspects, however, are not subjects of the paper.

REFERENCES


