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Use of Main Loop Isolating Valves Investigation in Case of SGTR for VVER440/V230

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Introduction

- **During the development of Symptom Based Emergency Operating Procedures for VVER 440 units at Kozloduy NPP a number of analyses have been performed using the RELAP5/MOD3.2 computer code.**
- **In this report are discussed advantages and disadvantages of Main Loop Isolation Valves (GZZs) use in case of Steam Generator Tube Rupture (SGTR) accident.**
- **The results demonstrate that sometimes GZZs could provide safety function but sometimes their closing and re-opening could make the situation worse.**
- **The reference power plant for this analysis is Unit 4 at Kozloduy NPP. This plant is a VVER 440/V230 pressurized water reactor that produced 1375 MW thermal power and generates 440 MW electric power.**

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A model of VVER 440/V230 was developed and validated at the INRNE - BAS. The model includes six coolant loops, each one including one main coolant pump and one horizontal steam generator.

The transient scenarios and acceptance failures are designed with the participation of leading specialist from Kozloduy NPP. The following acceptance criteria are used to analyse SGTR for VVER-440/V230:

- ▶ Fuel cladding temperature – not more than 1200 °C.**
- ▶ Safe and steady end state.**
- ▶ In this analysis it has been also investigated ability for fast depressurization using different systems – Spray in the pressurizer or Pressurizer PORV opening.**

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Base Case Calculations

- **Base Case, Variant A – Isolation the damaged SG #6 by closing Main Loop Isolation Valves (GZZs), Depressurization by Spray in the pressurizer and consequent GZZs re-opening.**
- **Base Case, Variant B – RCS cooling to reaching 14 °C under the temperature of saturation in SG #6, Depressurization by pressurizer PORV opening, GZZs re-opening, SG #6 cooling down to 155 °C**

Fail Case Calculations

- **Fail Case, Variant C – GZZ #1 on the hot leg fail to re-open, supporting of 60 °C primary subcooling margin**
- **Fail Case, Variant D - GZZ #1 on the hot leg fail to re-open, supporting of 40-45 °C primary subcooling margin**
- **Fail Case, Variant E - GZZ #1 on the hot leg fail to re-open plus Loss of AC power simultaneous with the reactor SCRAM**

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Assumptions

The broken tube is located in the middle layer of the tube bundle in SG #6 close to the cold collector.

In the initial state of the transient it is assumed:

- Reactor power to be nominal.
- Burn up status – corresponding to the end of life.
- Primary pressure and temperature to be nominal.
- Initial secondary pressure is assumed to be nominal too.
- Pressurizer level is assumed as nominal - 5.2 m.
- Steam Generator water level is assumed to be nominal – 2.12 m.

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Base Case - Variant A

Scenario:

- 1. The double ended break of one pipeline in SG #6 close to the cold collector.**
- 2. The operator starts one Makeup pump (6 m³/hr) to inject in primary loop.**
- 3. Switching on pressurizer heaters due to primary side pressure decreasing down to 120 kgf/cm²**
- 4. Actuation of Emergency Protection – I (AZ-1) according to the set point “Pressurizer water level < 2.6 m”.**
- 5. Switching off all Pressurizer heaters due to Pressurizer water level became less than 2.0 m.**
- 6. Actuation of only one system for automatic step by step loading (AASSL) according to the set point “Pressurizer water level < 2 m.”. Only HPP #1 starts to inject borated water with concentration of boric acid 39 g/kg.**

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- 7.** Closing of Turbine Stop Valves (TSVs) of the both turbines 10 sec after Emergency Protection - I actuation.
- 8.** BRU-Ks opening due to pressure in the Main Steam Header reaches level 50 kgf/cm² (4.9 MPa)
- 9.** The operator disconnects SG #6 from the feedwater and emergency feedwater lines after reaching 2.22 m.
- 10.** Water level in the damaged SG #6 increases up to 2.27 m. This is the reason for the following operator actions:
 - The operator switches off MCP #6;
 - The automatic closes GZZs to 99.5% of their flow area. The other 0.5% the operator tightens manually. Closing of GZZs takes approximately 978 sec.
- 11.** After Loop #6 isolation by GZZs closing:
 - The operator isolates ruptured SG #6 from the steam line (by BZOK closing or Main Steam Isolating Valve P-1 on its steam line);
 - The operator opens the Letdown system on the damaged SG #6.

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12. The operator stops HPP #1 when:

- Core exit subcooling margin is higher than 10 kgf/cm²;
- Primary side pressure is stable or increase;
- Pressurizer water level is higher than 3.5 m.

13. The operator starts to cooldown the RCS by BRU-Ks with speed 60 °C/hr.

14. RCS cooling stops after reaching core exit temperature with 10 °C less than the saturated temperature corresponding to the pressure in the damaged SG #6. The operator starts to support this temperature.

15. The operator starts depressurization of primary side by using the Spray in the pressurizer.

16. The operator stops depressurization by Spray (low Spray efficiency).

17. The operator disconnects the damaged SG #6 from its Letdown system when the pressure level in it became less than 46 kg/cm².

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- 18.** GZZs opening after primary side depressurization so that the pressure differences to be - 0.1 kg/cm² (10 kPa).
- 19.** After depressurization the operator starts to cooldown the RCS by BRU-Ks with speed 15 °C/hr.

Main List of Events:

Event	Time, s
Break	0.0
Actuation of Emergency Protection – I (AZ-1)	711.0
Switching on HPP #1 (PRZ water level drop to 2.0 m)	716.0
Turbine Stop Valves of the both turbine closing – 10 sec after Emergency Protection - I	721.0

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BRU-K #1, #2, #3 and #4 opening	731.0
The damaged SG #6 is disconnected from its feedwater and emergency feedwater lines (2.22 m water level in it)	805.0
The operator switches off MCP #6 (2.27 m water level in SG #6)	990.0
The operator actuates automatic GZZs closing on the Loop #6	990.0
The operator starts to close Main Steam Isolating Valve (MSIV) on the SG #6 steam line (after GZZs closing)	1968.0
Switching off HPP #1 by the operator (after MSIV closing)	2117.0
The operator starts to cool down the RCS with speed 60 °C/hr by BRU-Ks	2117.0

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The operator stops cooling the RCS (after primary side temperature became with 10 °C less than the saturated temperature corresponding to the pressure in the damaged SG #6)	2817.0
The operator starts depressurization of primary side by Spray in the pressurizer from the cold leg	2817.0
Spray is stopped – low efficiency	6950.0
GZZs re-opening so that the pressure difference of MCP #6 to be - 0.1 kg/cm ² (10 kPa).	6950.0
The operator starts to cooldown RCS by BRU-Ks with speed 15 °C/hr	6950.0
End of calculation	8000.0

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In the initial phase of double-ended single SG it could be observed decreasing of primary side pressure and respectively Pressurizer water level decreasing. Because of the break secondary side pressure in the damaged SG increases slowly.

At approximately 50 sec. during the transient time the operator starts one Makeup pump (6 m³/hr) to inject in primary loop but it can't support the primary side pressure. After reaching the set point "Primary pressure less than 120 kgf/cm²" at 250.0 sec all Pressurizer heaters switch on in attempt to maintain the primary side pressure (Fig. A.1.). In spite of that primary side pressure continues to decrease.

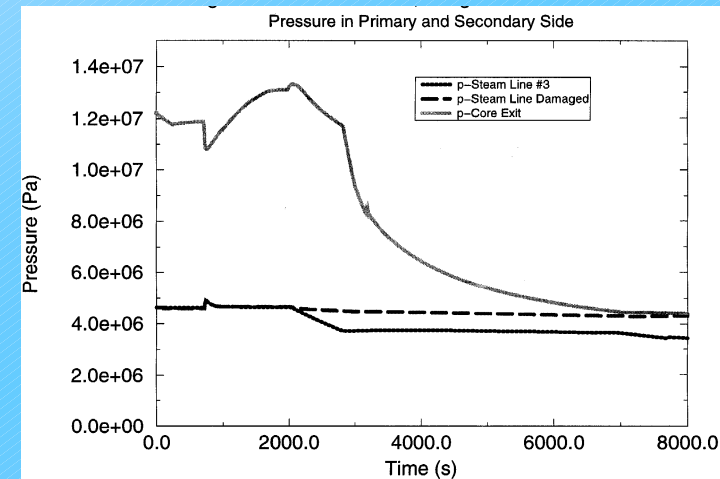


Fig.A.1.

At 2817.0 sec the operator starts to depressurize primary side by Spray in the pressurizer. The aim is averting SG safety valves opening after GZZs re-opening. Due to low Spray efficiency at 6950.0 sec the operator stops primary side depressurization before pressure equilibrium conditions to be established.

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The core exit temperature trend is shown in Fig. A.2.

At 2117.0 sec the operator starts to cool down RCS with speed 60 °C/hr by BRU-Ks. At 2817.0 sec the core exit temperature became with 10 °C less than the saturated temperature corresponding to the pressure in the damaged SG #6.

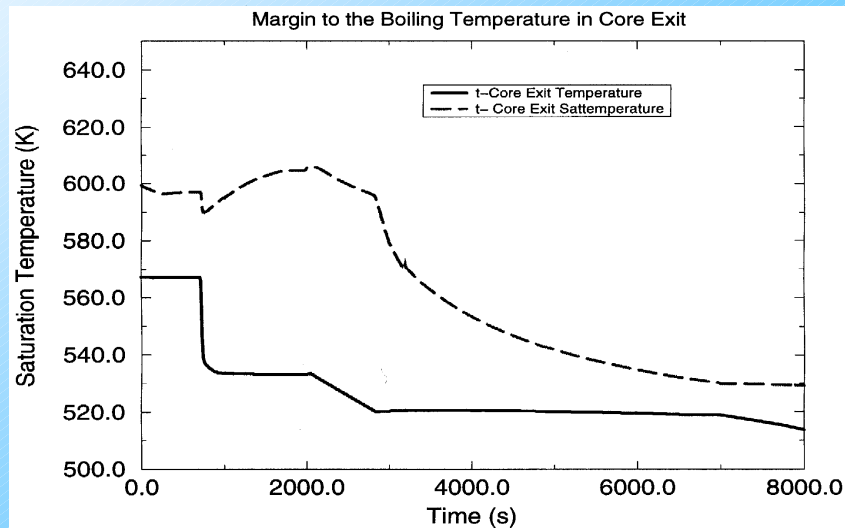


Fig.A.2

At 2817.0 sec there is a significant subcooling margin in primary side of approximately 75 °C (Fig. A.2.).

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The break flow rate is presented in Figure A.3. It reaches its maximum value of approximately 9.86 kg/s from the cold collector and 3.09 kg/s from the end of pipe line at 1968.0 sec. At 1968.0 sec the both GZZs on the damaged Loop #6 are completely closed by the operator.

At 6950.0 sec the break flow rate increases due to GZZs re-opening.

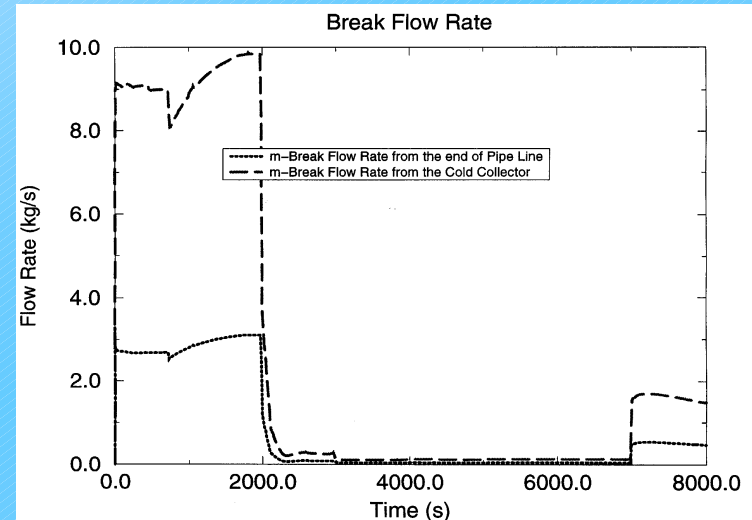


Fig.A.3.

In the initial stage of the transient Pressurizer Water Level (PWL) decreases. At 711.0 sec it reaches 2.6 m, which is the set point for actuation of Emergency Protection-I (AZ-1). After reaching 2.0 m PWL at 716.0 sec HPP #1 starts to inject.

At 2117.0 sec the operator stops HPP #1 due to PWL increasing up to 3.5 m.

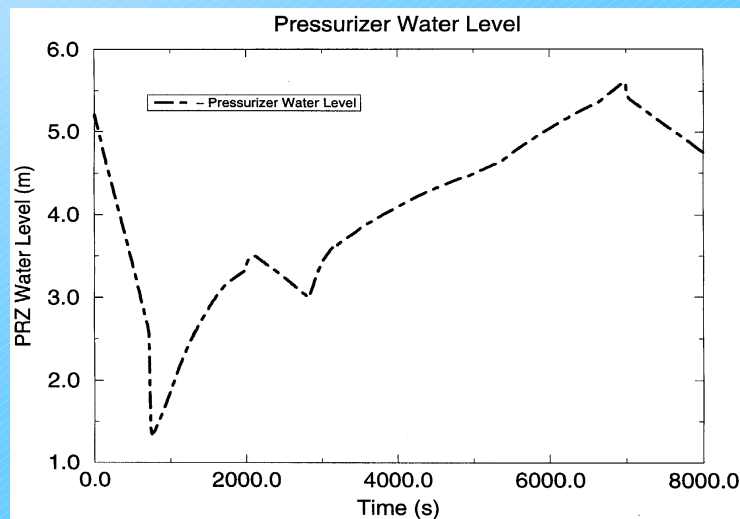


Fig.A.4.

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Conclusion:

The main conclusion for this calculation with GZZs closing, depressurization by Spray in the pressurizer and consequent GZZs re-opening is that the Spray system is not effective for deep depressurization of primary side, especially when the cold leg temperature is closed to the saturated temperature. To avoid this problem the operator have to cooldown primary side a little bit more but not more than 15 °C below the saturated temperature in the ruptured SG #6. According to the Technical specification the isolating by GZZs loop could be joined to the other working loops if the temperature difference between them is less than 15 °C.

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Base Case - Variant B

This transient demonstrates ability for fast primary depressurization by PORV opening. As in the previous case the damaged SG #6 has been isolated from primary circuit by GZZs closing. Consequent RCS cooling is performed to reaching a primary temperature level, which is with 14 °C less than the temperature of saturation in the damaged SG #6. Depressurization continues until primary pressure became equal to pressure in the damaged SG #6. In this way the operator prevents SG #6 safety valves opening and on the other hand eliminates break flow rate. The accepted strategy for SG #6 cooling down is GZZs re-opening so that the pump pressure difference to be - 0.1 kg/cm² (10 kPa). After that the operator starts to cooldown the RCS by BRU-Ks with speed 15 °C/hr. As a result of this subcooling margin in the primary side starts to increase and when it reaches 40 °C the operator starts to support it by Spray. The operator stops MCP #2 after reaching 200 °C coolant temperature.

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The most important parameters behaviour is shown in Fig. from B.1 through B.4.

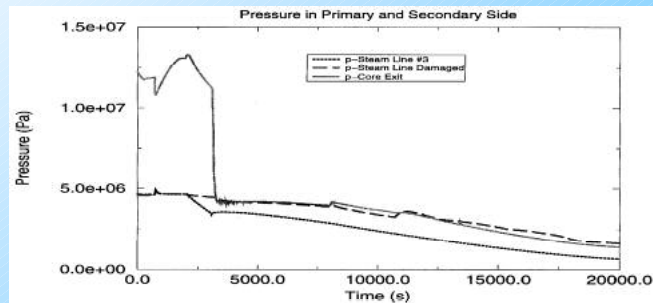


Fig.B.1.

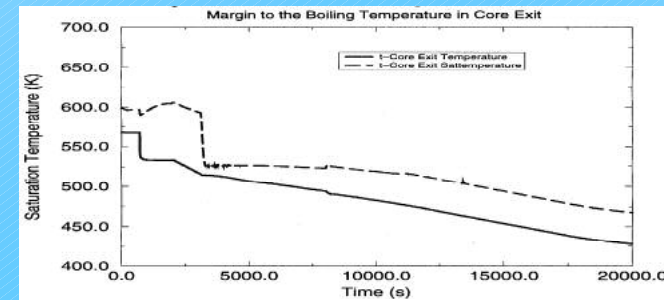


Fig.B.2.

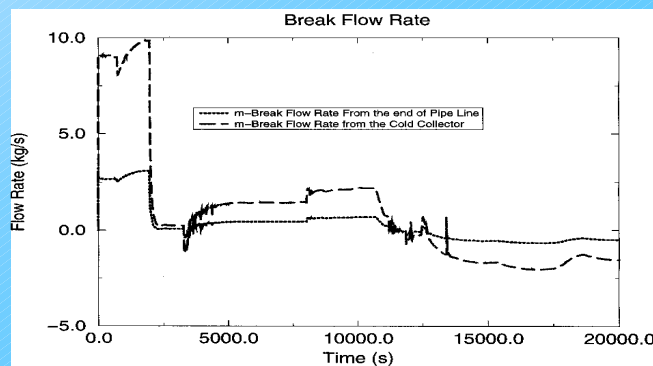


Fig.B.3.

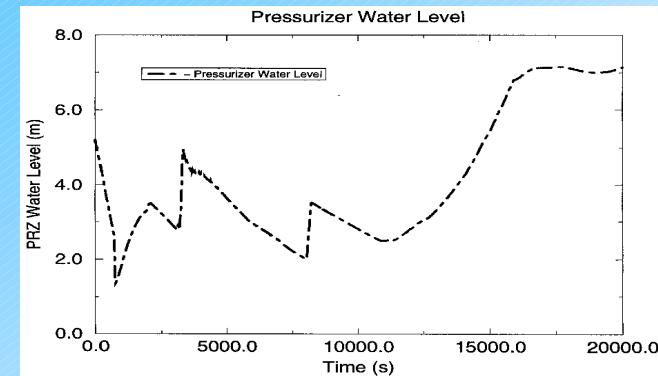


Fig.B.4.

The calculation was performed up to 20000 sec. into the transient time.

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Conclusion:

The main conclusion for Variant B calculation is that the suggested strategy is effective for successful and safe plant recovery. It allows SG #6 cooling down simultaneous with RCS cooling. At the end of calculation temperature in the damaged SG #6 is approximately 155 °C and there is no problem to continue its cooldown.

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Fail Case - Variant C

This scenario repeats the base case - Variant B through the end of primary side depressurization by pressurizer PORV opening. After depressurization by PORV the operator starts to re-open GZZs on the damaged loop #6 but one of them – the GZZ#1 on the hot leg – stuck in close position. As a result of this flow rate in the hot leg #6 is stagnant and there is no any opportunity for its cooling down. The operator could use break flow rate to cooldown cold leg #6 and ruptured SG #6. This method has low efficiency and will take much time.

SG #6 cooling down is organized by switching on Emergency Feedwater Pumps (EFWP) to inject in the ruptured SG #6 and opening letdown system of the damaged SG #6.

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It is also accepted RCS cooling down with maximum speed of 60 °C/hr by BRU-Ks. As a result of this primary subcooling margin increase. According to the Technical Specification the operator has to support subcooling margin from 40 °C to 80 °C. In the fail case calculations the operator supports it by Spray in the pressurizer. The earlier Spray actuation and supporting of small subcooling margin (40 °C) leads to reducing of Spray efficiency and pressurizer overfilling. On the other hand the later Spray actuation and supporting of big subcooling margin (60 °C) leads to pressurizer water level decreasing. It will cause actuation of HPP to support Pressurizer water level. For fail case calculations – Variant C it is accepted supporting of 60 °C primary side subcooling margin.

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The most important parameters behaviour is shown in Fig. from C.1 through C.4. The calculation was performed up to 18000 sec. into the transient time.

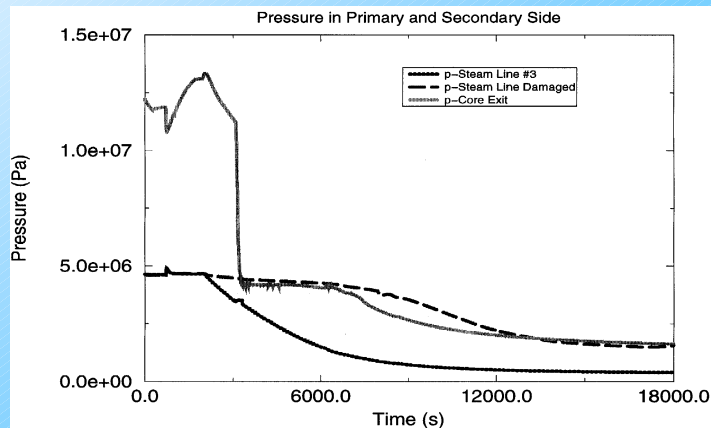


Fig.C.1.

At 3115.0 sec the operator starts to depressurize primary side by PORV opening due to reaching the set point 14 °C margin between the core exit temperature and the saturated temperature corresponding to the pressure (saturated) in the ruptured SG #6.

Depressurization continues to establishing of pressure equilibrium conditions between the primary side and the ruptured SG #6 at 3315.0 sec. At 3315.0 sec the operator starts to open GZZs but one of them – GZZ #1 on the hot leg #6 fail to re-open. The operator opens only GZZ #2 at 100%.

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The trend of Core Exit Temperature is presented in Figure C.2. According to the scenario after GZZs closing the operator starts to cooldown primary side with maximum speed 60 °C/hr by BRU-Ks. At approximately 7800.0 sec Core Exit Temperature gets to plate due to secondary pressure decreasing.

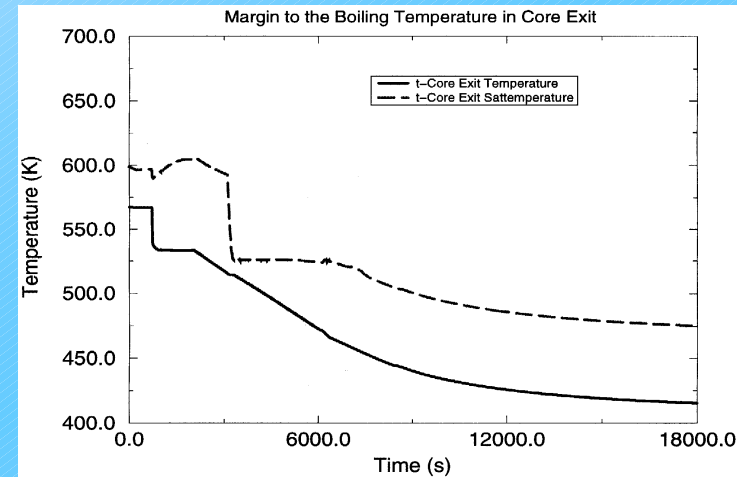


Fig.C.2.

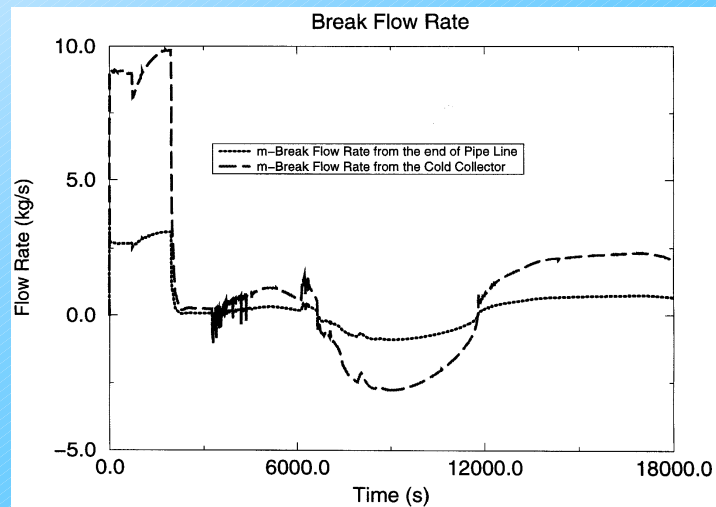


Fig.C.3.

At 6700.0 sec the operator actuates the Spray in the pressurizer and primary side pressure became significantly lower than the secondary side pressure. This is the reason for reverse break flow rate appearance. Due to work of SG#6 letdown system pressure in it decrease too. At 11750.0 sec primary side pressure became higher than pressure in the damaged SG #6 and the break flow rate reverses from primary to secondary side.

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The hot and cold leg temperatures in the damaged loop #6 measured from the side of the reactor (near to the outlet and inlet nozzles) and from the side of the damaged SG #6 are presented in Figure C.4.

Cooling of the hot leg #6 from the side of SG #6 follows the temperature trend in the damaged SG #6.

The hot leg coolant temperature from the side of the reactor vessel follows cooling down of the Pressurizer because in the model the Pressurizer is joined to the damaged loop #6. Temperature deviations of approximately 60 °C measured there are due to HPP #1 actuation at 6140.0 sec. Injection of HPP #1 organizes temporary flow from the reactor through the outlet nozzle of loop #6 towards the pressurizer.

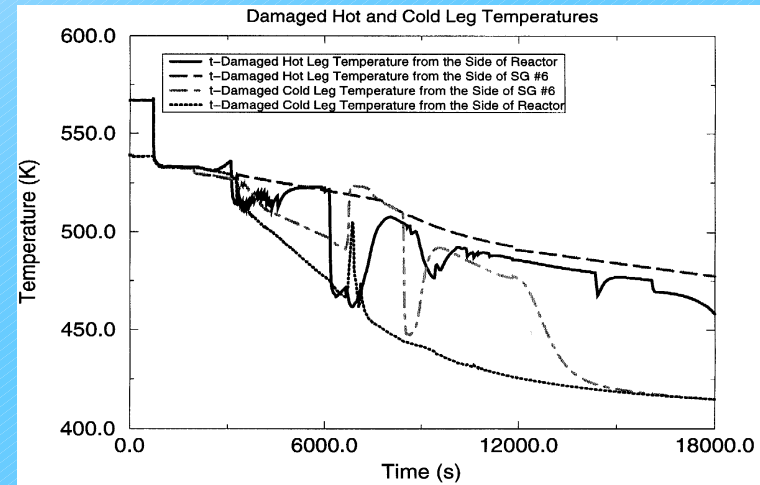


Fig.C.4.

More complicated is the situation in cold leg #6. In spite of GZZ #2 is completely open there is differences in the behaviour of the temperatures measured in the different parts of cold leg #6. This is due steam bubble generation around the 7200.0 sec in cold leg #6 and its bursting at approximately 8430.0 sec.

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Conclusion:

The main conclusion for fail case calculation – Variant C is that during the whole transient time the operator could not find successful way for hot leg #6 cooldown. Although of this temperatures calculated at the both sides of the damaged GZZ#1 indicates small decreasing. The later Spray actuation and supporting a big subcooling margin of 60 °C leads to pressurizer water level decreasing and consequent HPP#1 switching on. It creates temperature deviations of approximately 60 °C in the hot leg #6 from the side of the reactor.

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Fail Case - Variant D

The sequence of events is the same like in the fail case - Variant C but it is accepted supporting of 40 – 45 °C subcooling margin in primary side by Spray actuation. The operator actuates Spray earlier than in Variant C. At this time there is sufficient pressurizer water level in the pressurizer so it is not necessary HPP switching on. Due to low subcooling margin after a while the Spray is inefficient. To increase Spray efficiency at 6000 sec the operator starts to support 45 °C subcooling margin in primary side.

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The most important parameters behaviour is shown in Figures D.1 and D.2. The calculation was performed up to 18000 sec. into the transient time.

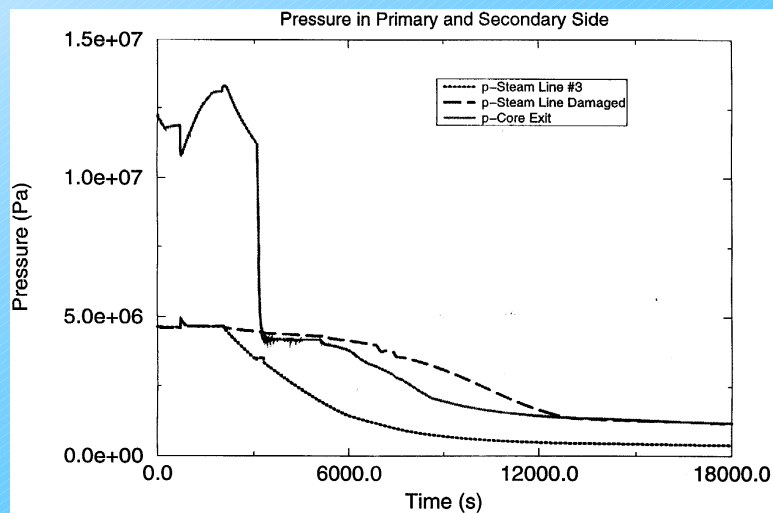


Fig.D.1.

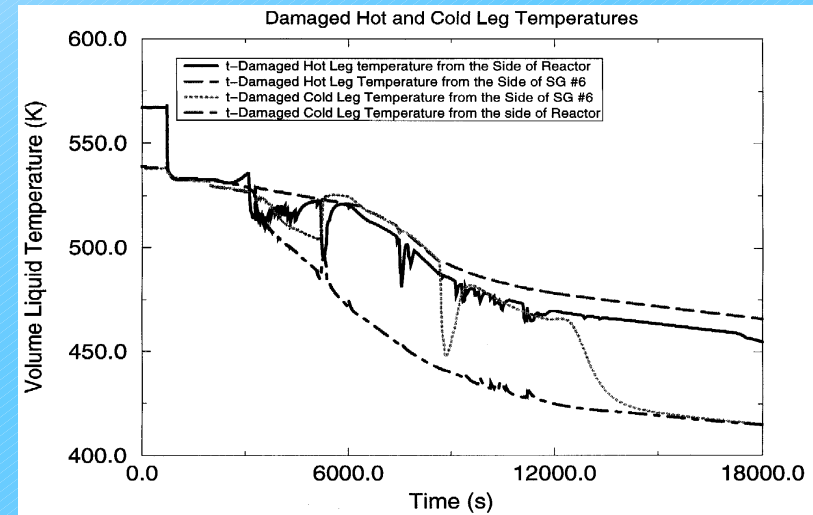


Fig.D.2.

As it seen from Fig.D.2 the hot leg temperature deviations are significantly lower than in Variant C because it isn't necessary HPP actuation.

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Conclusion:

The main conclusion for fail case calculations – Variant D is that at 40 °C primary subcooling margin Spray has low efficiency. That's why at 6000 sec the operator takes a decision to support 45 °C subcooling margin in primary side. On the other hand earlier Spray actuation prevents pressurizer water level decreasing to the set point for HPP switching on. As a result of this the disturbances in the hot and cold leg temperatures from the side of the reactor are significantly lower in comparison with fail case calculations – Variant C.

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Fail Case - Variant E

For this fail case calculation there were assumed the following equipment failures:

- ▶ **Loss of AC Power simultaneous with Reactor SCRAM**
- ▶ **Failure of GZZ#1 on the Hot leg #6 to re-open**

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The most important parameter behavior is presented in the Figures from E.1. through E.4.

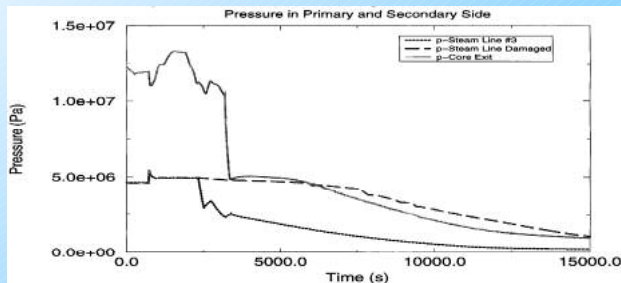


Fig.E.1.

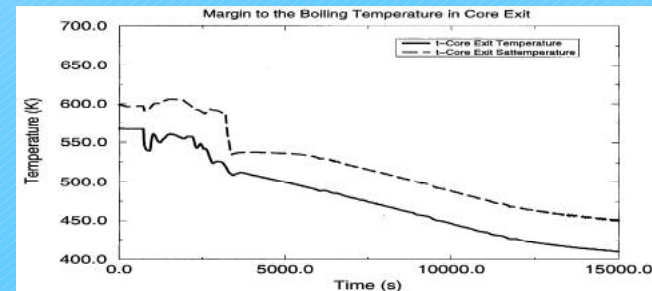


Fig.E.2.

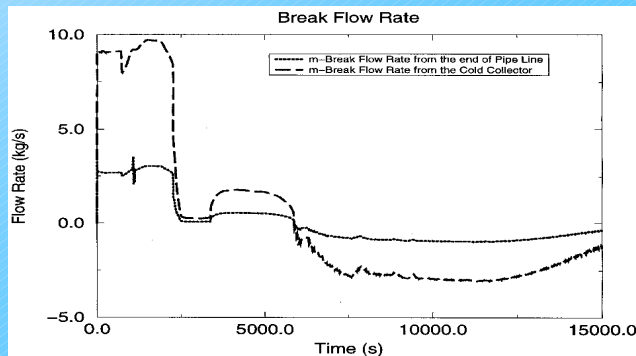


Fig.E.3.

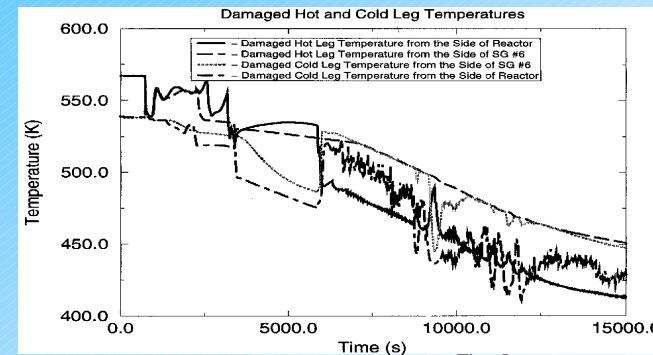


Fig.E.4.

The calculation was performed up to 15000.0 sec into the transient time.

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Conclusion:

The main conclusion for this fail case calculation – Variant E is that the safety systems and operator actions are effective for plant recovery. Appearance of natural circulation in primary side and inertness of primary coolant system after Loss of AC power make difficult supporting of precise cooldown rate. There are periods of several minutes during the transient when the cooldown rate is higher than 60 °C. In spite of that, average speed of RCS cooling for an hour transient time doesn't exceed 60 °C/hr. The operator continues primary cooling up to reaching core exit subcooling margin 40 °C and starts to support it by PORV. In this way the operator supports PRZ water level higher than 2.0 m and avoids HPP actuation.

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General Conclusions

Use of GZZs in case of primary to secondary leak accidents (SGTR) has some benefits and drawbacks. Actually benefits and drawbacks are also observed in case of non-use of GZZs for plant recovery. The thermal-hydraulic analysis of the calculations presented above shows that practically use of GZZs is possible and the operator could bring the plant to stable and safety condition. Although of that sometimes GZZs use could make the situation worse. If after isolation, the damaged SG is depressurized completely, the coolant in the isolated loop is cooled significantly. In case of inadvertent GZZs opening this cold water could get into the core. Also the thermal stresses on the both sizes of GZZs determine the possibility for appearance of additional equipment failures.

In the presented above scenarios with isolation the damaged SG, primary depressurization and consequent GZZs re-opening in a certain degree the benefits of the both approaches are integrated.