USE OF MAIN LOOP ISOLATING VALVES (GZZS) IN VVER 440

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ABSTRACT

This paper discusses the usage of Main Loop Isolation Valves (GZZs) in case of Steam Generator Tube Rupture (SGTR) accident in VVER440/V230. A double-ended single pipe break in SG #6 was chosen as representative. In the paper are investigated two cases. In the first one the operator isolates the affected loop by GZZs closing and after primary depressurization re-opens them to cooldown the damaged SG. The second case treats the situation, where GZZs fail to close with the necessary operator actions for managing plant recovery. RELAP5/MOD3.2 computer code has been used to simulate the SGTR accident in VVER440 NPP model. This model was developed and validated at Institute for Nuclear Research and Nuclear Energy - Bulgarian Academy of Sciences.

The results of analyses presented in this report demonstrate that in the both cases (with or without GZZs usage) the operator could bring the plant to stable and safety conditions.

I. INTRODUCTION

The reference power plant for these analyses 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. The VVER440/V230 design includes six coolant loops, each one including one main coolant pump and one horizontal steam generator. The behavior of the horizontal SGs is very different compared to the western type vertical SGs. For example, the secondary side of the horizontal steam generators contains much more water than the western type vertical SGs. The Russian type horizontal SGs are designed so that the internal steam generator natural circulation is organized. The internal steam generator natural circulation contributes water mixing and avoiding liquid temperature stratification in the SGs. Steam generators play very important role in the safe and reliable operation of VVER power plants. They determine the thermal-hydraulic responses of the primary coolant system during operational and accident transients.

II. PURPOSE OF THE ANALYSIS OF SGTR AND DEFINITION OF THE ACCEPTANCE CRITERION

The main reason for these analyses is investigation of SGTR in supporting of SB EOPs. The calculations are designed to give an opportunity for wide estimation of GZZs use in case of primary to secondary loss of coolant accident (SGTR). The transient scenarios are designed with the participation of leading specialists from Kozloduy NPP.

The following acceptance criteria are used to analyze SGTR for VVER–440/V230:

1.Fuel cladding temperature – not more than 1200 °C.

2.Safe and steady end state.

III. EVENT DESCRIPTION

This section contains a description of the expected plan response to a postulated Steam Generator Tube Rupture accident.

The initiating event of the analyses is a double-ended one-pipe rupture in the middle layer of the tube bundle in SG #6 close to the cold collector. Since the primary system pressure is initially much greater than the steam generator pressure, reactor coolant flows from the primary into the secondary side of the affected steam generator. In response of this loss of reactor coolant, the pressurizer level and RCS pressure decrease. For the expected case, pressurizer water level decreasing leads to an automatic reactor trip signal.

On the secondary side, leakage of contaminated primary coolant will increase the secondary coolant reactivity resulting in high radiation indications. As primary coolant accumulates in the affected steam generator, normal feed water flow is automatically reduced to compensate high steam generator level.

In this paper there are investigated two cases:

1. Case with isolation the damaged SG #6 by closing Main Loop Isolation Valves (GZZs), Depressurization by Spray in the pressurizer and consequent GZZs re-opening.

2. Case without GZZs closing (GZZs fail to close), Depressurization by Spray in the pressurizer.

The automatic systems alone will not terminate the primary to secondary leakage. When a tube failure has been identified, recovery actions begin by isolating feedwater flow to the affected steam generator (automatically).

In the first case - with GZZs closing - the operator closes both GZZs and switches off MCP on the affected loop after reaching level 2.27 m in the ruptured SG #6. After GZZs closing it is necessary isolation of the affected SG #6 from its steam line by closing Main Steam Isolating Valve or Fast Acting Steam Isolating Valve (BZOK). SG #6 letdown system opening could normalize water level in it. In this way the break is completely isolated and this gives an opportunity for primary temperature and pressure reducing to stable and safe conditions. The accepted strategy for post cooling down of the damaged SG #6 is GZZs re-opening after primary side depressurization. In order to avoid secondary radiological releases the operator have to reduce primary pressure under the set point for SG #6 safety valves opening before GZZs re-opening.

In the second case - without GZZs closing - it has been investigated a variant where the both GZZs fail to close. As in the previous case recovery actions begin by isolating feedwater flow to the affected steam generator, switching off the MCP on the damaged loop and isolating steam flow after reaching level 2.27 m in the affected SG. The main operator strategy in this situation is primary depressurization to prevent SG safety valves opening and secondary side contamination. To avoid SG SVs opening primary side depressurization, RCS cooling down and SG #6 isolation from its steam line begin simultaneous when water level in the damaged SG #6 reaches 2.27 m. RCS cooling down comes with maximum speed - BRU-Ks are in fully open position. In this way pressure in the damaged SG #6 and in the intact SGs starts to decrease rapidly.

IV. ASSUMPTIONS FOR THE BOTH CASES:

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

V. SINGLE SGTR IN VVER 440 – CASE WITH ISOLATION THE DAMAGED SG #6 BY CLOSING MAIN LOOP ISOLATION VALVES (GZZS), DEPRESSURIZATION BY SPRAY IN THE PRESSURIZER AND CONSEQUENT GZZS RE-OPENING.

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 m^3/hr) to inject in primary loop.

3. Switching on pressurizer heaters due to primary pressure decreasing down to 120 kgf/cm^2.

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 borate water with concentration of boric acid 39 g/kg.

7. Closing of Turbine Stop Valves (TSVs) of the both turbines 10 seconds after Emergency Protection-I actuation.

8. BRU-Ks opening due to pressure in the Main Steam Header reaches level 50 kgf/cm^2 (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 980 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.

12. The operator stops HPP #1 when the following conditions are executed:

- Core exit subcooling margin is higher than 10 kgf/cm^2;
- 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 ^{0}C/hr.

14. RCS cooling stops after reaching core exit temperature with 10 ^{0}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.

17. The operator disconnects the damaged SG #6 from its Letdown system when the pressure level in it became less than 46 kgf/cm^2.

18. GZZs opening after primary side depressurization so that the pressure differences to be - 0.1 kg/cm^2 (10^4 Pa).

19. After depressurization the operator starts to cooldown the RCS by BRU-Ks with speed 15 ^{0}C/hr.

The calculated sequence of events for this case is presented in the Table A.1.

Table A.1.

Event	Time, s
Break	0.0
Switching on one Makeup pump by the operator	50.0
Switching on Pressurizer heaters	250.0
Actuation of Emergency Protection – I (AZ-1)	711.0
Switching off all Pressurizer heaters (due to reaching the set point - 2.0 m pressurizer water level)	716.0

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
BRU-K #1, #2, #3 and #4 opening	731.0
Water level in the damaged SG #6 reaches 2.22 m	805.0
The damaged SG #6 is disconnected from its feedwater and emergency feedwater lines	805.0
Water level in the damaged SG #6 reaches 2.27 m	990.0
The operator switches off MCP #6	990.0
The operator actuates automatic GZZs closing on the Loop #6	990.0
The operator closes Letdown system on Loop #6	990.0
GZZs of the damaged Loop #6 are completely closed	1968.0
The operator starts to close Main Steam Isolating Valve on the SG #6 steam line (BZOK failed and operator actuates MSIV P-1)	1968.0
The operator opens SG #6 Letdown system	1968.0
The operator closes the Letdown system on the intact SGs	1968.0
The damaged SG #6 is completely disconnected from its steam line	2113.0
Switching off HPP #1 by the operator	2117.0
Max. break flow rate, 9.86 kg/s from the cold collector and 3.09 kg/s from the end of pipe line	2117.0
The operator starts to cooling down the RCS with speed 60 ^{0}C/hr by BRU-Ks	2117.0
The operator stops cooling the RCS (after primary side temperature became with 10 ^{0}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
The operator disconnect SG #6 from its Letdown system due to reaching 46 kgf/cm^2 in the damaged SG	2980.0
Spray is stopped – low efficiency	6950.0
GZZs opening so that the pressure difference of MCP #6 to be - 0.1 kg/cm^2 (10^4 Pa).	6950.0
The operator starts to cooldown RCS by BRU-Ks with speed 15 ^{0}C/hr	6950.0
End of calculation	8000.0

The most important parameters behavior is shown in the Figures from A.1. trough A.4. The calculation was performed up to 8000 sec into the transient time.

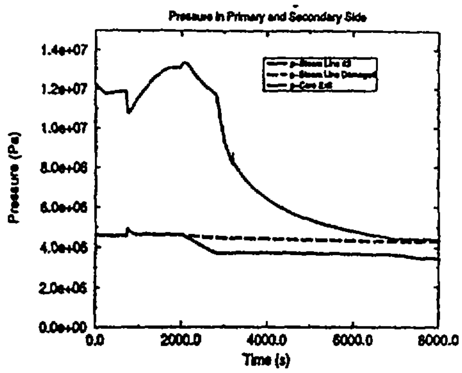

Fig. A.1.

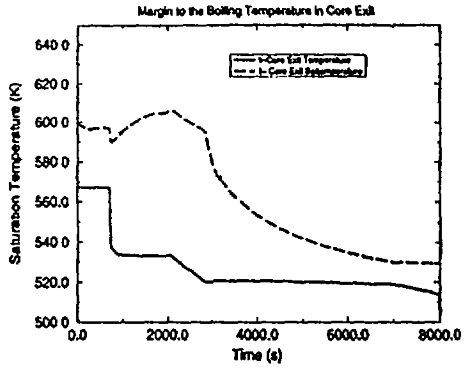

Fig. A.2.

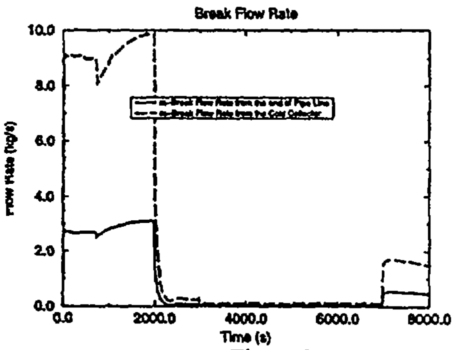

Fig. A.3.

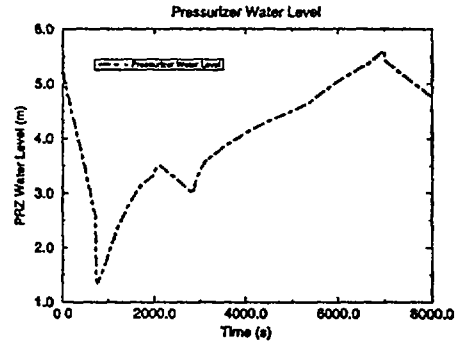

Fig. A.4.

The initial phase of double-ended single SG tube rupture initiates the following equence of events:

It causes decreasing of primary side pressure and respectively Pressurizer water level ecreasing. Because of the break secondary side pressure in the damaged SG increases lowly.

Initially SG #6 water level doesn't increase. Feedwater control system automatically ompensates the changes in SG water level due to primary to secondary leakage by reducing e feedwater flow rate. At 805 sec water level in the damaged SG #6 increases with 100 mm ver the nominal (2.12 m) and reaches 2.22 m. Because of that SG #6 is disconnected from edwater and emergency feedwater lines.

At approximately 50 sec. during the transient time the operator starts one Makeup ımp (6 m^3/hr) to inject in primary loop but it can't support the primary side pressure. After aching the set point "Primary pressure less than 120 kgf/cm^2" at 250.0 sec all Pressurizer aters switch on in attempt to maintain the primary side pressure (Figure A.1.). In spite of at primary side pressure continues to decrease.

Pressurizer Water Level (PWL) also decreases. At 711.0 sec it reaches 2.6 m, which is set point for actuation of Emergency Protection-I (AZ-1).

Following the reactor trip, reactor power rapidly decreases to decay heat levels. Turbine trip is initiated 10 seconds after the AZ-1 actuation. TSVs of the both turbines close at 721.0 sec. Steam flow to the turbine is terminated and the pressure in Main Steam Header starts to increase. At 731 sec it reaches 50 kgf/cm^2 and all four BRU-Ks open. Since the intact and ruptured steam generators are connected via the main steam header, no significant difference in pressures will be evident (see Figure A.1.).

At 716.0 sec after reaching the set point 2.0 m water level in the pressurizer HPP #1 starts to inject borated water with concentration of boric acid - 39 g/kg. This causes primary side pressure and Pressurizer water level increasing. There is significant core exit subcooling margin after the 716.0 sec (see Figure 2.). Due to reaching the set point 2.0 m pressurizer water level all Pressurizer heaters switch off.

After reaching 2.27 m SG water level at 990.0 sec the operator starts to close GZZs on Loop #6. The automatic closes 99.5% from GZZs flow area. The other 0.5% the operator tightens manually. It takes him 15 min (900 sec) and at the end of this period at 1968.0 sec the both GZZs on the damaged Loop #6 are completely closed. In this way the operator stops coolant blowdown from the reactor coolant system to SG #6 (see Figure A.3). Also at 1968.0 sec the break flow rate reaches its maximum of approximately 9.86 kg/s from the cold collector and 3.09 kg/s from the end of pipe line.

After GZZs closing the operator opens the SG #6 Letdown system and starts to close Main Steam Isolating Valve on the SG #6 steam line. It takes him 145 sec and at 2113.0 sec the ruptured SG #6 is completely disconnected from its steam line.

At 2117.0 sec the operator stops HPP #1 due to PWL increasing up to 3.5 m (see Figure A.4.).

The operator starts cooling down RCS with speed 60 ^{0}C/hr by BRU-Ks at 2117.0 sec (this is happened after HPP #1 switching off by the operator). At 2817.0 sec the core exit temperature became with 10 ^{0}C less than the saturated temperature corresponding to the pressure in the damaged SG #6. After that moment the operator stops RCS cooling down and starts to support primary coolant temperature. Pressure in the intact SGs decreases slowly due to coolant shrinkage in result of BRU-Ks work. The core exit temperature trend is shown in Figure A.2. There is a significant subcooling margin of approximately 75 ^{0}C at 2817.0 sec. This is the end of RCS cooling down and the beginning of primary depressurization.

At 2817.0 sec the operator starts to depressurize primary side by Spray in the pressurizer (Figure A.1.). The purpose is primary side pressure to become equal to the secondary side pressure in the damaged SG #6 so that after GZZs opening the break flow rate to be minimal and SG #6 safety valves opening to be avoided.

Due to low Spray efficiency the operator stops primary side depressurization before pressure equilibrium conditions to be established. Although the primary pressure is not completely equalized to the secondary pressure into the damaged SG #6, primary pressure reducing is sufficient for averting SG #6 safety valves opening.

Steam Generator Water Level (SGWL) in the ruptured SG #6 increases and reaches its maximum value at 1968.0 sec. After that moment it starts to decrease due to opening of its letdown system. The operator disconnects SG #6 from its letdown system after reaching 46 kgf/cm^2 at 2980.0 sec.

. At 6950.0 sec the operator starts to cool down primary system by BRU-Ks with speed 15 ^{0}C/hr. SG #6 cooling down comes simultaneous with RCS cooling down.

Conclusion:

The main conclusion for this calculation with GZZs closing, depressurization by Spray in the pressurizer and consequent GZZs re-opening is that the safety systems and operator actions are effective for plant recovery.
Fuel cladding temperature is less than 1200 ^{0}C during the whole transient.

VI. SINGLE SGTR IN VVER 440 - CASE WITHOUT GZZS CLOSING (GZZS FAIL TO CLOSE), PRIMARY DEPRESSURIZATION BY SPRAY IN THE PRESSURIZER.

Scenario:

1. The double-ended break of one pipeline in SG #6 close to the cold collector
2. The operator starts both Makeup pumps (6 m^3/hr each one) to inject in primary loop.
3. Switching on Pressurizer heaters due to primary side pressure decreasing down to 120 kgf/cm^2.
4. Actuation of Emergency Protection – I (AZ-1) according to the set point "low pressure in primary side – P_1<115 kgf/cm^2" or by set point "Pressurizer water level < 2.6 m". All control assemblies drop with emergency speed to the fully inserted position. Primary side pressure and temperature, Pressurizer water level and respectively secondary side pressure drop rapidly.
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 load (AASSL) according to the set point "low pressure in primary side - P_1< 105 kgf/cm^2 " or by set point "Pressurizer water level < 2 m". Only HPP #1 starts to inject borated water in cold legs #3 and #4 approximately 5 minutes after Emergency Protection – I actuation.
7. Closing of Turbine Stop Valves (TSVs) of both turbines 10 sec. after Emergency Protection – I actuation. It will cause secondary side pressure increasing.
8. BRU-K opening due to pressure in the Main Steam Header reaches level 50 kgf/cm^2 (4.9 MPa). BRU-K is trying to keep the pressure in the Main Steam Header equal to 47 kgf/cm^2 and when the pressure became less than this value closes. BRU-K opening causes radiological releases in the secondary side.
9. Water level in the damaged SG #6 increase up to 2.22 m (it is with 100 mm higher than the nominal value of the SG water level – 2.12 m in the beginning of the transient). After reaching this value SG #6 will be disconnected from the feedwater line by the operator.
10. When the SG #6 water level increase up to 2.27 m, the operator starts to close the Main Isolation Valves (GZZs) of the Loop #6 trying to isolated it from the damaged SG #6 but one of them failed to close.
11. The operator restores the normal work of the Loop #6.
12. Reaching 2.27 m water level in the SG #6 is the reason for the following operator actions:
   - The operator isolates SG #6 from the steam line by closing Main Isolating Valves on its steam line;

- The operator starts to cooling down the RCS with maximum speed by BRU-Ks when they are in fully open position;
- The operator starts depressurization of the primary side by using the Spray in the pressurizer from the cold leg.

13. The operator stops cooling down the reactor coolant system when the core exit temperature became with 10 ^{0}C less than the saturated temperature corresponding to the pressure in the damaged SG #6 and starts to support it (±2 ^{0}C) during the rest of the transient time.

14. Depressurization of the primary side continuos until one of the following three conditions became truth:

- Primary side pressure is less or equal than the pressure in the damaged SG #6 and the PWL is greater than 3.5 m
- PWL is greater than 6.8 m
- Core exit subcooling margin is less than 10 ^{0}C

15. Switching off HPP #1 by the operator, after reacing following conditions:

- Core exit subcooling margin higher than 10 kgf/cm^2;
- Primary side pressure became stable or start to increase;
- Water level in the intact SGs is nominal – 2.12 m;
- Core exit temperature decrease;
- Pressurizer water level is higher than 3.5 m.
- Pressurizer water level is higher than 6.8 m and the primary side pressure isn't still equal to the pressure in the damaged SG #6

16. If the pressurizer water level became less than 3.5 m after switching off HPP #1 the operator regulates it using the Makeup pumps.

The calculated sequence of events for this case SGTR – without GZZs closing is presented below.

Table B.1.

Event	Time, s
Break	0.0
Max. break flow rate, 9.12 kg/s from the cold collector and 3,30 kg/s from the end of pipe line	0.2
Switching on Makeup pumps by the operator	50.0
Switching on Pressurizer heaters	270.0
Actuation of Emergency Protection – I (AZ-1)	810.0
Switching on HPP #1	815.0
Turbine Stop Valves of the both turbine closing	820.0
BRU-K #1, #2, #3 and #4 opening	830.0
Switching off all Pressurizer heaters	830.0
Water level in the damaged SG #6 reaches 2.22 m	930.0
Water level in the damaged SG #6 reaches 2.27 m	1100.0
The operator isolates SG #6 from its steam line and from its Letdown system	1100.0
The operator starts to cooling down the RCS with maximum speed by BRU-Ks	1100.0
The operator starts depressurization of the primary side by using the	1100.0

Spray in the pressurizer from the cold leg	
The operator stops cooling the RCS (after primary side temperature became with 10 ^{0}C less than the saturated temperature corresponding to the pressure in the damaged SG #6)	1270.0
Switching off HPP #1 by the operator	1920.0
Depressurization stops when the primary side pressure became equal to the pressure in the damaged SG #6 and the PWL is greater than 3.5 m	3260.0
SG #6 water level reaches its max value 2.7 m	3500.0
End of calculation	3500.0

The most important parameter behavior is presented in the Figures from B.1. trough B.6. The calculation was performed up to 3500 sec into the transient time.

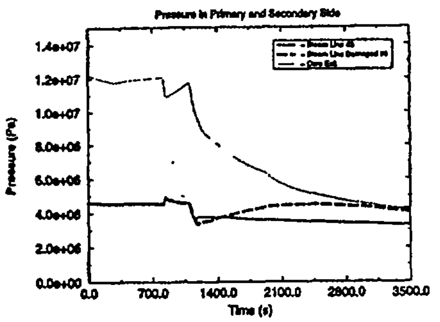

Fig. B.1.

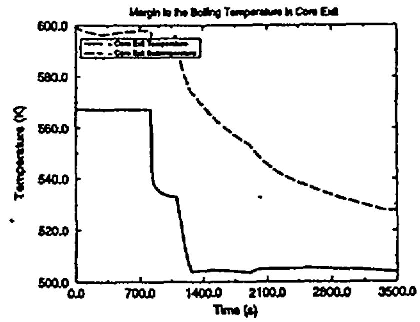

Fig. B.2.

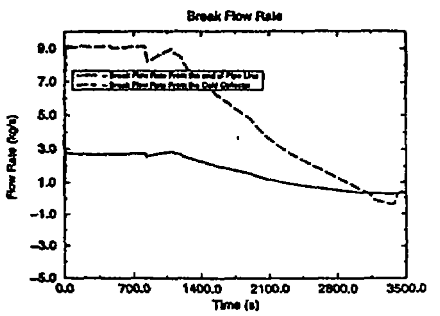

Fig. B.3.

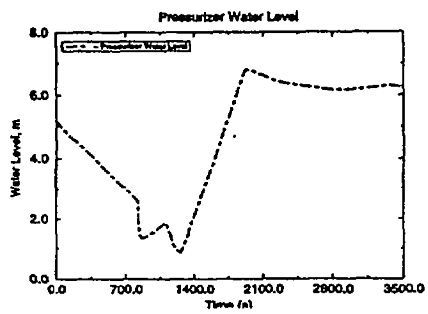

Fig. B.4.

Break opens at the 0.0 sec as it seen fron the Table B.1. The break opening causes decreasing of primary side pressure and respectively Pressurizer water level decreasing. Because of the break secondary side pressure in the damaged SG increase slowly. SG #6 water level doesen't increace very fast. Feedwater control system automatically compensates the changes in SG water level due to primarty to secondary leakage by reducing the feedwater flow rate. If the Steam generator water level increase with 100 mm over the nominal, SG #6 would be disconnected from the feedwater and emergency feedwater lines.

Primary and secondary pressure behavior is presented in the Figure B.1. SG #6 isolation from its steam line, RCS cooling and primary side depressurization start simultaneous at 1100.0 sec. Each one of these three operator actions exerts an influence on secondary side pressure in the damaged SG #6. If the SG #6 isolation from its steam line comes earlier than the other two operator actions, which are mentioned above, pressure in the affected SG #6 will increase and it will cause SVs of SG #6 opening. As it seen in the Figure B.1, after 1100.0 sec due to work of BRU-Ks secondary side pressure starts to decrease rapidly. RCS cooling by BRU-Ks was performed when they are in fully open position, so that the speed of cooling to be maximum.

Primary temperature trend could be seen in figure B.2.As it seen from Table B.1. at 1100.0 sec the operator starts cooling down RCS with maximum speed. Due to work of BRU-Ks RCS was cooled down with approximately 35 ^{0}C for about 170 sec. After reaching the required margin of 10 ^{0}C between the primary side temperature and the saturated temperature corresponding to the pressure in the ruptured SG #6, the operator stops RCS cooling and starts to support the reached primary temperature (±2 ^{0}C) for the rest of the transient time.

It is shown in Figure B.2. margin to boiling temperature. There is significant subcooling margin between Core exit temperature and Core exit sattemperature during the whole transient time and especially during the work of BRU-Ks. So in the hot legs and reactor core there is no void fraction appearance during the whole transient.

The break flow rate is presented in Figure B.3. It reaches its maximum value 12.42 kg/s at 0.2 sec. The flow discharge coefficients are assumed to be 1.0, 1.0. As it seen in the Figure B.4., after 1100.0 sec the break flow rate starts to decrease due to work of Spray in the pressurizer and approximately at 3260.0 sec coolant blowdown from the reactor coolant system to the SG #6 stops and reverse break flow rate appears.

Pressurizer water level behavior is presented in the Figure B.4. Five seconds after Emergency Protection-I actuation (at 815.0 sec) HPP #1 starts to inject borated water in primary circuit and that causes PWL increasing. At 1100.0 sec PWL starts to decrease because of the work of BRU-Ks – there is significant shrinkage of primary coolant. When the RCS cooling stops at 1270.0 sec and due to work of HPP #1 it starts to increase and reaches 6.8 m at 1920.0 sec. After HPP #1 switching off PWL decrease slowly.

Conclusion:

The main conclusion for this calculation is that the safety systems and operator actions are effective for primary side depressurization. The calculation demonstrates an effective strategy for preventing any secondary radiological release to the environment. The results demonstrate also a successful strategy for cooldown of the Reactor coolant system. There is additional ability for post SG cooling down by organization of "feed and bleed" or by backup filling through the break in the damaged SG.

Fuel cladding temperature is less than 1200 ^{0}C during the calculation.

VII. GENERAL CONCLUSION:

The thermal-hydraulic analysis of the calculations presented above show that practically in the both cases - with or without use of GZZs - the operator could bring the plant to stable and safety conditions.

VIII. REFERENCES:

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