Investigation of Steam Line Break Accident During the Development of Emergency Operating Procedures for VVER440/V230

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In this paper are presented the results of thermal hydraulic analyses of Steam Line Break (SLB) accident in supporting of Symptom Based Emergency Operating Procedures. This kind of analyses are designed to provide the response of monitored plant parameters to identify symptoms available to the operators, timing of the loss of critical safety functions and timing of operator actions to avoid the loss of critical safety functions or core damage. RELAP5/MOD3.2 computer code has been used to simulate the SLB accident in a VVER440 NPP model. This model was developed at the Institute for Nuclear Research and Nuclear Energy for analyses of operational occurrences, abnormal events and design basis scenarios. The model provides a significant analytical capability for the specialists working in the field of NPP safety.

I. Introduction

During the validation of Symptom Based Emergency Operating Procedures for VVER 440 units at Kozloduy NPP a number of calculations have been analyzed using the RELAP5/MOD3.2 computer code. One of them is leak from secondary side in case of double-ended Steam Line Break (ID 433 mm) upstream of BZOK. RELAP5 computer model represents Unit 4 at Kozloduy NPP. This unit is a VVER 440/V230 pressurized water reactor that produced 1375 MW thermal power and generates 440 MW electric power. The VVER440 design includes six coolant loops, each one including one main coolant pump and one horizontal steam generator.

Steam Line Break event is characterized by rapid decreasing of pressure in the failed Steam Generator and in the Main Steam Headers. Other symptoms include decreasing of water level in the failed SG and decreasing of primary system temperature and pressure. After a while primary pressure will reach the set point for HPIS actuation, which starts automatically. As a result of this primary side pressure increases while the coolant temperature decreases rapidly. In this situation the maximum challenged Critical Safety Function is primary side - Integrity.

To analyze the Steam Line Break event for VVER440/V230 the following acceptance criteria are used:

- Safe and steady final state
- Pressure Temperature relation must remain on the left side of the P-T limit
- Temperature decreasing in all RCS cold legs must remain less than 60^{0}C in the last 60 minutes

II. Methods

The analysis of the secondary leaks was performed using RELAP5/MOD3.2 computer code. The input model is prepared for analyzing of the Steam Line Break event. Operator actions are modeled on the base of Technical Documentation and experience of the operators. All this is necessary in order to determine the reserves of time and particular critical parameters that the operator has during the suspension of a certain accident.

Methodology for validation and verification of SB EOPs requires the most severe initial conditions to be chosen. This ensures the possibility for wider application of a certain procedure in case when a certain symptom is available. For investigation of "Integrity" CSF in case of Steam Line Break, it was taken decision to run calculations on "hot reactor shutdown" conditions but at normal operating pressure and temperature. It means that the reactor is subcritical and no decay heat was assumed. If the SLB accident begins at full initial power, the primary average temperature and pressure will initially decrease rapidly but after that the decay heat generated in the core immediately will begin to restore the primary temperature and pressure.

As a bounding condition it was also assumed that the water level in all SGs is minimal – 2.02 m. In this way there is minimum accumulated heat in secondary side.

III. Event Description

This section contains a description of the expected plant response to a postulated Steam Line Break accident and the actions, manual and automatic, which may occur during the recovery. A double ended guillotine break (ID 433 mm) upstream of the BZOK is assumed to be the initiating event. It occurs when the plant power is "zero" but the primary pressure and temperature are nominal. It is assumed that the break is in the SG #1 box. For Large Secondary Break an immediate pressure decreasing in faulted steam line and main steam headers (MSHs) occurs. Pressure in the MSHs reaches the set point 39 kgf/cm^2 in approximately 2 – 4 seconds, which results in turbine trips. This yields a Reactor SCRAM after closing Turbine Stop Valve (TSV) of the last working turbine. As a coincidence of rapid secondary pressure decreasing there is decreasing of average coolant temperature in primary side and primary pressure decreasing. Due to SG pressure signal $P_{SG} < 35$ kgf/cm^2 – there is actuation of BZOK closing, the faulted SG is isolated from feedwater line and the MCP on damaged loop switches off. The low primary side pressure signal or the signal for low Pressurizer water level actuates the safety injection systems.

In the beginning of the transient an uncontrolled pressure decreasing in the faulted SG could be observed and this SG is completely depressurized. The other symptoms include decreasing of water level in the faulted steam generator and an initially decreasing of primary pressure and temperature. A rapid, extensive cooldown of primary system occurs. The heat transfer to the faulted steam generator will be reduced and primary system cooldown will be reduced too, as the primary system temperature drops. This trend will continue to the point where the primary coolant shrinkage (caused by the cooldown) is overcome due to work of HPIS. Actuation HPPs results in primary pressure increasing and pressurizer water level restoration.

IV. Scenario

The following scenario has been prepared with the participation of the leading specialists from Kozloduy NPP in supporting of Symptom Based Emergency Operating Procedures.

1. Initial status

1.1. Power 0.0%, hot shutdown conditions. No decay heat (hot shutdown – reactor shutdown conditions at normal operating pressure and temperature). Minimal pressurizer water level of 4.90 m (minimum accumulated heat in primary side).

1.2. All three Safety systems are available.

1.3. Operator do not interact during the accident. Reactor Systems respond without operator actions.

1.4. It is assumed that the SGs water level is 2.02 m. SG regulators (VA 13) are in automatic regime.

II. Schedule of automatic and operator actions

II.1. By reaching a set point low water level in faulted SG - 2.02 m the Emergency feedwater pump starts to inject in SG. In this case the Emergency feedwater pump starts from the beginning of transient.

II.2. In accordance to the signal $P_{SH} < 35$ kgf/cm^2 the MCP of the damaged SG switches off. This signal also isolates the damaged SG from Feed Water Line (FWL) by closing VP-13 valve and from the Main Steam Header (MSH) by closing BZOK and isolating valve P-1. The isolating valve P-1 duplicates the function of BZOK. The Emergency feedwater line is isolated after reaching this signal, too.

II.3. By reaching $P_{SG\ box} > 0.2$ kgf/cm^2 in SG box starts an injection of sprinkler system.

II.4. In accordance to the signals $P_I < 120$ kgf/cm^2 all Pressurizer heaters are switched on automatically. After decreasing of water level in Pressurizer with 3.2 m from nominal water level of 5.2 m all Pressurizer heaters are switched off automatically.

II.5. In accordance to the signals $P_I < 105$ kgf/cm^2 or decreasing of water level in Pressurizer with 3.2 from the nominal water level of 5.2 m are switched on all three High Pressure Pumps (HPPs). Temperature of delivered emergency water was assumed to be minimal 55 ^{0}C.

V. Results

The calculated sequence of events for "Integrity" investigation is presented in Table 1.:

Table 1.

Event	Time, s
Double-ended Steam Line Break of steam line #1	0.0
MCP #1 is tripped	4.9
BZOK at faulted SG #1 closes	4.9
Isolation of feed water to SG #1	4.9
Minimum Pressurizer Water Level – 2.0 m	194.6
Starting of all three HPPs	194.6
Stabilization of primary circuit pressure at 13.3 MPa	350.0
Dryout of SG #1 (SG water level 3 cm.)	2000.0

The most important parameter behavior is shown in Figure 1 through 6 The calculation was performed up to 2000 s into the transient time.

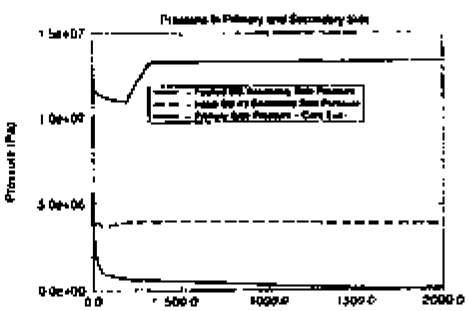

Fig. 1.

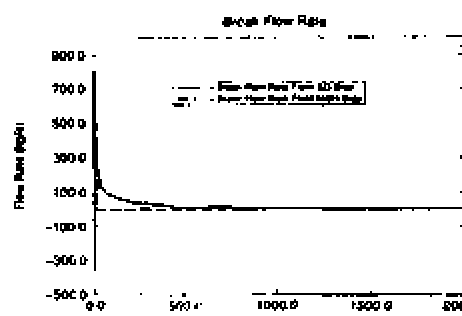

Fig. 2.

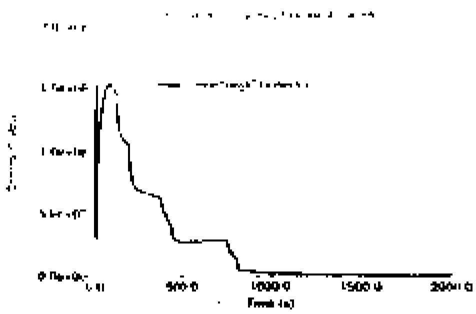

Fig. 3

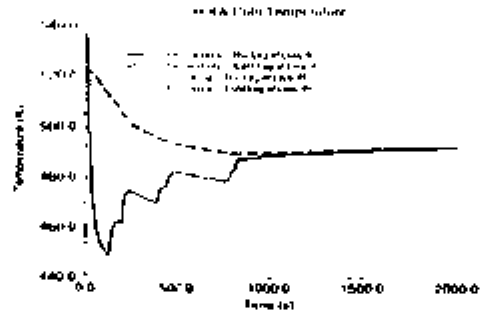

Fig. 4

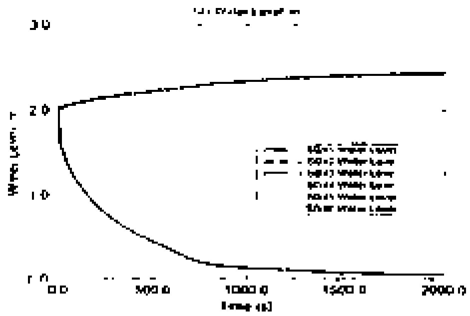

Fig. 5.

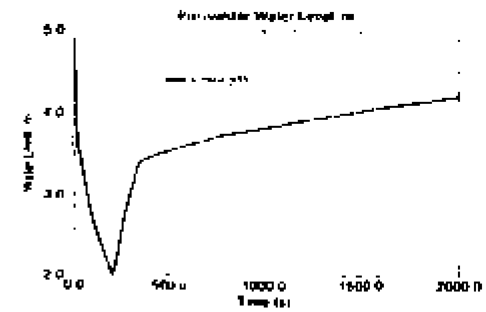

Fig. 6

Reactor system is subcritical at hot conditions. Core exit temperature for hot conditions was accepted 536.0 K.

Should a steam line break appear, MCP #1 is tripped at 4.9 sec. due to the signals $P_{SG} < 35$ kgf/cm^2. Due to the same signal the damaged SG is isolated from Feed Water Line (FWL) by closing VP-13 valve and from the Main Steam Header (MSH) by closing BZOK and isolating valve P-1. The isolating valve duplicates the function of BZOK.

The important system parameter trend for this break is an uncontrolled pressure decreasing in faulted SG and this SG is completely depressurized to the SG box pressure. After increasing SG box pressure with 0.2 kgf/cm^2 starts sprinkler system – the event comes after 1.0 sec. The behavior of faulted SG pressure is presented in Figure 1. The other symptoms include decreasing steam generator water level of faulted SG (presented in Figure 5.) and initially decreasing primary pressure (presented in Figure 1.) and temperature (presented in Figure 4.). A rapid, extensive primary system cooldown occurs at the beginning of transient. Primary to secondary heat transfer is presented in Figure 3. The primary system cooldown rate and the heat transfer to the steam generator (faulted SG) are reduced after first 800.0 sec. due to almost dryout of faulted SG and decreasing of primary system temperature. Heat transfer in faulted SG drops to 1.2 MW after dryout of SG#1 below 7 cm at 1600 sec. Maximum heat transfer 154.2 MW from primary to secondary side in faulted SG was reached at 75.0 sec. (see Figure 3.).

Behavior of cold and hot leg liquid temperature is presented in Figure 4. After 44.0 sec. intact SGs start to heat primary side. This trend continues to 830.0 sec. when primary system temperature becomes again more than secondary temperature in the intact SGs. Primary coolant is heated by Pressurizer heaters. After increasing of pressure more than 126 kgf/cm^2 only 5 & 6 group heaters (working heaters) continue to work.

The steam generator blowdown is almost completed in 400 sec. After that time mainly the HPPs and the feedwater flow to the other SGs control further cooldown of primary system. After

800 sec. transient time cooldown of the primary system is totally controlled by the HPPs, feedwater flow to the other SGs and Pressurizer heaters.

Comparison of pressure in primary and secondary side is shown in Figure 1.

During the whole transient time there is a reverse flow rate through faulted SG caused by work of other five MCPs.

The break flow rate is presented in Figure 2. Steam blowdown from steam line amounts more than 1 400 kg/s at the moment of break opening and decreases later on as it is presented in Figure 2. Upstream void fraction of break is equal to 1.0 during the entire transient time except the interval of time between 1.5 sec and 12.0 sec when upstream void fraction is between 0.965 and 1.0. The flow discharge coefficients at the break are assumed to be: 1.0, 1.0. The break flow rate from Main Steam Header side is reduced to 0.0 kg/s after 20 sec. due to closing of BZOK. The maximum break flow rate of 805 kg/s from SG side was reached at 1.46 sec. and the maximum break flow rate of 634 kg/s from MSH side was reached at 1.72 sec.

Figure 6. presents the behavior of Pressurizer water level. The Pressurizer water level was assumed to be 4.9 m in hot conditions instead of 5.2 m as in nominal. The Make up system doesn't work. HPPs start to work in support of low level in pressurizer after reaching 2.0 m at 194.6 sec. For the first 194.6 sec the fast decreasing of Pressurizer water level comes due to cooldown of primary side and it causes primary system water volume shrinkage, when the pressure drops rapidly. The reason of increasing the Pressurizer water level after the first 200.0 sec. comes from injection of HPPs in primary system.

VI. Conclusions

The calculation shows that with minimum resources and without operator actions the cooldown rate is in acceptable margin. The reactor system parameters are not in the dangerous area corresponding to cold over pressurization.

The main conclusion for this calculation is that the safety systems are effective for an automatic plant recovery.

This analysis have been possible through the participation of leading specialists from Kozloduy NPP and with assistance of the United States Department of Energy (USDOE) - Contract No 15/03.07.2000.

VII. References

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