
EPR: Steam Generator Tube Rupture analysis in Finland and in France

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Abstract:

Different requirements between Finland and France lead EPR designer to define different features (system or action) for management of accidents on Olkiluoto 3 EPR that is under-construction in Finland compared to Flamanville 3 EPR that is foreseen in France. One of these differences concerns the management of Steam Generator Tube Rupture since no primary coolant (liquid and steam) release to the environment is allowed in Finland unlike in France where primary steam releases are not forbidden. This leads to define on Finnish EPR a strategy that anticipates mitigation action compared to French EPR and that only uses the unaffected steam generators. This strategy is intended to reduce the release to the environment. IRSN has analysed another aspect of the Steam Generator Tube Rupture: the backflow (flow of unborated water from steam generator to the primary circuit). Indeed, if the Reactor Coolant Pumps have been shut down, the creation of an unborated water plug because of the backflow could lead to a reactivity accident in case of Reactor Coolant Pump restart. IRSN analysis shows that, using the current Olkiluoto 3 SGTR mitigation strategy and very penalizing assumptions, the amount of unborated water transferred to the primary circuit on the Finnish EPR could be higher than on the French EPR in the long term. Discussions are going on between STUK and TVO to finalize the SGTR strategy so that both releases into the environment and risk of backflow can be minimized.

1 INTRODUCTION

In France, the “Technical Guidelines for the design and construction of the next generation of nuclear power plants with pressurized water reactors” specify that “the emergency core cooling function can be provided through an optimized concept comprising a cold leg medium head safety injection (MHSI) with an operating pressure below the opening setpoint of the steam generator safety valve”. This aims at avoiding the discharge of liquid primary coolant to the environment in case of Steam Generator Tube Rupture (SGTR). The discharge of steam is implicitly permitted allowing for the activity release is largely lower in case of steam release compared to a liquid release.

In Finland, the YVL guide 1.0 specifies that “pressure management during PWR primary-to-secondary leaks shall be so arranged that no coolant discharges to the environment are required”. This implicitly forbids liquid and steam discharge to the environment.

Because of the different requirements, the management of SGTR accident on EPR reactor that is under construction in Finland is different from the EPR reactor that is planned to be built in France.

This difference has an impact on the releases to the environment but it can also have an impact on the amount of backflow of unborated water from the affected steam generator (SG) into the primary circuit.

The present study presents the different strategies and their impact on the secondary-to-primary backflow.

2 SGTR MANAGEMENT

2.1 SGTR management in France

Short term phase

The SGTR leads to a loss of primary coolant which is transferred to the Steam Generator (SG) affected by the rupture. The break induces a decrease of the Reactor Coolant System (RCS) pressure and a contamination of the secondary side due to SGTR direct flow rate.

The reactor trip occurs either on "Pressurizer pressure < MIN2" or on "SG level > MAX1" in affected SG.

The reactor trip signal automatically trips the turbine and with assumption of unavailability of the Main Steam Bypass (MSB) because of its non F1-classification or because of the loss of offsite power (LOOP) which is superposed at turbine trip, the SG pressure rapidly increases resulting in steam discharge to the atmosphere through the main steam relief trains (MSRT). Continuous loss of RCS coolant inventory and primary coolant contraction after reactor trip in case of an initial full power state lead to depressurize the primary side.

Either on Safety Injection (SI) signal or on "SG level > MAX2" in the affected SG (if not already actuated in SI signal), a partial cooldown is performed by MSRT of all SGs (included the faulted one) from a 95.5 bar secondary pressure down to 60 bar at a cooldown rate of -100K/h.

At end of partial cooldown, RCS pressure is given by the Medium Head Safety Injection (MHSI) shut off pressure (between 85 bar and 97 bar) and a contaminated SGTR direct flow still enters the affected SG, leading to its level increase. At this stage, a controlled state (SI and SGTR mass flow balance) is already reached.

On "SG level > MAX2" and after the end of partial cooldown, the affected SG is identified and automatically isolated on its steam side (closure of its Main Steam Isolation Valve (MSIV), the MSIV of the 3 unaffected SG remaining open, lifting-up of its MSRT pressure setpoint above the MHSI delivery pressure and below the Main Steam Safety Valves MSSV pressure setpoint).

The short term management of the SG is presented on the figure 1.

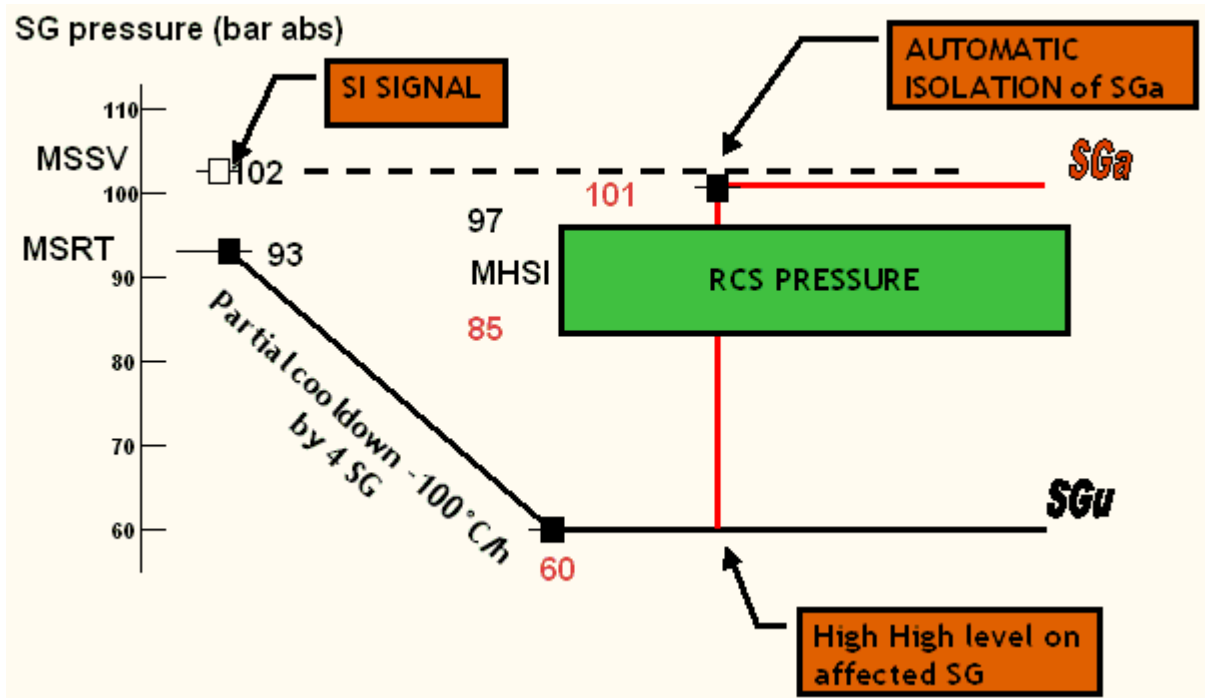


Figure 1: short term - French strategy

Then, the pressure balance between primary side and affected SG is reached and the leak is finally cancelled. This is the end of the short term phase.

The sequence described above does not credit non-F1A classified systems.

As a response of the activity signal (F1B classified), specific SGTR counter-measures can be actuated by the operator such as reactor and turbine trip, pressuriser spray to decrease primary pressure down to secondary pressure, cut off of pressuriser heaters, start up of both CVCS pump and reduction of the letdown flow to makeup SGTR flow.

Long term phase

The safe shutdown state is defined as a state where the Low Head Safety Injection (LHSI) is connected in Residual Heat Removal mode and the affected SG is isolated.

The sequence of actions to be performed by the operator to reach the safe shutdown state can be divided into 2 successive phases.

Boration and Cooldown

The boration is performed via the Emergency Boration System (EBS). In order to compensate the EBS injection (avoidance of primary pressure increase by high pressure EBS pumps) the plant is cooled down simultaneously by the unaffected SGs. The EBS is sized to balance the volume contraction and the reactivity insertion of a 50 k/h cooldown with both pumps in operation. If, as a single failure, one pump fails, the operator reduces the cooldown gradient to 25 k/h. As additional measure not to perturb the pressure balance between primary side and the affected SG, the MHSI is kept under operation (this maintains primary pressure).

Depressurization of RCS and Affected SG

The primary side and faulted SG depressurizations are performed, after completion of the boration and cooldown phase, by opening the MSRT of the affected SG, after isolation of MHSI and accumulators and EBS. If the MSRT fails for any reason, the depressurization can also be done via the bypass valve of the MS isolation valve (classified F1B) without any risk of back flow.

If the water level in the affected SG is too high (risk of water entrainment when the SG restarts to boil) some inventory reduction can be performed by opening the SG blowdown line between the affected SG and an unaffected one (blowdown line F1B classified) before depressurization.

2.2 SGTR management in Finland

With respect to the French management, the first difference is that the response of the activity signal is credited to anticipate mitigation actions. The second difference is that on activity signal, all main steam isolation valves are closed, the setpoint of the MSRT on the affected SG is increased to about 100 bar (above MHSI delivery pressure and below MSSV pressure setpoint) and the setpoint of the MSRT on the other SG is steply decreased down to 60 bar (see figure 2). This fast cooldown aims at reducing the duration of steam releases to the atmosphere.

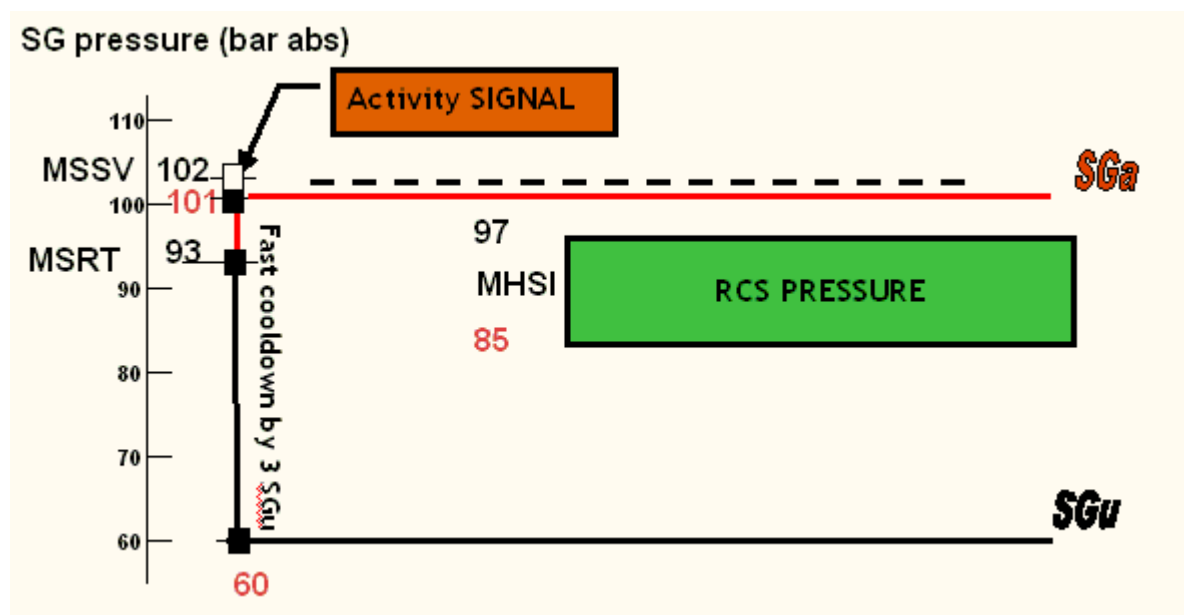


Figure 2: short term - Finnish strategy

Other differences are:

- restarting of reactor coolant pumps before cooldown, if they have been stopped because of a loss of offsite power (LOOP);
- EBS pumps run until cooldown completion.

3 SGTR ANALYSES

3.1 SGTR analyses in French and Finnish Safety Analysis Reports

The goal of SGTR analyses presented in the Safety Analyses Reports is to:

- check that there is no overfilling of the affected steam generator,
- evaluate the releases to the environment.

Two analyses are presented in both French and Finnish Safety Analysis Reports:

- 1 tube SGTR without CVCS in French PCC3 and Finnish DBC3,
- 2 tubes SGTR without CVCS in French PCC4 and Finnish DBC4.

Both are analysed with LOOP (maximization of the releases to the environment) and without LOOP (maximization of SG filling) assumed at the turbine trip depending on the goal of the studied cases.

An additional analysis is presented in the Finnish Safety Analysis Report: the 1 tube SGTR with CVCS.

3.2 SGTR and maximisation of the backflow

3.2.1 Studied SGTR

The goal of the present study is to maximize the secondary-to-primary backflow. Thus, a 2 tubes SGTR has been studied because it speeds up the primary depressurisation and allows a larger flow through the broken tube.

The thermal-hydraulic code CATHARE has been used to simulate the transient.

Both French and Finnish strategies have been simulated.

3.2.2 Assumptions

The goal of the present IRSN analysis is to maximize the secondary-to-primary flow. This lead to some differences on the assumptions.

In the French and Finnish Safety Analysis Reports, the following assumptions are assumed to maximize primary-to-secondary flow and release to the environment:

- CVCS charging flow is credited,
- maximum MHSI flow rate (97 bar shutoff pressure),
- minimum MSRT setpoints in the affected steam generator (94 bar before partial cooldown, 58.5 bar at the end of partial cooldown, 100 bar after setpoint lift-up),
- maximum MSRT setpoints in the safe steam generator (97 bar before partial cooldown, 61.5 bar at the end of partial cooldown).

In order to penalise the secondary-to-primary flow, assumptions that maximized secondary/primary flow are assumed in the present study:

- CVCS charging flow is not credited,
- minimum MHSI flow rate (85 bar shutoff pressure),
- maximum MSRT setpoints in the affected steam generator (97 bar before partial cooldown, 61.5 bar at the end of partial cooldown (only on French EPR), 100 bar after setpoint lift-up),
- maximum MSRT setpoints in the safe steam generator (97 bar before partial cooldown, 61.5 bar at the end of cooldown).

LOOP is assumed in the present study since unborated water injection in the primary circuit is problematic when the RCP have been stopped.

3.2.3 Objectives

In order to avoid the risk of return to criticality in case of heterogeneous dilution, the volume of the unborated water plug that is send to the core inlet in case of RCP restart shall be lower

than about 3 m³. This volume is the volume of backflow above which RCP restart shall not be allowed.

3.2.4 Results

In French EPR, the partial cooldown is performed by all SGs. At the end of the short term phase, the balance between RCS and SGa pressure is reached at the MHSI delivery pressure (see figure 3).

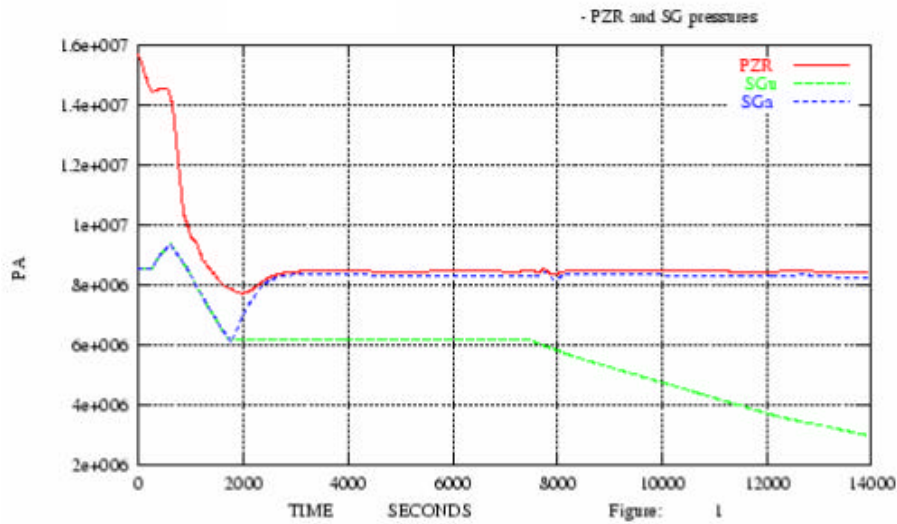


Figure 3: French case - primary and secondary pressures

So, the risk of SGTR backflow is prevented by the MHSI operation. Just before RCS depressurisation, 2 tons of unborated water have flowed from secondary to primary circuit (see figure 4).

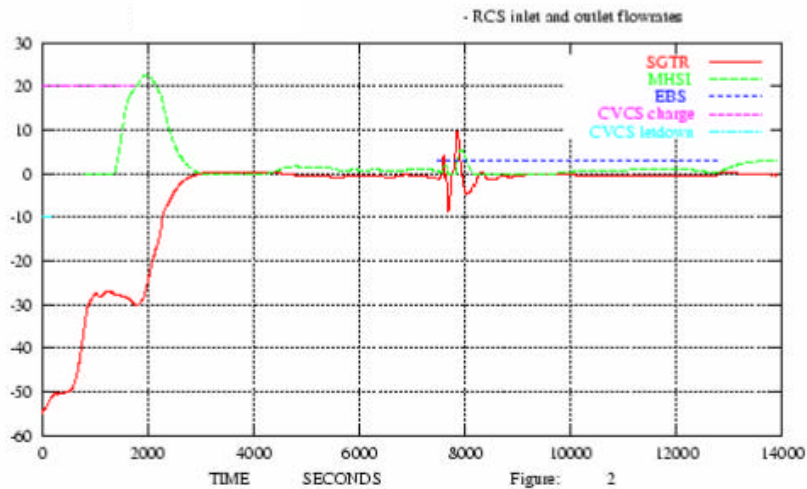


Figure 4: French case – RCS inlet and outlet flowrates

In Finnish EPR, the partial cooldown is performed only by the unaffected SG. The RCS depressurisation is limited by the isolation of SGa at its MSRT setpoint pressure. At the end of the short term phase, the balance between RCS and SGa pressure is not reached (see figure 5).

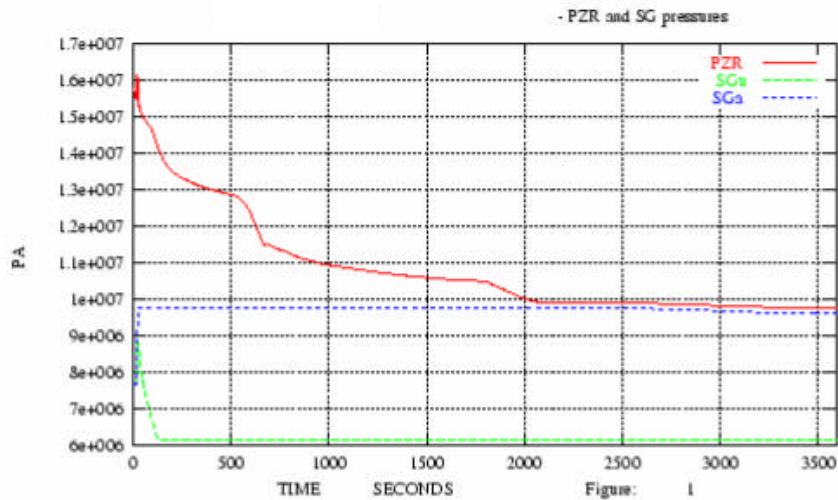


Figure 5: Finnish case – Short-term – primary and secondary pressures

The balance between RCS and SGa can be reached after a low depressurization of the affected SG to the MHSI delivery pressure during the long term phase. During this period, the MHSI does not inject into the RCS. Even if the EBS operation limits the SGTR backflow, the SGTR backflow can lead to transfer 18 tons of unborated water from secondary to primary side (figure 6).

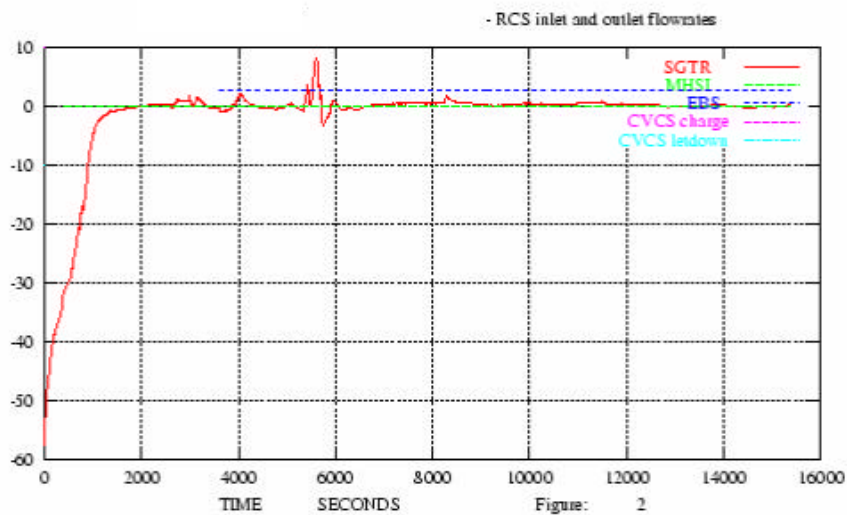


Figure 6: Finnish case – RCS inlet and outlet flowrates

If the EBS is stopped once the cold shutdown is reached, as is done in French EPR, the SGTR backflow is no more limited. More than 30 tons of unborated water is transferred from secondary to primary circuit (see figure7).

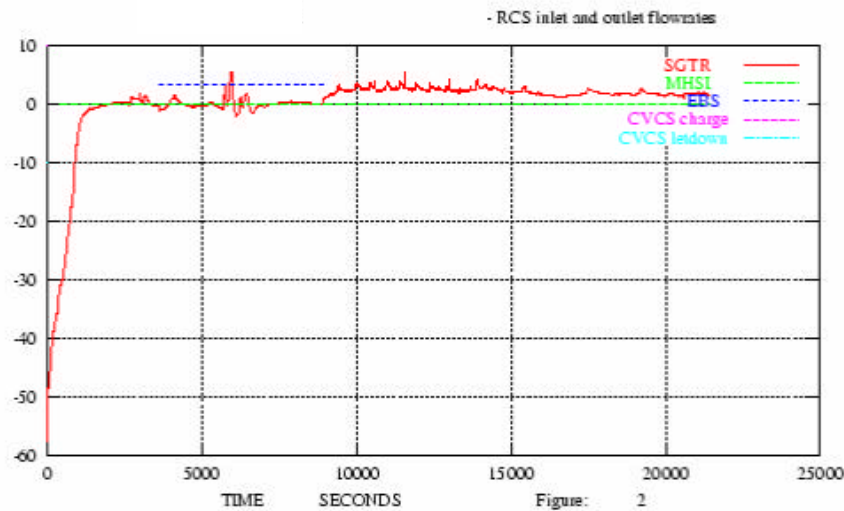


Figure 7: Finnish case – RCS inlet and outlet flowrates with early EBS cut-off

4 CONCLUSIONS

IRSN has analysed the impact of both French and Finnish strategies on the risk of backflow (secondary-to-primary flow) following a Steam Generator Tube Rupture. Indeed, if the Reactor Coolant Pumps have been stopped (for example because of LOOP), the creation of an unborated water plug higher than about 3 tons because of the backflow could lead to a reactivity accident in case of RCP restart. IRSN analysis shows that, using the current Olkiluoto 3 SGTR mitigation strategy and very penalizing assumptions, the amount of unborated water transferred from the secondary circuit to the primary circuit on the Finnish EPR is ten times more than on the French EPR in the long term.

The conclusions of this analysis have been discussed with the STUK. Based on their own analysis and supported by these discussions, STUK has asked AREVA NP and TVO to study this phenomenon and if necessary to propose a way to manage it.