Subject: EPR™ UK - GDA – GDA issue FS04 – Single Tube Steam Generator Tube Rupture Analysis for the UK EPR

Revision following TQ1603: Modification of the reference case to implement the procedure modification so as to avoid affected SG dry-out.

Please find attached the single tube SGTR analysis for the EPR™ Generic Design Assessment.

This transient analysis is consistent with the design option proposed in PEPR-F DC 38 Rev. A (Steam Generator Tube Rupture Strategy) i.e. the actuation of the reactor trip at 50 minutes.

This time delay corresponds to the bounding time allocated to the operator to perform the manual reactor trip following the class 1 activity detection. This includes the possibility of performing a smooth power decrease (at 5%NP per minute) before tripping the reactor, as it would be requested by Emergency Operating Procedures following a Steam Generator Tube Rupture.

Three sensitivity studies are performed in this analysis:

- **Case 1:** Design Basis Steam Generator Tube Rupture postulating that the VDA [MSRT] of the affected steam generator remains stuck open. The only manual action modelled is the manual reactor trip, the purpose of this calculation being to demonstrate that, in case of failure of any other operator action, the protection system protects the plant from the initiating event. This case corresponds to a sensitivity study on the PCSR limiting case regarding radiological consequences and is performed until leak cancellation.

- **Case 2:** Design Basis Steam Generator Tube Rupture accounting for all operator actions. The purpose of this analysis is to analyse the amount of releases from the affected steam generator, when modelling properly all relevant operator actions.

- **Case 3:** Realistic Steam Generator Tube Rupture taking only credit of manual reactor trip. The calculation is similar to Case 1, but postulates that all the operational means for mitigating the Steam Generator Tube Rupture are available. In particular GCT [MSB] is modelled in the calculation. The purpose of this calculation is to demonstrate that, under
realistic conditions, direct radiological consequences are negligible when postulating the operator performs only the manual reactor trip.

The conclusions of the analyses performed are the following:

- Under Design Basis conditions as well as under realistic conditions, postulating the manual reactor trip at 50 minutes leads to acceptable radiological consequences.
- Under Design Basis conditions, as well as under realistic conditions, the plant remains fully protected by the Protection System in case of Steam Generator Tube Rupture event, even if the operator only performs the adequate reactor trip.

The results of the present calculations will be assessed against a Human Factor analysis, as stated in the GDA issue FS04 resolution plan.
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1  Steam Generator Tube Rupture (Single Tube): Base case

1.1  Methods and Assumptions

1.1.1  Methods of Analysis

The SGTR analysis is performed with the CATHARE code in the frame of a realistic deterministic methodology.

The realistic deterministic methodology is characterized by two main features:

− the key code models are realistic though conservatively oriented, bounding the experimental results without excessive conservatism, and
− the initial and boundary conditions are conservatively selected.

The basic steps of the realistic deterministic methodology consist of:

− the phenomenological analysis of the accident scenario, and the identification of the key phenomena,
− the judgment of code adequacy to calculate the accident scenario, based on physical understanding, experimental data base, code assessment examination, and supplementation when necessary by sensitivity studies,
− the evaluation of calculation uncertainty with emphasis on dominant parameters (through sensitivity studies as necessary), or the check of a bounding conservative approach of key phenomena by the code, relying on the assessment matrix of the code,
− the introduction, when necessary, of conservative biases as close as possible to the uncertainty on the key phenomena; they are introduced either in a code model, in a nodalization scheme, or in a boundary condition, and
− the use of conservative assumptions for initial and boundary conditions.

The dominant phenomena of the SGTR transient are:

− the SGTR flowrate and resulting SG level increase,
− the moderate RCP [RCS] draining (PZR) and depressurization (equilibrium with affected SG pressure),
− the asymmetric RCP [RCS] heat removal via the unaffected SG in subcooled RCP [RCS] conditions.
All these phenomena are within the applicable range of the CATHARE code, for which validation is based on:

- the qualification of correlations and physical laws on separate effect tests (SET) or component tests, for example:
  - CATHARE SGTR operator for accurate SGTR break flow prediction,
- the validation of the axial SG model (with economizer of N4 SG-type) from MEGEVE small scale model tests,
- the overall verification of the code by simulation of integral effect tests (IET), covering a wide range of representative PWR transients on small-scale facilities, for example:
  - BETHSY 4.3b "6 SGTR" Test in which CATHARE correctly predicted the mass discharged at the faulted SG relief valve, the faulted SG mass inventory, the RCP [RCS] mass inventory and distribution (with formation of the large steam space inside the tubes of the faulted SG), the slow RCP [RCS] depressurization during the draining of the faulted SG, the restart of the loop circulation after the reactor coolant pump startup in the affected loop, and the consequent fast depressurization due to the condensation and collapse of the faulted SG tubes steam space.

1.1.2 Main Assumptions

1.1.2.1 Accident Definition

The case studied corresponds to the double-ended guillotine rupture of 1 tube in a steam generator, which allows unimpeded blowdown from both ends of the severed tube.

The tube rupture is located at the bottom of SG-tubes bundle, on the cold side. This location maximizes the SGTR leak flowrate (higher primary pressure and fluid density).

1.1.2.2 Protection and Mitigation Actions

In case of SGTR event, automatic protection systems and operator actions (by means of F1-classified systems) aim at tripping the reactor, removing the residual heat, cancelling primary to secondary leak flow rate, limiting contaminated SG liquid mass released to the atmosphere.

The different automatic protections and alarms, which could occur in the SGTR event mitigation, are linked either to the reactor coolant depressurization or to the level increase in the affected SG.

The possible F1A reactor trip is triggered on the following signals:

- “PZR pressure < MIN2”,
- “SG level in affected SG > MAX1”,

In the event of a leak rate that is insufficient to reach any of the above-mentioned F1A actions, a manual reactor trip may be credited after the first significant indication is received in the control room.
The other F1A automatic protections include the following:

- **Turbine trip**: on RT signal, the turbine trip is actuated,

- **Safety Injection & Partial Cooldown**: on the “PZR pressure < MIN3” signal, the RIS [SIS] is actuated and a partial cooldown performed by all SGs (including the affected one, unless it has been isolated by operator action) is initiated if it has not already been actuated,

- **Partial Cooldown**: on the “SG level > MAX2” signal (if partial cooldown has not already been actuated), a partial cooldown performed by all SGs (including the affected one, unless it has been isolated by operator action) is initiated,

- **Affected SG isolation (feed side)**: on the “SG level > MAX1” signal, the affected SG is isolated (isolation of full load ARE [MFW] and ASG [EFWS] line if ASG [EFWS] previously actuated).

- **Affected SG isolation (steam side)**: on the “SG level > MAX2” signal and end of partial cooldown, the affected SG is isolated (closure of VIV [MSIV], lifting up of VDA [MSRT] pressure setpoint over MHSI shut off head but below the MSSV pressure setpoint),

- **ASG [EFWS] actuation**: on “SG level < MIN2” the ASG [EFWS] train is actuated in the corresponding SG (SG specific). In case of a LOOP, ASG is actuated on an RIS [SIS] signal. The time delay between the setpoint being reached and the effective ASG [EFWS] flow injection is defined in accordance with the hypothesis of LOOP/no LOOP,

- **VDA [MSRT] actuation**: when the SG pressure reaches the VDA [MSRT] setpoint, “SG pressure > MAX1”, the VDA [MSRT] opens and performs the heat removal with pressure control,

- **VIV [MSIV] isolation**: on “SG pressure < MIN1” or “SG pressure drop > MAX1”, the VIV [MSIV] closure is initiated (all the MS lines are isolated, not SG specific),

- **VDA [MSRT] isolation**: when the SG pressure reaches the VDA [MSRT] setpoint, “SG pressure < MIN3”, the VDA [MSRT] of the corresponding SG is isolated unless permissive P-12 is activated (closure of the associated MSRIV, SG specific).

### 1.1.2.3 Operator Actions

No operator actions are considered until 50 minutes after the first significant information.

The delay of 50 minutes take into account a first operator action at 30 minutes after the activity detection and then a delay of 20 minutes for a power decrease. When local operator action is needed, the delay is extended to 1 hour.

The actions presented below are extracted from the Emergency Operating Procedures (EOP) available at the time of the study.

The F1B operator actions related to the affected SG isolation are:

- manual ASG [EFWS] isolation, if not done (SG level, secondary side activity)
- manual ARE [MFW] isolation, if not done (SG level, secondary side activity)
- manual VIV [MSIV] isolation, if not done (SG pressure)
- manual VDA [MSRT] setpoint increase, if not done (SG pressure)

The F1B operator action to cooldown the plant to RHR connection conditions is:

- manual actuation of cooldown, if not done (SG level, secondary side activity)
- Reactor coolant boration:
  The boration is automatically performed by the chemical and volume control system. In case this system is unavailable, the operator actuates the extra borating system.

In the event of a manual reactor trip, all of the above actions will be performed at the time of reactor trip. If the partial cooldown is already in progress at the time of reactor trip, the manual cooldown will be initiated after the completion of the partial cooldown.
1.2 Definition of Case Studied

1.2.1 Short-Term SGTR Analysis without LOOP from 102% Power

The short-term phase, as defined in the SGTR study, is the time period between SGTR initiation and leak cancellation. This phase includes reaching the controlled state, which corresponds to the state where the core is subcritical and SI flowrate or, if working properly, RCV [CVCS] flow rate compensates the SGTR leak rate.

The purpose of the study is to quantify the maximum amount of fluid released to the atmosphere from the affected SG prior to leak cancellation.

To quantify the maximum amount of activity release to the atmosphere, it is penalizing to maximize the power to be removed since, prior to the isolation of affected SG, there is only steam release. Therefore the event is started at 102% of full power, leading to maximum decay heat, and no LOOP is postulated, requiring the reactor coolant pump power to be removed in addition to decay heat.

To cause a maximum steam release from the affected SG, it is of interest to maximize the heat to be removed by the SGs.

Therefore, the most penalizing case is:
- maximum initial power (i.e. 102% FP)
- no LOOP

It is assumed that reactor coolant pumps remain running throughout the transient.
1.3 Analysis of SGTR

1.3.1 Choice of Single Failure (SF) and Preventive Maintenance (PM)

The single failure on the Main Steam Relief Control Valve (MSRCV) of the affected SG is assumed. The valve is assumed to remain stuck in its initial, fully-open position. Post-trip, SG pressure increase in the steam generator until opening the MSRT: MSRIV opens. When this occurs, the affected SG will begin an uncontrolled blowdown. The blowdown will continue until the MSRIV is shut on low SG pressure (< MIN3).

Aim of this calculation is to verify that neither SG overfilling nor SG dry out, and that the steam releases remains below an acceptable value.

No preventive maintenance is penalizing for this case.

1.3.2 Initial State

The initial state conditions, given in Table 1, are chosen to maximise the heat to be removed and the pressure difference between the RCP [RCS] and affected SG.

1.3.3 Specific Assumptions

- Neutronic data
  
  Core power is assumed constant at 102% (4590 MWt) of full power until reactor trip. Following RT, the time-dependent A term with 1.645 σ uncertainties on B+C term is used.

- Assumptions related to control systems

  Turbine: Turbine control maintains turbine flowrate at 102% until turbine trip on reactor trip.

  GCT [MSB]: Not considered

  ARE [MFWS]: SG level control is in operation at accident initiation and keeps working properly until isolation on reactor trip. This maximizes the activity transferred to the affected SG. High level MFW flow is isolated on reactor trip with no delay. Low level MFW is manually isolated by the operator.

  RCV [CVCS]: To maximize the pressure difference between RCP [RCS] and affected SG, the charging flowrate is maximized with 2 charging pumps in operation at the beginning of the transient. Both pumps continue operating until they are stopped automatically when the partial cooldown is complete and SG level reaches the MAX2 setpoint. Letdown is isolated on “PZR level < MIN3” (12%). RCV [CVCS] charging is isolated automatically following the combination of “SG level > MAX2” and the “end of partial cooldown” signals.

  Injection temperature is modeled as 270°C with letdown in operation. Injection temperature is reduced to 50°C when letdown is isolated.
**Heaters and Spray:** To maximize the pressure difference between the RCP [RCS] and affected SG, all heaters are initially actuated, which maximizes the primary pressure. Spray flowrate is not considered. Heaters shut-off on "PZR level < MIN3".

- **Assumptions related to F1 systems**

  Setpoints are given in Table 2.

**Reactor Trip:** With the RCV [CVCS] system in operation, the makeup flow is sufficient to maintain primary pressure above the reactor trip setpoint on low PZR pressure for the first 3000 seconds of the transient. The high activity signal is detected from the initiating event, a time of 3000 seconds is taken for the operator action. So a manual reactor trip is credited 3000 seconds after the break is opened.

**VDA [MSRT]:** A minimum setpoint for the VDA [MSRT] on the affected SG is assumed and a maximum setpoint on the unaffected SGs. This maximises the steam release from the affected SG.

After the manual reactor trip, the pressure raises in the SG, until opening of the VDA [MSRT]. It is assumed that the VDA [MSRT] in the affected SGs opens first (at 94 bar abs. The associated MSRCV stuck open, which lead to a global SG pressure decrease. The blowdown of the affected SG results in a “low-low primary circuit pressure” signal, which initiates a partial cooldown. The VDA [MSRT] setpoints are then decreased from 97.0 bar to 61.5 bar by the end of the partial cooldown, while in the affected SG, the VDA [MSRT] setpoint is raised to 99 bar abs.

**VIV [MSIV]:** The VIV [MSIV] of all SGs are closed on the low SG pressure signal ("SG pressure < MIN1") due to the depressurisation caused by blowdown of the affected SG. In case this would not occur the operator will perform it manually after partial cooldown is finished.

**ISMP [MHSI]:** SI is actuated on "PZR pressure < MIN3" (low-low PZR pressure, 115 + 1.5 bar) signal. This signal initiates the partial cooldown. The MHSI injects with a maximum flow rate, which begins injection at a pressuriser pressure below 97 bar. This maximises the pressure difference between the RCP [RCS] and the affected SG at the end of partial cooldown.

**ASG [EFWS]:** EFW flow is started to the intact SGs at the minimum flow rate and maximum temperature by the operator on the manual reactor trip. EFW to the affected SG is isolated at this time.

**MSSV:** To verify non-actuation of MSSV during the transient, the MSSV setpoint is the minimum value of 103.5 bar (105 - 1.5 bar).
**RBS [EBS]:** The RBS [EBS] pump(s) are started when the operator initiates the manual cooldown *(not modeled in the calculation).* The cooldown rate is determined by the number of RBS [EBS] available. If two trains are available, the cooldown proceeds at -50°C/hr. If only one train is available, the cooldown is limited to -25°C/hr.
1.4 Results

1.4.1 From the initiating event to the controlled state

Aim of the calculations is to present the leak cancellation without any manual operations except for the manual reactor trip and operations related to the steam generators feeding (stop of ARE [MFW] and ASG [EFWS] start up). The sequence of events for the case with MSRCV stuck open is given in Table 4.

The transient progress is shown graphically in Figure 1 to Figure 11. The results are discussed here below.

The break is opened at the start of the transient with an initial flow rate of about 28 kg/s. Pressuriser pressure decreases slowly and pressuriser level decreases steadily until the letdown flow is isolated on low pressuriser level at 1095 seconds. After letdown is isolated, the pressuriser level decreases at a slower rate. The primary circuit pressure continues to slowly decrease, which decreases the leakage flow rate and increases the RCV [CVCS] charging flow. This maintains the primary circuit pressure above the trip setpoint and the system approaches a new steady state condition at a lower pressure as the RCV [CVCS] charging flow increases to match the leakage flow.

50 minutes after the break is opened, the reactor is tripped manually. In addition to the reactor trip, the operator performs the following actions:

− Stops MFW flow to all SGs
− Disables EFW flow to the affected SG
− Starts EFW flow to the intact SGs

Rod insertion begins 0.4 second after RT and the turbine is isolated 2.5 second after RT. Following the turbine trip, the secondary pressure increases. It is assumed that the MSRT opens in the affected SG (at 94 bar). MSRCV and MSRIV open. MSRCV on the affected SG is assumed to have failed in the fully open position. This results in a rapid depressurisation of the affected SG. The depressurisation of the SG results in a cooldown of the primary circuit and a drop in primary circuit pressure. The low pressuriser pressure setpoint is reached about 50 seconds after the VDA [MSRT] in the affected SG opens and the low-low pressuriser pressure setpoint is reached about 45 seconds after that. The pressure in the intact SGs decreases as well.

The decrease in primary circuit pressure results in an increase in RCV [CVCS] charging flow and a decrease in break flow. After the reactor trip, the charging flow exceeds the break flow.

The “low-low pressuriser pressure” signal activates the safety injection system and initiates an automatic partial cooldown at -250°C/hr. The partial cooldown signal is ineffective because the failed-open MSRCV in the affected SG results in a cooldown slightly in excess of -250°C/hr. The depressurisation continues until the pressure in the SGs reaches the MIN1 setpoint at 3595 seconds.

The end of partial cooldown is detected after the VIV [MSIV] isolation, once the partial cooldown setpoint finally reaches 61.5 bar (3666s). Pressure keeps on decreasing in the affected SG. Finally, the MSRIV on the affected SG is shut, isolating the affected SG.

Because of RCV [CVCS] charging flow, the level as well as the pressure in the affected SG increases. The MSRTa, despite of the setpoint increase, opens again (at 8382s). The MSRCV being still stuck, the pressure decreases in the affected SGs. The MSRT is finally closed on MIN3 setpoint (8818s)
At 8418s seconds, the level in the affected SG reaches the MAX2 setpoint. An automatic signal is generated to stop the RCV [CVCS] charging flow on “Partial Cooldown Complete and SG Level > MAX2” and the RCV [CVCS] charging flow is isolated after a 41.5 second delay. After the RCV [CVCS] charging is isolated, the primary circuit pressure begins to decrease. At 14244 seconds, the differential pressure across the break is calculated to be less than one bar and the leak is considered to be halted. The transient is terminated 500 seconds later.

During this transient, where few operator actions are modeled, 218 tons of steam flow through the VDA [MSRT] of the affected SG (steam coming from the 4 SGs). About 450 kg of liquid is discharged from the VDA [MSRT] of the affected SG in the form of entrained moisture. The minimum liquid mass contained in the affected SG is 26 tons.

1.4.2 From the controlled state and safe shutdown state

The emergency operating procedures will be followed by the operator right after the manual reactor trip so as to reach the safe shutdown state. The safe shutdown state is defined as a state where the affected SG is isolated and at least one RIS/RRA [SIS/RHRS] train is connected to the RCP [RCS]. One out of four LHSI in RHR mode trains is sufficient to provide the required heat removal. The connection conditions are:

- RCP [RCS] hot leg pressure < 30 bar and,
- RCP [RCS] hot leg temperature < 180°C and,
- ΔTsat1 and Reactor Pressure Vessel Level (RPVL) consistent with LHSI in RHR mode suction conditions from the hot leg.

The sequence of actions to be performed by the operator to reach the safe shutdown can be divided into 2 successive phases: boration and RCP [RCS] cooldown, and final depressurisation. While performing these operations, the operator is asked for monitoring key safety functions (e.g. saturation margin) and some plant parameters, (e.g. PZR level).

Boration and RCP [RCS] Cooldown

The boration and RCP [RCS] cooldown actions are performed by the operator after reactor trip. The RBS [EBS] delivers a constant boration flow rate to the RCP [RCS], providing the negative reactivity required to reach the safe shutdown state. The allowed cooldown rate depends on the number of available RBS [EBS] trains:

- 25°C/h with 1 RBS [EBS] train in operation,
- 50°C/h with 2 RBS [EBS] trains in operation.

The RCP [RCS] cooldown is performed using the unaffected steam generators. This cooldown occurs with the MHSI operating to prevent perturbing the pressure balance between primary side and the affected SG.

Final Depressurisation

At the end of the RCP [RCS] cooldown phase, the RCP [RCS] pressure is higher than the LHSI in RHR mode maximum connecting pressure of 30 bars. If the affected SG level is too high, the operator first opens the transfer line between SGa and its partner SG to limit risks of water hammer in the SGa steam line. This also prevents overfilling of the affected SG and large activity release to the atmosphere.

Once the level in the affected SG falls below MAX2 (NR), the affected SG VDA [MSRT] is opened. This allows the depressurisation to 30 bars.

Safety Function monitoring

During the operations performed to reach the safe shutdown, the operator is still required to monitor some key plant parameter such as saturation margin and PZR level. It could then be
asked for using the normal spray, shut the MHSI one by one, etc. These operations would enable to avoid especially having the second VDA [MSRT] opening.

1.5 Conclusion

The present analysis of the single tube SGTR accident shows that despite the most penalizing single failure and preventive maintenance:

- The controlled state can be reached relying on following systems if a manual reactor trip is credited 50 minutes after the activity detection:
  - ASG [EFWS] and VDA [MSRT] (including partial cooldown) for RCP [RCS] heat removal,
  - CVCS charging for RCP [RCS] coolant inventory control.

With respect to radioactivity release, the maximum amount of contaminated fluid released from the affected SG, is:

- At full power, with reactor coolant pumps on, and no LOOP, 218 tons of steam is released directly to the atmosphere from the affected MSRT,

NB: The radioactive steam releases through the affected VDA [MSRT] are limited especially regarding the fact that the VIV [MSIV] being isolated after the partial cooldown, the steam released is coming from the 4 SG.

Neither overfilling nor dry out take place during the transient. The absence of liquid releases at the atmosphere (except in the form of residual vapour moisture) is guaranteed. Thus for the mass releases, only the residual moisture content of the vapour must be taken as assumption.

The affected SG pressure has been kept below or equal to the RCP [RCS] pressure during the transient, so the SGTR reverse flow has been limited as far as possible. The core remains covered throughout the transient, so the core cooling is never impaired and no clad heat-up is experienced.
2 Sensitivity cases

2.1 Case 1: Reference case without any manual actions

2.1.1 Description
The first case is a Design Basis Steam Generator Tube Rupture postulating that the VDA [MSRT] of the affected steam generator remains stuck open. The only manual action modelled is the manual reactor trip, the purpose of this calculation being to demonstrated that, in case of failure of the any other operator action, the protection system protects the plant from the initiating event. This case corresponds to a sensitivity on the PCSR limiting case regarding radiological consequences and is performed until leak cancellation.

2.1.2 Analysis and results
The case 1 with manual reactor trip at 3000 seconds is analyzed with the CVCS system in operation until isolated on signal for PCD over and SG level > MAX2.

With the CVCS in operation, no automatic reactor trip occurs. At 3000 seconds, the operator is assumed to manually trip the reactor. No other operator actions are credited.

One case is run with PZR heaters tripped on low PZR level. A second case is run with PZR heaters on for the entire transient. This is a decoupling assumption to keep the PZR pressure higher, thus increasing the leak flow rate. In both cases, the safety injection signal is actuated and leak cancellation is reached thanks to the following automatic actions:

- Partial cooldown
- Closure of MSIVs on SGa pressure threshold
- Closure of MSRIV on SGa pressure threshold
- Setpoint of MSRTa increase to 99bar and CVCS isolation on Partial Cooldown complete and SG level > MAX2.

The sequences of events are presented in Table 4.

The curves for the case with heaters trip on low PZR level are presented in Figure 12 to Figure 22.

The curves for the case with heaters on are presented in Figure 23 to Figure 33.

With respect to radioactivity release, the maximum amount of contaminated fluid released from the affected SG, is:

- For the case with Heaters trip on low PZR level:
  - 2037 tons of steam from the affected SG before isolation, of which
  - 193 tons of steam is released directly to the atmosphere from the affected MSRT and
No overfilling takes place during the transient. The absence of liquid releases at the atmosphere (except in the form of residual vapour moisture) is guaranteed. Thus for the mass releases, only the residual moisture content of the vapour must be taken as assumption.

- For the case with Heaters on:
  o 2039 tons of steam from the affected SG before isolation, of which
  o 190 tons of steam is released directly to the atmosphere from the affected MSRT and

No overfilling takes place during the transient. The absence of liquid releases at the atmosphere (except in the form of residual vapour moisture) is guaranteed. Thus for the mass releases, only the residual moisture content of the vapour must be taken as assumption.

### 2.2 Case 2: SGTR with manual action

#### 2.2.1 Description:

This case is a Design Basis Steam Generator Tube Rupture accounting for all operator actions,. The purpose of this analysis is to analyse the amount of releases from the affected steam generator, when modelling properly all relevant operator actions.

#### 2.2.2 Analysis and results

The current assumptions used for this case with manual actions are the following:

There are no single failures or preventative maintenance modeled. All equipment available to mitigate the accident is assumed to operate as designed.

- Steady State Conditions are presented in Table 5.
- Protection System Setpoints are presented in Table 6.

The reactor trip is actuated manually at 3000 seconds after the activity detection.

The following operator actions also occur at reactor trip:

- Start EBS pumps
- Start manual cooldown
- Shut MSIV in SG3
- Raise MSRT3 setpoint to 99 bar
- Shut off LL MFW to SG3
- Disable EFW to SG3

The manual cooldown is started at 3000 seconds by the operator. The cooldown is performed using the main steam bypass at 50°C/hr. The EBS pumps are also started at this time. Permissive P12 is activated also, which prevents activation of the partial cooldown signal and maintains the MSIVs open.

During the manual cooldown, PZR pressure is maintained in zone 2 using the heaters & spray.

MFW full load flow is stopped at reactor trip. Low load MFW flow continues and is used to maintain SG level (EFW is not actuated).
LL MFW continues to feed the intact SGs after reactor trip. Level is controlled to the normal steady state targets. In order to prepare SG4 to receive water from the affected SG, the operator reduces the SG level control setpoint in SG4 to 20% 900 seconds after the start of the manual cooldown. Both heaters & Spray are assumed to be operational.

The CVCS charging pumps are automatically isolated on high level in the PZR (>75%).

MSSVs and PSVs were set to their nominal opening setpoints, although they should not actuate during the transient.

The MSRTs were set to their nominal opening setpoints of 95.5 bar. The MSRTs for the intact SGs are not expected to actuate since the main steam bypass is operational with a 90 bar setpoint.

The safe shutdown state is reached via extra borating system which ensures the boration of the reactor coolant system during the manual cooldown since the chemical and volume control system is unavailable. The manual reactor coolant system cooldown gradient is limited to 50°C/h.

The sequences of events are presented in Table 7.

The curves are presented in Figure 34 to Figure 44.

With respect to radioactivity release, the maximum amount of contaminated fluid released from the affected SG, is:

- 1921 tons of steam from the affected SG before isolation, of which
- A negligible quantity of steam is released directly to the atmosphere from the affected MSRT and

No overfilling takes place during the transient. The absence of liquid releases at the atmosphere (except in the form of residual vapour moisture) is guaranteed. Thus for the mass releases, only the residual moisture content of the vapour must be taken as assumption.

2.3 Case 3: Realistic SGTR taking only credit of manual RT

2.3.1 Description

This Realistic Steam Generator Tube Rupture taking only credit of manual reactor trip. The calculation is similar to Case 1, but postulates that all the operational means for mitigating the Steam Generator Tube Rupture are available. In particular GCTc [MSB] is modelled in the calculation. The purpose of this calculation is to demonstrate that, under realistic conditions, direct radiological consequences are negligible when postulating the operator performs only the manual reactor trip.

If there is no operator action else than the reactor trip, the leak cancellation can be reached thanks to the protection on SG level > MAX2.

2.3.2 Analysis and results

The current assumptions used for the realistic case with manual actions are the following:

There are no single failures or preventative maintenance modeled. All equipment available to mitigate the accident is assumed to operate as designed.

The safe shutdown state is reached via extra borating system which ensures the boration of the reactor coolant system during the manual cooldown since the chemical and volume control system is unavailable. The manual reactor coolant system cooldown gradient is limited to 50°C/h.
- Steady State Conditions are presented in Table 5.
- Protection System Setpoints are presented in Table 6.

The sequences of events are presented in Table 8: Case 3: Sequences of events.

The curves are presented in Figure 45 to Figure 55.

With respect to radioactivity release, the maximum amount of contaminated fluid released from the affected SG, is:

- 2001 tons of steam from the affected SG before isolation, of which
- No steam is released directly to the atmosphere from the affected MSRT and

No overfilling takes place during the transient. The absence of liquid releases at the atmosphere (except in the form of residual vapour moisture) is guaranteed. Thus for the mass releases, only the residual moisture content of the vapour must be taken as assumption.
### Table 1. Initial Conditions for SGTR Accident

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial reactor</td>
<td>4590 MW</td>
</tr>
<tr>
<td>Initial average RCP [RCS] temperature</td>
<td>312.4 - 2.5 = 309.9°C</td>
</tr>
<tr>
<td>Initial reactor coolant pressure</td>
<td>155 + 2.5 = 157.5 bar</td>
</tr>
<tr>
<td>Reactor coolant flowrate</td>
<td>26986 m3/hr/loop</td>
</tr>
<tr>
<td>Bypass flowrate</td>
<td></td>
</tr>
<tr>
<td>- Total</td>
<td>5.53%</td>
</tr>
<tr>
<td>- Dome</td>
<td>0.51%</td>
</tr>
<tr>
<td>- Guide Tubes</td>
<td>3.01%</td>
</tr>
<tr>
<td>- Reflector</td>
<td>2.01%</td>
</tr>
<tr>
<td>PZR level</td>
<td>56% + 5% = 61%</td>
</tr>
<tr>
<td>Initial SG level</td>
<td>49% + 10.5% = 59.5% NR</td>
</tr>
<tr>
<td>Main feedwater flowrate</td>
<td>649 Kg/s</td>
</tr>
<tr>
<td>SG Pressure (Exit)</td>
<td>71.9 Bar</td>
</tr>
<tr>
<td>SG Saturation Pressure</td>
<td>72.1 Bar</td>
</tr>
<tr>
<td>SG Pressure (MFW)</td>
<td>72.2 Bar</td>
</tr>
<tr>
<td>Initial ARE [MFW] Enthalpy</td>
<td>991.18 KJ/Kg</td>
</tr>
<tr>
<td>Initial ARE [MFW] Temperature</td>
<td>230°C</td>
</tr>
<tr>
<td>Steam line pressure (MSRT Connection)</td>
<td>71.3 Bar</td>
</tr>
<tr>
<td>Steam header pressure</td>
<td>69.0 Bar</td>
</tr>
<tr>
<td>CVCS Injection temp. (letdown on)</td>
<td>270°C</td>
</tr>
<tr>
<td>CVCS Injection temp. (letdown off)</td>
<td>50°C</td>
</tr>
<tr>
<td>Function</td>
<td>Setpoint</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>----------</td>
</tr>
<tr>
<td>Intact MSRTs</td>
<td>97 bar</td>
</tr>
<tr>
<td>Affected MSRT</td>
<td>94 bar</td>
</tr>
<tr>
<td>PSV 1</td>
<td>175 bar</td>
</tr>
<tr>
<td>PSV 2</td>
<td>178 bar</td>
</tr>
<tr>
<td>PSV 2, 3</td>
<td>181 bar</td>
</tr>
<tr>
<td>MSSVs</td>
<td>103.5 bar</td>
</tr>
<tr>
<td>Low PZR pressure (MIN2)</td>
<td>133.5 bar</td>
</tr>
<tr>
<td>Low-low PZR pressure (MIN3)</td>
<td>116.5 bar</td>
</tr>
<tr>
<td>Low PZR level (MIN3)</td>
<td>12 %</td>
</tr>
<tr>
<td>High SG level (MAX1)</td>
<td>71% NR</td>
</tr>
<tr>
<td>High SG level (MAX2)</td>
<td>87% NR</td>
</tr>
<tr>
<td>High SG level (MAX1)</td>
<td>91% WR</td>
</tr>
<tr>
<td>High SG pressure dP/dt</td>
<td>-5 bar/min</td>
</tr>
<tr>
<td>Low SG level (MIN2)</td>
<td>38% WR</td>
</tr>
<tr>
<td>Low SG pressure (MIN1)</td>
<td>51.5 bar</td>
</tr>
<tr>
<td>Low SG pressure (MIN3)</td>
<td>38.5 bar</td>
</tr>
<tr>
<td>Low ΔP_{SAT}</td>
<td>10 bar</td>
</tr>
</tbody>
</table>
Table 3. Sequence of events for SGTR transient (MSRCV stuck open)

<table>
<thead>
<tr>
<th>Event</th>
<th>Time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Break opens</td>
<td>0</td>
</tr>
<tr>
<td>PZR level &lt; MIN3</td>
<td>1053</td>
</tr>
<tr>
<td>PZR heaters off</td>
<td>1055</td>
</tr>
<tr>
<td>Isolate letdown</td>
<td>1095</td>
</tr>
<tr>
<td>Reactor trip signal (manual)</td>
<td>3000</td>
</tr>
<tr>
<td>Turbine trip signal</td>
<td></td>
</tr>
<tr>
<td>High load ARE [MFWS] stopped to all SGs</td>
<td></td>
</tr>
<tr>
<td>Operator actions: Low load ARE [MFWS] isolation and ASG [EFWS] manual actuation in non affected SGs</td>
<td>3000</td>
</tr>
<tr>
<td>Rod insertion begins</td>
<td>3000.4</td>
</tr>
<tr>
<td>Turbine isolated</td>
<td>3002.5</td>
</tr>
<tr>
<td>EFW 1, 2 &amp; 4 flow starts</td>
<td>3015.9</td>
</tr>
<tr>
<td>MSRT opening on high SG pressure (in affected SG3) at 94 bar, MSRCV stuck open</td>
<td>3038</td>
</tr>
<tr>
<td>Low PZR pressure (133.5 b)</td>
<td>3091</td>
</tr>
<tr>
<td>Low-low PZR pressure (116.5 b)</td>
<td></td>
</tr>
<tr>
<td>SI Signal</td>
<td>3135</td>
</tr>
<tr>
<td>Start partial cooldown</td>
<td></td>
</tr>
<tr>
<td>MHSI/LHSI pumps started</td>
<td>3151</td>
</tr>
<tr>
<td>SG3 pressure &lt; MIN1</td>
<td>3595</td>
</tr>
<tr>
<td>Partial cooldown complete in unaffected SG</td>
<td>3667</td>
</tr>
<tr>
<td>VIV [MSIV] 1, 2, 3 &amp; 4 shut</td>
<td>3601</td>
</tr>
<tr>
<td>SG3 Pressure &lt; MIN3</td>
<td>3833</td>
</tr>
<tr>
<td>SG3 MSRIV shut</td>
<td>3838</td>
</tr>
<tr>
<td>MSRT opening on high SG pressure (in affected SG3) at 99 bar, MSRCV stuck open</td>
<td>8384</td>
</tr>
<tr>
<td>Partial cooldown complete and SG3 level &gt; MAX2</td>
<td>8418</td>
</tr>
<tr>
<td>Event</td>
<td>Time (s)</td>
</tr>
<tr>
<td>------------------------------</td>
<td>----------</td>
</tr>
<tr>
<td>Stop CVCS charging flow</td>
<td>8460</td>
</tr>
<tr>
<td>SG3 pressure &lt; MIN3</td>
<td>8818</td>
</tr>
<tr>
<td>SG3 MSRIV shut</td>
<td>8824</td>
</tr>
<tr>
<td>Leak cancelled</td>
<td>14245</td>
</tr>
<tr>
<td>Transient terminated</td>
<td>14745</td>
</tr>
</tbody>
</table>
Table 4: Case 1: Sequences of event

<table>
<thead>
<tr>
<th>CVCS On</th>
<th>Heaters Trip</th>
<th>Heaters Stay On</th>
</tr>
</thead>
<tbody>
<tr>
<td>Break opens</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Reactor/Turbine Trip</td>
<td>3000</td>
<td>3000</td>
</tr>
<tr>
<td>HL MFW Stopped</td>
<td>3000</td>
<td>3000</td>
</tr>
<tr>
<td>MSRT3 Opens (94 bar)</td>
<td>3033</td>
<td>3034</td>
</tr>
<tr>
<td>Low Low PZR Pressure</td>
<td>3094</td>
<td>3077</td>
</tr>
<tr>
<td>- PCD Starts</td>
<td>3094</td>
<td>3077</td>
</tr>
<tr>
<td>- MHSI Starts</td>
<td>3110</td>
<td>3093</td>
</tr>
<tr>
<td>LL MFW Stopped (3)</td>
<td>3254</td>
<td>3255</td>
</tr>
<tr>
<td>LL MFW Stopped (1, 2 &amp; 4)</td>
<td>3282</td>
<td>3286</td>
</tr>
<tr>
<td>PCD Complete</td>
<td>3546</td>
<td>3258</td>
</tr>
<tr>
<td>SG Pressure &lt; MIN1</td>
<td>3752</td>
<td>3743</td>
</tr>
<tr>
<td>- Close all MSIVs</td>
<td>3758</td>
<td>3749</td>
</tr>
<tr>
<td>SG Pressure &lt; MIN3</td>
<td>4061</td>
<td>4052</td>
</tr>
<tr>
<td>- Close MSRIV3 &amp; set to 94 bar</td>
<td>4067</td>
<td>4058</td>
</tr>
<tr>
<td>MSRT3 Opens (94 bar)</td>
<td>6997</td>
<td>6491</td>
</tr>
<tr>
<td>PCD Complete &amp; Level &gt; MAX2</td>
<td>7012</td>
<td>6493</td>
</tr>
<tr>
<td>- Isolate CVCS charging flow</td>
<td>7012</td>
<td>6503</td>
</tr>
<tr>
<td>- Raise MSRT3 Setpoint to 99 bar</td>
<td>7012</td>
<td>6503</td>
</tr>
<tr>
<td>Leak Cancelled</td>
<td>8760</td>
<td>8540</td>
</tr>
</tbody>
</table>
**Table 5 : Case 2 and 3 : Steady State Conditions**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>BE Value</th>
<th>PCSR Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial reactor power (% of nominal power)</td>
<td>100</td>
<td>102</td>
</tr>
<tr>
<td>Initial average RCP [RCS] temperature (°C)</td>
<td>312.5</td>
<td>312.4 - 2.5 = 309.9</td>
</tr>
<tr>
<td>Initial reactor coolant pressure (bar)</td>
<td>155</td>
<td>155 + 2.5 = 157.5 bar</td>
</tr>
<tr>
<td>Reactor coolant flowrate (m$^3$/hr/loop)</td>
<td>28320</td>
<td>27185</td>
</tr>
<tr>
<td>Bypass flowrate (%)</td>
<td>3.46</td>
<td>5.50</td>
</tr>
<tr>
<td>PZR level (% scale)</td>
<td>56</td>
<td>56 + 5 = 61</td>
</tr>
<tr>
<td>Initial unaffected SG level (% NR)</td>
<td>49</td>
<td>49 + 10.5 = 59.5</td>
</tr>
<tr>
<td>Main feedwater flow (% of nominal flow)</td>
<td>100</td>
<td>102</td>
</tr>
<tr>
<td>Initial ARE [MFW] temperature (°C)</td>
<td>230</td>
<td>230</td>
</tr>
</tbody>
</table>


### Table 6: Case 2 and 3: Protection system setpoints

<table>
<thead>
<tr>
<th>Trip</th>
<th>Setpoint</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low PZR Pressure</td>
<td>135.0 bar</td>
</tr>
<tr>
<td>Low-Low PZR Pressure</td>
<td>115.0 bar</td>
</tr>
<tr>
<td>EFW Startup</td>
<td>40%WR</td>
</tr>
<tr>
<td>EFW Isolation</td>
<td>89%WR</td>
</tr>
<tr>
<td>SG Level MAX2</td>
<td>85%NR</td>
</tr>
<tr>
<td>SG Pressure MIN3</td>
<td>40.0 bar</td>
</tr>
<tr>
<td>Major Events</td>
<td>Best-Estimate Case</td>
</tr>
<tr>
<td>-----------------------------------------------------------------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>Break opens</td>
<td>0</td>
</tr>
<tr>
<td>Reactor/Turbine Trip</td>
<td>3000</td>
</tr>
<tr>
<td>HL MFW Stopped</td>
<td>3000</td>
</tr>
<tr>
<td>LL MFW Stopped (SG 3)</td>
<td>3000</td>
</tr>
<tr>
<td>Start Manual Cooldown at -50°C/hr and borication via EBS</td>
<td>3000</td>
</tr>
<tr>
<td>SGa isolation</td>
<td>3000</td>
</tr>
<tr>
<td>MSRT3 Opens (99 bar)</td>
<td>3759</td>
</tr>
<tr>
<td>Isolate CVCS charging flow on high PZR level</td>
<td>5914</td>
</tr>
<tr>
<td>Leak Cancelled</td>
<td>6558</td>
</tr>
<tr>
<td>Major Events</td>
<td>BE Case with no operator actions</td>
</tr>
<tr>
<td>--------------------------------------------------</td>
<td>----------------------------------</td>
</tr>
<tr>
<td>Break opens</td>
<td>0</td>
</tr>
<tr>
<td>Reactor/Turbine Trip</td>
<td>3000</td>
</tr>
<tr>
<td>HL MFW Stopped</td>
<td>3000</td>
</tr>
<tr>
<td>LL MFW Stopped (SG 3)</td>
<td>4459</td>
</tr>
<tr>
<td>Start PCD on High Level in SG3</td>
<td>5794</td>
</tr>
<tr>
<td>LL MFW Stopped (SGs 1,2 &amp; 4)</td>
<td>6052</td>
</tr>
<tr>
<td>PCD Complete</td>
<td>6166</td>
</tr>
<tr>
<td>PCD Complete &amp; Level &gt; MAX2</td>
<td>8074</td>
</tr>
<tr>
<td>MSRTa setpoint increase to 99bars</td>
<td>8074</td>
</tr>
<tr>
<td>Closure of MSIV 3</td>
<td>8074</td>
</tr>
<tr>
<td>Isolate CVCS charging flow</td>
<td>8115</td>
</tr>
<tr>
<td>Leak Cancelled</td>
<td>10091</td>
</tr>
</tbody>
</table>
Figure 1. Primary and Secondary Pressures - Upper Plenum Level

PRESSURE - PZR and SG

UPPER PLENUM LIQUID LEVEL
Figure 2. Steam Generator Levels

SG LEVEL – WR

SG LEVEL – NR
Figure 3. Pressurizer Level

CALCULATED PRESSURIZER LEVEL

CATHARE MEASURED PRESSURIZER LEVEL
Figure 4. MSRT Liquid & Steam Flow

LIQUID MASS FLOW RATE THROUGH MSRT

VAPOR MASS FLOW RATE THROUGH MSRT
Figure 5. Main and Emergency Feedwater Flows

MASS FLOW RATE – MFW

MASS FLOW RATE – EFWS
Figure 6. CVCS and MHSI Flows

MASS FLOW RATE - CVCS

MASS FLOW RATE - MHSI
Figure 7. Steam Flows – CVCS and Leakage Flows

STEAM MASS FLOW RATE – SG

MASS FLOW RATE – SGTR AND TOTAL CVCS
Figure 8. Break Differential Pressure – Loop Temperatures

Differential Pressure Across Break

Loop Temperatures
Figure 9. Liquid Mass and Free Volume in Affected SG

![Graph showing liquid mass and free volume over time.](image)
Figure 10. Core and SG Riser Void Fraction – Pressurizer Heater Power

VOID FRACTION – CORE

HEATER POWER
Figure 11. Total Injection Flow and Leak Flow – SG Heat Transfer

[Figure: Graph showing total injection flow and leak flow over time.]

MASS FLOW RATE – SGTR AND TOTAL CVCS+SIS+EBS

[Figure: Graph showing heat transfer from PRI to SEC over time.]
Figure 12: Case 1 with Heaters trip on low PZR level: Primary and Secondary Pressures - Upper Plenum Level
Figure 13: Case 1 with Heaters trip on low PZR level: Steam Generator Levels

SG LEVEL - WR

SG LEVEL - NR
Figure 14: Case 1 with Heaters trip on low PZR level: Pressurizer Level

CALCULATED PRESSURIZER LEVEL

CATHARE MEASURED PRESSURIZER LEVEL
Figure 15: Case 1 with Heaters trip on low PZR level: MSRT Liquid & Steam Flow

Liquid Mass Flow Rate Through MSRT

Vapor Mass Flow Rate Through MSRT
Figure 16: Case 1 with Heaters trip on low PZR level: Main and Emergency Feedwater Flows

MASS FLOW RATE – MFW

MASS FLOW RATE – EFWS
Figure 17: Case 1 with Heaters trip on low PZR level: CVCS and MHSI Flows

Mass Flow Rate - CVCS

Mass Flow Rate - MHSI
Figure 18: Case 1 with Heaters trip on low PZR level: Steam Flows – CVCS and Leakage Flows

STEAM MASS FLOW RATE – SG

MASS FLOW RATE – SGTR AND TOTAL CVCS
Figure 19: Case 1 with Heaters trip on low PZR level: Break Differential Pressure – Loop Temperatures
Figure 20: Case 1 with Heaters trip on low PZR level: Liquid Mass and Free Volume in Affected SG
Figure 21: Case 1 with Heaters trip on low PZR level: Core and SG Riser Void Fraction – Pressurizer Heater Power

VOID FRACTION – CORE

HEATER POWER
Figure 22: Case 1 with Heaters trip on low PZR level: Total Injection Flow and Leak Flow – SG Heat Transfer

MASS FLOW RATE – SGTR AND TOTAL CVCS+SIS+EBS

Heat transfer from PRI to SEC
Figure 23 : Case 1 with heaters on: Primary and Secondary Pressures - Upper Plenum Level

PRESSURE – PZR and SG

UPPER PLENUM LIQUID LEVEL
Figure 24: Case 1 with heaters on: Steam Generator Levels

SG LEVEL - WR

SG LEVEL - NR
Figure 25: Case 1 with heaters on: Pressurizer Level

CALCULATED PRESSURIZER LEVEL

CATHARE MEASURED PRESSURIZER LEVEL
Figure 26: Case 1 with heaters on: MSRT Liquid & Steam Flow

LIQUID MASS FLOW RATE THROUGH MSRT

VAPOR MASS FLOW RATE THROUGH MSRT
Figure 27: Case 1 with heaters on: Main and Emergency Feedwater Flows

MASS FLOW RATE – MFW

MASS FLOW RATE – EFWS
Figure 28: Case 1 with heaters on: CVCS and MHSI Flows

MASS FLOW RATE - CVCS

MASS FLOW RATE - MHSI
Figure 29: Case 1 with heaters on: Steam Flows – CVCS and Leakage Flows

STEAM MASS FLOW RATE – SG

MASS FLOW RATE – SGTR AND TOTAL CVCS
Figure 30: Case 1 with heaters on: Break Differential Pressure – Loop Temperatures

Differential Pressure Across Break

Loop Temperatures
Figure 31: Case 1 with heaters on: Liquid Mass and Free Volume in Affected SG
Figure 32: Case 1 with heaters on: Core and SG Riser Void Fraction – Pressurizer Heater Power
Figure 33: Case 1 with heaters on: Total Injection Flow and Leak Flow – SG Heat Transfer

MASS FLOW RATE – SGTR AND TOTAL CVCS+SIS+EBS

Heat transfer from PRI to SEC
Figure 34: Case 2: Primary and Secondary Pressures - Upper Plenum Level

PRESSURE - PZR and SG

UPPER PLENUM LIQUID LEVEL
Figure 35: Case 2: Steam Generator Levels

SG LEVEL - WR

SG LEVEL - NR
Figure 36: Case 2: Pressurizer Level

CALCULATED PRESSURIZER LEVEL

CATHARE MEASURED PRESSURIZER LEVEL
Figure 37: Case 2: MSRT Liquid & Steam Flow

**Liquid Mass Flow Rate Through MSRT**

**Vapor Mass Flow Rate Through MSRT**
Figure 38: Case 2: Main and Emergency Feedwater Flows

** MASS FLOW RATE – MFW **

** MASS FLOW RATE – EFWS **
Figure 39: Case 2: CVCS and MHSI Flows

MASS FLOW RATE - CVCS

MASS FLOW RATE - MHSI
Figure 40: Case 2: Steam Flows – CVCS and Leakage Flows

STEAM MASS FLOW RATE – SG

MASS FLOW RATE – SGTR AND TOTAL CVCS
Figure 41: Case 2: Break Differential Pressure – Loop Temperatures
Figure 42: Case 2: Liquid Mass and Free Volume in Affected SG
Figure 43: Case 2: Core and SG Riser Void Fraction – Pressurizer Heater Power

VOID FRACTION – CORE

HEATER POWER
Figure 44: Case 2: Total Injection Flow and Leak Flow – SG Heat Transfer

Mass flow rate – SGTR and total CVCS+S1+S+EBS

Heat transfer from PRI to SEC
Figure 45: Case 3: Primary and Secondary Pressures - Upper Plenum Level

**Pressure - PZR and SG**

**Upper Plenum Liquid Level**
Figure 46: Case 3: Steam Generator Levels

SG LEVEL - WR

SG LEVEL - NR
Figure 47: Case 3: Pressurizer Level

CALCULATED PRESSURIZER LEVEL

CATHARE MEASURED PRESSURIZER LEVEL
Figure 48: Case 3: MSRT Liquid & Steam Flow

**LIQUID MASS FLOW RATE THROUGH MSRT**

**VAPOR MASS FLOW RATE THROUGH MSRT**
Figure 49: Case 3: Main and Emergency Feedwater Flows
Figure 50: Case 3: CVCS and MHSI Flows

MASS FLOW RATE – CVCS

MASS FLOW RATE – MHSI
Figure 51: Case 3: Steam Flows – CVCS and Leakage Flows

STEAM MASS FLOW RATE – SG

MASS FLOW RATE – SGTR AND TOTAL CVCS
Figure 52: Case 3: Break Differential Pressure – Loop Temperatures
Figure 53: Case 3: Liquid Mass and Free Volume in Affected SG
Figure 54: Case 3: Core and SG Riser Void Fraction – Pressurizer Heater Power

VOID FRACTION – CORE

HEATER POWER
Figure 55: Case 3: Total Injection Flow and Leak Flow – SG Heat Transfer

[Graph showing mass flow rate and heat transfer]