## 14.6 <u>LOSS OF FEEDWATER FLOW EVENT</u>

### 14.6.1 IDENTIFICATION OF EVENT AND CAUSE

The primary function of the feedwater regulating system is to maintain the liquid inventory in the SG at the normal operating level. The feedwater regulating valve controller, which is part of the three element control system (Chapter 10), automatically adjusts the position of the regulating valves to modulate the feedwater flow. During normal operation the controller matches the feedwater flow to the steam flow.

The feedwater flow trains to the SG consist of three electric motor-driven condensate pumps in parallel (usually one in standby), which take suction on the three condensers and discharge to the three parallel electric motor-driven condensate booster pumps (usually one in standby). These pumps deliver the condensate to the two parallel, steam turbine-driven SG feed pumps (Chapter 10).

Check valves in the condensate and feedwater system reduce the likelihood of a total LOFW and blowdown of both SGs due to a pipe break in the condensate or feedwater systems.

An LOFW Flow event is defined as a reduction in feedwater flow to the SG without a corresponding reduction in steam flow from the SG. The closure of the feedwater regulating valves, the loss of condensate or feedwater pumps, or a pipe break in the condensate or feedwater systems during steady-state operation would result in a LOFW Flow event.

The most limiting LOFW Flow event at HFP is an inadvertent closure of both feedwater regulating valves. An instantaneous closure of the regulating valves would cause the largest steam and feedwater flow mismatch and result in the most rapid reduction in the SG inventory.

The LOFW event has been analyzed with respect to RCS peak pressure, Main Steam System (MSS) peak pressure, and maximum SG inventory depletion. As the LOFW event results in increasing pressure and only a small reactor power increase, both the DNB and peak linear heat rate SAFDLs are bounded by more limiting events. The SG inventory depletion case is analyzed to ensure that the AFW System has sufficient capacity to provide its long-term heat removal function.

### 14.6.2 SEQUENCE OF EVENTS

An LOFW Flow event can result in the approach to the RCS and MSS Pressure Upset Limits (110% of design pressure). The action of either the high pressurizer pressure or low SG level reactor trip functions will provide event mitigation and prevent exceeding these limits. Since the SAFDLs are bounded by other events, no fuel pin failures are assumed to occur, and therefore, the site boundary dose limits specified in 10 CFR 50.67 are not approached.

The event is initiated at 102% of 2700 MW and at the RCS temperature and pressure Technical Specification limits. The event is postulated to occur due to a failure in the feedwater regulating system that instantaneously shuts both feedwater regulating valves. Closure of both valves results in a complete cessation of feedwater flow to both SGs.

The LOFW event relies on AFAS to provide AFW System actuation and maintain acceptable SG liquid inventories. The AFAS actuates based on wide range SG level indication. This signal is used to actuate AFW flow and isolate SG blowdown. The AFW System (Chapter 10) consists of two non-condensing, steam turbine-driven AFW pumps and one motor-driven AFW pump. Steam for the turbine-driven pumps can be supplied from the MSS or from the auxiliary boiler steam system.

The immediate system response is a steady decrease in SG liquid inventory. The temperature in the SG will increase due to the loss of subcooled feedwater flow and cause the SG pressure to increase correspondingly until the MSSV opening setpoint is reached. The RCS temperature and pressure will increase due to mismatch in primary-to-secondary heat transfer.

With the SG liquid inventory depleting and RCS pressure rising, a reactor trip will occur on either high pressurizer pressure or low SG water level. Both analysis setpoints protect the Technical Specification values and include uncertainty.

For the analyses that maximize RCS and SG pressures, pressures will continue to increase until the point at which the PSV and MSSV setpoints are reached and the valves lift to relieve pressure. For these analyses, neither the turbine bypass valves (TBVs) nor ADVs are credited, as this would relieve pressure. The impact on MSS overpressure of a reactor trip near concurrent with the first MSSV opening was investigated. Staggered MSSV setpoints compensate for tripping at a potentially higher secondary pressure. For the analysis that maximizes SG inventory depletion, the TBVs and ADVs are evaluated as this would increase the SG steam flow and could result in a more rapid SG liquid inventory depletion. The pressurizer PORVs are not credited in either the overpressure or SG inventory depletion cases.

The reactor trip rapidly decreases the core heat flux to decay heat levels. A turbine trip is assumed to occur on reactor trip. The analyses show that neither the RCS nor the MSS upset pressure limits are exceeded.

For the maximum inventory depletion case, the SG water level continues to decrease following the trip due to decay heat. The turbine and RCPs continue to run. The RCPs add heat. An AFAS is generated once the analysis setpoint is reached. The initiation of AFAS causes the AFW pumps to start and the SG blowdown isolation valves to close. The worst single-failure is assumed to occur in the AFW System resulting in the failure of the motor-driven AFW pump to deliver flow.

Reactor Coolant System temperature and pressure will initially decrease after the trip. After the initial decrease, RCS temperature and pressure will begin to slowly rise due to the inability of the SG to adequately remove decay and RCP heat. Steam generator pressure will initially stabilize just above the setpoint of the lowest credited pressure relief device. At ten minutes post-trip, operators are credited with an action to increase AFW flow provided by the turbine-driven AFW pump. Once the SG level has decreased to the point that heat transfer is significantly degraded, SG pressure begins decreasing. The decrease in SG pressure will cause the RCS pressure and temperature to begin to decrease. If sufficient AFW flow was not supplied soon after, RCS pressure and temperature would again increase due to the lack of heat transfer. Once the AFW flow is sufficient to exceed the decay and RCP heat removal demand, SG pressure and level increases and RCS temperature and pressure stabilizes.

### 14.6.3 CORE AND SYSTEM PERFORMANCE

#### 14.6.3.1 Mathematical Models

The NSSS response to the LOFW event is simulated using the S-RELAP5 computer code described in Section 14.1.4.2.

14.6.3.2 Input Parameters and Initial Conditions

Tables 14.6-1 and 14.6-2 present the limiting input parameters and initial conditions used to analyze the LOFW event to maximize peak RCS pressure, peak secondary pressure, and SG inventory depletion.

Sensitivity studies were performed to determine the most limiting set of initial conditions, provided in Tables 14.6-1 (RCS Pressure) and 14.6-2 (SG Inventory). Pressurizer pressure and level, SG level, RCS inlet temperature, and RCS flow rate were ranged, one parameter at a time.

14.6.3.3 Results

The SAFDLs are not explicitly determined for this event, since both SAFDLs criteria are bounded by other more limiting events. The LOFW event is an increasing pressure event and, therefore, the DNBR SAFDL is not limiting for this event. The LOFW event also results in small power increases, and therefore the linear heat rate limit is not challenged. Additional cases demonstrate that the pressurizer does not overfill.

a. To Maximize RCS Peak Pressure

The sequence of events for the LOFW Flow event analyzed to determine the peak RCS pressure is presented in Table 14.6-3. Figures 14.6-1 through 14.6-4 present the transient behavior of core power, RCS temperatures, RCS pressure, and SG pressure. Note that the SG pressure profile, Figure 14.6-4, does not include the liquid downcomer head. The worst case peak RCS analysis included a LOAC assumed to occur at the time of reactor trip. The maximum RCS pressure, including elevation head, was determined to be within 110% of the design RCS pressure (2750 psia), and is therefore acceptable.

b. To Maximize Steam Generator Pressure

The sequence of events for the LOFW Flow event analyzed to determine the peak SG pressure is presented in Table 14.6-4. Figures 14.6-5 through 14.6-8 present the transient behavior of core power, RCS temperatures, RCS pressure, and SG pressure. Note that the SG pressure profile, Figure 14.6-8, does not include the liquid downcomer head. The worst case peak SG pressure analysis was without a LOAC. The maximum SG pressure, including liquid downcomer head, was determined to be within 110% of the design MSS pressure (1116.5 psia), and is therefore acceptable.

c. To Maximize Steam Generator Inventory Depletion

The sequence of events for the LOFW Flow event analyzed to determine the minimum SG inventory is presented in Table 14.6-5. Figures 14.6-9 through 14.6-13 present the transient behavior of core power, RCS inlet temperature, RCS pressure, SG pressure, and SG inventory. Note that the SG pressure profile, Figure 14.6-12, does not include the liquid downcomer head. The worst case peak SG inventory depletion analysis was without a LOAC.

As shown on the figures, RCS temperature, RCS pressure, and SG pressure initially peak before the trip. Due to the reactor trip, the RCS parameters rapidly decrease. After the initial decrease, RCS parameters begin to rise again due to the primary-to-secondary heat transfer mismatch.

Steam generator pressure initially remains steady and then begins to drop due to the decreasing SG level and decreased SG heat transfer. Reactor Coolant System temperature and pressure peak at the values indicated in Table 14.6-5. As the SG inventory reaches its minimum level, AFW flow becomes sufficient to remove RCP and decay heat, following an assumed operator action to increase the turbine-driven AFW flow at ten minutes. Steam Generator inventory begins increasing and the RCS parameters begin to stabilize. Within one hour of event initiation, plant parameters have stabilized. Therefore, the actions of the RPS, AFAS, and AFW Systems are adequate to ensure long-term heat removal from the RCS, and ultimately recover the depleting steam generator inventory.

Operation of the ADVs and TBVs was found to be less limiting without the additional steam release. Additionally, MSSV setpoints at the low end of the allowable range were also found to be less limiting than those at the high end.

### 14.6.4 CONCLUSIONS

The analysis of the LOFW event demonstrates that the actions of the RPS, AFAS, and AFW Systems prevent exceeding the fuel SAFDLs, and the RCS and SG Pressure Upset Limits. The radiological consequence of opening the MSSVs during the event is a site boundary dose that is negligible compared to the 10 CFR 50.67 guidelines.

The LOFW Flow event is a heatup transient and is most limiting at BOC. Therefore, extended burnup has no adverse impact on this event.

## TABLE 14.6-1

## INITIAL CONDITIONS AND INPUT PARAMETERS FOR THE LOFW EVENT TO MAXIMIZE CALCULATED PEAK PRESSURE

| PARAMETER | UNITS | PEAK RCS PRESSURE | PEAK SECONDARY PRESSURE |
|---|---|---|---|
| Initial Core Power Level | MWt | 2754[a] | 2754[a] |
| Initial Core Inlet Coolant Temperature | °F | 546 | 550 |
| RCS Flow Rate | gpm | 412,000 | 370,000 |
| Initial Pressurizer Pressure | psia | 2164 | 2164 |
| Initial Pressurizer Liquid Level | % span | 67.2 | 32.2 |
| Pressurizer Spray | --- | no | yes |
| Plugged SG Tubes | % | 10 | 0 |
| MTC | x $10^{-4}$ $\Delta\rho$/°F | +0.15 | +0.15 |
| CEA Worth at Trip | %$\Delta\rho$ | -5.0 | -5.0 |
| High Pressurizer Pressure Analysis Trip Setpoint | psia | 2420.0 | 2420.0 |
| Low SG Water Water Level below normal | inches | N/A | 116.4 |
| Trip Delay Time | sec | 0.9 | 0.9 |
| LOAC at time of trip | --- | yes | no |
| PSV Setpoint – RC-200 | psia | 2575 | 2575 |
| PSV Setpoint – RC-201 | psia | 2600 | 2600 |
| MSSV Bank 1 Setpoint (2 per SG) | psia | 1019.7 | 1019.7 |
| MSSV Bank 2 Setpoint (2 per SG) | psia | 1049.7 | 1049.7 |
| MSSV Bank 3 Setpoint (4 per SG) | psia | 1064.7 | 1064.7 |

[a] Value does not include approximately 17 MWt of pump heat calculated by S-RELAP5.

## TABLE 14.6-2

## INITIAL CONDITIONS AND INPUT PARAMETERS FOR THE LOFW EVENT TO MAXIMIZE SG INVENTORY DEPLETION

| PARAMETER | UNITS | SETPOINT OR VALUE |
|---|---|---|
| Initial Core Power Level | MWt | 2754[(a)] |
| Initial RCS Inlet Coolant Temperature | °F | 550 |
| Vessel Flow Rate | gpm | 412,000 |
| Initial Pressurizer Pressure | psia | 2311 |
| Initial Pressurizer Liquid Level | % span | 67.2 |
| Pressurizer Spray | -- | Yes |
| Plugged SG Tubes | % | 0 |
| MTC | x $10^{-4}$ $\Delta\rho$/°F | +0.15 |
| CEA Worth at Trip | % $\Delta\rho$ | -5.0 |
| SG Water Level | % NR | 69 |
| High Pressurizer Pressure Analysis Trip Setpoint | psia | 2420.00 |
| Trip Delay Time | sec | 0.9 |
| AFW Actuation Analysis Setpoint | % WR | 42.4 |
| Steam-Driven AFW Response Time | sec | 180 |
| Steam-Driven AFW Flow Credited with Operator Action (per SG) | gpm | 200 |
| SG Blowdown Flow (total from both SG) | lbm/hr | ~150,000 |
| SG Blowdown Isolation Response Time | sec | 35 |
| ADVs (Begin to open/fully opened/fully closed) | °F | 540/557/535 |
| ADVs (Begin to open/fully opened/fully closed) | °F | 540/557/535 |
| TBVs (begin to open/fully opened) | psia | 895/905 |

(a) Value does not include approximately 17 MWt of pump heat.

**TABLE 14.6-3**

**SEQUENCE OF EVENTS FOR LOFW EVENT TO MAXIMIZE CALCULATED PEAK RCS PRESSURE**

| TIME (sec) | EVENT | SETPOINT OR VALUE |
|---|---|---|
| 0.0 | Event Initiation | --- |
| 40.5 | High Pressurizer Pressure Trip Setpoint Reached | 2420 psia |
| 41.4 | Reactor and Turbine Trip | --- |
| 41.7 | MSSVs Open | --- |
| 41.9 | CEA Insertion Begins | --- |
| 41.9 | Peak Reactor Power | 101.4% RTP |
| 44.3 | PSV RC-200 Opens | --- |
| 45.0 | Peak RCS Pressure | 2658.9 psia |
| 47.8 | PSV RC-200 Closes | --- |

**TABLE 14.6-4**

**SEQUENCE OF EVENTS FOR THE LOFW EVENT TO MAXIMIZE CALCULATED PEAK SECONDARY PRESSURE**

| TIME (sec) | EVENT | SETPOINT OR VALUE |
|---|---|---|
| 0.0 | Termination of Feedwater Flow | --- |
| 47.2/47.3 | MSSVs Open | --- |
| 52.3 | Peak Reactor Power | 101.49% RTP |
| 53.98 | Low SG Level Trip Setpoint | 0% NR |
| 54.89 | Reactor and Turbine Trip | --- |
| 55.39 | CEAs Insertion Begins | --- |
| 56.0 | Peak RCS Pressure | 2451.3 psia |
| 60.6 | Peak MSS Pressure | 1115.7 psia |
| 64.75 | Peak Reactor Vessel Inlet Temperature | 571.19°F |

## TABLE 14.6-5

## SEQUENCE OF EVENTS FOR THE LOFW EVENT TO MAXIMIZE STEAM GENERATOR INVENTORY DEPLETION

| TIME (sec) | EVENT | SETPOINT OR VALUE |
|---|---|---|
| 0.0 | Event Initiation | --- |
| 38.58 | High Pressurizer Pressure Trip | 2420 psia |
| 39.49 | Trip Breakers Open | --- |
| 40.0 | CEAs Insertion Begins | --- |
| 55.88 | AFAS Setpoint is Reached | 42.4% WR |
| 90.88 | SG Blowdown Isolation Valves Close | --- |
| 239.40 | AFW Flow Begins | 100 gpm/SG |
| 639.5 | Operators take Action to Increase AFW Flow | 200 gpm/SG |
| 639.6 | Minimum SG-2 Inventory is Reached | 490.7 lbm |
| 639.6 | Minimum SG-1 Inventory is Reached | 490.2 lbm |
| 1171.13 | RCS Peak Pressure Occurs (second peak) | 2365.3 psia |
| 3013.85 | Maximum RCS Inlet Temperature Occurs | 582.9°F |