1.2 Important Small-Break Loss-of-Coolant Accident Phenomena

The small-break LOCA (SBLOCA) transient can be subdivided into four different periods that characterize thermal-hydraulic phenomena. Those periods include the following:

- Blowdown - The initial depressurization from the plant operating pressure to the steam generator secondary-side pressure, after which the pressure stabilizes.
- Natural Circulation - The time period from the stabilization of the primary pressure with the secondary-side pressure until ADS-1 is activated. The primary reactor system is cooled by different modes of natural circulation; that is, single-phase natural circulation, two-phase natural circulation, and reflux condensation. Each cooling mode is dependent on the system mass inventory. As the mass is lost from the break, the cooling proceeds from single-phase, to two-phase, to reflux condensation cooling.
- ADS Stages 1, 2, and 3 Blowdown - Once the CMTs drain to their setpoint, the ADS stage 1 valve opens and the reactor system is depressurized through the ADS flow path in addition to the break. As the CMT continues to drain into the reactor vessel, additional valves are opened on the pressurizer to enhance the blowdown of the system.
- IRWST Injection - Stable injection from the IRWST indicates the complete depressurization of the primary system down to containment pressure. Also, injection from the IRWST indicates the end of the small-break transient and the beginning of the long-term cooling transient.

Using these different time periods, the important thermal-hydraulic phenomena have been identified and ranked in a Phenomena Identification and Ranking Table (PIRT), as given in Table 1-1. This PIRT table has been updated and made more complete as compared to that which was given in the *NOTRUMP Code Applicability Document.*[3] The individual phenomena were emphasized for the ADS system and other components have been added to the PIRT. The phenomena for each identified phase of the small-break transient relative to the AP600 small break performance is discussed in the following paragraphs.

For the blowdown phase, the reactor is assumed to be operating at normal full-power, steady-state conditions at the start of the blowdown. The break opens at time zero, and the pressurizer pressure begins to fall as mass is lost out the break. This depressurization is largely defined by critical flow through the break. With the break located at the bottom of the cold leg, a mixture flow exits the break for the majority of the transient, since the mixture level stays high in the reactor vessel. The pressurizer pressure falls below the safety signal setpoint, causing the reactor to trip. The safety systems actuation (S) signal follows and results in opening the CMT isolation valves. Once the residual fissions decrease, core power is defined by the decay heat model. The RCPs trip after a short delay. Pump performance both before and after the trip is modeled according to the pump characteristic for curves. After the pumps coast down, the primary reactor coolant system (RCS) is cooled by natural circulation, with energy removed from the primary system by the steam generators via their safety valves and the break. Stored energy from the thick and thin metal in the reactor vessel and pressurizer is transferred to the coolant. Note that all of these phenomena are essentially the same for AP600 as for conventional PWRs. The liquid in the upper plenum and upper head (depending on the temperature) will flash, and the upper head core start to drain.

Blowdown phase phenomena unique to the AP600 are those associated with the CMT delivery. Once the CMT isolation valves open on an S actuation signal, the CMT injects borated water due to gravity-driven recirculation into the RCS through the DVI lines. The CMT volume injected is replaced with hot liquid from the cold-leg, leaving the CMT which circulates through the cold-leg balance line (CLBL); this hot liquid collects at the top of the CMT. The downcomer fluid stays subcooled through the initial depressurization.

For the natural circulation phase of the transient, the primary system exists in a quasi-steady-state condition with the secondary side, with the decay energy being removed by the steam generator secondary side, as the primary system drains. The steam generator in AP600 plays a more limited role in the natural circulation cooling phase than for conventional plants because the generators drain relatively early in the transient. Since the PRHR is activated on an S signal during an SBLOCA, the IRWST becomes the primary heat sink for the RCS early in the transient; the PRHR will remove energy from the primary system, causing it to depressurize. The steam generator secondary side becomes a heat source once the PRHR reduces the primary pressure to that of the secondary side. The PRHR is ranked high in the PIRT since it becomes a significant heat removal path particularly after the primary pressure is less than the steam generator pressure. Therefore, any condensation in the steam generator tubes during AP600 small-break LOCA transients ceases early. The requirement for detailed models for condensation heat transfer in the steam generator tubes are not as significant for AP600 as for a conventional plant. The importance shifts to the PRHR performance and the IRWST heat sink behavior. The reverse heat transfer path due to the secondary heating of the RCS primary, continues until the generators drain. The CMT continues to deliver in the recirculation mode for a while, but eventually a vapor region forms at the top of the CMT volume and CMT draindown begins. As the CMT drains while injecting, its level falls to the ADS actuation setpoint, which initiates the third phase of the AP600 SBLOCA transient, the ADS blowdown phase. The downcomer and lower plenum are marked medium importance since they provide the driving head for natural circulation.

The ADS blowdown phase continues through ADS-1, ADS-2, ADS-3 and ADS-4 as the primary system completely depressurizes approximately the containment pressure. Table 1-1 relates AP600-specific components, events, and phenomena that occur during the automatic depressurization of the RCS to achieve water injection by gravity from the IRWST. Since ADS-1 creates an opening at the top of the pressurizer, the pressurizer two-phase fluid level increases markedly. Pressurizer tank level and surge line phenomena are significant factors in the depressurization behavior following ADS actuation. Flashing of fluid in the RCS occurs again due to the depressurization caused by the ADS.

Following actuation of ADS-1, ADS-2 and ADS-3 activate via timers. Accumulator injection begins once the pressure drops below 700 psia which reduces the flow delivered from the CMT, and CMT flow may even be stopped temporarily due to pressurization of the DVI line by the accumulator. The CMT drain rate, DVI line, and CLBL behaviors are significant because the ADS-4 actuation is based upon the CMT liquid level decreasing below a low-low setpoint value. Of somewhat less importance