14.3 REACTOR COOLANT SYSTEM PIPE RUPTURE (LOSS OF COOLANT ACCIDENT) 1

14.3.9 Containment and Recirculation Sump Analyses 1

Plant Configuration *2*

General Analyses Considerations *3*

14.3.9.1 Accidents Leading to Sump Recirculation 4

14.3.9.2 Accident Description – General System Performance 5

14.3.9.3 Containment Sump Inventory Analysis 9

14.3.9.3.1 Method of Analysis 9

14.3.9.3.1.1 Computer Code Utilized *9*

14.3.9.3.1.2 Assumptions *10*

14.3.9.3.1.3 Acceptance Criteria *12*

14.3.9.3.2 Results 13

14.3.9.3.3 Conclusions 15

14.3.9.4 Recirculation Sump Analyses 15

14.3.9.4.1 Debris Generation 16

14.3.9.4.1.1 Break Selection *16*

14.3.9.4.1.2 Debris Sources *19*

14.3.9.4.1.3 Results *20*

14.3.9.4.2 Debris Transport 20

14.3.9.4.2.1 Computer Code Utilized *21*

14.3.9.4.2.2 Method of Analysis *21*

Blowdown Transport *22*

Washdown Transport *23*

Pool Fill and Recirculation Transport *23*

14.3.9.4.2.3 Results *24*

14.3.9.4.3 Recirculation Sump Hydraulic Analysis 24

14.3.9.4.3.1 Computer Code Utilized *26*

14.3.9.4.3.2 Method of Analysis *26*
Design Input Parameters *26*
Forward Flow Cases *26*
Reverse Flow Case *27*
Vortex Evaluation *27*
14.3.9.4.3.3 Results *28*
Forward Flow Cases *28*
Reverse Flow Case *29*
Vortex Evaluation *29*
14.3.9.5 Recirculation Sump Strainer Head Loss 29
14.3.9.5.1 Recirculation Sump Strainer Debris Only Testing 29
14.3.9.5.2 Recirculation Sump Strainer Chemical Effects Testing 31
MFTL Testing *31*
Vuez Testing *32*
14.3.9.5.3 System Head Loss Determination 32
14.3.9.5.3.1 Method of Analysis *33*
14.3.9.5.3.2 System Head Loss Results *34*
14.3.9.6 Design Considerations for Upstream and Downstream Effects 36
14.3.9.6.1 Upstream Effects 36
14.3.9.6.2 Downstream Effects 38
14.3.9.6.2.1 Method of Analysis *38*
Ex-Vessel Recirculation Flow Path Blockage *39*
Ex-Vessel Recirculation Flow Path Wear *39*
In-Vessel Flow Path Blockage *39*
In-Vessel Fuel Rod Debris Deposition *39*
14.3.9.6.2.2 Assumptions *40*
14.3.9.6.2.3 Acceptance Criteria *40*
14.3.9.6.2.4 Results *41*
14.3.9.6.2.5 Conclusions *42*

14.3.9.7 References for Sections 14.3.9 42

14.3 REACTOR COOLANT SYSTEM PIPE RUPTURE (LOSS OF COOLANT ACCIDENT)

14.3.9 Containment and Recirculation Sump Analyses

Section 14.3.9 provides a description of the containment configuration, equipment design, and integrated analyses which were performed to demonstrate that the long-term core and containment cooling design functions specified in Section 6.2 and 6.3 are maintained following postulated accidents leading to sump recirculation. Long-term functionality during these scenarios depends on containment configuration and equipment that supports the transport of blowdown mass and ice melt to the recirculation sump (Upstream Effects), acceptable performance of the recirculation sump in the presence of debris-laden water including chemical effects (Strainer Head Loss), and operability of the ECCS and CTS while drawing filtered water from the recirculation sump (Downstream Effects). To address these issues, the containment and recirculation sump analyses include consideration of post-accident mass and energy release inside containment, fluid transport of blowdown and ice melt mass within the upper and lower containment and their subcompartments, debris generation, debris transport within the loop and annulus subcompartments of lower containment, and the performance of systems designed to support core and containment cooling functions by preventing/minimizing potential component blockage or wear due to operation with debris-laden fluid. Assessments of plant-specific containment debris sources and containment design features and their impacts on ECCS and containment spray performance conform to the requirements of Generic Letter 2004-02 (Reference 7).

To facilitate an understanding of the analyses scope and accident progression, a description of the plant layout and equipment involved in the containment and recirculation sump modeling is included below.

Plant Configuration

The Cook Nuclear Plant ice condenser containment consists of four uniquely defined and separated volumes:

1. upper containment,
2. ice condenser,
3. reactor cavity, and
4. lower containment.

The upper containment area, which does not contain any high energy piping, is physically separated from lower containment and the reactor cavity by the divider barrier and the ice condenser. The ice condenser forms an approximate 300 degree arc around containment between the containment wall and the crane wall. The ice condenser has 24 paired lower inlet doors in the loop compartment which open following a pipe break, allowing suppression of the initial pressure surge in containment. The intermediate deck doors are located just above the ice bed and at the top of the ice condenser section are the top deck doors which allow steam and non-condensable gases to vent to upper containment. The reactor cavity is the volume surrounding the reactor vessel. The physical communication path between the reactor cavity and the lower containment is through openings in the primary shield wall and above the flood-up overflow wall.

The lower containment consists of two subcompartments, the area inside the crane wall (loop compartment) and the area outside the crane wall (annulus). Post-accident blowdown and ice melt inventory initially accumulates in the loop compartment. The water inventory in the lower containment is referred to as the containment sump. The recirculation sump, on the other hand, refers to the enclosed area that accumulates water for direct suction by the RHR and containment spray pumps. The recirculation sump is made up of:

1. a main strainer module fit into the face of an enclosed compartment in front of the crane wall that deposits water into a sump that extends below the 598' 9 3/8" containment floor, under the crane wall extension, and to the RHR and containment spray pump suction lines, and
2. a remote strainer module located in the annulus that empties into a waterway that directs filtered water through a penetration in the crane wall into the front section of the recirculation sump (See Figure 14.3.9-13).

The main strainer has an effective surface area of 900 ft^2 and the remote strainer has an effective area of 1,072 ft^2. The recirculation sump strainers are designed to:

1. provide adequate filtration of expected debris generated by postulated accidents, thereby preventing adverse effects on systems and equipment from water drawn from the recirculation sump by RHR or CTS pumps, and
2. ensure minimal head loss so the necessary water level inside the recirculation sump is maintained.

General Analyses Considerations

The containment sump analysis, described in Section 14.3.9.3, verifies the minimum sump water level for a spectrum of LBLOCA, SBLOCA and MSLB pipe breaks to ensure that calculated water levels support the possible transition to the recirculation mode of operation. The amount of water required in the containment sump for the various pipe break scenarios is based on satisfying NPSH requirements for RHR and containment spray pumps, and to prohibit excessive air entrainment and the formation of a vortex when transferring to the recirculation mode of operation. The acceptability of the minimum containment sump water level design requirements was demonstrated through empirical testing.

The containment sump inventory analysis does not specifically consider the effects of debris in the water during the injection phase. Rather, it implicitly relies on physical plant equipment in containment to allow free water flow between the loop compartment and annulus, and to the main and remote strainers. The recirculation sump inventory analyses, described in Section 14.3.9.4, does not consider plant specific debris effects, which include the resulting differences in water level between the containment and recirculation sumps as debris is deposited on the main and remote strainers.

The general approach for recirculation sump performance, described in Section 14.3.9.4, begins with an analysis of the containment sump's dynamic inventory as a result of ice melt, mass blowdown and movement of water inside lower containment before sump recirculation begins.

Results from the containment sump inventory analysis are used as an input for recirculation sump analyses. The recirculation sump analysis assumes bounding flow rates through the ECCS and CTS to maximize the transport of debris to the strainers and corresponding head loss across the strainers. Physical plant changes installed to address sump debris issues ensured that component design functions would continue to be met despite the presence of debris-laden water and do not impact the conclusion from the containment sump inventory analysis. The recirculation sump analyses were generally performed in accordance with the guidance provided in NEI-04-07 (Reference 9).

Successful outcomes of recirculation sump performance occur when the containment sump inventory and the recirculation sump inventory analyses meet designated acceptance criteria.

The sections which follow:

1. identify the set of postulated high energy line breaks at Cook Nuclear Plant which can lead to the recirculation mode of post-accident operation,
2. provide accident progression from a sump inventory perspective for each identified accident,
3. describe methods of analyses for component performance affecting recirculation sump operation,
4. present analysis results for containment sump inventory,
5. describe the results of recirculation sump strainer debris loading analyses and testing including consideration of chemical effects, and
6. present analyses results and conclusions for recirculation sump performance.

14.3.9.1 Accidents Leading to Sump Recirculation

Specific accidents evaluated for sump recirculation in Section 14.3.9 are identified in Sections 14.3.9.3 and 14.3.9.4. The first set of accidents in Section 14.3.9.3 represents the broadest range of events that can lead to the entry conditions for sump recirculation, regardless of the need for sump recirculation for accident mitigation. This analysis determines the availability of a minimum containment sump inventory for each potential accident at the transition point when the shift from injection to recirculation cooling is to commence and during long-term sump recirculation. The second set of analyses in Section 14.3.9.4 constitutes that subset of the first set where worst case debris generation and transport is expected to occur and the need for long-term recirculation for accident mitigation is required. Since each set of analyses in Sections 14.3.9.3 and 14.3.9.4 represents a distinct group possible accident scenarios, the selected bounding accidents in each group are different. Taken together, however, successful outcomes in Sections 14.3.9.3 and 14.3.9.4 indicate that long-term core and containment recirculation cooling functions will be satisfied.

14.3.9.2 Accident Description – General System Performance

The D. C. Cook plant design includes passive and active design features to provide core cooling and containment pressure suppression in the event of a Loss of Coolant Accident (LOCA) or Main Steam Line Break (MSLB) inside containment. The passive features include the ice condenser inside containment which provides containment pressure suppression and mass for containment sump inventory, and safety injection (SI) system accumulators which automatically discharge into the RCS when the RCS pressure drops below the accumulator pressure. The active features include the ECCS trains for coolant injection and the containment spray system. Refer to Sections 14.3.9.3 and 14.3.9.4 for further discussion of the postulated accidents for which these systems are required to respond.

The physical arrangement of the containment structures and equipment is such that steam discharged from postulated pipe breaks in lower containment will be forced through the ice condenser to reach the upper containment. Pipe breaks postulated to occur in the annulus will also exhibit this behavior. However, the arrangement of the containment will not allow the steam discharge from such a break to directly enter the ice condenser. The steam will flow through openings in the crane wall into the loop compartment and then into the ice condenser.

After a postulated pipe break, the containment pressure will increase (at a rate dependent on the break size) as the steam discharges into containment. At very low containment pressures, the ice condenser lower inlet doors will open sufficiently for steam to enter the ice condenser. The steam entering the ice condenser will be condensed and the condensate and melted ice will drain into the loop compartment and, consequently, the containment and the recirculation sumps.

When a low pressurizer pressure or high containment pressure signal is received, the safeguards systems will initiate an SI signal. The SI signal will initiate several automatic actions, including: reactor trip, emergency diesel generator (EDG) start, opening the boron injection tank (BIT) isolation valves and charging pump suction valves from the RWST, and starting the centrifugal charging (CC) pumps, SI pumps, and residual heat removal (RHR) pumps. The high containment pressure input to the SI signal will also start the containment air recirculation (CEQ) fans. The effect of these actions will produce the following plant conditions:

- The CC pumps will be operating, delivering borated water from the RWST to the four RCS cold legs. The CC pumps are low flow, high pressure pumps and will provide injection for any postulated break size including very small break LOCAs. At a pre-determined RCS pressure, with an SI signal present, the minimum flow valves will open, returning pump discharge flow to the pump suction to prevent deadheading the pump. If the RCS pressure drops below the reset setpoint, the minimum flow valves will close.

- The SI pumps will be operating, attempting to deliver borated water from the RWST to the four RCS cold legs. The SI injection into the cold legs will be through the accumulator injection lines. This piping is separate from the CC injection location. The SI pumps are low flow, moderately high pressure pumps that will provide injection at pressures typical of certain small break LOCAs. During the injection phase, the minimum flow valves will be open, returning a portion of the discharge flow to the RWST through a pressure reducing orifice.
- The RHR pumps will be operating, attempting to deliver borated water from the RWST to the four RCS cold legs. The RHR pumps also inject through the accumulator discharge lines. The RHR pumps are high flow, low pressure pumps that will provide injection at pressures typical of large break LOCAs. At a pre-determined minimum flow rate, minimum flow line isolation valves will open, returning pump discharge flow to the pump suction to prevent deadheading. In addition, the RHR system has the capability to be re-aligned to discharge a portion of the RHR flow through separate containment spray ring headers in a containment spray mode of operation.
- The CEQ fans will begin operating after a delay of approximately five minutes (U1) and two minutes (U2) following a high containment pressure signal. The CEQ fans provide forced air circulation between the lower and upper containment through the ice condenser.

There are two redundant trains of Emergency Core Cooling System (ECCS) which include two CC pumps, two SI pumps, and two RHR pumps. Assuming no equipment failures, all six pumps will be operating. The EDGs will start and automatically load in the event that the LOCA is coincident with a loss of off-site power (LOOP). The system alignment described above is considered the injection phase of the accident.

Following receipt of a hi-hi containment pressure signal, the containment spray system (CTS) will actuate. The injection phase alignment of the CTS system draws suction from the RWST and discharges through upper and lower containment spray ring headers. The CTS flow in the upper containment drains to the refueling canal and to the CEQ Fan rooms. Water entering the refueling canal is returned to the loop compartment through two 12 inch and one 10 inch drain pipes at the bottom of the canal. For Unit 1, the water collected in the CEQ Fan Room Stairwell and Ventwell drains to the pipe tunnel sump in the annulus. In Unit 2, the CEQ Fan Room Stairwell and Ventwell lines drain to the lower containment sump in the loop compartment. The check valve internals were removed from the check valves for the Stairwell and Ventwell drains for both units to address the single failure and flooding concerns. Holes in the flood-up overflow wall allow water to flow freely between the annulus and loop compartment. (Reference 6)

The SI accumulators are vessels filled with borated water and pressurized with nitrogen gas. While the majority of the equipment associated with the injection mode is initiated by a safety injection signal, the accumulators require no power source or initiation signal. When the RCS pressure falls below the minimum value required by Technical Specifications, mechanically operated check valves normally isolating the accumulators from the RCS will open, injecting borated water into the four RCS cold legs. There are four accumulators, with one accumulator supplying each cold leg.

The main objectives of the injection phase are to provide immediate core cooling, replenish lost primary coolant, and suppress containment pressure. At the end of the injection phase, the usable contents of the RWST will have been transferred to the containment sump and RCS, and depending on the break size and RCS response, the SI accumulators may have also been discharged.

When the RWST low level alarm is received following the postulated LOCA, the switchover to recirculation mode can begin once sufficient water level is verified to be present in the containment sump. Successful completion of this objective assumes that the water sources supplied to the RCS and containment return to the containment sump. The validity of this assumption is addressed in Section 14.3.9.6.1, Upstream Effects. Operators will initiate the recirculation mode by securing the suctions of the RHR and CTS pumps, one train at a time. The CC and SI pumps will continue to inject into the RCS from the RWST until the low-low level alarm is reached. During this time period, the suction of each RHR and CTS pump will be aligned to the recirculation sump inside containment, one train at a time. This pump alignment will allow the spilled coolant, injected water, and melted ice that have collected in the containment and recirculation sumps during the injection phase to be recirculated through the RCS and containment atmosphere and back to the containment sump. In the recirculation mode, the CC and SI pumps will take suction from the RHR pump discharge. One CC pump and one SI pump will take suction from each RHR pump discharge. The switchover to recirculation mode will be complete when the suctions of all the operating CC and SI pumps are being supplied by RHR flow from the recirculation sump.

There are several other plant systems that will operate along with the ECCS and CTS to accomplish system functional objectives while in the recirculation mode. The RHR pump discharge will be routed through the RHR heat exchangers prior to injection back into the RCS. The RHR heat exchangers are cooled by the Component Cooling Water (CCW) system. The RHR heat exchangers are located between the RHR pumps and the CC and SI pump suction points, so the CC and SI pump injection water will also be cooled. The CTS pump discharge will be routed through the containment spray heat exchangers prior to discharge back into containment. The containment spray heat exchangers are cooled by the Essential Service Water (ESW) system. Thus, the containment is cooled by these two sets of heat exchangers.

The main objectives of the recirculation mode are to keep the core flooded, suppress containment pressure, and provide long-term core and containment cooling. Successful execution of these objectives assumes an ability of the ECCS and CTS to function while drawing filtered water from the recirculation sump. The validity of this assumption is described in Section 14.3.9.6.2, Downstream Effects. As the RCS and containment cool and de-pressurize, the operators will manually stop (or start) ECCS and CTS components as necessary to maintain the RCS/containment in the desired condition.

During a main steam line break event, a low pressurizer pressure, low steam line pressure, or high steam line differential pressure signal will initiate an SI signal. The sequence of events described above for a LOCA would be similar for a MSLB inside containment, except that transfer to the recirculation mode is not expected to occur. Refer to Section 14.3.9.4.1.1 for additional information. Additionally, main steam line isolation would occur and limit the secondary-side inventory discharged to containment. The ECCS pumps would start as described, but would only be providing makeup flow to the RCS system, since there would be no loss of reactor coolant.

Given successful Upstream Effects, which ensure that blowdown and injected RWST water reach the front of the recirculation sump, and Downstream Effects, which demonstrate tolerance for the quality of filtered water in the recirculation sump, satisfactory core and containment long-term cooling will depend on adequate containment and recirculation sump inventory at the time of recirculation switchover and thereafter. Further, there are unique features of the Cook Nuclear Plant ice condenser containment design that lead to directions of conservatism for accident parameters that are different than for peak containment pressure and peak clad temperature analyses. For these reasons, it is important to perform stand-alone analyses of sump inventory using worst-case assumptions for the range of scenarios in which recirculation cooling may be required.

14.3.9.3 Containment Sump Inventory Analysis

14.3.9.3.1 Method of Analysis

14.3.9.3.1.1 Computer Code Utilized

The containment sump inventory analysis (Reference 1) was performed using the MAAP4 code version 4.0.4.1 (FAI, 1999). (Note: the last digit in the code designation indicates an enhancement to the official internationally distributed version of 4.0.4. Version 4.0.4.1 was created to support this analysis and allows separate temperatures to be supplied on the cooling side of the containment spray heat exchangers and the RHR heat exchangers.) The MAAP4 code calculates the behavior of and interactions between the ECCS, RCS and containment following a postulated accident. It does not calculate debris-related effects on plant equipment or recirculation sump performance. These effects are addressed in Section 14.3.9.4. Consequently, the predicted containment sump inventory reflects time-dependent mass and energy inputs from ECCS/containment spray injection and recirculation, ice melt, RCS holdup, accumulator injection, and water flow between containment compartments.

The Cook Nuclear Plant reactor coolant system is represented as a typical Westinghouse 4-loop design available in MAAP4. Two RCS loops are included in the standard MAAP4 model, with one loop including a single steam generator and associated piping, and the other loop including the composite behavior of the remaining three steam generators and associated piping. The spectrum of RCS break sizes evaluated include a Double-Ended Cold Leg (DECL) and a variety of smaller breaks, including breaks on the reactor vessel itself. The MAAP4 primary system break flow model determines mass and energy releases for steam and water flows leaving the reactor coolant system by assuming they are in thermodynamic equilibrium. This characterization of the break flows maximizes water enthalpy, and minimizes steam release to containment atmosphere that is available to melt ice. For main steam line break cases, the MAAP4 break flow model assumes that saturated steam was released into the lower containment.

The physical arrangement of the D.C. Cook containment is modeled in MAAP4 by 14 nodes with 44 flow junctions coupling the various nodes. Typically, a simple free volume versus height table is used to represent each node, although a detailed volume versus height table is used for the reactor cavity. The flow junctions account for both forced and natural convection flows. Two junctions are included to represent holes in the primary shield wall between the loop compartment and the reactor cavity that accommodate Nuclear Instrumentation System (NIS) reach rods. Tables 14.3.9-1 and 14.3.9-2 list the 14 containment nodes and the 44 flow junctions, respectively, included in the Cook Nuclear Plant containment model. In addition to the physical arrangement of the Cook Nuclear Plant containment, the ice condenser lower inlet doors were determined to have a major effect on the containment response. The lower inlet doors control the flow of steam entering the ice condenser, and consequently the amounts of condensate and melted ice flowing back to the loop compartment. MAAP4 models the lower inlet door response (degree of opening) as a function of the imposed flow rate consistently with the lower inlet door characteristic shown in Figure 14.3.4-93. The MAAP4 ice melt model was extensively benchmarked against data from Westinghouse Waltz Mill tests (Reference 2) and Pacific Northwest Laboratories tests (Reference 3).

14.3.9.3.1.2 Assumptions

The objective of the MAAP4 analyses of containment sump inventory was to determine if there was a sufficient amount of water in the containment sump to support recirculation without considering the effects of debris-laden fluid and recirculation sump strainer blockage.

The directions of conservatism for key parameters in the containment sump inventory analysis were evaluated and validated by a formal Failure Modes and Effects Analysis that was performed to identify the key parameters and appropriate directions of conservatism. These key parameter values were determined to either minimize the amount of water available to collect in the containment sump or to affect the rate that water accumulated in the containment sump. For example, an assumption that increases the rate of RCS cooldown would increase the amount of water held-up in the RCS and would affect both the rate that water accumulates in containment and the total amount of water available to containment. An assumption that increases heat removal from the lower containment atmosphere would reduce the amount of energy reaching the ice condenser; this would reduce the rate of ice melting and, consequently, the rate that water from ice melt accumulates in the containment. The following major input assumptions are used in the MAAP4 analysis for containment sump inventory.

1. Two sets of initial conditions are analyzed:

    a. Mode 1: The plant is initially operating at a core power level of 3250 MWt plus reactor coolant pump heat, which remains conservative and bounding for the Measurement Uncertainty Recapture (MUR) power uprate. Effective break size diameters ranging from a full Double-Ended Cold Leg Guillotine (DECLG) to 0.5 inches were assumed. Both the loop compartment and the reactor cavity were considered as potential break locations.

b. Mode 3: The plant is at the lower temperature bound of Mode 3 (350°F & 1000 psig). A maximum effective break size diameter of 6 inches was assumed. Both the loop compartment and the reactor cavity were considered as potential break locations.

2. A best-estimate core residual heat generation based upon the ANS 1979 decay heat model without uncertainty was assumed.

3. Maximum safeguards are employed for ECCS/CTS pumps, e.g., two CTS pumps and two containment spray heat exchangers; two residual heat removal pumps and two residual heat removal heat exchangers; two safety injection pumps; and two centrifugal charging pumps.

4. Minimum containment air recirculation, i.e., one of two CEQ fans operating at conservatively low flow (consistent with the peak containment pressure analysis). Note that the FMEA determined that the most limiting single failure was a failure of one CEQ fan.

5. A conservatively low value for ice mass is assumed in the ice condenser at accident initiation. The ice temperature is also set to a conservatively low value. This temperature maximizes heat absorption by the ice before melting, which tends to decrease ice mass melt rate.

6. ESW cooling water supplied to the CTS heat exchangers at minimum temperature and conservatively high flow rate.

7. CCW cooling water supplied to the RHR heat exchangers at minimum temperature and conservatively high flow rate.

8. Maximum RHR and CTS heat exchanger performance (i.e., UA).

9. Uncertainties are applied to the high containment pressure ESF signals' setpoints to cause CTS actuation at the lowest containment pressure possible (i.e., cause CTS to initiate as early as possible). The uncertainties are applied consistently so the CEQ fan also starts at the lowest containment pressure possible.

10. Maximum ice condenser bypass flow area as documented in Reference 1.

11. Minimum delivered RWST inventory at the minimum water temperature allowed by Technical Specifications.
12. Minimum accumulator inventory allowed by Technical Specifications at the minimum pressure allowed by Technical Specifications and at the minimum containment temperature allowed by Technical Specifications.
13. Maximum allowable ECCS leakage outside containment following switchover to recirculation.
14. Maximum initial containment pressure allowed by Technical Specifications.
15. Minimum initial containment gas temperatures allowed by Technical Specifications.
16. Maximum RCS cooldown rate allowed by the Emergency Operating Procedures.

14.3.9.3.1.3 Acceptance Criteria

The purpose of the analysis is to demonstrate that there is sufficient water inventory available to the containment sump to preclude vortex formation in the recirculation sump. High levels of air ingested into the suction of the ECCS/CTS pumps can potentially result in damage to those pumps. Thus, air ingression is typically limited to values between 2% and 5% by equipment manufacturers. If vortex formation is precluded in the water pool used as the suction source to the pumps, then air is prevented from entering the pumps.

As demonstrated in Reference 1, the minimum containment sump water level required to preclude pump vortexing is not the same fixed elevation value for all conditions. The minimum containment sump water level to preclude vortexing is a function of the total amount of water being drawn from the recirculation sump once the plant initiates recirculation. The recirculation sump flow demand is determined by the number of CTS pumps operating and the combination of the number of ECCS pumps operating, RCS pressure, and head loss across the recirculation sump strainers. As will be seen, small break LOCA events typically do not depressurize similarly to a large break LOCA event. Even though all six ECCS pumps may be in operation for some smaller breaks, only the CC pumps and potentially the SI pumps are actually providing positive flow to the RCS. As long as RCS pressure remains above the shutoff head of the RHR pumps, the RHR pumps will not be drawing additional water from the recirculation sump inventory.

For this analysis the criterion for acceptable containment sump water level performance was established as follows. A minimum containment recirculation sump level greater than or equal to 602'-10" was required for Mode 1 events. This containment sump water level elevation was determined to preclude vortex formation in the ECCS pump suction flow for all ECCS/CTS flow demand by scale recirculation sump testing. As noted above and as documented in Reference 1, this criterion includes margin for smaller break sizes in Mode 1 as the typical recirculation sump flow demand decreases with decreasing break size. This margin was not explicitly credited in the assessment of the acceptability of the recirculation sump in Mode 1.

Certain Mode 3 LOCA events were determined to achieve minimum containment sump levels slightly less than 602'-10" for short periods of time following switchover to recirculation. This is due to the lower mass and energy release from the RCS experienced during a Mode 3 LOCA and the resultant decrease in ice condenser ice melt rate. However, overall ECCS and CTS flow required for mitigation of a Mode 3 LOCA is less than the maximum flow used in the original containment sump demonstration tests. As shown in Reference 1, the analysis demonstrates that minimum containment sump levels below 602'-10" are acceptable to prevent vortexing in the recirculation sump, at flows less than the maximum flows used in the original containment sump demonstration tests. For Mode 3 LOCA events, the analysis demonstrated that minimum containment sump levels less than 602'-10" was still sufficient to prevent vortexing at the reduced ECCS and CTS flow rates expected.

14.3.9.3.2 Results

The results of three transients are presented. Time profiles of ice bed mass, reactor cavity water level, containment sump water level, and RCS pressure are presented for each case. Figures 14.3.9-1 through 14.3.9-4 show the relevant parameters following a DECLG LOCA in Mode 1. Figures 14.3.9-5 through 14.3.9-8 show the same parameters for the limiting water level case in Mode 1 (a 1 inch break on the cold leg nozzle that partially feeds the reactor cavity). Figures 14.3.9-9 through 14.3.9-12 show parameters for the limiting water level case in Mode 3 (a 6 inch break on the cold leg nozzle that partially feeds the reactor).

The most limiting case for the minimum containment sump level during recirculation is that break size in which the containment sprays are initiated but there is minimal ice melting when the sprays are operating. These are situations in which the steam partial pressure in the loop compartment is minimized (small break LOCA) and the potential for condensation is maximized (the coldest spray temperature).

For the DECL break case, the initial discharge of steam and energy is sufficient to melt enough of the ice bed such that the minimum containment water level at any given time is at least several feet above the applicable vortex limit for Mode 1 at all times (Figures 14.3.9-1 through 4). Thus, the large DECL break does not result in conditions that challenge the Mode 1 acceptance criterion.

For the spectrum of LOCA conditions evaluated in the loop compartment for Mode 1, a break with an effective diameter of 1" represents the minimum condition where sprays would be initiated and the steam partial pressure in the loop compartment would be the lowest. This condition represents the most limiting case for a break directly into the loop compartment. The minimum level in the containment sump for this most limiting transient is 9 inches above the appropriate limit for vortexing of 602'10".

For postulated breaks in the cold leg inside the primary shield wall (referred to as reactor cavity breaks), the water discharge from the break is represented as having a 50/50 split between the reactor cavity and the loop compartment based on jet impingement analyses of the two-phase discharge. For these types of breaks, the most limiting case of a 1 inch effective break diameter results in a minimum level in the containment sump of 603'1-1/2" which is 3-1/2 inches above the Mode 1 acceptance criterion of 602'10" (Figures 14.3.9.5 through 8).

Possible break locations were also considered for the RPV lower and upper heads. The maximum break size in the lower head is a rupture (severing) of an in-core instrument penetration tube which provides a break diameter of 0.61 inches with a discharge coefficient of less than 0.6. This is not sufficient to actuate the containment sprays. Thus, the containment sump water level is well above the 602'10" at the time of recirculation which is in excess of 36 hours. A review of possible upper head breaks concludes that two size ruptures should be considered: a failure of a CRDM and the severing of the 0.6 inch diameter reactor head vent. The former initiates the containment sprays and has a minimum level above that of the 1" break in the reactor cavity. The latter case, like the instrument line break, does not result in the sprays being actuated. Therefore, the Mode 1 LOCA cases assuming breaks on the reactor pressure vessel into the reactor cavity result in containment sump water levels during recirculation which are greater than the appropriate design basis limit for vortexing.

Several Mode 3 cases were examined ranging from a 6 inch break to a 2 inch break. The 6 inch break into the loop compartment results in a water level above the acceptance criterion (Figures 14.3.9-9 through 12). The 2 inch break does not actuate the sprays, and the containment sump water level is always above the vortex criterion. This break size spectrum was examined for breaks into the loop compartment as well as the reactor cavity (split flow conditions). While some of these resulted in minimum levels below the Mode 1 acceptance criterion, given the consideration that the reduced sump demand flows for these LOCAs which are smaller than the design basis DECL, there is a sufficient water level to prevent vortexing based on the Cook Nuclear Plant specific sump tests (Reference 1).

The assessment of main steam line breaks into the containment for two different size breaks results in a water level in the containment sump that is above the Mode 1 acceptance criterion to preclude vortex formation. Furthermore, since there is no break in the RCS, there is no long term need for the containment sprays and the injection to the RCS is only that needed to maintain the pressurizer level as the RCS cools down. In addition, the contents of the faulted steam generator are added to the containment sump increasing the amount of water available. Hence, the minimum containment sump water level in these sequences is always above the appropriate criterion for vortexing.

14.3.9.3.3 Conclusions

The analysis demonstrates that RWST delivered inventory, ice melt, and RCS and safety injection accumulator water inventory released to containment, are sufficient to ensure that the minimum containment sump level is sufficient to preclude vortex formation in the suction flow to the RHR/CTS pumps. The containment sump inventory analysis includes consideration of limiting single failures of ECCS and CTS components, determination of the limiting break size and locations, and envelope the range of potential plant operation.

14.3.9.4 Recirculation Sump Analyses

The recirculation sump analyses were performed in accordance with Generic Letter 2004-02 requirements (Reference 7). The recirculation sump analyses include

1. design modifications to significantly reduce the potential effects of post-accident debris and latent material on the functions of the ECCS and CTS during sump recirculation,
2. testing and/or analysis to determine break locations, identity and quantity of debris sources, determination of debris transport fractions, determination of upstream and downstream effects, and confirmation of the recirculation function,
3. implementation of Technical Specifications to reflect the plant modifications and the change to a mechanistic recirculation sump strainer blockage evaluation,

4. use of an Alternate Evaluation methodology that includes operator actions to reduce recirculation flow if the containment recirculation sump water level instruments indicate an increased head loss across the recirculation sump strainers that threatens vortex limits for RHR and CTS pumps,
5. changes to programs, processes, and procedures to limit the introduction of materials into containment that could adversely impact the recirculation function,
6. monitoring programs to ensure containment conditions continue to support the recirculation function, and
7. application of conservative measures to assure adequate margins in actions taken to address Generic Letter 2004-02.

The analytical and testing aspects of the response to Generic Letter 2004-02 requirements are provided below.

14.3.9.4.1 Debris Generation

14.3.9.4.1.1 Break Selection

Break selection for recirculation sump inventory analyses was based on determining the size and location of High Energy Line Breaks (HELBs) which produce debris and potentially present the greatest challenge to recirculation sump performance. Only those breaks requiring recirculation for Cook Nuclear Plant accident mitigation were to be considered, in accordance with References 9 and 12. These potentially include LBLOCA's, certain SBLOCA's, and MSLB's.

Resolution of Large Break Loss of Coolant Accidents (LBLOCAs) in Generic Letter 2004-02 for recirculation sump inventory analyses can be addressed through either a classical evaluation of the largest RCS Double Ended Guillotine Break (DEGB), i.e., those with a total cross sectional break area $\geq$1.0 ft^2, and its effects or by use of an Alternate Evaluation approach defined in Section 6 of References 9 and 12. Cook Nuclear Plant has selected the Alternate Evaluation approach. This approach requires evaluation of two distinct pipe break scenarios for the large break LOCA, each with their own set of allowed assumptions and methodologies. The first scenario requires a 10 CFR 50.46 design basis, long-term cooling evaluation of all LOCA break sizes up to a defined Debris Generation Break Size (DGBS) that is smaller than a Double Ended Guillotine Break (DEGB) of the largest RCS pipe. This regime of break sizes is referred to as Region I and is defined as either a complete guillotine break of the largest diameter pipe connected to the main RCS coolant loop piping or an area equivalent to a guillotine break of a 14 inch schedule 160 line, which equates to an effective break area of 196.6 square inches assuming both sides of the break are pressurized. The second scenario (Region II breaks) requires that long-term cooling requirements be demonstrated for break sizes above the DGBS and up to the DEGB of the largest RCS pipe. Due to the reduced likelihood of occurrence; however, References 9 and 12 provide guidance that can be used to justify more realistic evaluation techniques and inputs for the DEGB, and they allow the use of operator actions to mitigate the consequences of sump blockage, when specified justification can be provided.

A rupture of the RCS pressure boundary less than 1.0 ft^2 total cross sectional area is classified as a SBLOCA. The minimum size break required to be analyzed for debris generation and transport is 2 inches per Section 3.3.4.1 of Reference 9. The evaluation determined that there are no SBLOCA's outside the crane wall that result in sump recirculation. Further, from a debris generation and transport standpoint, SBLOCAs are bounded by the results of LBLOCAs. As a result, SBLOCA's were not analyzed for recirculation sump inventory.

While LOCAs are considered the most likely type of debris generating HELBs that could lead to sump recirculation, other break scenarios were examined to determine if they resulted in debris generation and the need for ECCS recirculation as a means of long-term cooling. WCAP-15302 (Reference 10) defines the MSLB as a short-term event compared to a LOCA event and states that containment recirculation is not assumed to occur within the duration for which the transient is analyzed. An evaluation was performed to determine if a MSLB needed to be evaluated per the GL 2004-02 requirements. This evaluation determined that the licensing basis analysis for the MSLB mass and energy releases into containment does not include the availability of long-term recirculation water for event mitigation. For Cook Nuclear Plant, the MSLB bounds the feedwater line break for mass and energy release within containment. As a result, secondary system breaks were not analyzed for recirculation sump inventory.

Ultimately, the following general break locations were considered in the recirculation sump inventory analyses because they represented bounding variations in debris generation by size, quantity, and type of debris:

1. Breaks in the RCS with the largest potential for debris
2. Large breaks with two or more different types of debris
3. Breaks in the most direct path to the recirculation sump
4. Large breaks with the largest potential particulate debris to insulation ratio by weight
5. Breaks that generate a "thin bed" – high particulate with 1/8" fiber bed

Several break locations within the RCS have the potential to generate the largest quantity of debris. These include a break in the crossover leg piping on each of the four loops, a reactor nozzle break in the reactor cavity, an alternate break in the pressurizer surge line, and an alternate break in each of the four RCS loops. The alternate breaks are those considered as DGBS breaks.

For each of the above break locations, the corresponding zone of influence (ZOI) was established to determine the amount of material destroyed by the break. The ZOI is defined as the spherical volume centered at the break location in which the jet pressure is greater than or equal to the destruction damage pressure of the insulation, coatings, and other materials impacted by the break jet. The radius of the sphere is determined by the pipe diameter and the destruction pressures of the potential target debris material. The break with the largest potential for debris generation is the Reactor Coolant System (RCS) crossover line.

The debris generated by the most limiting cases in Break No. 1 will bound Break No. 2 because each of the breaks for Break No. 1 create at least two different types of debris. Break No. 1 at the RCS Loop 2 crossover leg will provide the greatest potential for debris transport to the recirculation sump. Break No. 1 also envelopes Break No. 3 since the RCS Loop 2 piping has the most direct path to the recirculation sump. Break No. 4 is included to generate the largest insulation particulate debris combination of calcium silicate, Min-K and Marinite. Therefore, only Break types 1, 4 and 5 are applicable for debris generation analysis.

For the DGBS, the ZOI was established using a hemispherical volume oriented such that the maximum quantity of debris would be generated from the break. The use of the hemispherical volume was performed per Section 6.3.4 of References 9 and 12.

14.3.9.4.1.2 Debris Sources

In order to evaluate recirculation sump strainer blockage, debris sources inside containment with the potential to be transported to the recirculation sump strainers were identified. The following general debris sources exist in containment:

a. Insulation Debris

b. Coatings Debris

c. Latent Debris

d. Containment Materials

The insulation debris sources which were evaluated for recirculation sump blockage are reflective metallic insulation (RMI), fibrous insulation, calcium silicate (Cal-Sil), Marinite and Min-K. Table 14.3.9-3 contains the location and quantities of the bounding insulation debris sources assumed in the analyses. The quantity of insulation materials from Unit 2 were used since they bound the quantities in Unit 1.

Closed-cell foam insulation is installed on various service water piping lines inside lower containment. All closed-cell foam insulation installed in the loop compartment up to the 650 ft elevation has been installed with two layers of stainless steel jacketing. Testing was performed on this jacketing configuration and it was demonstrated that the closed-cell foam insulation remains encapsulated following the break. Therefore, closed-cell foam insulation is not considered a debris source for recirculation sump blockage.

There are two types of coatings in use at D.C. Cook, qualified and unqualified coatings. The qualified coatings are epoxy coating systems and the unqualified coatings consist of epoxy, alkyd and cold galvanizing coating systems. Qualified and unqualified coatings within a break ZOI are postulated to fail as a result of direct impingement. The break ZOI for qualified coatings is a distance of five pipe diameters from the break, or 5D, and the break ZOI for unqualified coatings is 10D. Qualified coatings outside of a break ZOI will remain intact whereas unqualified coatings outside of a break ZOI are postulated to fail as a result of the post-accident environmental conditions. The size distribution of the unqualified coating debris changes depending on whether the unqualified coating is within or outside of the break ZOI. Table 14.3.9-4 presents the coatings debris source for the DEGB within the ZOI and Table 14.3.9-5 presents the coatings debris source for the DGBS within the ZOI. Table 14.3.9-6 presents the unqualified coatings debris source outside of the ZOI, for either break size.

Latent debris is defined as dirt, dust, paint chips, fibers, pieces of paper, plastic, tape, adhesive labels or other materials that are present inside the containment building prior to a LOCA. Electromark labels are used inside the containment building. These labels represent latent debris if they are located in a break ZOI, applied to a painted surface, or if they are submerged. All unqualified labels are assumed to fail inside containment during a LOCA. Fire barrier tape is installed on conduits inside containment for the purpose of electrical separation. This fire barrier tape is classified as latent debris within a break ZOI. Outside a break ZOI, the fire barrier tape does not fail as it is secured at each end by stainless steel fasteners. Flexible conduit PVC jacketing located in the loop compartment is postulated to fail during a LOCA and therefore represents a latent debris source. Small amounts of foreign material are present in the ice condenser. This ice condenser foreign material constitutes a latent debris source. Table 14.3.9-7 documents the bounding quantity of latent debris evaluated inside the containment building by location. Tables 14.3.9-22 and 14.3.9-23 provide the bounding quantity of debris for sacrificial strainer area consideration for the main and remote strainers for the DEGB and DGBS.

Containment materials may also be considered a debris source if they produce a chemical precipitate when the material is either submerged or subjected to containment spray. Table 14.3.9-8 identifies the containment materials considered as chemical effects debris sources, the amount of the material, and whether the material is submerged or non-submerged.

14.3.9.4.1.3 Results

Two break locations have been identified as bounding for this analysis. These bounding breaks are a double ended guillotine break (DEGB) of the crossover leg in loop 4 and the alternate break in the loop 4 crossover leg which produces the maximum debris load for the debris generation break size (DGBS) break.

14.3.9.4.2 Debris Transport

Debris transport predicts the blowdown, washdown, pool fill, and recirculation transport of the debris that would be generated from a high energy line break requiring recirculation. The transport analysis includes computational fluid dynamics (CFD) modeling of the containment pool during both the pool fill and recirculation phases. Debris transport was determined for each type/size of debris at each of the break locations postulated in the Cook Nuclear Plant debris generation analysis. The debris generation analysis determined that 10 cases should be analyzed for debris transport. These cases are for a break in the crossover leg piping on each of the four loops, a reactor nozzle break in the reactor cavity, an alternate break in the pressurizer surge line and an alternate break in each of the four primary loops.

14.3.9.4.2.1 Computer Code Utilized

The Computation Fluid Dynamics (CFD) calculation for pool fill and recirculation flow in the Cook Nuclear Plant containment pool was performed using Flow-3D Version 9.0. Flow-3D is a general-purpose computer code for modeling the dynamic behavior of liquids and gases influenced by a wide variety of physical processes. The program is based on the fundamental laws of mass, momentum, and energy conservation for the treatment of time-dependent multi-dimensional problems.

A three-dimensional CAD model of the Cook Nuclear Plant containment building was constructed based on structural drawings of the containment building. The CAD model was built from a point below the floor of the containment building (elevation 598.78') to the top of the dog houses (elevation 695.00').

14.3.9.4.2.2 Method of Analysis

Debris transport is the estimation of the fraction of debris that is transported from the break location to the recirculation sump strainers. The four major debris transport modes are:

- *Blowdown transport* – the vertical and horizontal transport of debris to all areas of containment by the break jet.
- *Washdown transport* – the vertical (downward) transport of debris by the containment sprays and break flow.
- *Pool fill transport* – the transport of debris by break and containment spray flows from the refueling water storage tank (RWST) to regions that may be active or inactive during recirculation.
- *Recirculation transport* – the horizontal transport of debris from the active portions of the recirculation pool to the recirculation sump strainers by the flow through the emergency core cooling system (ECCS).

The methodology used in this analysis is based on NEI 04-07 (Reference 9). The specific effect of each mode of transport was analyzed for each type of debris generated, and a logic tree was developed to determine the total transport to the recirculation sump strainers.

The general methodology for the transport analysis includes:

1. Creation of a three-dimensional model of the containment building and determine transport flow paths.
2. Evaluation of the debris types, size distributions and transport fractions.
3. Inclusion of the ice melt and containment spray flows in the CFD calculation to model the effects on the containment pool. Bounding containment spray flow rates of 4,556 gpm for upper containment, 1,638 gpm for the loop compartment and 606 gpm for the annulus were used.
4. Development and use of transporting metrics to evaluate the potential for debris transport in the Cook Nuclear Plant containment pool. Metrics for predicting debris transport have been adopted or derived from data. The transport mechanisms involved are:
   a. Carrying of suspended debris by bulk flow to the sump
   b. Tumbling/sliding of sunken debris to the sump
   c. Lifting of sunken debris over a curb
5. Determination of the fraction of debris in the loop compartment that would be transported to the main strainer and annulus during pool fill-up.
6. Determination of the fraction of debris that would be transported to the main strainer and to the remote strainer during recirculation.
7. Determination of the overall transport fraction for each type of debris.

Blowdown Transport

The blowdown following a LOCA would impact the debris sources in the vicinity of the break location. Steam from the blowdown, carrying debris with it, would be relieved through openings in the crane wall to the annulus, through the ice condenser lower inlet doors, and through openings to the reactor cavity. Based on the Transient Mass Distribution (TMD) analysis (Section 14.3.4.2.7), seventy percent of the mass and energy release is directed to the ice condenser, twenty-two percent is directed to the annulus and the remaining eight percent is directed towards the reactor cavity. Fine debris is easily transported with the blowdown flow so the fraction of fine debris blown into the ice condenser, annulus and reactor cavity was assumed to be proportional to the TMD flow split.

Pieces of RMI, Cal-Sil, Marinite, Electromark labels and fire barrier tape would also be blown toward the same locations. For conservatism, it was assumed that neither small nor large pieces of debris would be blown into and remain within the ice condenser or the reactor cavity. Some of the small pieces could be blown over the top of the overflow wall and through the crane wall openings in the overflow wall to the annulus.

Washdown Transport

During the washdown phase, debris in upper containment, which includes failed unqualified coatings, is washed down to the loop compartment by the Containment Spray System via the refueling canal drains. Any debris resident in the ice condenser as a result of the blowdown will be washed down to the loop compartment by the ice melt via the ice condenser drains. Washdown may also occur from the CEQ fan rooms through the floor drain lines. Although the floor drain lines are protected from transporting large debris sources due to the installed debris interceptors, small debris sources will pass through the drain lines into lower containment. In Unit 1, the water from the CEQ fan room will drain to the pipe tunnel sump in the annulus. In Unit 2, the CEQ fan room will drain to the lower containment sump in the loop compartment.

Pool Fill and Recirculation Transport

During pool fill, the flow of water would transport insulation debris from the break location and other containment debris sources to all areas of the containment sump. As water enters the containment sump, it initially flows in shallow, high velocity sheets. As the water level rises, debris would be transported to the main strainer and the debris interceptor located in front of the holes in the flood-up overflow wall.

During pool fill, the temperature ranges from a maximum of 190 °F during blowdown to 160 °F at the beginning of recirculation. During the pool fill debris transport analysis, the flow through the main strainer was calculated to be approximately 7100 gpm. This flow rate was determined using a combined resistance factor for the strainer system. The pool fill and recirculation CFD analysis used a water temperature of 160 °F. In terms of debris transport, a large change in water temperature does not make a significant difference in the CFD calculation since it was determined that a hot pool develops approximately the same velocity and turbulence as a cooler pool. The total injection and recirculation flow rate for this analysis, using maximum ECCS and CTS pump flow is 15,500 gpm and 14,400 gpm, respectively.

The pool fill and recirculation debris transport fractions were determined using CFD modeling. The result of this modeling was a three-dimensional model showing the turbulence and fluid velocities within the pool. By comparing the direction of pool flow, the magnitude of the turbulence and velocity, the initial location of debris, and the specific debris transport metrics, the transport of each type/size of debris was determined.

14.3.9.4.2.3 Results

Blowdown following a LOCA in the loop compartment will carry a large fraction of fine debris into the ice condenser, as well as some debris to the annulus and to the reactor cavity. Due to the large ice melt and spray flows, the majority of transportable debris located in these flow paths will be washed to lower containment. During the pool fill phase of the accident, a large fraction of the debris will be transported to the main strainer. The transport analysis determined that most of the fine debris will be transported to either the main or the remote strainers. Small and large pieces of debris will not be transported to the remote strainer since there are no breaks located in the annulus and due to the location of the debris interceptors installed in the loop compartment. Following determination of the debris transport for each of the break locations associated with the RCS loop piping, an evaluation was performed to determine the bounding breaks for both the DEGB and DGBS. These break locations were determined to be the RCS Loop 4 crossover leg for the DEGB and the alternate break in RCS Loop 4 for the DGBS. Table 14.3.9-10 shows the debris transported to the main strainer at the end of the pool fill phase, overall transport to the main strainer, and overall transport to the remote strainer for the DEGB. Table 14.3.9-11 shows the debris transported to the main strainer at the end of the pool fill phase, overall transport to the main strainer, and overall transport to the remote strainer for the DGBS. The breaks in the reactor cavity and pressurizer surge line were determined to be bounded by the DEGB in the RCS piping and the DGBS break in the RCS piping, respectively.

14.3.9.4.3 Recirculation Sump Hydraulic Analysis

Postulated LOCAs for which sump recirculation is required are in the loop compartment or reactor cavity. For a LBLOCA, once water level in the loop compartment exceeds the height of the main strainer curb during the injection phase, debris-laden water would begin to flow through the main strainer into the recirculation sump. When level in the recirculation sump reaches slightly above floor level, strained water from the recirculation sump would begin to flow through the waterway toward the remote strainer. Initially, this would only fill the waterway until the water level reaches the height of the lowest set of strainer elements in the remote strainer. When the loop compartment water level exceeds this height, strained water would begin back-flowing out of the remote strainer into the annulus.

Additionally, when water level in the loop compartment exceeds approximately 5 inches, debris-laden water will begin flowing through the openings in the flood-up overflow wall, filling the space between the flood-up overflow wall and the curb at the crane wall opening. Once water level in this area exceeds approximately 12 inches, debris-laden water will begin flowing into the annulus through this flow path.

Once recirculation flow is established, reverse flow through the remote strainer will cease. Water will then flow into the recirculation sump through both the main strainer and the remote strainer and waterway. Since a pipe break requiring recirculation is not postulated to occur in the annulus, debris at the remote strainer would have been transported from the loop compartment to the annulus during the initial blowdown, or transported to the annulus through the overflow wall flow holes during pool fill-up, or it would have consisted of latent debris resident in the annulus prior to the event. As a result, the remote strainer would be essentially debris free at the beginning of recirculation. Due to the waterway head loss, the preferential flow path for recirculation flow would be through the main strainer, until the main strainer becomes substantially blocked by debris. The division of flow between the main and remote strainers is a function of the head loss through the associated strainer and the waterway.

A recirculation sump hydraulics analysis was performed to analyze the above flow characteristics of the main and remote strainer system under various bounding strainer loading conditions. The purpose of the analysis was to ensure that the required sump recirculation flow rate could be achieved for all postulated conditions. The analysis used Computational Fluid Dynamics (CFD) calculations of flow through the main and remote strainers for the following cases to determine the flow split between the main strainer and the remote strainer and their associated head loss.

1. Forward Flow – Clean Main and Remote Strainers
2. Forward Flow – Main Strainer 90% Blocked, Remote Strainer Clean
3. Forward Flow – Main Strainer 100% Blocked, Remote Strainer Clean
4. Reverse Flow – Flow Enters into Main Strainer and Out of Remote Strainer during Pool Fill

The recirculation sump hydraulic analysis also evaluated the potential for vortex formation in the recirculation sump during RHR and CTS operation, as a function of water level inside the recirculation sump. This analysis, performed with the same methodology that was used for the original Alden Laboratories analysis (Froude number correlation), concluded that an air entraining vortex would not occur with a water level inside the recirculation sump of 601'-6".

This analysis also assumed that the column height of water being considered was directly above the recirculation sump suction piping openings.

Finally, the analysis included a calculation of the maximum pressure load on the waterway considering both forward and reverse flow to ensure an acceptable structural design (Reference Section 6.2.2).

14.3.9.4.3.1 Computer Code Utilized

The CFD calculation for sump flow through the recirculation sump strainers and waterway was performed using Flow-3D Version 9.0. The CFD analysis of the flow through the strainers is based on the CAD model, as discussed in Section 14.3.9.4.2.1, which represents the physical construction of the containment building and flow domain. The CFD model was developed to simulate fluid flow in the recirculation sump to predict flow patterns which would occur during the recirculation phase of a LOCA.

14.3.9.4.3.2 Method of Analysis

Design Input Parameters

1. The maximum ECCS flow rate during recirculation is 14,400 gpm.
2. Water level: 5.9 ft above the containment sump floor, or elevation 604.7 ft, was used as the minimum water level during recirculation for the analyzed accidents. This is conservative since the lowest water level produces the highest flow velocities and turbulence levels, thus resulting in the highest transport fractions.
3. Water temperature: The water temperature was 190°F for the forward flow case, and the water temperature for the reverse flow case was 200°F.
4. Total recirculation sump strainer area is 1,938 ft2, with the main strainer having 900 ft2 and the remote strainer 1,038 ft2. (Analyzed recirculation sump strainer size is conservatively smaller than the installed recirculation sump strainer.)

Forward Flow Cases

The objective of the flow analyses was to determine the flow distribution through the main strainer and the remote strainer and associated waterway. As discussed in Section 14.3.9.4.3, three forward flow hydraulic flow cases were analyzed. For the clean case, both the main and remote strainers were completely open and unrestricted by debris. This case provides the minimum pressure drop through the system. This established the recirculation sump hydraulic conditions for various stages of main strainer loading to determine the bounding cases for flow to/from the remote strainer. For the 100% blocked main strainer case, the main strainer area was assumed to be completely blocked by debris and the remote strainer was debris free. In this case, the remote strainer had to pass the full recirculation flow. This established the worst case head loss across the remote strainer and the highest pressure load for the waterway.

Reverse Flow Case

The hydrostatic pressure in the containment sump is greater than the annulus hydrostatic pressure during the pool fill phase. This hydrostatic pressure difference drives flow from the containment sump to the annulus through the remote strainer waterway and remote strainer. This is defined as the reverse flow case. The reverse flow case was evaluated to determine the pressure load on the wall surfaces of the remote strainer waterway during the pool fill phase. The maximum reverse flow rate for this analysis is 6,400 gpm. This flow rate was determined by establishing flow resistance values for each of the components within the flow path.

Vortex Evaluation

The adequacy of the original recirculation sump design with respect to prevention of significant air entrainment following a LOCA was tested using a 1:2.5 scale model of the Cook Nuclear Plant design in 1978. This testing, which was performed by Alden Laboratories and documented in Reference 5, demonstrated that neither vortex formation nor air ingestion by the ECCS or CTS pumps would likely occur if the water outside the recirculation sump was at or above elevation 602'-3", with 50% of the screen area blocked. The basis for the 602'-3" limit was to ensure there was a sufficient height of water to provide the necessary flow over the curb and blocked portions of the screen. This limit was found to be acceptable in Reference 5 since it was less than the minimum water level of 602'-10" expected in the containment sump.

The original Alden testing evaluated vortex formation considering the water level in the containment sump with 50% of the screen area not blocked. This allowed for visual evaluation of the development of surface swirls and vortices since the water level inside the recirculation sump was essentially at the same level as the containment sump.

Since the original Alden testing did not evaluate a condition under which a head loss could develop due to debris loading across the entire surface of the strainer, resulting in a water level difference between the containment sump and recirculation sump, an additional vortex analysis was performed using the Alden test cases. This analysis, performed with the same methodology that was used for the original Alden Laboratories analysis (Froude number correlation), concluded that an air entraining vortex would not occur with a water level inside the recirculation sump of 601'-6". This analysis also assumed that the column height of water being considered was directly above the recirculation sump suction piping openings. This water level defined the acceptance criterion for minimum recirculation sump water level against which the analyses of the bounding forward flow cases identified in Section 14.3.9.4.3 were judged. In addition, the minimum water level was used in establishing the alarm setpoint for Containment Recirculation Sump Water Level instruments, installed inside the recirculation sump. These instruments, qualified to RG 1.97 requirements, annunciate if water level during sump recirculation drops inside the recirculation sump to a value that is indicative of a significant head loss across the recirculation sump strainers.

An additional concern associated with vortexing is the potential for air to be ingested from the surface of the containment sump pool, through the strainer, and into the recirculation sump. This is of particular concern when conditions of minimum submergence exist. As a result, testing was performed at the recirculation sump strainer vendor's facilities. Water level was intentionally lowered during this testing to approximately 2 inches above the strainer pockets at maximum head loss conditions to determine if any vortices would form on the surface of the containment sump. The testing determined that no vortices would form.

14.3.9.4.3.3 Results

Forward Flow Cases

Analyses of bounding flow scenarios through the main and remote strainer/waterway system were performed to estimate the flow split between the remote strainer and the main strainer and to determine the associated head loss through the strainer system, the latter being indicated by the resulting water level inside the recirculation sump. Results indicated that the flow split and head loss change rapidly when the main strainer blockage was changed from fully blocked to 10% open. Figure 14.3.9-14 provides the performance curve for the recirculation sump strainer system, indicating the variance in flow split for the main and remote strainers as a function of blockage of the main strainer, and the strainer system head loss as a function of blockage of the main strainer. The predicted maximum head loss across the recirculation sump strainer was 2.8 ft-H_2O for the main strainer fully blocked case. This head loss is approximately the same as the available hydrostatic head from water in the containment sump.

Review of the forward flow cases indicates that the largest pressure load through the remote strainer/waterway system occurs when the main strainer is completely blocked and all recirculation flow is entering the remote strainer. The estimated pressure load for this case is bounding for all forward and reverse flow cases at 4.5 ft-H_2O. This maximum pressure load was found to be acceptable.

Reverse Flow Case

A Reverse Flow Case was evaluated to determine the pressure load on wall surfaces of the remote strainer waterway during the pool fill phase. During pool fill, the hydrostatic pressure in the loop compartment pool is greater than the hydrostatic pressure in the annulus. This hydrostatic pressure difference drives flow from the containment sump to the annulus through the main strainer, remote strainer waterway, and remote strainer. The maximum reverse flow rate through the remote waterway and remote strainer corresponds to the maximum head loss through the remote strainer system. The head loss through the remote strainer system, for the reverse flow case is 1.85 ft-H_2O. The maximum pressure load on the remote strainer waterway is 1.75 ft-H_2O. This maximum pressure load was found to be acceptable.

Vortex Evaluation

The vortex evaluation determined that air entraining vortex formation in the recirculation sump will not occur if the minimum recirculation sump water level is above 601'-6". Containment Recirculation Sump Water Level instruments are installed inside the recirculation sump with control room indication and alarm to warn the operators of excessive recirculation sump strainer blockage during sump recirculation. (See Table 7.8-1)

14.3.9.5 Recirculation Sump Strainer Head Loss

Plant-specific impacts on the recirculation sump strainer system due to postulated debris buildup and chemical effects on the main and remote strainers were determined through a series of scaled tests. Three different test loop configurations were used for head loss testing of the recirculation sump strainers. These included:

- Large Scale Test Loop
- Multi Functional Test Loop (MFTL)
- Vuez Facility Tank Test Loop

The Large Scale Test Loop was used for debris only testing and the MFTL and Vuez Facility Test Loop were used for chemical effects testing. Clean strainer head loss testing was performed on all three loops to establish the baseline head loss before debris or chemical addition. Details of the tests are provided below.

14.3.9.5.1 Recirculation Sump Strainer Debris Only Testing

The Large Scale Test Loop utilized a strainer assembly with segregated approach areas for main and remote strainer sections that allowed separate debris additions to either strainer section.

Approximate flow distribution between the main and remote strainer sections was collected during testing. The test configuration differed from the Cook Nuclear Plant installation in that there was no waterway in the test facility and no vent pipe for the modeled sump. These divergences were addressed during evaluations of the test results.

A scaling factor of 41 was used for the Large Scale Test Loop, based on test loop flow rate capability. This scaling factor resulted in the use of 15 strainer pockets for the main strainer side and 18 strainer pockets for the remote strainer side. This number of pockets represents the equivalent of 824 ft^2 for the main strainer and 989 ft^2 for the remote strainer. The remaining recirculation sump strainer area, 76 ft^2 for the main strainer and 83 ft^2 for the remote strainer, represents sacrificial strainer area. Sacrificial strainer area is used for debris sources, such as tags, labels, tape, and other similar materials. Refer to Section 14.3.9.4.1.2 for information pertaining to quantities of debris sources in containment.

Debris only strainer head loss testing was performed on the Large Scale Test Loop for both the DEGB and the DGBS scenarios. The tests were the standard head loss tests consisting of stepped flow rates and stepped homogeneous debris additions, debris sequence tests, event sequence tests, and flow reduction sequences.

Debris sequence testing was designed to pre-load the test strainer with purely fibrous debris prior to addition of debris with both fiber and particulate, followed by other particulate, and then RMI. This test was performed to determine if the debris quantities could form a thin bed that would result in higher head losses than a homogeneously mixed debris test sequence.

Event sequence testing was performed to simulate, to the extent practical, a conservatively calculated, homogeneous mixed delivery of debris to the main strainer during pool fill, with its corresponding flow rate, followed by an increase to a similarly conservative quantity of homogeneously mixed debris to both the main and remote strainer with a stepped increase in flow to the 100% recirculation flow rate.

Flow reduction sequence tests were performed during the standard homogeneous debris addition tests to determine the impact the flow reduction would have on the system head loss. These tests were performed by reducing flow equivalent to removal of a CTS pump, followed by reducing flow equivalent to removal of another CTS pump, reducing flow equivalent to removal of an RHR pump, and then securing all flow followed by restoring flow equivalent to restarting an RHR pump, followed by sequential restoration of flow equivalent to restarting the remaining RHR and CTS pumps.

Debris quantities used for the DEGB and the DGBS tests for the main strainer are provided in Table 14.3.9-12. Debris quantities used for the DEGB and the DGBS tests for the remote strainer are provided in Table 14.3.9-13.

The head loss results from the DEGB tests are shown in Figures 14.3.9-15 through 14.3.9-17. The head loss results from the DGBS tests are shown in Figures 14.3.9-18 through 14.3.9-20. Based on the analysis of this testing, the testing performed in the Large Scale Test Loop was determined to provide the data necessary to establish system head loss values. The results from this testing were used as an input to a calculation that establishes the overall system clean strainer head loss that considers the series-parallel configuration of the installed strainer system. The system head loss analysis is described in Section 14.3.9.5.3.

14.3.9.5.2 Recirculation Sump Strainer Chemical Effects Testing

MFTL Testing

The MFTL utilized a strainer assembly representative of a non-vented main strainer only. This was due to the limitation of the MFTL to model the physically separate strainers at Cook Nuclear Plant, but was adequate for testing to determine the increase in strainer head loss above the debris only cases as a result of chemical effects.

Testing on the MFTL included testing of both the DEGB and DGBS scenarios. A scaling factor of 19.2 was used for this testing based on the available test strainer area. To establish the effects of chemical precipitates on the debris only head loss, extended tests were performed to establish a baseline debris only head loss. Chemicals were then added to the test loop to generate the expected chemical precipitates, based on bench top testing that considered the expected quantities of precipitates that would be formed, as established by WCAP-16530-NP, Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191 (Reference 8). For both the DEGB and DGBS tests, sodium aluminate solution was added to achieve 40%, 70%, 100%, 120%, and 140% of the predicted total quantity. For the DEGB test, calcium chloride and sodium silicate solutions were added to the test loop in the same percentages as the sodium aluminate solution. For the DGBS test, the calcium chloride and sodium silicate solutions were added in three separate additions with a final percentage of the predicted quantity of 287% and 298%, respectively.

The debris quantities used for the DEGB and DGBS tests are provided in Table 14.3.9-14. The chemical quantities used for the DEGB and DGBS are provided in Tables 14.3.9-15 and 14.3.9-16.

The head loss result from the DEGB test is shown in Figure 14.3.9-21. The head loss result from the DGBS test is shown in Figure 14.3.9-22. The application of the limiting head loss from these tests is described in Section 14.3.9.5.3.2.

Vuez Testing

The Vuez facility tank test loop was used for longer term integrated chemical effects testing. It utilized a four-pocket strainer assembly that was representative of the main strainer only. The Vuez test loop determined the impact of chemical precipitates formed through the interaction of expected chemicals and materials in containment following a LOCA. Testing on this loop was performed for a 30-day duration and considered DEGB debris quantities except for RMI. The testing was initiated at the expected maximum sump temperature of 190^{o}F and then gradually reduced over the test duration to 80^{o}F, the conservatively minimum temperature expected to be achieved following an accident. Testing accommodated the expected pH changes during the initial stages of the accident in both the containment sump pool and CTS spray. Materials that exist in containment, or equivalent surrogates, were included in the test tank, either submerged or in the region where spray would interact with the materials. For this testing, spray was maintained for 48 hours to maximize the interaction of the spray with exposed materials that would not be submerged in the containment sump pool. Application of the limiting head loss from this test is described in Section 14.3.9.5.3.2.

The debris quantities used for this test are provided in Table 14.3.9-17. The containment materials and their quantities considered for these tests are provided in Tables 14.3.9-18 and 14.3.9-19.

The time history response of this test is shown in Figure 14.3.9-23.

14.3.9.5.3 System Head Loss Determination

As described in Sections 14.3.9.5.1 and 14.3.9.5.2, the testing that was performed did not model the installed plant configuration of a main strainer in parallel with the remote strainer and associated waterway. The debris only head loss testing performed in the Large Scale Test Loop provided a combined head loss across the in-parallel main and remote strainers, without consideration of the head loss across the waterway. The testing performed in the MFTL and Vuez test loops provided the head loss across an equivalent main strainer only. Nevertheless, the testing performed in these loops provided the data needed to determine the expected increase in debris only head loss due to the additional impact of chemical precipitate interaction with the debris bed. Methods used to extrapolate the test data to an appropriate debris only and chemical effects head loss factors are addressed below.

14.3.9.5.3.1 Method of Analysis

To establish a system head loss for the installed recirculation sump strainer system, utilizing the data obtained from the testing described in Section 14.3.9.5.1, a mathematical model was developed. The model was designed to correlate the test data with the calculated hydraulic analysis described in Section 14.3.9.4.3.3. To address test data collected at different temperatures, the model normalized the data to a common temperature input value.

The selected method for determining system head loss identified an appropriate K-factor for the strainer system, based on the hydraulic analysis (CFD) described in Section 14.3.9.4.3 and the clean strainer head loss testing performed in the Large Scale Test Loop. This was accomplished by determining the flow split between the main and remote strainer sections with the data obtained, correlating the scaled strainer test areas to the installed plant configuration, and then including the head loss of the waterway in series with the remote strainer. This approach was used for the standard homogeneous debris test results and the event sequence test results from the large scale test loop cases described in Section 14.3.9.5.1. To account for uncertainties, an additional conservatism was applied to the results of the debris only system head loss analysis. The calculated head loss was increased by 50%.

To account for the increase in system head loss resulting from chemical precipitate interaction with the strainer debris bed (chemical effects), the percentage increase in head loss from MFTL and Vuez testing, described in Section 14.3.9.5.2, was determined. MFTL test results indicated a worst case increase in debris only head loss for the DEGB and DGBS of approximately 43% and 53% respectively, while the Vuez testing determined an increase of approximately 40%. To account for uncertainties with the testing, an additional margin was added to bound the test results. The selected value for the increase in debris only head loss as a result of chemical effects is 70%. Similar to the method used to address uncertainties in the debris only test results, the 70% chemical effects increase is applied to the measured system head loss. This provides additional conservatism in that the chemical effects testing was performed on an equivalent main strainer only, the strainer section that will be most heavily loaded with debris resulting in a higher debris only head loss than the remote strainer. The resulting composite multiplication factor for overall recirculation sump strainer system head loss from the debris only test results is 1.5 x 1.7 = 2.55. Application of this head loss increase factor provides margin for uncertainties in analysis and testing for debris and chemical effects.

Allowable head loss across the recirculation sump strainers is a function of the height of water in the containment sump pool since Cook Nuclear Plant has a fully vented recirculation sump. The allowable head loss design limit is based on the available driving head of water at the fully vented recirculation sump, subject to the stipulations contained in NUREG/CR-6808, "Knowledge Base for the Effect of Debris on Pressurized Water Reactor Emergency Core Cooling Sump Performance," dated February 2003, Section 1.3.2 (Reference 11). As noted therein, the effective maximum hydrostatic head loss allowed across a debris bed for a partially submerged sump screen (for which a fully vented sump is considered) is approximately equal to one half the height of the sump pool. If the head loss across a sump strainer due to debris accumulation exceeds this hydrostatic head, the volumetric flow to the pumps drawing on the sump will decrease below the required flow. This will result in decreasing level inside the recirculation sump. For Cook Nuclear Plant, the design maximum head loss for DEGB, DGBS, and 2" SBLOCA were determined by taking one half the available pool height (minus 0.3 ft for the curb height). Table 14.3.9-20 provides the water level at the initiation of recirculation, the minimum water level during recirculation, the time from event initiation until the minimum water level is reached, and the minimum submergence (height of water over the strainer) for the main and remote strainers for the DEGB, the DGBS and the SBLOCA scenarios. The resulting strainer design maximum head loss at minimum recirculation water level for a DEGB is 2.8 ft H_2O. The strainer design maximum head loss at minimum recirculation water level for a DGBS is 2.65 ft H_2O. The strainer design maximum head loss at minimum recirculation water level for a 2" SBLOCA is 2.4 ft H_2O. These head loss limits protect the calculated vortex limit of 601'-6" described in Section 14.3.9.4. As discussed in Section 6.1, the elevation associated with the required NPSH for the pumps taking suction from the recirculation sump is substantially below the elevation associated with the assumed maximum head loss.

14.3.9.5.3.2 System Head Loss Results

The following discussion utilized the results of testing that were provided in millibar and subsequently converted to inches of water to provide a relationship between the head loss and water level inside the recirculation sump.

The limiting debris only head loss test case for the DEGB was determined to be an all debris case, designated as Test Case T2121-3, and run on the Large Scale Test Loop described in Section 14.3.9.5.1. After achieving 100% debris and 100% flow, this test was allowed to run for 24 hours. The highest head loss achieved during the 24-hour run was 11.3 inches H_2O at approximately 16 hours after 100% debris, 100% flow was achieved. The head loss at the end of 24 hours from the 100% debris, 100% flow point was approximately 9.5 inches H_2O and slowly decreasing. The head loss values provided are at a conservatively low normalized temperature value. The time history response of this test is shown in Figure 14.3.9-15.

For the DEGB, the maximum, temperature-normalized strainer head loss of 11.3 inches H_2O resulted in a calculated system head loss for the installed system of approximately 1.046 ft H_2O. Applying the uncertainty factor of 2.55, described in Section 14.3.9.5.3.1, results in a maximum head loss across the recirculation sump strainer system of 2.67 ft H_2O. This head loss is slightly below the maximum allowed head loss of 2.8 ft H_2O, thus confirming that the recirculation strainers will pass sufficient flow to protect the 601' 6" vortex limit. The margin between the minimum expected water level inside the recirculation sump and the vortex limit, for the DEGB, is approximately 0.5 ft H_2O. In the event that the strainer system head loss does exceed the maximum allowable head loss of 2.8 ft H_2O, water level inside the recirculation sump will decrease to the level where the recirculation sump level switches will alarm in the control room, prompting flow reduction in accordance with emergency procedures.

The limiting debris head loss case for the DGBS was determined to be an event sequence test, designated as Test T2121-6, and run on the Large Scale Test Loop described in Section 14.3.9.5.1. The highest head loss achieved during this test was 7.2 inches H_2O approximately 3 3/4 hours after reaching 100% flow. At the end of the test, the head loss was approximately 7.0 inches H_2O and decreasing slowly. The head loss values are at the normalized temperature value. The time history response of this test is shown in Figure 14.3.9-19.

For the DGBS, the maximum, temperature-normalized strainer head loss of 7.2 inches H_2O resulted in a calculated system head loss for the installed system of approximately 0.819 ft H_2O. Applying the uncertainty factor of 2.55, described in Section 14.3.9.5.3.1, results in a maximum head loss across the recirculation sump strainer system of 2.09 ft H_2O. This head loss is substantially below the maximum allowed head loss of 2.65 ft H_2O and is bounded by the results of the DEGB. The margin between the minimum expected water level inside the recirculation sump and the vortex limit, for the DGBS, is approximately 0.8 ft H_2O.

Specific strainer head loss testing was not performed for the 2" SBLOCA. Conservatively applying the strainer system head loss results from the DGBS analysis results in a head loss of 2.09 ft H_2O. This head loss is below the maximum allowed head loss of 2.4 ft H_2O. This is also conservative in that the expected flow rate for the ESF systems would be below the full flow value assumed for the larger breaks, thus decreasing the head loss across the strainer system. The margin between the minimum expected water level inside the recirculation sump and the vortex limit for the full flow rate applied to the SBLOCA, is approximately 0.3 ft H_2O.

Given the Alternate Evaluation approach used for recirculation sump inventory analyses, as described in Section 14.3.9.4.1.1, it is acceptable to rely on operator actions to mitigate the consequences of debris loading in excess of allowable design limits. To determine the effects of reducing ECCS and/or CTS pump flow in this eventuality, the DEGB testing on the Large Scale Test Loop included a flow reduction sequence to simulate the removal of one pump from service at a time until flow was stopped, followed by returning flow to the equivalent 100% value. The head loss following the first flow reduction step (equivalent to removal of a CTS pump) was approximately 5.9 inches H_2O (non-normalized). Following the second flow reduction, the head loss was approximately 3.2 inches H_2O (non-normalized). The head loss following restoration of flow to 100% was approximately 5.4 inches H_2O (non-normalized). These test results demonstrated the positive effects of flow reduction on head loss across the main recirculation strainer and provided evidence that operator actions in response to Emergency Operating Procedures for recirculation sump level instrument alarms in the control room could reduce flow across the strainers and restore water level inside the recirculation sump. This ensures air entraining vortices do not occur.

14.3.9.6 Design Considerations for Upstream and Downstream Effects

14.3.9.6.1 Upstream Effects

An Upstream Effects assessment was performed in concert with the incorporation of Generic Letter 2004-02 into Cook Nuclear Plant's licensing basis. The assessment evaluated flow paths associated with the recirculation function of the containment sump to ensure they would not hold up inventory that should flow to the containment and recirculation sumps and possibly impact the RHR and CTS pumps ability to provide the necessary flow for core and containment cooling. Potential choke points identified in the Upstream Effects evaluation of the flow paths are identified and described below.

The lower containment is made up of two compartments—the area inside the crane wall (loop compartment) and the area outside the crane wall (annulus). These two areas are primarily connected by five 10-inch holes drilled through the flood-up overflow wall and two approximately 4-ft by 10-ft openings in the crane wall. A debris interceptor protects the flood-up overflow wall holes on the loop compartment side of the overflow wall. This debris interceptor consists of vertical perforated plates with a solid top cover plate, with an approximate 6-inch gap between the top and the sides. Analytically, it is assumed that the perforated plate section becomes blocked by debris and all water flow passes through the gap. The top plate is solid to prevent debris generated from the accident from falling into the area between the flood-up overflow wall hole and the perforated plate section of debris interceptor. To properly address the functionality of the debris interceptor installed at the flood-up overflow, its flow characteristics were included in the CFD model for both pool fill and recirculation (Section 14.3.9.4.2). Further information regarding the construction of this debris interceptor is provided in Section 6.2.2.

The overflow wall holes are protected on the annulus side of the flood-up overflow wall by a set of 2-foot tall radiation shields that are set back from the holes by approximately 16-inches with gaps at the bottom of the shields of approximately 2-inches. Openings exist at the ends of the shields which further promote flow through this region. The two larger openings in the crane wall have installed trash racks designed to block the transport of large pieces of debris. No credit has been taken in the debris transport analysis for the crane wall opening trash racks to block debris from transporting between the loop compartment and the annulus. The design of the flood-up overflow wall debris interceptor ensures that it will not become a choke point which will adversely affect the recirculation sump inventory analyses.

Other potential upstream blockage points include the ice condenser drain lines, the refueling canal spray drain lines, and the CEQ fan room drain lines.

There are twenty-one 12-inch ice condenser drain lines for draining the melting ice into the loop compartment. If one of these drains were to become blocked, the water would simply flow to the other drains or the melted ice flow would spill over to the loop compartment through the ice condenser lower inlet doors. As a result, this flow path is not considered a choke point which will adversely affect the recirculation sump inventory analyses.

The plant is designed so that the majority of the upper containment spray water flows to lower containment through the three drain lines in the bottom of the refueling canal. The drains include two 12-inch drain lines and one 10-inch drain line, which discharge directly below the refueling canal. By design, the refueling canal drains are separated by sufficient distance to ensure that any credible missile generated in upper containment will not block more than half the total flow area. If one of these lines was to become blocked with debris, the other two lines are sufficiently sized to drain the upper containment spray flow, resulting in overall pool flow patterns that are essentially the same. As a result, refueling canal drains are not considered a choke point which will adversely affect the recirculation sump inventory analyses.

The fraction of upper containment spray that sprays or drains down into the CEQ fan rooms is drained to the pipe tunnel sump for Unit 1 and to the lower containment sump for Unit 2 through a set of 3-inch floor drains. The CEQ fan room drains consist of one drain in the east CEQ fan room and two drains in the west CEQ fan room. Debris blockage of these drain lines would result in decreasing containment sump inventory over time and decreasing the available head for flow through the main and remote strainers. Debris interceptors are installed at the openings to the CEQ fan room drains to prevent them from being blocked by debris. Openings exist at both the Unit 1 pipe tunnel sump and the Unit 2 lower containment sump to allow the water entering the sumps from the CEQ fan rooms to enter the containment sump pool. As a result, the CEQ fan room drains are not considered choke points which will adversely affect the recirculation sump inventory analyses.

14.3.9.6.2 Downstream Effects

Achieving long-term core and containment cooling functions pursuant to Generic Letter 2004-02 requires proper performance of the ECCS and CTS while drawing filtered water from the recirculation sump. The execution of these functions is documented in the Downstream Effects evaluations. These evaluations determined the post-LOCA impact of debris-laden fluid drawn from inside the recirculation sump on successful functioning of downstream equipment in the recirculation flow path during the component's mission time. Downstream Effects evaluations included potential debris effects on ECCS and CTS pumps, throttle valves in the injection flow paths, orifices, spray nozzles, process instruments, heat exchangers, reactor vessel flow path components, and reactor core fuel flow path components. Considerations included potential blockage of equipment flowpaths, wear and abrasion of surfaces, blockage of flow clearances through fuel assemblies, and debris deposition on the fuel clad surface.

The scope of the Downstream Effects evaluations included:

1. Ex-Vessel Recirculation Flow Path Blockage
2. Ex-Vessel Recirculation Flow Path Component Wear
3. In-Vessel Flow Path Blockage
4. In-Vessel Fuel Rod Debris Deposition

The recirculation flow paths for the ECCS and CTS are shown on Figures 14.3.9-24 and 14.3.9-25 respectively.

14.3.9.6.2.1 Method of Analysis

Downstream Effects evaluations were performed in accordance with WCAP-16406-P, "Evaluation of Downstream Sump Debris Effects in Support of GSI-191" (References 13 and 14) and WCAP-16793-NP, "Evaluation of Long-Term Cooling Considering Particulate, Fibrous and Chemical Debris in the Recirculating Fluid" (Reference 15). The debris materials in the recirculation fluid were taken from those debris sources described in Section 14.3.9.4.1.2.

Downstream Effects evaluations include consideration of long and short-term ECCS and CTS operating lineups, conditions of operation, and mission times for LOCA mitigation. Mission times for the systems were determined through review of UFSAR LOCA accident analyses and in consideration of the need to demonstrate that bulk and local temperatures are stable or continuously decreasing and that there is no credible mechanism for debris entrained in the recirculating water to unacceptably affect the stable heat removal mechanism.

Ex-Vessel Recirculation Flow Path Blockage

The ex-vessel recirculation flow path blockage evaluation was performed in accordance with Reference 13 and 14. This evaluation determined the openings and expected flow rates which exist for the components in the recirculation flow path ensures that debris would not block the required flow paths.

Ex-Vessel Recirculation Flow Path Wear

The ex-vessel recirculation flow path wear evaluation was performed in accordance with References 13 and 14. This evaluation determined the clearances and material thicknesses for components and sub-components in the recirculation flow path to ensure debris-laden fluid would not result in component failure that would challenge the ability to provide the necessary core and containment cooling for the required mission time. The types of sub-components evaluated include pump seals, impellers, wear rings, bushings, and bearings, heat exchanger tubes, valve plugs and seats, and orifice edge openings. An evaluation was also performed to establish that the system flow characteristics remained within an acceptable operating range to ensure continued core and containment cooling via the recirculation function.

In-Vessel Flow Path Blockage

The in-vessel blockage evaluation was performed in accordance with References 13 and 15. This evaluation determined the thickness of the fiber bed that could form on the fuel assembly bottom nozzles as a function of the fibrous debris that could bypass the recirculation sump strainers. Estimates of the fibrous debris bypassing the strainer were based on testing performed at the strainer vendor test facility with additional consideration for fibrous material contained in other insulation and fire barrier materials, as described in Section 14.3.9.4.1.2.

In-Vessel Fuel Rod Debris Deposition

The in-vessel fuel rod deposition evaluation was performed in accordance with Reference 15 using the LOCADM code, Version 1.0. The evaluation considered both Unit 1 and Unit 2 using core thermal power values of 3315 MWt and 3482 MWt, respectively, and minimum and maximum containment sump volumes. The debris source term used for the evaluation is described in Section 14.3.4.9.1.2.

14.3.9.6.2.2 Assumptions

The ex-vessel recirculation flow path blockage evaluation conservatively assumed a nominal strainer opening of 1/8 inch diameter. This opening size results in an assumed maximum debris size of 1/4 inch passing through the recirculation sump strainers. This assumption is consistent with the guidance provided in Reference 13.

The ex-vessel recirculation flow path wear evaluation conservatively assumed debris sizes and quantities which resulted in maximum wear of the affected components. This evaluation also conservatively neglected the filtration of particulate debris by the recirculation sump strainers, the fuel assembly bottom nozzles, and the fuel assembly spacer grids. This evaluation did assume the only particulate debris reduction mechanism to be settling in the reactor vessel lower plenum and that particulate debris would not be reduced in size during transport through the recirculation flow path. For all pumps within the recirculation flow path, it was assumed that the pumps were at their minimum operability limits for performing the hydraulic analysis verification at the beginning of recirculation, and multi-stage pumps were within their In-Service Testing flow limits for determination of mechanical verification (vibration) due to pumping debris-laden water for the required mission time.

The in-vessel flow path blockage evaluation conservatively used values of fibrous debris available for filtration by the recirculation sump strainers in excess of those values assumed to be generated during a LOCA.

The in-vessel fuel rod debris deposition analysis conservatively assumed that all deposition within the recirculation flow path occurs on fuel heat transfer surfaces, no carryover of debris from core boil-off, impurity deposition on the fuel clad surface is directly related to core power distribution, and deposits will not be thinned by flow attrition or by dissolution.

14.3.9.6.2.3 Acceptance Criteria

The acceptance criteria for the ex-vessel recirculation flow path blockage evaluation are that no required component in the recirculation flow path will be blocked by debris with particle sizes less than or equal to 1/4 inch, and that debris will not accumulate within the systems or components resulting in blockage of the flow path.

Acceptance criteria for the ex-vessel recirculation flow path wear evaluation are that the required core and containment cooling functions will be provided for the necessary mission time while satisfying accident analysis inputs and assumptions described elsewhere in Chapter 14 (Unit 1 and Unit 2). This includes criteria which demonstrate that ECCS and CTS pumps, in the presence of system and component debris-related degradation, continue to provide minimum flowrates to meet cold and hot leg recirculation needs and not exceed pump runout limits. Relative to mission times, reviews of post-LOCA accident analyses and related Emergency Operating Procedures indicate that no Safety Injection pump flow requirements are needed beyond 30 hours. Given the potential need for RHR, CCP and CTS operations beyond 30 hours, the associated Downstream Effects were evaluated for a 30 day operating duration for these systems. This extended duration is reasonable given the conservative nature of the methodology used to develop inputs to head loss testing and the LOCA analyses timelines contained in UFSAR Chapter 14. It is also consistent with Section 2.3 of Reference 17.

The acceptance criterion for the in-vessel flow blockage evaluation is that the thickness of the fibrous debris bed formed on the fuel assembly bottom nozzles is less than 0.125 inches thick. (Reference 13)

The first acceptance criterion for the in-vessel fuel rod debris deposition analysis is that the maximum fuel cladding temperature maintained during periods when the core is covered will not exceed a core average clad temperature of 800°F. This acceptance criterion is applied after the initial quench of the core (Reference 15) and is consistent with the long-term core cooling requirements stated in 10 CFR 50.46(b)(4) and 10 CFR 50.46(b)(5). The second acceptance criterion is that the total debris deposition on the fuel rods (oxide + crud + precipitate) is less than 50 mils. This criterion ensures that bridging of debris between adjacent fuel rods will not occur. (References 15 and 16)

14.3.9.6.2.4 Results

Results of the ex-vessel recirculation flow path blockage evaluation determined that there were no required systems or components within the recirculation flow path that would become blocked by debris.

Results of the ex-vessel recirculation flow path wear evaluation determined that the systems would provide the required flow for core and containment cooling for the assigned mission times. This evaluation also determined that the intermediate head injection pumps (SI) were susceptible to excessive vibration due to increased clearances within the pump from debris-laden fluid wear after approximately 15 days. Specifically, the SI pumps were found to be capable of operating for at least 15 days, the CTS pumps for at least 30 days, and the RHR and CCP pumps in excess of 30 days. Considering the wear in the systems and the pumps, an evaluation was performed that determined the system minimum flow requirements would continue to be met. Additionally, this evaluation determined that none of the pumps would reach run-out flow conditions.

Results from the in-vessel flow blockage evaluation determined that the maximum filter bed thickness on fuel assembly bottom nozzles is 0.028 inches. This result is acceptable because it satisfies the maximum thickness criterion of 0.125 inches.

Results from the in-vessel fuel rod debris deposition analysis determined that the maximum average fuel cladding temperature for Unit 1 is 365.71°F, and for Unit 2 is 358.10°F. The maximum debris deposition thickness on the fuel rods for Unit 1 is 17 mils and is 16 mils for Unit 2. These results are acceptable because they meet the acceptance criteria for the maximum cladding temperature and maximum debris deposition thickness of 800°F and 50 mils, respectively. Table 14.3.9-21 provides the results of all cases analyzed for both Unit 1 and Unit 2.

14.3.9.6.2.5 Conclusions

Downstream Effects evaluations found that debris-related degradation of ECCS and CTS did not prevent these systems from performing their core and containment cooling functions in mitigating the consequences of a LOCA.

14.3.9.7 References for Sections 14.3.9

1. I&M to NRC letter C1099-08, "Technical Specification Change Request – Containment Recirculation Sump Water Inventory," Attachment 7, FAI-99-77, "Containment Sump Level Evaluation for the D.C. Cook Plant," dated October 1, 1999.
2. Salvatori, R., 1974, - Final Report: Ice Condenser Full-Scale Section Test at the Waltz Mill Facility, Westinghouse Proprietary Class 2 Report, WCAP-8282.
3. Ligotke, M. W. et al., 1991, - Ice-Condenser Aerosol Test, NUREG/CR-5768, PNL-7765.
4. MPR Associates, Inc., - Containment Sump Level Design Condition and Failure Effects Analysis for Potential Draindown Scenarios, September 1999.
5. Padmanabhan, M., - Hydraulic Model Investigation of Vortexing and Swirl Within a Reactor Containment Recirculation Sump, Donald C. Cook Nuclear Power Station, Alden Research Laboratory Report 108-78/M178PF, 1978.

6. SER N99124 dated 12/13/1999, Amendments 234 & 217: Containment Recirculation Sump Water Inventory.
7. NRC Generic Letter 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors," dated September 13, 2004, including associated I&M to NRC letters.
8. WCAP-16530-NP, "Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191", dated June 2005.
9. NEI-04-07, "Pressurized Water Reactor Sump Performance Methodology," dated December 2004, ML041550332.
10. I&M to NRC letter C1099-08, "Technical Specification Change Request – Containment Recirculation Sump Water Inventory," Attachment 10, WCAP-15302, "Modifications to the Containment Systems, Westinghouse Safety Evaluation (SECL 99-076, Revision 3)," dated September 1999.
11. NUREG/CR-6808, "Knowledge Base for the Effect of Debris on Pressurized Water Reactor Emergency Core Cooling Sump Performance," dated February 2003.
12. NRC Letter, "Pressurized Water Reactor Containment Sump Evaluation Methodology," of December 6, 2004 with attached NRC Staff Safety Evaluation on NEI 04-07, ML043280007 and ML043280631
13. Westinghouse WCAP-16406-P, "Evaluation of Downstream Sump Debris Effects in Support of GSI-191," Rev. 1 of August 2007
14. NRC Document, "Safety Evaluation by the Office of Nuclear Reactor Regulation Topical Report (TR) WCAP-16406-P, Revision 1, Evaluation of Downstream Sump Debris Effects in Support of GSI-191, Pressurized Water Reactor Owners Group, Project No. 694," of December 20, 2007, ML073480324 and ML073520295.
15. Westinghouse WCAP-16793, "Evaluation of Long-Term Cooling Considering Particulate, Fibrous and Chemical Debris in the Recirculating Fluid," Rev. 0 of May 2007
16. PWROG Letter OG-08-18, Responses to the NRC Request for Clarification to Request for Additional Information (RAI) on WCAP-16793-NP, 'Evaluation of

Long-Term Cooling Considering Particulate, Fibrous and Chemical Debris in the Recirculating Fluid' (PA-SEE-0312)," of January 17, 2008.

17. NRC Letter, "Revised Guidance for Review of Final Licensee Responses to Generic Letter 2004-02, 'Potential Impact of Debris Blockage on Emergency Recirculation during Design Basis Accidents at Pressurized-Water Reactors'," William H Ruland to Anthony R. Pietrangelo, of March 28, 2008