19R Probabilistic Flooding Analysis

19R.1 Introduction and Summary

The ABWR has been designed to withstand the effects of postulated flooding internal to the plant. This appendix discusses the capabilities of the ABWR to withstand internal flooding (e.g., service water, suppression pool line breaks).

Results of the ABWR probabilistic flood analysis show:

(1) The only buildings where potential flooding could damage safety-related equipment or cause plant transients are the turbine, control, service and reactor buildings and the Reactor Service Water (RSW) pump house. The radwaste building does not contain safety-related equipment and flooding cannot affect safety-related equipment in other buildings. Failure of seals in the radwaste tunnels between buildings was determined to result in several orders of magnitude lower core damage frequency than direct flooding due to pipe breaks in each building and was not included in the flooding event trees.

(2) The flood concern for the turbine building is water filling up the condenser pit or the TCW equipment room and flowing into the service building tunnel which is the access path to the reactor and control buildings. The reactor and control buildings contain safe shutdown equipment. The turbine building has the potential to be flooded by two unlimited sources: circulating water and turbine service water. The condenser pit and the TCW equipment room contain redundant water level sensors (in a two-out-of-four logic) which send an alarm to alert the operator to potential flooding and automatically trip the circulating water system (CWS) and the turbine service water (TSW) pumps and close CWS and TSW isolation valves and open CWS and TSW siphon break valves. In the unlikely event this automatic protection fails and the operator fails to take any action, potential flood waters would still be prevented from reaching the service building. Potential flood waters would be expected to exit the turbine building through the non-watertight truck entrance door. Also, there is a normally closed and alarmed door separating the turbine and service building access tunnel. If this door were to open due to water pressure from the flood, watertight doors at the entrances to the reactor and control buildings from the service building should prevent damage to safety-related equipment. Thus, no impact on plant safety is expected from potential turbine building flooding. The estimated core damage frequency from turbine building flooding is extremely small for a plant with a low power cycle heat sink (PCHS) and is slightly higher for a high PCHS.

(3) The control building could potentially be flooded by the reactor service water (RSW) system which is an unlimited source or by breaks in the Fire Water System. The control building has six floors but floor drains and stairwells would direct all potential flood waters to the bottom floor where the safety-related reactor building cooling water (RCW) system components are located. There are three divisions of RCW/RSW in physically separate rooms with watertight doors. The RCW/RSW rooms in the control building lower level contain two sets of water level sensors in

each division in a two-out-of-four logic. The first set of sensors send an alarm signal to the operator at 0.4 meters. The second set of sensors are actuated at 1.5 meters and send an alarm signal to the operator and trip the RSW pumps and close RSW system isolation valves in the affected division. Water remaining in the lines between the control building and the ultimate heat sink could be drained into the control building. The water pumped into the control building prior to isolation of the RSW system and the water drained in from the RSW line outside is limited to affecting only one RCW division. The two other safety divisions (or alternate means) would remain undamaged and able to be used to achieve safe shutdown if necessary. The estimated core damage frequency from RSW flooding is extremely small.

Fire Water System breaks could cause flooding in all three safety divisions on a given floor since doors separating the divisions do not have sills. Floor drains and other floor openings in all three divisions ensure that postulated fire water breaks, if unisolated, will be directed to the first floor. The CDF for fire water flooding in the Control Building is extremely small.

The total control building flooding CDF is extremely small.

(4) The reactor building is adequately protected from flooding concerns by the following:

(a) Inside secondary containment, extensive flooding sources in ECCS divisional rooms at the lowest elevation are limited to impacting no more than one safety division by watertight doors. Extensive flooding in non-divisional rooms (i.e., corridors) is prevented from entering divisional rooms by watertight doors. In addition, the corridor volume is large enough to contain the largest flood source (Suppression pool). At higher elevations, potential flooding in systems such as Fire Water is directed to the first (bottom) level by floor drains and stairwells. The CDF for flooding inside secondary containment is extremely small.

(b) Outside secondary containment, floor drains direct all flood sources to the sumps on floor B1F. If the sump pumps fail or flood rates exceed sump pump capacity, a sump overfill line directs water to the corridor of floor B3F inside secondary containment where it can be contained as discussed above. Emergency diesel generator lube or fuel oil leaks are contained within the individual rooms until a portable pump can be brought in to remove the oil. The estimated core damage frequency for reactor building flooding outside secondary containment is extremely small.

(c) The total reactor building flooding CDF is extremely small.

(5) The RSW pump house could also be potentially flooded by breaks in the RSW system, which is an unlimited source of water from the Ultimate Heat Sink (UHS). The RSW pump house has two floors, the pump room floor and the electrical and HVAC room floor, and is divided into three physically separate sections by 3-hour fire-rated concrete walls and 3-hour fire-rated watertight doors between the pump

rooms and between the electrical and HVAC rooms. The watertight doors provide emergency and maintenance access to the rooms on each level. The watertight doors are capable of withstanding full flood pressure in either direction, and are alarmed at a security alarm station if open, and in the control room if not dogged closed.

The roof of the RSW pump house is above the Design Basis Flood level. There are no openings into the RSW pump house below the Design Basis Flood level. The entrance to the RSW pump house is from the roof.

Within each RSW pump room, two lines from the UHS supply water to the two horizontal RSW pumps in each division through a normally open, locked open, manual valve. After the RSW pump, the associated RSW strainer, and the pump discharge isolation motor operated valve (MOV), the RSW supply lines combine into a single supply line per division with a division isolation MOV. RSW then passes into the divisionally separated RSW tunnel to supply the RSW/RCW heat exchangers in the basement of the control building. Return from the RSW/RCW heat exchangers enters the associated divisionally separated RSW tunnel, enters and passes through the RSW pump room, the return isolation MOV, and discharges to the UHS basin above the UHS operating water level.

The RSW supply line to each RSW pump is designed in accordance with break exclusion criteria, which eliminates pipe stress as a potential failure mechanism. In addition, UHS water is treated to minimize the effects of corrosion and fouling and the reinforced concrete wall common to the UHS basin and RSW pump house is designed with reduced allowable stresses to minimize the potential for concrete cracking.

Two sets of water level sensors in each division pump room are arranged in a two-out-of-four logic. The first set of sensors send an alarm signal to the operator at 0.4 meters. The second set of sensors are actuated at 1.5 meters and send an alarm signal to the operator and trip the RSW pumps and close the RSW motor-operated isolation valves in the affected division. The RSW line before the automatic isolation valve in the pump discharge is isolable with operator action to unlock and close the normally open, locked open manual suction isolation valve.

With an unisolable break in a RSW line, the pump room will flood, the electrical and HVAC room above the pump room will flood, and water will exit the RSW pump house through HVAC ventilation intake and discharge penetrations in the roof of the RSW pump house (one set for each division), disabling the associated RCW and emergency core cooling system division. The other two safety divisions (or alternate means) would remain undamaged and able to be used to achieve safe shutdown. The estimated core damage frequency from RSW pump house flooding is extremely small.

Firewater System breaks could cause flooding in a single RSW division, but the division separation described above serves to limit the effects of firewater system breaks to that RSW division. The expected flood effects from firewater system breaks in a single RSW division are not expected to be as severe as the RSW piping breaks analyzed because the flow rates are significantly less, allowing more time for operator action to stop or reduce the flow. The core damage frequency for firewater flooding in the RSW pump house is extremely small.

The total RSW pump house flooding core damage frequency is extremely small.

(6) The estimated total core damage frequency from internal flooding is very small for a low PCHS and slightly higher for a high PCHS. This low risk level is attributable to the relatively low probability of large internal floods and the physical separation of certain safety equipment in the ABWR design. It is highly unlikely that a single flood can result in loss of more than one safety division. Where there is a potential for large flood sources to affect equipment in more than one division, instrumentation for detecting the flood and isolating the flood source is provided. The two remaining safety divisions and alternate core cooling and decay heat removal features (e.g., AC independent water addition, power conversion system) give high assurance of achieving safe shut down.

19R.2 Scope of Analysis

The ABWR flooding analysis covers all phases of plant operation. It addresses all potential flooding sources and their impact on safe shutdown of the plant. The effect on safety systems that are required to achieve and maintain safe shutdown is covered.

The analysis is completed in three steps. First, a listing is completed of all internal water sources and the buildings that they serve. This list is then screened to determine the sources and buildings that have a potential to prevent safe shutdown.

Following the screening analysis, the ability of the plant to achieve safe shutdown is analyzed both deterministically and probabilistically. The deterministic analysis describes plant features that are designed to either prevent or mitigate potential flooding concerns. This analysis focuses on plant features such as physical separation of buildings and rooms within buildings, isolation mechanisms to limit flooding, and the ability of the plant to contain potential flood waters due to room size and sump pumps. The intent of the deterministic analysis is to show that, for all postulated water sources, the ABWR design features can, with realistic operator actions, successfully achieve safe shutdown.

The probabilistic flooding analysis involves the use of event trees to evaluate the frequency of core damage for pipe breaks in various systems and buildings. Pipe breaks for each building of concern are evaluated and shown to have a negligible contribution to core damage frequency.

The results of the analysis are presented in terms of insights gained from the study and interface requirements that came out of the study which will be used as input for the inspections, tests, analysis and acceptance criteria (ITAAC), reliability assurance program (RAP), and emergency procedure guideline programs. Lastly, the main conclusions from the flooding analysis are presented which support the ABWR's capability to withstand postulated internal floods.

19R.3 Screening Analysis (Water Sources and Buildings)

In order to focus the flooding analysis on buildings and water sources that have the potential to cause flooding concerns, a screening analysis was completed to eliminate sources and buildings that, for various reasons, do not require further analysis.

The screening analysis was carried out for each of the buildings. From a safe shutdown perspective, the radwaste building does not contain any equipment that is required for safe shutdown and because of physical separation, flooding cannot affect safe shutdown equipment in other buildings. Therefore, the radwaste building was not evaluated further for flooding concerns. Failure of seals in the radwaste tunnels between buildings was determined to result in several orders of magnitude lower core damage frequency than direct flooding due to pipe breaks in the buildings and was not included in the flooding event trees. Adequacy of these seals should be confirmed by the COL applicant. The turbine building does not contain any safe shutdown equipment but a flood could cause a turbine trip which is an accident initiator. Also, the turbine building is next to the service building which is the access to the reactor and control buildings and so flooding between the two buildings must be considered. The reactor and the control buildings, and the RSW pump house contain safe shutdown equipment (e.g., RHR, RCIC, HPCF, RSW, Class 1E batteries). The flooding analysis will thus focus on the turbine, control, service and reactor buildings, and the RSW pump house, all of which either contain safety-related equipment or where flood damage could result in plant transients.

The sources of water in the ABWR are shown in Table 19R-1. As will be shown later, some of the smaller water sources (e.g., HVAC) can be eliminated due to insufficient volume to cause flooding concerns (i.e., damage safety-related equipment).

Potential flooding in the main steam tunnel and inside the drywell are adequately addressed in the LOCA discussion included in the full power PRA (Appendix 19D) and will not be further discussed in this appendix. In addition, the spent fuel pool is a seismic Category I structure that is fully lined and does not contain any drain lines. Therefore, flooding due to leaks in the spent fuel pool was also not considered in the study.

19R.4 Deterministic Flood Analysis

This subsection summarizes the physical design features of the ABWR that are capable of mitigating the effects of potential floods. A more detailed discussion of ABWR flooding features is contained in Tier 2 Subsection 3.4. The analysis will focus on the turbine, control, and reactor buildings, and the RSW pump house.

19R.4.1 Analysis Assumptions

The following general assumptions apply to all buildings in this deterministic flooding analysis:

(1) In moderate energy piping larger than nominal one inch diameter, leakage cracks are postulated to occur in accordance with ANSI/ANS 56.11, "Design Criteria for Protection Against the Effects of Compartment Flooding in Light Water Reactor Plants."

(2) No credit is taken for operation of the drain sump pumps although they are expected to operate during some of the postulated flooding events.

(3) When flooding can be identified and terminated by operator action from the control room, a 10-minute response time is assumed. If flooding is identified only visually and subsequent local or control room action is required to mitigate the flood, a 30-minute response time is assumed.

(4) A single active failure of flood mitigating systems is assumed following the flood.

19R.4.2 General Design Features

In each ABWR building with a potential flooding concern, there are common design features that are capable of mitigating potential floods. These features include:

- Wall and floor penetrations for cables and pipes
- Automatic pump trips on high water level or high system flow rate in a room
- Room barriers that are capable of containing water within a room or preventing water from entering another room
- Alarmed watertight room doors to ensure integrity
- Floor drains
- Pipes within or between rooms contained in pipe chases

These features are described in more detail below.

19R.4.2.1 Penetrations

Whenever an electrical cable, pipe, or HVAC duct must pass through a wall or a floor separating areas of different safety-related divisions, a penetration seal is provided to ensure the integrity of the room.

Cable tray penetrations are furnace tested to 1089 K (1900°F) and subjected to a hose stream test [38.1-cm (1.5-inch) hose operating at 0.618 MPa]. This ensures that flooding by hot sources such as reactor water cleanup (CUW) will not cause failure of the penetration.

Piping penetrations have been minimized throughout the plant to reduce the potential for loss of barrier integrity. No high pressure or high temperature piping lines penetrate walls or floors separating two different safety divisions. Piping penetrations are qualified to the same differential pressure requirements as the walls or floors they penetrate.

HVAC ducts have also been minimized throughout the plant. In areas where isolation is essential (e.g., secondary containment), motor operated positive shutoff valves are provided in the HVAC duct.

19R.4.2.2 Automatic Pump Trips

Some rooms contain level sensors to detect the presence of water in the room. In general, one set of level sensors alerts the operator of a potential flooding condition and a second (higher level) set of sensors actuate to trip pumps that could be causing the water level to increase in the room. These sensors are safety or non-safety grade (depending on the application), diverse, and typically arranged in a two-out-of-four logic.

Some systems (e.g., fire water) have high flow rate sensors to detect leaks in the system. In this case, the operator would be warned of a high flow rate instead of high room water level. Appropriate action would then be taken to isolate the leak.

19R.4.2.3 Room Barriers

Except in primary containment and the control room complex, divisional areas are separated from each other by 3-hour rated fire barrier walls and floors.

These walls are made of concrete and are at least 15.24 cm (6 inches) thick. They are designed to ensure that fires are not propagated between safety-related divisions and thus act as effective flood barriers. As with penetration seals, the fire barriers are flame and hydrostatically tested to ensure their high temperature performance and thus will not fail due to flooding by hot water sources.

19R.4.2.4 Watertight Doors

ECCS equipment rooms on the first floor of the reactor and control buildings, the RSW pump rooms, and the RSW electrical and HVAC rooms have watertight doors. Also, external entrances to the control and reactor buildings below flood level have watertight doors. The external entrance to the RSW pump house is above the design basis flood level. The entrance to other divisional rooms have fire rated doors. These doors are normally closed and are included in the security surveillance system. These doors can be opened only with a card key and if left open security personnel will be alerted immediately. This system gives high assurance that the divisional separation will not be breached due to a door being inadvertently left open. The alarm system can detect if a watertight door is closed but not if it is dogged. The watertight doors in the RSW pump house are alarmed in the Control Room if the door is not dogged. A once per shift walkdown will ensure that watertight doors remain dogged when not in use.

In cases where a fire door must be opened due to maintenance or surveillance activities, administrative controls are implemented to require that a watch be posted near the door until the activity is completed and the door returned to its normally closed position. In the event of a flood in an ECCS room when the other two ECCS rooms are opened, plant procedures should direct operators to ensure that at least one of the two unflooded room doors be closed before opening the door to the flooded ECCS room.

19R.4.2.5 Floor Drains

The reactor and control buildings, and the RSW pump house contain floor drains to direct potential flood waters to rooms where sumps and sump pumps are located. The drain system is sized to withstand breaks in the fire water system which is the most probable flood source for these two buildings. Sizing of the drain system will include provisions for plugging of some drains by debris.

The drain system will be designed so that floor drains in ECCS rooms will be connected to the corresponding divisional sump in the ECCS rooms on the first floor. Non-divisional rooms will drain to the non-divisional sumps on appropriate floors.

Floor B1F of the reactor building has overfill lines on the non-divisional sumps outside secondary containment. If the sump pumps fail or the flow rate exceeds the sump pump capacity, the lines will direct water to the non-divisional corridor of the first floor (B3F) inside secondary containment. A water seal is provided to maintain secondary containment integrity.

19R.4.2.6 Pipe Chases

When pipes are run between certain buildings(e.g., main steam feedwater lines between the reactor building and the turbine building) they are encased in sections called “chases.” The chases are capable of retaining the water or steam that may be deposited due to a pipe break or leak. In essence, the pipe chase acts as a divisional barrier similar to a fire wall or floor.

19R.4.2.7 Equipment Mounting

All electrical equipment is mounted 20.32 cm (8 inches) off the floor to help protect against damage from potential flood sources.

19R.4.2.8 Electrical Equipment Design

Electric motors are all of drip proof design and motor control centers have NEMA Type 4 enclosures. Both of these features protect electrical equipment from water spray and dripping water from above.

The above general design features all contribute to limiting the risk due to potential internal flooding in the ABWR. The following discussion addresses specific features of the turbine, control, and reactor buildings that prevent or mitigate postulated ABWR internal floods.

19R.4.2.9 Shutdown Considerations

During shutdown, increased maintenance activities introduce the potential for flooding to impact more than one safety division. As discussed in Subsection 19Q.6, it is recommended that maintenance during shutdown be completed on one division at a time. The recommended shutdown configuration is: one RHR division and support systems operating, one safety division administratively controlled to not be in maintenance and its barriers intact, and the third division undergoing maintenance.

In this configuration, flooding in any division will still result in at least one division being available for decay heat removal. If flooding occurred in the intact division, the water would be contained in that division and the operating division would continue to supply decay heat removal capability. The watertight doors are designed to stop water from entering the room (i.e., the door seals seat with water pressure from flooding external to the room) but only small leakage is expected past the seals from flooding in the ECCS room. If flooding occurred in either of the two other divisions, even if barriers in both divisions were breached for maintenance, the intact division would be available.

Due to maintenance activities there is also greater potential for debris clogging floor drains and preventing proper drainage of flood waters. The ABWR contains an adequate number of floor drains that if some were to become plugged the remaining drains would be available to direct water to the sump tanks. Some backup of water may occur but equipment mounted at least 20.32 cm off the floor would ensure that no equipment was damaged. Also, normal housekeeping tasks required by NRC regulations would keep debris to a minimum.

19R.4.3 Turbine Building

The turbine building is included as part of the detailed flood analysis because it contains equipment (e.g., condenser, condensate pumps) that could be used to achieve safe shutdown if required, and because it is connected to the control and reactor buildings through the service building access tunnel. Since the control and reactor buildings contain safety-related equipment, interbuilding flooding must be addressed.

The water sources contained in the Turbine Building are shown in Table 19R-1. These are:

- Circulating water

- Turbine service water
- Turbine cooling water
- HVAC normal cooling water
- Fire water
- Make up water (condensate)
- Reactor feedwater

The flood concern in the turbine building is filling up the condenser pit or the TCW equipment room until it overflows, at which point water has the potential to enter the service building. Of all the turbine building water sources, only the circulating water or turbine service water (both unlimited sources) are capable of flooding the turbine building and causing a flood concern.

If either the circulating or turbine service water systems were to develop a leak and flood the turbine building, several features exist to mitigate the consequences of the flood. There are four circulating water pumps and three turbine service water pumps with four circulating water pumps and two turbine service water pumps in operation supplying water from the intake structure to the screenhouse to the turbine building. Each pump has an associated motor operated isolation valve, with the isolation valve on any idle circulating water pump closed. The condenser pit and the TCW equipment room have redundant water level sensors arranged in a two-out-of-four logic. If flooding were to occur, the level sensors would alert the control room operator, trip the CWS and TSW pumps and close CWS and TSW isolation valves and open CWS and TSW siphon break valves.

If, for some reason, failure of one or more pumps or valves allowed the water level to rise up to the top of the condenser pit or the TCW equipment room and start flooding the grade level, the following additional flood protection features can mitigate the flood. At the ends of the turbine building there are non-watertight truck entrance doors. Water would be expected to flow under and around these doors and exit on the ground outside the turbine building. In addition, between the turbine building and service building is a normally closed and alarmed door. It is opened for passage and immediately closed. If the door is not closed immediately, the operator in the control room and plant security would be notified and a security guard sent to investigate. This door has an 20.32-cm (8-inch) step up from the turbine building to divert water away from the service building.

From the above, it can be concluded that the ABWR contains adequate mitigating features such that flooding in the turbine building would not prevent safe shutdown of the plant.

19R.4.4 Control Building

The control building contains safety-related equipment that could be used to achieve safe shutdown. Potential flooding of the control building could thus negatively impact the plants ability to reach and maintain safe shutdown.

Of the five sources of water in the control building listed in Table 19R-1, three of them (RCW, HNCW, and HECW) are relatively small and available room volumes and floor drains are adequate to mitigate flooding from these sources. Fire water is located on all floors (typically in the corridors not in equipment rooms). The fire water system flowrate is low and the system contains a flow alarm to alert the operator to a potential flooding condition. Adequate time would be available to locate and isolate fire water system leaks before any safety-related equipment would be damaged.

The main flooding concern in the control building are potential leaks in the reactor service water (RSW) system which is an unlimited source. Leaks in the RSW system could cause flooding damage to the reactor building cooling water (RCW) pump motors which are located on the bottom floor (i.e., -13150 mm level). The three divisions of RCW are physically separated in rooms with watertight doors and each RCW/RSW room is equipped with a sump pump.

All floors above the bottom floor contain divisionally separated floor drains. These floor drains direct any water in the rooms to the bottom floor where sump pumps are located. Safety-related equipment located in upper floor rooms (e.g., electrical control panels, emergency HVAC, divisional batteries) will be protected from flooding damage by equipment installed 20.32 cm (8 inches) from the floor and floor drains which will divert accumulated water to the bottom floor. Figure 19R-1 shows an elevation view of the control building.

The RCW/RSW rooms contain two sets of diverse level sensors in a two out of four logic. The first set of level sensors located at 0.4 meters from the floor are not safety grade and are intended to alert the control room operator to investigate for the presence of water in the RCW/RSW rooms. The second set of safety grade sensors are located at 1.5 meters and informs the control room operators that a serious condition exists that needs immediate attention. In addition, the upper level sensors trip the RSW pumps and close redundant supply side motor operated isolation valves in the RSW system of the affected division. Redundant motor-operated valves are provided to ensure that the UHS basin water does not gravity drain to the control building.

Figure 19R-2 depicts the RSW system. Given that the pumps have tripped, actuation of the redundant automatic isolation capability will terminate the flood. The ABWR UHS cannot gravity drain into the control building.

From the above, it is concluded that the only flooding concern in the control building is a leak in the RSW system that threatens the RCW system motors in the RCW/RSW rooms. If the upper level sensor alarms, it is a clear indication of a major RSW system leak in the RCW/RSW room.

The following assumptions are used in this “worst case” control building flood:

(1) The ultimate heat sink (UHS) is at an elevation higher than the control building RCW/RSW rooms such that draining of UHS water through the RSW system to the RCW/RSW rooms is possible.

(2) There is a maximum of 2000 meters of pipe (1000 each for supply and return) between the UHS and the RCW/RSW room which can be discharged to the RCW/RSW room following RSW pump trip.

(3) The size of the RSW crack is about 24 cm^2 (3.8 in^2) per ANSI/ANS-58.2 and BTP MEB 3-1.

(4) The leak occurs in the RCW/RSW room.

(5) No operator action was assumed.

The results of this “worst case” control building flood are:

(1) A leak occurs in the RCW/RSW room with the RSW pump running and the lower level sensor alarms at 0.4 meters.

(2) The water level continues to rise and reaches the high level sensor. The RSW pumps in the leaking division are tripped and redundant supply isolation valves are automatically isolated at 1.5 meters.

(3) Water flows into the RCW/RSW room from a maximum of 2000 meters of RSW pipe outside the control building.

(4) No water leaves the flooded room and only one division of RCW is affected.

From the above, it is concluded that there are no flooding concerns in the control building because most sources of water are either not large enough or leak at small enough rates that no equipment damage could reasonably occur. The only potential water source of concern is the RSW system but automatic isolation of a potential leak would occur and only one division of RCW would be affected. The reactor could be brought to safe shutdown using equipment from the other two divisions.

19R.4.5 Reactor Building

The reactor building flooding analysis will be presented in two parts: flooding inside and outside secondary containment. For both cases flooding concerns on each floor will be discussed as appropriate.

From Table 19R-1 it can be seen that there are several sources of water in the reactor building. Of these sources, fire water is the main concern (i.e., capable of damaging electrical equipment) on all floors outside secondary containment and on floors B1F and above inside secondary containment. Inside secondary containment on floors B3F and B2F potential flooding from breaks in the suppression pool and condensate make up lines are the major flood concerns. The other water sources are smaller and thus are of lesser concern. The following flooding discussion will thus focus on potential flooding damage from suppression pool and fire water breaks. Potential breaks in the emergency diesel generators fuel and lube oil systems will be treated separately. Table 19R-2 summarizes the reactor building flood sources and safety-related equipment for each floor.

Inside Secondary Containment

Floor B3F

This is the lowest floor in the reactor building and is entirely within secondary containment. The equipment that could be damaged by potential flooding are ECCS equipment (e.g., HPCF, RCIC, RHR), the CRD hydraulic control units, and the CRD pumps. (Figure 19R-3).

Flooding on this floor could occur from breaks in lines attached to the suppression pool or condensate storage tank (CST) and result in water accumulation in one of the three ECCS divisional rooms or within the divisional corridors. The ECCS rooms each contain watertight doors and have individual sump pumps. Flooding inside these rooms would result in loss of the ECCS function for that division. Suppression pool flooding in an ECCS room will reach an equilibrium level below the ceiling of each ECCS room. The watertight doors open into the corridor so that some water in the ECCS room may leak past the door seal into the corridor.

In the divisional corridor, maximum flooding could occur from line leaks associated with the suppression pool cleanup system. In addition, breaks in fire water standpipes on B3F or other floors inside secondary containment would accumulate in the B3F corridor. This is because all inside secondary containment floor drain lines are routed to the B3F corridor. The corridor volume is large enough to contain all of the water from the suppression pool or CST that could enter the corridor. The ECCS watertight doors would prevent any damage to ECCS equipment. The corridor sump pump alarms would alert the operator to flooding in these areas.

Flooding could also occur in the HPCF and RCIC rooms due to a leak in the line to the CST. The CST volume is less than the suppression pool but since it is located at a higher elevation, more water could potentially enter the reactor building (i.e., flood volume not limited by water level equilibrium conditions). The operator could close the CST isolation valve from the control room based on ECCS room sump pump operation and indication of a decreasing water level in the CST. It is expected that the operator would close the CST isolation valve before the low CST level was reached. If not, the ECCS system is designed to automatically shift HPCF or RCIC suction to the suppression pool. In this case, the normally closed suppression pool suction valve would be under water and not expected to open. Even if the suction valve were to open, suppression pool water would fill the ECCS room and flow on to the floor of B2F where it would return to the B3F corridor of the same division via floor drains. The volume of the ECCS

Room and the divisional corridor are sufficient to contain the flood water from both the CST and suppression pool.

Floor B2F

Inside secondary containment potential flooding on this floor could occur from the same sources as on B3F (i.e., suppression pool and fire water). A leak in the ECCS chase in each of the divisional valve rooms would cause water to flow down floor drains to the ECCS divisional room on B3F and be processed as previously discussed. Flooding in other areas would be routed through floor drains to the divisional corridor in B3F (Figure 19R-4).

Floors B1F-4F

All inside secondary containment flooding sources on floors B1F-4F would be routed through floor drains to the corridor of B3F and mitigated as discussed above for flooding on B3F.

CUW Line Breaks

The effects of an unisolated reactor water cleanup (CUW) break were analyzed to determine the potential impact on ECCS equipment. The specific effects considered were the possibility of a CUW break rupturing an ECCS wall due to pressure, and the possibility of a CUW break flooding an ECCS room.

The analysis was based on the ABWR secondary subcompartment pressurization analysis (SSPA) model, which postulates a break in each subcompartment through which a CUW high energy line passes. For each postulated break, pressure and temperature transients for each subcompartment were determined using the same methodology as used for compartment pressurization analyses reported in Subsection 6.2.3.

Since there are no common walls between ECCS and CUW quadrants, the pressure in the El(-)8200 mm corridor is the only CUW break source that could rupture an ECCS wall. The worst-case CUW break was determined from the SSPA to be a 200 mm double-ended break in the El(-)8200 mm pump rooms. The worst-case break in this analysis was defined as the break which will result in the highest pressure in the El(-)8200 mm Division B corridor. The entire corridor at elevation (-)8200 mm is modeled as one volume, assuming that divisional separation doors (at this elevation) are open and remain open during the high energy line break events (Figure 19R-3).

Break flow is comprised of flow from the reactor side (upstream of break) and from the balance-of-system (BOS) side (downstream of break to check valve). Reactor side break flow is modeled in two distinct phases: a period of unsteady flow called the inventory depletion period followed by steady, critical flow choked at flow venturi FE-001 (Figure 5.4-12, Sheet 1 of 4) inside the primary containment. BOS break flow consists of inventory depletion period flow only since check valves isolate this side of the break from feedwater, the downstream pressure source. The analysis conservatively assumes the complete BOS volume of water, including heat exchangers and filter-demineralizers, will flow out of the break. Steady critical flow is calculated using the Moody Homogenous Equilibrium Critical Flow model.

Analysis results showed that the maximum pressure and temperature values for the EL(-)8200 mm corridor during the worst-case CUW break are 0.028 MPaG and 381 K (107.9°C) respectively. These values are below the design pressure and temperature conditions (Tables 6.2-3 and 3I.3-15).

The volume of water released from the worst-case CUW break was determined to be 439 cubic meters, based on the density of water at 381 K (107.9°C). This calculation also assumed that the operator depressurizes the reactor 30 minutes after the break terminating the flood. Assuming conservatively that the Division B corridor contained all the released water. This volume of water will fill the corridor to a level of approximately 1.4 m. The ECCS watertight doors will ensure that no water enters any of the ECCS rooms. If the break were to occur during shutdown, administrative procedures ensure that at least one ECCS division will be available.

In view of the above, a CUW line break is not expected to cause failure of any ECCS walls. Also, the flood volume will be contained within the corridor.

Outside Secondary Containment

Flooding sources outside secondary containment are dominated by fire water leaks. Areas outside secondary containment start at level B1F (i.e., B3F and B2F are entirely within secondary containment.) B1F contains two sump pumps, one each in the Division B and C areas. Floors 1F-4F contain floor drains which all terminate on floor B1F.

The following discussion addresses specific flooding concerns on each floor outside secondary containment.

B1F

B1F contains the three emergency electric rooms. Flood damage in these rooms would affect power supplies to safety-related equipment. The major flooding source is fire water contained in standpipes in Division B and C areas outside the electrical rooms and in the clean access path near the entrance to all three divisional areas (Figure 19R-5). There is no water source in the Division A area or in the emergency electrical rooms of Division B or C.

Fire water breaks in Division B or C would be mitigated by the sump pumps in each area in conjunction with operation of sump overfill lines if necessary. The sump overfill lines are installed to mitigate the result of sump pump failures or flood rates in excess of sump pump capability [i.e. $0.0091 m^3/s$ (150 GPM)]. The sump overfill feature is a drain line through the B1F floor to the corridor of floor B3F inside secondary containment. The line contains a water filled loop seal which acts as the secondary containment boundary. If the water level were to rise above the sump, it would enter the overfill line and be directed to the B3F corridor. The flood would then be mitigated as previously discussed.

For a fire water break in the clean access area (i.e., outside entrance to all three divisional areas), the water could flow under the Division B and C fire doors and enter the sumps in those areas or, if necessary, the sump overfill lines as discussed above. The Division A room does not contain a sump but all equipment is mounted 20.32 cm (8 inches) off the floor and flood levels will not damage the equipment.

1F (Grade)

Fire Water flooding on this floor would be routed by floor drains to B1F and mitigated as discussed above. The emergency diesel generator (EDG) rooms could be flooded by fuel or lubricating oil. In order to preclude the possibility of oil plugging the other floor drains, the EDG rooms can contain any potential oil spills until a portable pump can be used to remove the oil. Figure 19R-6 is a schematic of floor if showing equipment that could be damaged by floods.

2F-4F

Flooding on these floors would be routed by floor drains either to B1F or the EDG rooms (for fuel oil or lubricating oil leaks) and mitigated as discussed above.

Summary of Reactor Building Deterministic Flooding Analysis

Flooding in the reactor building can be mitigated for all postulated flood sources by the following features:

(1) Inside secondary containment-floor drains in all floors above the first floor direct potential flood water to either the non-divisional corridor or, for ECCS line breaks, into the ECCS room on the first (B3F) floor. For flooding outside the ECCS rooms in the non-divisional corridor, watertight doors on each ECCS room prevents water from damaging electrical equipment. The corridor volume is large enough to contain any postulated water source. Flooding inside an ECCS room would only damage electrical equipment in the affected division. For large flooding sources leaking into an ECCS room, the water would eventually leak out into the corridor either:

   (a) Past the watertight door seals (since the doors open into the corridor)

   (b) Continue flooding up to the valve room on floor B2F and then flow under the fire door and down the floor drain to the B3F corridor.

(2) Outside secondary containment-floor drains in all floors above B1F route potential flood sources either to the sumps on B1F or, in the case of EDG oil leaks, to the EDG room. The sump pumps would deliver the water to the plant draining system. If the sump pumps fail or if flooding exceeds sump pump capacity [0.0091 m^3/s (150 GPM) per pump], sump overfill lines route the water to the B3F corridor inside secondary containment. The corridor can safely contain the flood waters. EDG oil flooding is contained within the EDG room for later removal with a portable pump.

From the above, it is concluded that all postulated internal flooding can be mitigated by the ABWR design. No more than one safety division of electrical equipment would be affected and the plant would be able to achieve safe shutdown using either of the two remaining safety divisions or other features (e.g., feedwater, condensate, AC independent water addition system).

19R.4.6 RSW Pump House

The RSW pump house contains the safety-related RSW pumps and support equipment that could be used to achieve safe shutdown. Potential flooding of the RSW pump house could thus negatively impact the plant's ability to reach and maintain safe shutdown.

Of the two sources of water in the RSW pump house listed in Table 19R-1, the firewater system flow rate is low, and the system contains a flow alarm to alert the operator to a potential flooding condition. Adequate time would be available to locate and isolate fire water system leaks before any safety-related equipment would be damaged.

The only flooding concern in the RSW pump house is potential leaks in the RSW system from the UHS, which is an unlimited source. Leaks in the RSW piping could cause flooding damage to the RSW pumps in the bottom floor and, if unisolated, the electrical and HVAC equipment in the floor above. The three RSW divisions are physically separated into watertight compartments to the roof level. Each room is equipped with a sump pump.

Two sets of water level sensors in each division pump room are arranged in a two-out-of-four logic. The first set of sensors send an alarm signal to the operator at 0.4 meters. The second set of sensors are actuated at 1.5 meters and send an alarm signal to the operator and trip the RSW pumps and close the RSW motor-operated isolation valves in the affected division. The RSW line before the automatic isolation valve in the pump discharge is isolable with operator action to unlock and close the normally open, locked open manual suction isolation valve.

From the above, it is concluded that the only flooding concern in the RSW pump house is an unisolable leak in the RSW piping that threatens the RSW motors and associated support equipment. If the upper level sensor alarms, it is a clear indication of a major RSW system leak in the RSW pump house.

The following assumptions are used in this “worst case” RSW pump house flood:

(1) The size of the RSW crack is approximately 103 cm^2 (16 in^2) per ANSI/ANS-58.2 and BTP MEB 3-1.

(2) The leak occurs in the RSW pump room.

(3) No operator action was assumed.

The results of this “worst case” RSW pump house flood are:

(1) A leak occurs in the RSW pump room and the lower level sensor alarms at 0.4 meters.

(2) The water level continues to rise and reaches the high level sensor. The RSW pumps in the leaking division are tripped at 1.5 meters.

(3) Water flows into the RSW room from the UHS.

(4) No water leaves the flooded division until it exits the HVAC supply and return at the roof of the RSW pump house. Only a single division of RSW and ECCS is affected.

From the above, it is concluded that there are no flooding concerns in the RSW pump house because most sources of water are either not large enough or leak at small enough rates that no equipment damage could reasonably occur. The only potential water source of concern is the RSW system and only one division of RSW would be affected. The reactor could be brought to safe shutdown using equipment from the other two divisions.

19R.5 Probabilistic Flood Assessment

19R.5.1 Introduction

The objective of the ABWR internal probabilistic flood analysis is to identify and provide a quantitative assessment of the core damage frequency due to internal flood events. Internal floods may be caused from large leaks due to rupture or cracking of pipes, piping components, or water containers such as storage tanks. Other possible flooding causes are the operation of fire protection equipment and human errors during maintenance. The spraying or dripping of water from high energy pipe breaks or fire protection equipment onto safety equipment are also considered in the analysis.

The internal flooding event may contribute to core damage frequency by:

(1) Initiating an accident sequence which in combination with the probability of random failure events could lead to core damage, and/or

(2) Disabling safety equipment required to achieve plant safe shutdown.

Therefore, both types of contributions are identified in the evaluation of internal flooding.

19R.5.2 Methodology

Event tree analysis is used to estimate core damage frequency due to internal flooding. The information developed in the deterministic phase of internal flooding analysis is used to construct event trees. Each node in an event tree diagram is dependent on the occurrence of previous events. Therefore, the event tree approach allows the dependence among the flooding initiating event and the success or failure of flooding detection, mitigation, and safe shutdown operation events to be combined properly. Thus, the probability of a specific flooding sequence will be the product of all system failure probabilities in the sequence.

In the ABWR probabilistic flooding analysis, one or more event trees are constructed for each building of flooding concern which is identified in the deterministic flood analysis (i.e., turbine, control, and reactor buildings). Floods in the remaining buildings were eliminated from the study based on a screening analysis. Each node in the event tree represents a different stage in the flooding progression. The first stage depicts the flooding initiating event. The existing nuclear power plant operating data and the data in the Hatch internal flood analysis are used to assess the ABWR flooding initiation frequency for each building of concern. The subsequent nodes represent the success or failure of flooding detection and mitigation features. The important equipment and their failure modes shown in Table 19R-4 are used to evaluate these events. The final node represents the plant safe shutdown operation. Success or failure at this point may lead either to a safe shutdown or to a core damage event. The probability of failure of this event is dependent upon the availability of systems (which survive internal flooding events). The conditional core damage given failure of the specific mitigating systems is obtained from the ABWR full power PRA.

Since the internal flooding contribution to the ABWR core damage frequency is expected to be very small, a bounding analysis approach is adapted in this study to simplify the computation. The following assumptions are used to construct and quantify the event trees:

(1) Any flooding event in a given building is assumed to be the worst case flood possible (i.e., a double ended shear of the largest pipe). This is a very conservative assumption because, in general, most floods result in leaks, not double ended breaks.

(2) When a flooding event progresses to fail equipment in a safety division, the complete division is assumed to have failed.

(3) Given the failure of a safety division, there is a conditional probability that plant shutdown using the other two divisions may result in core damage. This conditional probability of core damage has been evaluated using the ABWR full power PRA model. It has been determined from that PRA that the probability of core damage following loss of division 2 or 3 is equal and also greater than that for the loss of division 1. Conservatively, the division 2 (or 3) core damage probability was used in the study irrespective of which division was damaged by the postulated flood. Other conditional core damage probabilities (e.g., turbine trip without bypass) were also taken from the full power PRA.

(4) When the plant is shutdown, at least one division of equipment will be administratively controlled to ensure that all systems are available (i.e., not in maintenance). This is in addition to the operating division. (See Subsection 19Q.7 for a discussion of the ABWR shutdown maintenance recommendations). Flooding in

the intact division will be contained and will not affect the operating division and flooding in other divisions will not affect the intact division due to the presence of watertight doors and other flood barriers.

(5) For the RSW pump house flood evaluation, the data developed to quantify the Control Building flooding is used to perform a similar bounding evaluation of the consequences of flooding in the RSW pump house.

19R.5.3 Turbine Building

The turbine building does not contain any safety-related equipment with the exception of instrumentation associated with the Reactor Protection System and condensate pump motor trip circuit breakers. Although the instrumentation and the circuit breakers are located at or above elevation 19700 mm TMSL, well above the internal flood level described below and the external design basis flood level, and therefore protected from flooding, the flooding of the turbine building can initiate a reactor trip and may impact the safe shutdown of the plant if the water reaches the control building through the service building access tunnel. There are several water sources listed in Table 19R-1 that may leak into the turbine building. Only the two unlimited water sources (circulating water and turbine service water) are capable of flooding the turbine building and threatening safety equipment in the control building.

The circulating water system (CWS) has four pumps located in the main intake structure and each pump has an associated motor operated isolation (shutoff) valve. All of the four pumps are normally operating. The turbine service water (TSW) system has three pumps and three motor operated isolation valves. For a high power cycle heat sink plant design (i.e., the heat sink is at an elevation higher than grade level of the turbine building), an additional isolation valve is installed in each line. All of these are classified as non-safety grade equipment. If a large pipe break develops either in the CWS or TSW piping and initiates flooding in the turbine building, it is necessary either to trip all of the pumps (for a low heat sink) or to close all of the valves of both CWS and TSW systems to terminate the flood. Four redundant water level sensors (operating in a two-out-of-four logic) in the condenser pit and the TCW equipment room of the turbine building will generate a signal to alert the control room operator and trip all pumps and close all isolation valves and open siphon break valves in the CWS and TSW. A turbine trip and reactor shutdown will be initiated as a consequence of turbine building flooding.

If one or more pumps fail to trip or its associated valves fail to close, the water level may rise up to the top of the condenser pit or the TCW equipment room and reach grade level. If the operator received an alarm from the level sensors, even though the automatic protective features failed, the operator could open the truck entrance door (roll up type door) to allow the flood water to exit the building. If the operator does not receive an alarm, it is assumed that insufficient time will be available for the operator to open the truck door for a CWS or TSW break before the water level would effectively cause binding of the door and prevent opening.

Even if the door could not be opened, leakage past the door could be sufficient to keep the flood level below the bottom of the door entering into the service building. There is a 20.32-cm

(8-inch) step up from the turbine building to the service building door. If the flood level were to increase above 20.32 cm (8 inches), the service building door is a normally closed alarmed door that will offer resistance to flooding. If the door remains closed (it opens into the service building), the flood rate into the service building would be low enough that personnel in the service building would discover the flooding. There would be sufficient time to mitigate the flood before any damage to safety-related equipment could occur because the service building must flood before water could start to enter either the reactor or control buildings.

If the service building door fails open, the flood rate into the service building could be high enough to flood the service building to a significant level. Since the service building is the main entrance to the plant, personnel would hear or see the flood water and alert operators in the control room. Operator action could then be taken to manually trip the CWS or TSW pumps or close CWS and TSW isolation valves and open CWS and TSW siphon break valves. This is assuming that the level sensors failed but control circuitry for pump trip/valve isolation was still available.

If these actions failed, the flood waters would fill up the service building and could potentially enter the control or reactor buildings through several external normally closed watertight doors. On the first floor of the service building there is a watertight door which allows entrance to the reactor building cooling water (RCW) heat exchanger rooms. Failure of this door could allow the flood waters to damage equipment in all three safety divisions and potentially the battery room on the next level. If the watertight door to the RCW rooms does not fail, the water level would rise up in the service building to the next level where there are two watertight doors, one to the battery rooms of the control building and another to the reactor building clean access area. Failure of the watertight door to the battery rooms is assumed to result in core damage as loss of all DC (batteries and battery chargers) will occur. DC power is required for control of safe shutdown systems or to depressurize and use non-safety-related makeup sources such as condensate or AC independent water addition systems. Failure of the watertight door to the reactor building clean access area could result in damage to all three electrical divisions. If none of these watertight doors fail, flooding could continue to the next level where a normally open watertight door allows access to the control room area. Given the extensive flooding which had occurred to this point, the operators would have sufficient time and warning to close this watertight door. If the door failed or the operators failed to close it, no core damage should occur because automatic initiation of safety systems such as the high pressure core flooder would ensure that the core remained covered with water. Continued flooding would then reach grade level where the water could exit the service building through the main entrance. It is assumed that failure of any of the external watertight doors (except the control room door) results in core damage.

For the turbine building flooding for low and high Power Cycle Heat Sink (PCHS) configurations, respectively, the accident progression due to a large pipe break in the CWS (the worst case flooding) is described below. The CWS break is bounding for TSW flooding. The success or failure of each flood mitigating feature may have a significant impact on the result of accident progression. The description of events follows:

(1) A large CWS pipe break occurs in the turbine building (flooding initiator).

(2) Four redundant water level sensors (operating in two-out-of-four-logic) in the condenser pit of the turbine building detect and alert control room operators about flooding (detection).

(3) The bus breaker and/or pump breakers of CWS and TSW pumps open and trip all operating pumps (flooding prevention for low PCHS). Although siphoning could occur if the PCHS was higher than the bottom of the condenser pit, the siphon could not cause flooding to grade level. Therefore, the flood would be contained within the turbine building. In case of high PCHS, this feature is not credited for turbine building flood mitigation.

(4) CWS and TSW isolation valves close and siphon break valves open (flooding prevention for high or low PCHS).

(5) If the water level sensors alerted the operator to the flooding condition but the automatic flood protection features failed (CWS or TSW pump trip and valve isolation), time may be available for an operator to open the roll up truck entrance door to ensure that flood waters would exit the turbine building to the ground outside. If the water level sensors failed, it is assumed that by the time the operator becomes aware of the flooding condition that the water level will have reached the truck door and the water pressure against the door will not allow it to be opened.

(6) The roll up truck entrance door is not watertight and it is expected that it will leak if flooding occurs. The door may not fail open but it will buckle and could leak at a rate high enough to keep the flooding level below the level of the service building door [20.32 cm (8 inches)].

(7) The service building door is a normally closed and alarmed security door. It is not watertight but it should give significant resistance to flooding. If the door remains closed, the flood rate into the service building will be low.

(8) The control room operator can prevent flood damage to safety-related equipment by manually tripping the CWS pumps or closing the CWS and TSW isolation valves and open the CWS and TSW siphon break valves. It is assumed that if automatic features failed (given that the sensors did not fail) that control room actuations would also fail. If the sensors failed though, it may be possible to manually close the valves or trip the pumps from the control room once the operator is aware of the flooding condition. The probability of success is higher if the sensors did not fail because the operator would receive two indications of flooding: early in the scenario from the sensors in the turbine building and later from personnel in the service building if the flood were to propagate to that point. In either case, the watertight doors in the control and reactor buildings can prevent damage to safety-related equipment.

(9) Once the flood is terminated, the plant is manually shutdown using equipment not damaged by the flood. Failure to terminate the flood and any external watertight door failure is assumed to result in core damage.

The description of flooding for a high PCHS is the same as for a low PCHS except that the pump tripping feature is not credited.

The core damage frequency for turbine building flooding is extremely small for a low PCHS and slightly higher for a high PCHS.

19R.5.4 Control Building

The control building contains safety-related equipment and the potential flooding of the control building could impact the ability of the reactor to shutdown. The major flooding source in the control building is reactor service water (RSW) which is used to remove the heat from the RCW heat exchangers. The control building could potentially be flooded by the RSW system which is an unlimited water source. Unisolated breaks in the fire water system could cause inter-divisional flooding since doors separating safety divisions do not have sills. The control building has six floors (Figure 19R-1) but floor drains and stairwells would direct all potential flood waters which could potentially impact safe shutdown equipment to the bottom floor (-8,200 mm level).

19R.5.4.1 RSW Line Breaks

The RSW system is the only unlimited water source that could cause substantial flooding in the control building (Table 19R-1). It is highly unlikely that RSW flooding could damage more than one safety division. But the occurrence of several unlikely random failures and operator errors could result in flooding damage to equipment in all three RCW divisions.

The safety-related RCW motors are located on the -8,200 mm elevation (the lowest level of the control building) in three RSW/RCW rooms which are physically separated from each other by concrete walls and watertight doors. Each RSW/RCW room is also equipped with a sump pump.

Each of the three RSW divisions has two safety grade pumps and safety grade motor-operated isolation (shutoff) valves (Figure 19R-2). During normal operation, one pump in each division is operating and the other pump is in standby. If a large leak or a pipe break develops in any one of the RSW/RCW rooms, tripping the pump and closing the associated valves in the affected division will stop the flooding. If the RSW pump trips and one isolation valve fails to close, then the redundant set of isolation valves prevents continued flooding. Four redundant non-safety grade water level sensors (operating in a two-out-of-four logic) at the lower level (0.4 meters) of the control building will generate a signal to alert the control room operator. If the control room operator fails to take appropriate action to stop the water flow, the second set of safety grade level sensors will actuate when the water reaches the 1.5 meter level of the room. At this level, the sensors (operating in two-out-of-four logic) not only send an alarm signal to the operator but also trip the affected RSW pump and close all the isolation valves. The upper level sensors are diverse from the lower level sensors.

It is assumed that only one division of RCW is lost if the affected RSW pump trips or the isolation valves close. In case the level sensors fail to detect the flood, the water will rise to the second floor level and may start flowing into the other two remaining divisional RCW/RSW rooms. The level sensors in these two divisional rooms will generate a signal to alert the operator about the flood. If the sensors in the first division failed, the sensors in the other divisions are assumed to fail with a high probability to account for common cause failures (CCF). Only one division is assumed lost if the operator is successful in isolating the flood, otherwise the loss of all three safety divisions is possible.

Flooding in the RSW pump house was not addressed because the ultimate heat sink including the RSW pump house is outside the scope. The COL applicant must complete a plant specific probabilistic analysis of flooding in the RSW pump house.

For the accident progression for a control building RSW flood, a large pipe break in the RSW in the RSW/RCW heat exchanger room is considered to be the worst case flooding in the control building. The description of events follows:

(1) A large RSW pipe break occurs in the RCW/RSW room in the control building (flooding initiator).

(2) Four redundant non-safety grade water level sensors located at the 0.4 m level detect and alert the control room operator about flooding (detection).

(3) The operator investigates the presence of water and isolates the flooding by tripping the affected pump and/or closing the isolation valve (flooding prevention).

(4) If the first level of detection fails or the operator fails to isolate the flowing water, then water continues rising in the room and the second set of diverse sensors located at 1.5 meters detects the water and trips the affected pump and closes all motor operated valves in the RSW system. Meanwhile the signal alerts the control room operator of the flooding condition (flooding prevention).

(5) If the operator is successful in isolating the flooding, one safety division is assumed lost, otherwise the loss of all three safety divisions may occur (flooding mitigation).

(6) The pump breaker of the affected RSW pump opens to trip the pump and/or the isolation valves close automatically (flooding isolation).

(7) In the unlikely event that the flood is not mitigated by automatic means or operator action, the water rises to the second floor level and starts flowing into the other two remaining RCW/RSW rooms. The first set of level sensors in these two divisional rooms detects the water and alerts the operator the third time (flooding detection).

This operator action is considered separately from the previous high water alarm action because the alarm would occur approximately 45 minutes later and be annunciated as occurring from a different division.

(8) Reactor safe shutdown using available equipment (reactor shutdown).

The core damage probability for an RSW flood is estimated to be extremely small.

19R.5.4.2 Fire Water System Breaks

The ABWR fire water system is a moderate energy system that is designed to withstand a 0.3g seismic event. The system is very rugged and large breaks of the eight inch header piping are not expected. The most probable failure mechanism for the fire water piping would be a crack which would not propagate to a large break because of the low pressure of the system (approximately 0.69 MPa). In keeping with the bounding analysis methodology used in other parts of the flooding PRA, a large break (0.086 m^3/s) will be assumed. The frequency of this bounding case large break of the fire water piping is small. This value was obtained from a review of the Limerick Generating Station flooding PRA for a fire suppression system pipe double ended shear.

For fire water system flooding in the Control Building, the system unavailabilities are taken from the ABWR full power PRA and the operator failure probabilities are based on methods used in Chapter 10 of Swain and Guttman given the many sources of information available indicating a fire water system break and the simple action of stopping the fire water pumps.

Fire water standpipes are located on all floors of the Control Building. A large break on any upper floor will result in a 0.086 m^3/s flood which will be directed by the floor drain system to the RCW rooms on the first floor.

The ABWR does not contain sills on doors between safety divisions and fire doors can have up to a 1.9 cm gap at the bottom per National Fire Protection Association (NFPA 80) requirements. The floor drain system, although not finalized yet, will be designed so that this break flow can be accommodated taking into account all the drain lines in the three safety divisions. In addition, water may flow under the fire doors and down stairwells and elevator shafts. Due to the available drainage sources, the water level on any upper floor will not exceed 20.32 cm which is the minimum height that all water sensitive equipment must be mounted from the floor (ABWR Tier 2 Section 3.4). Therefore, no damage to equipment on any of the upper floors will occur due to emersion in the flood water. Spray onto safety-related equipment is not a concern because all fire water system flow will be directed to the three RCW rooms on the first floor.

Following a break in the fire water piping, the operator will receive indication that the fire water system pump(s) have started due to low system header pressure. Within a few minutes, he will also receive indication of excessive sump pump operation in the Control Building. As no fire alarm will accompany the fire water system actuation, the operator would send someone to confirm the nonexistence of a fire in the Control Building. Water flowing past hose stations causes actuation of audible alarms in each hose station. These alarms will alert personnel to actuation of the fire suppression system and help direct them to the break location. Once it has been determined that no fire exists, an operator can trip the fire pumps locally and close manual valves, if necessary, to terminate the flood. It is estimated that it will take a minimum of 30 minutes to isolate the flood (i.e., no credit for operator action within 30 minutes).

Based on the size of the three RCW rooms and the maximum fire water flow rate, it will take over one hour to flood the three RCW rooms up to the bottom of the RCW motors (minimum of 400 mm from the floor). If the flood is not terminated in approximately one hour, all three divisions of RCW are assumed lost. This assumes a double ended shear of the fire water piping. If a design basis crack (ANSI/ANS 56.11) were to occur (the more probable occurrence) it would take approximately 10 hours for water to accumulate to a level of 400 mm.

Given that three divisions of ECCS are lost due to the loss of RCW, the plant must then be manually shutdown per Technical Specifications using feedwater/condensate and the main condenser. After isolation of the fire water system flood, fire water would also be available for make up if required. RCIC does not require direct cooling by RCW, so it would be available for make up during this event.

The CDF for fire water flooding in the control Building is extremely small.

19R.5.5 Reactor Building

The reactor building contains safety-related equipment and the potential flooding of the reactor building could impact the safe shutdown of the plant. From the flooding stand point, the reactor building is divided into two parts:

(1) Inside secondary containment

(2) Outside secondary containment

19R.5.5.1 Flooding Inside Secondary Containment

The major flooding sources inside of the secondary containment are the suppression pool, condensate makeup and fire water. The rest of the potential flooding sources are listed in Table 19R-1. The lowest floor of the reactor building (B3F) is entirely within the secondary containment. The safety-related equipment that can be damaged by potential flooding are in the three divisional ECCS rooms. Each of these rooms have watertight doors and individual sump pumps. The flooding inside these rooms would result in loss of ECCS equipment (e.g., HPCF, RCIC, RHR).

Flooding on this floor (B3F) could occur due to a pipe break attached to the suppression pool and result in water accumulation in one of the three ECCS divisional rooms or within the non-divisional corridor. The ECCS rooms are large enough to contain the water that could enter from a suppression line break (described in Subsection 19R.4.5). The watertight door of the affected ECCS room opens into the corridor and the corridor sump pump alarms alert the operator to the flooding in this area. The watertight door of the unaffected ECCS room prevents the water in the corridor from entering the other ECCS rooms. Therefore, flooding on this floor can not impact more than one division due to:

(1) The corridor volume is large enough to contain the largest flood source (suppression pool)

(2) The watertight doors prevent the water from entering the unaffected ECCS rooms. Common cause failure of the watertight doors is addressed.

At higher elevations, the potential flooding due to the largest water source (fire water) is directed to the B3F corridor (the lowest level) by floor drains and stairwells. The corridor volume is large enough to contain any one of the upper level water sources.

The flooding sources outside secondary containment are dominated by fire water leaks. Areas outside secondary containment start at level B1F. This level contains two sump pumps, one each in the Division B and C areas. Floors 1F through 4F contain floor drains which all terminate on floor B1F. Floor drains in all floors above B1F route potential flood sources to the sumps on B1F. The sump pumps would deliver the flooding water to the plant drainage system. If the sump pumps fail or if flooding exceeds sump pump capacity, sump over-fill lines route the water to the B3F corridor inside secondary containment. The corridor can safely contain the flood waters. In the case of emergency diesel generator (EDG) oil leaks, the EDG room can contain the spill until portable pumps can be brought in to remove the oil. As described in detail in Subsection 19R.4.5, the flooding outside secondary containment can not impact more than one safety division.

The worst case reactor building flooding could potentially occur in the HPCF or RCIC rooms (inside secondary containment) due to a leak in the line to the condensate storage tank (CST). If the operator fails to close the CST isolation valve (in spite of sump pump alarm and the indication of CST water level decreasing), the suction line of the affected ECCS system automatically realigns to the suppression pool on low CST level. In this case, the normally closed suppression pool suction valve would be under water and not expected to open. Even if the suction valve were to open, the suppression pool water would fill the ECCS room and flow to the floor of B2F where it would return to the B3F corridor via floor drains. The volume of the ECCS room and the divisional corridor are sufficient to contain the flood water from the CST or the suppression pool.

If a leak were to occur during shutdown, some of the ECCS rooms may be open for maintenance. ABWR procedures specify that one safety division will be maintained intact at all times during shutdown. If a leak were to occur in the intact division, the operator would be directed to close the ECCS door to an unaffected division before attempting to mitigate the flood in the protected division. The ABWR Technical Specifications require at least two ECCS divisions be operable during shutdown except under certain conditions in mode 5 (reactor cavity flooded). Thus, in general, one other safety division would be available to maintain decay heat removal. Also, non-safety grade equipment (e.g., condensate, AC independent water addition system) can be used if necessary for decay heat removal. Appendix 19Q discusses the ABWR decay heat removal reliability during shutdown.

Flooding in the reactor building on floor B3F inside an ECCS room, flooding on B3F in the divisional corridor, and fire water flooding outside secondary containment are the three worst case reactor building floods.

Flooding inside an ECCS room due to a leak in the suppression pool suction line upstream of the isolation valve results in an unisolable suppression pool leak. The first indication of a flood will be actuation of the ECCS sump pump. No operator action to stop the flooding is possible, but the ECCS room volume is large enough to contain the amount of water that will enter the ECCS room before the water levels in the ECCS room and suppression pool reach equilibrium. Equipment in the affected ECCS room would be damaged but the watertight doors would prevent water from damaging the other two safety divisions. Failure of the watertight doors results in loss of all three ECCS rooms and only the AC independent water addition is available for shutting down the plant. The core damage probability for this event is extremely small. As mentioned in Subsection 19R.4.5, a break in a CST line could potentially allow more water to enter the rooms than a suppression pool line break, but the leak could be isolated and the results are the same (i.e., loss of only one ECCS division). Therefore, the core damage probability will be lower than for an unisolable suppression pool line break and no event tree was completed for a CST line break.

For flooding in the non-divisional corridor from a break in the suppression pool line, the sumps high water alarm would alert the operators to the presence of a flood. In this case, the flooding can be stopped by appropriate operator action. If the operator fails to stop the flooding, the corridor volume is large enough to contain the amount of water that could enter from the suppression pool. The watertight doors on the ECCS rooms will prevent any damage to safety equipment and the plant can be safely shutdown using the three divisions of safety equipment. The core damage probability for this event is extremely small.

In the Reactor Building, fire water flooding inside secondary containment is bounded by flooding due to postulated breaks in lines from the suppression pool or condensate storage tank (CST). The maximum water level inside secondary containment is approximately the same for breaks in the fire water system, CST, or lines from the suppression pool since they each are capable of supplying the same volume of water but it would take over seven hours to drain the fire water system. By contrast, a break in a line from the suppression pool would result in an equilibrium level in the corridor in approximately one hour and it would take over five hours for the CST to drain. Even if the fire water flood was not isolated within 7 hours, the watertight doors on the ECCS rooms would prevent damage to any safety-related equipment. Therefore, fire water system flooding inside secondary containment will have a very low CDF and since is dominated by breaks in lines from the suppression pool, a separate event tree was not completed.

19R.5.5.2 Flooding Outside Secondary Containment

Flooding outside secondary containment could affect the emergency electric motor control rooms and other equipment for all three safety divisions. The flooding concern is a break in a fire water standpipe. For breaks in the fire water system outside secondary containment, the situation is similar to flooding in the Control Building. Floor B1F is the lowest floor outside secondary containment and floods on all floors above this are directed to B1F via floor drains. Floor B1F contains two sumps outside secondary containment. The overfill lines direct water in excess of the sump pump capacity to the corridor of the first floor (B3F) inside secondary containment. As the sump pump capacity will not handle a full header break, some water will enter the overfill lines and flow into the B3F corridor. The overfill lines may not be able to pass full fire water system flow either, so water will flow under fire doors and may enter the three Class 1E electrical equipment rooms. Equipment in these rooms is raised at 20.32 cm off the floor and it is estimated that will take over one hour for the flood to damage equipment in these rooms. Water could also flow down the stairwells to the first floor but this was conservatively excluded.

The initiating events frequency will be very low and similar to the Control Building since the same pipe and configuration are used and the length of piping is similar. The time for operator action is approximately the same as for the Control Building (one hour) and the effect of not isolating the flood is loss of the three ECCS divisions due to loss of power. RCIC will not be affected by the power loss and thus is assumed to be available for this scenario. As in the case of the Control Building, feedwater/condensate, the main condenser, and fire water (after isolation of the break) will be available. The CDF for fire water system flooding outside secondary containment is extremely small.

19R.5.6 RSW Pump House

The RSW pump house contains the safety-related RSW system, which is used to remove the heat from the RCW heat exchangers. The RSW pump house could potentially be flooded by the RSW system which is an unlimited water source. Unisolated breaks in the fire water system could cause inter-divisional flooding since the RSW divisional separation splits the RSW pump house into three, watertight compartments. Watertight doors separate the RSW divisions.

19R.5.6.1 RSW Line Breaks

The UHS is an unlimited water source that could cause substantial flooding in the RSW pump house (Table 19R-1). It is highly unlikely that RSW flooding could damage more than one safety division. But the occurrence of several unlikely random failures and operator errors could result in flooding damage to equipment in all three RSW divisions.

The safety-related RSW pump motors are located on the lowest level of the RSW pump house in three RSW pump rooms which are physically separated from each other by concrete walls and watertight doors. Each RSW pump room is also equipped with a sump pump.

Each of the three RSW divisions has two safety grade pumps, safety grade discharge MOVs, a common header supply and return MOV and manually operated, normally open and locked open pump suction isolation valves. During normal operation, one pump in each division is operating and the other pump is in standby. If a large leak or a pipe break develops in any one of the RSW rooms, tripping the pump and closing the associated MOVs in the affected division will stop the flooding if it is downstream of the pump discharge MOV or in the RSW return line to the UHS. If the break is upstream of the RSW discharge MOV, the break is unisolable without operator action to close the manually operated suction isolation valves. Four redundant non-safety grade water level sensors (operating in a two-out-of-four logic) at the lower level (0.4 meters) of the RSW pump room will generate a signal to alert the control room operator. If the control room operator fails to take appropriate action to stop the water flow, the second set of safety grade level sensors will actuate when the water reaches the 1.5 meter level of the room. At this level, the sensors (operating in two-out-of-four logic) not only send an alarm signal to the operator but also trip the affected RSW pump and close all the isolation valves. The upper level sensors are diverse from the lower level sensors.

It is assumed that one division of RSW is lost in the event of flooding in the RSW pump room. Failure of the watertight doors between the RSW divisions will allow the flood water into a second or third RSW pump room. Failure of all RSW pump rooms will require core cooling from the power conversion system or the AC independent water addition system (ACIWA).

A large pipe break in the RSW supply line in the RSW pump room is considered to be the worst case flooding in the RSW pump house. The description of events follows:

(1) A large RSW pipe break occurs in an RSW pump room (flooding initiator).

(2) Four redundant non-safety grade water level sensors located at the 0.4 m level detect and alert the control room operator about flooding (detection).

(3) The operator investigates the presence of water and isolates the flooding by tripping the affected pump and/or closing the manually operated suction isolation valve (flooding prevention).

(4) If the first level of detection fails or the operator fails to isolate the flowing water, then water continues rising in the room and the second set of diverse sensors located at 1.5 meters detects the water and trips the affected pump and closes the five automatic motor operated valves in the RSW division. Meanwhile the signal alerts the control room operator of the flooding condition (flooding prevention).

(5) If the operator is successful in isolating the flooding, one safety division is assumed lost, otherwise the loss of all three safety divisions may occur (flooding mitigation).

(6) In the unlikely event that the flood is not mitigated by automatic means or operator action, the water rises to the electrical and HVAC room and floods the entire RSW compartment. Water exits the compartment through the HVAC intake and discharge vents.

(7) Failure of a watertight door at the pump room or the electrical and HVAC room could allow a second division of RSW to become flooded.

(8) Common cause failure of multiple watertight doors will disable the entire RSW system, forcing the plant to rely on the Power Conversion System and the ACIWA.

(9) Reactor safe shutdown using available equipment (reactor shutdown).

The core damage probability for an RSW pump house flood is estimated to be extremely small.

19R.6 Results and Interface Requirements

This subsection summarizes the results of the ABWR probabilistic flooding analysis including insights gained from the analysis, important flooding design features, operator actions to prevent/mitigate potential flooding, system reliability goals to ensure validation of probabilistic core damage estimates, and the conclusions reached on the ability of the ABWR to withstand postulated internal flooding.

19R.6.1 Results

This conservative bounding analysis for the turbine, control and reactor buildings, and the RSW pump house shows that the CDF for internal flooding is very small and is less than the total plant CDF.

19R.6.2 Insights Gained from Analysis

Completion of the ABWR probabilistic flooding analysis has led to the following insights on the flooding mitigation capability of the ABWR:

(1) The ABWR due to its basic layout and safety design features is inherently capable of mitigating potential internal flooding. Safety system redundancy and physical separation for flooding by large water sources along with alternate safe shutdown features in buildings separated from flooding of safety systems give the ABWR significant flooding mitigation capability. Also, fire protection features such as floor and wall penetrations and fire barriers help to contain potential flood sources.

(2) Due to the inherent ABWR flooding capability discussed above, only a small number of flooding specific design features must be relied on to mitigate all potential flood sources. The flood specific features are: watertight doors on control and reactor building entrances, ECCS rooms, RCW rooms, and all levels of the RSW pump house; floor drains in reactor and control building; RSW pump trip, redundant isolation valve closure on high water level in the RCW rooms or RSW pump rooms; CWS and TSW pump trip and valve closure on high water level in the condenser pit or the TCW equipment room; and sump overfill lines on floor B1F of the reactor building.

(3) All postulated floods can be mitigated without taking credit for operation of sump pumps.

(4) While timely operator action can limit potential flood damage, all postulated floods can be adequately mitigated (from a risk perspective) without operator action.

19R.6.3 Important Design Features

Table 19R-7 lists the features of the ABWR design that contribute to its ability to withstand postulated flooding. The list includes general features as well as specific features in each building for identified potential flood sources. Also included is the rationale for how each feature could prevent/mitigate flood damage. The table also identifies the new features that were added as a result of the flooding PRA.

The features that are considered important to mitigate flooding in the ABWR are discussed in Subsection 19.8.5.

19R.6.4 Operator Actions

From a flooding perspective there are several operator actions that, if taken in a timely manner, could mitigate the effects of potential internal flooding. These are:

(1) Isolation of flood sources following detection by sump pump operation and alarms or floor water level detectors. Potential flood sources as listed in Table 19R-1 can, in general, all be isolated by appropriate operator actions.

(2) A leak in the suppression pool line upstream of the HPCF/RCIC suction valve cannot be isolated but operator action to ensure other divisional watertight doors are closed could prevent damage to equipment in more than one safety division.

(3) Open doors or hatches to divert water from safety-related equipment following postulated floods.

(4) Close watertight door at entrance to the control room area if floods in the turbine building result in service building flooding.

(5) Open the truck entrance door in the turbine building to prevent a CWS or TSW break from entering the service building. This will prevent external flooding of the control and reactor buildings from a CWS or TSW line break.

(6) A leak in the RSW supply line before the manually-operated, locked open suction isolation valve cannot be isolated. This line is designed to break exclusion criteria which minimizes the likelihood of a major failure or leak.

In the PRA, operator action of responding to a flood alarm has been modeled. Floods in the turbine, control and reactor buildings, or the RSW pump house result in alarms in the control room. It is assumed that flood procedures exist and operators are well trained to respond to flooding events. The operator failure probability depends upon the time available for taking action and are conservative values based on engineering judgment. The operator actions are not important in the sense that automatic actions will prevent core damage. However, timely operator action could limit the consequences of flood events.

19R.6.5 Reliability Goals (Input to RAP)

The results of the probabilistic flooding analysis indicate that the following equipment is important to reducing the risk due to internal floods and should be included in the ABWR reliability assurance program:

- Watertight doors
- Sump level switches
- Pump trip
- Isolation valve closure

19R.6.6 Conclusions

The conclusions from the ABWR probabilistic flooding analysis is that the risk from internal flooding is acceptably low. The estimated core damage frequency from all internal flood sources is very small for a low PCHS and slightly higher for a high PCHS.

The ABWR is inherently safe regarding internal flood events and no operator actions are required to mitigate postulated floods although timely operator action can reduce damage to equipment and flood severity. All potential floods have been analyzed and it has been shown that the plant can be safely shutdown with low risk to plant personnel and the general public.

Table 19R-1 Sources of Water

Source	Capacity	Flow Rate	Turbine Building	Control Building	RWS Pump House	Reactor Building	Service Building	Radwaste Building
Reactor Service Water (RSW)	Unlimited	675 liters/sec/pump (10,700 GPM/pump) (6 pumps)		X	X			
Turbine Service Water (TSW)	Unlimited	1,278 liters/s/pump (20,255 GPM/Pump) (3 pumps)	X					
Circulating Water (CW)	Unlimited	18,927 liters/s/pump (300,000 GPM/pump) (4 pumps)	X					
Fire Water	1,249,182 liters/tank (330,000 gal/tank) (2 tanks)	94.6 liters/s/pump (1503 GPM/pump) (2 pumps)	X	X	X	X	X	X
Reactor Building Cooling Water (RCW)	257,407 liters/div. (68,000 gal/div)	394 liters/s (A,B) (6252 GPM (A,B)) 344 liters/s (C) (5466 GPM (C))		X		X		X
HVAC Normal Cooling Water (HNCW)	113,562 liters (30,000 gal)	156 liters/s (2466 GPM) (5 pumps)	X	X		X	X	X
HVAC Emergency Cooling Water (HECW)	113,562 liters (30,000 gal)	7.57–15.77 liters/s (120–250 GPM) (Chilled) 21.51–35.58 liters/s (341–564 GPM) (Condenser)		X		X	X	X
Makeup Water (Condensate)	2,108,468 liters (557,000 gal)	104.10 liters/s (1,650 GPM)	X			X		X
Makeup Water (Purified)	757,080 liters (200,000 gal)	19.43 liters/s (308 GPM)				X		

Table 19R-1 Sources of Water (Continued)

Source	Capacity	Flow Rate	Turbine Building	Control Building	RWS Pump House	Reactor Building	Service Building	Radwaste Building
Turbine Cooling Water (TCW)	378,540 liters (100,000 gal)	2524 liters/s (40,000 GPM)	X					
Feedwater	757,080 liters (200,000 gal)	2750 liters/s (43,600 GPM) (4 pumps)	X			X		
City Water	Unlimited	12.62 liters/s (200 GPM)					X	
Suppression Pool	3,579,754 liters (945,674 gal)					X		

Table 19R-2 Reactor Building Floor Descriptions

Designation	Elevation (mm) (TMSL)*	Safe Shutdown Equipment	Potential Flooding Sources
100 (B3F)	-8200	HPCF, RHR (LPFL), RCIC	Condensate Storage Tank (CST), Suppression Pool (SP), Fire Water (FW), Reactor Building Cooling Water (RCW), Purified Makeup Water (MP)
200 (B2F)	-1700	Instrument Racks (e.g., RCIC)	CST, SP, FW, RCW, MP
300 (B1F)	4800	IE MCCs, Remote Shutdown Panel	FW, RCW, CST, MP
400 (1F)	12300 (Grade)	EDGs and EDG Control Panel, and Valve Rooms Oil (LO), EDG Fuel Oil (FO)	FW, RCW, CST, MP, EDG Lube
500 (2F)	18100	EDG Control Panels and Cooling Fans	FW, RCW, MP
600 (3F)	23500	EDG Auxiliaries (e.g., Air Compressor, Fuel Oil Tank), Standby Liquid Control (SLC)	FO, FW, RCW, SLC, MP
700 (M4F)	27200	Emergency HVAC	HVAC, FW, RCW,MP
800 (4F)	31700	RCW Surge Tank, EDG Exhaust Fan	RCW, FW, MP

* Typical mean seawater level

Table 19R-3 Not Used

Table 19R-4 Important Equipment for ABWR Probabilistic Flood Analysis

Failure Mode or Common Cause Factor Component, Element	Failure Mode
1. Level Sensors	Fail to operate Fail to operate (standby)
2. Isolation Valve	Fail to close
3. Motor Driven Pump	Fail to trip pump (Breaker fails to open)
4. Operator Fails to Act	Available time < 12 min Available time < 30 min Available time < 1 h Available time > 1 h
5. Common Cause Factor (multiple Greek letter)	Beta Gamma Delta Others
6. Over Fill Line	Clogged
7. Sump Pump	Exceeding the design capacity
8. Watertight Doors	Fail to stay closed Common cause

Data obtained from the following references:

1. EPRI ALWR Utility Requirement Document
2. “Handbook for Human Reliability Analysis with Emphasis on Nuclear Power Applications”, NUREG-CR-1287

Table 19R-5 Not Used

Table 19R-6 Not Used

Table 19R-7 ABWR Features to Prevent/Mitigate Flooding

Feature	Benefit
General Features	
Floor/wall penetrations are sealed.	Restricts water flow from entering or leaving divisional rooms.
Alarmed doors.	Alert operator to loss of room integrity.
Pipe chases.	Contains potential flooding of high pressure systems (e.g., feedwater and main steam in tunnel between reactor and control buildings).
High pressure or high temperature lines not routed through floors or walls separating two different safety divisions.	Reduces potential for high energy pipe break to affect more than one safety division.
Room sump pumps and alarms.	Remove water from rooms to protect equipment and to alert operators to potential flooding conditions.
Floor drains.	Directs water from room to lower floors for removal by sump pumps or other means.
Room water level alarms, pump trips, and isolation valve closures.	Alert operator to potential flooding and isolate flooding source(s).
Fire water flow initiation alarmed in the control room.	Alerts operator to initiation of fire water flow and possible flood concern.
*Motor control centers have NEMA Type 4 enclosures.	Protects MCCs from damage due to water from pipe break or fire hose.
Drip proof motors.	Protects motors from falling liquids.
Turbine Building	
*Four water level sensors in condenser pit and TCW equipment room in two-out-of-four logic. When actuated they alarm and trip circulating water and turbine service water pumps, close isolation valves and open siphon break valves. They will also alert the operator to other floods such as TSW.	Isolates flooding source and alerts operator to potential flooding.
Non-watertight truck entrance door.	Expected to allow any internal flood water to leak out of turbine building to the outside and thereby not allow water to reach control or reactor buildings.
Normally closed and alarmed fire door between turbine building and service building tunnel (access to control and reactor buildings).	Restricts potential flood water in turbine building from entering control or reactor buildings via the service building.

Table 19R-7 ABWR Features to Prevent/Mitigate Flooding (Continued)

Feature	Benefit
A 20.32-cm (8-inch) step up to the door between turbine building and service building.	Direct flood water away from service building back into the turbine building thus preventing potential flooding in reactor and control building.
Control Building	
RCW/RSW rooms and entrances to control building from the service building have watertight doors.	Prevent flooding in one division from affecting other divisions and external flooding from the service building due to potential CWS or TSW floods in the turbine building.
Floor drains route water to first floor (RCW/RSW rooms).	Protects equipment in rooms from water damage and directs water to sump pumps.
RCW/RSW rooms have sump pumps.	Remove flood water from room to prevent damage to equipment.
RCW/RSW room floor water level sensors alarm at 0.4 meters and trip RSW pumps and close redundant isolation valves at 1.5 meters in affected division.	Alert operator to RCW leak and shutoff RSW supply if flooding were to continue.
RSW Pump House	
RSW pump rooms and electrical and HVAC rooms have watertight doors.	Prevent flooding in one division from affecting other divisions.
Watertight doors in the RSW pump house are alarmed in the Control Room if not dogged closed.	Additional barrier to ensure watertight integrity between pump rooms is maintained.
Floor drains route water to first floor (RSW pump rooms).	Protects equipment in rooms from water damage and directs water to sump pumps.
RSW pump rooms have sump pumps.	Remove flood water from room to prevent damage to equipment.
RSW pump room floor water level sensors alarm at 0.4 meters and trip RSW pumps and close redundant isolation valves at 1.5 meters in affected division.	Alert operator to RSW leak and shutoff RSW supply if flooding were to continue.
Reactor Building	
Rooms on floors B2F-4F have floor drains. Inside containment floor drains collect on floor B3F. Outside containment floor drains (except EDG room) collect on floor B1F. EDG room oil leaks are contained in the room.	Potential flood waters routed to rooms with sump pumps for processing by plant waste system. EDG potential oil flooding has relatively small volume and the oil is contained until a portable pump can be brought in to remove the oil.

Table 19R-7 ABWR Features to Prevent/Mitigate Flooding (Continued)

Feature	Benefit
*Wall penetrations through ECCS rooms on floor B3F must be above specified high water mark or sealed and tested to prevent leakage.	Prevent leakage into ECCS divisional rooms from potential flooding in corridors.
Fire water not routed through ECCS rooms.	Reduces probability of flood from broken fire water lines impacting ECCS equipment.
Equipment in all rooms mounted 20.32 cm off the floor.	Enhance ability to survive potential flooding.
High level alarms in room sumps.	Alert operator to potential flooding.
Steamline tunnel pipe chase.	Contains potential flooding from high pressure main steam and feedwater.
ECCS rooms (Floor B3F) have watertight doors. Doors open into corridor.	Prevent flooding in corridor from entering ECCS Rooms. Contains leaks in ECCS room to limit damage to one safety division (small leakage past door seals may occur).
Entrances to the reactor building control room and clean access areas from the service building have watertight doors.	Prevents flooding of these areas due to turbine building CWS or TSW leaks that propagate to the service building.
Floor B3F corridor volume adequate to contain single largest flood source (suppression pool).	Largest flood mitigated without need to rely on active components (sump pumps).
*CRD rooms have non-watertight doors. Doors open into corridor.	Restricts water in corridor from entering room. Flooding in CRD room will leak out into corridor.
*Sumps on floor B1F outside secondary containment have overfill lines to B3F corridor.	Ensure adequate mitigation for outside containment flooding if sump pumps fail or flood rate exceeds sump pump capacity.

* New Feature

The following figure is located in Chapter 21:

Figure 19R-1 Control Building (See Figure 1.2-15 and Figure 9A.4-11)

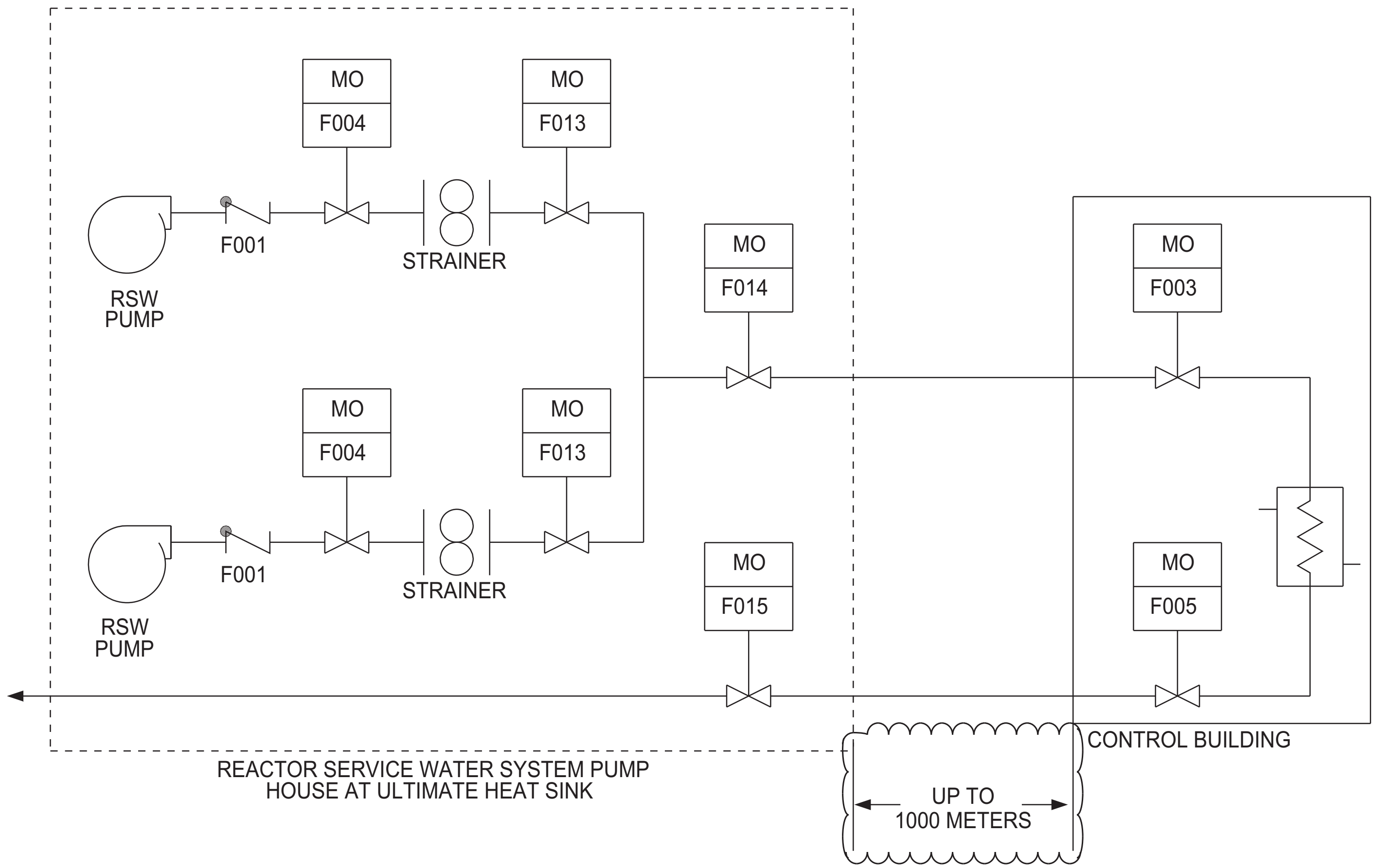

Figure 19R-2 Reactor Service Water System

The following figures are located in Chapter 21:

Figure 19R-3 Reactor Building Arrangement-Elevation -8200 mm (B3F)

(See Figure 1.2-4 and Figure 9A.4-1)

Figure 19R-4 Reactor Building Arrangement-Elevation -1700 mm (B2F)

(See Figure 1.2-5 and Figure 9A.4-2)

Figure 19R-5 Reactor Building Arrangement-Elevation 4800 mm (B1F)

(See Figure 1.2-6 and Figure 9A.4-3)

Figure 19R-6 Reactor Building Arrangement-Elevation 12300 mm (1F)

(See Figure 1.2-8 and Figure 9A.4-4)

The following figures are not used in the DCD:

Figure 19R-7

Figure 19R-8

Figure 19R-9

Figure 19R-10

Figure 19R-11

Figure 19R-12

Figure 19R-13