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5.0 CONTAINMENT, REACTOR BUILDING, AND ASSOCIATED SYSTEMS

Learning Objectives:

1. State the purposes of the containment vessel and the reactor building, and describe their structures.

2. State the purposes, and describe the operation, of the containment spray system.

3. State the purpose, and describe the operation, of the annulus emergency exhaust system.

4. Describe the major differences between the US-APWR structures and systems described in this chapter and their counterparts in currently operating PWRs.

5.1 Introduction

The containment, a Seismic Category 1 structure, is a prestressed, post-tensioned concrete building, often referred to as a prestressed concrete containment vessel. It is cylindrical with a hemispherical dome. The containment structure houses the reactor coolant system and other related systems. It ensures leak tightness during normal operations and withstands the worst-case postulated piping failure without exceeding its design pressure.

Surrounding the containment, and sharing a common basemat with it, is the reactor building, also a Seismic Category I structure. It houses safety-related pumps and heat exchangers and the fuel handling area. The reactor building annulus, consisting of walled areas around the containment, contains penetrations and equipment which can handle radioactive fluids. The annulus is kept at a slightly negative pressure to minimize the release of radioactivity to the environment.

The safety-related containment spray system, in response to a large piping failure inside containment, is designed to limit the peak containment pressure to less than the containment design pressure, and then to reduce the pressure to limit the driving force for radioactive leakage. The containment spray system removes heat by spraying cool water from a ring header into the containment atmosphere. The system also satisfies the fission product removal function by raising the pH of the water in the refueling water storage pit to enhance iodine retention.

In the event of an accident inside containment, the safety-related annulus emergency exhaust system is designed to limit fission product release to the environment by filtering the air it exhausts from the reactor building annulus areas. The system is automatically initiated by accident conditions to maintain a negative pressure in the annulus penetration and safeguard component areas, so that any radioactivity leaking from the containment is directed through its filtering units.

5.2 Containment

The containment is designed as an essentially leak-tight barrier that will safely and reliably accommodate the calculated temperature and pressure conditions resulting from the complete spectrum of piping breaks, up to and including a double-ended, guillotine-type break of a reactor coolant or main steam line.

The containment is designed to be compatible with all environmental effects experienced during normal operations. These include, but are not limited to, containment temperature, pressure, and humidity, the presence of fluids (e.g., equipment lubricants and borated reactor coolant), and other assorted environmental effects of reactor operation, testing, and maintenance.

The containment is also designed to accommodate conditions during and following postulated accidents, such as the design-basis loss-of-coolant accident (LOCA). These conditions include elevated temperature, pressure and humidity. These conditions also include the presence of radioactive fission products, dissolved sodium tetraborate (NaTB), and borated water. The peak pressure for the most severe postulated accident does not exceed the containment internal design pressure, which is 68 psig.

The systems and components inside containment are designed, supported, and restrained to withstand postulated normal, seismic and accident dynamic effects.

The containment function described above is maintained also in Modes 3 and 4 (shutdown conditions), when the postulated accident could cause a release of radioactive material into the containment and an increase in containment pressure and temperature. The conditions for Mode 1 or Mode 2 are assumed for the containment analyses in this section because the energy sources, including reactor coolant fluid and metal energy, steam generator fluid and metal energy, core stored energy, and decay heat, are much larger than those in the Modes 3 and 4 conditions.

5.2.1 Design Bases

The containment is designed and constructed to withstand a broad spectrum of seismic events. To comply with general design criterion (GDC) 16, the containment is designed to ensure leak tightness during normal operations, and, under postulated accident conditions, the containment is designed and built to safely withstand an internal pressure of 68 psig. The containment design pressure of 68 psig is based on the LOCA event, which bounds the steam line break (SLB) event from the containment peak pressure standpoint. Adequate design margin is demonstrated by a containment test pressure of 78.2 psig. The containment design temperature is 300°F.

Table 5-1 summarizes containment temperature and pressure (and comparisons to design pressure), for the worst-case combination of postulated break and assumed system and component failures. In addition, the accident-analysis plots of containment internal pressure and temperature versus time for the most severe primary and secondary system piping failures show that the internal containment pressure is reduced to less than 50% of the peak value 24 hours after event initiation.

Table 5-1 is based on evaluations in which uncertainties and tolerances with respect to the containment and its heat removal systems are biased to generate conservatively high values. The results show that the containment heat removal system is adequate to maintain containment conditions within design limits assuming a worst single-failure condition in addition to one heat removal train being out of service. For primary system piping breaks, the loss of offsite power (LOOP) is assumed. For secondary system piping breaks, the cases in which the LOOP is not assumed are also considered, since the LOOP can possibly reduce releases to the containment.

The single-failure condition related to containment pressure and temperature calculations is the failure of one of the four emergency power sources. In addition, another emergency power source is assumed to be out of service, which leads to only two emergency power sources being available. This results in the minimum containment heat removal capability and the minimum safety injection flow. The effect of maximum injection flow is evaluated assuming all four trains of pumped safety injection are operating, combined with the failure of one train plus the outage of another train of the four-train containment heat removal system.

The containment depressurization rate is established by two trains of the containment heat removal systems. The internal containment pressure is reduced to less than 50% of the peak value within 24 hours after event initiation, which is consistent with the assumptions used in the calculations of the offsite radiological consequences of the accident.

5.2.2 Containment Description

5.2.2.1 General Arrangement

The containment is described as a “prestressed concrete containment vessel” (PCCV). The geometric shape of the PCCV is a vertically oriented cylinder topped by a hemispherical dome, with no ring girder at the dome/cylinder interface. The PCCV is anchored to a foundation basemat that it shares with the reactor building and the containment internal structure. The PCCV has an inside diameter of 149 ft, 2 in. and an inside height of 226 ft, 5 in. The thickness is 4 ft, 4 in. for the cylinder and 3 ft, 8 in. for the dome. Areas around the large openings are thickened to provide additional strength and to provide space for the prestressing tendons that are deflected around the openings.

Table 5-2 lists basic specifications for the PCCV. Figures 5-1 and 5-2 display containment details.

The PCCV consists of a prestressed concrete shell containing unbonded tendons and reinforcing steel. Prestressing is obtained through post-tensioning – a method by which tendons are tensioned after concrete has hardened. Reinforcing steel is provided overall in the cylinder and in the dome. Additional reinforcement is provided at discontinuities, such as the cylinder/basemat interface, around penetrations and openings, at buttresses, and at other areas.

The concrete shell inner surface is lined with a minimum 1/4-in. carbon steel plate that is anchored to the concrete shell and dome to provide the required pressure boundary leak tightness. Areas around penetrations, support brackets, inner walls, and heavy component bases have thickened steel liner plates. The other items integrally welded to the liner form part of the overall pressure boundary, including but not limited to the equipment hatch, two personnel airlocks, various piping and electrical penetrations, and miscellaneous supports that are embedded in the concrete shell such as the polar crane brackets. The liner plate system is not designed or considered as a structural member in providing for the overall PCCV load resistance. The liner plate system is attached to the PCCV shell with an anchorage system that is depicted on Figure 5-2.

The US-APWR containment is designed to withstand a negative pressure of 3.9 psi (vacuum) relative to ambient (i.e., an external pressure 3.9 psig higher than the internal pressure). An evaluation concludes that this design feature provides sufficient margin in the event of containment pressure reduction caused by the inadvertent initiation of the containment spray system.

The containment has a 60-year design life.

5.2.2.2 Penetrations

The containment is constructed with three large openings: two personnel airlocks and one equipment hatch. The hatch is located at centerline elevation 86 ft, 3 in., 40° azimuth. It is a 27 ft, 11 in. diameter spherical dish with a convex profile projecting into the PCCV volume. The containment internal pressure places the hatch head into compression against a double-sealed seat on the frame. The space between the two seals is capable of pressure testing for leakage across either seal. The lower personnel airlock is located at centerline elevation 28 ft, 10 in., 24° azimuth, and the upper airlock is located at centerline elevation 80 ft, 2 in., 120° azimuth. Each airlock’s inside diameter is 8 ft, 6-3/8 in.

The fuel transfer tube penetrates the PCCV wall near 0° azimuth, connecting the fuel handling canal in the reactor building with the refueling canal in the interior of the PCCV. The fuel transfer tube penetration is sealed with the PCCV wall in a fashion similar to that of other mechanical penetrations. The containment boundary is a double-gasketed blind flange at the refueling canal end.

All other containment penetrations, both electrical and mechanical, terminate in the reactor building annulus. Piping which penetrates the containment is provided with isolation valves (some penetrations require inside and outside isolation valves). The annulus emergency exhaust system (subsection 5.5.) automatically establishes a slightly negative pressure in the annulus following a safety injection (SI) signal, and filters the exhaust air before discharging it to the environment.

5.2.2.3 Prestressing Configuration

Horizontal hoop tendons are used in the cylindrical and lower dome portions of the containment structure. The horizontal tendons wrap around the entire circumference, and are anchored at two vertical buttresses 180 degrees apart. The anchors for the horizontal tendons are staggered such that adjacent tendons are anchored on opposite buttresses. The horizontal tendons anchored at the two vertical buttresses are accessed for servicing through vertical chases provided in the reactor building at the buttresses.

The inverted U tendons run vertically up the cylinder, over the dome in a nonradial mesh pattern, and down the cylinder on the opposite side. These inverted U tendons are anchored at each end in a tendon gallery. The circular tendon gallery allows for the servicing and installation of these tendons and is located entirely within the reinforced concrete basemat foundation. The tendon gallery is accessed through a hallway, which passes horizontally through the basemat to the exterior plant yard.

5.2.2.4 Refueling Water Storage Pit

The refueling water storage pit (RWSP) is located at the bottom of the containment, at elevation 3 ft, 7 in. The RWSP is roughly configured as a horseshoe-shaped box around the containment perimeter. The open end of the RWSP is oriented at 0° azimuth (plant north), where the reactor coolant drain tank, the reactor coolant drain pumps, and the containment sump are located. Figure 5-3 presents a sectional view of the RWSP, while Table 5-3 presents RWSP design and containment-related features.

The US-APWR containment is basically a PWR large dry containment design. However, it differs from many other PWR containments, in that the source of emergency core cooling water for the safety injection system (SIS) and the source of containment cooling water for the containment spray system (CSS) is located inside the containment. Thus, there is no need for any “switchover” of the suctions for these systems from an external source to the containment recirculation sump.

Containment cavities and pits where water may be trapped and not drain to the RWSP during SIS and CSS operation, are accounted for in the containment design evaluations. Piping is provided through several partitions above the RWSP where water could otherwise be trapped. In particular, piping that allows free communication and drainage is installed between the refueling cavity and the pressure equalizing chamber. These communication pipes are closed with flanges at both ends during refueling. Drain piping also is provided between the pressure equalizing chamber and the RWSP.

The RWSP is designed as a seismic category I, Safety Class 2 system, with an RWSP design peak water temperature following a LOCA of 270°F. Pressure in the RWSP air space is relieved to the containment atmosphere. The inside walls and floor of the RWSP (in contact with 4,000-ppm boric acid solution) are clad with stainless steel plate. The RWSP ceiling (the underside of the floor at containment elevation 25 ft, 3 in.) is not expected to be in contact with the RWSP boric acid solution, but it is clad with stainless steel plate nevertheless.

5.3 Reactor Building

5.3.1 General Arrangement

The reactor building has five main floors. The building contains the PCCV and containment internal structure at its center, and is founded on a common basemat with the PCCV. The outer perimeter of the reactor building is rectangular, and is constructed of reinforced concrete walls, floors, and roofs. The height of the building varies between elevations 101 ft, 0 in. and 154 ft, 6 in., except for the PCCV dome, which extends to an elevation of 232 ft, 0 in.

The reactor building consists of the following five areas, defined by their functions.

- PCCV and containment internal structure,
- Safety system pump and heat exchanger area,
- Fuel handling area,
- Main steam and feed water area, and
- Safety-related electrical area.

The PCCV is discussed in detail in subsection 5.2. The PCCV includes the containment internal structure, including the primary shield wall and the interior compartmentalization. Outside the PCCV and within the reactor building is the annulus. The annulus, which consists of concrete walled areas around the PCCV, serves a secondary containment function. It comprises all areas with containment penetrations. It is maintained at a slightly negative pressure to control the release of any radioactive materials to the environment.

The safety system pump and heat exchanger areas are located at the lowest level of the reactor building to secure the required net positive suction heads.

The fuel handling area is located on the plant-northern side of the reactor building at the same level as the containment operating floor, and houses the following facilities:

- Spent fuel pit crane,
- Fuel transfer system,
- Cask loading pit with the fuel handling area crane,
- New fuel pit,
- Decontamination pit, and
- Spent fuel pit and storage racks.

The main steam and feedwater area is located on the plant-southern side of the reactor building, between the PCCV and the turbine building. The piping rooms are located on the top floor of this area, where the pipes pass between the PCCV and the turbine building.

The safety-related electrical area has two floors located on the plant-southern side of the reactor building, under the main steam and feedwater area. This is a nonradioactive zone which is completely separated from the radioactive zones of the reactor building. This area houses the following safety-related facilities:

- Main control room (MCR),
- Switchgear and batteries, and
- Instrumentation and control cabinet room.

Four redundant divisions of safety systems containing potentially radioactive material are located in the four quadrants surrounding the containment structure. Each of the quadrant areas is separated from the others by physical barriers to assure that the functions of the safety-related systems are maintained in the event of postulated incidents such as fires, floods, and high energy pipe-break events.

Nonradioactive safety systems such as the essential service water system, the component cooling water system, and the electrical system, are located in the plant-southern area of the reactor building. This area is also separated into four divisions by physical barriers to assure that the functions of the safety-related systems are maintained in the event of postulated incidents such as fires, floods, and high energy line-break events.

5.3.2 Foundation

The reactor building, with the PCCV and containment internal structure at its center, is built on a common basemat and isolated from the adjacent auxiliary building, east and west power source buildings, and turbine building. The basemat of the reactor building is a rectangular reinforced concrete mat composed of two parts. One part of the basemat is for the PCCV and the containment internal structure, and the other part is the seismic category I basemat for the reactor building. The length of the basemat in the north-south direction is 309 ft, 0 in., and in the east-west direction is 210 ft, 0 in. The central region,generally circular with a diameter of approximately 187 ft, supports the PCCV and containment internal structure with a thickness of approximately 38 ft, 2 in. The peripheral portion which supports the reactor building is 9 ft, 11 in. thick.

The basemat includes hollow portions such as the tendon gallery, tendon gallery access tunnel, incore chase, and containment recirculation sump. Since the vertical tendons are anchored at the roof of the tendon gallery, the upper part of the tendon gallery is structurally important.

The basemat reinforcement consists of a top horizontal layer of reinforcement, a bottom horizontal layer of reinforcement, and vertical shear reinforcement. The bottom layer of reinforcement is arranged in a rectangular grid. The top layer of reinforcement is arranged in a rectangular grid at the center of the mat and radiates outward in a polar pattern in order to avoid interference with PCCV reinforcement. The top and bottom reinforcement at the upper portion of the tendon gallery is in a polar pattern.

5.4 Containment Spray System

The containment spray system is a dual-function engineered safety feature (ESF) system; it provides both fission product removal and containment cooling. The CSS and the residual heat removal system (RHRS) share major components, which are the containment spray/residual heat removal (CS/RHR) pumps and heat exchangers.

There are four 50%-capacity trains of containment spray, using four dual-purpose CS/RHR RWSP suction lines, four dual-purpose CS/RHR spray pumps, four dual-purpose CS/RHR heat exchangers, and a spray ring header composed of four concentric interconnected rings. To ensure a reliable containment spray pattern of coverage, each spray ring is located at a different containment elevation, and all spray rings are supplied from each of the four trains.

5.4.1 Design Bases

The CSS is designed to perform the following major functions:

- Containment heat removal, and
- Fission product removal.

These functions are provided by safety-related equipment with redundancy to deal with single failure, environmental qualification, and protection from external hazards.

5.4.1.1 Containment Heat Removal

In the unlikely event of a design-basis LOCA or secondary system piping failure, the CSS is designed to limit and control the containment pressure, such that:

- The peak containment accident pressure is well below the containment design pressure, and
- The containment pressure is reduced to less than 50% of the peak calculated pressure for the design-basis LOCA within 24 hours after the postulated accident.

The ability of the containment heat removal system is evaluated assuming the worst single failure, which removes one train from service, concurrent with an outage that removes a second train from service. For primary system piping breaks, a LOOP is assumed. For secondary system piping breaks, the cases where a LOOP is not assumed are also considered, since the LOOP can possibly reduce releases to the containment.

5.4.1.2 Fission Product Removal

The fission product removal feature of the containment spray system is accomplished by increasing the pH of the RWSP water from its normal value of approximately 4.3, to a post-design-basis-accident pH of at least 7.0. The RWSP is the ESF source for borated water for the containment spray and safety injection systems; there is no automatic switchover to a borated ESF coolant source external to the containment.

Radioactive iodine is the primary concern in evaluating and mitigating the potential radiological consequences of a design-basis accident. Without an outside agent to reduce precipitation, radioactive iodine can deposit on components in the containment or leak from the containment. The containment spray enhances iodine retention over an extended time period to allow decay of the longest lived radioactive iodine isotope (iodine-131, with a half-life of eight days).

The containment spray system is started as follows:

- In a design basis accident, elevated containment pressure actuates the containment spray system automatically.
- If high radiation is detected in the containment, the MCR operator manually starts the containment spray function.

Crystalline NaTB is used to raise the pH of the RWSP contents from 4.3 to at least 7.0 after containment spray actuation. Twenty-three baskets of NaTB are positioned inside containment. As discussed in Chapter 4, containment spray water dissolves the NaTB, and the resulting solution drains into the RWSP. The basket locations ensure full wetting and dissolution of the NaTB.

Following a design-basis accident, the containment pressure approaches atmospheric pressure. When the containment pressure is reduced sufficiently and the operator determines that containment spray is no longer required, the operator terminates containment spray.

5.4.1.3 Reliability Design Bases

The reliability of the CSS has been considered in establishing the system's functional requirements, selecting the particular components and their locations, and designing the connected piping. Redundant components are provided where the loss of one component would impair reliability. Redundant sources of the containment spray actuation (P) signal are available so that the proper and timely operation of the CSS is ensured. Sufficient instrumentation is available so that the failure of an instrument does not impair the readiness of the system. The active components of the CSS are powered from separate buses, which are normally energized from offsite power supplies. In addition, redundant emergency onsite power is available from the emergency power sources to ensure adequate power for all CSS requirements. Each emergency power source is capable of driving all pumps, valves, and instruments associated with one train of the CSS.

The CSS components and piping are located in the reactor building and in the containment. Both structures are Seismic Category I and provide tornado missile barriers to protect the CSS. The CSS includes four 50%-capacity CS/RHR pump trains; for worst-case considerations one is assumed out of service for maintenance and one becomes inoperative due to a single failure upon the initiation of the CSS. The CSS is designed with sufficient redundancy to ensure reliable performance, including the failure of any component coincident with the occurrence of a design-basis event.

All valves required to be actuated during CSS operation are located to prevent vulnerability to flooding.

5.4.2 System Description

Figure 5-4 is the flow diagram of the CSS, showing the major components and instruments and the appropriate system interconnections. Table 5-4 presents design and performance data for CSS components.

The CSS receives electrical power for its operation and control from onsite emergency power sources and offsite sources. In the unlikely event of a LOCA or secondary system line break that significantly increases the containment pressure, the containment spray automatically initiates to limit the peak containment pressure to well below the containment design pressure. In addition to preserving containment structural integrity, containment spray limits the potential post-accident radioactive leakage by reducing the pressure differential between the containment atmosphere and the environment.

The CS/RHR system can be manually initiated and operated from the MCR and the remote shutdown console (RSC). In addition to the typical system status and operating information (e.g., valve position indication, pump run status), the containment temperature and pressure are indicated and recorded in the MCR and at the RSC.

The dual-use components in the system are the CS/RHR heat exchangers and CS/RHR pumps. Motor-operated valves permit containment spray operation or residual heat removal via recirculation of reactor coolant. The four CSS spray header containment isolation valves are normally closed, but open automatically on a P signal. A CSS train’s containment isolation valve is interlocked so that it is allowed to open only if either of the two in-series RHR hot leg suction isolation valves of the associated train is closed. Further, an RHR train’s hot leg suction valves are interlocked so that they cannot be opened unless the corresponding CSS containment isolation valve is closed. This arrangement prevents the reactor vessel water inventory from being sprayed into the containment.

The CS/RHR pumps take suction from the RWSP. The RWSP contains 81,230 ft^3 of water borated to at least 4,000 ppm boron, resulting in a pH of approximately 4.3. The spray water dissolves crystalline NaTB stored in baskets at the operating level in containment. The chemical composition of NaTB is $Na_2B_4O_7 \cdot 10\ H_2O$.

There are 348 containment spray nozzles arrayed in four spray rings positioned high in the containment. The nozzle design and manufacturer, orientation, supply pressure, and array on the headers are commonly used in US nuclear power applications.

Approximately 60% of the containment net free volume is sprayed. Unsprayed regions include those areas covered by the containment structure (e.g., pressurizer subcompartment top cover). Significant natural convection mixing flow between sprayed and unsprayed regions is established by the large difference between the sprayed and unsprayed percentages of the containment volume.

Following a design-basis accident, the containment pressure approaches atmospheric pressure. When the containment pressure is reduced sufficiently and the operator determines that containment spray is no longer required, the operator terminates containment spray. The operator closes the containment spray header isolation valves and aligns system flow through the CS/RHR heat exchangers back to the RWSP through the full flow test lines. The pit water is then recirculated and cooled.

Potential voids, caused by insufficient venting, may be formed in the CS/RHR lines. Inservice testing includes periodic testing through the full-flow test lines, which discharge to the RWSP. These tests periodically discharge potential voids, minimize unacceptable dynamic effects such as water hammer, and ensure operability of the suction and discharge lines.

5.4.3 Component Descriptions

5.4.3.1 CS/RHR Pumps

These components are included in the RHRS. Four dual-purpose CS/RHR pumps are provided, one for each of the four 50%-capacity trains. They are motor-driven centrifugal pumps with mechanical seals. The pumps are sized to deliver 3,000 gpm at a discharge head of 410 ft. The 100%-capacity design flow rate (from two of four 50%-capacity CS/RHR pumps) is based on 15.2 gpm flow per nozzle and 348 nozzles. With a minimum recirculation flow rate for each pump of 355 gpm, the required two-pump 100% flow rate is thus 6,000 gpm. The CS/RHR pump discharge head is based on a static head of 215 ft and pressure losses equivalent to 165 ft, including a margin of 30 ft. The design head of the CS/RHR pumps is 410 ft.

All four CS/RHR pumps automatically start and the spray header containment isolation valves automatically open on the receipt of a P signal, delivering a flow from four CSS trains to the CSS spray rings. Initiating signals, setpoints, logic, and control are described in Chapter 8.

5.4.3.2 CS/RHR Heat Exchangers

These components are included in the RHRS. Four CS/RHR heat exchangers are provided. They are horizontal tube-and-shell heat exchangers. The CS/RHR system water flows through the tubes, and the component cooling water flows through the shells.

5.4.3.3 Containment Spray Piping

Each of the RWSP suction valves is normally open to ensure that the suction piping remains full and aligned to provide a ready flow path to the CS/RHR pumps. Each CSS train’s discharge line to the containment spray rings is provided with a normally closed, motor-operated containment isolation gate valve.

The system piping is normally filled and vented to the containment isolation valves (CSS-MOV-004A, B, C, and D) at elevation 36.75 ft (typical for all four 50% containment spray trains) prior to plant startup. The minimum piping “keep-full” level corresponds to the RWSP 100% water level at elevation 19.5 ft. A conservative 100-sec time delay is assumed between system initiation and the start of spray ring flow for the LOCA and containment response analyses.

5.4.3.4 Containment Spray Nozzles

The containment spray nozzles are of the type and manufacture commonly used in United States commercial nuclear applications. The nozzles are fabricated from 304 stainless steel, and each is fitted with a 0.375-in. orifice. The one-piece construction provides a large, unobstructed flow passage that resists clogging by particles, while producing a hollow-cone spray pattern. The nozzle orientations are such that some spray directly downward, some spray downward at 45° from vertical, and some spray horizontally. Also, four nozzles (one for each spray ring) are oriented to spray directly upward. In addition to their spray function, these nozzles also serve as the high point vents on the spray rings.

5.4.3.5 Refueling Water Storage Pit

The RWSP is the protected, reliable, and safety-related source of borated water for the containment spray and safety injection (SI) systems. (Chapter 4 describes the SI function for the US-APWR emergency core cooling systems [ECCSs].) The RWSP is also used to fill the refueling cavity in support of refueling operations. The RWSP is located on the lowest floor inside the containment, with a minimum available capacity of 81,230 ft^3; it is has sufficient capacity to meet long-term post-LOCA cooling needs, including holdup volume losses. Figure 5-3 presents a sectional view of the RWSP.

The RWSP is designed as Equipment Class 2, Seismic Category I, with a maximum operating temperature of 250°F. Pressure in the RWSP air space is relieved to the containment atmosphere, but the RWSP is designed to withstand a containment pressure of 9.6 psi. (9.6 psi is the differential pressure between the containment atmosphere and the RWSP air space during a LOCA.) The inside walls and floor of the RWSP in contact with the 4,000-ppm boric acid solution are lined with stainless steel plate. The RWSP ceiling (the underside of the floor at containment elevation 25 ft, 3 in.) is not normally in contact with the RWSP water, but it is also clad with stainless steel plate.

The coolant and associated debris from a pipe or component rupture, and the containment spray drain into the RWSP through transfer pipes. The pipes are installed through the RWSP ceiling, ending as openings into the containment floor at elevation 25 ft, 3 in. Each transfer pipe opening into the containment is protected from large debris by vertical debris interceptor bars that are capped by a ceiling plate. There are ten transfer pipes distributed around the containment at elevation 25 ft, 3 in. To minimize containment humidity (due to evaporation from the RWSP), the transfer pipes extend from the containment floor and through the RWSP ceiling to below the normal 100% RWSP water level.

The RWSP vents are installed through the RWSP ceiling and discharge into the containment atmosphere above. The vents act to equalize the RWSP and containment free volume air pressures when the SI or CS/RHR pumps take suction and draw down the RWSP water level. Five pairs of vents allow communication between the RWSP and the containment free volume. Each vent pipe terminates below the normal RWSP water level to minimize the release of vaporized RWSP water into the containment atmosphere during normal plant operation.

As shown in Figure 5-5, each quadrant of the RWSP contains paired suction piping and suction pit arrangements for the CS/RHR pumps and SI pumps. The open end of each suction pipe is equipped with a debris strainer (emergency core cooling/containment spray [ECC/CS] strainer) that satisfies NEI 04-07, "PWR Sump Performance Evaluation Methodology," and that conforms to the guidance in RG 1.82.

The RWSP also is equipped with two spargers (diffusers), which are large stainless steel right circular cylinders that are capped and drilled; each sparger is located near the bottom of the RWSP at containment 90° (plant east) and 270° (plant west) azimuth. The spargers receive, and diffuse into the RWSP water, high energy water at low volumetric flow rates from the emergency letdown lines and the CS/RHR pump suction relief valves. The emergency letdown lines (described in Chapter 4) are directed to separate RWSP spargers. The RWSP is equipped with an overflow pipe to accommodate a level change from such discharges.

5.4.3.6 ECC/CS Strainers

These components are included in the ECCS. Figure 5-5 shows four independent sets of ECC/CS strainers located in the RWSP. The strainer design includes redundancy, a large surface area to account for potential debris blockage and to maintain safety performance, corrosion resistance, and a strainer hole size which minimizes downstream effects. Additional design attributes are described in the US-APWR sump strainer performance document.

The ECC/CS strainers are Equipment Class 2, Seismic Category I.

5.4.3.7 Major Valves

CS/RHR Pump RWSP Suction Isolation Valves: There is a normally open motor-operated gate valve in each of the four CS/RHR pump suction lines from the RWSP. These valves would remain open during normal and emergency operations. The valves are remotely closed by operator action from the MCR or RSC only if the CSS has to be isolated from the RWSP to terminate a leak or to isolate the CSS from the RHRS for shutdown cooling. These valves are also closed for pump or valve maintenance. The positions for these valves are indicated in the MCR and at the RSC. The four CS/RHR pump RWSP suction isolation valves (CSS-MOV-001A, B, C, and D) are Equipment Class 2, Seismic Category I.

Each valve is interlocked and allowed to open only if the two in-series RHR hot leg suction isolation valves of the associated train are closed.

Containment Spray Header Containment Isolation Valves: There is a normally closed motor-operated gate valve in each CS/RHR heat exchanger outlet line. These valves open automatically on receipt of a containment spray actuation signal.

The valves can be closed remotely by operator action from the MCR or RSC if containment isolation is required or during RHRS shutdown cooling operation, during which isolation from the containment spray headers is required. The positions for these valves are indicated in the MCR and at the RSC. The four containment spray header containment isolation valves (CSS-MOV-004A, B, C, and D) are Equipment Class 2, Seismic Category I.

Each valve is interlocked and allowed to open only if the two in-series RHR hot leg suction isolation valves of the associated train are closed. In addition, the electrical power for these valves is removed to prevent an inadvertent opening and actuation of containment spray during RHRS shutdown cooling operation.

Containment Spray Header Containment Isolation Check Valves: One swing check valve is provided in each CS/RHR heat exchanger outlet line as a containment isolation valve. The containment spray header containment isolation check valves (CSS-VLV-005A, B, C, and D) are Equipment Class 2, Seismic Category I.

5.5 Annulus Emergency Exhaust System

The annulus emergency exhaust system is an ESF filter system designed for fission product removal and retention by filtering the air it exhausts following accidents from the following areas:

- Penetration areas, and
- Safeguard component areas.

The penetration areas are located adjacent to the containment and include all piping and electrical penetration areas. The safeguard component areas are located adjacent to the containment and contain ECCS components and CSS components that are located outside of containment.

The annulus emergency exhaust system is automatically initiated by the ECCS actuation signal and is initiated manually for non-ECCS actuation conditions (e.g., a rod ejection accident or a containment radiation level in excess of the normal operating range). This system establishes and maintains a negative pressure in the penetration areas and safeguard component areas relative to adjacent areas. Any airborne radioactive material in the penetration areas and safeguard component areas is directed to the annulus emergency exhaust system, avoiding an uncontrolled release to the environment.

5.5.1 Design Bases

The annulus emergency exhaust system is designed to Equipment Class 2 and Seismic Category I requirements. Fan motors receive Class 1E power. The annulus emergency exhaust system is designed to establish a -1/4-in. water gauge (WG) pressure in the penetration areas and the safeguard component areas within 240 seconds to mitigate the potential leakage to the environment of fission products from the containment following a LOCA. The filtration units operate with at least

99% efficiency for particulate removal. Table 5-5 presents the component design specifications for the annulus emergency exhaust system.

5.5.2 System Description

Figure 5-6 is a flow diagram of the annulus emergency exhaust system, including ducting shared with the auxiliary building heating, ventilation, and air conditioning (HVAC) system. The annulus emergency exhaust system consists of two independent and redundant 100% trains, with each train containing a filtration unit and a filtration unit fan. As shown, each train is protected by normally closed outlet and exhaust dampers. These dampers block the auxiliary building HVAC system flow into each train during normal operation, thus preserving and extending the useful service life of the annulus air filtration media.

Each filtration unit contains, in airflow order:

- A high efficiency prefilter, and
- A high efficiency particulate air (HEPA) filter.

The annulus emergency exhaust filtration unit fans direct flow to the vent stack.

The annulus emergency exhaust filtration unit fan in each train automatically starts on an ECCS actuation signal. The ECCS actuation signal also closes auxiliary building HVAC system isolation dampers as follows:

- Supply lines to the penetration areas and safeguard component areas, and
- Exhaust lines from the penetration areas and safeguard component areas.

In addition, the signal starting the annulus emergency exhaust filtration unit fans opens the corresponding filtration unit outlet dampers and the exhaust dampers from the penetration areas and safeguard component areas.

An annulus emergency exhaust filtration unit fan is manually started by MCR operators if the containment radiation level exceeds the normal operating range. For such a circumstance, the following auxiliary building HVAC system isolation dampers are manually closed:

- Supply lines to the penetration areas and safeguard component areas, and
- Exhaust lines from the penetration areas and safeguard component areas.

5.5.3 Component Descriptions

5.5.3.1 Annulus Emergency Exhaust Filtration Units

Each of the two 100%-capacity annulus emergency exhaust filtration units, arranged in parallel, includes a high efficiency prefilter and a HEPA filter. The prefilter removes the larger airborne particulates from the air stream and prevents excessive loading of the HEPA filter. The annulus emergency exhaust filtration units are Equipment Class 2, Seismic Category I components located in the reactor building.

5.5.3.2 Annulus Emergency Exhaust Filtration Unit Fans

The two 100%-capacity annulus emergency exhaust filtration unit fans are designed to establish a negative pressure in the penetration and safeguard component areas, relative to adjacent areas, subsequent to the onset of an accident condition. The annulus emergency exhaust filtration unit fans are started as follows:

- An ECCS actuation signal starts both annulus emergency exhaust filtration unit fans.
- If high radiation is detected in the containment, the main control room operator manually starts one annulus emergency exhaust filtration unit fan.

The annulus emergency exhaust filtration unit fans are powered from Class 1E power supplies.

The annulus emergency exhaust filtration unit fans are Equipment Class 2, Seismic Category I components located in the reactor building.

5.5.3.3 Penetration Area Supply and Exhaust Line Isolation Dampers

As shown in Figure 5-6, four supply and four exhaust line isolation dampers are normally open to provide ventilation to, and to maintain a slightly negative pressure in, the penetration areas during normal operation. These isolation dampers close upon the receipt of an ECCS actuation signal. Each supply and exhaust line has two isolation dampers in series for single-failure considerations. The penetration area supply and exhaust line isolation dampers are Equipment Class 2, Seismic Category I components.

5.5.3.4 Safeguard Component Area Supply and Exhaust Line Isolation Dampers

As shown in Figure 5-6, eight supply and eight exhaust line isolation dampers are normally open to provide ventilation to, and to maintain a slightly negative pressure in, the four safeguard component areas during normal operation. These isolation dampers close upon the receipt of an ECCS actuation signal. Each supply and exhaust line (one supply and one exhaust line for each component area) has two isolation dampers in series for single-failure considerations. The safeguard component area supply and exhaust line isolation dampers are Equipment Class 2, Seismic Category I components.

5.5.3.5 Annulus Emergency Exhaust Filtration Unit Outlet Dampers

As shown in Figure 5-6, one electrohydraulic annulus emergency exhaust filtration unit outlet damper is installed at each fan outlet and interlocked with the annulus emergency exhaust filtration unit fan. These shutoff dampers open upon the receipt of an annulus emergency exhaust filtration unit fan run signal. The annulus emergency exhaust filtration unit outlet dampers are Equipment Class 2, Seismic Category I components. The annulus emergency exhaust filtration unit outlet dampers are powered from Class 1E power supplies.

5.5.3.6 Safeguard Component Area Exhaust Dampers

As shown in Figure 5-6, two safeguard component area exhaust electrohydraulic shutoff dampers are installed in parallel between the annulus emergency exhaust filtration unit inlets and the safeguard component areas. These shutoff dampers open upon the receipt of an annulus emergency exhaust filtration unit fan run signal to maintain a negative pressure in the safeguard component areas during post-accident operation. The safeguard component area exhaust dampers are Equipment Class 2, Seismic Category I components. The safeguard component area exhaust dampers are powered from Class 1E power supplies.

5.5.3.7 Penetration Area Exhaust Dampers

As shown in Figure 5-6, two penetration area exhaust electrohydraulic shutoff dampers are installed in parallel between the annulus emergency exhaust filtration units and the penetration areas. These shutoff dampers open upon the receipt of an annulus emergency exhaust filtration unit fan run signal to maintain a negative pressure in the penetration areas during post-accident operation. The penetration area exhaust dampers are Equipment Class 2, Seismic Category I components. The penetration area exhaust dampers are powered from Class 1E power supplies.

5.5.3.8 Exhaust Backdraft Dampers

As shown in Figure 5-6, backdraft dampers are installed in the common exhaust duct from the A and B penetration areas, in the common exhaust duct from the C and D penetration areas, and in all four exhaust ducts from the safeguard component areas. These backdraft dampers close to prevent drawing airflow backwards through the annulus emergency exhaust system while nonsafety-related ventilation is operating. These backdraft dampers must open and remain functional when the annulus emergency exhaust system is operating to ensure flow from the penetration and safeguard component areas to maintain them at a negative pressure. All exhaust backdraft dampers are Equipment Class 2, Seismic Category I components located in the reactor building.

5.5.4 System Performance

The US-APWR analysis of the design-basis LOCA concludes that the annulus emergency exhaust system limits the maximum radiation dose to the exclusion area boundary (EAB) and low population zone (LPZ) occupant to less than 10 CFR 50.34 guidelines.

The US-APWR analysis of the design-basis rod ejection accident concludes that the annulus emergency exhaust system limits the maximum radiation dose to the EAB and low population zone (LPZ) to less than RG 1.183 guidelines.

Table 5-1 Summary of Calculated Containment Temperature and Pressure Results for the Worst-Case Postulated Piping Failure Scenario

Parameter	Calculated Value
Pipe Break Location and Break Type	Cold Leg (Pump Suction), Double Ended
Design Pressure, psig	68
Peak Pressure, psig	59.5
Peak Atmospheric Temperature, °F	284
Time of Peak Pressure, seconds	1781
Energy Released to Containment up to the End of Blowdown, Btu	4.76×10^{8}

Table 5-2 US-APWR PCCV Basic Design Specification

	US-APWR	Remarks
Design Condition		
Design Pressure (P_d)	68 psig	
Test Pressure (P_t)	78.2 psig	
Design External Pressure (P)	-3.9 psig	
Design Accident Temperature	300°F	
Dimension		
Inner Diameter	149 ft - 2 in.	
Inner Height	226 ft - 5 in.	
Wall Thickness (Cylinder)	4 ft - 4 in.	
Wall Thickness (Dome)	3 ft - 8 in.	
Liner Thickness	0.25 in.	
Large Opening		
Equipment Hatch	ID 27 ft - 11 in.	One Set
Personnel Air Lock	ID 8 ft - 6 3/8 in.	Two Sets
Free Volume	2.80×10^6 ft^3	
Design Leakage Rate	0.1% mass/24 hours	
Design Life	60 years	
Material		
Concrete Design Strength	7000 psi	PCCV
	4000 psi	Basemat & Modules
Reinforcement	ASTM A615 Gr. 60 or ASTM A706 Gr. 60	
Liner Plate	ASTM A516 Gr. 60	
Tendon Specification		
PS System	VSL (or BBR)	
Tendon Capacity	13 MN Class	
Strands	ASTM A416 Grade 1860 #15 (Lower Relaxation)	
Number of Strands per Tendon	49	
Number of Cylinder Hoop Tendons	94	1 ft – 6 in. Pitch
Number of Cyl. Dome Tendons	18	2.5° Radial Pitch
Number of Inverted U-shape Tendons	90	2° Radial Pitch

Table 5-3 RWSP Design Features

Parameters	Value
Nominal Liquid Surface Area	4985 ft^2
Normal Liquid Volume (Water volume of 96 % water level excluding water below 0% level)	584,000 gallons
Return Water on the Way to RWSP (During a postulated accident)	137,000 gallons
Ineffective Pool	297,000 gallons
Minimum Liquid Volume	149,000 gallons

Table 5-4 CSS Equipment Design Parameters (Sheet 1 of 2)

Containment Spray/Residual Heat Removal Pump	
Number	4
Type	Horizontal, centrifugal type
Power Requirement (kW)	400
Design Flow Rate (gpm)	3,000
Design Head (ft)	410
Minimum Flow Rate (gpm)	355
Maximum Flow Rate (gpm)	3,650
Design Pressure (psig)	900
Design Temperature (° F)	400
Material	Stainless Steel
Normal Operating Temperature (° F)	32 ~ 356
Fluid	Reactor coolant, Boric acid water
Radioactive Concentration (kBq/cm^3)	≥ 37
NPSH Available	17.9 ft at 3,650 gpm
NPSH Required	16.4 ft at 3,650 gpm
Equipment Class	2

Containment Spray / Residual Heat Exchanger		
Number	4	
Type	Horizontal U-tube type	
Heat Transfer Rate (Btu/h)	17.1 x 10^6	
Overall heat Transfer Coefficient and the effective heat transfer area, UA (Btu/h/° F)	1.852 x 10^6	
	Tube side	Shell side
Design Pressure (psig)	900	200
Design Temperature (° F)	400	200
Design Flow Rate (lb/h)	1.5 x 10^6	2.2 x 10^6
Design Inlet Temperature (° F)	120	99.7
Design Outlet Temperature (° F)	108.7	107.4
Material	Stainless steel	Carbon Steel
Fluid	Reactor coolant, boric water	Component cooling water
Radioactive Concentration (kBq/cm^3)	≥ 37	<37
Equipment Class	2	3

Table 5-4 CSS Equipment Design Parameters (Sheet 2 of 2)

CSS SPRAY NOZZLES	
Quantity	348
Type	Ramp Bottom, 0.375 in orifice
Spray Pattern	Hollow Cone
Flow per Nozzle	15.2 gpm at 40 psig
Material	Stainless steel

Table 5-5 Annulus Emergency Exhaust System – Equipment Specifications

Description	Specification
1. Annulus Emergency Exhaust Filtration Units	
Auxiliaries	High-efficiency prefilter, HEPA filter
Quantity	Two 100% capacity trains
HEPA particulate removal efficiency	99% minimum
HEPA Filter Type	No. Designation 8 (Table FC-4110, ASME AG-1, based on 2,000 scfm*)
2. Annulus Emergency Exhaust Filtration Unit Fans	
Quantity	2 (1 per Train)
Type	Centrifugal
Design Air Flow Rate	5,600 ft^3/min

Note:

* Cubic foot of air per minute with a standard density.