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5.2 PASSIVE CONTAINMENT COOLING SYSTEM

Learning Objectives:

1. State the purpose of the passive containment cooling system.

2. Describe how the system cools the containment atmosphere.

3. Describe how the following components and features contribute to the containment cooling function:

   a. Passive containment cooling water storage tank
   b. Passive containment cooling water storage tank isolation valves
   c. Water distribution bucket
   d. Water distribution weir system
   e. Containment air baffle
   f. Passive containment cooling ancillary water storage tank

5.2.1 Introduction

The passive containment cooling system (PCS) is an engineered safety features system. Its functional objective is to reduce the containment temperature and pressure following a loss-of-coolant accident (LOCA) or main steam line break (MSLB) accident inside the containment by removing thermal energy from the containment atmosphere. The passive containment cooling system also serves as the means of transferring heat to the safety-related ultimate heat sink for other events resulting in a significant increase in containment pressure and temperature.

The passive containment cooling system limits releases of radioactivity (post-accident) by reducing the pressure differential between the containment atmosphere and the external environment, thereby diminishing the driving force for leakage of fission products from the containment to the atmosphere. This subsection describes the safety design bases of the safety-related containment cooling function. Non-safety-related containment cooling is a function of the containment recirculation cooling system.

The passive containment cooling system also provides a source of makeup water to the spent fuel pool in the event of a prolonged loss of normal spent fuel pool cooling.

5.2.2 System Description

The passive containment cooling system is a safety-related system which is capable of transferring heat directly from the steel containment vessel to the environment. This transfer of heat prevents the containment from exceeding the design pressure and temperature following a postulated design-basis accident. The passive containment cooling system makes use of the steel containment vessel and the concrete shield building surrounding the containment. The major components of the passive containment cooling system are:

- The passive containment cooling water storage tank (PCCWST), which is incorporated into the shield building structure above the containment;
- Redundant piping with fail-open isolation valves for delivery of the PCCWST contents to the containment vessel;
- A water distribution system, mounted on the outside surface of the steel containment vessel, which functions to distribute water flow on the containment;
- An air baffle, located between the steel containment vessel and the concrete shield building, which defines the cooling air flowpaths; and
- Air inlets and an air exhaust, also incorporated into the shield building structure.

The air inlets, baffle, and exhaust define a natural-circulation air flow path; the containment vessel water film transfers energy to the circulating air via convection and evaporation. In addition, a passive containment cooling ancillary water storage tank and two recirculation pumps are provided for onsite storage of additional passive containment cooling system cooling water, to transfer the inventory to the passive containment cooling water storage tank, and to provide a backup supply to the fire protection system (FPS) seismic standpipe system.

A normally isolated, manually-opened flow path is available between the passive containment cooling system water storage tank and the spent fuel pool.

A recirculation path is provided to control the passive containment cooling water storage tank water chemistry and to provide heating for freeze protection. Passive containment cooling water storage tank filling operations and normal makeup needs are provided by the demineralized water transfer and storage system.

The safety-related portions of the passive containment cooling system are located within the shield building structure. This building (including the safety-related portions of the passive containment cooling system) is designed to withstand the effects of natural phenomena such as earthquakes, winds, tornadoes, or floods. Components of the passive containment cooling system are designed to withstand the effects of ambient temperature extremes.

The portions of the passive containment cooling system which provide a long-term (post-72-hour) water supply for containment wetting are located in Seismic Category I or Seismic Category II structures, excluding the passive containment ancillary water storage tank and associated valves located outside of the auxiliary building. The water storage tank and the anchorage for the associated valves are Seismic Category II. The features of these structures which protect this function are analyzed and designed for Category 5 hurricanes including the effects of sustained winds, maximum gusts, and associated wind-borne missiles.

Operation of the containment cooling system is initiated automatically following the receipt of a Hi-2 containment pressure signal. The use of this signal provides for system actuation during transients which result in mass and energy releases to containment, while avoiding unnecessary actuations. System actuation requires the opening of any of the three PCCWST isolation valves, with no other actions required to initiate the post-accident heat removal function since the cooling air flow path is always open. Operation of the passive containment cooling system may also be initiated from the main control room and from the remote shutdown workstation.

The active components of the passive containment cooling system, the isolation valves, are located in three redundant pipe lines. Failure of a component in one train does not affect the operability of the other mechanical train or the overall system performance. The fail-open, air-operated valves require no electrical power to move to their safe (open) position. The normally open motor-operated valves are powered from separate redundant Class 1E dc power sources.

Capability is provided to periodically test actuation of the passive containment cooling system. Active components can be tested periodically during plant operation to verify operability. The system can be inspected during unit shutdown.

There are four instrument lines that penetrate containment and are required to remain functional following an accident; they are used to sense the pressure of the containment atmosphere and to convey it to pressure transmitters outside containment. The pressure transmitters, tubing, and pressure sensors inside containment comprise a sealed, fluid-filled assembly forming a double barrier between inside and outside containment. Possible instrument line breaks do not result in leakage of the containment atmosphere. The pressure sensors, tubing, and pressure transmitters are designed and tested for seismic Category I service.

The containment pressure analyses are based on an ambient air temperature of 115°F dry bulb and 86.1°F coincident wet bulb. The passive containment cooling water storage tank water temperature basis is 120°F. Results of the analyses are provided in subsection 5.1.

System parameters are listed in Table 5.2-1. A simplified system sketch is included as Figure 5.2-1.

5.2.3 Component Descriptions

Table 5.2-2 provides component design parameters.

5.2.3.1 Passive Containment Cooling Water Storage Tank

The passive containment cooling water storage tank is incorporated into the shield building structure above the containment vessel. The inside wetted walls of the tank are lined with stainless steel plate. It is filled with demineralized water and has the minimum required usable volume for the passive containment cooling function, as shown in Table 5.2-1. The passive containment cooling system functions as the safety-related ultimate heat sink. The passive containment cooling water storage tank is seismically designed and missile protected.

The surrounding reinforced concrete supporting structure is designed to ACI 349. The welded seams of the plates forming part of the leak-tight boundary are examined by liquid penetrant testing after fabrication to confirm that the boundary does not leak.

The tank also has redundant level measurement channels and alarms for monitoring the tank water level and redundant temperature measurement channels to monitor and alarm for potential freezing. To maintain system operability, a recirculation loop that provides chemistry and temperature control is connected to the tank.

The tank is constructed to provide sufficient thermal inertia and insulation such that draindown can be accomplished without heater operation.

In addition to its containment heat removal function, the passive containment cooling water storage tank also serves as a source of makeup water to the spent fuel pool and as a Seismic Category I water storage reservoir for fire protection following a safe shutdown earthquake.

The PCCWST suction pipe for the fire protection system is configured so that actuation of the fire protection system will not infringe on the usable capacity allocated to the passive containment cooling function, as shown in Table 5.2-1.

5.2.3.2 Passive Containment Cooling Water Storage Tank Isolation Valves

The passive containment cooling system water storage tank outlet piping is equipped with three sets of redundant isolation valves. In two sets, air-operated butterfly valves are normally closed and open upon receipt of a Hi-2 containment pressure signal. These valves fail open, providing a fail-safe position, on the loss of air or the loss of Class 1E dc power. In series with these valves are normally open motor-operated gate valves located upstream of the butterfly valves. They are provided to allow for testing or maintenance of the butterfly valves. The third set consists of two motor-operated gate valves in series. One valve is normally closed, and the other is normally open. Based on PRA insights, diversity requirements are adopted for these valves to minimize the probability of common-mode failure.

The storage tank isolation valves, along with the passive containment cooling water storage tank discharge piping and associated instrumentation between the passive containment cooling water storage tank and the downstream side of the isolation valves, are contained within a temperature-controlled valve room to prevent freezing. Valve room heating is provided to maintain the room temperature above 50°F.

5.2.3.3 Flow Control Orifices

Orifices are installed in each of the four passive containment cooling water storage tank outlet pipes. They, along with the different elevations of the outlet pipes, control the flow of water from the passive containment cooling water storage tank as a function of water level. The orifices are located within the temperature-controlled valve room.

5.2.3.4 Water Distribution Bucket

A water distribution bucket is provided to deliver water to the outer surface of the containment dome. The redundant passive containment cooling water delivery pipes and auxiliary water source piping discharge into the bucket, below its operational water level, to prevent excessive splashing. A set of circumferentially spaced distribution slots are included around the top of the bucket. The bucket is hung from the shield building roof and suspended just above the containment dome for optimum water delivery. The structural requirements for safety-related structural steel apply to the water distribution bucket.

5.2.3.5 Water Distribution Weir System

A weir-type water delivery system is provided to optimize the wetted coverage of the containment shell during passive containment cooling system operation. Water is delivered to the center of the containment dome by the water distribution bucket, evenly distributed by slots in the distribution bucket. Vertical divider plates attached to the containment dome originate at the distribution bucket and extend radially along the surface of the dome to the first distribution weir. The divider plates limit maldistribution of flow, which might otherwise occur due to variations in the slope of the containment dome. At the first distribution weir set, the water in that sector is collected and then redistributed onto the containment utilizing channeling walls and collection troughs equipped with distribution weirs. A second set of weirs is installed on the containment dome at a greater radius to again collect and then redistribute the cooling water to enhance shell coverage. The distribution system is capable of functioning during extremely low or high ambient temperature conditions. The structural requirements for safety-related structural steel and cold-formed steel structures apply to the water distribution weir system.

5.2.3.6 Containment Air Baffle

An air flow path is provided to direct air along the outside of the containment shell to provide containment cooling. The air flow path includes a screened shield building inlet, an air baffle that divides the outer and inner flow annuli, and a chimney to increase buoyancy.

The containment air baffle is located within the upper annulus of the shield building, providing an air flow path for the passive containment cooling system. The air baffle separates the downward air flow entering at the air inlets from the upward air flow that cools the containment vessel and flows out of the discharge stack. The upper portion is supported from the shield building roof and the remainder is supported from the containment vessel. The air baffle is a Seismic Category I structure designed to withstand wind and tornadoes. The baffle includes the following sections:

- A wall supported off the shield building roof,
- A series of panels attached to the containment vessel cylindrical wall and the knuckle region of the dome,
- A sliding plate closing the gap between the wall and the panels fixed to the containment vessel, designed to accommodate the differential movements between the containment vessel and the shield building, and
- Flow guides attached at the bottom of the air baffle to minimize pressure drop.

The air baffle is designed to meet the following functional requirements:

- The baffle and its supports are configured to minimize pressure losses as air flows through the system.
- The baffle and its supports have a design objective of 60 years.
- The baffle and its supports are configured to permit visual inspection and maintenance of the air baffle as well as the containment vessel. Periodic visual inspections are primarily to inspect the condition of the coatings.
- The baffle is designed to maintain its function during postulated design-basis accidents. The baffle is designed to maintain its function under specified external events, including earthquakes, hurricanes and tornadoes.

The portion of the air baffle attached to the containment cylinder comprises 60 panels circumferentially in each of seven rows vertically, with each panel subtending an arc of six degrees (approximately 6 ft, 11 in. wide). Each panel is supported by horizontal beams spaced approximately 13 ft, 8 in. apart. These horizontal beams span the six-degree arc and are bolted to U-shaped attachments welded to the containment vessel. The attachment locations are established considering the containment vessel plate and ring assemblies. The lowest attachments are at the bottom of the middle containment ring subassembly. The upper attachments are on the head. The attachments can be installed in the subassembly area and, therefore, should not interfere with the containment vessel erection welds. The only penetrations through the containment vessel above the operating deck at elevation 135′ 3″ are the main equipment hatch and personnel airlock. Five panels are deleted at the equipment hatch, and two flow guides are deleted at the personnel airlock.

Two rows of panels are attached to the containment vessel above the cylindrical portion. The panels are curved to follow the curvature of the knuckle region of the head and then become flat, forming a conical baffle that provides a transitional flow region into the upper shield building. A vertical sliding plate is provided between this upper row of panels and the air baffle that is attached directly to the shield building roof. This sliding plate rests on the 12-in.-wide horizontal top surface of the upper row of panels. At ambient conditions the vertical sliding plate is approximately centered on the horizontal plate. The sliding plate is set at ambient conditions to permit relative movements from minus two in. to plus three in. radially and minus one in. to plus four in. vertically. This accommodates the differential movement between the containment vessel and the shield building, based on the absolute sum of the containment pressure and temperature deflections and the seismic deflections, such that the integrity of the air baffle is maintained.

The panels accommodate displacements between each panel due to containment pressure and thermal growth. Radial and circumferential growth of the containment vessel is accommodated by slip at the bolts between the horizontal beams and the U-shaped attachments, resulting in small gaps between adjacent panels. Vertical growth is accommodated by slip between the panel and the horizontal beam supporting the top of the panel. Cover plates between the panels limit leakage during and after occurrence of these differential displacements.

5.2.3.7 Passive Containment Cooling Ancillary Water Storage Tank

The passive containment cooling ancillary water storage tank is a cylindrical steel tank located at ground level near the auxiliary building. It is filled with demineralized water and has a usable volume which is greater than required for makeup to the passive containment cooling water storage tank and the spent fuel pool, as shown in Table 5.2-2. The tank is analyzed, designed, and constructed using the methods and criteria for Seismic Category II building structures. The tank is designed and analyzed for Category 5 hurricanes, including the effects of sustained winds, maximum gusts, and associated wind-borne missiles.

The tank has a level measurement, an alarm for monitoring the tank water level, and a temperature measurement channel to monitor and alarm for potential freezing. To maintain system operability, an internal heater, controlled by the temperature instrument, is provided to maintain water contents above freezing. Chemistry can be adjusted through operation of the passive containment cooling water storage tank recirculation loop.

The tank is insulated to assure that sufficient thermal inertia of the contents is available to prevent freezing for seven days without heater operation. The transfer piping is maintained dry also to preclude freezing.

5.2.3.8 Chemical Addition Tank

The chemical addition tank is a small, vertical, cylindrical tank that is sized to inject a solution of hydrogen peroxide to maintain a passive containment cooling water storage tank concentration sufficient to limit algae growth.

5.2.3.9 Recirculation Pumps

Each recirculation pump is a 100-percent capacity centrifugal pump with wetted components made of austenitic stainless steel. Each pump is sized to recirculate the entire volume of PCCWST water once every week. Each pump is capable of providing makeup flow to both the PCCWST and the spent fuel pool simultaneously. Both pumps are operated in parallel to meet fire protection system requirements.

5.2.3.10 Recirculation Heater

The recirculation heater is provided for freeze protection. The heater is sized based on heat losses from the passive containment cooling water storage tank and from recirculation piping at the minimum site temperature.

5.2.4 System Performance

5.2.4.1 Safety Design Basis

The safety design basis of the passive containment cooling system incorporates the following attributes:

- The passive containment cooling system is designed to withstand the effects of natural phenomena such as ambient temperature extremes, earthquakes, winds, tornadoes, or floods.

- Passive containment cooling system operation is automatically initiated upon receipt of a Hi-2 containment pressure signal.

- The passive containment cooling system is designed so that a single failure of an active component, assuming the loss of offsite or onsite ac power sources, will not impair the capability of the system to perform its safety-related function.

- Active components of the passive containment cooling system are capable of being tested during plant operation. Provisions are made for inspection of major components in accordance with the intervals specified in the ASME Code, Section XI.

- The passive containment cooling system components required to mitigate the consequences of an accident are designed to remain functional in the accident environment and to withstand the dynamic effects of the accident.

- The passive containment cooling system is capable of removing sufficient thermal energy, including subsequent decay heat, from the containment atmosphere following a design-basis event resulting in containment pressurization such that the containment pressure remains below the design value with no operator action required for 72 hours.

- The passive containment cooling system is designed and fabricated to appropriate codes consistent with Regulatory Guides 1.26 and 1.32 and in accordance with Regulatory Guide 1.29.

5.2.4.2 System Operation

Operation of the passive containment cooling system is initiated upon receipt of two-out-of-four Hi-2 containment pressure signals. Manual actuation by the operator is also possible from either the main control room or the remote shutdown workstation. System actuation consists of opening the passive containment cooling water storage tank isolation valves. This allows the passive containment cooling water storage tank water to be delivered to the top, external surface of the steel containment shell. The flow of water, provided entirely by the force of gravity, forms a water film over the dome and side walls of the containment structure.

The flow of water to the containment outer surface is initially established for short-term containment cooling following a large high-energy line break inside containment. The flow rate is reduced over a period of not less than 72 hours. This flow provides the desired reduction in containment pressure over time and removes decay heat. The flow rate change is dependent only upon the decreasing water level in the passive containment cooling water storage tank. Prior to 72 hours after the event, operator actions are taken to align the passive containment ancillary water storage tank to the suction of the passive containment cooling system recirculation pumps to replenish the cooling water supply to the passive containment cooling water storage tank. Sufficient inventory is available within the passive containment cooling ancillary water storage tank to maintain the minimum flow rate for an additional 4 days. The passive containment cooling system performance parameters are identified in Table 5.2-1.

To adequately wet the containment surface, the water is delivered to the distribution bucket above the center of the containment dome; the bucket subsequently delivers the water to the containment surface. A weir-type water distribution system on the dome surface distributes the water for effective wetting of the dome and vertical sides of the containment shell. The weir system contains radial arms and weirs located considering the effects of tolerances of the containment vessel design and construction. A corrosion-resistant paint or coating for the containment vessel is specified to enhance surface wetability and film formation.

The cooling water not evaporated from the vessel wall flows down to the bottom of the inner containment annulus into annulus drains. The redundant annulus drains route the excess water out of the upper annulus. The annulus drains are located in the shield building wall slightly above the floor level to minimize the potential for clogging of the drains by debris. The drains are horizontal or have a slight slope to promote drainage. The drains are always open (without isolation valves), and each is sized to accept maximum passive containment cooling system flow. The outside ends of the drains are located above catch basins or other storm drain collectors.

A path for the natural circulation of air upward along the outside walls of the containment structure is always open. The natural circulation air flow path begins at the shield building inlets, where atmospheric air is turned upward from the horizontal by louvers in the concrete structure. Air flows past the set of fixed louvers and is forced to turn downward into an outer annulus. This outer shield building annulus is encompassed by the concrete shield building on the outside and the air baffle on the inside. At the bottom of the baffle wall, curved vanes aid in turning the flow upward 180 degrees into the inner containment annulus. This inner annulus is encompassed by the baffle on the outside and the steel containment vessel on the inside. Air flows up through the inner annulus to the top of the containment vessel and then exhausts through the shield building chimney.

As the containment structure heats up in response to high containment temperature, heat is removed from within the containment via conduction through the steel containment vessel, convection from the containment surface to the water film, convection and evaporation from the water film to the air, and radiation from the water film to the air baffle. As heat and water vapor are transferred to the air space between the containment structure and air baffle, the air becomes less dense than the air in the outer annulus. This density difference causes an increase in the natural circulation of the air upward between the containment structure and the air baffle, with the air finally exiting at the top center of the shield building.

The passive containment cooling water storage tank provides water for containment wetting for at least 72 hours following system actuation. Operator action can be taken to replenish this water supply from the passive containment cooling ancillary water storage tank or to provide an alternate water source directly to the containment shell through an installed safety-related seismic piping connection. In addition, water sources used for normal filling operations can be used to replenish the water supply.

The arrangement of the air inlets and air exhaust in the shield building structure has been selected so that wind effects aid the natural air circulation. The air inlets are placed at the top of the shield building cylinder, providing a symmetrical inlet air flow that reduces the effects of wind speed, wind direction, or adjacent structures. The air/water vapor exhaust structure is elevated above the air inlet to provide additional buoyancy; this arrangement reduces the potential for exhaust air to be drawn into the air inlets. The air flow inlets and chimney regions are both designed to protect against ice or snow buildup and to prevent foreign objects from entering the air flow path.

Inadvertent actuation of the passive containment cooling system is terminated remotely by the operator by closing either of the series isolation valves in the PCCWST discharge piping.

The passive containment cooling system can provide makeup water to the spent fuel pool to provide for continued maintenance of spent fuel pool inventory and heat removal. The passive containment cooling water storage tank provides makeup to the spent fuel pool when the inventory is not required for passive containment cooling system operation. An installed long-term makeup connection for the passive containment cooling system and the spent fuel pool is provided as a part of the passive containment cooling system. The passive containment cooling ancillary water storage tank and the passive containment cooling system recirculation pumps may also be utilized for makeup to the spent fuel pool.

5.2.5 Summary

The passive containment cooling system is an engineered safety features system which functions to reduce the containment temperature and pressure following a loss-of-coolant accident (LOCA) or main steam line break (MSLB) accident inside the containment by removing thermal energy from the containment atmosphere. Reducing the containment pressure reduces the driving force for leakage of fission products from inside containment. The system provides the passive containment cooling function for 72 hours following a design-basis accident.

Upon actuation by a Hi-2 containment pressure signal, the passive containment cooling water storage tank isolation valves open to drain the contents of the passive containment cooling water storage tank to the top, external surface of the steel containment shell. The flow of water, provided entirely by the force of gravity, forms a water film over the dome and side walls of the containment structure, thereby removing heat conducted through the containment vessel. Heat and water vapor are transferred to the air circulating between the containment vessel outer surface and the containment air baffle and exhausted out the shield building chimney.

Table 5.2-1

PASSIVE CONTAINMENT COOLING SYSTEM PERFORMANCE PARAMETERS

PCCWST useable capacity for PCS (gal) - Minimum	756,700
PCCWST useable capacity for FPS[(2)] (gal) - Minimum	18,000
Flow duration from PCCWST (days) - Minimum	3
PCCWST minimum temperature (°F)	40
PCCWST maximum temperature (°F)	120
Upper annulus drain rate (per drain) - Minimum	525 gpm
PCCAWST[(4)] long-term makeup rate to containment - Minimum[(7)]	100 gpm
PCCAWST long-term makeup to spent fuel pool – Minimum[(7)]	35 gpm
PCCAWST long-term makeup duration - Minimum	4 days
PCCWST long-term makeup to spent fuel pool – Minimum	118 gpm

PCCWST Water Elevation (Note 3) (feet)	Nominal Design Flow (gpm)	Minimum Design Flow (gpm)	Safety Analysis Flow (gpm)	Wetted Coverage (Note 3) (% of circumference)
27.5	494.6 (Note 5)	471.1	469.1	90
24.1	247.1	238.4	226.6	90
20.3	190.8	184.0	176.3	72.9
16.8	157.1	151.4	144.2	59.6
4.0 (Note 6)	113.1	109.6		
			100.7 @ 72 hours	41.6

Notes:

1. PCCWST = passive containment cooling water storage tank
2. FPS = fire protection system
3. PCCWST Water Elevation corresponds to the nominal standpipe elevations in feet above the tank floor (Reference Plant Elevation 293′-9″, see Figure 3.8.4-2). Wetted coverage is measured as the linear percentage of the containment shell circumference wetted measured at the upper spring line for the safety analysis flow rate conditions.
4. PCCAWST = passive containment cooling ancillary water storage tank
5. The initial nominal design flow is based on the nominal PCCWST water elevation.
6. This elevation is the calculated water level at 72 hours after initiation of PCS flow, based on the minimum design flow rates.
7. These flow rates apply when the plant is not refueling. The minimum makeup flow rates required when the plant is being refueled are 80 gpm to the containment and 50 gpm to the spent fuel pool. The minimum makeup flow rates are adjusted because more decay heat is located in the spent fuel pool.

Table 5.2-2

COMPONENT DATA
PASSIVE CONTAINMENT COOLING SYSTEM
(NOMINAL)

Passive Containment Cooling Water Storage Tank	
Volume (gal) - Minimum	756,700
Design temperature (°F)	125
Design pressure (psig)	Atmospheric
Material	Concrete with stainless steel liner
Standpipe Elevations Above Bottom of Tank Floor (Plant Elevation 293′-9″)	
Overflow (ft) – Nominal	28.5
Top standpipe (ft) - Nominal	24.1
Second standpipe (ft) - Nominal	20.3
Third standpipe (ft) - Nominal	16.8
Bottom standpipe (ft)	0.5
Passive Containment Ancillary Cooling Water Storage Tank	
Volume (gal) - Nominal	780,000
Design temperature (°F)	125
Design pressure (psig)	Atmospheric
Material	Carbon steel
Water Distribution Bucket	
Volume (gal) - Nominal	42
Design temperature (°F)	150
Design pressure (psig)	Atmospheric
Material	Stainless steel
Water Distribution Collection Troughs and Weirs	
Design temperature (°F)	N/A
Design pressure (psig)	Atmospheric
Material	Stainless steel
Passive Containment Cooling Recirculation Pump	
Quantity	2
Type	Centrifugal
Design capacity (gpm)	135
Design total differential head (ft)	375