6.4 CONTAINMENT SPRAY SYSTEM

6.4.1 DESIGN BASIS

The function of the Containment Spray System is to limit the containment atmosphere pressure and temperature after a LOCA, and thus reduce the possibility of leakage of airborne radioactivity to the outside environment.

The original sizing of the containment air coolers for design and procurement was based on the heat removal capability, using three coolers, ($240x10^6$ Btu/hr) required to maintain the post-LOCA containment atmospheric pressure within the containment design pressure. Likewise, the original sizing of the containment spray system for design and procurement was based on the heat removal capability ($240x10^6$ Btu/hr) required to maintain the LOCA containment atmospheric pressure within the containment design pressure. The analysis of these systems operating together post-LOCA in accordance with the Technical Specification requirements is presented in Section 14.20.

Gas accumulation in this water system can result in water hammer, pump cavitation and pumping of non-condensable gas into the reactor vessel. These effects may result in the system being unable to perform its specified safety function. The NRC issued Generic Letter 2008-01, Managing Gas Accumulation, to address the issue of gas accumulation in this system. See UFSAR Section 1.8.5 for further information.

6.4.2 SYSTEM DESCRIPTION

The Containment Spray System is shown in Figures 6-1 (Unit 1) and 6-10 (Unit 2). The system sprays cold borated water into the containment atmosphere and then recirculates and cools the water through the shutdown cooling heat exchangers. The Containment Spray System is redundant with the containment air cooling system and consists of two 50% capacity electric motor-driven pumps, two heat exchangers (the shutdown cooling system heat exchangers), two containment spray headers and nozzles, and all necessary piping, valves, instruments and accessories. The pumps discharge borated water from the RWT through the heat exchangers to the spray headers and nozzles located in the containment. The spray nozzles are arranged in the headers to give complete spray coverage at the containment horizontal cross-section area.

After an assumed LOCA, suction for the Containment Spray and SI Systems will be taken from the RWT. The water introduced into the containment in this manner will be intimately mixed with the water from the RCS. The resultant mixture will be used in the spray and injection systems only after the inventory of the RWT is nearly depleted.

The Technical Specifications require a minimum inventory of 412,350 gallons be maintained in the RWT. Additional RWT data is provided in Table 6-4. The technical specification limit and RAS setpoint level have been established to ensure the RWT provides at least 373,615 gallons of usable water before the RAS is actuated. The capacity of the RCS is 77,800 gallons. The water in the RWT contains dissolved boric acid yielding a solution with a pH of approximately 5.0 at 80°F. If the reactor coolant has a pH of 10.0 due to an excess of LiOH produced from the radiolytic decomposition of boric acid and this reactor coolant is mixed with the water from the RWT, then a chemical acid-base reaction will occur, using up all the LiOH present, and the resulting solution will have a pH of 5.05. Therefore, the effect of the reactor coolant pH on the spray solution is controlled by the large volume of water from the RWT.

When the RWT level reaches the RAS setpoint, an RAS occurs which opens the containment sump discharge valves and continuation of containment spray is accomplished by automatic supply of the pump suction from the containment sump. The switchover is initiated, other than by operator action, on coincident low level signals from level switches located in the RWT. Prior to discharge into the containment, the recirculated water is cooled by the shutdown cooling heat exchangers, using water from the component cooling water system.

The boric acid spray, with a pH of approximately 5, will come in contact with most surfaces in the containment including the equipment required for post-LOCA and, in some cases, on internal as well as external surfaces. To prevent chloride stress corrosion cracking of certain metals during operation of the ECCS, the spray water pH will be raised with sodium tetraborate (STB). The STB, located in the containment basement, is stored in baskets designed to allow dissolved STB to flow out. Each basket is constructed of stainless steel with 80 mesh screen sides, solid bottom and open top. The SI water will dissolve the chemical as it fills the containment. Mixing will be achieved as the solution is continuously recirculated and the final pH will be approximately 7.0. The minimum quantity of STB required to raise the pH to 7.0 has been calculated based on the boron concentration of the containment sump water following a LOCA (Reference 1).

All components and materials of the ESF located inside the containment have been designed to operate properly in the post-accident atmosphere. One of the major design considerations was the proper selection of components and materials which would not corrode or deteriorate in a manner that would hinder the operation of the ESF. All components were considered, including the transmitters, electrical wiring, equipment, valving and motors.

The electrical cables were subjected to environmental tests which proved that the cables remained in acceptable operating condition. The cables were flame-tested and subjected to environmental conditions to demonstrate the ability to operate successfully in the post-accident containment environment of radiation, temperature, pressure, boron concentration and the humidity as specified under LOCA conditions.

The flame propagation tests performed by BGE are summarized in IEEE published paper 71CP585-PWR, "Flame Propagation Tests on 600 Volt Control and Power Cables in Trays for Calvert Cliffs Nuclear Power Plant," presented at the IEEE Summer Power Meeting in Portland, Oregon, July 23, 1971. The major insulation selected for plant control, instrumentation and small power wiring was silicone-rubber (methyl-phenyl-vinyl base) with fiberglass and asbestos braid jackets. These cable makeups functioned satisfactorily both during and after exposure to severe oil fires. For large power cables, which are hard to ignite, the insulation consisted of cross-linked polyethylene (XLP) and ethylene-propylene-rubber (EPR) compounds which survived oil fires up to periods of 12 to 16 minutes.

The cables were also subjected to environmental tests performed by combinations of consulting laboratories and manufacturers' own test facilities. Cables (XLP, EPR, HTKerite and silicone-rubber) were actually subjected to the specified radiation and steam-boric acid exposures. All cables were affected in varying degrees both physically and in their insulating characteristics by the environmental exposures, but there was no significant degradation of any material's insulating ability after irradiation alone. The following table shows two critical parameters, tensile strength and elongation, before and after exposures.

	Tensile, psi		Elongation Percent	
Insulation	Original	After Exp.	Original	After Exp.
XLP	2403	2424	225	100
EPR	1050	600	375	80
HTK	800	670	380	220
Silicon Rubber	1260 to 1102	675 to 187	570 to 400	44 to 14

(All irradiation was by Cobalt-60 sources)

The tested insulations were all shown to be capable of satisfactory performance after exposure to the specified environmental conditions.

All valves in the containment are constructed of stainless steel or painted carbon steel, neither of which corrodes. Corrodible materials such as zinc and aluminum were strictly prohibited except where specifically approved. For example, aluminum was allowed to be used for the rotor of the motors which drive the containment cooler fans. These rotors are enclosed in the motor, and are further protected from the spray solution by two coats of epoxy. Examination of the motors, after operating in a simulated post-accident temperature, pressure, and spray environment, showed no degradation of any components. Galvanized surfaces were only approved for use in applications which would not interfere with the proper operation of any safety feature system, such as grating, ducting, and component casings. In general, all ESF were designed and/or tested to ensure that no harmful corrosion and/or deterioration would occur with pH potentials as high as 10.5.

Performance of the post-accident monitoring instrumentation will likewise not be harmfully affected by the post-accident environment. Identical components have been subjected to applicable temperature, pressure, boric acid, and radiation environmental tests, which proved that the instruments performed properly and did not deteriorate in any manner. All instrumentation has been located to reduce or eliminate the effects of post-LOCA environment. Instrumentation was located outside the containment or shielded within the containment to the maximum extent possible.

The original design capacity of the two containment spray pumps is such that they can limit the containment pressure to less than its design value following a LOCA without giving credit to the containment coolers. The containment pressure/temperature analysis with the containment spray system and the containment air coolers operating together post-LOCA in accordance with the Technical Specification requirements is provided in Section 14.20. A description of the components of the containment spray system is given in Table 6-6.

It is expected that the containment spray will be effective in removing fission products from the containment atmosphere. The method used for calculating the effectiveness of the spray is based on the methodologies detailed in References 3 through 5.

6.4.3 DESIGN EVALUATION

Separate suction headers from the refueling water storage tank are provided, one to each of the two separate and shielded rooms which house the pumps of the ESF systems. One pump room contains one spray pump, one LPSI pump and one HPSI pump. The other room contains one spray pump, one LPSI pump and two HPSI pumps. Separate headers, one to each of these pump rooms, are also provided from the containment sump.

Both suction recirculation headers from the emergency containment sump are completely enclosed by a structure consisting of a concrete curb and stainless steel plates reinforced by structural steel. Cassette type suction strainers filter the sump water (maximum opening is 1/16 inch diameter) which then feed into a stainless steel duct. This duct penetrates the concrete curb thus allowing the filtered water to reach the recirculation headers. This strainer design meets the requirements of Generic Letter 2004-02 (Reference 2). Drawing series 15960 provides the documents containing the details of the emergency containment sump strainer design.

This design constitutes a strong construction and will withstand severe shock and loading. With the wideness of the projected flow areas, it is very unlikely that the strainer will clog. Due to the extremely low flow velocity through the strainer box, the resulting pressure drop of the box construction will be negligible.

The system design is based on the spray water being heated to the temperature of the steam-air mixture within the containment. The nozzles will spray droplets with a mean diameter of approximately 700 microns with the spray system operating at design conditions and the containment at design pressure. In order that the spray droplets attain thermal equilibrium during the fall, adequate distance is provided between the spray nozzles and the highest obstruction in the containment.

The evaluation of post-incident containment pressure/temperature response is provided in Section 14.20.

6.4.4 SYSTEM RELIABILITY

The Containment Spray System has been designed to Seismic Category I criteria, including piping, valves, and containment spray pumps. The piping and valves have been purchased, designed, fabricated, inspected, cleaned, tested, and subject to material control in accordance with the quality assurance criteria presented in 10 CFR Part 50, Appendix B.

The containment spray pumps have been subjected to an extensive quality assurance program by which the manufacturer has controlled the material and manufacturing of these pumps. The pump castings were radiographed to assure their soundness and structural integrity. The manufacturer has performance-tested each containment spray pump and thereby demonstrated that the design requirements are satisfied. In addition, one spray pump was subjected to a thermal shock test, in which the temperature of the pumped fluid was raised from 100°F to 330°F in 10 seconds, to demonstrate that the pump will withstand the thermal shock that occurs when the recirculation mode begins after a LOCA. The manufacturer's shop has been audited to show that he can perform quality work in keeping with the requirements of 10 CFR Part 50, Appendix B.

All electrical equipment within the containment, which must function during and following a LOCA, has been qualified for the initial peak temperature and pressure environment and the subsequent long-term environment, including containment spray operation, as described in Section 14.20. Therefore, no equipment or component should be adversely affected by the containment spray operating during the post-accident period.

The containment spray pumps are initiated by SIAS (Section 7.3.2.2). To prevent an inadvertent actuation of containment spray in the case of an undesired trip of SIAS, the containment spray valves are opened only by a containment spray actuation signal (CSAS). In the event that a SIAS has been received without a CSAS, the containment spray pump will be activated with its flow directed back to the RWT via the mini-flow recirculation lines. Since the mini-flow isolation valves close on a RAS, it is necessary to secure the containment spray pumps prior to the RAS to avoid dead-heading the pumps.

However, inadvertent initiation of the spray system will not affect the safety of the plant, since all the instruments are drip proof or weatherproof and all motors are drip proof. All piping or equipment insulation which may come in contact with sprays is metallic jacketed, fiberglass cloth covered, or of the metal reflective type, in order to prevent large quantities of cold water from penetrating the insulation and coming in contact with hot piping; however a small amount of seepage or absorption will not present significant thermal shocking to any hot equipment. Additionally, for the sections of piping that are fiberglass cloth covered (i.e., not covered with metallic jacketing), the lines have been evaluated for the effects of water absorption on the piping stresses and support loads. These were determined to be acceptable for both static and seismic loads.

Inadvertent operation of the system is alarmed when the spray pumps are operated. Flow indication and valve position indication are also provided for the operator, so the situation would be quickly observed and remedial action taken.

Protection against missile damage is provided by direct shielding or by physical separation of duplicate equipment.

The single failure characteristics of the Containment Spray System are given in Table 6-7.

6.4.5 TESTING

The spray pumps and heat exchangers are located outside the containment to permit access for periodic testing and maintenance during normal plant operation.

A recirculation line is provided on the discharge of each spray pump for testing, which can be accomplished by recirculating water back to the RWT. The recirculation line is sized to pass the minimum allowable pump flow of 50 gpm.

Figure 6-5 shows the containment spray pump characteristic curve. Also shown in this figure are the required NPSH, the pump efficiency and the brake horsepower curves. These curves are drawn from the manufacturer's performance test data. The head capacity of the pump at the design flow of 1400 gpm (1350 gpm spray + 50 gpm minimum recirculation) is greater than the design required head of 370' of water.

Each spray pump has been shop-tested at sufficient head capacity points to generate complete performance curves. NPSH requirements for the capacity range were verified by a suction pressure suppression test for each pump. A shop thermal transient test from ambient temperature to 300°F in 10 seconds was performed on one pump to assure the design is suitable for the switchover from the injection to the recirculation mode.

6.4.6 REFERENCES

1. Calculation CA06963, Mass of Sodium Tetraborate Decahydrate (STB) Buffer Required for Post LOCA Containment Building Sump pH Control
2. Generic Letter 2004-02, dated September 13, 2004, Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors
3. SRP 6.5.2, Revision 2, December 1988, Containment Spray as a Fission Product Cleanup System
4. NUREG/CR-5966, June 1993, A Simplified Model of Aerosol Removal by Containment Sprays
5. Regulatory Guide 1.183, July 2000, Alternative Radiological Source Terms for Evaluating Design Basis Accidents at Nuclear Power Reactors

TABLE 6-4

REFUELING WATER TANK DATA

Quantity	1
Total Volume, gal.	420,000
Water volume, gal.	412,350
Design pressure, psig	Atm.
Design temperature, °F	0
Material	Type 304 stainless steel
Seismic requirements	Category I

TABLE 6-6

CONTAINMENT SPRAY SYSTEM COMPONENT DESCRIPTION

CONTAINMENT SPRAY PUMPS

Quantity	-	2
Type	-	Vertically split, horizontal centrifugal with mechanical seals backed up with an auxiliary gland.
Material	-	American Society for Testing and Materials (ASTM) A296, Gr CA-15[c][d]
Codes	-	Motor: National Electrical Manufacturers Association (NEMA); Pump: Standards of the Hydraulic Institute

	Mode of Operation	
	Injection (Pre-RAS)	Recirculation (Post-RAS)
Design Specification Flow[b] (each)	1,400 gpm[a]	1,350 gpm
Head	385'	390'
NPSH available	86'	23.2'
NPSH required	19.0'	18.5'
Transient temp.	40 - 300°F in 10 seconds	
Motor	200 hp, 3 phase, 60 Hz, 4000 Volts (A 300 hp motor may also be installed)	

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[a] Includes 50 gpm for minimum flow recirculation.

[b] The design specification flow rates are based on the values listed in Specification 6750-M-62, the actual flow may be different from this value. The NPSH required and Head are obtained from initial acceptance test data at the specified flow.

[c] Acceptable alternate material for pump cover is A-743, Gr CA6NM (ES200600162-000).

[d] Containment spray pump's casing and impellers were supplied per ASTM A351, Gr. CA-15.

PIPING, FITTINGS AND VALVES

A. Suction material - Type 304 stainless steel

Pipe Sizes	Wall Thickness
2" and smaller	Sch. 40S
2 1/2 through 12"	Sch. 10S
14" through 20"	0.250" nominal wall
24"	0.375" nominal wall

Design Pressure		-	60 psig from Containment Sump/RWT to source isolation MOVs
		-	200 psig from source isolation MOVs to pump suction
Design Temperature		-	300°F
Construction	2 1/2" and larger	-	Butt-welded except at flanged equipment
	2" and smaller	-	Socket-welded except at screwed equipment
Valves	2 1/2" and larger	-	Stainless steel, butt-welded, 150 lb.
	2" and smaller	-	Stainless steel, socket-welded, 150 lb.
Testing		-	As required by ANSI B31.7
Code		-	ANSI B31.7, Class II

TABLE 6-6

CONTAINMENT SPRAY SYSTEM COMPONENT DESCRIPTION

B. Discharge material (upstream of containment isolation valves) - Type 304 stainless steel

Pipe Sizes	Wall Thickness
8" and smaller	Sch. 40S
10" through 14"	0.250" nominal wall

Design Pressure - 500 psig
Design Temperature - 350°F

Valves	2 1/2" and larger	-	Stainless steel, butt-welded, 300 lbs.
	2" and smaller	-	Stainless steel, socket-welded, 600 lbs.
	Relief valve setpoint	-	500 psig (on tie to HPSI pump suction)
Testing		-	As required by ANSI B31.7
Code		-	ANSI B31.7, Class II
Spray Nozzles	Type	-	Hollow cone, centrifugal nozzle with vanes
	Material	-	Stainless Steel
	Number	-	90 nozzles per spray header (except the inner ring of Unit 1 which has 89)
	Pressure drop	-	40 psi at a nozzle flow of 15.2 gpm
	Spray droplet size	-	700 microns (mean)

TABLE 6-7

SINGLE FAILURE CHARACTERISTICS OF CONTAINMENT SPRAY SYSTEM

	COMPONENT	MALFUNCTION	COMMENTS AND CONSEQUENCES
1.	Check Valve in Spray Header Line	Sticks closed	Second header will supply 50% flow and the system will be supplemented by four containment air cooling units.
2.	Air-Operated Valve in Spray Header Line	Fails to open	Second header will supply 50% flow and the system will be supplemented by four containment air cooling units.
3.	Containment Spray Pump	Pump fails to start	Second spray pump will supply 50% flow and the system will be supplemented by four containment air cooling units.