ATTACHMENT FOUR

PROPOSED TECHNICAL SPECIFICATION REVISIONS

REPLACE WITH ATTACHED LCO AND SRs.

CONTAINMENT SYSTEMS

SPRAY ADDITIVE SYSTEM

LIMITING CONDITION FOR OPERATION

3.6.2.2 The Spray Additive System shall be OPERABLE with:

a. A spray additive tank containing a volume of between 4340 and 4540 gallons of between 31% and 34% by weight NaOH solution, and

b. Two spray additive eductors each capable of adding NaOH solution from the chemical additive tank to a Containment Spray System pump flow.

APPLICABILITY: MODES 1, 2, 3, and 4.

ACTION:

With the Spray Additive System inoperable, restore the system to OPERABLE status within 72 hours or be in at least HOT STANDBY within the next 6 hours; restore the Spray Additive System to OPERABLE status within the next 48 hours or be in COLD SHUTDOWN within the following 30 hours.

SURVEILLANCE REQUIREMENTS

4.6.2.2 The Spray Additive System shall be demonstrated OPERABLE:

a. At least once per 31 days by verifying that each valve (manual, power-operated, or automatic) in the flow path that is not locked, sealed, or otherwise secured in position, is in its correct position;

b. At least once per 6 months by:

1) Verifying the contained solution volume in the tank, and

2) Verifying the concentration of the NaOH solution by chemical analysis.

c. At least once per 18 months during shutdown, by verifying that each automatic valve in the flow path actuates to its correct position on a Containment Pressure-High-3 (CSAS) test signal; and

d. At least once per 5 years by verifying

1) Each eductor flow rate is greater than or equal to 52 gpm using the RWST as the test source throttled to 17 psig at the eductor inlet, and

2) The lines between the spray additive tank and the eductors are not blocked by verifying flow.

CONTAINMENT SYSTEMS

RECIRCULATION FLUID pH CONTROL (RFPC) SYSTEM

LIMITING CONDITION FOR OPERATION

3.6.2.2 The RFPC System shall be OPERABLE with each of the two storage baskets (one within the confines of each of the two containment recirculation sumps) containing a minimum of 19", but not to exceed 36.8" (uniform depth), of granular trisodium phosphate dodecahydrate (TSP-C).

APPLICABILITY: MODES 1, 2, 3, and 4

ACTION:

With the RFPC System inoperable, restore the system to OPERABLE status within 72 hours or be in at least HOT STANDBY within the next 6 hours; restore the RFPC System to OPERABLE status within the next 48 hours or be in COLD SHUTDOWN within the following 30 hours.

SURVEILLANCE REQUIREMENTS

4.6.2.2 The RFPC System shall be demonstrated OPERABLE at least once per 18 months by verifying that:

(a) One TSP-C storage basket is in place in the confines of each containment recirculation sump, and

(b) Both baskets show no evidence of structural distress or abnormal corrosion, and

(c) Each basket contains between 19" and 36.8" (uniform depth) of granular TSP-C.

REFUELING WATER STORAGE TANK (Continued)

The contained water volume limit includes an allowance for water not usable because of tank discharge line location or other physical characteristics.

The limits on contained water volume and boron concentration of the RWST also ensure a ~~pH value of between 8.5 and 11.0~~ minimum equilibrium sump pH of 7.1 for the solution recirculated within containment after a LOCA. This pH ~~band~~ level minimizes the evolution of iodine and minimizes the effect of chloride and caustic stress corrosion on mechanical systems and components.

REVISION 1

3/4.6.1.7 CONTAINMENT VENTILATION SYSTEM

The 36-inch containment purge supply and exhaust isolation valves are required to be closed and blank flanged during plant operations since these valves have not been demonstrated capable of closing during a LOCA or steam line break accident. Maintaining these valves closed and blank flanged during plant operation ensures that excessive quantities of radioactive material will not be released via the Containment Purge System. To provide assurance that the 36-inch containment valves cannot be inadvertently opened, the valves are blank flanged.

The use of the containment mini-purge lines is restricted to the 18-inch purge supply and exhaust isolation valves since, unlike the 36-inch valves, the 18-inch valves are capable of closing during a LOCA or steam line break accident. Therefore, the SITE BOUNDARY dose guideline values of 10 CFR Part 100 would not be exceeded in the event of an accident during containment purging operation. Operation will be limited to 2000 hours during a calendar year. The total time the Containment Purge (vent) System isolation values may be open during MODES 1, 2, 3, and 4 in a calendar year is a function of anticipated need and operating experience. Only safety-related reasons; e.g., containment pressure control or the reduction of airborne radioactivity to facilitate personnel access for surveillance and maintenance activities, should be used to support additional time requests. Only safety-related reasons should be used to justify the opening of these isolation valves during MODES 1, 2, 3, and 4 in any calendar year regardless of the allowable hours.

Leakage integrity tests with a maximum allowable leakage rate for containment purge supply and exhaust supply valves will provide early indication of resilient material seal degradation and will allow opportunity for repair before gross leakage failures could develop. The 0.60 L_a leakage limit of Specification 3.6.1.2b. shall not be exceeded when the leakage rates determined by the leakage integrity tests of these valves are added to the previously determined total for all valves and penetrations subject to Type B and C tests.

3/4.6.2 DEPRESSURIZATION AND COOLING SYSTEMS

3/4.6.2.1 CONTAINMENT SPRAY SYSTEM

The OPERABILITY of the Containment Spray System ensures that containment depressurization and cooling capability will be available in the event of a LOCA or steam line break. The pressure reduction and resultant lower containment leakage rate are consistent with the assumptions used in the safety analyses.

The Containment Spray System and the Containment Cooling System are redundant to each other in providing post-accident cooling of the Containment atmosphere. However, the Containment Spray System also provides a mechanism for removing iodine from the containment atmosphere and therefore the time requirements for restoring an inoperable spray system to OPERABLE status have been maintained consistent with that assigned other inoperable ESF equipment.

~~3/4.6.2.2 SPRAY ADDITIVE SYSTEM~~ REPLACE WITH ATTACHED BASES.

~~The OPERABILITY of the Spray Additive System ensures that sufficient NaOH is added to the containment spray in the event of a LOCA. The limits on NaOH volume and concentration ensure a pH value of between 8.5 and 11.0 for the~~

SPRAY ADDITIVE SYSTEM (Continued)

~~solution recirculated within containment after a LOCA. This pH band minimizes the evolution of iodine and minimizes the effect of chloride and caustic stress corrosion on mechanical systems and components. The contained solution volume limit includes an allowance for solution not usable because of tank discharge line location or other physical characteristics. The eductor flow test of 52 gpm with RWST water is equivalent to 40 gpm NaOH solution. These assumptions are consistent with the iodine removal efficiency assumed in the safety analyses.~~

3/4.6.2.3 CONTAINMENT COOLING SYSTEM

The OPERABILITY of the Containment Cooling System ensures that: (1) the containment air temperature will be maintained within limits during normal operation, and (2) adequate heat removal capacity is available when operated in conjunction with the Containment Spray Systems during post-LOCA conditions.

The Containment Cooling System and the Containment Spray System are redundant to each other in providing post-accident cooling of the Containment atmosphere. As a result of this redundancy in cooling capability, the allowable out-of-service time requirements for the Containment Cooling System have been appropriately adjusted. However, the allowable out-of-service time requirements for the Containment Spray System have been maintained consistent with that assigned other inoperable ESF equipment since the Containment Spray System also provides a mechanism for removing iodine from the containment atmosphere.

3/4.6.3 CONTAINMENT ISOLATION VALVES

The OPERABILITY of the containment isolation valves ensures that the containment atmosphere will be isolated from the outside environment in the event of a release of radioactive material to the containment atmosphere or pressurization of the containment and is consistent with the requirements of GDC 54 thru 57 of Appendix A to 10 CFR Part 50. Containment isolation within the time limits specified for those isolation valves designed to close automatically ensures that the release of radioactive material to the environment will be consistent with the assumptions used in the analyses for a LOCA.

3/4.6.4 COMBUSTIBLE GAS CONTROL

The OPERABILITY of the equipment and systems required for the detection and control of hydrogen gas ensures that this equipment will be available to maintain the hydrogen concentration within containment below its flammable limit during post-LOCA conditions. Either recombiner unit (or the Purge System) is capable of controlling the expected hydrogen generation associated with: (1) zirconium-water reactions, (2) radiolytic decomposition of water, and (3) corrosion of metals within containment. The Hydrogen Purge Subsystem discharges directly to the Emergency Exhaust System. Operation of the Emergency Exhaust System with the heaters operating for at least 10 continuous hours in a 31-day period is sufficient to reduce the buildup of moisture on the adsorbers and HEPA filters. These hydrogen control systems are consistent with the recommendations of Regulatory Guide 1.7, "Control of Combustible Gas Concentrations in Containment Following a Loss-of-Coolant Accident," Revision 2, November 1978.

BASES

3/4.6.2.2 RECIRCULATION FLUID pH CONTROL (RFPC) SYSTEM

The operability of the RFPC System ensures that there exists adequate TSP-C in the containment such that a post-LOCA equilibrium sump pH of greater than or equal to 7.1 is maintained during the recirculation phase. The minimum depth of 19" inches ensures that 5000 lbm of TSP-C is available for dissolution to yield a minimum equilibrium sump pH of 7.1. This pH level minimizes the evolution of iodine and minimizes the effect of chloride and caustic stress corrosion on mechanical systems and components. The upper limit of 36.8" corresponds to the basket design capacity.

CONTAINMENT SYSTEMS

RECIRCULATION FLUID pH CONTROL (RFPC) SYSTEM

LIMITING CONDITION FOR OPERATION

3.6.2.2 The RFPC System shall be OPERABLE with each of the two storage baskets (one within the confines of each of the two containment recirculation sumps) containing a minimum of 19", but not to exceed 36.8" (uniform depth), of granular trisodium phosphate dodecahydrate (TSP-C).

APPLICABILITY: MODES 1, 2, 3, and 4

ACTION:

With the RFPC System inoperable, restore the system to OPERABLE status within 72 hours or be in at least HOT STANDBY within the next 6 hours; restore the RFPC System to OPERABLE status within the next 48 hours or be in COLD SHUTDOWN within the following 30 hours.

SURVEILLANCE REQUIREMENTS

4.6.2.2 The RFPC System shall be demonstrated OPERABLE at least once per 18 months by verifying that:

(a) One TSP-C storage basket is in place in the confines of each containment recirculation sump, and

(b) Both baskets show no evidence of structural distress or abnormal corrosion, and

(c) Each basket contains between 19" and 36.8" (uniform depth) of granular TSP-C.

REFUELING WATER STORAGE TANK (Continued)

The contained water volume limit includes an allowance for water not usable because of tank discharge line location or other physical characteristics.

The limits on contained water volume and boron concentration of the RWST also ensure a minimum equilibrium sump pH of 7.1 for the solution recirculated within containment after a LOCA. This pH level minimizes the evolution of iodine and minimizes the effect of chloride and caustic stress corrosion on mechanical systems and components.

3/4.6.1.7 CONTAINMENT VENTILATION SYSTEM

The 36-inch containment purge supply and exhaust isolation valves are required to be closed and blank flanged during plant operations since these valves have not been demonstrated capable of closing during a LOCA or steam line break accident. Maintaining these valves closed and blank flanged during plant operation ensures that excessive quantities of radioactive material will not be released via the Containment Purge System. To provide assurance that the 36-inch containment purge valves cannot be inadvertently opened, the valves are blank flanged.

The use of the containment mini-purge lines is restricted to the 18-inch purge supply and exhaust isolation valves since, unlike the 36-inch valves, the 18-inch valves are capable of closing during a LOCA or steam line break accident. Therefore, the SITE BOUNDARY dose guideline values of 10 CFR Part 100 would not be exceeded in the event of an accident during containment purging operation. Operation will be limited to 2000 hours during a calendar year. The total time the Containment Purge (vent) System isolation valves may be open during MODES 1, 2, 3, and 4 in a calendar year is a function of anticipated need and operating experience. Only safety-related reasons; e.g., containment pressure control or the reduction of airborne radioactivity to facilitate personnel access for surveillance and maintenance activities, should be used to support additional time requests. Only safety-related reasons should be used to justify the opening of these isolation valves during MODES 1, 2, 3, and 4 in any calendar year regardless of the allowable hours.

Leakage integrity tests with a maximum allowable leakage rate for containment purge supply and exhaust isolation valves will provide early indication of resilient material seal degradation and will allow opportunity for repair before gross leakage failures could develop. The 0.60 L_a leakage limit of Specification 3.6.1.2b. shall not be exceeded when the leakage rates determined by the leakage integrity tests of these valves are added to the previously determined total for all valves and penetrations subject to Type B and C tests.

3/4.6.2 DEPRESSURIZATION AND COOLING SYSTEMS

3/4.6.2.1 CONTAINMENT SPRAY SYSTEM

The OPERABILITY of the Containment Spray System ensures that containment depressurization and cooling capability will be available in the event of a LOCA or steam line break. The pressure reduction and resultant lower containment leakage rate are consistent with the assumptions used in the safety analyses.

The Containment Spray System and the Containment Cooling System are redundant to each other in providing post-accident cooling of the Containment atmosphere. However, the Containment Spray System also provides a mechanism for removing iodine from the containment atmosphere and therefore the time requirements for restoring an inoperable spray system to OPERABLE status have been maintained consistent with that assigned other inoperable ESF equipment.

3/4.6.2.2 RECIRCULATION FLUID pH CONTROL (RFPC) SYSTEM

The operability of the RFPC System ensures that there exists adequate TSP-C in the containment such that a post-LOCA equilibrium sump pH of greater than or equal to 7.1 is

3/4.6.2.2 RECIRCULATION FLUID pH CONTROL (RFPC) SYSTEM (Continued)

maintained during the recirculation phase. The minimum depth of 19" ensures that 5000 lbm of TSP-C is available for dissolution to yield a minimum equilibrium sump pH of 7.1. This pH level minimizes the evolution of iodine and minimizes the effect of chloride and caustic stress corrosion on mechanical systems and components. The upper limit of 36.8" corresponds to the basket design capacity.

3/4.6.2.3 CONTAINMENT COOLING SYSTEM

The OPERABILITY of the Containment Cooling System ensures that: (1) the containment air temperature will be maintained within limits during normal operation, and (2) adequate heat removal capacity is available when operated in conjunction with the Containment Spray System during post-LOCA conditions.

The Containment Cooling System and the Containment Spray System are redundant to each other in providing post-accident cooling of the Containment atmosphere. As a result of this redundancy in cooling capability, the allowable out-of-service time requirements for the Containment Cooling System have been appropriately adjusted. However, the allowable out-of-service time requirements for the Containment Spray System have been maintained consistent with that assigned other inoperable ESF equipment since the Containment Spray System also provides a mechanism for removing iodine from the containment atmosphere.

3/4.6.3 CONTAINMENT ISOLATION VALVES

The OPERABILITY of the containment isolation valves ensures that the containment atmosphere will be isolated from the outside environment in the event of a release of radioactive material to the containment atmosphere or pressurization of the containment and is consistent with the requirements of GDC 54 thru 57 of Appendix A to 10 CFR Part 50. Containment isolation within the time limits specified for those isolation valves designed to close automatically ensures that the release of radioactive material to the environment will be consistent with the assumptions used in the analyses for a LOCA.

3/4.6.4 COMBUSTIBLE GAS CONTROL

The OPERABILITY of the equipment and systems required for the detection and control of hydrogen gas ensures that this equipment will be available to maintain the hydrogen concentration within containment below its flammable limit during post-LOCA conditions. Either recombiner unit (or the Purge System) is capable of controlling the expected hydrogen generation associated with: (1) zirconium-water reactions, (2) radiolytic decomposition of water, and (3) corrosion of metals within containment. The Hydrogen Purge Subsystem discharges directly to the Emergency Exhaust System. Operation of the Emergency Exhaust System with the heaters operating for at least 10 continuous hours in a 31-day period is sufficient to reduce the buildup of moisture on the adsorbers and HEPA filters. These hydrogen control systems are consistent with the recommendations of Regulatory Guide 1.7, "Control of Combustible Gas Concentrations in Containment Following a Loss-of-Coolant Accident," Revision 2, November 1978.

ATTACHMENT FIVE

FSAR MARK-UPS

conditions is described below. The post-accident parameters used in the equipment review are provided in summary form in Table 3.11(B)-2 and as used in the review, in Figures 3.11(B)-1 through 84.

Radiation

Using the guidance of NUREG-0588, post-LOCA radiation environments were determined in all areas of the containment. The original fission product release data used in this analysis were obtained from Westinghouse. The isotopic inventory provided by Westinghouse was for an equilibrium cycle Callaway core. The data were calculated at the end of cycle life and, therefore, represent maximums suitable for post-accident evaluations. This source term is referred to as the licensing basis EQ source term, applicable to the initial core load. Subsequent cycles have seen changes in fuel type (from STD/LOPAR to OFA to VANTAGE 5), power level (from 3425 MWt to 3579 MWt), and burnup (up to 60,000 MWd/MTU as discussed in Section 4.2.1). The doses reported in Table 3.11(B)-4 have been increased by 5% to account for these effects. In addition, the airborne gamma doses were increased by another 3% to account for the replacement of the active spray additive system with a passive system of baskets in the containment recirculation sumps containing trisodium phosphate. The following discussion refers to the initial calculations performed with the licensing basis EQ source term and a 50% cesium release fraction.

The accident scenario assumed that a LOCA event occurred causing core damage. The entire source of 100 percent noble gas inventory, 50 percent of the core halogen inventory, 50 percent of the cesium, and 1 percent of the other solids was released to the containment. This release was conservatively assumed to occur at time zero. For the liquid source, 50 percent of the halogens, 50 percent of the cesium, and 1 percent of the remaining fission product solids were assumed to go directly to the sump and were diluted by the volume of the refueling water storage tank (RWST) and the liquid volume of the reactor coolant system. For the airborne source, 100 percent of the noble gases and 50 percent of core halogens were assumed to be released to the free volume of the containment. The simultaneous release of 50 percent of the halogens to the atmosphere and to the sump introduced additional conservatism.

Credit was taken for mechanistic removal of the airborne iodine via containment spray and plateout. The spray removal lambdas for elemental and particulate iodine ($25.7\ hr^{-1}$ and $0.73\ hr^{-1}$) were taken from ~~Section 6.5~~ the calculated values listed in Table 6.5-2. The plate-out removal lambda ($1.58\ hr^{-1}$) was calculated ~~was determined~~ using methodology outlined in NUREG/CR-0009. The surface area available for plateout was assumed to be equivalent to the heat sink area used in the containment pressure analysis given in Table 6.2.1-4. In addition, two of the four hydrogen mixing fans were assumed to be operating, at 42,500 cfm each, to provide mixing between the sprayed (86 percent) and unsprayed (14 percent) regions of the containment. These removal processes were assumed to persist until the elemental and particulate iodine in the

sprayed region were reduced by factors of 200 and 10,000, respectively. INSERT 1

To determine the gamma dose rate inside the containment, the multigroup, three-dimensional, point kernal code QAD-CG was used to take credit for all major internal structures. The containment was divided into regions, and the maximum dose rate within each region as a function of time was determined. These dose rates were assumed to apply to all equipment within that

INSERT 1

These decontamination factors (DFs) were taken from Reference 22. The spray removal rate for elemental iodine was calculated in Section 6.5A.2 to be 25.7 hr^{-1}. This spray removal rate plus the plateout removal rate (25.7 hr^{-1} + 1.58 hr^{-1}) were assumed to be effective in the sprayed region until an elemental iodine decontamination factor (DF) of 200 was reached in the EQ dose calculations. Only the plateout removal rate was assumed to be effective in the unsprayed region until an elemental iodine DF of 2 was reached in the EQ dose calculations. The spray removal rate for particulate iodine was calculated to be 0.73 hr^{-1} in Section 6.5A.1 and was assumed to be effective in the sprayed region until a particulate iodine DF of 10,000 was reached in the EQ dose calculations.

It is noted that the offsite and control room doses discussed in Section 15.6.5 were calculated using an elemental iodine spray removal rate of 10 hr^{-1} and a particulate iodine spray removal rate of 0.45 hr^{-1}, until a DF of 28.7 was reached for elemental species and a DF of 50 was reached for particulate species. No plateout removal lambda was used in the Section 15.6.5 dose calculations since credit was taken for the instantaneous plateout of half of the iodines released to the containment atmosphere (i.e. 25% of the core iodines).

With the replacement of the spray additive system with trisodium phosphate baskets in the containment recirculation sumps, the minimum equilibrium sump fluid pH is reduced to 7.1. This reduced pH results in a reduced spray partition coefficient (H, from Equation 6.5A-15 on page 6.5A-7) of 1100 per Reference 23. Using Equation 6.5A-15, the resulting elemental iodine DF was calculated to be 28.7 for the analysis of offsite and control room doses discussed in Section 15.6.5. Per Reference 24, the particulate iodine spray removal rate, calculated using Equation 6.5A-1 on page 6.5A-2, can conservatively be based on an assumed E/D of 10 per meter initially, changing to 1 per meter after a DF of 50. After the particulate iodine spray removal rate is reduced, there is no DF limit. However, for simplicity and conservatism, removal was assumed to stop after a DF of 50 was reached in the analysis of offsite and control room doses. With consideration given to these reduced DF values for elemental and particulate iodines, airborne gamma doses listed in Table 3.11(B)-4 have been estimated to increase by 3% as a result of the use of the trisodium phosphate baskets.

region. Each dose rate was numerically integrated to obtain the 180-day integrated dose for each region. The beta dose rate as a function of time was obtained assuming a semi-infinite cloud model. These dose rate values were also numerically integrated to obtain the 180-day beta doses for each region. The gamma plate-out was modeled using a cylinder with a height and radius equal to that of the containment. The dose rate was obtained at the center of the cylinder without taking credit for air attenuation. Beta dose rate contributions due to plate-out were obtained assuming a contact dose rate.

The resulting containment integrated dose curves are provided as Figures 3.11(B)-50 through 3.11(B)-84.

Per the commitments to Regulatory Guides 1.7 and 1.89 in Appendix 3A, a 1% cesium source term is sufficient for Callaway. However, the radiation levels reported in Table 3.11(B)-4, obtained using a 50% cesium source term, were utilized during the NUREG-0588 review. Due to the extreme conservatism in the equipment specifications, most components were qualified to this radiation level. For the isolated cases where the 50% cesium source term radiation proved too severe (i.e. electrical specifications, E-018, J-301, J-481, J-1030, ~~J-1034,~~ ESE-3A and mechanical specifications ESE-21, ESE-48A), the equipment was evaluated against a 1% cesium source term.

Pressure, Temperature, and Humidity

Callaway unique containment pressure-temperature profiles were utilized for the current equipment evaluation to NUREG-0588. The temperature and pressure conditions were evaluated for both LOCA and MSLB accidents. The resulting containment temperature and pressure profiles are provided in Figures 3.11(B)-1 through 6. The maximum containment temperatures are 308.6 F and 384.9 F for LOCA and MSLB conditions, respectively. The maximum containment pressure utilized for evaluating both accidents is 63 psia.

For the evaluation of equipment located inside containment, pressure-temperature enveloping profiles for Callaway have been generated. These environments were generated for a spectrum of MSLBs and LOCAs. For LOCAs, full and partial double-ended breaks and split breaks in the pump suction line were evaluated. Full double-ended hot and cold leg breaks were also analyzed. For the main steam lines, a spectrum of break sizes (split and double-ended) at various power levels with minimum entrainment were evaluated. For these evaluations, loss of offsite power and a worst single failure were assumed. Pressure and temperature mitigation from the operation of safety-related containment sprays, air coolers, and heat transfer to structures was considered.

All methods applied in the determination of environments are in accordance with Sections 1.1 and 1.2 of NUREG-0588, Revision 1 for Category I plants. The evaluation of mass and energy

a. The peak qualification temperature envelopes the peak uprating temperature with significant margin (384.9°F vs. 352°F).

b. The total heat transferred into the equipment is greater for the previous EQ profile (Fig. 3.11(B)-3) than for the uprating profile, particularly at 45 seconds. This is possible since the EQ pressure at 45 seconds is higher than the uprating pressure (55 psia vs. 45 psia) and the condensing heat transfer coefficient is orders of magnitude greater than convective heat transfer coefficient.

c. The equipments' thermal lag makes small deviations from an accident profile insignificant in comparison to the overall profile.

Therefore, there was no impact on equipment qualification as a result of the plant uprating to 3579 MWt.

Containment Spray

The Callaway design utilizes two redundant trains to supply containment spray for temperature and pressure reduction and fission product removal from the containment atmosphere. Table 3.11(B)-5 identifies the containment spray requirements. The Standard Review Plan indicates that single failures should be evaluated to determine the worst case chemical concentrations. The worst case concentrations ~~, resulting from a single failure,~~ are pH = 4.0 and pH = **11.0**, as discussed in Section 6.5.2.3.

A caustic spray with an upper limit of pH = 11.0 ~~is~~ will be used in ~~the~~ EQ reviews. ~~, however, it is recognized that this event will only occur for a short period.~~ A boron concentration of 2050 ppm was used in the EQ reviews. The Cycle 4 change to an RWST boron concentration of 2350-2500 ppm has a negligible effect on peak pH, therefore the corrosive effects of the containment spray are not increased. As such, there is no adverse EQ impact arising from this change in RWST boron concentration.

3.11(B).1.2.3 Accident Environments - Outside Containment

Radiation

Using the guidance of NUREG-0588 and NUREG-0737, post-LOCA dose rates and doses were determined in those areas of the auxiliary building where safety-related equipment qualification would be reviewed. The fission product release data used in this analysis were the same as discussed in Section 6.2.1. The analysis for the auxiliary building yielded a conservative upper bound estimate for the doses to all safety-related electrical equipment as required by NUREG-0588. See Section 3.11(B).1.2.2 regarding source term changes since the initial core load. [INSERT 2] The following discussion refers to the initial calculations performed with the licensing basis EQ source term and a 50% cesium release fraction.

INSERT 2

With the replacement of the spray additive system with trisodium phosphate baskets in the containment recirculation sumps, the doses in penetration rooms 1409-1412 and 1506-1509 in Table 3.11(B)-2 have been estimated to increase by 8% due to the harder spectrum of gamma energies associated with the iodines.

17. SLNRC 83-054, "Instrumentation and Control Systems Branch Review," October 27, 1983.

18. WCAP-9230, Rev. 0, "Report on the Consequences of a Postulated Main Feedline Rupture, Proprietary."

20. ULNRC-1471 "Callaway Plant Uprating Submittal", March 31, 1987.

21. ULNRC-1618 "Responses to Questions on Callaway Uprating", September 18, 1987.

INSERT 3

INSERT 3

22. NUREG-0588, Revision 1, "Interim Staff Position on Environmental Qualification of Safety-Related Electrical Equipment," Part II, Appendix D, page IID-4, July 1981.

23. E. C. Beahm, W. E. Shockley, C. F. Weber, S. J. Wisbey, and Y. M. Wang, "Chemistry and Transport of Iodine in Containment," NUREG/CR-4697, October 1986.

24. NUREG-0800, Standard Review Plan Section 6.5.2, Revision 2, "Containment Spray as a Fission Product Cleanup System," December 1988.

TABLE 3.11(B)-2 (Sheet 3)

Room No.	Area	DBA Pressure Max. (psig)(9)	DBA Temp. Max. F(8)(9)	DBA RH % Max.(8)(9)	DBA Dose (Rad)(14)	Environmental ph DBA
Auxiliary Building						
1325(16)	Auxiliary feedpump (motor) room	Atmospheric	104	70	7.26×10^2	
1326(16)	Auxiliary feedpump (motor) room	Atmospheric	104	70	6.66×10^1	
1327	Feedwater pump valve compartment No. 2	Atmospheric	104	70	8.79×10^2	
1328	Feedwater pump valve compartment No. 3	Atmospheric	104	70	8.79×10^2	
1329	Vestibule	1.0	110	73	8.79×10^2	
1330	Feedwater pump valve compartment No. 4	Atmospheric	104	70	8.79×10^2	
1331	Auxiliary feedpump (turbine) room	Atmospheric	142	100	8.85×10^1	
1401(16)	CCW pump room	1.0	106	71	4.48×10^1	
1402	Corridor No. 1, El. 2026'	1.0	106	71	1.55×10^2	
1406(16)	CCW pump room	1.0	106	71	4.85×10^2	
1408	Corridor	1.0	106	71	7.88×10^2	
1409	Electrical penetration room	1.0	106	71	~~1.10~~ $\times 10^6$ 1.27	
1410	Electrical penetration room	1.0	106	71	~~1.61~~ $\times 10^6$ 1.74	
1411	Main feedwater room No. 1	6.7	324(18)	100	~~1.07~~ $\times 10^6$ 1.16	
1412	Main feedwater room No. 2	6.7	324(18)	100	~~1.09~~ $\times 10^6$ 1.18	
1413	Auxiliary shutdown panel room	1.0	106	71	1.10×10^2	
1501	Control room a/c equip. room	Atmospheric	104	71	7.14×10^1	
1502	CCW surge tank area (B)	1.0	106	71	8.92×10^2	
1503	CCW surge tank area (A)	1.0	106	71	9.58×10^2	
1504	Ctmt. purge exhaust and mech. equip. room (B)	1.0	106	71	3.97×10^2	
1506	Ctmt. purge supply air handling unit room (A)	Same as room 1504 conditions			~~7.22~~ $\times 10^5$ 7.80	
1507	Personnel hatch area El. 2047'-6"	1.0	106	71	~~1.01~~ $\times 10^6$ 1.09	

TABLE 3.11(B)-2 (Sheet 4)

Room No.	Area	DBA Pressure Max. (psig)[9]	DBA Temp. Max. F[8][9]	DBA RH % Max.[8][9]	DBA Dose (Rad)[14]	Environmental ph DB
Auxiliary Building						
1508	Main steam/main feedwater isolation valve room[9]	6.7	324[18]	100	~~1.07~~ 1.16 $\times 10^6$	
1509	Main steam/main feedwater isolation valve room[9]	6.7	324[18]	100	~~1.09~~ 1.18 $\times 10^6$	
1512	Control room a/c equip. room	Atmospheric	104	71	3.13×10^2	
1513	Control bldg a/c equip. room	1.0	106	71	3.13×10^2	
Control Building						
3101	Pipe space tank area El. 1974'	Atmospheric	120	95	<2.5	
3105	Control building cable chase	Atmospheric	120	95	<2.5	
3106	Control building cable chase	Atmospheric	120	95	<2.5	
3222	Health physicists office, El. 1984'	Atmospheric	120	95	<2.5	
3224	Vestibule No. 2 El. 1984'	Atmospheric	120	95	<2.5	
3229	Control building cable chase	Atmospheric	120	95	<2.5	
3230	Control building cable chase	Atmospheric	120	95	<2.5	
3301[17]	ESF switchgear room	Atmospheric	90	70	<2.5	
3302[17]	ESF switchgear room	Atmospheric	90	70	<2.5	
3404[17]	Switchboard room (No. 4)	Atmospheric	90	70	<0.0005	
3405[17]	Battery room	Atmospheric	90	70	<2.5	
3407[17]	Battery room	Atmospheric	90	70	<2.5	
3408[17]	Switchboard room (No. 1)	Atmospheric	90	70	<0.0005	
3410[17]	Switchboard room (No. 2)	Atmospheric	90	70	<0.0005	
3411[17]	Battery room	Atmospheric	90	70	<2.5	
3413[17]	Battery room	Atmospheric	90	70	<2.5	
3414[17]	Switchboard room (No. 3)	Atmospheric	90	70	<0.0005	

TABLE 3.11(B)-4

CONTAINMENT WORST CASE

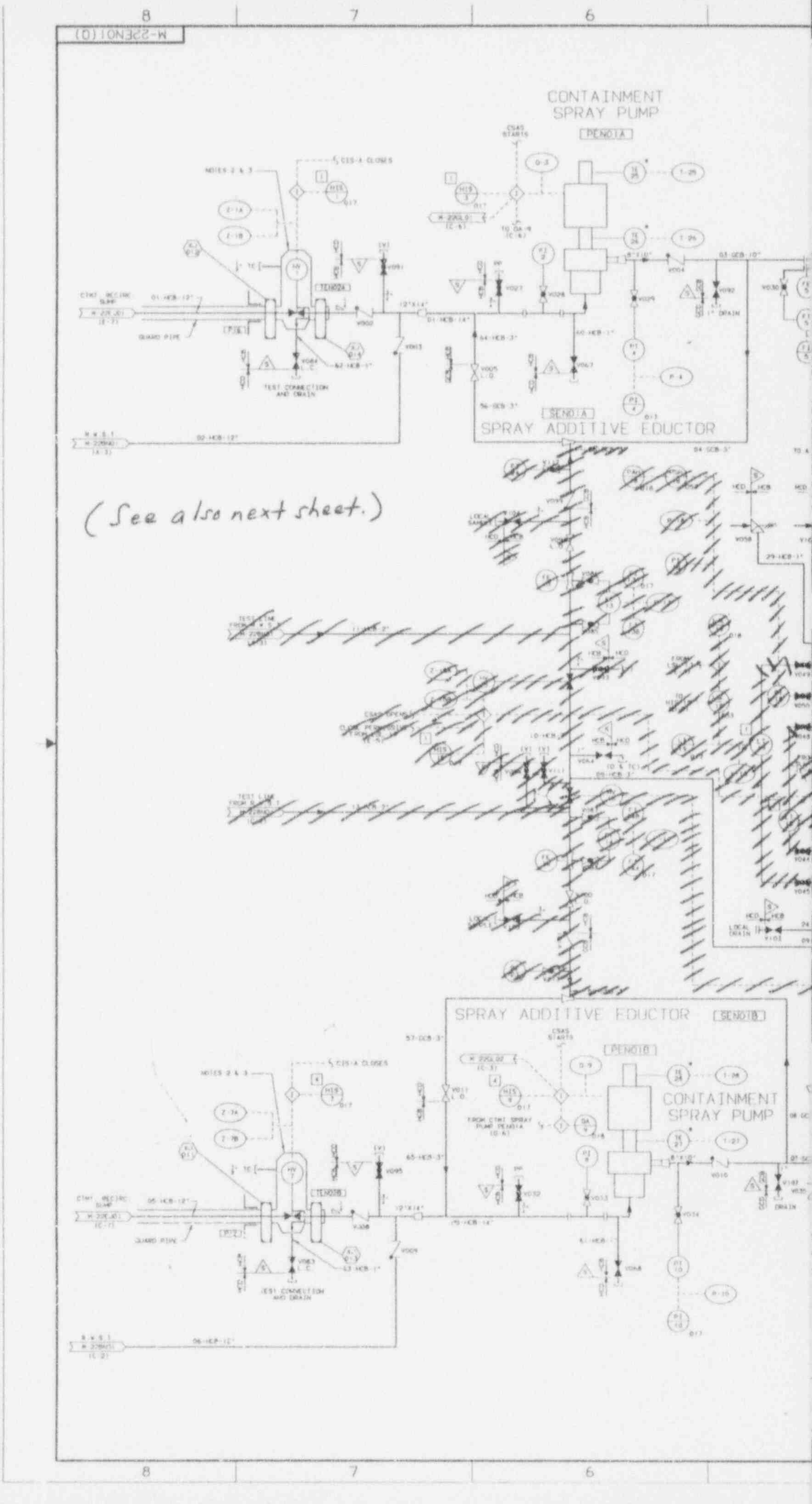
RADIATION LEVELS (MRADs)

SOURCE	UPPER CTMT.	ABOVE SUMP	SUBMERGED IN SUMP
Gamma			
Airborne Source	~~8.54~~ 8.80 + 0	~~3.01~~ 3.10 + 0	Negl.
Liquid Source	1.52 + 1	6.32 + 1	1.26 + 2
Plateout Source	9.24 - 2	1.39 - 1	Negl.
Total	~~2.30~~ 2.41 + 1	~~6.64~~ 6.65 + 1	1.26 + 2
Beta			
Airborne Source	1.46 + 2	1.46 + 2	0
Liquid Source	0	0	1.55 + 1
Plateout Source	1.40 + 1	2.08 + 1	0
Total	1.60 + 2	1.67 + 2	1.55 + 1
Total	1.84 + 2	2.33 + 2	1.42 + 2

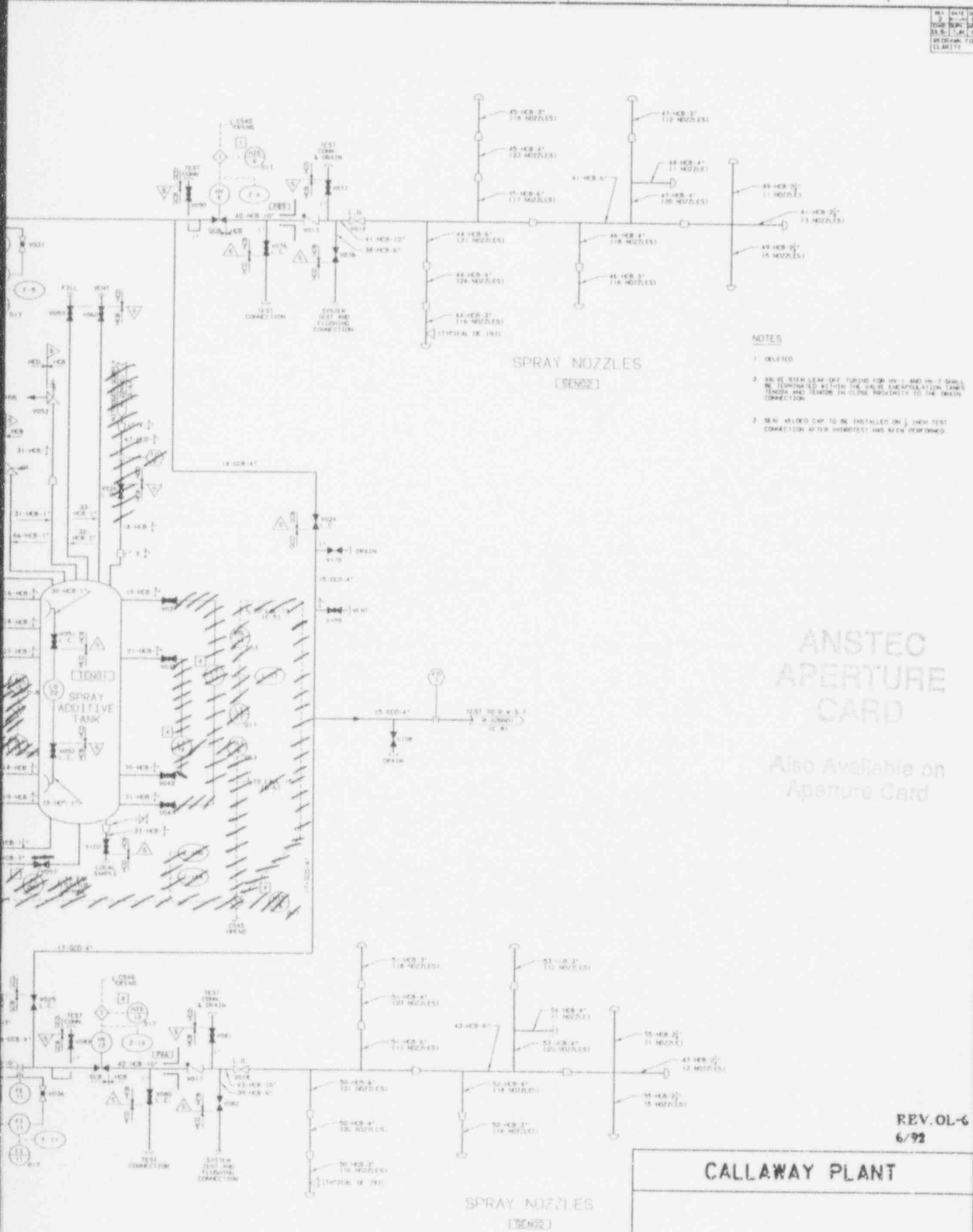
TABLE 3.11(B)-5

CONTAINMENT
SPRAY REQUIREMENTS

Sprayed Fluid	Injection Phase	
	Aqueous Solution, pH ~~(max.)~~	~~11.0~~ 4.0-7.0
	Boric Acid, ppm boron (max./min.)	2,500/2,350
Sprayed Fluid	Recirculation Phase	
	~~(with continued NaOH addition)~~	
	Aqueous Solution, pH ~~(max.)~~	~~11.0~~ 7.1-11.0
	Boric Acid, ppm boron (max./min.)	2,500/~~1,900~~ 2,007
~~Sprayed Fluid~~	~~Recirculation Phase~~	
	~~Aqueous Solution, pH~~	~~8.0-10.0~~
	~~Boric Acid, ppm boron (max./min.)~~	~~2,500/1,900~~
Final Equilibrium Sump Fluid	Aqueous Solution, pH	~~8.5-10.0~~ 7.1-9.0
	Boric Acid, ppm boron (max./min.)	2,500/~~1,970~~ 2,007



8
7
6
M-22EN01(Q)
CONTAINMENT
SPRAY PUMP
PEN01A
SEN01A
SPRAY ADDITIVE EDUCTOR
(See also next sheet.)
SPRAY ADDITIVE EDUCTOR
SEN01B
PEN01B
CONTAINMENT
SPRAY PUMP
TEST CONNECTION
AND DRAIN



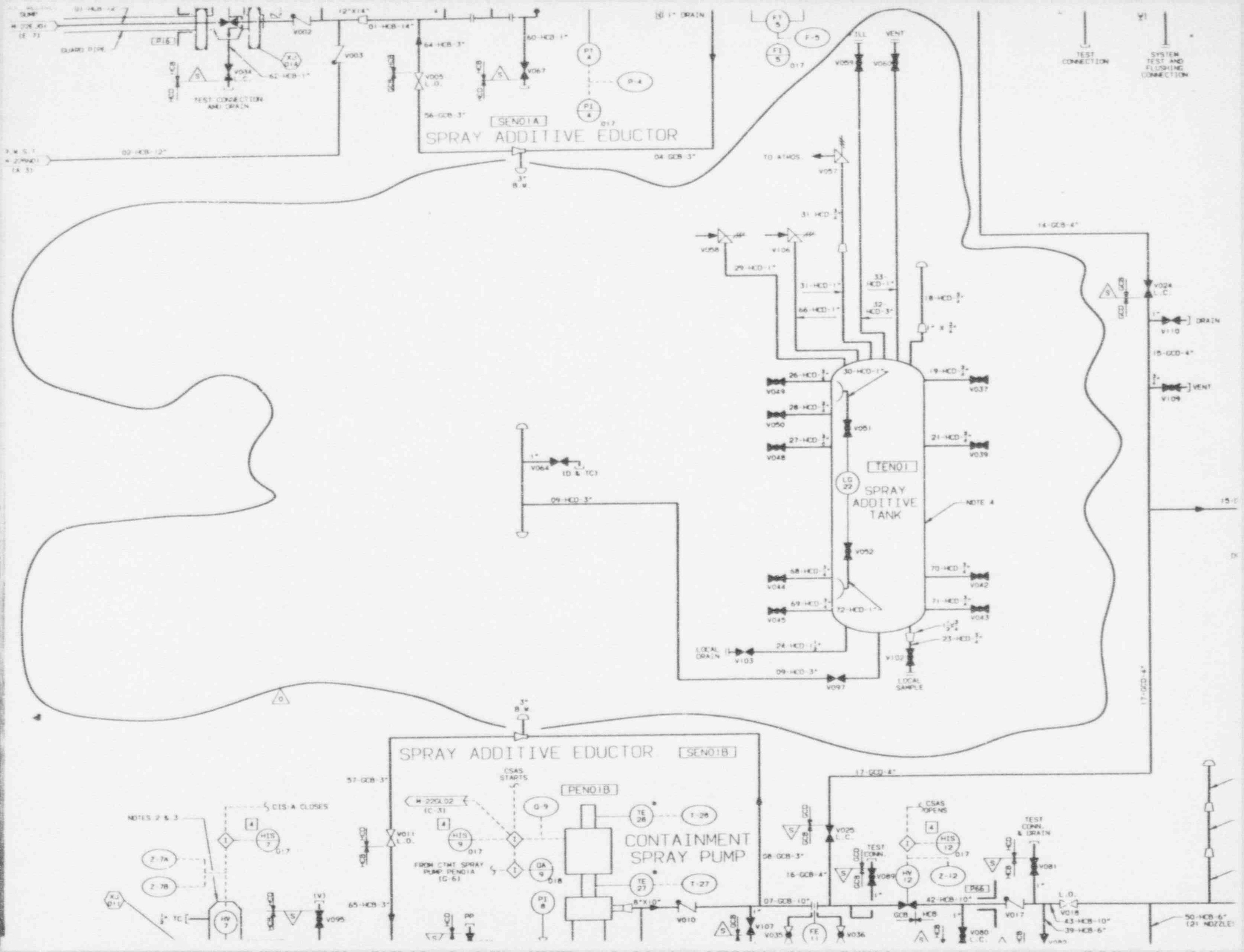
REV. OL-6
6/92

CALLAWAY PLANT

FIGURE 6.2.2-1

CONTAINMENT SPRAY SYSTEM
(M-22EN01(Q)-2)

9408150332-01



SUMP
M-22EJ01
(E-7)
01-HCB-12"
GUARD PIPE
P16
XJ
014
V002
12"X14"
01-HCB-14"
V003
62-HCB-1"
V034
L.C.
TEST CONNECTION AND DRAIN
R.W.S.T.
M-22BN01
(A-3)
02-HCB-12"
64-HCB-3"
V005
L.O.
60-HCB-1"
V067
56-GCB-3"
SEN01A
SPRAY ADDITIVE EDUCTOR
3"
B.W.
1" DRAIN
PT
4
PI
4
017
P-4
04-GCB-3"
FT
5
FI
5
017
F-5
FILL
VENT
V059
V060
TEST CONNECTION
SYSTEM TEST AND FLUSHING CONNECTION
TO ATMOS.
V057
31-HCD-3/4"
V058
V106
29-HCD-1"
31-HCD-1"
66-HCD-1"
33-HCD-1"
32-HCD-3"
18-HCD-3/4"
1" X 3/4"
14-GCB-4"
V024
L.C.
1"
V110
DRAIN
15-GCD-4"
V109
VENT
26-HCD-3/4"
30-HCD-1"
19-HCD-3/4"
V049
V037
28-HCD-3/4"
V050
V051
27-HCD-3/4"
V048
21-HCD-3/4"
V039
V064
(D & TC)
LG
22
TEN01
SPRAY ADDITIVE TANK
NOTE 4
09-HCD-3"
V052
68-HCD-3/4"
V044
70-HCD-3/4"
V042
69-HCD-3/4"
72-HCD-1"
V045
71-HCD-3/4"
V043
23-HCD-3/4"
LOCAL DRAIN
V103
24-HCD-1 1/2"
V102
09-HCD-3"
V097
LOCAL SAMPLE
17-GCD-4"
15-C
3"
B.W.
SPRAY ADDITIVE EDUCTOR
SEN01B
57-GCB-3"
CSAS STARTS
PEN01B
NOTES 2 & 3
CIS-A CLOSES
M-22SL02
(C-3)
G-9
TE
28
T-28
4
HIS
7
017
V011
L.O.
HIS
9
017
CONTAINMENT SPRAY PUMP
Z-7A
Z-7B
FROM CTMT SPRAY PUMP PEN01A
(G-6)
QA
9
018
TE
27
T-27
58-GCB-3"
XJ
011
1/2" TC
HV
7
V095
65-HCB-3"
PI
8
PP
8"X10"
V010
V107
V035
FE
11
V036
07-GCB-10"
17-GCD-4"
V025
L.C.
16-GCB-4"
TEST CONN.
V089
CSAS OPENS
HIS
12
017
HV
12
Z-12
P66
42-HCB-10"
GCB
HCB
V080
L.C.
V017
TEST CONN. & DRAIN
V081
L.O.
V018
43-HCB-10"
39-HCB-6"
50-HCB-6"
(21 NOZZLE)

Radioiodine in its various forms is the fission product of primary concern in the evaluation of a LOCA. It is absorbed by the containment spray from the containment atmosphere. To enhance this iodine absorption capacity of the spray, the spray solution is adjusted to an alkaline pH which promotes iodine hydrolysis, in which iodine is converted to nonvolatile forms tending to plate out on containment structures or to be retained in the containment recirculation sumps.

The physical characteristics of the CSS are discussed in Section 6.2.2.1. Discussed herein is ~~are~~ the ~~spray additive portion of the system and the~~ containment spray system's fission product removal capability following a LOCA.

6.5.2.1 <u>Design Bases</u>

6.5.2.1.1 Safety Design Bases

SAFETY DESIGN BASIS ONE - The CSS is designed to provide an INSERT 4 ~~spray solution while the spray additive portion of the system is in operation in the pH range of 9.3 to 11.0 and a final containment recirculation sump solution with a pH of at least 8.5.~~

SAFETY DESIGN BASIS TWO - The CSS is capable of reducing the iodine and particulate fission product inventories in the containment atmosphere such that the offsite radiation exposures resulting from a design basis LOCA are within the plant siting dose guidelines of 10 CFR 100.

Additional safety design bases are included in Section 6.2.2.1, in which the capability of the spray system to remove heat from the containment atmosphere is discussed.

6.5.2.1.2 Power Generation Design Basis

The CSS has no power generation design basis.

6.5.2.2 <u>System Design</u>

6.5.2.2.1 General Description

~~The containment spray additive portion of the CSS provides for eduction of 31-34 weight percent sodium hydroxide into the spray injection solution. This yields a spray mixture with a pH of from 9.3 to 11.0 during the injection phase, when radioiodine is being removed from the containment atmosphere.~~

The spray additive tank has been retired in place and associated lines have been capped, as ~~subsystem of the CSS,~~ shown schematically in Figure 6.2.2-1. ~~consists of one spray additive tank, two eductors, valves, and connecting piping. The system uses the containment spray pumps and spray headers, as described in Section 6.2.2.1, to deliver and distribute the spray additive~~

INSERT 4

equilibrium sump solution pH of greater than or equal to 7.1 following the complete dissolution of the trisodium phosphate stored in baskets within the confines of the containment recirculation sumps.

~~solution to the containment atmosphere.~~ Initially, water from the refueling water storage tank (RWST) is used for containment spraying followed by water from the containment recirculation sumps. ~~Sodium hydroxide is educted from the spray additive tank into the water from the RWST and containment recirculation sumps and pumped to the spray ring headers and nozzles.~~

Those parts of the system in contact with containment spray fluids ~~borated water or the sodium hydroxide spray additive, or mixtures of the two,~~ are stainless steel or an equivalent corrosion-resistant material. The trisodium phosphate (TSP-C) baskets constructed of stainless steel mounted to carbon steel supports ~~stainless steel spray additive tank~~ contain ~~s~~ sufficient TSP-C ~~31-34 weight percent sodium hydroxide spray additive solution~~ to bring the equilibrium sump fluid to a minimum pH of ~~8.5~~ 7.1 upon mixing with the borated water from the refueling water storage tank, ~~the boron injection tank,~~ the accumulators, and reactor coolant. This assures continued iodine retention effectiveness of the sump water during the recirculation phase.

~~The two spray additive eductors are 3-inch mixing eductors. The units draw the 31-34 weight percent sodium hydroxide spray additive solution into their suction by using borated water, discharged by the containment spray pumps, as their motive flow.~~

The spray header design, including the number of nozzles per header, nozzle spacing, and nozzle orientation, is provided in Section 6.2.2.1 and shown in Figures 6.2.2-2 and 6.2.2-4. Each spray header layout is oriented to provide more than 90-percent area coverage at the operating deck of the reactor building.

Total containment free volume, unsprayed containment free volume, specific unsprayed regions and volumes, and post-accident ventilation between sprayed and unsprayed volumes are provided in Table 6.5-2. Operability of dampers, ductwork, etc., for which credit is taken post-accident is discussed in Section 6.2.2.2.

6.5.2.2.2 Component Description

~~The mechanical components of the spray additive subsystem are described in this section. Other components in the containment spray system are described in Section 6.2.2.1. Spray additive subsystem component design parameters are given in Table 6.5-3.~~

The containment spray additive tank, located at El. 2,000 feet in the auxiliary building, is a stainless steel tank that has been retired in place. ~~with a nitrogen gas blanket designed to contain 31-34 percent by weight sodium hydroxide solution. The capacity of the tank is given in Table 6.5-3. A local sample connection allows periodic~~

~~chemical analysis of the contents, and fill and drain connections provide for initial fill, concentration adjustments, and maintenance. A manway is also provided for tank internal inspection. Tank level, pressure indication, and alarm instrumentation are provided.~~

~~An interlock is provided from the tank level transmitters to preclude closure of the discharge valves before sufficient NaOH has been added to the spray solution to comply with the sump pH criterion. Heat tracing of the spray additive tank and associated piping containing 31-34 weight percent NaOH is not required since the auxiliary building rooms (areas containing this tank and the associated piping) are heated to maintain temperatures at no less than 60 F. The containment spray additive tank is provided with overpressure protection and vacuum relief. Setpoints of the relief devices are provided in Table 6.5-3.~~

~~Sodium hydroxide is added to the spray liquid by a liquid jet eductor, a device which uses kinetic energy of a pressurized liquid to entrain another liquid, mix the two, and discharge the mixture against a counter pressure. The pressurized liquid in this case is the spray pump discharge which is used to entrain the sodium hydroxide solution and discharge the mixture into the suction of the spray pumps. The eductors are designed to assure a minimum pH of 9.3 for the spray mixture.~~

Component descriptions of the nozzles are provided in Section 6.2.2.1. Special tests performed on the spray nozzles include capacity and droplet size distribution. Figures 6.5-4, 6.5-2, and 6.5-3 provide the test results for the spray nozzles (Ref. 1).

The spray nozzle was flow tested at a range of inlet pressures from 3 to 100 psig to determine that the actual flow at 40 psi differential across the nozzle was in accordance with the design value of 15.2 gpm, as depicted in Figure 6.5-1.

Droplet-size distribution measurements were performed at the design pressure differential of 40 psi and the design flowrate of 15.2 gpm. At these conditions, the spray distribution was obtained by measuring the spray volume distribution in two perpendicular planes over a timed interval (Ref. 1).

For the droplet size distribution measurement, a television camera and light source were mounted on a flat beam. A protective covering was constructed with a slot which allowed spray droplets to fall between the camera and light source. Measurements of drop count in each micron increment were recorded at 4-inch increments from the outer edge of the spray cone to the spray axis.

At the design pressure, the droplet size distribution was recorded by high speed photographic methods. The droplet images were measured, and droplets with a diameter in the micron increment being counted were registered. Figure 6.5-2 shows the relative frequency for each droplet size. The results of testing performed on the spray nozzle are provided in Table 6.5-2. The containment spray envelope reduction factor as a function of post-LOCA containment saturation temperature is provided in Figure 6.5-4. This envelope reduction factor was applied to the throw distance and elliptic coverage values presented in Table 6.5-2.

6.5.2.2.3 System Operation

Summary of the design basis LOCA and MSLB chronology for the CSS is presented in Table 6.2.2-3.

The spray system is actuated either manually from the control room or on coincidence of two-out-of-four CSAS containment pressure signals. Either of these actuation mechanisms starts the containment spray pumps~~,~~ [and] opens the discharge valves to the spray headers. ~~and opens the valves associated with the spray additive tank.~~

On actuation, approximately 5 percent of each spray pump's discharge flow is [recirculated.] ~~diverted through each spray additive eductor to draw sodium hydroxide from the spray additive tank. The sodium hydroxide solution mixes with the liquid entering the suction line of the pumps to give a solution suitable for removal of iodine from the containment atmosphere.~~

When the refueling water storage tank has reached its specified low-low-2 level limit, recirculation spray flow is manually initiated. The operator can remotely initiate recirculation flow by use of either or both of the spray pumps. Sections 6.2.2.1.5 and 6.5.2.5 address the instrumentation and information displays available to the operator, in order for manual switchover of the CSS to take place.

System flow rates and the duration of operational modes are presented in Section 6.2.2.1.2.3.

Design operation of the CSS ~~and the containment spray additive subsystem~~ is such that LOCA iodine removal requirements are fulfilled during the injection phase and the amount of ~~NaOH~~ [TSP-C provided] ~~added~~ is sufficient to ensure long-term iodine retention. ~~Operation of the containment spray additive subsystem is remote-manually terminated following the eduction of the prescribed quantity of NaOH which assures a minimum long-term sump pH of at least 8.5. Automatic isolation of the containment spray additive subsystem occurs upon receipt of a low-low level signal from the spray additive tank level instruments.~~ [INSERT 5] The containment iodine removal credit assumed in the calculation of offsite doses~~,~~ following a LOCA~~,~~ is provided in ~~Chapter 15.0.~~ [Table 15.6-6.]

INSERT 5

Following a large break LOCA, the containment spray during the injection phase will be a boric acid solution having a pH of about 4.5. The desired pH level is greater than 7.0 to assure iodine retention in the sumps, to limit corrosion and the associated production of hydrogen, and to limit chloride induced stress-corrosion cracking of austenitic stainless steels. To adjust the sump solution pH into the desired range, a minimum of 5000 pounds of trisodium phosphate dodecahydrate ($Na_3PO_4 \bullet 12\ H_2O \bullet 1/4\ NaOH$) is stored in two baskets, one within the confines of each containment recirculation sump, which will be submerged after a LOCA. This amount of trisodium phosphate is sufficient to assure that the equilibrium sump solution pH will be greater than or equal to 7.1.

6.5.2.3 Safety Evaluation

The safety evaluations are numbered to correspond to the safety design bases.

SAFETY EVALUATION ONE - The system's capability to reduce the airborne fission product inventory is based on the ~~pH~~ *surface area* of the spray solution for removal during injection and *on sump solution pH* for retention during recirculation, and on the system's capability to provide spray for essentially all regions of the containment, considering post-accident conditions.

~~The design minimum spray solution pH of 9.3, which assures a pH of 9.0 while the spray is in the containment atmosphere, coupled with the dependent parameters identified in Safety Evaluation Two below, assure the minimum elemental iodine removal coefficient of 10.0 per hour during the injection phase.~~ *INSERT 6* The ~~long-term~~ minimum *equilibrium* sump pH of ~~8.5~~ *7.1* assures iodine retention in the recirculated spray liquid.

~~Without a failure in the spray additive subsystem, the maximum pH of the spray solution in the CSS during the injection phase is 11.0, based on the maximum allowable eductor sodium hydroxide flow rate and minimum boric acid concentration in the RWST. Also, the total volume of sodium hydroxide added during the injection phase, without a single system failure in the spray additive subsystem, yields a short-term pH of at least 8.4 in the sumps at the end of the injection phase. NaOH eduction will continue during the recirculation phase to ensure a long-term minimum pH of 8.5 in the sumps.~~

~~Based on a single failure of one of the motor operated valves to open in the discharge line from the containment spray additive tank to the spray additive eductor and (a) runout flowrates for the emergency core cooling systems (ECCS) per Table 6.3-1, (b) runout flowrate for the containment spray system per Table 6.2.2-7, (c) ECCS switchover to recirculation, as described in Section 6.3.2, and (d) minimum RWST volume, sodium hydroxide would have to be educted during the recirculation phase to meet the long-term minimum sump pH criterion of at least 8.5.~~

The system is designed to provide a spray solution ~~in the CSS~~ during the recirculation phase with a ~~maximum~~ *minimum equilibrium* pH of ~~less than 11.0 based on a long-term sump pH of at least 8.5 (due to prior addition of NaOH), design spray recirculation flow rate, as noted in Table 6.2.2-2, and design spray additive flow rate of 44 gpm. To preclude closure of the isolation valve between the spray additive tank and the spray additive eductors before sufficient NaOH has been added to meet the sump pH criterion, an interlock is provided on the motor-operated valves from the spray additive tank to prohibit closure of the valves before the prescribed amount of NaOH has been added to the sump.~~ *7.1.* The total ~~volume of sodium hydroxide added to the containment following a LOCA~~ *mass of TSP-C* results in ~~a long-term~~ *this* minimum pH ~~of 8.5~~ *level* in the sumps. ~~and the rate of addition maintains the spray solution pH in the CSS between~~

INSERT 6

During injection, the effectiveness of the spray against elemental iodine vapor is chiefly determined by the rate at which fresh solution surface area is introduced into the containment atmosphere, as discussed in Reference 3. The first-order spray removal coefficient calculated per Reference 3, as discussed in Section 6.5A.3, is 37 hr^{-1}. Thus, the elemental iodine removal coefficient of 10 hr^{-1} used in Section 15.6.5 is conservative.

{during the injection phase would be greater than or equal to 4.0 but less than 7.0 when

~~9.3 and 11.0 during the injection phase and between 8.0 and 10.0 during the recirculation phase.~~ The worst case concentrations~~, resulting from a single failure, are pH = 4.0 and pH 11.0. The value of pH = 4.0 results from a single failure of one of the containment spray additive tank isolation valves. If one of these two valves fails to open,~~ water from the refueling water storage tank ~~(pH = 4.0)~~ is sprayed directly to the containment. ~~via the affected train without NaOH being added. A failure of one of these valves to operate is an unlikely event. Prior to fuel load a jumper is installed around the thermal overloads to ensure that power to open the valves is not interrupted. The valves are powered from safety-related power sources that have multiple sources (including the diesel generators). If one of these two valves should fail to open due to a loss of power, it is probable that the rest of the affected train would also not have power to operate. Therefore, no spray would be introduced from that train. In the unlikely event that one of these valves did fail to operate and the rest of the affected train did function, this condition would be immediately identified in the control room on the ESF status panel. If one of these valves does not open (and no resulting operator action is taken), the resulting condition will be one train providing spray at pH = 4.0 while the other train provides spray at pH ≥10.0. Since the spray header is redundant the components being sprayed will receive spray from both headers. The resultant pH at the component should be approximately 7.0. Additionally, the~~ The injection phase is the only time that this pH = 4.0 condition could exist. The injection phase is short (1 hour) relative to the entire spray duration (approximately 24 hours). During the recirculation phase, the spray pH range is ~~8.0 - 10.0~~ 7.1 - 9.0. This spray is directed through the same spray headers and, therefore, should rinse all of the previously sprayed equilibrium components (for a period of approximately 23 hours).

~~The normal spray pH during the injection phase is 9.5 to 10.5. The higher value occurs early during the injection phase. As the level in the spray additive tank decreases, the head on the spray additive eductors decreases; accordingly, the pH level decreases in the spray. It is possible during the beginning of the recirculation phase to still be adding sodium hydroxide via the eductor(s). During this short period (≤1 minute), it is possible to have an elevated pH > 11.0. Assuming a single failure in the spray system, this period could last up to 30 minutes. For the remainder of the recirculation phase (22 to 23.5 hours), the spray pH = 8.0-10.0. Single failure analysis for the spray additive subsystem is given in Table 6.5-4. The sump pH, as a function of time, is provided in Figure 6.5-5. The Cycle 4 changes have an insignificant impact on Figure 6.5-5, thus it is provided for information only.~~

INSERT 7 →

SAFETY EVALUATION TWO - The spray iodine removal analysis is based on the assumptions that:

a. Only one out of two spray pumps is operating

b. The ECCS is operating at its maximum capacity

INSERT 7

The minimum equilibrium sump pH of 7.1 is based on the Technical Specification minimum of 5000 lbm of TSP-C in the baskets and the maximum sump solution boric acid concentration of 2500 ppm boron. With the Technical Specification maximum of 13,440 lbm of TSP-C in the baskets and the minimum sump solution boric acid concentration of 2007 ppm boron, the maximum equilibrium sump pH would be less than 9.0.

The previously evaluated upper bound for containment spray pH of 11.0 will continue to be cited, consistent with Section 3.11(B).1.2.2, for the purpose of performing EQ reviews.

Another issue that has been reviewed is the unlikely, but possible, event in which an initially concentrated solution of TSP-C occupies the stagnant volume of an inoperable sump. This situation would not last for long since, as the recirculated sump fluid is cooled in the RHR heat exchangers, sufficient buoyancy-driven circulation within containment will result to displace the stagnant solution and eventually yield a uniform, equilibrium solution.

The spray system is assumed to spray approximately 85 percent of the total containment net free volume. This volume consists of those areas directly sprayed plus those volumes which have good communication with the directly sprayed volumes. The remaining 15 percent of the containment free volume has restricted communication with the sprayed volumes and is assumed to be unsprayed. A description of the unsprayed volumes is presented in Table 6.5-2.

~~The containment spray additive subsystem is used to maintain the spray solution at a minimum pH of 9.3 during NaOH injection to ensure efficient and rapid removal of the iodine from the containment atmosphere.~~

The performance of the spray system was evaluated at the containment post-LOCA calculated saturation temperature corresponding to the calculated peak pressures and containment design pressure provided in Table 6.2.1-2. The net spray flow rate of 3,131 gpm (see Table 6.5-2) per train was used in the calculations described in Appendix 6.5A.

Based on Regulatory Guide 1.4, three species of airborne iodine are postulated to exist in the containment atmosphere following a LOCA. These are elemental, particulate, and organic species.

It has been assumed in these evaluations of spray removal effectiveness that organic iodine forms are not removed by the ~~sodium hydroxide~~ containment spray. A limited credit for the removal of airborne particulates ~~containing~~ and elemental iodine has been taken in the offsite and control room dose calculation, assuming that the spray removal rate is $10\ hr^{-1}$ for elemental iodine until a decontamination factor (DF) of ~~100~~ 28.7 is attained, and that the spray removal rate is $0.45\ hr^{-1}$ until a decontamination factor of 50 is attained for particulates. These assumptions underestimate the actual amounts of iodine removed and thus result in calculated accident doses higher than could realistically be expected.

Utilizing the dose analysis input parameters indicated above, in Table 6.5-2, and in Appendix 15A, the dose analysis of ~~Chapter 15.0~~ Section 15.6.5 demonstrates that offsite radiation exposures resulting from a design basis LOCA are within the plant siting dose guidelines of 10 CFR 100.

Appendix 6.5A provides the model used to calculate the iodine removal coefficients provided in Table 6.5-2.

6.5.2.4 <u>Tests and Inspections</u>

~~All active components in the spray additive subsystem are tested both by performance tests in the manufacturer's shop and by in-place testing after installation.~~

~~Preoperational testing is described in Chapter 14.0. During the initial preoperational tests of the system, the performance of the eductor is checked by running the containment spray~~

pumps with the spray additive tank filled with water. Calibration curves, which correlate water flow with 30 weight-percent NaOH flow, are provided by the manufacturer, based on shop tests. In addition, during the initial preoperational tests, calibration curves are generated for water flow, under the conditions of periodic plant tests when the spray pump will be operating at shutoff head (miniflow only).

Routine periodic testing of the spray additive system components and all necessary support systems at power is planned. Included is a periodic sampling of the NaOH in the spray additive tank through the local sampling connection.

The spray eductors are tested singly by opening the valves in the spray pump miniflow lines to the RWST and the valve in the eductor suction line from the RWST and running the respective pump. The operator observes the eductor suction flow and suction pressure.

The spray additive tank isolation valves can be opened periodically for testing. The contents of the tank are periodically sampled to determine that the required solution is maintained.

~~Additional~~ CSS tests and inspections are discussed in Section 6.2.2.1.4, including spray nozzle tests and inspections.

6.5.2.5 Instrumentation Requirements

Instrumentation and associated analog and logic channels employed for the initiation of spray additive system operation are discussed in Section 7.3.8.

The following describes the instrumentation which is employed for monitoring the spray additive subsystem during normal plant operation and during post-accident operation. All alarms are annunciated in the control room.

a. Spray Additive Tank Pressure

A locally mounted indicator on the spray additive tank provides means to monitor the tank pressure while adding nitrogen and during periodic inspections.

b. Spray Additive Flow

A flow element is located in each discharge line from the spray additive tank to the eductors. Readout is local and on the main control board to provide flow indication during flow testing.

c. Spray Additive Tank Level

1. Redundant level instruments are provided to alarm the imminent depletion of the spray additive tank and to provide automatic closure of the spray additive tank discharge line valves.

2. Redundant level instruments are also provided to annunciate at the time that sufficient ad-ditive has been educted from the tank to meet the pH criteria of the system. These level instruments are interlocked with the spray additive tank discharge line valves to preclude premature closure of those valves.

d. Spray Additive Eductor Suction Pressure

A locally mounted indicator on the eductor suction line provides eductor suction pressure during flow testing.

e. Containment spray instrumentation is also discussed in Section 6.2.2.1.5.

6.5.2.6 Materials

The containment spray additive subsystem is constructed primarily of corrosion-resistant austenitic stainless steel. The spray additive tank, in which the NaOH is stored, is constructed of austenitic stainless steel. Construction materials for the spray additive subsystem are provided in Table 6.5-3.

The chemical compositions of the NaOH stored in the spray additive tank, of the containment spray fluid entering the spray header during the injection phase of containment spray, and the containment spray fluid in the system during the recirculation phase of containment spray (containment recirculation sump solution) are provided in Table 6.5-5.

None of the materials used is subject to decomposition by the radiation or thermal environment. All specifications require that the materials be unaffected when exposed to the equipment design temperature and total integrated radiation dose.

The corrosion of materials in the NSSS and the containment building, resulting from the spray solution used for iodine absorption, has been tested by the Reactor Division at ORNL (Ref. 2). The spray solutions provided in Table 6.5-5 result in negligible corrosion, based on these studies.

Sodium hydroxide TSP-C does not undergo radiolytic decomposition in the post-LOCA environment. Sodium has a low neutron absorption cross section and will not undergo significant activation.

With respect to the potential for ~~pyrolytic~~ decomposition, ~~NaOH~~ TSP-C is stable to at least ~~its melting point temperature of 604°F.~~ 158°F. ~~It may convert to sodium oxide (Na_2O) upon removal of the water.~~ Temperatures above 158°F may result in the loss of H_2O from the TSP-C but will not affect its caustic properties.

6.5.3 FISSION PRODUCT CONTROL SYSTEMS

6.5.3.1 Primary Containment

The containment consists of a prestressed post-tensioned, reinforced concrete structure with cylindrical walls, hemispherical dome, and base slab lined with a welded quarter-inch carbon steel liner plate, which forms a continuous, leaktight membrane. Details of the containment structural design are discussed in Section 3.8. Layout drawings of the containment structure and the related items are given in the general arrangement drawings of Section 1.2.

The containment walls, liner plate, penetrations, and isolation valves function to limit the release of radioactive materials, subsequent to postulated accidents, such that the resulting offsite doses are less than the guideline values of 10 CFR 100. Containment parameters affecting fission product release accident analyses are given in Appendix 15A.

Long-term containment pressure response to the design basis LOCA is shown in Figure 6.2.1-1. Relative to this time period, the CSS is operated to reduce iodine concentrations and containment atmospheric temperature and pressure commencing with system initiation, at approximately 60 seconds, as shown in Table 6.2.2-3 and ending when containment pressure has returned to normal. For the purpose of post-LOCA dose calculations discussed in Chapter 15.0, two dose models have been assumed, the 0-2 hour case and the 0-30 day case, as shown in Appendix 15A.
The containment minipurge system may be operated for personnel access to the containment when the reactor is at power, as discussed in Section 9.4.6.

Redundant, safety-related hydrogen recombiners are provided in the containment as the primary means of controlling postaccident hydrogen concentrations. A hydrogen purge system is provided for backup hydrogen control. See Section 6.2.5.3 (Safety Evaluation Eight).

Containment combustible gas control systems are discussed in detail in Section 6.2.5.

6.5.3.2 Secondary Containment

This section is not applicable to SNUPPS.

6.5.4 ICE CONDENSER AS A FISSION PRODUCT CLEANUP SYSTEM

This section is not applicable to SNUPPS.

6.5.5 REFERENCES

1. Spraying Systems Company Topical Report No. SSCO-15215-1C-304SS-6.3-NP, April 1977, "Containment Spray Nozzles for Nuclear Power Plants"

2. "Design Considerations of Reactor Containment Spray Systems, The Corrosion of Materials in Spray Solutions," ORNL-TM-2412 Part III, December 1969

3. NUREG-0800, Standard Review Plan Section 6.5.2, Revision 2, "Containment Spray as a Fission Product Cleanup System," December 1988.

TABLE 6.5-1

ESF FILTRATION SYSTEMS INPUT PARAMETERS TO CHAPTER 15.0 ACCIDENT ANALYSIS

Emergency exhaust filter adsorber unit efficiencies (percent)	90
Emergency exhaust system flowrate (SCFM)	9,000
Control room filter adsorber unit efficiency (percent)	~~90~~ 95
Control room air conditioning system flowrate (SCFM) per train	
Filtered intake from control building	540
Filtered recirculation from control room	1,440

TABLE 6.5-2

INPUT PARAMETERS AND RESULTS OF SPRAY IODINE REMOVAL ANALYSIS

Core power rating	3,565 MWt
Total containment free volume	2.50×10^6 ft^3
Unsprayed containment free volume	<15.0 percent
Area coverage at the operating deck design Calculated	 >90 percent >93 percent
Mixing rate between sprayed and unsprayed volumes	85,000 cfm
Dose model	One region
Minimum vertical distance to operating deck from lowest spray header	118 feet - 2 in.
Net spray flow rate per train, injection phase	3,131 gpm
~~Design NaOH flow rate per eductor~~	~~44.0 gpm~~
Number of spray pumps operating	1
Spray solution pH	~~9.3 to 11.0~~ 4.0-7.0 (injection phase) $\geq$7.1 (recirculation phase at equilibrium)
Elemental iodine absorption coefficient, λ_s, used in ~~accident~~ LOCA offsite and control room dose calculations	10 hr^{-1} ← (1)
~~Expected~~ Calculated λ_s	25.7 hr^{-1} ← (2) 37 hr^{-1}
Particulate iodine absorption coefficient, λ_p, used in LOCA offsite and control room ~~accident~~ dose calculations	0.45 hr^{-1} ← (3)
Calculated λ_p	0.73 hr^{-1} ← (4)
Spray drop size, design	See Figure 6.5-2

TABLE 6.5-2 (Sheet 2)

Schmidt number (see Section 6.5A.2)	11.58
Gas diffusivity (see Section 6.5A.2)	0.064 cm^2/sec
Partition coefficient (see Section 6.5A.2)	5,000
Gas phase mass transfer coefficient (see Section 6.5A.3)	9.5 ft/min
Terminal mass-mean drop velocity (see Section 6.5A.3)	790 ft/min
Partition coefficient (see Section 6.5A.3)	1100

~~* Used DFs of up to 100.~~

~~** As calculated from Appendix 6.5A.~~

(1) Until DF = 28.7.

(2) λ_s of 25.7 hr^{-1} was calculated in Section 6.5A.2 and used in the EQ dose calculations discussed in Section 3.11(B).1.2.2. λ_s of 37 hr^{-1} was calculated in Section 6.5A.3 but 10 hr^{-1} was used in the offsite and control room dose calculations discussed in Section 15.6.5.

(3) Until DF = 50.

(4) λ_p of 0.73 hr^{-1} was calculated in Section 6.5A.1 and used in the EQ dose calculations.

TABLE 6.5-3

SPRAY ADDITIVE SUBSYSTEM-DESIGN PARAMETERS

Eductors	
Quantity	2
Eductor inlet (motive)	
Operating fluid	Borated water
Operating temperature	Ambient
Eductor Suction Fluid	
NaOH concentration, wt percent	31-34
Specific gravity	~1.35
Viscosity (design), cp	~20
Operating temperature	Ambient
Material	Stainless steel
Spray Additive Tank	
Number	1
Total volume, usable gallons	4,700
NaOH concentration, wt percent	31-34
Design temperature, F	200
External design pressure, psig	3
Internal design pressure, psig	10
Operating temperature, F	Ambient
Operating pressure, psig	~1*
Material	Stainless steel
High pressure relief valve set point, psig	5
Vacuum relief valves setpoint, in. Hg	2
Spray Additive System Piping	
Material	Stainless steel

*During normal conditions, there is a 1 to 2 psig nitrogen gas blanket. During accident injection, the tank pressure will fall below atmospheric pressure; redundant vacuum breakers are provided in order to assure that tank external design pressure is not exceeded relative to the tank internal vacuum.

DELETED

TABLE 6.5-4

SPRAY ADDITIVE SUBSYSTEM - SINGLE FAILURE ANALYSIS

Component	Malfunction	Comments and Consequences
Automatically operated spray additive tank outlet isolation valve	Fails to open	Two provided in parallel. Operation of one required.
	Fails to close	Potential exists for losing one train. Operation of only one train required.
Spray additive tank vacuum breaker	Fails to open	Two provided. Operation of one required.

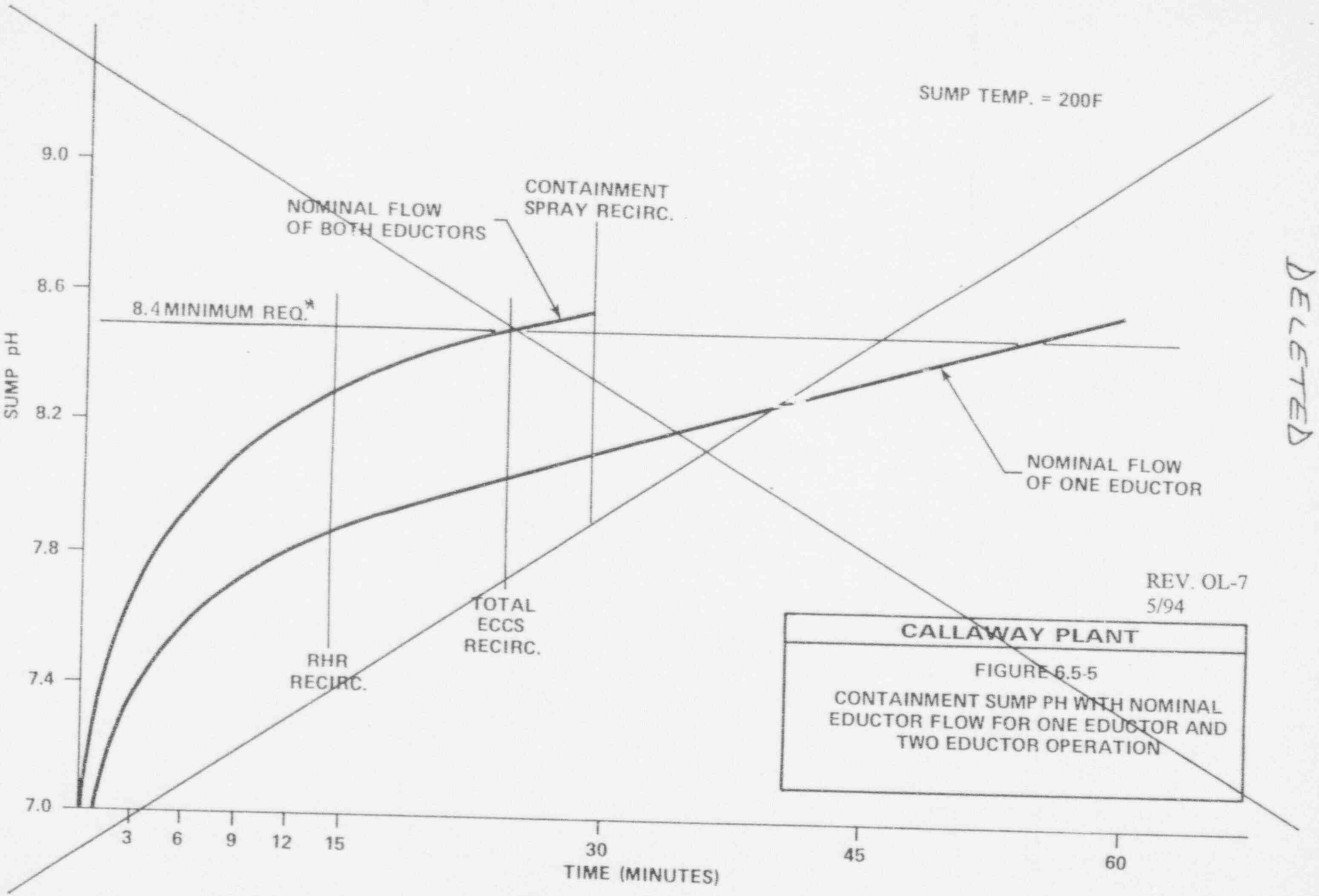
DELETED

{Trisodium Phosphate Dodecahydrate (TSP-C)
($Na_3PO_4 \cdot 12H_2O \cdot 1/4\ NaOH$)

TABLE 6.5-5

CONTAINMENT SPRAY SYSTEM
FLUID CHEMISTRY

I.	Containment Spray Additive	
	~~Sodium hydroxide, weight percent~~ Trisodium Phosphate Dodecahydrate (TSP-C) ($Na_3PO_4 \cdot 12H_2O \cdot 1/4\ NaOH$)	~~31-34~~ 5000 lbm minimum
	Temperature range, °F	~~60-104~~ 50-120
II.	Sprayed Fluid - Injection Phase	
	Aqueous solution, pH	4.0 - 7.0 ~~-11.0~~
	Chloride, ppm, max	100
	Fluoride, ppm, max	100
	Boric acid, ppm boron, max/min	2,500/2,350
	~~Sodium hydroxide, ppm~~	~~0-7,530~~
	Temperature range, °F	37-120
III.	Sprayed Fluid - Recirculation Phase	
	Aqueous solution, pH	~~8.0-11.0~~ 7.1-11.0
	Boric acid, ppm boron, max/min	2,500/~~1,900~~ 2,007
	~~Sodium hydroxide, ppm, max~~	~~10,300~~
	Temperature range, °F	120-255
IV.	Final Equilibrium Recirculation Sump Fluid	
	Aqueous solution, pH	~~8.5-10.0~~ 7.1-9.0
	Boric acid, ppm boron, max/min	2,500/~~1,970~~ 2,007
	~~Sodium hydroxide, ppm, max~~	~~5,000~~
	Temperature range, °F	120-255



REV. OL-7
5/94

CALLAWAY PLANT

FIGURE 6.5-5

CONTAINMENT SUMP PH WITH NOMINAL EDUCTOR FLOW FOR ONE EDUCTOR AND TWO EDUCTOR OPERATION

* At end of injection phase; long-term minimum is 8.5.

6.5A.1 PARTICULATE IODINE MODEL

The spray washout model for aerosol particles is represented in equation form as follows:

$$\lambda P = \frac{3hEF}{2dV} \qquad (6.5A\text{-}1)$$

Where:

- λP = spray removal constant for particles
- h = drop fall height
- E = total collection efficiency for a single drop
- F = spray volumetric flow rate
- d = mean drop diameter
- V = volume of sprayed region

The capture of particles by falling drops results from Brownian diffusion, diffusiophoresis, interception, and impaction. Early in the injection phase, particles are removed mainly by impaction. Following injection, when the larger particles have already been removed, the removal rate is controlled by diffusiophoresis, which is the collection of particulates by steam condensing on the spray drops. The single drop collection efficiency, E, is taken as 0.0015, the minimum value observed in experimental tests (Ref. 1). The minimum collection efficiency, 0.0015, was only attained after the major fraction of airborne particles was removed. For early time periods, the removal rates were much higher than the minimum values ultimately reached. INSERT 8

The spray removal constant (λP) for particulate iodine has been calculated to be 0.73/hr, based on equation 6.5A-1, and used in Section 3.11(B).1.2.2.

A limited and conservative credit for spray removal of airborne particulates containing iodine has been taken in Section 15.6.5, assuming the spray removal constant is 0.45/hr, ~~for the 0- to 2-hour period~~ until a decontamination factor of 50 is reached, following the postulated LOCA (see Table 6.5-2).

Particle spray removal constants considerably larger and of longer duration than those conservatively chosen above have been reported from the Battelle Northwest Containment Systems Experiment (Ref. 2) and by the Oak Ridge National Laboratories Nuclear Safety Pilot Plant (Ref. 4).

6.5A.2 ELEMENTAL IODINE MODEL FOR EQ DOSE CALCULATIONS

The spray system, by virtue of the large surface area provided between the droplets and the containment atmosphere, will afford an excellent means of absorbing elemental radioactive

INSERT 8

Per Reference 11, it is conservative to assume that E/D is 10 per meter initially (i.e., 1% efficiency for spray drops of one millimeter in diameter), changing abruptly to one per meter after the aerosol mass has been depleted by a DF of 50 (i.e., 98% of the particulate mass is ten times more readily removed than the remaining 2%). Using the 831 micron mean drop diameter identified in Table 6.5-2 and the minimum collection efficiency of 0.0015 from Reference 1, E/D would be 1.8 per meter which is consistent with the value from Reference 11 after a DF of 50 is attained.

iodine released as a consequence of a LOCA. ~~Sodium hydroxide will be added to the spray fluid to increase the solubility of iodine in the spray to the point where~~ The rate of absorption is largely dependent on the concentration of radioiodine in the air surrounding the drops.

INSERT 9 → The basic model of the containment atmosphere and spray system is given by Parsley (Ref. 4). The containment atmosphere is viewed as a "black box" having a sprayed volume, V, and containing iodine at some uniform concentration Cg. Liquid enters at a flow of F volumes per unit time, containing iodine at a concentration of CL1, and leaves at the same flow, at concentration CL2. A material balance for the containment vessel as a function of time is given by:

$$-VdCg = F(CL2 - CL1)dt \qquad (6.5A\text{-}2)$$

Where:

CL1 = the iodine concentration in the liquid entering the dispersed phase, gm/cm^3

CL2 = the iodine concentration in the liquid leaving the dispersed phase, gm/cm^3

V = sprayed volume of containment, cm^3

Cg = the iodine concentration in the containment atmosphere, gm/cm^3

F = the spray volumetric flow rate, cm^3/sec

t = spray time, sec

A drop absorption efficiency, E, which may be described as the fraction of saturation, is defined as:

$$E = (CL2 - CL1)/(CL^* - CL1) \qquad (6.5A\text{-}3)$$

In addition, the equilibrium distribution of iodine between the vapor and liquid phases is given by:

$$H = CL^*/Cg \qquad (6.5A\text{-}4)$$

Where:

H = the iodine partition coefficient (gm/liter of liquids)/(gm/liter of gas)

CL* = the equilibrium concentration in the liquid, gm/cm^3

INSERT 9

The following discussion is based on the pH dependent correlation for the elemental iodine spray removal constant discussed in Reference 12 and used in the EQ dose calculations of Section 3.11(B).1.2.2 (see Equations 6.5A-9 and 6.5A-17). Section 6.5A.3 discusses the surface area dependent correlation for the elemental iodine spray removal constant discussed in Reference 11 and used in the offsite and control room dose calculations of Section 15.6.5. Both of these correlations are applicable for the injection phase only.

Substitution of equation 6.5A-4 into equation 6.5A-3 yields

$$E = (CL2 - CL1)/(HCg - CL1) \qquad (6.5A\text{-}5)$$

Solving equation 6.5A-5 for (CL2 - CL1) and inserting the result into equation 6.5A-2 gives

$$-(V)dCg = EF(HCg - CL1)dt \qquad (6.5A\text{-}6)$$

During the injection phase, CL1 = 0, so that

$$-(V)dCg = (EFHCg)dt \qquad (6.5A\text{-}7)$$

Equation 6.5A-7 can be integrated to solve for Cg. The concentration of iodine in the containment atmosphere during injection as a function of time is given by:

$$Cg = Cg_o \exp[-EHFt/V] \qquad (6.5A\text{-}8)$$

Where:

Cg_o = the initial iodine concentration in the containment atmosphere, gm/cm^3

Equation 6.5A-8 is applicable up to the time the spray solution is recirculated and is based on the following assumptions:

a. Cg is uniform throughout the containment

b. There are no iodine sources after the initial release

c. The concentration of iodine in the spray solution entering the containment is zero

From equation 6.5A-8, the spray removal constant, λ_s, is given by

$$\lambda_s = \frac{EHF}{V} \qquad (6.5A\text{-}9)$$

The above equation for λ is independent of the models on which the numerical evaluation of the drop absorption efficiency, E, and the iodine partition coefficient, H, may be based.

Absorption efficiency for elemental iodine may be calculated from the time-dependent diffusion equation for a rigid sphere, with the gas film mass transfer resistance as a boundary condition. This mass transfer model was suggested by L. F.

interface, is in equilibrium with the iodine concentration in the gas phase outside the drop. The expression in this reference model is:

$$E = 1 - \exp\left(-\frac{6 k_g t_e}{dH}\right) \quad (6.5A\text{-}14)$$

The absorption efficiency is a function of the drop diameter, the gas phase mass transfer coefficient, diffusivity of iodine in the liquid drop, the partition coefficient, and the drop exposure time.

Eggleton's equation (Ref. 8) for the equilibrium elemental iodine decontamination factors, DF, is given by:

$$DF = 1 + H(VL)/(VG) \quad (6.5A\text{-}15)$$

Where:

H = equilibrium iodine partition coefficient

DF = ratio of the ~~total~~ initial iodine concentration in the ~~sump liquid and~~ containment atmosphere to ~~that in~~ the equilibrium iodine concentration in the containment atmosphere $= C_{g_0} / C_g$

VG = net free containment volume minus VL

VL = volume of liquid in the containment sumps plus overflow from the sumps, which may be used for calculation of the partition coefficient, H, for a given value of the DF. ~~However,~~ Equation 6.5A-15 was not used in the ~~present analysis,~~ EQ dose calculations discussed in Section 3.11(B).1.2.2; instead, a numerical value of 5,000 for H, the minimum found from Containment Systems Experiment (CSE) tests (Refs. 9 and 10) for sodium hydroxide spray, was used in the evaluation of λ. INSERT 10

Since the spray does not consist of a uniform droplet size, a spectrum of drop sizes and their corresponding volume percentage (for the specific nozzle design) were used to determine the individual spray removal constant for each droplet size. The total spray removal constant is equal to the sum of the individual spray removal constants, i.e.:

$$\lambda = \sum_{i=1}^{n} \lambda_i = \sum_{i=1}^{n} \sum_{\ell=1}^{m} \lambda_{i_\ell} \quad (6.5A\text{-}16)$$

Since the drop exposure time, t_e, is dependent on distance from the spray header to the operating deck, and each spray header consists of ring headers (ℓ) located at various levels, λ_i was calculated for each spray ring header (ℓ), utilizing the appropriate drop distance for each header.

INSERT 10

While a value of 5000 for H was used to calculate the elemental iodine spray removal constant of 25.7 hr^{-1} used in the EQ dose calculations, it is noted that Section 6.5A.3 calculates an elemental iodine spray removal constant of 37 hr^{-1}. In any event, for dose calculations the spray removal constant is not as important as the DF in determining EQ doses.

Therefore,

$$\lambda_{i_\ell} = \frac{E_{i_\ell} \; H \; F_{i_\ell}}{V} \qquad (6.5A\text{-}17)$$

Where:

E_{i_ℓ} = collection efficiency for a single drop of micron increment i for ring header ℓ

F_{i_ℓ} = spray flow rate for micron increment i for header ℓ

and,

$$F_{i_\ell} = (F_i/\text{nozzle}) \cdot (N_\ell) \qquad (6.5A\text{-}18)$$

Where:

$$F_i/\text{nozzle} = \frac{(15.2\text{ gpm})(N_i)\cdot(V_i)}{\sum_{i=1}^{n} N_i V_i}$$

N_ℓ = number of nozzles on ring header ℓ

N_i = number frequency for micron increment i (Figure 6.5-2)

V_i = volume of a drop in micron increment i

As the spray solution enters the high-temperature containment atmosphere, steam will condense on the spray drops. The amount of condensation is easily calculated by a mass balance of the drop:

$$mh + m_c h_g = m'h_f$$

where:

m and m' = the mass of the drop before and after condensation, lbs

m_c = the mass of condensate, lbs

h = the initial enthalpy of the drop, Btu/lb

h_g and h_f = The saturation enthalpy of water vapor and liquid, Btu/lb

The increase in each drop diameter in the distribution, therefore, is given by:

$$\left(\frac{d'}{d}\right)^3 = \left(\frac{v}{v_f}\right) \cdot \left(\frac{h_g - h}{h_{fg}}\right)$$

Where:

vf = the specific volume of liquid at saturation, ft^3/lb

v = the specific volume of the drop before condensation, ft^3/lb

h_{fg} = the latent heat of evaporation, Btu/lb

h_g = the enthalpy of steam at saturation, Btu/lb

d and d' = the drop diameter before and after condensation, cm

Postma and Pasedag (Ref. 6) conclude that condensation will tend to increase the iodine washout rate due to the increased volume of the spray. Their effect has been conservatively ignored.

The drop exposure time calculated is based on the assumption that the drops were sprayed in such a manner that the initial downward velocity of the drops at the spray ring header elevation was zero. The drops fall under the effect of gravity from the spray ring header to the operating deck. The minimum height is given in Table 6.5-2. As the drop size increases, the average exposure time decreases from about 20 to 5 seconds. Incorporating the above parameters into equation 6.5A-16 with the sprayed containment volume, V, and assuming a single spray header flow rate, the value of the spray removal coefficient calculated (25.7 hr^{-1}) is presented in Table 6.5-2.

The resulting elemental iodine A spray removal constant is greater than 10/hr. ~~Only this~~ conservative removal constant of 10/hr is assumed and used in the design basis LOCA evaluations presented in Section 15.6.5.

INSERT 11 →

6.5A.~~3~~ 4 REFERENCES

1. Hilliard, R. K., Coleman L. F., "Natural Transport Effects of Fission Product Behavior in the Containment System Experiment," BNWL-1457, Battelle Pacific Northwest Laboratories, Richland, Washington, December 1970.

INSERT 11

6.5A.3 ELEMENTAL IODINE MODEL FOR OFFSITE AND CONTROL ROOM DOSE CALCULATIONS

As discussed in Reference 11, the effectiveness of the spray during the injection phase against elemental iodine vapor is chiefly determined by the rate at which fresh solution surface area is introduced into the containment atmosphere. The rate of solution created per unit gas volume in the containment atmosphere may be estimated as (6F/VD), where F is the spray volumetric flow rate, V is the volume of the sprayed region, and D is the mean diameter of the spray drops. The first-order spray removal constant for elemental iodine, λ_S, may be taken to be:

$$\lambda_S = \frac{6k_gTF}{VD}$$

where k_g is the gas phase mass transfer coefficient and T is the drop fall time (or drop exposure time), which may be estimated by the ratio of the average fall height to the terminal velocity of the average drop. The above expression represents a first-order approximation if a well-mixed droplet model is used for spray absorption efficiency. This expression is valid for λ_S values equal to or greater than 10 per hour but less than 20 per hour. Using this expression and the values contained in Table 6.5-2 a value of 37 hr^{-1} is calculated. A value of 10 per hour will continue to be used in the dose calculations of Section 15.6.5.

Spray removal of elemental iodine continues until the DF of Equation 6.5A-15 is reached. Although the VL term in Equation 6.5A-15 represents the volume of the sumps plus any overflow from the sumps, it is conservative to just use the volume of the sumps for VL since a lower DF will result. The value for the partition coefficient, H, in Equation 6.5A-15 was taken from Figure 6 of Reference 13 using the 323°K plot at 14 hours (representative of the average conditions during a LOCA). The value of 1100 used is considered to be conservative since the sump fluid temperature at 14 hours would be greater than 323°K per Figure 6.2.1-17 and Figure 6 of Reference 13 shows that higher temperatures would be associated with higher partition coefficients. The resulting DF is calculated to be 28.7.

2. Hilliard, R. K., et al, "Removal of Iodine and Particulates from Containment Atmospheres by Sprays - Containment Systems Experiment Interim Report," BNWL-1244, 1970.

3. Perkins, J. F., "Decay of U235 Fission Products," Physical Science Laboratory, RR-TR-63-11, U.S. Army Missile Command Redstone Arsenal, Alabama, July 25, 1963.

4. Parsley, Jr., L. F., "Design Considerations of Reactor Containment Spray Systems - Part VII," ORNL TM 2412, Part 7, 1970.

5. Ranz, W.E., and Marshall, Jr., W.R., "Evaporation from Drops," Chemical Engineering Progress 48, 141-46, 173-80, 1952.

6. Postma, A. K., and Pasedag, W. F., "A Review of Mathematical Models for Predicting Spray Removal of Fission Products in Reactor Containment Vessels," WASH-1329, U.S. Atomic Energy Commission, June 1974.

7. Griffiths, V., "The Removal of Iodine from the Atmosphere by Sprays," Report No. AHSB(S)R45, United Kingdom Atomic Energy Authority, London, 1963.

8. Eggleton, A. E. J., "A Theoretical Examination of Iodine-Water Partition Coefficient," AERE (R)-4887, 1967.

9. Postma, A. K., Coleman, L. F., and Hilliard, R. K., "Iodine Removal from Containment Atmospheres by Boric Acid Spray," BNP-100, Battelle-Northwest, Richland, Washington, 1970.

10. Coleman, L. F., "Iodine Gas-Liquid Partition," Nuclear Safety Quarterly Report, February, March, April 1970, BNWL-1315-2, Battelle-Northwest, Richland, Washington, p. 2.12-2.19, 1970.

INSERT 12

INSERT 12

11. NUREG-0800, Standard Review Plan Section 6.5.2, Revision 2, "Containment Spray as a Fission Product Cleanup System," December 1988.

12. ANSI/ANS-56.5-1979, "PWR and BWR Containment Spray System Design Criteria."

13. E. C. Beahm, W. E. Shockley, C. F. Weber, S. J. Wisbey, and Y. M. Wang, "Chemistry and Transport of Iodine in Containment," NUREG/CR-4697, October 1986.

assumed to plateout onto the internal surfaces of the containment or adhere to internal components. The remaining iodine and the noble gas activity are assumed to be immediately available for leakage from the containment.

Once the gaseous fission product activity is released to the containment atmosphere, it is subject to various mechanisms of removal which operate simultaneously to reduce the amount of activity in the containment. The removal mechanisms include radioactive decay, containment sprays, and containment leakage. For the noble gas fission products, the only removal processes considered in the containment are radioactive decay and containment leakage.

a. Radioactive Decay - Credit for radioactive decay for fission product concentrations located within the containment is assumed throughout the course of the accident. Once the activity is released to the environment, no credit for radioactive decay or deposition is taken.

b. Containment Sprays - The containment spray system is designed to absorb airborne iodine fission products within the containment atmosphere. To enhance the iodine ~~removal~~ retention capability of the containment sprays, trisodium phosphate ~~sodium hydroxide~~ is added to the spray solution via baskets within the sumps. The spray effectiveness for the ~~removal~~ retention of iodine is dependent on maintaining a long-term sump pH greater than 7.0. ~~the iodine chemical form.~~

c. Containment Leakage - The containment leaks at a rate of 0.2 volume percent/day as incorporated as a Technical Specification requirement at peak calculated internal containment pressure for the first 24 hours and at 50 percent of this leak rate for the remaining duration of the accident. The containment leakage is assumed to be directly to the environment.

ASSUMPTIONS AND CONDITIONS - The major assumptions and parameters assumed in the analysis are itemized in Tables 15A-1 and 15.6-6, and discussed in Section 6.5A.3.

In the evaluation of a LOCA, all the fission product release assumptions of Regulatory Guide 1.4 have been followed. The following specific assumptions were used in the analysis. Table 15.6-7 provides a comparison of the analysis to the requirements of Regulatory Guide 1.4.

a. The reactor core equilibrium noble gas and iodine inventories are based on long-term operation at a core power level of 3,636 MWt.

b. One hundred percent of the core equilibrium radioactive noble gas inventory is immediately available for leakage from the containment.

c. Twenty-five percent of the core equilibrium radioactive iodine inventory is immediately available for leakage from the containment. *The other 25% released to the containment atmosphere instantaneously plates out.*

d. Of the iodine fission product inventory released to the containment, 91 percent is in the form of elemental iodine, 5 percent is in the form of particulate iodine, and 4 percent is in the form of organic iodine.

e. Credit for iodine removal by the containment spray system is taken, starting at time zero and continuing until a decontamination factor of ~~100~~ *28.7* for the elemental ~~and particulate~~ species *and 50 for the particulate species* has been achieved.

f. The following iodine remov[al] constants for the containment spray system are [as]sumed in the analysis:

Elemental iodine	-	10.0 per hr
Organic iodine	-	0.0 per hr
Particulate iodine	-	0.45 per hr

g. The following parameters were used in the two-region spray model:

Fraction of containment sprayed - 0.85
Fraction of containment unsprayed - 0.15
Mixing rate (cfm) between sprayed and unsprayed regions - 85,000

Section 6.5 contains a detailed analysis of the sprayed and unsprayed volumes and includes an explanation of the mixing rate between the sprayed and unsprayed regions.

h. The containment is assumed to leak at 0.2 volume percent/day during the first 24 hours immediately following the accident and 0.1 volume percent/day thereafter.

i. The containment leakage is assumed to be direct unfiltered to the environment.

j. The ~~ESF~~ *control building and control room* filters will be ~~90~~ *95* percent efficient in the removal of all species of iodine.

MATHEMATICAL MODELS USED IN THE ANALYSIS - Mathematical models used in the analysis are described in the following sections:

a. The mathematical models used to analyze the activity released during the course of the accident are described in Section 15A.2.

b. The atmospheric dispersion factors used in the analysis were calculated, based on the onsite meteorological measurements program described in Section 2.3 of the Site Addendum, and are provided in Table 15A-2.

c. The thyroid inhalation and total-body immersion doses to a receptor exposed at the exclusion area boundary and the outer boundary of the low population zone were analyzed, using the models described in Sections 15A.2.4 and 15A.2.5, respectively.

d. Buildup of activity in the control room and the integrated doses to the control room personnel are analyzed, based on models described in Section 15A.3.

IDENTIFICATION OF LEAKAGE PATHWAYS AND RESULTANT LEAKAGE ACTIVITY - For evaluating the radiological consequences of a postulated LOCA, the resultant activity released to the containment atmosphere is assumed to leak directly to the environment.

No credit is taken for ground deposition or radioactive decay during transit to the exclusion area boundary or LPZ outer boundary.

15.6.5.4.1.2 Radioactive Releases Due to Leakage from ECCS and Containment Spray Recirculation Lines

Subsequent to the injection phase of ESF system operation, the water in the containment recirculation sumps is recirculated by the residual heat removal, centrifugal charging and safety injection pumps, and the containment spray pumps. Due to the operation of the ECCS and the containment spray system, most of the radioiodine released from the core would be contained in the containment sump. It is conservatively assumed that a leakage rate of 2 gpm from the ECCS and containment spray recirculation lines exists for the duration of the LOCA. This leakage would occur inside the containment as well as inside the auxiliary building. For this analysis, all the leakage is assumed to occur inside the auxiliary building. Only trace quantities of radioiodine are expected to be airborne within the auxiliary building due to the temperature and pH level of the recirculated water. However, 10 percent of the radioiodine in the leaked water is assumed to become airborne and exhausted from the unit vent to the environment through ~~safety grade~~ *the auxiliary building emergency exhaust* filters (90% efficient). No credit is taken for holdup (i.e. decay) or mixing in the auxiliary building; however, mixing and holdup in the sumps are factored into the release and decay removal constants for this pathway.

loadings are in accordance with Regulatory Guide 1.52, which limits the maximum loading to 2.5 mg of iodine per gram of activated charcoal. The 100 percent efficiency assumption is conservative for the purpose of checking filter loading and is not to be confused with the ~~90%~~ 95% efficiency assumption used for radiological consequences as listed in Table~~s 15.6-6 and~~ 15.A-1.

15.6.5.4.3.2 Doses to a Receptor at the Exclusion Area Boundary and Low Population Zone Outer Boundary

The potential radiological consequences resulting from the occurrence of the postulated LOCA have been conservatively analyzed, using assumptions and models described in previous sections.

The total-body dose due to immersion and the thyroid dose due to inhalation have been analyzed for the 0-2 hour dose at the exclusion area boundary and for the duration of the accident at the LPZ outer boundary. The results, with margin, are listed in Table 15.6-8. The resultant doses are within the guideline values of 10 CFR 100.

15.6.5.4.3.3 Doses to Control Room Personnel

Radiation doses to control room personnel following a postulated LOCA are based on the ventilation, cavity dilution, and dose model discussed in Section 15A.3.

Control room personnel are subject to a total-body dose due to immersion and a thyroid dose due to inhalation. These doses have been analyzed, and are provided in Table 15.6-8. The listed doses, with margin, are within the limits established by GDC-19.

15.6.6 A NUMBER OF BWR TRANSIENTS

This section is not applicable to the Callaway Plant.

15.6.7 REFERENCES

1. Burnett, T. W. T., et. al., "LOFTRAN Code Description", WCAP-7907-P-A (Proprietary), WCAP-7907-A (Non-Proprietary), April 1984.

2. Chelemer, H., Boman, L. H., Sharp, D. R., "Improved Thermal Design Procedures", WCAP-8587, July 1975.

3. SGTR Analysis letters SLNRC 86-01 (1-8-86), SLNRC 86-03 (2-11-86) SLNRC 86-05 (4-1-86), SLNRC 86-08 (9-4-86), ULNRC-1442 (2-3-87), ULNRC-1518 (5-27-87), ULNRC-1849 (10-21-88), ULNRC-2145 (1-29-90), and the NRC SER dated 8-6-90.

4. "Reactor Safety Study - An Assessment of Accident-Risk in U.S. Commercial Nuclear Power Plants," WASH-1400, NUREG-75/014, October 1975.

TABLE 15.6-6

PARAMETERS USED IN EVALUATING THE RADIOLOGICAL CONSEQUENCES OF A LOSS-OF-COOLANT-ACCIDENT

I. Source Data

a. Core power level, MWt — 3,636
b. Burnup, full power days — 1,000
c. Percent of core activity initially airborne in the containment

1. Noble gas — 100
2. Iodine — ~~25~~ 50*

d. Percent of core activity immediately deposited in containment sump ~~@ 0.47 hours~~

1. Noble gases — 0
2. Iodine — 50

e. Core inventories — Table 15A-3
f. Iodine distribution, percent

1. Elemental — 91
2. Organic — 4
3. Particulate — 5

II. Atmospheric Dispersion Factors — See Table 15A-2

III. Activity Release Data

a. Containment leak rate, volume percent/day

1. 0-24 hours — 0.20
2. 1-30 days — 0.10

b. Percent of containment leakage that is unfiltered — 100

c. Credit for containment sprays

1. Spray iodine removal constants (per hour)

a. Elemental — 10.0
b. Organic — 0.0
c. Particulate — 0.45

* Half instantaneously plates out leaving 25% immediately available for leakage from the containment.

TABLE 15.6-6 (Sheet 2)

2. Maximum iodine decontamination factors for the containment atmosphere	
a. Elemental	~~100~~ 28.7
b. Organic	0
c. Particulate	~~100~~ 50
3. Sprayed volume, percent	85
4. Unsprayed volume, percent	15
5. Sprayed-unsprayed mixing rate, CFM	85,000
6. Containment volume, ft^3	2.5E+6
d. ECCS recirculation leakage	
1. Leak rate (0.47 hours-30 days), gpm	2.0
2. Sump volume, gal.	460,000
3. Fraction iodine airborne	0.1
4. Emergency exhaust ESF filter efficiency, %	90.0
e. RWST leakage	
1. Leak rate (0.47 hours - 30 days), gpm	3.0
2. RWST volume, gal.	400,000
3. Fraction iodine airborne	0.1
IV. Control room parameters	Tables 15A-1 and 15A-2

TABLE 15A-1

PARAMETERS USED IN ACCIDENT ANALYSIS

I.	General	
	1. Core power level, Mwt	3636 (102% power)
	2. Number of fuel assemblies in the core	193
	3. Maximum radial peaking factor	1.65
	4. Percentage of failed fuel	1.0
	5. Steam generator tube leak, lb/hr	500
II.	Sources	
	1. Core inventories, Ci	Table 15A-3
	2. Gap inventories, Ci	Table 15A-3
	3. Primary coolant specific activities, μCi/gm	Table 11.1-5*
	4. Primary coolant activity, technical specification limit for iodines - I-131 dose equivalent, μCi/gm	1.0
	5. Secondary coolant activity technical specification limit for iodines - I-131 dose equivalent, μCi/gm	0.1
III.	Activity Release Parameters	
	1. Free volume of containment, ft^3	2.5×10^6
	2. Containment leak rate	
	i. 0-24 hours, % per day	0.2
	ii. after 24 hrs, % per day	0.1
IV.	Control Room Dose Analysis (for LOCA)	
	1. Control building	
	i. Mixing volume, cf	150,000
	ii. Filtered intake, cfm	
	Prior to operator action (0-30 minutes)	900
	After operator action (30 minutes - 720 hours)	450
	iii. Unfiltered inleakage, cfm	300
	iv. Filter efficiency (all forms of iodine), %	~~90~~ 95
	2. Control room	
	i. Volume, cf	100,000
	ii. Filtered flow from control building, cfm	540

*Except for SGTR events for which Table 11.I-4 is used.

TABLE 15A-1 (Sheet 2)

	iii.	Unfiltered flow from control building, cfm	
		Prior to operator action (0-30 minutes)	540
		After operator action (30 minutes - 720 hours)	0
	iv.	Filtered recirculation, cfm	1440
	v.	Filter efficiency (all forms of iodine), %	~~90~~ 95
V.	Miscellaneous		
	1.	Atmospheric dispersion factors, χ/Q sec/m^3	Table 15A-2
	2.	Dose conversion factors	
		i. total body and beta skin, rem-meter^3/Ci-sec	Table 15A-4
		ii. thyroid, rem/Ci	Table 15A-4
	3.	Breathing rates, meter^3/sec	
		i. control room at all times	3.47×10^{-4}
		ii. offsite	
		0-8 hrs	3.47×10^{-4}
		8-24 hrs	1.75×10^{-4}
		24-720 hrs	2.32×10^{-4}
	4.	Control room occupancy fractions	
		0-24 hrs	1.0
		24-96 hrs	0.6
		96-720 hrs	0.4