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C.1 PURPOSE OF CHEMICAL ADDITION TO CONTAINMENT SPRAY

The containment spray system in this pressurized water reactor facility is one of the engineered safety features which is employed inside the containment to reduce the pressure and temperature of the atmosphere following a loss of coolant accident. The flow rate and inlet subcooling of the spray are sufficient to provide thermal capacity for condensing steam produced by dissipation of heat in the reactor and its associated systems. Minimum operability of these systems with on site power and under a single component failure contingency will prevent pressurization of containment above the design pressure with substantial margin.

The spray system also serves as a removal mechanism for fission products postulated to be dispersed in the containment atmosphere. The source term used for the LOCA dose analysis assumes major core degradation and is defined in Regulatory Guide 1.183 as being a release of gap activity (noble gases, iodines, and alkali metal nuclides) over a half-hour period followed by a core melt that releases additional activity in those three nuclide groups plus additional nuclides over a 1.3 hour duration. The iodine activity is assumed to be primarily in the particulate form (cesium iodide) with small fractions of the iodine in the elemental and organic forms. Nuclides other than the iodines and noble gases are all modeled as being in the particulate form. The sprays are effective at removing elemental iodine and particulates from the containment atmosphere but the organic iodine and the noble gases are not subject to removal by the sprays.

The chemistry of the spray solution is modified by adding NaOH, raising the pH to within the acceptable range of 7.0 to 10.5. The minimum pH in the containment sump needed to keep iodine in the iodate form is 7.0. A pH of greater than 7.0 assures the iodine removed by the spray is retained in the sump. The maximum pH is based on equipment qualification considerations and is set at 10.5 (Reference 1).

TECHNICAL BASIS FOR IODINE REMOVAL FACTOR

1. ELEMENTAL IODINE REMOVAL

The elemental iodine spray removal coefficient was calculated using the mathematical model given in SRP 6.5.2, Rev. 4 (Reference 2). An actual value of >20 hr^{-1} was calculated during injection; however, as directed in SRP 6.5.2, Rev. 4, the removal coefficient was limited to 20 hr^{-1} in the LOCA radiological analysis.

The removal rate constant was determined as follows:

$$\lambda_S = \frac{6(K_g)(T)(F)}{(V)(D)}$$

Where: λ_S = Spray Removal Constant, hr^{-1}

K_g = Gas Phase Mass Transfer Coefficient, ft/min

T = Time of Fall of the Spray Drops, min

F = Volume Flow Rate of Sprays, ft^3/hr

V = Containment Sprayed Volume, ft^3

D = Mass Mean Diameter of the Spray Drops, ft

Gas Phase Mass Transfer Coefficient:

K_g = 3 m/min = 9.84 ft/min (the minimum observed Kg, BNL-Technical Report A-3788, dated 8/12/86, p A-18, 21.)

Time of Fall of the Spray Drops:

T = 0.0893 min (calculated for injection based on spray flow rate, fall height, containment temperature and pressure.)

Volume of Flow Rate of Sprays:

F = 1,070 gpm (0.1337 ft^3/gal)(60 min/hr) = 8583 ft^3/hr

Containment Sprayed Volume:

V = 582,000 ft^3

Although SRP 6.5.2 states that the containment free volume is to be used, the spray removal coefficients have been calculated based only on the sprayed containment volume. In the dose calculations these removal coefficients only apply to activity while it is in the sprayed region of containment. This applies to both the elemental and particulate iodine removal coefficients.

Mass Mean Diameter of the Spray Drops:

D = 3.609E-3 ft (calculated for injection based on spray flow rate, fall height, containment temperature and pressure.)

$$\lambda_S = \frac{6(9.84 ft/min)(0.0893 min)(8583) ft^3/hr)}{(582,000 ft^3)(3.609\text{E}-3\text{ ft})} = 21.5 hr^{-1}$$

Recirculation spray has a flow rate of 900 gpm (7220 ft^3/hr), an associated fall time of 0.0899 minutes, and a drop diameter of 3.56E-3 ft., resulting in a calculated removal coefficient of 18.4/hr. This is conservatively reduced to 9.2/hr. for use in the analysis to address loading of the recirculating solution with elemental iodine.

2. PARTICULATE IODINE REMOVAL

The particulate iodine spray removal coefficient was calculated using the mathematical model given in SRP 6.5.2, Rev. 4 . The removal rate constant was determined as follows:

$$\lambda_p = \frac{3(h)(F)(E)}{2(V)(D)}$$

Where: λ_p = Spray Removal Constant hr^{-1}

h = Drop Fall Height, ft

F = Volume of Flow Rate of Sprays, ft^3/hr

V = Containment Sprayed Volume, ft^3

E/D = Ratio of a Dimensionless Collection Efficiency E to the Average Drop Diameter D.

Spray Drop Fall Height:

h = 131.58 - 66.0 = 65.58 ft — The fall height is defined as the distance from the operating deck to the lowest spray ring header.

Volume Flow Rate of Sprays for injection:

$F = 1{,}070 \text{ gpm } (0.1337 \text{ ft}^3/\text{gal})(60 \text{ min/hr}) = 8583 \text{ ft}^3/\text{hr}$

Containment Sprayed Volume:

$V = 582{,}000 \text{ ft}^3$

E/D ratio: These values were taken from SRP 6.5.2

$E/D = 10 \text{ m}^{-1}$ for $M_o/M_t \le 50$ used to calculate λ_{p-1}

$E/D = 1 \text{ m}^{-1}$ for $M_o/M_t > 50$ used to calculate λ_{p-2}

Where Mo/Mt is the ratio of the initial aerosol mass to the aerosol mass at time t

$$\lambda_{p-1} = \frac{3(65.58ft)(8583ft^3/hr)(10m^{-1})(0.3048m/ft)}{2(582,000ft^3)} = 4.42hr^{-1}$$

$$\lambda_{p-2} = 0.1 \times 4.42hr^{-1} = 0.442hr^{-1}$$

Recirculation spray has a flow rate of 900 gpm (7220 ft^3/hr), resulting in calculated removal coefficients of 3.72/hr and 0.372/hr.

3. ELEMENTAL IODINE DECONTAMINATION FACTOR

The maximum achievable elemental iodine decontamination factor (DF) for the containment atmosphere achieved by the containment spray system was calculated using the mathematical model from SRP 6.5.2, Rev. 4. The elemental iodine DF for the containment atmosphere is determined by the following equation:

$$DF = 1 + [V_S/(V_C - V_S)](PC)$$

Where: DF = decontamination factor

V_S = volume of liquid in containment sump and sump overflow, ft^3

PC = partition coefficient for iodine in water

V_C = containment net free volume, ft^3

Volume of Liquid in Containment Sump and Sump Overflow = 243,000 gal = 3.25 E4 ft^3

Containment Net Free Volume

V_C = 1.0E6 ft^3

Partition Coefficient for Iodine in Water

PC = 10,000

Figure 33 from NUREG/CR 2900, "Predicted Rates of Formation of Iodine Hydrolysis Species at pH Levels, Concentrations, and Temperatures Anticipated in LWR Accidents," which shows partition coefficient for different pH solutions as a function of time (the PC increases with time) for water at 100°C was used to determine the appropriate partition coefficient. Using a pH of 7.0, the partition coefficient is 2000 at 100 seconds (0.0278 hr), and even higher as time continues. From these values, a partition coefficient of 10,000 would be a conservative value to use since the spray will be used for at least 60 minutes.

$$DF = 1 + \frac{(3.25E4)(1.0E4)}{(1.0E6 - 3.25E4)} = 337$$

The effectiveness of the spray in removing elemental iodine is presumed to end when the maximum elemental iodine DF is reached. As specified by SRP 6.5.2 the analysis limits the DF to a value of 200.

REFERENCES

1. Point Beach Calculation 2000-0036, "pH of Post LOCA Sump and Containment Spray," Revision 2, July 31, 2007.

2. NUREG-0800 Standard Review Plan, Section 6.5.2 "Containment Spray as a Fission Product Cleanup System, Revision 4, March 2007.

3. NRC Safety Evaluation "Issuance of License Amendments Regarding Use of Alternate Source Term," April 14, 2011.