RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

APR1400 Design Certification

Korea Electric Power Corporation / Korea Hydro & Nuclear Power Co., LTD

Docket No. 52-046

RAI No.:	**362-8445**
SRP Section:	**15.00.03 - Design Basis Accidents Radiological Consequence Analyses for Advanced Light Water Reactors**
Application Section:	**15.0.3**
Date of RAI Issue:	**01/11/2016**

Question No. 15.00.03-31

FSAR Tier 2 Chapter 15.0.3 does not provide the data for parameters affecting the pH of the containment sump after the LOCA. The pH Calculation Report (Calc. No. 1-035-N387-008) provided for auditing to the staff under Section 6.5.2 review does not contain the estimated pH over a thirty-day period. In order to ensure that the pH remains within the bounds of the pH required over the thirty-day period of the event, the trend of these variables would need to be estimated and the pH calculated based on the changes in all the values affecting pH.

1. Provide the estimated pH over the thirty-day period at reasonable intervals.

2. Provide the data for the thirty-day period on which these calculations are based.

Response

TS

1.

2. KHNP performed the pH analysis of the IRWST water for the 30 days after LOCA onset based on the following approach.

   ① Time interval to be analyzed

   The pH variation in IRWST after 1 day, 1 week, and 1 month following onset of the LOCA is analyzed.

   ② Time dependent total integrated dose (TID) in IRWST during LOCA condition

The maximum values of the time dependent total integrate doses (TIDs) of gamma and beta rays in the Containment Building are as follows;

Table 1 Time dependent TIDs

TS

③ Time dependent molarity of the materials which can impact pH in IRWST.

a. Total water volume in IRWST.

The available amounts of water from these sources have been calculated in the IRWST pH calculation (1-035-N387-008, Rev.2), and the total amount of water is 3,306,850 liters.

There are numerous chemicals which can impact the pH of the water in the IRWST resulting from a LOCA and the refueling water chemistry is complex. The following provides an analysis of the more significant chemicals:

b. Boron Oxides (acidic)

For the purpose of a conservative analysis, the boron concentration is assumed to not be diluted to the maximum value of 4,400 ppm in IRWST water. Therefore, the initial boron molarity is **0.407 mole/liter** (1-035-N387-008, Rev.2).

c. Tri-sodium phosphate (basic)

The amount of TSP required to produce a 2000 ppm PO_4 is calculated, the required weight of the TSP is 26,471,123 grams, and the molarity of the TSP is **0.0211 mole/liter** (= 26,471,123 g / (380.12 g/mole x 3,306,850 liter), based on a molecular weight of 380.12 grams/mole.

d. Cesium compounds (basic) from the fission products

TS

The available cesium is the left-over cesium after CsI is formed. This amount of CsOH is a relatively small amount of the estimate of HCl (hydrochloric acid) generation. CsOH is a strong base, as compared to the strong hydrochloric acid. For the purpose of this analysis, the presence of CsOH in the IRWST is assumed to be neutralized by the effect of the strong acid in the short term. It is conservative to consider the effect of CsOH in the unmitigated long term pH calculation.

e. Hydriodic acid (HI) (acidic) from the iodine

According to NUREG/CR-5950 (1992), hydriodic acid (HI) is a strong acid, but relatively small amounts are likely to be present in the containment. NUREG/CR-5950 states that iodine entering containment from the RCS may be described as 5% in the form of elemental iodine and HI, with not less than 1% as either elemental Iodine or HI; the remaining 95% would be CsI.

According to USNRC RG 1.183 which is based on the alternative source terms of NUREG-1465 (1995), the distribution of chemical forms of iodine is specified as 95% CsI, 4.85% elemental iodine, and 0.15% organic iodide. Of this 100% iodines, the fraction that is released from the damaged fuel assembly is 40%. Since HI is a strong acid, assuming a maximum fraction of iodine in the form of HI is conservative for the pH analysis. Based on the most recent understanding of chemical forms of iodine from the USNRC perspective, if 95% of iodine is assumed as CsI, then the maximum fraction that can reasonably be assumed for HI is 5%, ignoring the formation of elemental iodine and organic iodide; and that this amount (5% of iodine) is released into the containment as HI. This assumption (5% as HI) was also used in the Grand Gulf calculation submitted to the USNRC. The NRC review indicated that this assumption was conservative (ORNL/NRC/LTR-00/07).

The estimated maximum amount of HI released to the containment and the maximum amount of iodine that can be removed by containment spray are estimated below:

TS

Table 2 Total amount of the iodine and HI, and the morality of the HI

f. Carbon dioxide (acidic) from air

Carbonic acid is generated in the IRWST from the absorption of CO_2 in the containment air by containment spray water, which is collected in the IRWST. The amount of CO_2 absorbed by IRWST water is controlled by the equilibrium between CO_2 in the containment gas phase and CO_2 in the IRWST liquid phase. Since the carbonic acid is a weak acid, and the presence of CO_2 is limited, it is expected that the absorbed amount would not be significant, this chemical is therefore not considered in the pH calculation.

g. Nitric acid (acidic) from water

Nitric acid (HNO_3) is produced by the irradiation of water and air. The radiation G value (molecules/100 eV) for nitric acid formation based on radiation absorption by water is 0.007 molecules/100 eV absorbed in water (Ref. NUREG/CR-5950). This radiation G value corresponds to 7.265×10^{-6} mole HNO_3/(L· Mrad). Based on the radiation tests at ORNL, which indicates that nitric acid only appears in water but not in gas, irradiation of air was not considered in NUREG/CR-5950. Here as in NUREG/CR-5950, only nitric acid generation from radiolysis of water is considered. The total amount of HNO_3 generation, $MHNO_3$, is then given by

$$M_{HNO3} = G_{HNO3} \times M_w \times (D_{gamma} + D_{beta})$$

Where,

M_w is the total maximum water mass, and is 3,268,992 kg given from 1-035-N387-008, Rev.2. This mass of water can be subject to irradiation.

$(D_{gamma} + D_{beta})$ is the total TID value and determined as shown in Table 1.

The amount of HNO_3 generated at 1 day, 7 days, and 30 days after a LOCA is then estimated as follows;

TS

Table 3 Nitric Acid Amount and Concentration.

h. Hydrochloric acid (acidic) from cable insulation

The total rate of HCl generation, R, is the rate of HCl generation from gamma radiolysis (R_γ) plus the rate of HCl generation from beta radiolysis (R_β).

$R = R_{\gamma} + R_{ß}$

Where,

$R_{\gamma} = G \cdot \dot{D}_{\gamma} \cdot M$

$R_{ß} = G \cdot \dot{D}_{ß} \cdot M$

The HCl generation rate from gamma and beta radiolysis is given by the G value multiplied by the gamma dose rate $\dot{D}_{\gamma}$ (and the beta dose rate $\dot{D}_{ß}$)(Gy/hr or J/kg·hr) multiplied by the Hypalon mass M (kg). Since the detailed design have not been developed for the APR1400 DC project, the total Hypalon mass is obtained from Barakah Nuclear Power Plant (Table 6.2.5-5 in BNPP1/2, FSAR), which is of same APR1400 design and has a Hypalon mass of 149,819 lbm (67,956 kg).

The amount of HCl generated at 1 day, 7 days, and 30 days after a LOCA is then given as follows;

TS

Table 4 Hydrochloric Acid Amount and Concentration.

④ Time dependent temperature of the IRWST water during the LOCA condition.

The containment pressure, temperature, and IRWST water temperature response histories are depicted in Figures 6.2.1-1 through 6.2.1-5, in the post-LOCA condition, the IRWST water temperature is changed from 120 F to about 240 F. Even though the differences of pH in this range of temperature are relatively small (<~pH 0.1), the conservative pH value can be obtained in the lower temperature condition. Hence, the lower temperature of 120 F was selected for the pH analysis.

⑤ Calculation Model

a. SOLGASMIX_PV Calculation

The pH with TSP, Boric Acid and the other acidic chemicals at the equilibrium in the IRWST can be determined by the analysis of the minimum Gibbs free energy. The Gibbs free energy minimization in the IRWST is performed using SOLGASMIX-PV code (1977), a computer program to calculate equilibrium relationships in complex chemical systems. The coefficients for the estimation of the Gibbs free energy for the various chemicals are listed in Table 5 for the pH analysis.

TS

Table 5 Chemicals and Free Energy Coefficients

b. pH Calculation.

The concentrations of all of the chemical species needed to calculate the pH are entered as inputs to the SOLGASMIX-PV code, which is then used to solve for the equilibrium concentrations of chemical species in the resulting solution. The model determines the equilibrium amount of hydronium ions (H^+) and the corresponding equilibrium amount of aqueous H_2O. Then, the new concentration of H^+ can be calculated from

$$[H^+] = \frac{Equilibrium\ mole\ of\ H^+}{Equilibrium\ mole\ of\ H_2O}$$

The pH is then given by

$$pH = -log_{10}[H^+]$$

c. Comparison with the previous pH Calculation.

Table 6 provides a comparison of the pH analysis using two different methods: the chemical equilibrium constant method and the SOLGASMIX-PV computer model. The chemical equilibrium constant method calculation of pH at the post-LOCA conditions is performed in the short term pH calculation (1-035-N387-008). The SOLGASMIX-PV calculation yields a slightly higher pH than the short term pH calculation. Lower pH, using the chemical equilibrium constant method, results in more challenging condition for corrosion consideration; and is therefore more conservative than that of the SOLGASMIX-PV calculation.

TS

Table 6 Comparison of pH Analysis Results Using Chemical Equilibrium Constant Method and SOLGASMIX-PV Computer Model

⑥ Results from pH calculation

Based on the data determined above, the pH values of the IRWST water in the LOCA conditions for 30 days are provided below:

TS

Table 7 pH Values of the IRWST during 30days

Impact on DCD

DCD Section 6.5.2.3.2 will be revised as indicated in attachment 1.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specifications.

Impact on Technical/Topical/Environmental Reports

There is no impact on any Technical, Topical, or Environment Report.

6.5.2.3.2 Containment Spray pH Control

The pH of IRWST water is evaluated to provide reasonable assurance that the calculated minimum and maximum pH values under any possible water chemistry conditions caused by a LOCA are between 7.0 and 8.5.

After a LOCA, the spray water from the spray nozzles removes the fission product from the containment atmosphere drops to the floor of the containment. The spray water that drops to the containment floor accumulates in the HVT. During a LOCA, TSP stored in baskets in the HVT becomes immersed in water, and the resulting solution overflows into the IRWST. If the pH of IRWST water during the post-accident is maintained above 7.0, the radioactive iodine dissolved into IRWST water does not re-evaporate into the containment atmosphere.

Stainless steel baskets, which are attached to the walls of the HVT, have a solid top and bottom with mesh sides to permit submergence of the TSP. The elevation of the baskets is below the IRWST spillway.

The principal water sources that contribute to the pH control are from the IRWST, the RCS including the pressurizer, the safety injection tanks (SITs), safety injection system piping, and CSS piping.

The volume of TSP required to establish a minimum pH of 7.0 in the recirculated containment spray solution is calculated using the following conservative assumptions:

a. Maximum boron concentration for each water source

b. Maximum water sources

c. Minimum IRWST water temperature

For this analysis, it is assumed that one CS pump is running.

On the other hand, the maximum pH is conservatively calculated using the previously determined TSP volume and the following initial conditions:

~200min post LOCA

a. Minimum boron concentrations for each water source

b. Minimum water sources

c. Maximum IRWST water temperature

The major parameters used in pH calculations are presented in Table 6.5-4. The results of the calculations show that the time required to reach a pH of 7.0 for the minimum pH condition is estimated to be 157 minutes after the onset of a LOCA. The maximum pH value is calculated not to exceed 8.5 for the maximum pH condition. Therefore, the pH of IRWST water is maintained between 7.0 and 8.5 after 157 minutes.

6.5.2.3.3 Airborne Fission Product Removal Coefficient

The fission products are released from the RCS into the containment atmosphere following a DBA through the three steps: coolant activity release, gap activity release, and early in-vessel release according to NUREG-1465 (Reference 11). Fission products are divided into eight radionuclide groups on the basis of chemical behavior. Of the radioiodine released from the RCS to the containment atmosphere, 95 percent is particulate iodine, 4.85 percent is elemental iodine, and 0.15 percent is organic iodine. With the exception of elemental and organic iodine and noble gases, fission products are assumed to be in a particulate form.

The removal of airborne radioactivity in the containment by natural deposition is credited by acceptable models for elimination of iodine and aerosols in SRP 6.5.2 and in NUREG/CR-6189 (Reference 12). The removal of airborne radioactivity in the containment by CSS is credited by acceptance models in SRP 6.5.2.

The removal rates of elemental and particulate iodine by natural deposition (process) or by containment spray are used based on the above regulations and as described below.

Elemental Iodine Removal by Containment Spray

The elemental iodine removal coefficients are estimated using the following equation:

Insert "A" in next page

A

~30 days post LOCA

Additionally, the pH of the water inside the IRWST remains above a value of 7 after the short term through the thirty-day period of the post-LOCA event. The pH analysis is calculated using the following basis:

a. The maximum boron concentration for the maximum water volume
b. The TSP concentration is based on the amount of TSP available for pH control in the HVT for the recirculating water inside the IRWST
c. Strong acids, such as HCl, HNO_3, and HI, which are generated from the LOCA event, are included in the analysis
d. Severe radiation condition in the containment building; and
e. The lower IRWST water temperature

157 minutes after the onset of LOCA, the pH value increases up to 7.0. The pH value decreases slightly, less than 0.1 pH units, for the unmitigated post LOCA conditions due to the generation of the Acidic chemicals, which impacts on the pH of the recirculating water in the IRWST.