Non-Proprietary

REVISED 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**

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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 – (Rev. 1)

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2. KHNP performed two pH analysis calculations for the IRWST water for 30 days after LOCA onset based on the following approach. The first pH Calculation Report (Calc. No. 1-035-N387-008) was provided to the Staff for auditing under Section 6.5.2 review. The second calculation, "Long Term pH Analysis", Calculation # 1-035-N387-009, was prepared to address the complex chemical and radiological water chemistry in the IRWST using the SOLGASMIX-PV computer program developed by ORNL in 1977. It is noted that the second pH calculation involves new and conservative input parameters, assumptions, and calculation methodology, which results in new and updated parametric values and pH results. The new values and results are high-lighted in blue fonts for tracking purposes.

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.

　　a. Total water volume in IRWST.

The total amount of water in the IRWST pH calculation is 3,306,850 liters (extracted from Calculation 1-035-N387-008, Rev.2).

The refueling water chemistry resulting from a LOCA is complex. The numerous chemicals which can have an impact on the pH of the IRWST water are summarized as follows:

　　b. Boron Oxides (acidic)

For the purpose of a conservative analysis, the boron concentration is assumed to be at 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 (TSP, alkalinotic)

The amount of TSP required to produce a 2000 ppm PO_4 is calculated, the calculated 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

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]^{TS} This amount of CsOH is a relatively small amount when it is compared to the estimate amount 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 not 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; 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 approximately 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, 95% of iodine is assumed to be CsI, and the balance fraction (5%) can reasonably be assumed as HI, ignoring the formation of elemental iodine and organic iodide. It is further assumed that this amount (5% of iodine) is released into the containment as HI. This assumption (5% as HI and its release from damaged fuel) 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:

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

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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 radiological 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 radiological G value corresponds to 7.265×10^{-6} mole $HNO_3/(L \cdot Mrad)$. 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;

Table 3 Nitric Acid Amount and Concentration.

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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).

$R = R_\gamma + R_\beta$

Where,

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

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

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 $\dot{D}_\beta$) (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;

Table 4 Hydrochloric Acid Amount and Concentration.   TS

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 resulting from neutralization 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 (ORNL1977), a computer program developed to calculate the 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 this pH analysis.

Table 5 Chemicals and Free Energy Coefficients   TS

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 computer model is used for this calculation due to the complexity of the chemical and radiological conditions in the IRWST water. The SOLGASMIX-PV computer model yields a slightly higher pH than the short term pH calculation. It should be noted that the pH analysis is based on a set of conservative assumptions, which includes the quantities of HCl and HNO_3 acids that are generously estimated.

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

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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;

Table 7 pH Values of the IRWST during 30days

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For clarify, the DCD Tier 2, Subsection 6.5.2.3.2 will be revised as indicated in attachment.

Impact on DCD

DCD Subsection 6.5.2.3.2 will be revised as indicated in attachment.

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.

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.

~30 days post LOCA

Additionally, the pH of the water inside the IRWST remains above a value of ~~7 after the short term~~ 7.0 after a short period of time (about 3 hours) through the thirty-day period ~~of~~ in the post-LOCA event.   The pH analysis ~~is calculated using~~ includes the following basis:

a.   The maximum boron concentration ~~for~~ at the maximum water volume

b.   The TSP concentration is based on the amount of TSP available ~~for pH control in the HVT for~~ in the HVT for pH control using 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, including the IRWST; 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.~~

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

The pH value decreases slightly, less than 0.1 pH units, from the maximum value at 200-minutes post LOCA conditions due to the generation of acidic chemicals, which impacts the pH of the recirculating water in the IRWST.