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TOKYO, JAPAN

August 18, 2009

Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Attention: Mr. Jeffrey A. Ciocco

Docket No. 52-021
MHI Ref: UAP-HF-09423

Subject: MHI's Response to US-APWR DCD RAI No. 416-2912 Rev. 0

- Reference:** 1) "Request for Additional Information No. 416-2912 Revision 0, SRP Section: 06.05.02 – Containment Spray as a Fission Product Cleanup System, Application Section: 6.5.2" dated 6/29/2009.
2) Letter MHI Ref: UAP-HF-09407 from Y. Ogata (MHI) to U.S. NRC, "MHI's Responses to US-APWR DCD RAI No. 416" dated July 28, 2009

With this letter, Mitsubishi Heavy Industries, Ltd. ("MHI") transmits to the U.S. Nuclear Regulatory Commission ("NRC") documents entitled "Response to Request for Additional Information No. 416-2912 Rev. 0".

Enclosed is the second response to 2 RAIs contained within Reference 1. In the initial responses submitted with Reference 2, MHI committed to submit responses to RAI #6.5.2-6 by 28th of August 2009.

Please contact Dr. C. Keith Paulson, Senior Technical Manager, Mitsubishi Nuclear Energy Systems, Inc. if the NRC has questions concerning any aspect of the submittals. His contact information is below.

Sincerely,

Yoshiki Ogata,
General Manager- APWR Promoting Department
Mitsubishi Heavy Industries, LTD.

Enclosure:

1. Response to Request for Additional Information No. 416-2912 Revision 0

CC: J. A. Ciocco
C. K. Paulson

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Contact Information

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Docket No. 52-021
MHI Ref: UAP-HF-09423

Enclosure 1

UAP-HF-09423
Docket No. 52-021

Response to Request for Additional Information No. 416-2912
Revision 0

August 2009

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

8/18/2009

US-APWR Design Certification

Mitsubishi Heavy Industries

Docket No. 52-021

RAI NO.: NO. 416-2912 REVISION 0
SRP SECTION: 06.05.02 – CONTAINMENT SPRAY AS A FISSION PRODUCT CLEANUP SYSTEM
APPLICATION SECTION: 6.5.2
DATE OF RAI ISSUE: 6/29/2009

QUESTION NO.: 06.05.02-6

Background

RAI 06.05.02-2 (Reference 1) requested that the applicant explain how “ineffective pools” in containment will affect the dissolution and retention of fission products (particularly iodine). They were asked to explain the pH of such pools, the concentration of borate, and the concentrations of iodine and other fission products. This explanation was desired because there was concern that the pH control chemical (NaTB) might not reach some of these pools, allowing dissolved iodine to volatilize and evaporate.

The applicant’s response (Reference 2) mentions principal locations where ineffective pools would be located. For one (containment recirculation air distribution chamber), it was stated that a connection to the RWSP would ensure that this region would have a pH identical to the RWSP itself. For other regions, it was stated that bulk pH was lower than re-circulating water. However, a numerical pH was not provided. In reference to the ineffective pools the response also stated, “the surface of these pools would be exposed to re-circulating water.” This explanation is unclear to the staff. Does the statement imply that some of the ineffective pools will eventually be diluted by higher-pH containment spray water such that their pH will increase with time? Regarding the distribution of borate in ineffective pools, the staff has reworded its question to clarify that a quantitative response is needed. The applicant does provide a good estimate of the distribution of fission product iodine in the various ineffective pool locations.

Requested Information

1. Define what is meant by “ineffective pools.” Provide a more detailed description of all containment locations containing water that do not directly participate in recirculation through containment sprays. Note how they accumulate water. If water volumes are indirectly connected to the RWSP, provide detail on how they are connected (pipe size, expected flow patterns, etc.). Note any volumes that are completely unconnected to the RWSP, but that still could accumulate spray water.
2. For all volumes not directly a part of the RWSP-spray recirculation loop (i.e., those noted in question 1), provide an estimate of the (time-varying) pH, NaTB concentration, and fission product concentration.

References

1. "Request for Additional Information No. 234-2040 Revision 1, SRP Section: 06.05.02 - Containment Spray as a Fission Product Cleanup System, Application Section: Section 6.5.2" dated February 26, 2009. (ADAMS Accession No. ML0906102970)
 2. Letter from Yoshiki Ogata, MHI, to NRC dated March 24, 2009; Docket No. 52-021 MHI Ref: UAP-HF-09121; Subject: MHI's Response to US-APWR DCD RAI No. 234 (ADAMS Accession No. ML0908502111)
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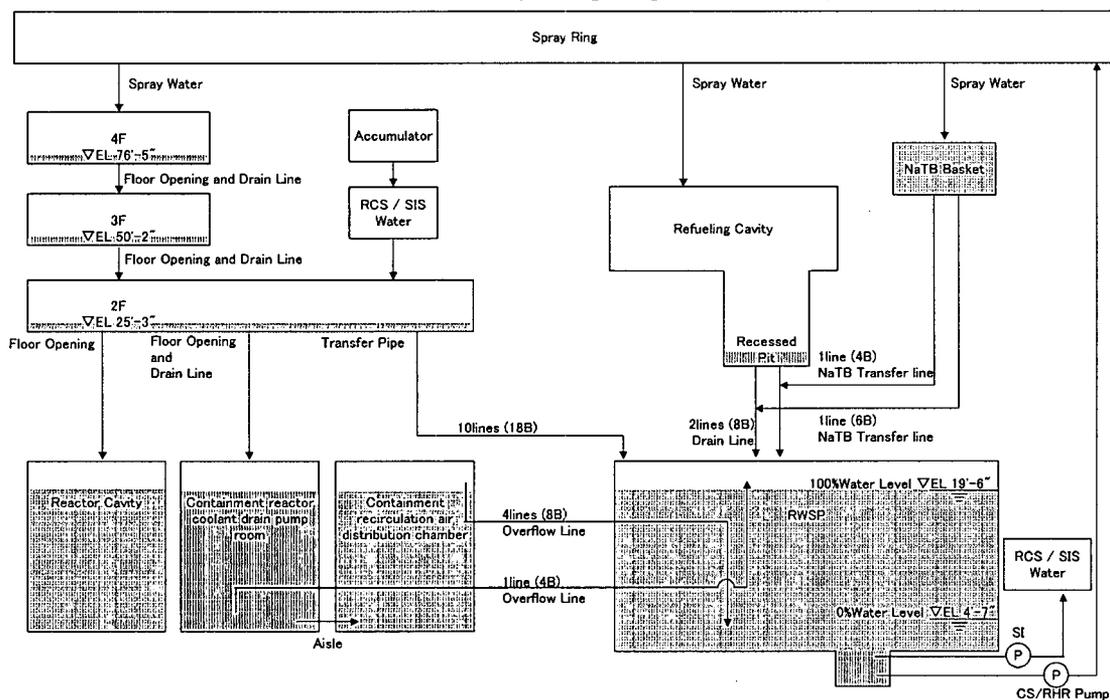
ANSWER:

1. "Ineffective pools" is defined in the report (Reference 1) as a hold-up volume that entraps return water which will not contribute to recovering the RWSP water level. Detailed description of all containment locations containing water that do not directly participate in recirculation through containment sprays are described in the report (Reference 1) and the reply of RAI 331-935 "c. Ineffective pit volume (retained water)" as follows;

- Reactor cavity
- Containment recirculation air distribution chamber
- Containment reactor coolant drain pump room
- Recessed pits in the refueling cavity

The outline of the water path regarding with ineffective pools is shown in following figure. Reactor cavity is completely unconnected to the RWSP and accumulates spray water. Containment recirculation air distribution chamber and containment reactor coolant drain pump room are indirectly connected to RWSP with 4 numbers overflow lines of 8B pipe and one line of 4B overflow pipe respectively. The recessed pits in the refueling cavity are considered as ineffective pools. And the 8B drain lines are connected from the recessed pit to RWSP. In addition, NaTB baskets have ineffective water which is indirectly connected to the RWSP.

The outline of the water path regarding with ineffective pools



2. In the response to RAI No.234, it was described that the surface of these pools would be exposed to recirculating water. The iodine volatilization is expected to be hard to occur under such condition. It is because the effect of cover water with pH seven or more on ineffective water can be considered. And the effect of much larger cesium than iodine at LOCA can be also considered. Therefore, pH, NaTB concentration and fission product concentration in each ineffective pool is not evaluated. The bases which lead this conclusion are on the following discussions.

(1) About "ineffective pools covered with water of pH higher than 7"

The following discussion is the rate of the release of iodine to the gas phase when water of pH lower than 7 was covered by spraying with water of pH higher than 7 in ineffective pools. If iodine molecules (I_2) in water of pH lower than 7 move to water of pH higher than 7, the iodine is expected to dissolve in the water by the reaction below.



When instantaneous equilibrium is established by the reaction in (1-1), the ratio of $I_{2(aq)}$ to the total amount of iodine is very small and negligible at pHs higher than 7. Therefore the ratio of iodine molecules (I_2) to be dissolved in water during the residence period of iodine in covering water from the reaction rate of (1-1) is evaluated.

Evaluate the residence time of iodine in covering water from its diffusion velocity in water. Assuming the unidirectional diffusion of iodine molecules to NaTB-containing covering water from general theory of diffusion, the relational expression below holds:

$$V \cdot C_{Ave} = -D / (1-X) (\partial C / \partial Z)_{z=0} \quad (1-2)$$

Where:

V: Diffusion velocity of iodine molecules in water (cm/sec)

C_{Ave} : Average concentration of iodine molecules in covering water (mol/cm³)

Half of the concentration of I_2 ($= 2.02 \times 10^{-6}/2$) assuming that the HI in water is transformed into I_2 in LOCA

D: Diffusion coefficient of iodine molecules in water (cm^2/sec)

Calculate D using the Wilke-Chang expression shown on page 104 of the Chemical Engineering Journal, 5th Edition. For the molecular volume of iodine at boiling point $V_{m,1}$ (cm^3/mol), use 71.5 as given on page 15 of the journal.

Wilke, C.R. and P.Chang, A.I. Ch. E. Journal, 1, 264 (1955)

X: Molar fraction of iodine molecules (-):

Approximately set as 0 because this molar fraction is very low.

$-(\partial C/\partial Z)_{z=0}$: Concentration gradient of iodine molecules in covering water in the direction of movement ($mol/cm^3/cm$)

Conservatively, assuming that the concentration of iodine is zero on the surface in contact with the gas phase as the condition under which the concentration gradient reaches the maximum, the concentration gradient becomes the concentration of all iodine molecules/Z in water in LOCA ($= 2.02 \times 10^{-6}/Z$).

Z: Thickness of covering water (cm).

Based on this thickness, shift the value parametrically.

Under the conditions shown above, calculate V from Expression (1-3).

$$V = -D(\partial C/\partial Z)_{z=0} / C_{Ave} \quad (1-3)$$

Next, calculate the residence time of iodine τ (sec) in covering water using the expression below.

$$\tau = Z/V \quad (1-4)$$

Then, the reduction rate (ratio) of $I_{2(aq)}$ from the reaction in (1-1) is evaluated.

Assuming that the hydrolysis reaction rate constant is set as k (1/sec), the reduction ratio $I_{2(aq)}/I_{2(aq)0}$ of $I_{2(aq)}$ can be evaluated with the expression below:

$$I_{2(aq)}/I_{2(aq)0} = \exp(-k\tau) \quad (1-5)$$

<Diffusion coefficient of iodine molecules in water>

Calculate the diffusion coefficient of iodine molecules in water using the Wilke-Chang expression shown on page 104 of the Chemical Engineering Journal, 5th Edition.

$$D(cm^2/sec) = 7.4 \times 10^{-8} (\beta \cdot M_{r2})^{0.5} \cdot T / \eta_2 / V_{m,1}^{0.6} \quad (1-6)$$

Where

β : Interacting factor 2.6

M_{r2} : Molecular weight of solvent, water 18

T: Absolute temperature $^{\circ}K$ $273.15+t$ ($^{\circ}C$)

η_2 : Viscosity of solvent, water (C · P) or (mPa · s)

Page II-37, Chemical Guideline – Basic II 4th Edition

$$\eta(mPa \cdot s) = A \cdot \exp[(1+B \cdot T)/(C \cdot T + D \cdot T^2)]$$

T: $^{\circ}K$ A: 0.0126 B: -0.581×10^{-2}

C: 0.113×10^{-2} D: -0.572×10^{-5}

When the temperature is higher than $100^{\circ}C$, use the value in the gas-liquid equilibrium.

Page II-35, Chemical Guideline – Basic II 4th Edition $181.9 \mu Pa$ sec at $150^{\circ}C$

$V_{m,1}$: Molecular volume of iodine at the boiling point (cm^3/mol) 71.5

<Residence time in covering water>

Table 1-1 shows the calculation results of the residence time of iodine molecules when the thicknesses of covering water are 0.1 cm, 1 cm, and 10 cm.

<Reduction ratio of I₂>

Reaction rate constant of Expression (1-5) k*: 3sec⁻¹

*:J.T.Bell et al. NUREG/CR-2900 (1982)

As shown in Table 1-1, the residence time of iodine in water decreases as the temperature increases and the thickness of covering water decreases. However, even when the thickness of covering water is 0.1 cm, the residence time of iodine is approximately 50 seconds or longer. Since reaction rate constant of Expression (1-5) k is 3 sec⁻¹, the reduction ratio $I_{2(aq)}/I_{2(aq)0}$ of I_{2(aq)} obtained from Expression (1-5) will be extremely low. Additionally, the iodine migrating to the gas phase (I_{2(aq)}) is negligible when the effect of the partition factor is taken into account.

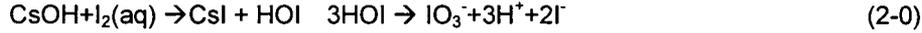
Table 1-1 Residence Time of Iodine in Covering Water

| t°C | 50 | 100 | 150 |
|---|-----------|-----------|----------|
| T°K=273.15+t | 323 | 373 | 423 |
| β: Interacting factor | 2.6 | 2.6 | 2.6 |
| M _{r2} : Molecule weight of solvent, water | 18 | 18 | 18 |
| A | 1.26E-02 | 1.26E-02 | --- |
| B | -5.81E-03 | -5.81E-03 | --- |
| C | 1.13E-03 | 1.13E-03 | --- |
| D | -5.72E-06 | -5.72E-06 | --- |
| η (mPa · s) =A*exp[(1+B*T)/(C*T+D*T ²)](Note 1) | 5.53E-01 | 2.85E-01 | 1.82E-01 |
| V _{m,1} : Molecular volume of iodine at boiling point (cm ³ /mol) | 71.5 | 71.5 | 71.5 |
| D(cm ² /sec) =7.4×10 ⁻⁸ (β*M _{r2}) ^{0.5} *T/η ₂ / V _{m,1} ^{0.6} | 2.28E-05 | 5.12E-05 | 9.08E-05 |
| C _{Ave} : Average concentration of iodine molecules in covering water (mol/cm ³) | 5.05E-07 | 5.05E-07 | 5.05E-07 |
| (∂C/∂Z) _{Z=0} : Concentration gradient of iodine molecules in covering water in the direction of movement (mol/cm ³ /cm) 2.02×10 ⁻⁶ /2/Z Z=0.1cm | 1.01E-05 | 1.01E-05 | 1.01E-05 |
| (∂C/∂Z) _{Z=0} : Concentration gradient of iodine molecules in covering water in the direction of movement (mol/cm ³ /cm) 2.02×10 ⁻⁶ /2/Z Z=1cm | 1.01E-06 | 1.01E-06 | 1.01E-06 |
| (∂C/∂Z) _{Z=0} : Concentration gradient of iodine molecules in covering water in the direction of movement (mol/cm ³ /cm) 2.02×10 ⁻⁶ /2/Z Z=10cm | 1.01E-07 | 1.01E-07 | 1.01E-07 |
| V=-D(∂C/∂Z) _{Z=0} /C _{Ave} (cm/sec) Z=0.1cm | 4.56E-04 | 1.02E-03 | 1.82E-03 |
| V=-D(∂C/∂Z) _{Z=0} /C _{Ave} (cm/sec) Z=1cm | 4.56E-05 | 1.02E-04 | 1.82E-04 |
| V=-D(∂C/∂Z) _{Z=0} /C _{Ave} (cm/sec) Z=10cm | 4.56E-06 | 1.02E-05 | 1.82E-05 |
| Residence time: τ(sec) Z=0.1cm | 2.19E+02 | 9.77E+01 | 5.50E+01 |
| Residence time: τ(sec) Z=1cm | 2.19E+04 | 9.77E+03 | 5.50E+03 |
| Residence time: τ(sec) Z=10cm | 2.19E+06 | 9.77E+05 | 5.50E+05 |

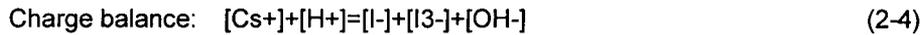
(Note 1) For 150°C, the value of gas-liquid equilibrium (on page 35, Chemical Guideline – Basic II 4th Edition) is used.

(2) About "difficult to volatilize if Cs is rich"

In the session (1), it is described that iodine is hard to release to the gas phase by considering the reaction of iodine and water (Eq.(1-1)). Here, it is described that the molecular iodine is reduced more effectively when cesium is rich. The amount of mols released in case of LOCA is about ten times higher in cesium than in iodine. Under this condition of rich cesium, 95% of iodine becomes cesium iodide (Csl), and 5% is transformed into HI. The remaining cesium exists as cesium hydroxide (CsOH). Consequently, water in the containment is rich in cesium and alkaline, and iodine molecules are promptly hydrolyzed by the reaction below:



Here, the impact of alkali by CsOH is not conservatively considered, and all of the iodine released at the time of LOCA is assumed to be Csl. Evaluate the existence ratio of $\text{I}_2(\text{aq})$ that could migrate to the gas phase. The following three major reaction formulas must be taken into account:



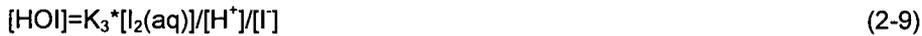
From Expressions (2-4) and (2-5):



From Formula (2-1):



From Formula (2-2):



From Expressions (2-7) to (2-9):

$$[\text{I}^-] = 1/2 * \{ \lambda + (\lambda^2 + 4\omega)^{0.5} \} \quad (2-10)$$

$$\lambda = [\text{Cs}^+] / (1 + K_2 * [\text{I}_2(\text{aq})]) \quad (2-11)$$

$$\omega = K_3 * [\text{I}_2(\text{aq})] / [\text{H}^+] / (1 + K_2 * [\text{I}_2(\text{aq})]) \quad (2-12)$$

The following is the procedure to calculate the existence ratio of $[\text{I}_2(\text{aq})]$ to the iodine released: ($= [\text{I}_2(\text{aq})] / [\text{I}]_{\text{aq(T)}}$).

1. Set the initial concentrations of $[\text{Cs}^+]$ and $[\text{I}]_{\text{aq(T)}}$ according to the amount of iodine released in case of an accident. However, assume that cesium is released as Csl, $[\text{Cs}^+] = [\text{I}]_{\text{aq(T)}}$.
2. Calculate $[\text{I}^-]$ from Expressions (2-10) to (2-12) with pH ($[\text{H}^+]$) given and $[\text{I}_2(\text{aq})]$ set as a parameter. Additionally, obtain $[\text{I}_3^-]$ and $[\text{HIO}]$ from Expressions (2-8) and (2-9).
3. Calculate $[\text{I}]_{\text{aq(T)}}$ from Expression (2-6) for iodine balance, and keep $[\text{I}_2(\text{aq})]$ changing until it becomes equal to the initial concentration set

- in 1.
4. Calculate $[I_2(aq)]/[I]_{aq(T)}$ from the $[I_2(aq)]$ and $[I]_{aq(T)}$ obtained in 3.

Tables 2-1 and 2-2 show the calculation results of the existence ratio of $[I_2(aq)]$ to the total amount of iodine released when pH is 4 and 7, respectively. As shown in Tables 2-1 and 2-2, the ratio of $[I_2(aq)]$ to the total amount of iodine released is extremely low at each pH level. The iodine migrating to the gas phase is also negligible if the effect of the partition factor is taken into account. The reason that the ratio of $[I_2(aq)]$ is low is because the ratio of $[I^-]$ increases as $[Cs^+]$ rises in Expressions (2-10) to (2-12).

Table 2-1 Existence Ratio of $[I_2(aq)]$ (pH = 4)

| t°C | 50 | 100 | 150 |
|---|-----------|-----------|-----------|
| $T^{\circ}K=273+t$ | 323 | 373 | 423 |
| $K_2=\exp(-111.98+16.725\ln T+6952.3/T)$ (*) | 4.81E+02 | 2.98E+02 | 2.70E+02 |
| K_3 = Reading from table (*) | 4.80E-12 | 1.50E-10 | 2.00E-09 |
| pH | 4.00 | 4.00 | 4.00 |
| $[H^+]=10^{-pH}$ | 1.00E-04 | 1.00E-04 | 1.00E-04 |
| $[I_{2aq}]^{(**)}$ | 9.86E-13 | 5.79E-13 | 9.26E-14 |
| $[Cs^+]$ | 2.02E-06 | 2.02E-06 | 2.02E-06 |
| $\lambda=[Cs^+]/(1+K_2*[I_{2aq}])$ | 2.02E-06 | 2.02E-06 | 2.02E-06 |
| $\omega=K_3*[I_{2aq}]/[H^+]/(1+K_2*[I_{2aq}])$ | 4.73E-20 | 8.69E-19 | 1.85E-18 |
| $[I^-]=1/2*\{\lambda+(\lambda^2+4\omega)^{0.5}\}$ | 2.02E-06 | 2.02E-06 | 2.02E-06 |
| $[HIO]=K_3[I_{2aq}]/[H^+]/[I^-]$ | 2.34E-14 | 4.30E-13 | 9.17E-13 |
| $[I_3]=K_2[I_{2aq}][I^-]$ | 9.57E-16 | 3.49E-16 | 5.05E-17 |
| $[I_{2aqT}]$ Analyzed value M_1 | 2.02E-06 | 2.02E-06 | 2.02E-06 |
| $[I_{aqT}]=2[I_{2aq}]+[HIO]+[I^-]+3*[I_3]$ M_2 | 2.02E-06 | 2.02E-06 | 2.02E-06 |
| Mass Balance $\Delta M=M_1-M_2$ | -2.02E-12 | -2.02E-12 | -2.02E-12 |
| Ratio of deviation from analyzed value $\Delta M/M_1=\Delta M/2.02E-6$ | -1.00E-06 | -1.00E-06 | -1.00E-06 |
| $[I_2(aq)]/[I_{aqT}]$ | 4.88E-07 | 2.87E-07 | 4.59E-08 |

(*) The reaction formula and the equilibrium constant are based on ORNL-TM-2412 IV.

(**) $[I_{2aq}]$ is kept changing until M_1 and M_2 become equal to each other.

Table 2-2 Existence Ratio of $[I_2(aq)]$ (pH = 7)

| t°C | 50 | 100 | 150 |
|---|-----------|-----------|-----------|
| T°K=273+t | 323 | 373 | 423 |
| $K_2 = \exp(-111.98 + 16.725 \ln T + 6952.3/T)$ (*) | 4.81E+02 | 2.98E+02 | 2.70E+02 |
| $K_3 =$ Reading from table (*) | 4.80E-12 | 1.50E-10 | 2.00E-09 |
| pH | 7.00 | 7.00 | 7.00 |
| $[H^+] = 10^{-pH}$ | 1.00E-07 | 1.00E-07 | 1.00E-07 |
| $[I_{2(aq)}]$ (**) | 4.08E-14 | 1.36E-15 | 1.02E-16 |
| $[Cs^+]$ | 2.02E-06 | 2.02E-06 | 2.02E-06 |
| $\lambda = [Cs^+] / (1 + K_2 * [I_{2(aq)}])$ | 2.02E-06 | 2.02E-06 | 2.02E-06 |
| $\omega = K_3 * [I_{2(aq)}] / ([H^+] * (1 + K_2 * [I_{2(aq)}]))$ | 1.96E-18 | 2.04E-18 | 2.04E-18 |
| $[I^-] = 1/2 * \{\lambda + (\lambda^2 + 4\omega)^{0.5}\}$ | 2.02E-06 | 2.02E-06 | 2.02E-06 |
| $[HIO] = K_3 [I_{2(aq)}] / [H^+] / [I^-]$ | 9.69E-13 | 1.01E-12 | 1.01E-12 |
| $[I_3^-] = K_2 [I_{2(aq)}] [I^-]$ | 3.96E-17 | 8.18E-19 | 5.56E-20 |
| $[I_{aqT}]$ Analyzed value M_1 | 2.02E-06 | 2.02E-06 | 2.02E-06 |
| $[I_{aqT}] = 2[I_{2(aq)}] + [HIO] + [I^-] + 3*[I_3^-]$ M_2 | 2.02E-06 | 2.02E-06 | 2.02E-06 |
| Mass Balance $\Delta M = M_1 - M_2$ | -2.02E-12 | -2.02E-12 | -2.02E-12 |
| Ratio of deviation from analyzed value $\Delta M / M_1 = \Delta M / 2.02E-6$ | -1.00E-06 | -1.00E-06 | -1.00E-06 |
| $[I_2(aq)] / [I_{aqT}]$ | 2.02E-08 | 6.72E-10 | 5.05E-11 |

(*) The reaction formula and the equilibrium constant are based on ORNL-TM-2412 IV.

(**) $[I_{2(aq)}]$ is kept changing until M_1 and M_2 become equal to each other.

Reference

1. MUAOP-08001-P(R2), US-APWR Sump Strainer Performance, December 20089, Mitsubishi Heavy Industries, Ltd.

Impact on DCD

NaTB basket is added to the Figure 6.2.1-9 in the DCD.

Impact on COLA

There is no impact on the COLA.

Impact on PRA

There is no impact on the PRA.