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Proprietary Notice

This letter forwards proprietary information in accordance with 10CFR2.390. Upon the removal of Enclosure 2, the balance of this letter may be considered non-proprietary.

MFN 08-373

Docket No. 52-010

May 16, 2008

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

Subject: Response to Portion of NRC Request for Additional Information Letter Nos. 90 and 142 Related to ESBWR Design Certification Application ESBWR – Safety Analyses – RAI Numbers 15.4-29 and 15.4-41

The purpose of this letter is to submit the GE Hitachi Nuclear Energy (GEH) response to the U.S. Nuclear Regulatory Commission (NRC) Request for Additional Information (RAI) sent by NRC letters dated January 29, 2007 (Reference 1) and January 14, 2008 (Reference 2), respectively. GEH response to RAI Numbers 15.4-29 and 15.4-41 are addressed in Enclosure 1.

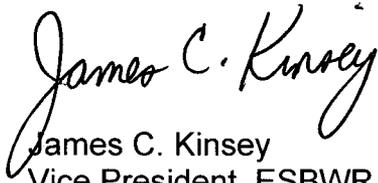
Enclosure 2 entitled: "*Iodine Re-Volatilization from the Reactor Pressure Vessel During Late-Stage ESBWR LOCA*" contains GEH proprietary information as defined by 10 CFR 2.390. GEH customarily maintains this information in confidence and withholds it from public disclosure. A non-proprietary version of "*Iodine Re-Volatilization from the Reactor Pressure Vessel During Late-Stage ESBWR LOCA*" is provided in Enclosure 3.

The affidavit contained in Enclosure 4 identifies that the information contained in Enclosure 2 has been handled and classified as proprietary to GEH. GEH hereby requests that the information of Enclosure 2 be withheld from public disclosure in accordance with the provisions of 10 CFR 2.390 and 9.17.

DC68
NRC

If you have any questions or require additional information, please contact me.

Sincerely,



James C. Kinsey
Vice President, ESBWR Licensing

References:

1. MFN 07-084, Letter from U.S. Nuclear Regulatory Commission to Robert E. Brown, GEH, *Request For Additional Information Letter No. 90 Related To ESBWR Design Certification Application*, dated January 29, 2007.
2. MFN 08-032, Letter from U.S. Nuclear Regulatory Commission to Robert E. Brown, GEH, *Request For Additional Information Letter No. 142 Related To ESBWR Design Certification Application*, dated January 14, 2008.

Enclosures:

1. Response to Portion of NRC Request for Additional Information Letter Nos. 90 and 142 Related to ESBWR Design Certification Application ESBWR – Safety Analyses – RAI Numbers 15.4-29 and 15.4-41
2. MFN 08-373 – Iodine Re-Volatilization from the Reactor Pressure Vessel During Late-Stage ESBWR LOCA – GEH Proprietary Information
3. MFN 08-373 – Iodine Re-Volatilization from the Reactor Pressure Vessel During Late-Stage ESBWR LOCA – Non-Proprietary Version
4. MFN 08-373 – Affidavit for GE-Hitachi Nuclear Energy Americas LLC Proprietary Information for the NRC – Executed by Larry J. Tucker, May 16, 2008

cc: AE Cabbage USNRC (with enclosure)
GB Stramback GEH/San Jose (with enclosure)
RE Brown GEH/Wilmington (with enclosure)
eDRF 0000-0075-9312 for RAI 15.4-29
 0000-0084-2733 for RAI 15.4-41

Enclosure 1

MFN 08-373

**Response to Portion of NRC Request for
Additional Information Letter Nos. 90 and 142
Related to ESBWR Design Certification Application**

Safety Analyses

RAI Numbers 15.4-29 and 15.4-41

NRC RAI 15.4-29:

General Electric Research Report No. VTT-R-04413-06, "Estimation and Modeling of Effective Fission Product Decontamination Factor for ESBWR Containment - Part 1, October 2006," (VTT report) Section 3, "Goal," stated that "The purpose of this work is to investigate the capacity of [passive containment cooling system] PCCS condenser to remove airborne fission products from the containment atmosphere." The report concluded in Section 1, "Executive Summary," stating that "Both the experimental and modeling result suggest that aerosol deposition by diffusiophoresis could remove as much as 50 percent of particles from the gas flow. However, aerosol did not accumulate to the heat exchanger. In all experiments condensed water rinsed deposited particles from the tube walls....". Therefore, GE's analysis implicitly assumed that the PCCS drove the iodine in aerosol form into the condensate and that it never came out of the solution with basic pH.

Explain the iodine transport phenomena in the containment and perform a rate analysis of steady state iodine transport within the containment including iodine re-volatilization (iodine production) from the melted fuel in the intact reactor pressure vessel and iodine removal by the PCCS condensers (iodine sink).

GEH Response:

The GEH analyses did ultimately determine that the bulk of the aerosols removed from the containment atmosphere were flushed from the Passive Containment Cooling System (PCCS) via the condensate from the PCC condensers themselves. The condensate was then directed to the Gravity-Driven Cooling System (GDCCS) pool, and ultimately re-injected into the reactor pressure vessel (RPV). This process continues for the duration of the event. Initial analyses implied that the pH in the RPV remained above 7 for the duration of the event; therefore, re-evolution of iodine was neglected.

GEH has reviewed the potential impact of the re-evolution of iodine from the RPV as documented in the attached write-up, "Iodine Re-Volatilization from the Reactor Pressure Vessel During Late-Stage ESBWR LOCA." To provide additional conservatism, GEH is only crediting 50% of the CsOH available for the licensing basis case (discussed in detail in response to RAI 15.4-39 via GEH letter 08-315 dated April 11, 2008). Re-evolution of iodine from the RPV is qualitatively considered for the licensing basis case. Timing for the pH dropping below 7 is based on VTT-R-006671-07, "Estimation and Modeling of Effective Fission Product Decontamination Factor for ESBWR Containment – Part 3," Revision 2, which was submitted to the NRC via GEH letter MFN 07-466, Supplement 1, dated March 31, 2008. The RPV does not become acidic until very late into the event: ~29 days for the "low pressure" bottom drain line break (AS-1) and ~28 days for the "high pressure" bottom drain line break (AS-2). The RPV does not become acidic for the loss of feedwater/loss of preferred power event (AS-3).

Natural deposition of elemental iodine is credited in determining the dose consequences from a LOCA. NEDE-33279P, "ESBWR Containment Fission Product Removal Evaluation Model," Revision 1 assumed a plate-out coefficient of 0.86 hr^{-1} based on the

ESBWR containment design. The removal coefficient was determined based on guidance obtained from NUREG-0800, *US NRC Standard Review Plan*, Section 6.5.2, "Containment Spray as a Fission Product Cleanup System."

The GEH review of the re-evolution of iodine in the RPV evaluated the impact of crediting deposition of the elemental iodine after it re-evolves. The report demonstrates that if natural deposition is credited, there is not a significant increase in the airborne iodine as the re-evolution rate is approximately equal to the plate-out from natural deposition. There would be a negligible impact to the calculated doses if a rigorous model was developed, due not only to natural deposition but also to the timing when the RPV is considered to go acidic (i.e., $\text{pH} < 7$). Essentially all iodine that could potentially re-evolve would either plate out in containment, or be held up in containment as containment integrity is assumed for the entire 30-day duration. Also, the Reactor Building or the main condenser would hold up the bulk of the iodine that is released from the containment. Finally, since re-evolution from the RPV occurs late in the event, the bulk of the iodine has decayed, thus significantly reducing the overall source term available for release. As such, any additional dose from re-evolution is within the conservatisms currently in the analysis, such as conservatively neglecting the decay time during the coolant release phase, and not crediting removal of airborne particulates after 24 hours, etc. Therefore, no changes to the design basis LOCA dose calculation are warranted as a result of this RAI.

DCD Impact:

No DCD changes will be made in response to this RAI.

NRC RAI 15.4-41:

MFN 07-466, dated August 24, 2007:

Of all the pH scenarios reviewed, which is the bounding scenario, and the most conservative, and why?

GEH Response:

VTT-R-006671-07, "Estimation and Modeling of Effective Fission Product Decontamination Factor for ESBWR Containment – Part 3," Revision 2, which was submitted to the NRC via MFN 07-466, Supplement 1 dated March 31, 2008 documents the pH dose analysis that GEH considers the licensing basis for the ESBWR pH calculations. GEH will conservatively credit only 50% of CsOH available following assumed reaction with iodine in the licensing basis pH evaluations for the ESBWR, rather than the 100% assumed in the previous analyses. Revision 2 of this report contains cases assuming 50% CsOH, which will be used as the licensing basis for the ESBWR (See GEH response to RAI 15.4-39 submitted to the NRC via letter MFN 08-315, dated April 11, 2008).

The summary for the results of the pH analyses is found in Table II of the VTT "Part 3" Revision 2 report:

- **Reactor Pressure Vessel (RPV):** Review of the results indicates that the RPV could become acidic late in the event for Accident Scenario (AS) AS-1 [low-pressure bottom drain line break] (29.34 days) and AS-2 [high-pressure bottom drain line break] (27.92 days). Calculations indicate that the pH remains > 7 for AS-3 [loss of feedwater/loss of AC power] in the RPV. Although AS-2 becomes acidic 1 day earlier than AS-1, the dose consequences for either case are negligible and there is no significant difference.
- **Lower Drywell (LDW):** Calculations indicate that the lower drywell could become acidic for all three scenarios. Calculations indicate that the LDW could become acidic around 25 days for AS-1 and around 24 days for AS-2; however, for AS-3, it could become acidic as early as 8.62 days. Figure 27 shows roughly 3.8 kg of CsI in the LDW pool after 8 days. While this is not an insignificant amount, the dose consequences from this contributor would not cause AS-3 to become the bounding scenario. The dose consequences from re-evolution will be included in Revision 2 of the Licensing Topical Report (LTR) NEDE-33279P, "ESBWR Containment Fission Product Removal Evaluation Model".
- **Gravity Driven Cooling System (GDSCS) Pool:** The GDSCS pool could become acidic between 8 to 12 hours following the break. At this time in the accident scenario, the pool volume is essentially depleted as the GDSCS has injected into the RPV; this is discussed in Section 4.1.2.3 of NEDE-33279P. Further, there is only a small amount of iodine in the pool (see Figures 5, 16 and 27 of the VTT Part 3 report for AS-1, AS-2 and AS-3, respectively), and the airspace is relatively isolated; therefore, bulk movement of air would not be expected. There

is little difference in the three accident scenarios with respect to GDCS pool pH analyses.

- **Wetwell:** Calculations determined that the wetwell pH remains > 7 for the duration of the event.

Although calculations indicate that the RPV could become acidic late in the event (~28 days), the dose consequences have been evaluated and determined to be negligible due to late release timing, and hold-up and plateout in containment subsequent to re-evolution (as discussed in GEH response to RAI 15.4-29).

Based on timing and iodine source mass-at-risk considerations, AS-3 is bounding with respect to pH analyses. In AS-3, the lower drywell becomes acidic ~8 days into the event. The dose consequences would not necessarily be negligible; however, they are not sufficient to cause AS-3 to become the bounding dose scenario. Re-evolution from the LDW will be included in the dose consequences for AS-3 in NEDE-33279P, Revision 2.

DCD Impact:

No DCD changes will be made in response to this RAI.

NEDE-33279P, "ESBWR Containment Fission Product Removal Evaluation Model," Revision 2 will include the dose consequences for the re-evolution of iodine in the LDW for AS-3 as discussed above. Anticipated submittal date to the NRC is June 30, 2008.

Enclosure 3

MFN 08-373

**Iodine Re-Volatilization from the Reactor Pressure Vessel
During Late-Stage ESBWR LOCA**

Non-Proprietary Version

Iodine Re-Volatilization from the Reactor Pressure Vessel During Late-Stage ESBWR LOCA

Executive Summary

This report is in response to NRC RAI 15.4-29, providing an analysis of iodine re-volatilization from the ESBWR RPV liquid pool at low pH, and subsequent transport of molecular iodine in containment.

Iodine present in the water pool covering damaged fuel within the reactor pressure vessel in the course of a design-basis loss-of-coolant accident is expected to remain in the ionic form so long as the aqueous solution remains alkaline. In certain accident scenarios and under certain conditions, the RPV liquid pool may become acidic. Under acidic conditions there is a pH-dependent equilibrium between volatile molecular I_2 and ionic iodine that drives evolution of I_2 from the pressure vessel into the containment volume. This report analyzes two accident scenarios, each under conditions of 25% and 50% utilization of CsOH. Accident scenario 1 (AS-1, low pressure) is defined as: *bottom drain line break with Automatic Depressurization System (ADS)*. Accident scenario 2 (AS-2, high pressure) is defined as: *bottom drain line break without ADS*. Based on VTT Report 3, Rev 2 [Ref. 2], in these scenarios, the liquid pool in the RPV remains basic until, at times ranging from 650 to 704 hours post-loss of coolant accident (LOCA), there is an abrupt change to a pH of 4. Resulting iodine inventories have been tracked in the reactor vessel, the containment volume, and in leakage from the containment to the reactor building and to the turbine building via MSIV leakage for times extending to 720 hours post accident. As expected, the effect of plateout on containment surfaces, whether credited or not, is observed to be a key consideration in the assessment of iodine releases to reactor and turbine buildings.

Examples of the results of this study are as follows: For AS-2 (high pressure) with 50% CsOH utilization, the reactor pressure vessel (RPV) water volume contains 1 kg of iodine, equivalent to about 2 kg of CsI, when, at 670 hours post LOCA, the pool pH abruptly changes from alkaline to acidic conditions, at pH = 4 [Ref. 2]. By 30 days post LOCA, with no design margin applied in calculations and with plateout credited, 0.0643 kg of iodine, in molecular form, has been re-volatilized, of which 0.0629 kg has plated on containment surfaces, 1.52×10^{-5} kg of iodine has been transferred by leakage to the reactor building, and 3.80×10^{-5} kg has been removed from containment via MSIV leakage. Residual inventories in the RPV and in the containment atmosphere are 0.936 and 0.00141 kg.

Introduction

In NRC review of the ESBWR DCD and supporting documentation, NRC requested in RAI 15.4-29 the following: "Explain the iodine transport phenomena in the containment and perform a rate analysis of steady state iodine transport within the containment including iodine re-volatilization (iodine production) from the melted fuel in the intact pressure vessel and iodine removal by the PCCS condensers (iodine sink)." This report addresses the evolution of iodine in the volatile I_2 form in the event of a change in pH of the water pool in the reactor pressure vessel (RPV) from alkaline to acidic conditions in the course of a LOCA.

The accident scenarios chosen for analysis are the *bottom drain line break with ADS (low pressure) and without ADS (high pressure).* These Accident Scenarios 1 and 2 are examined thoroughly in Refs. [1] and [2], which report work of the Technical Research Center of Finland. The early-stage scenario for AS-2 may be summarized as follows: The Bottom Drain Line Break without ADS and initially degraded core cooling (Accident Scenario 2) leads to lowest airborne concentration of CsI aerosol in the containment. The fission product release from the fuel and from the RPV begins at about 1540 s into the accident. The release of fission products takes place mostly into the Suppression Pool via Safety Relief Valves operating in the pressure relief mode. The key removal processes of the fission product aerosols are the pool scrubbing and the deposition by gravitation. This is the only scenario where the Lower Head of the RPV dries out, resulting in a fission product leak path also to the Lower Drywell gas space. The fission product release is terminated by recovery of ADS and restoration of sufficient core cooling early in the accident. The fission product retention in the RPV is highest in this scenario.

The late-stage LOCA scenarios are described in Part 3 of the VTT study, Ref. [2]. In these scenarios, the liquid pool in the RPV remains basic until, at times ranging from 650 to 704 hours post LOCA, there is an abrupt change to pH as low as 4.

Review of Late-Stage Accident Scenarios

Results of the Part 3 VTT report, Ref. [2], relevant to the re-volatilization issue are illustrated in the following four figures:

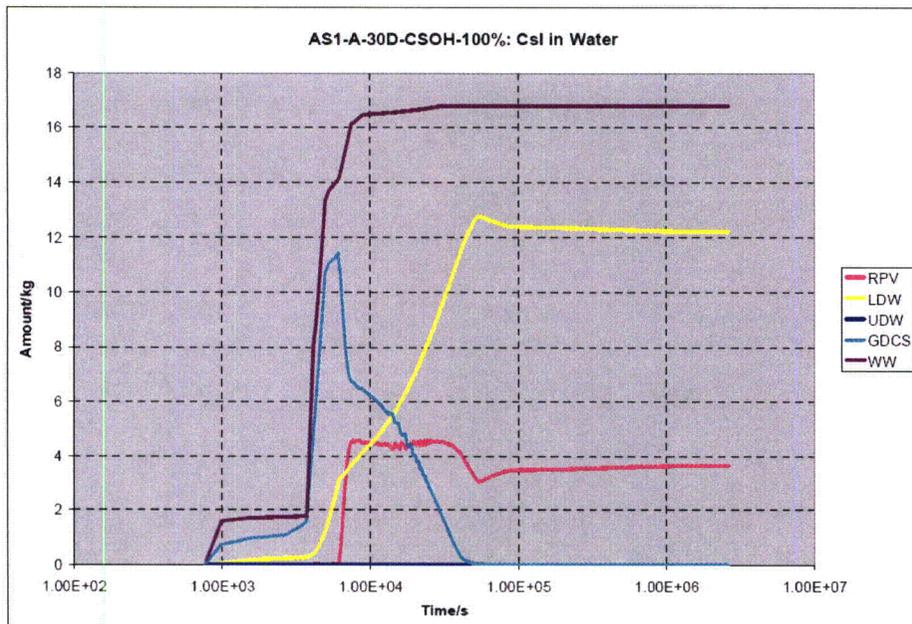


Fig. 1. Calculated CsI Amounts in Pools in Low-pressure Scenario AS-1 as a Function of Time. Source: Fig. 5 of Ref [2].

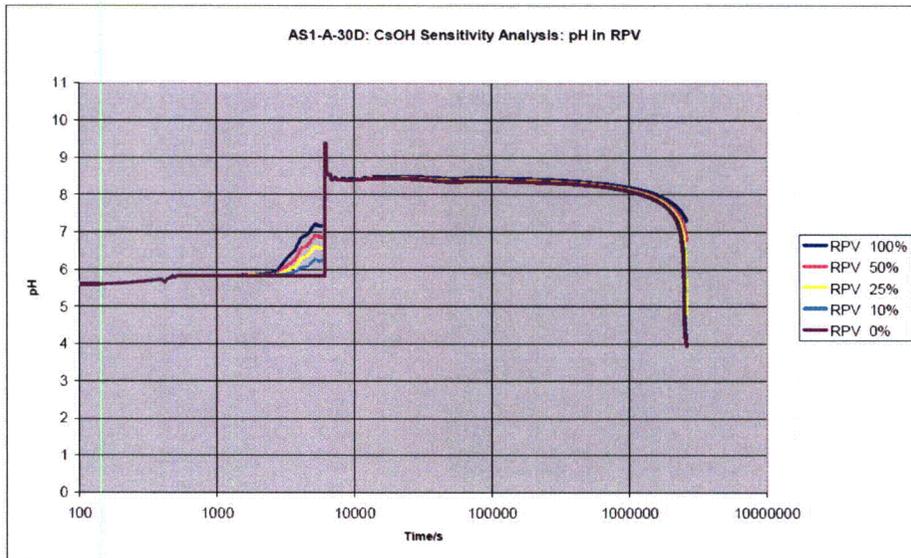


Fig. 2. pH in RPV in Low-pressure Accident Scenario AS-1 with Scaled Amounts of CsOH as a Function of Post-LOCA Time. Source: Fig. 8 of Ref. [2].

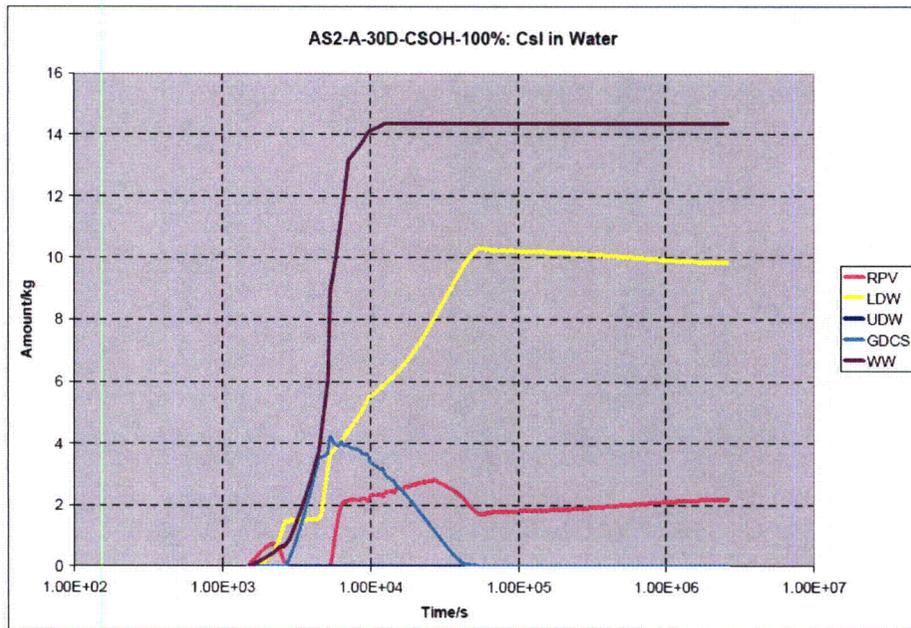


Fig. 3. Calculated CsI Amounts in Pools in High-pressure Scenario AS-2 as a Function of Time. Source: Fig. 16 of Ref [2].

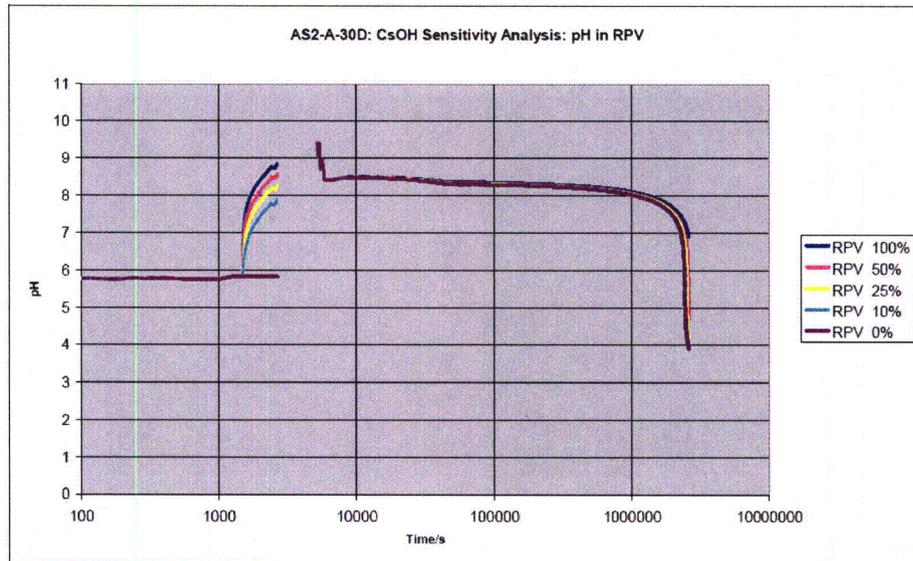


Fig. 4. pH in RPV in High-pressure Accident Scenario AS-2 with Scaled Amounts of CsOH as a Function of Post-LOCA Time. Source: Fig. 19 of Ref. [2].

Problem Formulation

Figures 1 and 3 show that iodine content in the RPV changes very little in the late stage of the LOCA. For AS-1, the CsI mass in the RPV is approximately 3.6 kg. This corresponds to an iodine mass of about 1.8 kg. For AS-2, the corresponding masses are 2 kg of CsI or about 1 kg of iodine. Figures 2 and 4 show that pH in the RPV remains above 7 until, for 25% and 50% CsOH utilization, 650 to 704 hours post LOCA, at which time the pH abruptly falls as low as 4. This relative static stage of a LOCA lends itself into a mass-balance rate analysis aimed at an assessment of the potential consequences of (1) acidic conditions in the RPV pool, and (2) molecular iodine plateout in containment.

The analysis is based on specification of the following parameters: liquid mass in the RPV pool is assumed to remain constant; water vapor evolved from the RPV is assumed to be exactly replaced by condensate return flow from the GDCS pool; and the pool pH is assumed to remain constant after a sudden change from alkaline conditions. Material-balance rate equations then describe first the rate of evolution of molecular I_2 from the RPV, and thus the variation of iodine concentration in the RPV pool, and then the inventories of airborne and plated-out I_2 in the containment open volume.

Molecular iodine attributable to re-evolution and released from the containment may be derived from the results of this calculation. As described below, the approximation is made that, as water is vaporized in the RPV, the ratio of mole fractions I_2 to H_2O in the vapor phase is governed by the relative volatility of iodine to H_2O . Radioactive decay is not taken into account in this analysis.

Notation:

P	decay heat thermal power (J/s)
L	latent heat of vaporization of water (J/kg)
M	mass of water in RPV (kg)
m_c	mass of I_2 in containment atmosphere (kg)
m_r	mass of total iodine in RPV water pool (kg)
λ_b	rate constant for I_2 boiling evolution from RPV to containment (s^{-1})
λ_p	rate constant for I_2 elimination by plateout inside containment (s^{-1})
λ_{rb}	rate constant for I_2 release via leakage from containment (s^{-1})
λ_{ms}	rate constant for I_2 release via MSIV leakage (s^{-1})
λ_{tot}	$\lambda_{ms} + \lambda_p + \lambda_{rb}$ = total rate constant for removal from containment
F	release factor, ratio of I_2 mass to total iodine mass in RPV pool
α	relative volatility (vapor pressure of iodine relative to water)
ρ	water density (kg/m^3)

Material Balance

[[

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Problem Parameters, Assumptions and Approximations

Decay heat rate, P: Decay heat rates for the ESBWR are based on Ref. [3] with added two-sigma uncertainty. Fractions of full thermal power vs. time post LOCA are approximated to a simple equation, namely:

$$\text{fraction} \approx a + bt^c$$

in which t is the post-LOCA time and a , b , and c are constants. For time expressed in seconds, values of the constants are: $a = -0.001563456$, $b = 0.01687668$, and $c = -0.251071596$. Based on 4590 MW full power, decay heat rates at 24, 360, and 720 hours post LOCA are 27703, 10496, and 7673 kW. Based, for example, on latent heat of 2210 kJ/kg, steaming rates are 12.54, 4.74, and 3.47 kg/s. According to Ref. [2], Fig. 12, the steaming rate, assumed constant 1 to 30 days post LOCA, for AS-2 is 11.14 kg/s.

Latent heat of vaporization, L: This parameter is based on long-term conditions in the RPV for AS-2 as tabulated in Appendix D of Ref. [2], namely, a temperature of 164°C. From Ref. [4], the corresponding saturation pressure is 0.683 MPa, and the latent heat of vaporization is 2069 kJ/kg.

RPV pool mass and physical properties: From Ref. [2], the average masses M of water in the RPV are 399, 270 kg for AS-1 and 422,545 kg for AS-2.

Containment plateout removal rate constant for I_2 , λ_p : Based on Ref. [5], adjusted for drywell volume of $2.54 \times 10^5 \text{ ft}^3$, this containment plateout removal rate constant value is taken to be $0.86 \text{ h}^{-1} = 0.000239 \text{ s}^{-1}$.

Leakage to reactor building removal rate constant for I_2 , λ_{rb} : Based on Refs. [5] and [6], this removal rate constant value is taken conservatively to be 0.5% per day, i.e., $\lambda_{rb} = 5.787 \times 10^{-8} \text{ s}^{-1}$.

Leakage via MSIV removal rate constant for I_2 , λ_{ms} : Based on Ref. [5], the leakage volumetric rate is taken to be 2.2 cfm and the containment open volume to be 2.54×10^5 cubic feet. Thus, $\lambda_{ms} = 2.2 / 2.54 \times 10^5 = 8.661 \times 10^{-6} \text{ m}^{-1} = 1.444 \times 10^{-7} \text{ s}^{-1}$.

Initial masses of iodine in RPV, $m_r(0)$: From Figs 1 and 3, the iodine content in the RPV, expressed as Csl, is about 3.6 kg (AS-1) and 2.0 kg (AS-2) late in the 30-day post-LOCA period. Based on atomic weights of 126 for iodine and 133 for Cs (approximately equal), the masses of iodine are about 1.8 and 1.0 kg for AS-1 and AS-2. The pre-accident core inventory of iodine is 37.27 kg [Ref. 1, Table 14].

Release factor, mass fraction of aqueous iodine in molecular form, F: This factor is based on data from Ref. [8] and is described in Appendix B. Calculations are performed using Eq. 5-3 of Ref. [9], which was derived using Ref. [8] methodology. The release factor is a function of pH and the total aqueous iodine concentration $[I]_{aq}$ in units of gram-atoms per liter, i.e., $[1000m_r / 126.9] / [1000M / \rho] = (m_r \rho / 126.9M)$.

Relative volatility, α : This factor, a function of temperature, is the ratio of the vapor pressure of iodine relative to water. Iodine vapor pressure is taken from Ref. [10], p. 3-47, and water vapor pressure from Ref. [4]. For temperatures from 350 to 450°K, the factor is well fit by the equation

$$\alpha = (a + bT + cT^2 + dT^3)^{-1}$$

Where: $a = 2086.606826$, $b = -14.58801121$, $c = 0.034227454$, $d = -2.67986E-05$, and temperature T is in °K.

Mass fraction iodine in RPV vapor effluent: This determination is based on the treatment of binary pool boiling of binary mixtures, as described by Collier and Thome, Ref. [11]. With the assumption of ideal behavior, i.e., behavior following Raoult's law, the ratio of mole or mass fractions of iodine to water in the vapor phase to the ratio in the liquid phase is given by:

$$\frac{[I_2]_{vap}}{[H_2O]_{vap}} = \alpha \frac{[I_2]_{liq}}{[H_2O]_{liq}},$$

where the relative volatility α is previously defined.

Conservatism in Calculations

The principal uncertainty in these calculations is the relationship between the liquid-phase iodine concentration in the boiling RPV pool and the vapor-phase concentration in the effluent reaching the containment space. In the calculations reported herein, a reference case is based on the treatment of pool boiling of binary mixtures, as described by Collier and Thome, Ref. [11]. With the assumption of ideal behavior, i.e., behavior following Raoult's law, the ratio of mole or mass fractions of iodine to water in the vapor phase to the ratio in the liquid phase is given by:

$$\frac{[I_2]_{vap}}{[H_2O]_{vap}} = \alpha \frac{[I_2]_{liq}}{[H_2O]_{liq}},$$

Where: α is the relative volatility (ratio of vapor pressures) of iodine with respect to water. This approach is supported in Ref. [10], p. 4-65, as a useful approximation for solutions approaching ideal behavior (components of similar molecular size and chemical nature). This reference case is identified in the results as "no margin." There are significant uncertainties in this approach due to possible non-ideal behavior of the iodine-water mixture and due to the possibility of droplet entrainment and evaporation. Actual relative volatility is on the order of 0.1. To account for non-idealities and other uncertainties, a substantial design margin of 5 is applied in evaluating the vapor phase mass fraction of iodine. Results are reported with and without design margin and it is believed that this very substantial margin encompasses any other uncertainties in the calculations or approximations.

Results of Calculations

Table 1 lists results of calculations for the two accident scenarios, for two cases of CsOH utilization, and for crediting or not crediting plateout on containment surfaces. The table also distinguishes between applying or not applying a design margin to the relationship between mass fraction of iodine in the RPV boiling liquid and in the steam evolved.

The table clearly demonstrates how important plateout is in determining iodine release from containment by MSIV leakage or leakage to the reactor building. This is true under all cases examined. With 50% CsOH utilization, scenario AS-2 (high pressure) leads to the greatest iodine release from containment, largely because of the pool becoming acidic earlier. With 25% CsOH utilization, scenario AS-1 (low pressure) leads to the greatest iodine release when plateout is credited, but AS-2 leads to slightly greater iodine release when plateout is not credited. However, in terms of the fraction of the RPV inventory present at pH change, scenario AS-2 leads to greater release fraction in all scenarios. Tables 3 and 4 are provided to facilitate radiological assessment calculations. In these tables, results are presented in terms of fractions of the pre-accident core inventory of iodine re-evolved from the RPV during specific post-LOCA time intervals.

Table 1. Iodine Re-evolution from the ESBWR Reactor Pressure Vessel from the Time of Pool Change to pH = 4 Until 720 hours post LOCA.
Case 1: No margin on iodine/water relative volatility.

Accident Scenario	Iodine in RPV at pH change (kg)	CsOH utilization (%)	Time post LOCA of pH change (h)	Plateout credited	Residual total iodine (kg)		Cumulative transfer to reactor building (kg)	Cumulative plateout in containment (kg)	Cumulative loss via MSIV leakage (kg)
					RPV	Containment			
1	1.8	50	704	yes	1.75	3.45E-03	1.09E-05	4.50E-02	2.72E-05
				no	1.75	4.82E-02	8.04E-05	0	2.01E-04
				yes	1.67	3.24E-03	3.15E-05	1.30E-01	7.86E-05
				no	1.67	1.31E-01	6.29E-04	0	1.57E-03
2	1	50	670	yes	0.936	1.41E-03	1.52E-05	6.29E-02	3.80E-05
				no	0.936	6.31E-02	3.36E-04	0	8.40E-04
				yes	0.911	1.36E-03	2.12E-05	8.76E-02	5.29E-05
				no	0.911	8.67E-02	6.55E-04	0	1.63E-03

Table 2. Iodine re-evolution from the ESBWR reactor pressure vessel from the time of pool change to pH = 4 until 720 hours post LOCA.
Case 2: Factor of 5 margin on iodine/water relative volatility.

Accident Scenario	Iodine in RPV at pH change (kg)	CsOH utilization (%)	Time post LOCA of pH change (h)	Plateout credited	Residual total iodine (kg)		Cumulative transfer to reactor building (kg)	Cumulative plateout in containment (kg)	Cumulative loss via MSIV leakage (kg)
					RPV	Containment			
1	1.8	50	704	yes	1.57	1.52E-02	5.12E-05	2.12E-01	1.28E-04
				no	1.57	2.26E-01	3.85E-04	0	9.60E-04
				yes	1.24	1.12E-02	1.32E-04	5.45E-01	3.29E-04
				no	1.24	5.47E-01	2.79E-03	0	6.95E-03
2	1	50	670	yes	0.728	5.02E-03	6.46E-05	2.67E-01	1.61E-04
				no	0.728	2.67E-01	1.50E-03	0	3.75E-03
				yes	0.646	4.24E-03	8.46E-05	3.49E-01	2.11E-04
				no	0.646	3.44E-01	2.80E-03	0	6.99E-03

Table 3. Iodine released from RPV and removed from containment by plateout and leakage, expressed as a fraction of the pre-accident core inventory of 37.27 kg of iodine, and computed for selected post-LOCA time intervals, for two scenarios, and for two levels of CsOH utilization.

Case 1: No margin on iodine/water relative volatility.

Accident Scenario	Iodine in RPV at pH change (kg)	CsOH utilization (%)	Time post LOCA of pH change (h)	Post-LOCA time interval (h)	Plateout credited	Fraction released from RPV	Fraction removed by leakage to reactor building	Fraction removed by plateout in containment	Fraction removed via MSIV leakage	
1	1.8	50	704	704-720	yes	1.30E-03	2.93E-07	1.21E-03	7.30E-07	
					no	1.30E-03	2.16E-06	0	5.38E-06	
					yes	1.97E-03	4.53E-07	1.87E-03	1.13E-06	
			25	675		no	1.97E-03	4.91E-06	0	1.23E-05
					yes	1.62E-03	3.92E-07	1.62E-03	9.78E-07	
					no	1.62E-03	1.20E-05	0	2.99E-05	
2	1	50	670	670-694	yes	8.55E-04	1.97E-07	8.14E-04	4.92E-07	
					no	8.55E-04	2.13E-06	0	5.32E-06	
					yes	8.06E-04	1.96E-07	8.08E-04	4.88E-07	
					no	8.06E-04	6.21E-06	0	1.55E-05	
					yes	6.51E-05	1.58E-08	6.52E-05	3.94E-08	
					no	6.51E-05	6.92E-07	0	1.73E-06	
			25	650	650-674	yes	8.66E-04	2.00E-07	8.24E-04	4.98E-07
					no	8.66E-04	2.16E-06	0	5.39E-06	
					yes	8.16E-04	1.98E-07	8.17E-04	4.94E-07	
					no	8.16E-04	6.28E-06	0	1.57E-05	
					yes	7.07E-04	1.72E-07	7.09E-04	4.28E-07	
					no	7.07E-04	9.12E-06	0	2.28E-05	

Table 4. Iodine released from RPV and removed from containment by plateout and leakage, expressed as a fraction of the pre-accident core inventory of 37.27 kg of iodine, and computed for selected post-LOCA time intervals, for two scenarios, and for two levels of CsOH utilization.

Case 2: Factor of 5 margin on iodine/water relative volatility.

Accident Scenario	Iodine in RPV at pH change (kg)	CsOH utilization (%)	Time post LOCA of pH change (h)	Post-LOCA time interval (h)	Plateout credited	Fraction released from RPV	Fraction removed by leakage to reactor building	Fraction removed by plateout in containment	Fraction removed via MSIV leakage		
1	1.8	50	704	704-720	yes	6.09E-03	1.37E-06	5.68E-03	3.43E-06		
					no	6.09E-03	1.03E-05	0	2.58E-05		
			25	675	675-699	yes	8.89E-03	2.06E-06	8.50E-03	5.14E-06	
						no	8.89E-03	2.30E-05	0	5.73E-05	
						699-720	yes	6.04E-03	1.48E-06	6.12E-03	3.69E-06
							no	6.04E-03	5.18E-05	0	1.29E-04
2	1	50	670	670-694	yes	3.93E-03	9.09E-07	3.75E-03	2.27E-06		
					no	3.93E-03	1.01E-05	0	2.51E-05		
					694-718	yes	3.14E-03	7.67E-07	3.17E-03	1.91E-06	
						no	3.14E-03	2.73E-05	0	6.81E-05	
					718-720	yes	2.32E-04	5.67E-08	2.34E-04	1.41E-07	
						no	2.32E-04	2.93E-06	0	7.31E-06	
			25	650	650-674	yes	3.97E-03	9.20E-07	3.80E-03	2.30E-06	
						no	3.97E-03	1.02E-05	0	2.54E-05	
						674-698	yes	3.16E-03	7.74E-07	3.19E-03	1.93E-06
							no	3.16E-03	2.76E-05	0	6.89E-05
						698-720	yes	2.35E-03	5.76E-07	2.38E-03	1.44E-06
							no	2.35E-03	3.73E-05	0	9.32E-05

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4. Haar, L., J.S. Gallagher, and G.S. Kell, "NBS/NRC Steam Tables: Thermodynamic and Transport Properties and Computer Programs for Vapor and Liquid States of Water in SI Units," Hemisphere Publishing Co., 1984.
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8. ORNL/TM-12242, NUREG/CR-5950, "Iodine Evolution and pH Control," by E.C. Beahm, R.A. Lorenz, and C.F. Weber, 1992.
9. GGNS-98-0039, Rev 3, "Entergy Operations Engineering Report for Suppression Pool pH and Iodine Re-evolution Methodology." [Available from the NRC Public Document Room.]
10. Chemical Engineers' Handbook, 5th ed., R.H. Perry & C. Chilton, eds, McGraw-Hill, NY 1973 (p. 3-47).
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Appendix A

Solution of Material Balance Equations

Governing Equations

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Appendix B

Effect of pH on Iodine Evolution from Aqueous Systems

The effect of pH on the equilibrium between molecular iodine, I_2 , and ionic I^- is taken up in Refs. [7] and [8]. Both state that, at $pH < 3$, virtually all iodine is in the I_2 form. For $pH > 7$, only a tiny fraction is in the I_2 form. Figure 3, from Ref. [8], shows how the equilibrium shifts as the molarity of I_2 varies. It shows that, as iodine is depleted from a solution, the equilibrium shifts, favoring the ionic form.

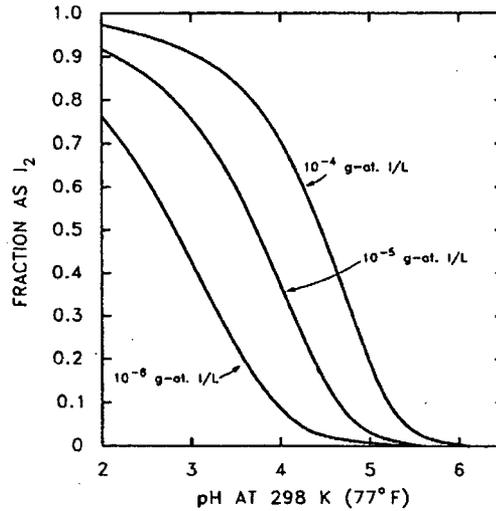


Figure 3. Release factor F (mass fraction of total iodine present as molecular iodine) as a function of pH and iodine molar concentration. Source: Ref. [8].

This factor is based on data from Ref. [8]. Reference [9] uses the methods of Ref. [8] to derive a working equation for computing the release factor, which is defined as the fraction of the mass of iodine in the RPV pool present in the form of molecular iodine:

$$F = 1 + \frac{d + e \times 10^{-pH}}{4[I]_{aq} \times 10^{-2pH}} - \frac{1}{4 \times 10^{-pH} [I]_{aq}} \sqrt{\frac{(d + e \times 10^{-pH})^2}{10^{-2pH}} + 8[I]_{aq} (d + e \times 10^{-pH})}, \quad (B1)$$

Where: $d = 4.22E-14$ and $e = 1.47E-09$. The quantity $[I]_{aq}$ is the total iodine concentration in the RPV pool, in units of g-atoms/liter, namely, $m_r \rho / 126.9M$.

Enclosure 4

MFN 08-373

**Affidavit for GE-Hitachi Nuclear Energy Americas LLC
Proprietary Information for the NRC**

Executed by Larry J. Tucker, May 16, 2008

GE-Hitachi Nuclear Energy Americas LLC

AFFIDAVIT

I, **Larry J. Tucker**, state as follows:

- (1) I am Manager, ESBWR Engineering, GE-Hitachi Nuclear Energy Americas LLC ("GEH"), have been delegated the function of reviewing the information described in paragraph (2) which is sought to be withheld, and have been authorized to apply for its withholding.
- (2) The information to be discussed and sought to be withheld is delineated in the letter from Mr. James C. Kinsey to U.S. Nuclear Regulatory Commission, entitled "Response to Portion of NRC Request for Additional Information Letter Nos. 90 and 142 Related to the ESBWR Design Certification, Safety Analyses, RAI Numbers 15.4-29 and 15.4-41," dated May 16, 2008. The information in Enclosure 2, which is entitled *MFN 08-373 Iodine Re-Volatilization from the Reactor Pressure Vessel During Late-Stage ESBWR LOC – GEH Proprietary Information*, contains proprietary information, and is identified by [[dotted underline inside double square brackets^{3}]]. Figures and other large objects are identified with double square brackets before and after the object. In each case, the superscript notation ^{3} refers to Paragraph (3) of this affidavit, which provides the basis for the proprietary determination.
- (3) In making this application for withholding of proprietary information of which it is the owner or licensee, GEH relies upon the exemption from disclosure set forth in the Freedom of Information Act ("FOIA"), 5 USC Sec. 552(b)(4), and the Trade Secrets Act, 18 USC Sec. 1905, and NRC regulations 10 CFR 9.17(a)(4), and 2.390(a)(4) for "trade secrets" (Exemption 4). The material for which exemption from disclosure is here sought also qualify under the narrower definition of "trade secret", within the meanings assigned to those terms for purposes of FOIA Exemption 4 in, respectively, Critical Mass Energy Project v. Nuclear Regulatory Commission, 975F2d871 (DC Cir. 1992), and Public Citizen Health Research Group v. FDA, 704F2d1280 (DC Cir. 1983).
- (4) Some examples of categories of information which fit into the definition of proprietary information are:
 - a. Information that discloses a process, method, or apparatus, including supporting data and analyses, where prevention of its use by GEH's competitors without license from GEH constitutes a competitive economic advantage over other companies;
 - b. Information which, if used by a competitor, would reduce his expenditure of resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing of a similar product;

- c. Information which reveals aspects of past, present, or future GEH customer-funded development plans and programs, resulting in potential products to GEH;
- d. Information which discloses patentable subject matter for which it may be desirable to obtain patent protection.

The information sought to be withheld is considered to be proprietary for the reasons set forth in paragraphs (4)a. and (4)b. above.

- (5) To address 10 CFR 2.390(b)(4), the information sought to be withheld is being submitted to NRC in confidence. The information is of a sort customarily held in confidence by GEH, and is in fact so held. The information sought to be withheld has, to the best of my knowledge and belief, consistently been held in confidence by GEH, no public disclosure has been made, and it is not available in public sources. All disclosures to third parties, including any required transmittals to NRC, have been made, or must be made, pursuant to regulatory provisions or proprietary agreements which provide for maintenance of the information in confidence. Its initial designation as proprietary information, and the subsequent steps taken to prevent its unauthorized disclosure, are as set forth in paragraphs (6) and (7) following.
- (6) Initial approval of proprietary treatment of a document is made by the manager of the originating component, the person most likely to be acquainted with the value and sensitivity of the information in relation to industry knowledge, or subject to the terms under which it was licensed to GEH. Access to such documents within GEH is limited on a "need to know" basis.
- (7) The procedure for approval of external release of such a document typically requires review by the staff manager, project manager, principal scientist, or other equivalent authority for technical content, competitive effect, and determination of the accuracy of the proprietary designation. Disclosures outside GEH are limited to regulatory bodies, customers, and potential customers, and their agents, suppliers, and licensees, and others with a legitimate need for the information, and then only in accordance with appropriate regulatory provisions or proprietary agreements.
- (8) The information identified in paragraph (2) above is classified as proprietary because it contains dose assessment calculation inputs developed by GEH for analyzed accident scenarios. Development of this dose assessment calculation inputs was achieved at a significant cost to GEH, on the order of fifty thousand dollars.
- (9) Public disclosure of the information sought to be withheld is likely to cause substantial harm to GEH's competitive position and foreclose or reduce the availability of profit-making opportunities. The information is part of GEH's comprehensive BWR safety and technology base, and its commercial value extends beyond the original development cost. The value of the technology base goes beyond the extensive physical database and analytical methodology and

includes development of the expertise to determine and apply the appropriate evaluation process. In addition, the technology base includes the value derived from providing analyses done with NRC-approved methods.

The research, development, engineering, analytical and NRC review costs comprise a substantial investment of time and money by GEH.

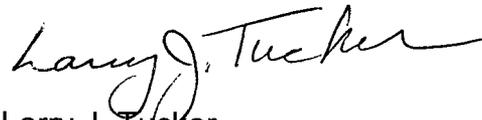
The precise value of the expertise to devise an evaluation process and apply the correct analytical methodology is difficult to quantify, but it clearly is substantial.

GEH's competitive advantage will be lost if its competitors are able to use the results of the GEH experience to normalize or verify their own process or if they are able to claim an equivalent understanding by demonstrating that they can arrive at the same or similar conclusions.

The value of this information to GEH would be lost if the information were disclosed to the public. Making such information available to competitors without their having been required to undertake a similar expenditure of resources would unfairly provide competitors with a windfall, and deprive GEH of the opportunity to exercise its competitive advantage to seek an adequate return on its large investment in developing and obtaining these very valuable analytical tools.

I declare under penalty of perjury that the foregoing affidavit and the matters stated therein are true and correct to the best of my knowledge, information, and belief.

Executed on this 16th day of May 2008.



Larry J. Tucker
GE-Hitachi Nuclear Energy Americas LLC