

# Dependence of the Corrosive Environment in BWRs on Operating Conditions

Yoichi Wada, Kazushige Ishida,  
Nobuyuki Ota, and Makoto Nagase

## ABSTRACT

The effects of core management in a boiling water reactor (BWR) on radiolytic oxygen and hydrogen peroxide concentrations in the reactor water have been studied based on a radiolysis model. An increase in core flow promoted radiolysis of water in the core region since the amount of water present in the core region became larger and mass transfer from water to steam slowed down. Also, a decrease in core peripheral power at the end of the cycle reduced the effectiveness of hydrogen water chemistry (HWC) applied to reduce radiolytic oxygen and hydrogen peroxide and the subsequent electrochemical corrosion potential for mitigation of stress corrosion cracking since the downcomer dose rate became weaker with operation. These caused an increase in the sum of the oxygen and hydrogen peroxide concentrations at the same hydrogen injection rates and the effectiveness of HWC decreased. The effectiveness of noble metal chemical addition was not affected by changes in operating conditions at a  $0.5 \text{ mg} \cdot \text{kg}^{-1}$  hydrogen injection rate.

## NOMENCLATURE AND ABBREVIATIONS

BOC	beginning of cycle
BWR	boiling water reactor
ECP	electrochemical corrosion potential
EOC	end of cycle
FW	feedwater
HWC	hydrogen water chemistry
MS	main steam
Ni-alloys	nickel-based alloys
NMCA	noble metal chemical addition or application
NWC	normal water chemistry
PLR	primary loop recirculation system
SCC	stress corrosion cracking
SHE	standard hydrogen electrode
SIMFONY	Hitachi's radiolysis calculation code
SS	stainless steel
$C_i, C_s$	liquid phase concentrations of species $i$ and $s$
$C_i^g$	gas phase concentrations of species $i$
$\varepsilon, \varepsilon^*$	gas release coefficient and gas absorption coefficient
$F_c$	core flow rate
$F_{FW}$	feedwater flow rate

$F_s$	steam flow rate
$G_i^{\gamma}, G_i^n$	G-values of species $i$ for gamma-rays and neutrons,
$[\text{H}_2\text{O}_2]$	hydrogen peroxide concentration
$h_B$	onset of boiling from the bottom of active fuel
$H_{FW}$	enthalpy of feedwater
$H_{in}$	enthalpy at core inlet
$H_{out}$	enthalpy at core outlet
$k_{lm}$	reaction rate constant of the reaction between chemical species $l$ and $m$
$k_{is}$	reaction rate constant of the reaction between chemical species $i$ and $s$
$L$	fuel length
$N_s$	number of chemical species related to the radiolysis of high purity water
$[\text{O}_2]$	oxygen concentration
$[\text{O}_2]_{\text{eff}}$	effective oxygen concentration
$q$	steam quality
$Q$	total thermal power
$Q^{\gamma}$ and $Q^n$	absorbed energy density of gamma-rays and neutrons
$V_f$	void fraction

## INTRODUCTION

It is accepted that the stress corrosion cracking (SCC) of stainless steels (SSs) and nickel-based alloys (Ni-alloys) used in a boiling water reactor (BWR) occurs and propagates when effects overlap, including degradation of the corrosion resistance of SSs and Ni-alloys, generation of residual stress at welds, and the presence of a corrosive environment (high oxidant concentration, high electrochemical corrosion potential (ECP)) and high caustic impurity concentrations as shown in Figure 1. Then, either hydrogen water chemistry (HWC) or noble metal chemical addition or application (NMCA) is applied to a BWR in order to mitigate the corrosive environment as a countermeasure for SCC worldwide. The core flow rate or power distribution of the core of a BWR is changed during a power operation cycle by core management. Changes in these operating parameters affect the radiolysis of the water which is used as coolant of the core in a BWR and the effectiveness of HWC or NMCA, especially during long-term cycle operation such as 18 months and 24 months. For example, the measured ECP in the primary loop recirculation system (PLR) was found to change with time as operating conditions such as core flow rate and downcomer dose rate were changed by core management [1]. Also, the effects of core power change in a power uprate of a BWR have been studied with a radiolysis model [2,3].

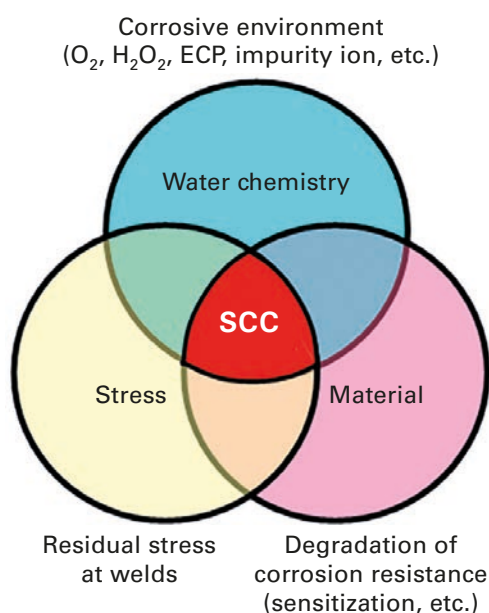


Figure 1:  
Image of SCC occurrence and propagation as a result of overlapping effects including corrosive environment, material, and stress.

Therefore, the objective of this study was to evaluate the influence of core management such as core flow rate or power distribution in the core on the effectiveness of HWC or NMCA with a radiolysis model and an ECP model.

## THEORETICAL

Concentration distributions in a BWR primary cooling circuit were calculated with the radiolysis model "SIMFONY" [4] for chemical species such as  $O_2$ ,  $H_2$ , and  $H_2O_2$ . Plant parameters such as  $\gamma$ -rays and neutron dose rates were used as input conditions. The ECP of SSs at the locations of various components was calculated based upon the mixed potential theory by using the concentrations obtained by SIMFONY, an anodic polarization curve, and plant parameters such as linear flow velocities in each region [5,6]. Here, the main equation for our radiolysis model is shown briefly below. The concentration of a chemical species,  $i$  ( $= O_2, H_2, H_2O_2$ , etc.), with respect to time,  $t$ , in reactor water is given by the following differential in a two-phase flow under irradiation (as an example, only a second order reaction is shown):

$$\frac{dC_i}{dt} = (g_i^\gamma Q^\gamma + g_i^n Q^n) + \sum_l \sum_m^{Ns} k_{lm} C_l C_m - C_i \sum_s^{Ns} k_{is} C_s - \frac{V_f}{1-V_f} (-\varepsilon C_i + \varepsilon^* C_i^g) \quad (1)$$

where,  $C_i$  and  $C_s$  are the liquid phase concentrations of species  $i$  and  $s$  [ $\text{mol} \cdot \text{dm}^{-3}$ ],  $C_i^g$  is the gas phase concentration of species  $i$  [ $\text{mol} \cdot \text{dm}^{-3}$ ],  $G_i^\gamma$  and  $G_i^n$  are the G values of species  $i$  for gamma-rays and neutrons, respectively [ $\text{mol} \cdot \text{J}^{-1}$ ],  $Q^\gamma$  and  $Q^n$  are the absorbed energy density of gamma-rays and neutrons [ $\text{W} \cdot \text{dm}^{-3}$ ],  $N_s$  is the number of chemical species related to the radiolysis of high purity water (in this work it is 12),  $k_{lm}$  is the reaction rate constant of the reaction between chemical species  $l$  and  $m$  [ $\text{mol}^{-1} \cdot \text{dm}^3 \cdot \text{s}^{-1}$  for a second order reaction], and  $k_{is}$  is the reaction rate constant of the reaction between chemical species  $i$  and  $s$  [ $\text{mol}^{-1} \cdot \text{dm}^3 \cdot \text{s}^{-1}$  for a second order reaction].  $V_f$  is the void fraction [–],  $\varepsilon$  is the gas release coefficient [–], and  $\varepsilon^*$  is the gas absorption coefficient [–].

The 1100MWe class BWR type-5 was chosen as an analysis object plant since this is the most common type of BWR in Japan. The design specifications of the 1100MWe class BWR type-5 are shown in Table 1. As analysis conditions, the following conditions and assumptions were employed.

Parameters at rated power	Value
Thermal power	3293 MW
Power density	50 W · cm <sup>-3</sup>
Feedwater flow rate	6.416 × 10 <sup>3</sup> t · h <sup>-1</sup>
Core flow rate	4.830 × 10 <sup>4</sup> t · h <sup>-1</sup>
Steam quality	13 %
Jet pump M ratio	2.3
Feedwater temperature	215.6 °C
Reactor water temperature (core inlet temperature)	278.1 °C (at 100 % core flow)
Core outlet temperature	286.1 °C
Pressure	7.03 MPa
Feedwater enthalpy	924.9 kJ · kg <sup>-1</sup>
Core inlet enthalpy	1226.3 kJ · kg <sup>-1</sup>
Core outlet enthalpy	1269.0 kJ · kg <sup>-1</sup>
Latent heat of vaporization	1503.2 kJ · kg <sup>-1</sup>

Table 1:  
Design specifications of 1100 MW class BWR type-5.

1. Thermal power was constant throughout one operating cycle as constant heat operation.
2. Reactor pressure and core outlet temperature of saturated water were unchanged during operation.
3. Feedwater flow rate ( $\approx$  steam flow rate) was constant throughout one operating cycle.
4. The M-ratio of jet pumps (defined as suctioned flow rate/drive flow rate) was constant although the M-ratio changes slightly because of crud deposition during operation.
5. Axial power distribution in the core was not changed during power operation although this was affected by the control rod pattern and core flow rate during power operation.
6. Gamma-ray dose rate distribution and neutron dose distribution were not changed since power distribution was assumed not to be changed.

Under these assumptions, the core flow rate was changed from 80 % to 120 % at power operation beyond the actual operating range to see how the core flow rate affects water chemistry. Also, the effects of changes in the power distribution due to fuel burnup on the water chemistry were considered assuming that the downcomer dose rate at the end of the cycle (EOC) decreased to 90 % of that at the beginning of the cycle (BOC) since peripheral core power was weaker at the EOC than at the BOC. The degree of weakness of the core peripheral power at the EOC to BOC depends on the design of the BWR and the core history of the plant.

## RESULTS AND DISCUSSIONS

### Effect of Core Flow Rate on Thermal and Flow Conditions

When the core flow rate is changed, thermal and flow conditions in the core of the BWR change. Calculated reactor water temperature (core inlet temperature), onset of boiling from the bottom of active fuel, and the void fraction at the core outlet are shown in Figure 2. Reactor water temperature increased with an increase in the core flow rate because the dilution ratio of colder feedwater to core flow decreased. To obtain reactor water temperature as input for the radiolysis model, the enthalpy of each location needs to be calculated. Enthalpy at the core inlet,  $H_{in}$ , is given as below.

$$H_{in} = \frac{H_{out}(F_C - F_{FW}) - H_{FW}F_{FW}}{F_C} = H_{out} - (H_{out} + H_{FW})q \quad 2)$$

Here,  $H_{out}$  is the enthalpy at the core outlet,  $F_C$  is the core flow rate,  $F_{FW}$  is the feedwater flow rate (= steam flow rate,  $F_S$ ),  $H_{FW}$  is the enthalpy of the feedwater, and  $q$  is the steam quality (=  $F_S/F_C$ ). When the core flow rate,  $F_C$ , increases, the  $q$  becomes smaller because of constant  $F_S$ . Then,  $H_{in}$  becomes larger and the temperature of the reactor water after the feedwater mix with reactor water from the core becomes higher and vice versa.

At the same time, the void fraction at the core outlet,  $V_r$ , according to the radiolysis model calculation decreased with an increase in the core

flow rate. Then, subsequently, the water amount in the core region increased with an increase in the core flow rate.

However, the onset of boiling from the bottom of the active fuel in the core did not change. At a lower core flow rate, the mass of water to heat on fuels decreased, but the temperature of the water was lower and the total heat required to start boiling was the same as that at a high flow rate with high water temperature conditions. The onset of boiling from the bottom of the active fuel,  $h_B$ , is given as below with assumption of uniform heating on the fuel.

$$h_B = \frac{Q - F_C(H_{out} - H_{in})}{Q} L \quad (3)$$

Here,  $Q$  is the total thermal power and  $L$  is the fuel length. From Eq. (2) and Eq. (3),  $h_B$  is rewritten as below.

$$h_B = \left( 1 - \frac{F_{FW}(H_{out} + H_{FW})}{Q} \right) L \quad (4)$$

Eq. (4) does not depend on the core flow rate and is constant since the  $F_{FW}$ , the  $H_{out}$ , the  $H_{FW}$ , the  $Q$ , and  $L$  are constant by plant design and assumption.

### Effect of Flow Rate on Water Chemistry

Calculated results of the dependence of the  $O_2$  and  $H_2O_2$  concentrations at the core outlet in normal water chemistry (NWC, no hydrogen is injected, that is, HWC at  $0 \text{ mg} \cdot \text{kg}^{-1}$ ) on core flow rate are shown in Figure 3. Oxygen and  $H_2O_2$  concentrations became higher with an increase in the core flow rate. Also, as shown in Figure 4, calculated results of the dependence of the  $O_2$  and  $H_2$  concentrations in the main steam at the core outlet in both NWC and HWC show that their concentrations became higher with an increase in the core flow rate. The increase in radiolytic  $H_2$ ,  $O_2$ , and  $H_2O_2$  concentrations with an increase in the core flow rate is caused by an increase in the amount of water present in the core region where radiolysis of water takes place in a unit time. Because of constant thermal power, the dose rates of both gamma-rays and neutrons are also constant and subsequent generation of radiolytic products is proportional to the water amount at the core in a unit time. In contrast, the steam flow rate is constant throughout one operating cycle and the  $q$  decreases with an increase in the core flow rate. Most of the gaseous  $H_2$  and  $O_2$  produced by radiolysis moves to the steam to reach equilibrium. Since smaller amounts of  $H_2$  and  $O_2$  are required to approach equilibrium at low  $q$  at high flow rates, more accumulation of  $O_2$  and  $H_2O_2$  in the reactor water takes place. On the other hand, more  $H_2$  and  $O_2$

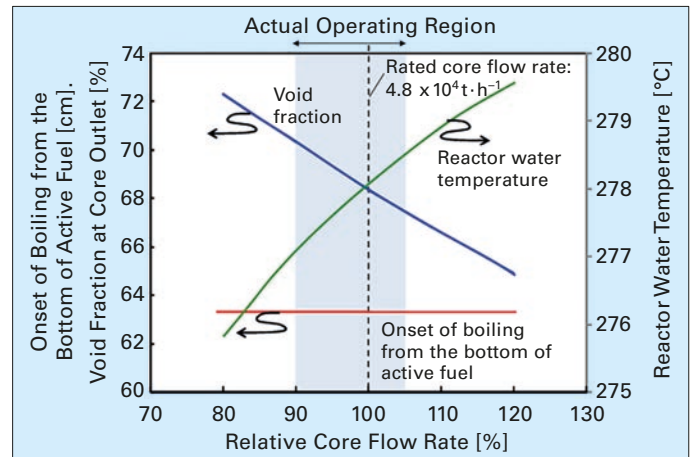


Figure 2:  
Effects of core flow rate on two-phase flow conditions in the core region.

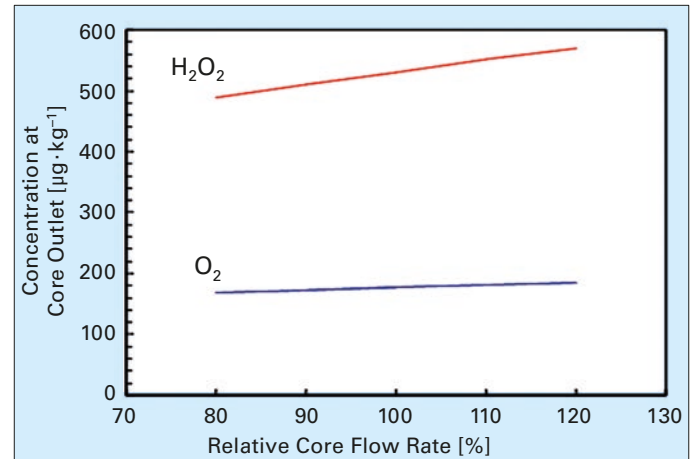


Figure 3:  
Effects of core flow rate on radiolysis of water in the core region.

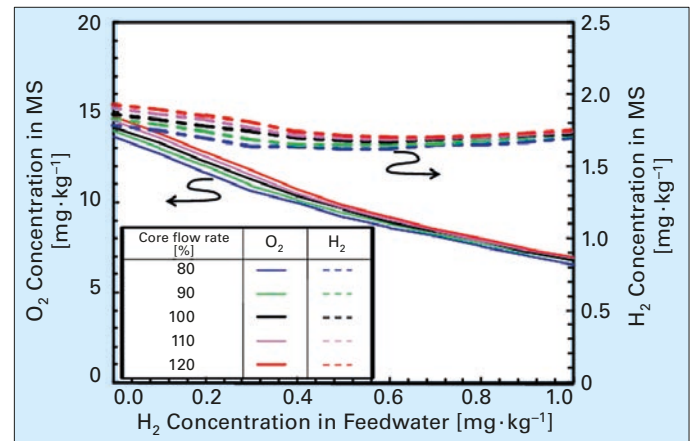


Figure 4:  
Effects of core flow rate on oxygen and hydrogen concentration in the main steam line.



in the water needs to release to the steam to increase its concentration in the steam at high  $q$ . Accumulation of less volatile hydrogen peroxide is promoted at a higher core flow rate since more  $O_2$  is produced by radiolysis of water. This is considered in the model as the effect of the void fraction: lower  $V_f$  at a higher core flow rate causes slower mass transfer between the main steam and the reactor water in the core region, and then promotes accumulation of  $O_2$  and  $H_2O_2$  based on the 4th term of Eq. (1),  $V_f/(1-V_f)$

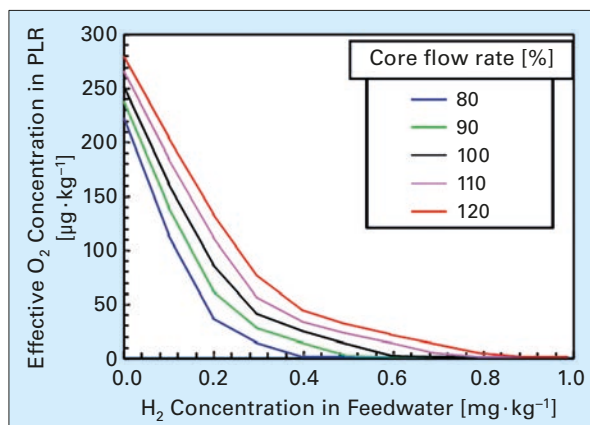


Figure 5:  
Effects of core flow rate on hydrogen water chemistry effectiveness in the PLR.

Calculated results of the dependence of the effective oxygen concentration ( $[O_2]_{\text{eff}} = [O_2] + \frac{1}{2}[H_2O_2]$ ) in the PLR in HWC on the core flow rate are shown in Figure 5. At rated power operation (100% thermal power and 100% core flow), the  $[O_2]_{\text{eff}}$  in the PLR in NWC was calculated as ca.  $250 \mu\text{g} \cdot \text{kg}^{-1}$ . When the core flow rate was reduced to 80%, the  $[O_2]_{\text{eff}}$  in the PLR in NWC became ca.  $220 \mu\text{g} \cdot \text{kg}^{-1}$  and this showed that the  $[O_2]_{\text{eff}}$  was lowered by 12% with a decrease in the core flow rate. In contrast, when the core flow rate was increased to 120%, the  $[O_2]_{\text{eff}}$  in the PLR in NWC became ca.  $280 \mu\text{g} \cdot \text{kg}^{-1}$  and this showed that the  $[O_2]_{\text{eff}}$  was increased by 12% with an increase in the core flow rate. As previously stated, an increase in the core flow rate caused an increase in the effective oxygen concentration in the PLR.

In HWC, when the core flow rate was increased, the  $[O_2]_{\text{eff}}$  in the PLR was increased at each hydrogen concentration in the feedwater. When the core flow rate increased, the number of times the water passed through the core region increased and the void fraction in the core was reduced. Then, subsequent radiolysis of water was promoted and radiolytic oxygen and hydrogen peroxide concentrations increased. Also, when the hydrogen concentration in the feedwater was constant during power operation, the

hydrogen concentration in the reactor water at the mixing point of the feedwater and reactor water in the reactor pressure vessel decreased with an increase in the core flow rate. Then, recombination efficiency in the downcomer region was reduced by an increase in the core flow rate and subsequently the  $[O_2]_{\text{eff}}$  in the reactor water increased. The amount of hydrogen required to suppress the  $[O_2]_{\text{eff}}$  in the PLR to the  $10 \mu\text{g} \cdot \text{kg}^{-1}$  level became 2.1 times when the core flow rate increased from 80% to 120%, that is, 1.5 times.

Similarly, the calculated  $[O_2]_{\text{eff}}$  in the PLR was replotted to the effective hydrogen concentration (= hydrogen concentration in the feedwater  $\times q$ , as net  $H_2$  amount flowing into the reactor core) by the core flow rate as shown in Figure 6 to eliminate the dilution effect of feedwater hydrogen at the mixing point when the core flow rate increases. Dependency of the  $[O_2]_{\text{eff}}$  in the PLR on the core flow rate is the same as the plot based on the feedwater hydrogen concentration. However, the overlapping promotion of radiolysis of water and the dilution effect of added  $H_2$  can still be seen when the core flow rate increased. However, the amount of hydrogen required to suppress the  $[O_2]_{\text{eff}}$  in the PLR to the  $10 \mu\text{g} \cdot \text{kg}^{-1}$  level lowered to 1.4 times with an increase in the core flow rate from 80% to 120%. Therefore, the dilution effect can be mitigated by effective  $H_2$  management.

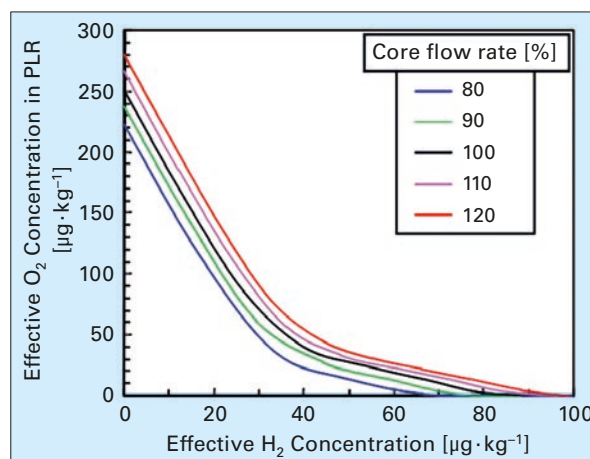


Figure 6:  
Effects of core flow caused by core flow rate change on recombination efficiency in the PLR.

### Effect of Fuel Power Distribution on Water Chemistry

Calculation was conducted for NWC,  $0.5 \text{ mg} \cdot \text{kg}^{-1}$  and  $1.0 \text{ mg} \cdot \text{kg}^{-1}$ . HWC at  $0.5 \text{ mg} \cdot \text{kg}^{-1}$  is typical in Japan since the main steam dose rate can be kept within 2 times in NWC. Calculated re-

sults of the dependence of the  $[O_2]_{\text{eff}}$  in the PLR in HWC on the core flow rate are shown in Figure 7. As explained above, the  $[O_2]_{\text{eff}}$  in the PLR in HWC increased at each hydrogen injection rate when the core flow rate increased. Then, at relatively low hydrogen injection rates such as  $0.5 \text{ mg} \cdot \text{kg}^{-1}$ , the  $[O_2]_{\text{eff}}$  in the PLR was also subject to the core flow rate since the  $[O_2]_{\text{eff}}$  in the PLR showed large changes with changes in the hydrogen concentration in the feedwater. Also, at  $0.5 \text{ mg} \cdot \text{kg}^{-1}$  hydrogen concentration in the feedwater, the  $[O_2]_{\text{eff}}$  in the PLR was also subject to the core power distribution compared to  $0 \text{ mg} \cdot \text{kg}^{-1}$  or  $1.0 \text{ mg} \cdot \text{kg}^{-1}$  hydrogen concentration in the feedwater. When the outermost fuel power got weak and the gamma-ray dose rate became lower at the EOC, recombination efficiency in the downcomer region in HWC was affected and reduced. Then, it was found that there was some core flow rate region in which the  $[O_2]_{\text{eff}}$  in the PLR at the EOC became higher than that at the BOC.

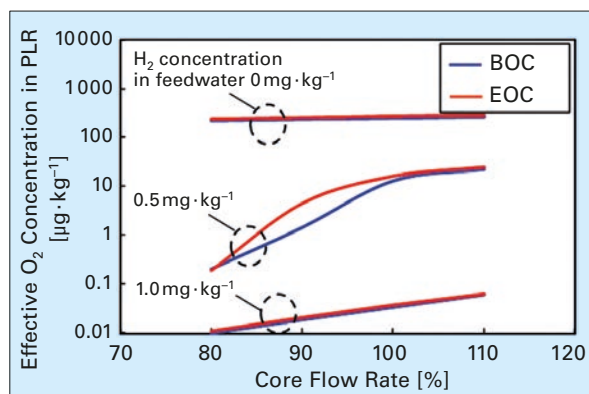


Figure 7: Effects of core flow rate at different core peripheral power on hydrogen water chemistry effectiveness.

### Effect of Core Management on ECP

Calculated results of the dependence of ECP in the PLR on the core flow rate are shown in Figure 8. ECP in the PLR in HWC only at  $0.5 \text{ mg} \cdot \text{kg}^{-1}$  hydrogen concentration in the feedwater increased when the core flow rate increased for both the EOC and BOC. Since  $O_2$  and  $H_2O_2$  concentrations are too high in NWC and sufficiently low at  $1.0 \text{ mg} \cdot \text{kg}^{-1}$ , the ECP in NWC (HWC at  $0 \text{ mg} \cdot \text{kg}^{-1}$ ) and at  $1.0 \text{ mg} \cdot \text{kg}^{-1}$  was not affected by core flow rates. The ECP at  $0.5 \text{ mg} \cdot \text{kg}^{-1}$  was subject to the core flow rate since the  $O_2$  and  $H_2O_2$  concentrations in the reactor water were both distributed in the range of  $0.2$  to  $20 \mu\text{g} \cdot \text{kg}^{-1}$  as shown in Figure 7 and the ECP of SS is sensitive in such low oxidant concentration regions; especially  $H_2O_2$  present at even a few  $\mu\text{g} \cdot \text{kg}^{-1}$  raises the ECP

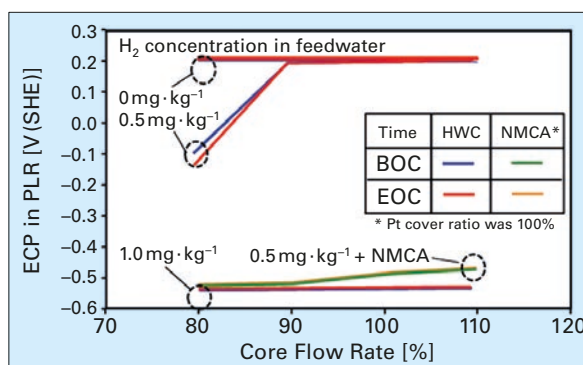


Figure 8: Effect of core management on electrochemical corrosion potential in the PLR in hydrogen water chemistry and noble metal chemical application.

drastically. The ECP of SS is  $-0.5 \text{ V(SHE)}$  below  $1 \mu\text{g} \cdot \text{kg}^{-1}$  but rises sharply at  $2\text{--}3 \mu\text{g} \cdot \text{kg}^{-1}$  and then reaches about  $0 \text{ V(SHE)}$  at  $10 \mu\text{g} \cdot \text{kg}^{-1}$  even under stagnant conditions [7]. Also, a high flow rate raises the ECP of the SS at the same concentration by enhancing the mass flux rate on a metal surface. This influence of core management was actually found in the ECP monitoring in smaller plants in Japan [1]. It was found that the core management had a big influence on the ECP at  $H_2$  concentrations in the feedwater where  $O_2$  and  $H_2O_2$  concentrations were in the range of  $0.1$  to  $10 \mu\text{g} \cdot \text{kg}^{-1}$ .

In contrast, the ECP of the PLR in NMCA with  $0.5 \text{ mg} \cdot \text{kg}^{-1}$  HWC was not greatly affected by the core flow rate and showed below  $-0.4 \text{ V(SHE)}$  in the wide core flow rate range for both the BOC and EOC. In this calculation, it was assumed that the platinum (Pt) deposition amount on the surface of structural materials was sufficient to show catalytic behaviour, that is, the Pt cover ratio on the SS surface was 1. Then, if the NMCA is applied to a BWR, it is expected that the ECP of the NMCA treated surfaces of piping and components will remain low enough to mitigate SCC during one operating cycle in the combination of NMCA with HWC to provide a hydrogen amount that exceeds that of oxidants in stoichiometry. The influence of core management on ECP was less than that in HWC only. However, a lower amount of Pt deposition and a lower hydrogen injection rate in HWC must affect the ECP in HWC with NMCA. Adequate evaluation and measurement of ECP during actual plant operation are required in the implementation of corrosive environment mitigation technologies.

## CONCLUSIONS

The effects of operating conditions in a BWR on the corrosive environment in reactor water have been studied with a radiolysis model and ECP model. In this model analysis, 1100MWe class BWR type-5 was selected to calculate  $O_2$  and  $H_2O_2$  concentrations as the corrosive environment.

- Radiolysis of water in the core region increased and consequently oxidant concentration in the reactor water increased when the core flow rate was increased under constant thermal power conditions. This is because promotion of radiolysis of the water is caused by the increase in the number of times of the water passes through the core region and also by a decrease in the void fraction, which affects the mass transfer between water and steam.
- Increase in the core flow rate and decrease in the peripheral fuel power caused higher oxidant concentrations in the reactor water and deteriorated the effectiveness of HWC. This is due to the overlapping effect of the acceleration of radiolysis and the dilution effect of feedwater mixing with reactor water, as well as a decrease in recombination efficiency at weaker dose rates respectively.
- Core management also affected the ECP at  $H_2$  concentrations in the feedwater where the effective  $O_2$  concentration was in the range of 0.1 to  $10\mu g \cdot kg^{-1}$ . However, by applying NMCA, the ECP in HWC became robust during one operating cycle if a sufficient amount of Pt was present on the surface and the amount of hydrogen exceeded that of oxidants in stoichiometry.

## REFERENCES

- [1] Wada, Y., Ishida, K., Tachibana, M., Ota, N., Nagase, M., "Electrochemical Corrosion Potential Monitoring in BWRs", *PowerPlant Chemistry* **2019**, 21(1), 6.
- [2] Wang, M. Y., Yeh, T. K., "Impact of Power Uprate on the Water Chemistry in the Primary Coolant Circuit of a Boiling Water Reactor Operating under a Fixed Core Flow Rate", *Journal of Nuclear Science and Technology* **2008**, 45(8), 802.
- [3] Yeh, T. K., Wang, M. Y., "The Impact of Power Uprate on the Corrosion Mitigation Effectiveness of Hydrogen Water Chemistry in Boiling Water Reactors", *Nuclear Science and Engineering* **2008**, 160(1), 98.
- [4] Ibe, E., Sakagami, M., Uchida, S., "Theoretical Model Analyses for Effects of Hydrogen Injection on Radiolysis of Coolant Water in BWR", *Journal of Nuclear Science and Technology* **1986**, 23(1), 11.
- [5] Wada, Y., Ishida, K., Tachibana, M., Aizawa, M., Fuse, M., Kadoi, E., Takiguchi, H., "Hydrazine and Hydrogen Co-injection to Mitigate Stress Corrosion Cracking of Structural Materials in Boiling Water Reactors (IV) Reaction Mechanism and Plant Feasibility Analysis", *Journal of Nuclear Science and Technology* **2007**, 44(4), 607.
- [6] Wada, Y., Ishida, K., Tachibana, M., "Effectiveness Analysis of Noble Metal Treatment to Mitigation of Intergranular Stress Corrosion Cracking of Stainless Steel in BWR Reactor Water Environment", *Proc., 11th Int. Symposium on Environmental Degradation of Materials in Nuclear Power Systems-Water Reactors*, **2003** (Stevenson, WA, USA), NACE/TMS/ANS, 488.
- [7] Wada, Y., Watanabe, A., Tachibana, M., Ishida, K., Uetake, N., Uchida, S., Akamine, K., Sambongi, M., Suzuki, S., Ishigure, K., "Effects of Hydrogen Peroxide on Intergranular Stress Corrosion Cracking of Stainless Steel in High Temperature Water, (IV) Effects of Oxide Film on Electrochemical Corrosion Potential", *Journal of Nuclear Science and Technology* **2001**, 38(3), 183.

## THE AUTHORS

**Yoichi Wada** (Ph.D., Engineering, Tohoku University, Japan) joined Hitachi, Ltd., in 1991 and has a 28-year background in research and development for water chemistry, in particular corrosive environment mitigation for BWRs, at Hitachi, Ltd. He is a senior researcher and has been working at Hitachi Europe Ltd. in the UK since 2018.

**Kazushige Ishida** (Ph.D., Engineering, Saitama University, Japan) joined Hitachi, Ltd., in 1994 and has a 25-year background in research and development for water chemistry, in particular corrosive environment mitigation for BWRs, at Hitachi, Ltd.

**Nobuyuki Ota** (B.A., Engineering, Tokyo University of Fisheries, Japan) joined Hitachi-Engineering, Ltd., in 1989 and has a 30-year background in the design of BWR water chemistry, in particular corrosive environment mitigation for BWRs. He is a senior engineer and has been working at Hitachi-GE Nuclear Energy, Ltd., since 2007.

**Makoto Nagase** (Ph.D., Engineering, Tokyo University, Japan) joined Hitachi, Ltd., in 1984 and has a 23-year background in research and development for water chemistry, in particular radioactive corrosion product behavior and chemical decontamination for BWRs, at Hitachi, Ltd., as well as an 12-year background in engineering, in particular chemical decontamination and recontamination reduction, at Hitachi-GE Nuclear Energy, Ltd. He is a chief engineer and has been working at Hitachi-GE Nuclear Energy, Ltd., since 2007.

## CONTACT

Yoichi Wada  
European R&D Centre  
Hitachi Europe Ltd.  
12th Floor 125 London Wall  
London EC2Y 5AJ  
United Kingdom

E-mail:

[Yoichi.wada@Hitachi-eu.com](mailto:Yoichi.wada@Hitachi-eu.com)

[yoichiwada.ya@hitachi.com](mailto:yoichiwada.ya@hitachi.com)



**THE INTERNATIONAL  
WATER  
CONFERENCE  
(IWC)**

Sponsored by the Engineers'  
Society of Western Pennsylvania  
**ESWP.COM**

November 8-12, 2020  
San Antonio, TX, USA