功率提昇狀態下核一、二廠加氫水化學防蝕效益的變化

The Impact of Power Uprate on the Corrosion Mitigation Effectiveness of Hydrogen Water Chemistry in Kuosheng and Chinshan Boiling Water Reactors

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中華民國98年12月16日

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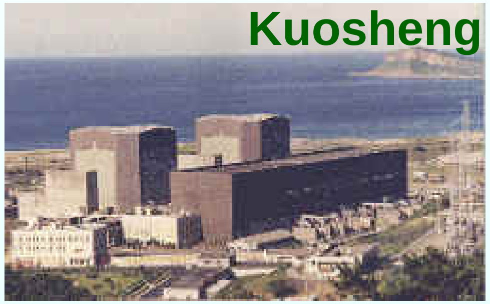
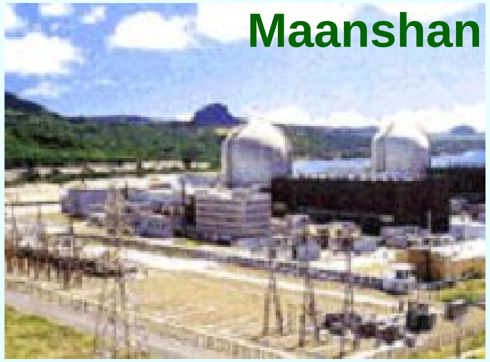
Nuclear Power Plants in Taiwan (1/3)


Chinshan


Kuosheng


Maanshan

**Adapted from Taipower Website at* http://www.taipower.com.tw/TaipowerWeb//upload/images/11/powerimage.gif

Nuclear Power Plants in Taiwan (2/3)

❑ Current Status of Nuclear Power in Taiwan

Number of Operating Units	6 **(4 BWRs/GE and 2 PWRs/WH)**
Total GWe of Operating Unit	4.88
Number of Units under Construction	2 **(The Longmen Project, first commercial operation scheduled in 2011)**
Total GWe of Units under Construction	2.70
Number of Units Being Planned	0
Nuclear Share in Electricity in 2008	16.7%*

*** It was 22.9% in 2002.**

Nuclear Power Plants in Taiwan (3/3)

❑ **Current Status of Operating Nuclear Power Plants**

Name of the Plant	**Chinshan**	**Kuoshang**	**Maanshan**
Reactor Type	**GE BWR/4**	**GE BWR/6**	**Westinghouse 3-loop PWR**
Number of Units	2	2	2
Electric Power MWe	636	985	951
First Commercial Operation	**#1: Dec 1978** **#2: Jul 1979**	**#1: Dec 1981** **#2: Mar 1983**	**#1: Jul 1984** **#2: May 1985**
Years of Operation	**~31**	**~28**	**25**

1. Introduction (1/5)

- **The intergranular stress corrosion cracking (IGSCC) susceptibility of structural materials in boiling water reactors (BWRs) has been well known to influence by the electrochemical corrosion potential (ECP).**
- **The ECP on the other hand is mainly controlled by the amounts of oxidizing and reducing species in the reactor coolant and affected by the hydrodynamic water flow condition of the coolant.**
- **Variations in the power level of a BWR which in turn affect the mass flow rate and degree of radiolysis of the coolant are accordingly bound to alter the ECP in the primary coolant circuit (PCC).**

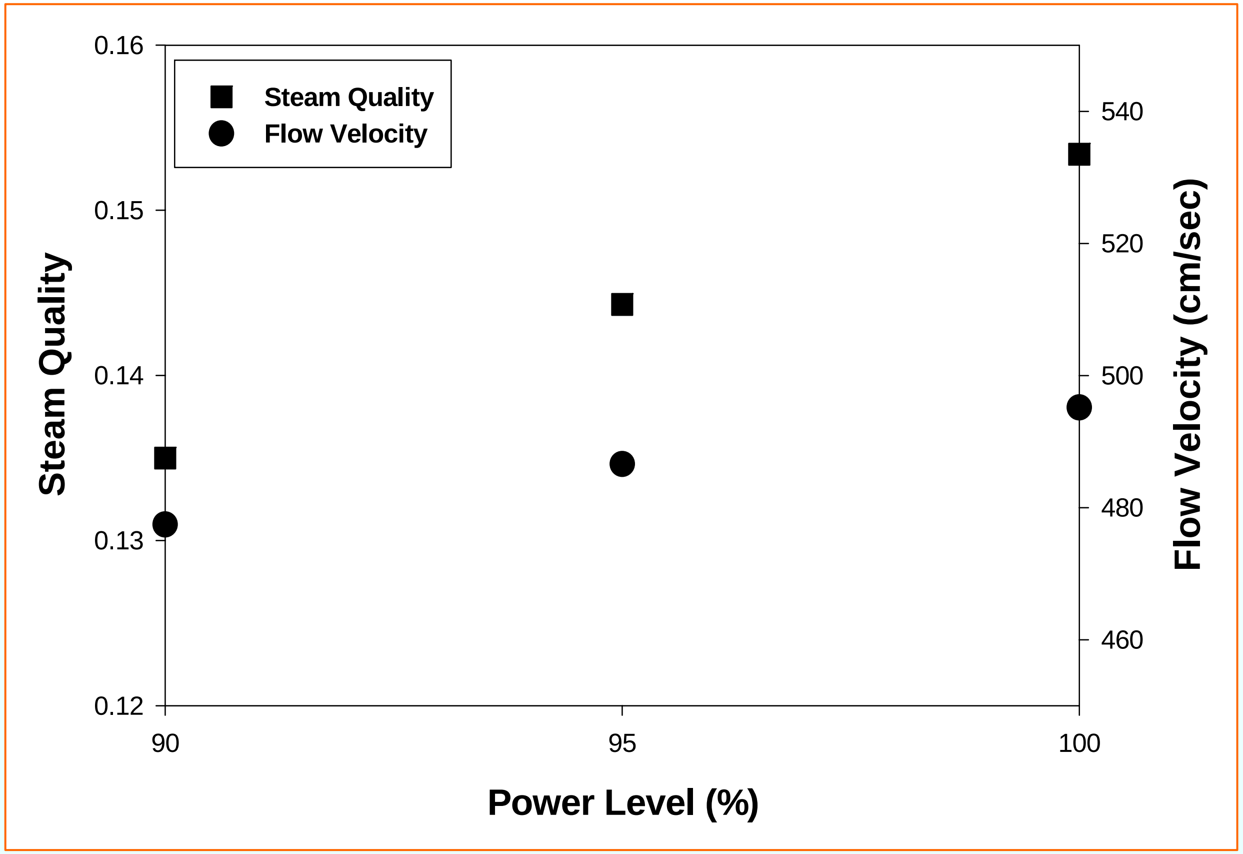
1. Introduction (2/5)

- **Current light water reactors (LWRs) produce electric energy at their rated power level until the reactivity-limited burnup is reached.**
- **When all control rods are fully withdrawn and core flow is at or near the rated value to generate maximum power in an LWR near the end of its fuel cycle, a coastdown operation (i.e. gradually reduced power) may commence.**
- **A typical coastdown duration may last from a week to a month with a terminal operating power level at 90% to less than 100% of the rated value. The operating power would decrease one percent in about every two days.**

1. Introduction (3/5)

- **A BWR may undergo a power coastdown operation near the end of a fuel cycle when the fuel in the core is sufficiently depleted earlier than scheduled and the rated power can no longer be maintained.**
- **Upon the power coastdown of a BWR, the power density and coolant velocity in the reactor core would accordingly change, followed by water chemistry variations due to reduced radiolysis of water and extended coolant residence times in the near-core regions.**

1. Introduction (4/5)



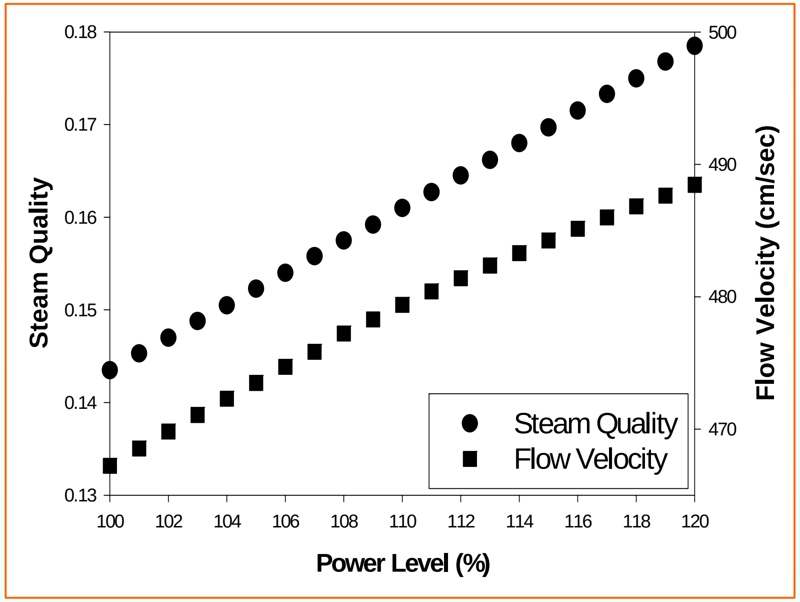
Steam quality and liquid coolant flow velocity as a function of power level at the core exit of Reactor X operating at the rated mass flow rate. The circular dot indicates the increase in the steam quality was proportional to that in reactor power level.

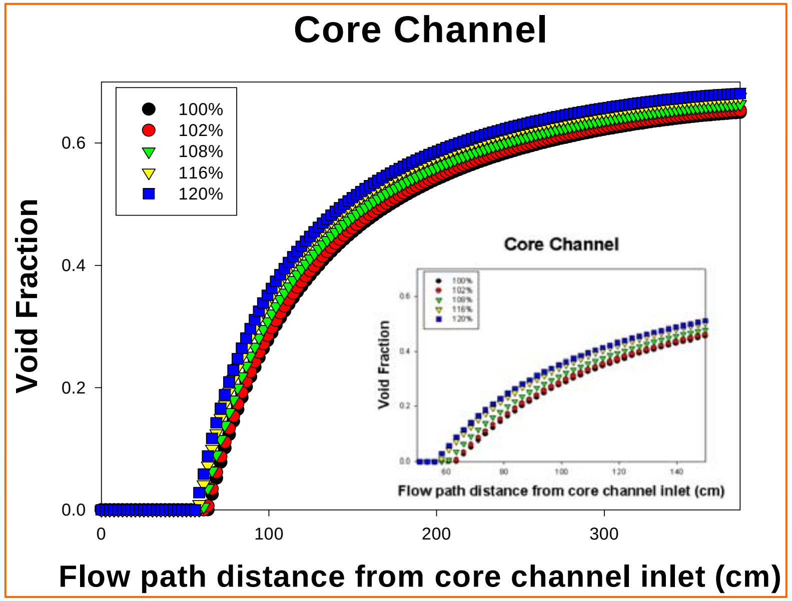
1. Introduction (5/5)

- **For a BWR that has adopted hydrogen water chemistry (HWC), variations in the water chemistry of the reactor coolant could lead to a change in the required feedwater hydrogen concentration ($[H_2]_{FW}$).**
- **In view of the limited, measurable water chemistry data in a BWR, we intend to evaluate the impact of power coastdown on the water chemistry and ECP in the PCC of a BWR operating under normal water chemistry or HWC via theoretical computer modeling.**
- **A commercial BWR (Reactor X) was selected to be the modeling target, and the impacts of power coasdown at 5% and 10% on this BWR were assessed.**

2. Past Experiences (1/4)

Impact of Power Uprate (1/2)





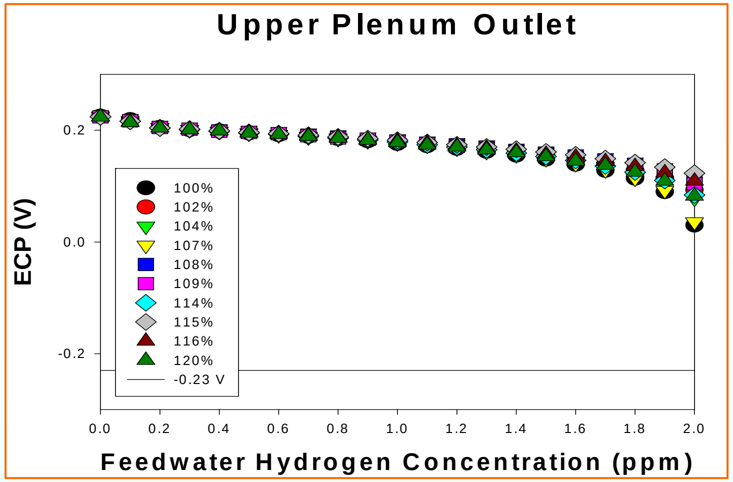
Left : **Steam quality and liquid coolant flow velocity as a function of power level at the core exit of Reactor X operating at a fixed mass flow rate. The circular dot indicates the increase in the steam quality was proportional to that in reactor power level.**

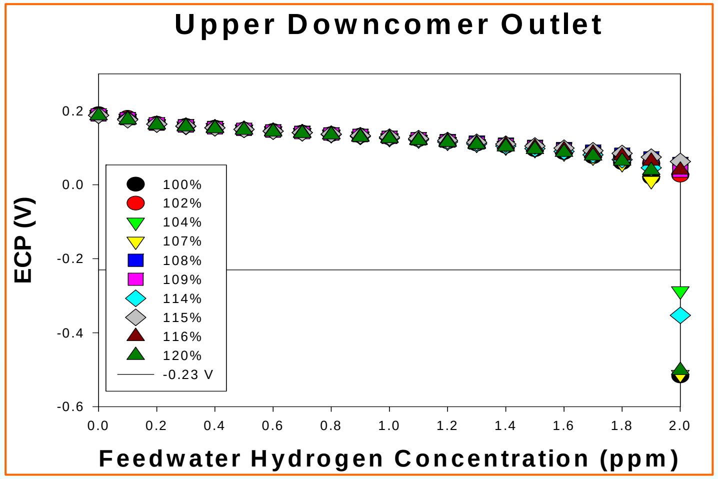
Right : **Variations in void fraction along the core channel region of Reactor X under different power levels.**

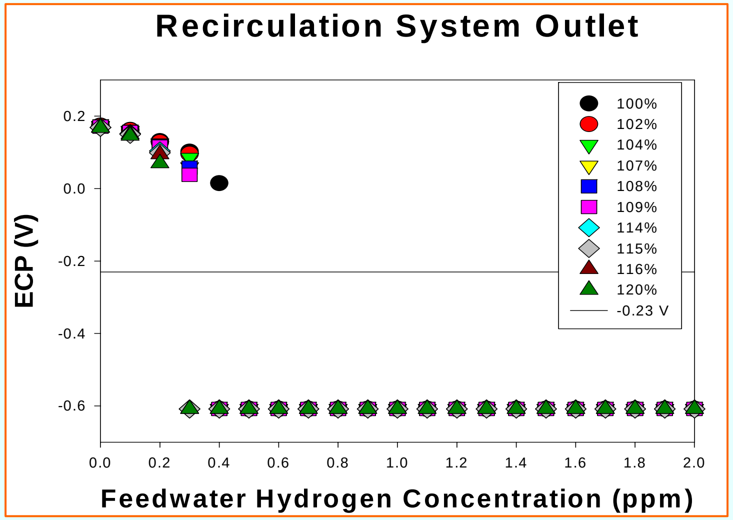
Mei-Ya Wang and Tsung-Kuang Yeh, *Journal of Nuclear Science and Technology*, v. 45, p. 802-811 (2008).
Tsung-Kuang Yeh and Mei-Ya Wang, *Nuclear Science and Engineering*, v. 160, p. 98-107 (2008).

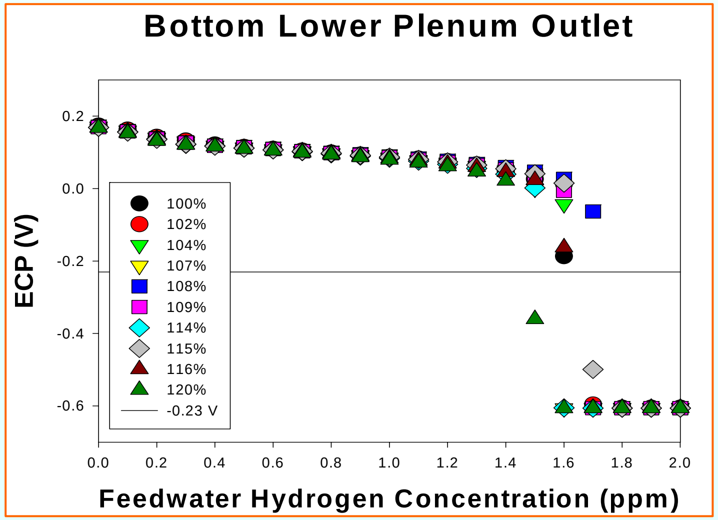
2. Past Experiences (2/4)

Impact of Power Uprate (2/2)


Upper Plenum Outlet

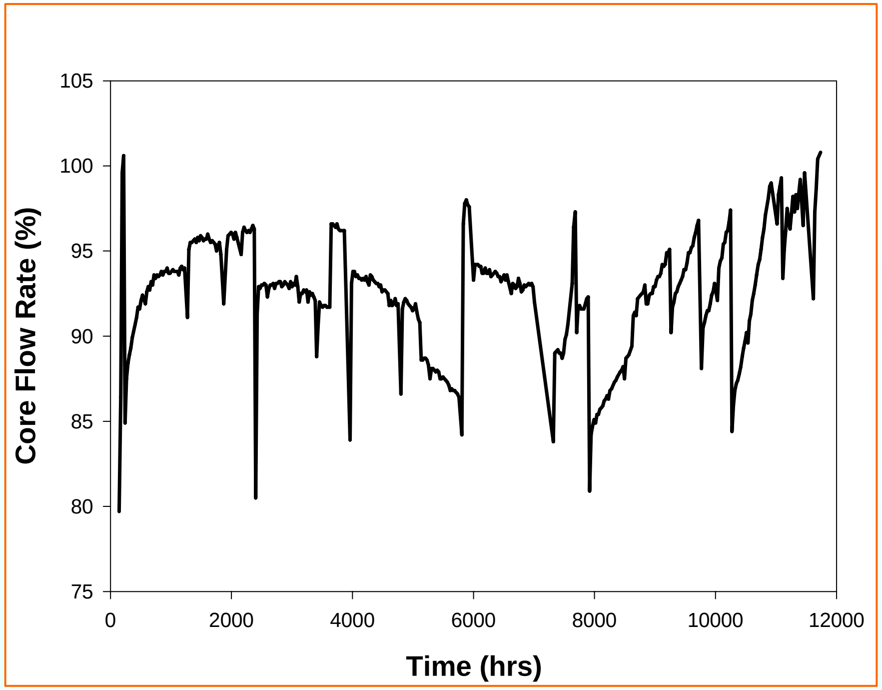

Upper Downcomer Outlet

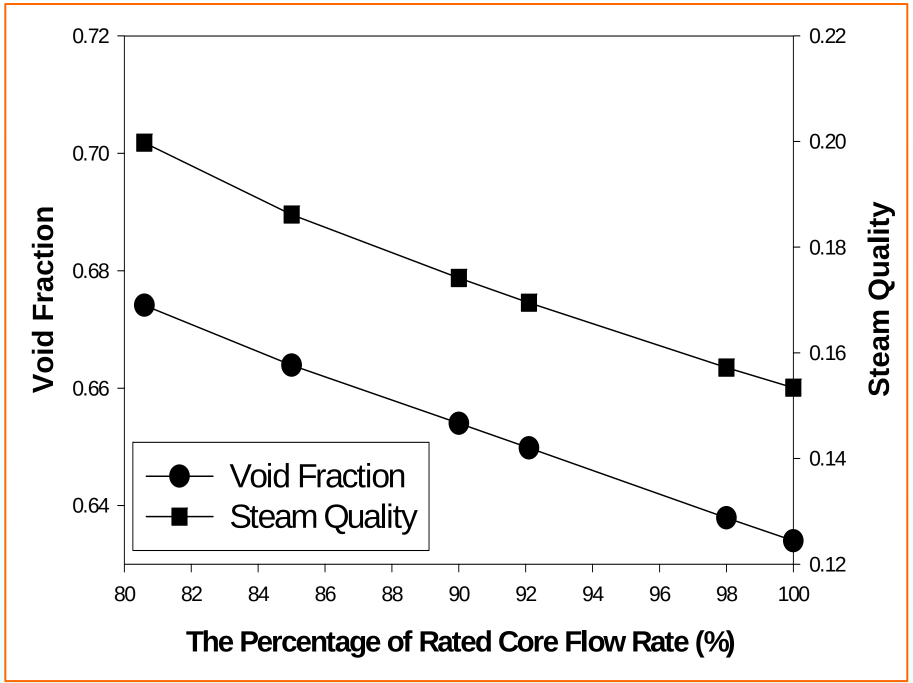

Recirculation System Outlet


Bottom Lower Plenum Outlet

2. Past Experiences (3/4)

Impact of Core Flow Rate (1/2)





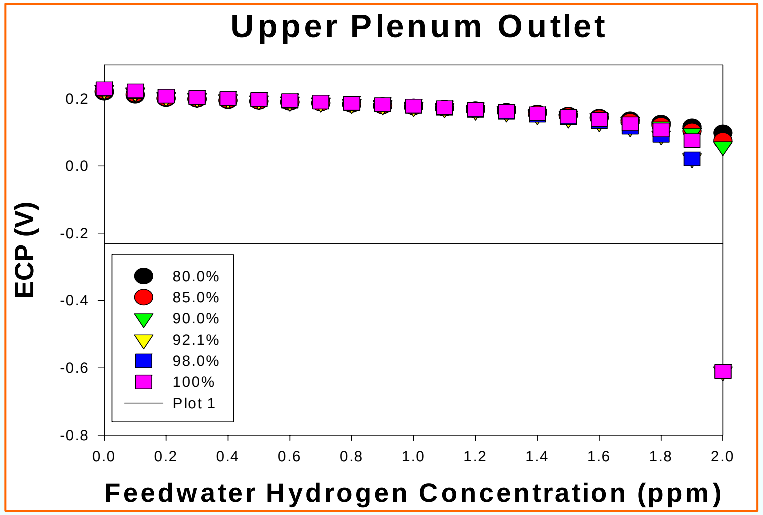
Left : The CFR variations in a commercial BWR during a normal fuel cycle.

Right : Void fraction and steam quality as a function of core flow rate at the core exit of Reactor X operating at 100% rated power.

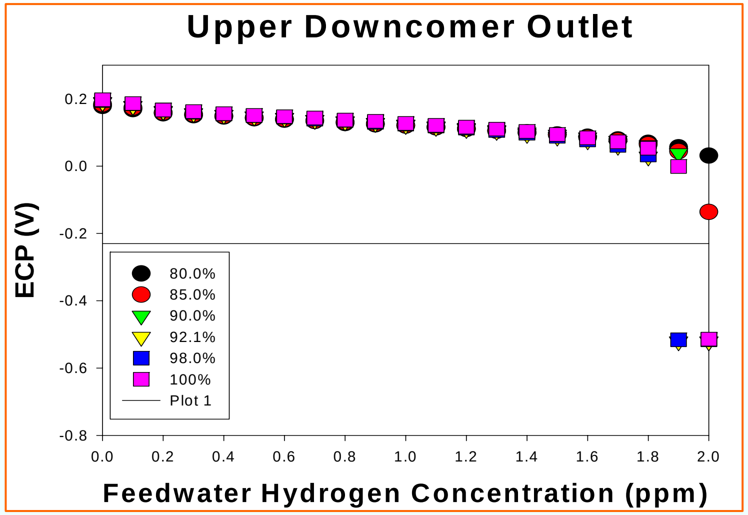
Mei-Ya Wang, T. K. Yeh, Fang Chu, and Ching Chang, *Nuclear Engineering and Design*, v. 239, p. 781-789 (2009).
Tsung-Kuang Yeh and Mei-Ya Wang, *Nuclear Science and Engineering*, v. 161, p. 235-244 (2009).

2. Past Experiences (4/4)

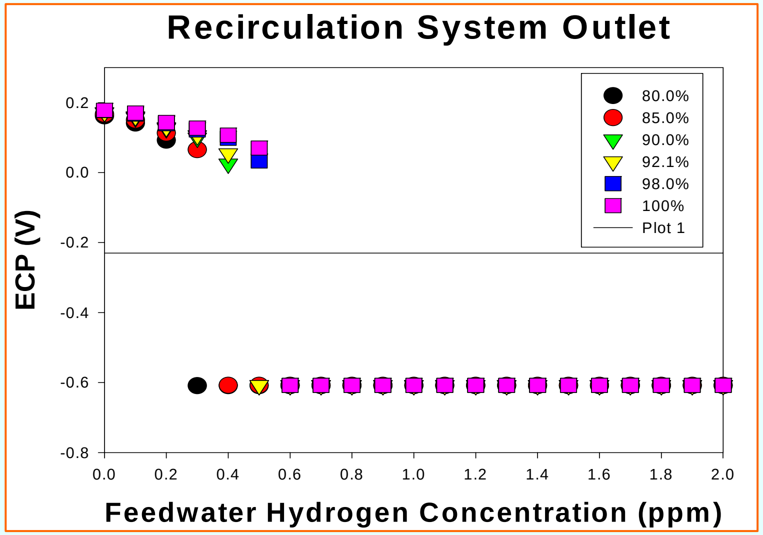
Impact of Core Flow Rate (2/2)



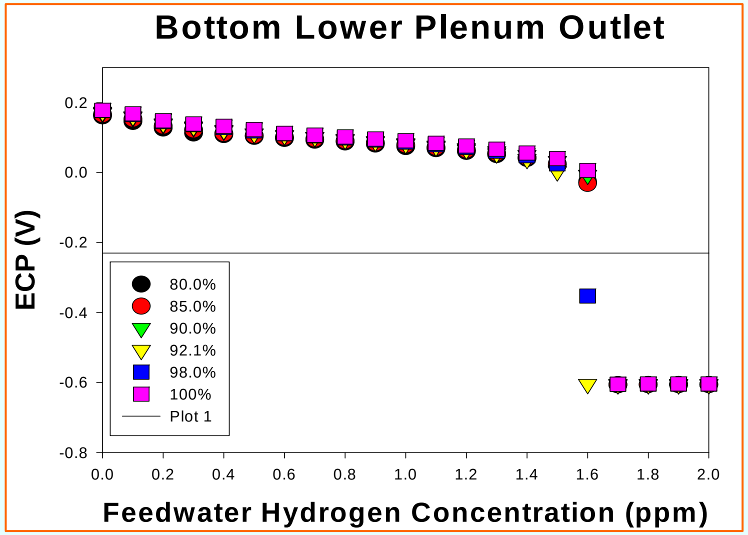
Upper Plenum Outlet



Upper Downcomer Outlet



Recirculation System Outlet



Bottom Lower Plenum Outlet

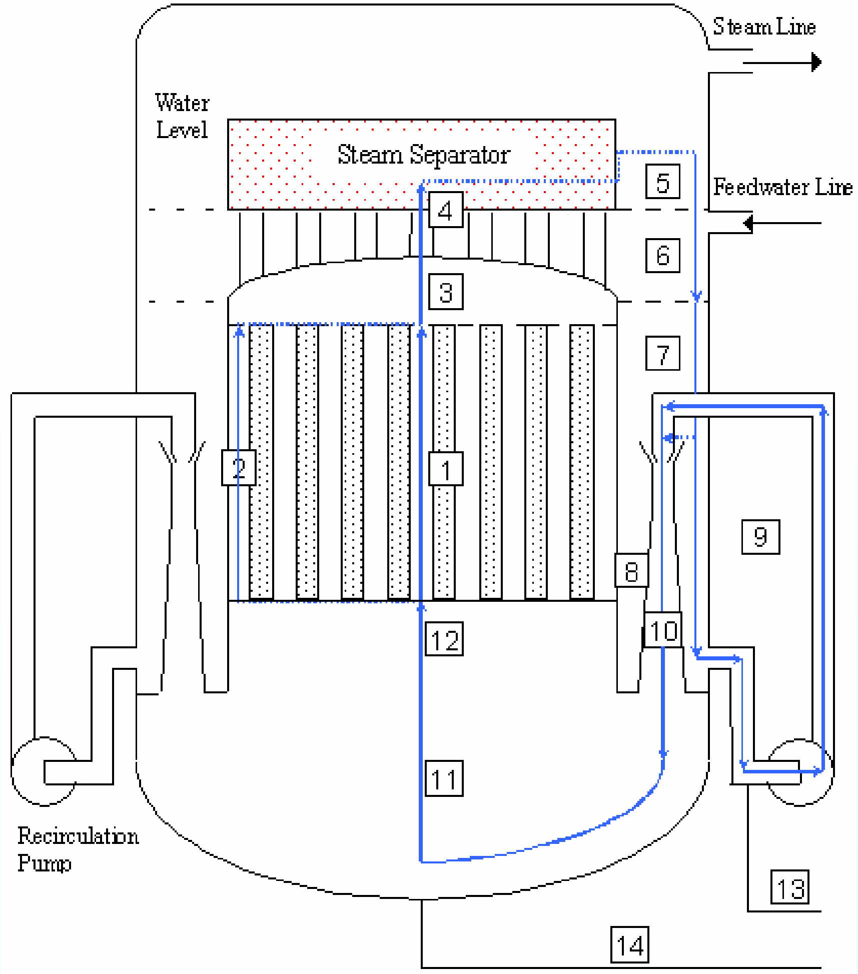
3. Modeling Basic (1/3)

- **Simulations were carried out for $[H2]_{FW}$s ranging from 0.0 to 2.0 parts per million and for power levels ranging from 90% to 100% at rated flow rate.**
- **Upon the adoption of a power coastdown, lower dose rates of neutron and gamma photon would reduce the radiolysis of water.**
- **On the other hand, due to a longer coolant residence time in that region, the water radiolysis effect might be lengthened and therefore increase the production of oxidizing species (e.g. H_2O_2 and O_2).**
- **In the meantime, the recombination of oxidizing species and hydrogen in the downcomer region of a BWR would be decreased.**

3. Modeling Basic (2/3)

- **Modelled Regions in a Typical BWR**

1. **Core Channel**
2. **Core Bypass**
3. **Upper Plenum**
4. **Stand Pipe**
5. **Separator Sideway**
6. **Mixing Plenum**
7. **Upper Downcomer**
8. **Lower Downcomer**
9. **Recirculation System**
10. **Jet Pump**
11. **Bottom Lower Plenum**
12. **Top Lower Plenum**



3. Modeling Basic (3/3)

- **ZEBRA code : for two phase flow in a BWR core**
- **DEMACE code :**

  1. WCHEM - for chemical species concentrations

$$(\frac{G_i^{\gamma}\Gamma^{\gamma}}{100N_V}+\frac{G_i^{n}\Gamma^{n}}{100N_V})\tilde{F}\rho dV+(\sum_{s=1}^{N}\sum_{m=1}^{N}k_{sm}C_sC_m-C_i\sum_{s=1}^{N}k_{si}C_s)dV+[\frac{d(uC_i)}{dx}]\pm(\mu_i^{*}C_i^{b}-\mu_iC_i^{f})dV_g=0$$

  2. MPM - for electrochemical corrosion potential

$$\sum_{j=1}^{N}i_{R/O,j}(E)+i_{corr}(E)=0$$

  3. CEFM - for crack growth rates

$$i_{crack}A_{crack}+\int_S i_c^N\,dS=0$$

- **During the course of a coastdown operation in a BWR, the core flow rate in the BWR is usually maintained at the rated value in order to generate the greatest power**.

4. Simulation Results (1/11)

❁ Species Concentrations vs. Power Level (1/6)

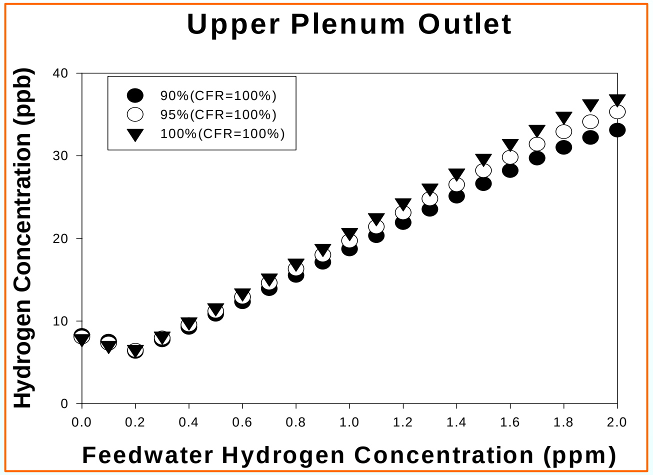
Hydrogen

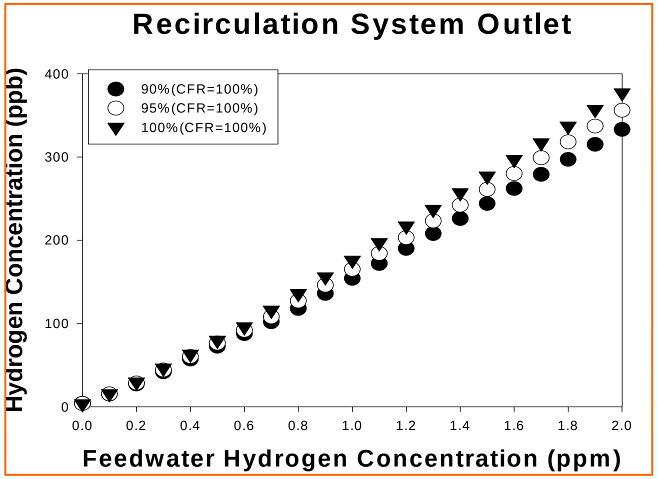
- The $[H_2]$ increased with increasing $[H_2]_{FW}$ and was indifferent to changes in power level at low $[H_2]_{FW}$s (i.e. <0.6 ppm) in all 12 modeled regions.
- Under power coastdown conditions, it seemed that a lower power level would lead to a lower $[H_2]$ in the reactor coolant at all four locations.

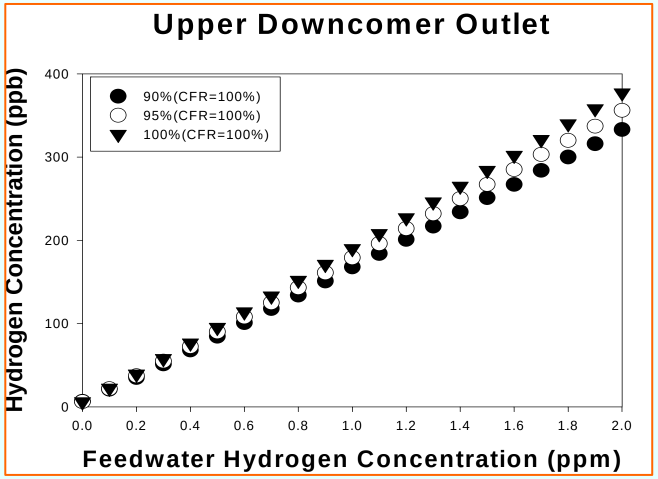
4. Simulation Results (2/11)

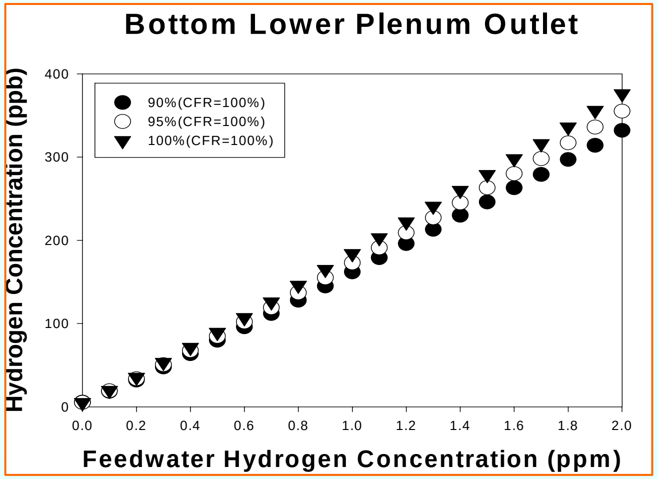
☸ Species Concentrations vs. Power Level (2/6)

Hydrogen


Upper Plenum Outlet


Recirculation System Outlet


Upper Downcomer Outlet


Bottom Lower Plenum Outlet

4. Simulation Results (3/11)

☸ Species Concentrations vs. Power Level (3/6)

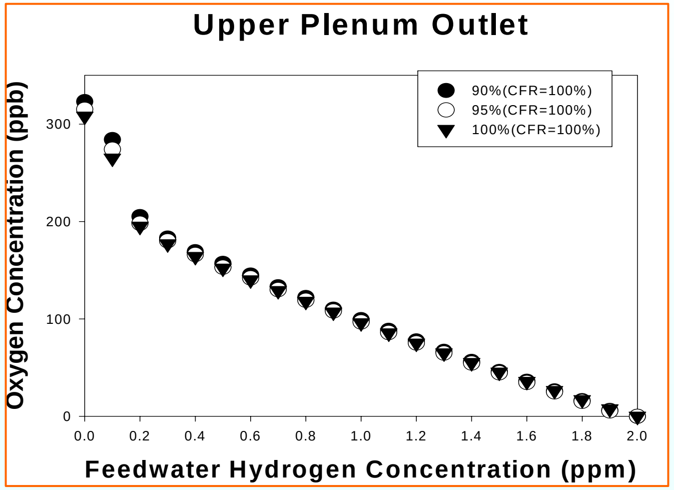
Oxygen

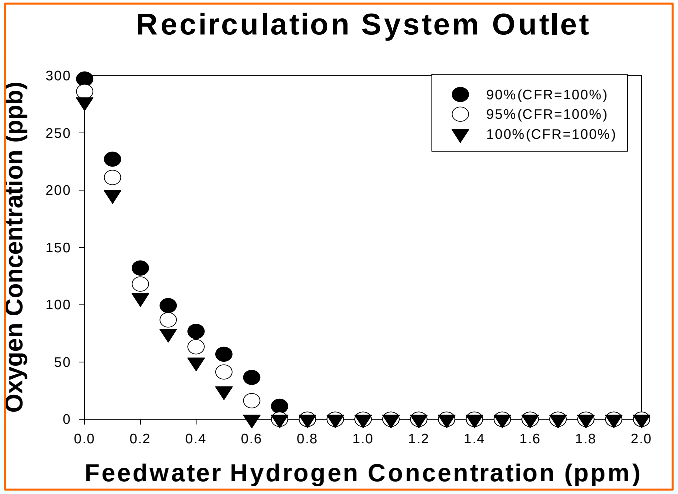
- With increasing $[H_2]_{FW}$, the $[O_2]$ gradually decreased because of the recombination of O_2 and H_2.
- At the recirculation system outlet $[H_2]_{FW}$s of 0.6, 0.7, and 0.8 ppm were required to effectively reduce the $[O_2]$ at 100, 95, and 90% power levels, respectively.
- The $[O_2]$ at either one of the selected power levels was not fully depleted until the $[H_2]_{FW}$ reached 1.9 ppm and 1.7 ppm at the upper downcomer outlet and at the bottom lower plenum outlet, respectively.
- A 90% power coastdown operation causing undesirably higher $[O_2]$s at low $[H_2]_{FW}$s would eventually influence the effectiveness of HWC on corrosion mitigation in Reactor X.

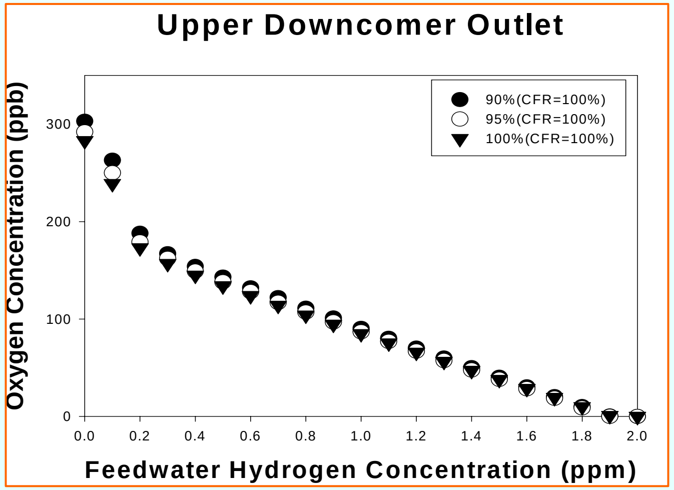
4. Simulation Results (4/11)

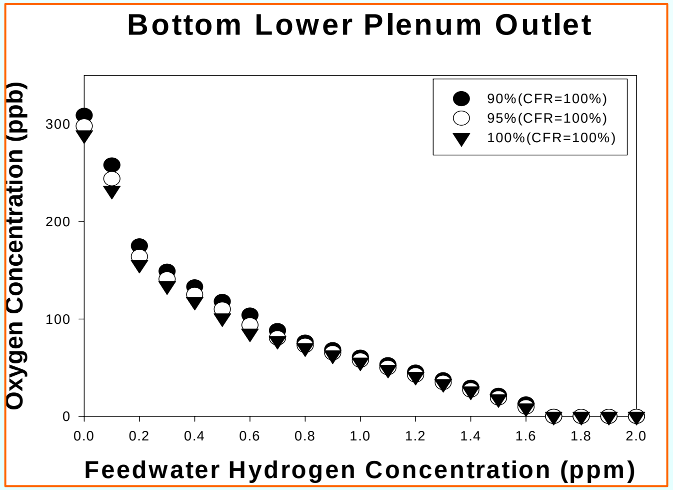
❁ Species Concentrations vs. Power Level (4/6)

Oxygen


Upper Plenum Outlet


Recirculation System Outlet


Upper Downcomer Outlet


Bottom Lower Plenum Outlet

4. Simulation Results (5/11)

☸ Species Concentrations vs. Power Level (5/6)

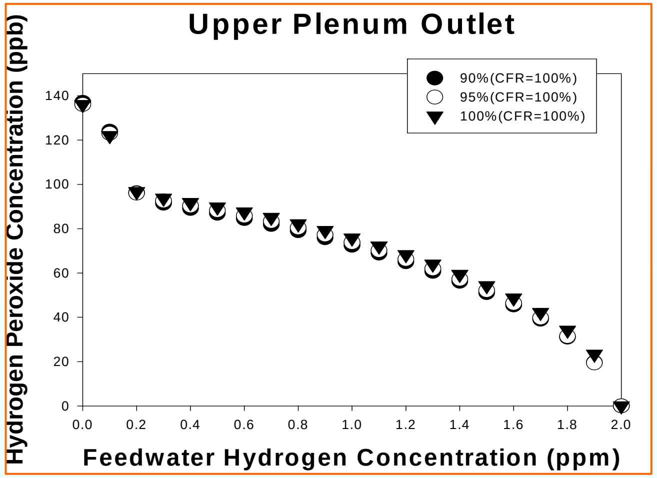
Hydrogen Peroxide

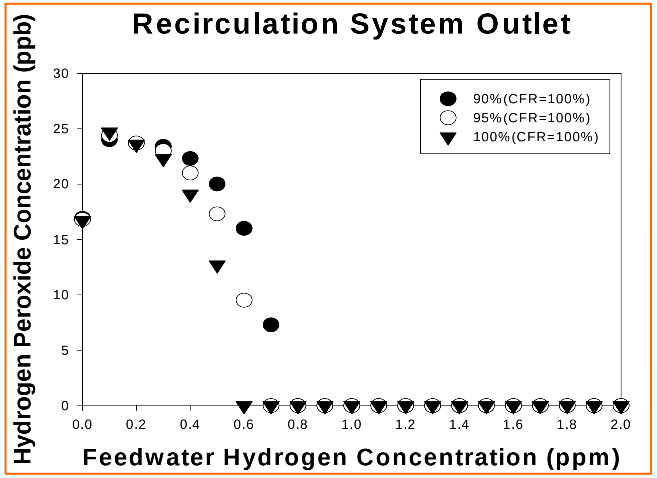
- At the upper plenum outlet , the [H_2O_2] at the 90% power level was initially higher than that at the rated power at low [H_2]$_{FW}$s (i.e. <0.2 ppm) and then became comparatively lower at high [H_2]$_{FW}$s.
- A 2.0 ppm [H_2]$_{FW}$ was required to scavenge all H_2O_2 at the upper downcomer outlet at all selected power levels. The inconsistent result of a 95% power level leading to a relatively more H_2O_2 reduction efficiency appeared at Reactor X at 1.9 ppm [H_2]$_{FW}$.
- A higher power level would instead lead to a more effective reduction in [H_2O_2] at the recirculation system outlet.

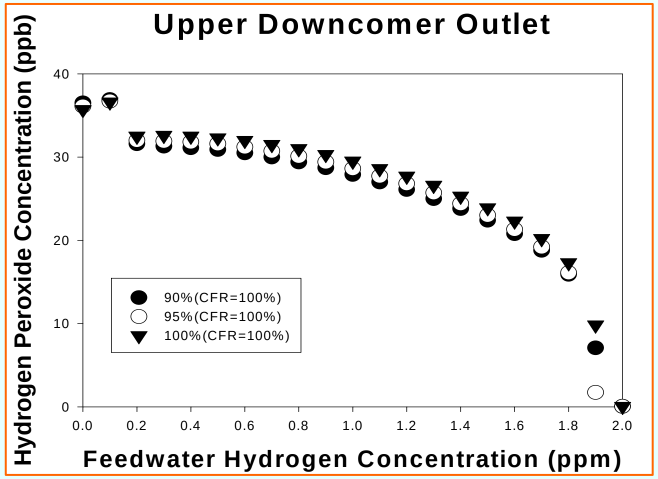
4. Simulation Results (6/11)

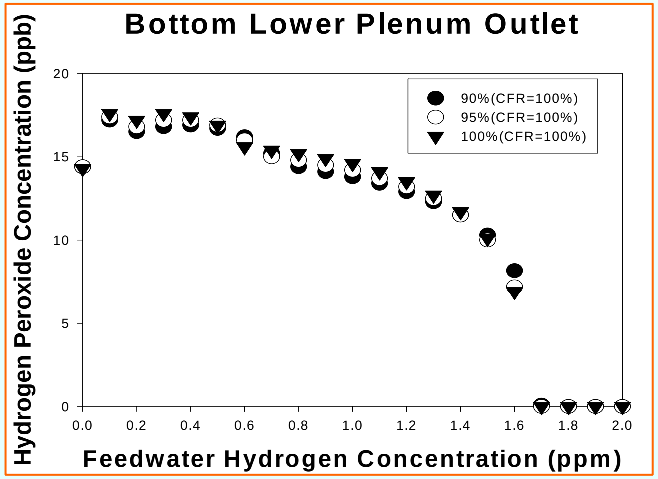
❁ Species Concentrations vs. Power Level (6/6)

Hydrogen Peroxide









4. Simulation Results (7/11)

ECP vs. Power Level (1/3)

- At the upper plenum outlet and the upper downcomer outlet, the $[H_2]_{FW}$ required for reducing the ECP below the E_{crit} at all selected power coastdown was 2.0 ppm.
- At the bottom lower plenum outlet, the required $[H_2]_{FW}$ remained unchanged at 1.7 ppm regardless of the changes in power level.
- At the three foregoing locations of Reactor X power levels did not pose any discernable influence on the required $[H_2]_{FW}$ for the ECP to shift below the E_{crit}.
- At the outlet of recirculation system, the ECP response to $[H_2]_{FW}$ and power level was comparatively straightforward. The ECP monotonically increased with decreasing power level.

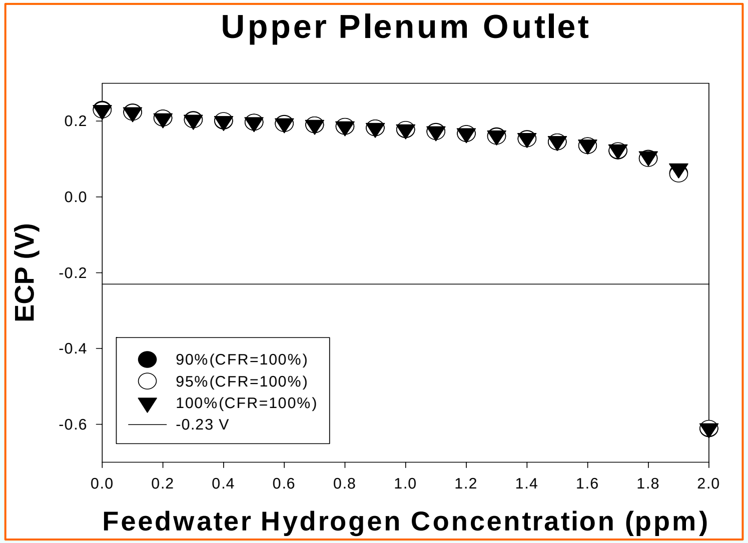
4. Simulation Results (8/11)

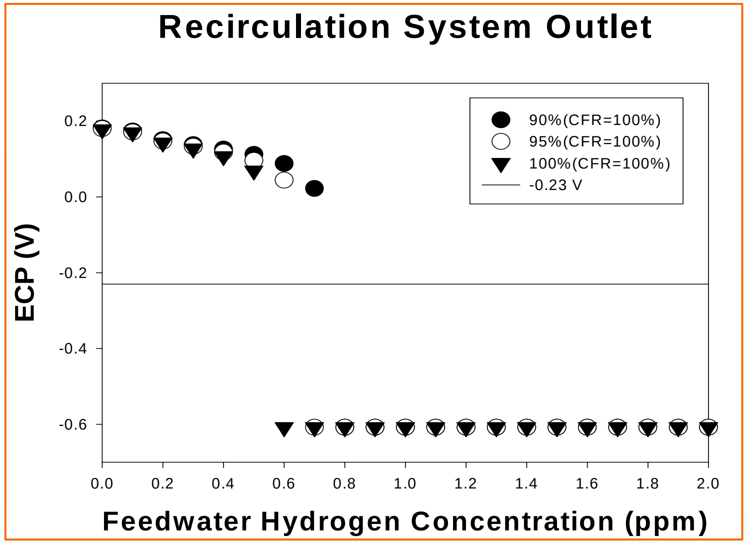
ECP vs. Power Level (2/3)

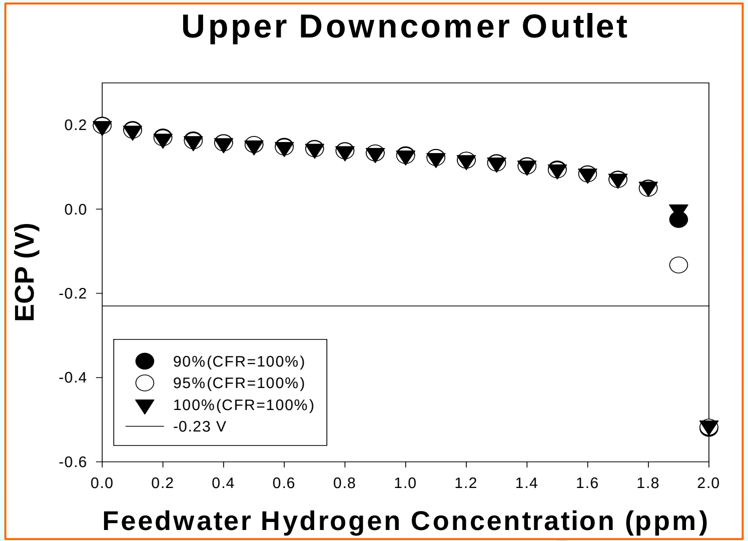
- No significant ECP differences due to power coastdown were observed when the $[H_2]_{FW}$ was either much less or greater than the critical concentration at which the ECP markedly decreased to below the E_{crit}.
- It is theoretically possible that a particular coastdown percentage would induce a more oxidizing environment at different locations in a BWR and hence led to a varied HWC efficiency.

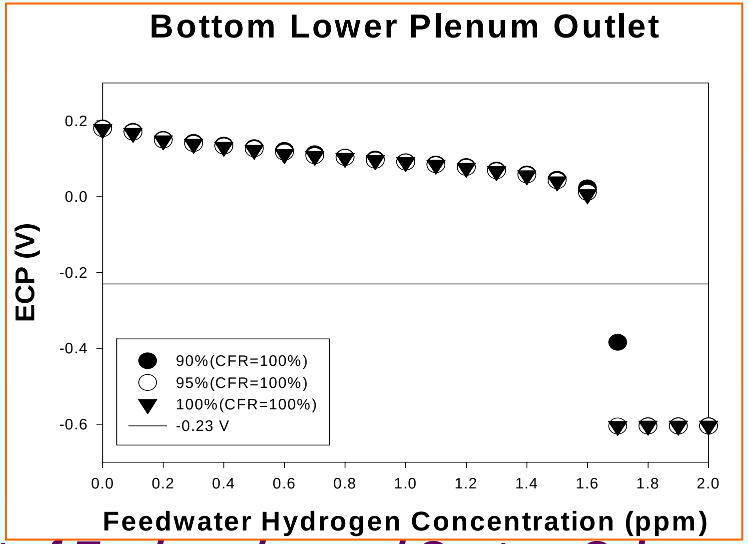
4. Simulation Results (9/11)

☸ ECP vs. Power Level (3/3)


Upper Plenum Outlet


Recirculation System Outlet


Upper Downcomer Outlet


Bottom Lower Plenum Outlet

4. Simulation Results (10/11)

Power Coastdown vs. $[H_2]_{FW}$ (1/2)

- The required $[H_2]_{FW}$ means the critical hydrogen injection concentration at which the ECP markedly decreases to below the E_{crit}.

Chinshan-1: the required $[H_2]_{FW}$ to reduce the ECP below the E_{crit} (ppm)				
Power (%) \Location	**U. Plenum**	**U. Downcomer**	**Recir. system**	**B. L. plenum**
100	1.74	1.58	0.54	1.35
95	1.76	1.61	0.61	1.4
90	1.67	1.55	0.67	1.37

Chinshan-1: the required H_2 injecting amount to reduce the ECP below the E_{crit} (*scfm*)				
Power (%) \Location	**U. Plenum**	**U. Downcomer**	**Recir. system**	**B. L. plenum**
100	42.6	38.7	13.2	33.1
95	40.7	37.3	14.1	32.4
90	36.4	33.8	14.6	29.9

※ *scfm*---- standard cubic foot per minute

4. Simulation Results (11/11)

Power Coastdown vs. $[H_2]_{FW}$ (2/2)

- The ratio of feedwater flow rate to mass core rate would be different due to power coastdown.
- Under one fixed H_2 injection rate, the $[H_2]_{FW}$ (ppm) would still be different due to changes in feedwater flow rate.

Kuosheng-1: the required $[H_2]_{FW}$ to reduce the ECP below the E_{crit} (ppm)

Power (%) \Location	U. Plenum	U. Downcomer	Recir. system	B. L. plenum
100	1.98	1.93	0.57	1.66
95	1.97	1.91	0.63	1.67
90	1.97	1.92	0.73	1.7

Kuosheng-1: the required H_2 injecting amount to reduce the ECP below the E_{crit} (*scfm*)

Power (%) \Location	U. Plenum	U. Downcomer	Recir. system	B. L. plenum
100	79.2	77.2	22.8	66.4
95	74.4	72.2	23.8	63.1
90	70.1	68.3	26.0	60.5

※ *scfm*---- standard cubic foot per minute

5. Summary (1/2)

- Upon a power coastdown operation, the degree of radiolysis and coolant residence time in the core of a BWR may vary, causing changes in radiolytic species concentrations and resulting in varied HWC efficiency at different locations.
- For the outlets of the upper plenum, the upper downcomer, and the bottom lower plenum of Reactor X, the HWC efficiency did not experience any significant changes upon power coastdown operations at these locations.
- The [O_2], [H_2O_2], and the ECP monotonically increased with decreasing power level at the recirculation system outlets.

5. Summary (2/2)

- **No consistent trend could be found for changes in the effective $[H_2]_{FW}$ as a function of decreased power level in the PCC of Reactor X.**
- **The impact of power coastdown on the HWC effectiveness in a BWR is expected to vary from location to location and eventually from plant to plant due to different radiation dose rates and physical dimensions.**
- **The foregoing statement also holds for the cases of power uprate and core flow rate variation.**

6. Acknowledgements

The authors gratefully acknowledge the funding support from Taiwan Power Company, Atomic Energy Council and National Science Council of Taiwan.