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A Review of Reactor Coolant Chemistry Behavior during Flexible Reactor Operation of PWR NPP

Seung-Ho Lee *, Hyuk-Chul Kwon, Cho-Rong Kim, Yong-Sang Cho, Wook Sohn

Korea Hydro & Nuclear Power Co, Ltd. Central Research Institute
**Corresponding author: Davidlee@khnp.co.kr*

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1. Introduction

Most nuclear power plants(NPPs) in Korea maintain full power operation throughout the entire period. However, recently, flexible operation corresponding to load-following operation has been implemented due to changes in power demand. As power output variations increase, changes in the primary and secondary system water chemistry have been reported. In order to evaluate safety, gap analysis based on operational data was performed. This paper describes the analytical methodology and results for reactor coolant chemistry behavior under flexible operation

2. Gap Analysis Method

Domestic nuclear power plants perform output reduction operation of approximately 20% (100% to 80%). Chemistry data from six units that experienced power reduction were analyzed. Output fluctuation data were compared with normal operation conditions. The reactor coolant chemistry changes were evaluated considering boron injection and dilution, theoretical pH variation due to boron and lithium concentration changes, hydrogen concentration changes due to oxygen ingress, and ammonia generation due to nitrogen ingress. Correlation analysis between chemistry data and radiation monitoring data was performed.

3. RCS Water Chemistry Gap Analysis Result

Based on the chemistry data of five operating cycles with power reduction operation, comparative analysis with normal operation was conducted. Variations in boron and lithium concentration due to boron injection and dilution were evaluated. Changes in hydrogen concentration due to oxygen ingress and ammonia generation due to nitrogen ingress were calculated. The relationship between boron dilution and chemistry parameter variation was confirmed through correlation analysis.

3.1 Changes in RCS pH and Lithium Concentration

For power reduction operation, boric acid is injected into the reactor coolant system, and pH decreases as boron concentration increases and lithium is diluted. During power increase operation, boron concentration decreases and lithium concentration decreases due to boron dilution. The variations of pH and lithium concentration during flexible operation were evaluated.

Table 1. Calculation data of pHt and Li during Flexible Operation

RX 100%			**RX(→80%)**		**RX (→100%)**		**Difference**	
Boron (ppm)	**Li (ppm)**	**pHt(2)**	**Li (1) (ppm)**	**pHt(2)**	**Li (1) (ppm)**	**pHt(2)**	**Li (1) (ppm)**	**pHt(2)**
1500	3.5	7.16	3.45	7.15	3.36	7.15	0.14	0.01
1000	2.58	7.2	2.54	7.18	2.44	7.18	0.14	0.02
500	1.42	7.2	1.4	7.16	1.28	7.16	0.14	0.04
300	0.98	7.2	0.97	7.15	0.83	7.13	0.15	0.07

(1) Calculation Boration and Dilution mass into MOC Boron worth(-7.75 pcm/ppm) and Power Defect
(2) Calculation pH (at 310℃) into EPRI pH Calculator

Table 2. Plant analysis data of pHt and Li during Flexible Operation

Classification	**RX 100%**			**RX(→80%)**		**RX (→100%)**		**Difference**	
	Boron(ppm)	**Li (ppm)**	**pHt**	**Li (ppm)**	**pHt**	**Li (ppm)**	**pHt**	**Li (ppm)**	**pHt**
UNIT-A	679	1.94	7.23	1.93	7.22	1.76	7.19	0.18	0.04
UNIT-B	862	2.58	7.26	2.58	7.26	2.56	7.26	0.02	0.00
UNIT-C	819	2.2	7.21	2.19	7.20	2.23	7.21	-0.03	0.00
UNIT-D	681	1.57	7.14	1.57	7.13	1.54	7.13	0.03	0.01
UNIT-E	916	2.26	7.18	2.25	7.18	2.25	7.18	0.01	0.00
UNIT-F	527	1.55	7.22	1.54	7.21	1.50	7.21	0.05	0.07

3.2 Changes in Dissolved Oxygen and Hydrogen in RCS

When Calculating the influent concentrations of DO(Dissolved Oxygen) from Reactor Makeup Water Tank and Refueling Water Storage Tank as 100ppb and 8 ppm respectively, the change in DH(disolved hydrogen) concentration is calculated to be 0.2 ~ 0.23 cc/kg·H_2O. It is evaluated that DO influx during flexible operation has a mininal effect on DH level, maintaining them within control limits

Table 3. Calculation of Hydrogen Consumption in the RCS

Boron(ppm)	**Boration(ℓ)**	**Dilution(ℓ)**	**O_2 Ingress(g)**	**Hydrogen Consumption(cc/kg)**
1500	**3677.01**	**6057.39**	**30.43**	**0.199**
1000	**3452.87**	**10154.12**	**29.02**	**0.189**
500	**3359.13**	**22451.84**	**29.49**	**0.193**
300	**3760.13**	**42364.68**	**34.73**	**0.227**

3.3 Effect of Boronation and Dilution on Dissolved Nitrogen in RCS

Nitrogen introduced into the reactor coolant system through boric acid and dilution water generate ammonia under high radiation condition and is removed by ion exchanger. Also nitrogen ingress can generate carbon-14 through reactions, only ammonia generation was calculated to evaluate chemical impacts.

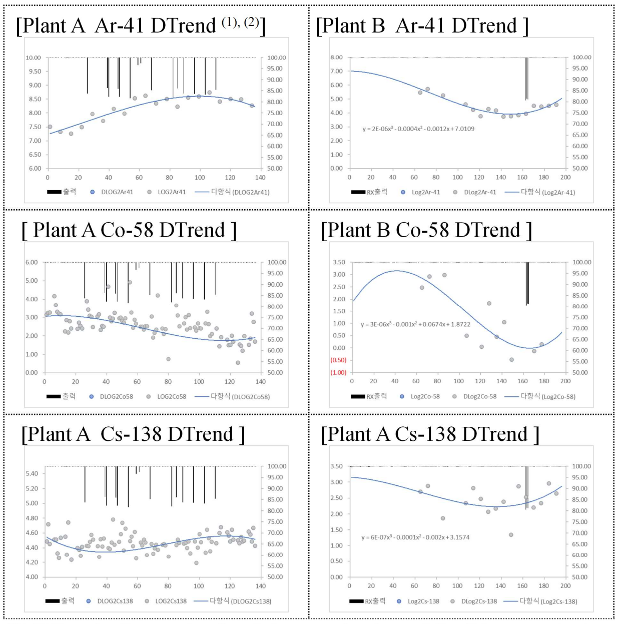
Table 4. Calculation of Ammonia Generation in the RCS

Boron(ppm)	Boration(ℓ)	Dilution(ℓ)	N_2 Ingress$^{(1)}$(ℓ)	NH_3 Gen.$^{(2)}$(ppm)
1500	3677.01	6057.39	157.54	0.82
1000	3474.78	10216.70	221.58	1.15
500	3359.13	22451.84	417.72	2.17
300	3760.13	42364.68	746.48	3.87
100	3734.28	113422.16	1896.06	9.83

(1) N_2 Solubility 0.000578 mol/kg(25℃, 1atm)
(2) Chemical Reaction : $N_2 + 3H_2 \rightarrow 2NH_3$

3.4 RCS Activity Transition

Radioactive corrosion products in the RCS are mainly activated to Co-58, Co-60, Mn-54, and Cr-51. The inventory of radionuclides depends on diverse parameters, including operating duration, power density and fuel cycle. Although reported that Reactor power changes may increase radioactivity up to approximately 400%, no consistent correlation with power variation was observed in the six cases. Transient increases in Ar-41 due to boric acid and make-up water injection and decreases in Cs-138 due to the reduction in neutron-induced fission, whereas Co-58 variation was not significant.


[Plant A Ar-41 DTrend $^{(1), (2)}$]
[Plant B Ar-41 DTrend]
[Plant A Co-58 DTrend]
[Plant B Co-58 DTrend]
[Plant A Cs-138 DTrend]
[Plant A Cs-138 DTrend]

(1) DTrend : Converting Log2 (except the data of flexible operation)
(2) Trend line : Third order polynomial equation

Fig. 1. Analysis of radioactivity in RCS

3.5 Correlation of RCS Activity

Correlation analysis of radioactive material behavior in the reactor coolant system using Pearson correlation coefficients did not show a clear correlation with power variation.

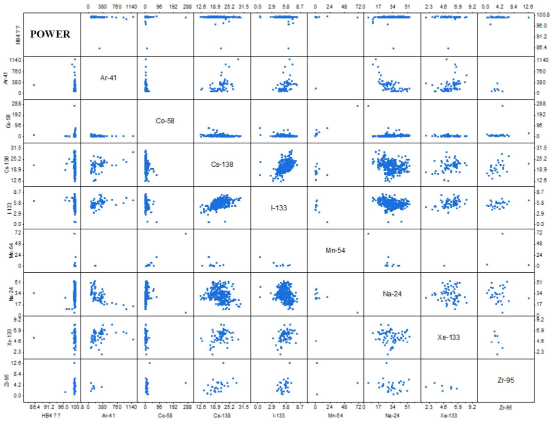


Fig. 2. Correlation Analysis between Reactor Power and RCS activity

4. Conclusion

The chemical fluctuation of flexible operation (100–80–100%) in six unit data were evaluated. The chemical variations resulting from flexible operation were calculated, and it was confirmed that they remain within the reference range. As the operation period increase, the chemical impact of flexible operation also rises. If the magnitude of flexible operations increase toward the end of cycle, proactive chemical control is required. Radionuclides are clssified into fission products, activated corrosion product and impurities nuclides, each exhibiting distinct tendencies. Fission products such as Cs-138, I-135 show a correlation with each other. however, no significant correlation with reactor power has been identified. While activated corrosion products such as Co-58, Mn-54 exhibit increased fluctuations during reactor power transitions, the results are plant-specific, necessitation further comparative sudies. The influx of impurities like Ar-41 through boration and dilution leads to substantial variation in activity. These impurities are evaluated to have the most significant impact on the rise of tatal activity during flexible opeation at the end of the cycle.

Futher verification is planned using continuous monitering equipment, such as ISOCS and CZT.

REFERENCES

[1] J. McElrath, Flexible Operations: Gap Assessment of Impacts upon PWR Chemistry, EPRI, TR-3002008062. pp.5-4, 2016.