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SG Tube Leakage Monitoring System Using Capillary Ion Chromatography

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1. Introduction

A steam generator for transferring heat toward the turbine of a nuclear power plant (Steam Generator, SG) have frequently occurred an accident of the tube rupture which caused by deterioration according to the long-term operation, such as corrosion caused by deposits of the upper support plate of the tube. The leakage of radioactive material from the primary system to the secondary system (Primary-to-Secondary Leak, PSL) has a bad effect on the safety promotion about nuclear power plants (NPPs), a public image management, and external environmental pollution [1,2].

Currently, the existing monitoring technology by using certain radionuclides produced by nuclear fission (^{16}N, ^{3}H, Xe, etc.) have many weaknesses which can be applied in terms of more than 20% of the reactor power. Therefore, it happens frequently the coolant leaks accidents domestic nuclear overseas NPPs as well as domestic those.

The alternative monitoring method of SG tube have been recommended by domestic regulatory authority (KINS) and the Electric Power Research Institute (EPRI) all over the world, because it can't be accurately detected the tube leakage monitoring during low-power operation with slow neutron rate [2,3]. This study was performed a new method using capillary tube ion chromatography (IC) enhanced peak resolutions and the stability of the equipment in order to seek for the field applicability as the on-line measuring instrument.

2. Methods and Results

2.1 Materials and Methods

For the purpose of simulated anion chemical composition contained in the secondary system of the NPPs, sodium fluoride (NaF, 99%), sodium acetate (CH_3COONa, 99 %, Sigma Aldrich), glycolic acid (1,000 mg/L in H_2O), and formic acid (1,000 mg/L in H_2O) which is generated by ethanolamine (ETA) as a by-product was used 1 ppm, respectively, as shown in Table 1. And, hydrazine hydrate ($NH_2NH_2{\cdot}H_2O$, 99.9%, Sigma Aldrich), ethanolamine (ETA; $NH_2CH_2CH_2OH$, 99.5%, Sigma Aldrich), ammonia solution (2M in ethanol, Sigma Aldrich) was used each 0.1, 5, and 1 ppm to treated the liquid state, in order to review the effect of the cation in the secondary system. Boron (B) concentration as the simulated sample was 5, 50 ppb. They were carried out each of the reproducibility and the recovery rate. The monitoring condition using capillary IC for determining the trace level of boron is shown in Table I. Moreover, it showed the analysis results of the secondary water system in the HB #5 (Table II).

Table I: Condition of boron analysis using capillary IC

Column	Anion exchange Separation column (0.4×250mm)
Eluent Source	0.8 M Sorbitol / *8~65 mM Potassium Hydroxide
Flow Rate	0.01 mℓ/min
Sample Volume	5 μℓ
Column Temp.	30 ℃
Cell heater Temp.	35 ℃
Detector	Suppressed Conductivity detector
Suppressor current	12 mA
Analysis time	15 min

*8~65 mM Potassium Hydroxide: Auto-eluent generator

Table II: Chemical analysis of the secondary system water.

Constituent	Equipment	Unit	Concentration	
			2013.02	2014.12
ETA	IC	ppm	4.06	5.3
Hydrazine (N_2H_4)	DR5000	ppb	105.4	140
Ammonium (NH_4^+)	IC	ppm	1.84	1.06

2.2 Analysis

Figure 1 shows a flowchart diagram of SG leakage monitoring system which is based on capillary IC used in this study. In the event of an emergency, the sample has gone through towards the outlet along the bypass line without getting into the leakage monitoring system when only SV-2 (Solenoid Valve STHAD-021S, SYNTEK) was closed, on the contrary to this, SV-1 was opened. Two pressure sensors, PS-1 (Pressure Sensor; ISE-80, SMC) and PS-2 are installed at both ends of pretreatment filter in order to determine whether the saturation of the pre-treatment filter.

3. Results and Discussion

3.1 Standard Calibration report

As shown in Table III, the calibration curve that it used standard solution of boron with the concentration of 5, 10, 50 and 100 ppb showed good reliability, which indicates a correlation coefficient of 0.99981.

Table III: Boron standard calibration report

Peak	#points	Time(min)	R^2	Slope
Boron	4	6.71	0.99981	0.007

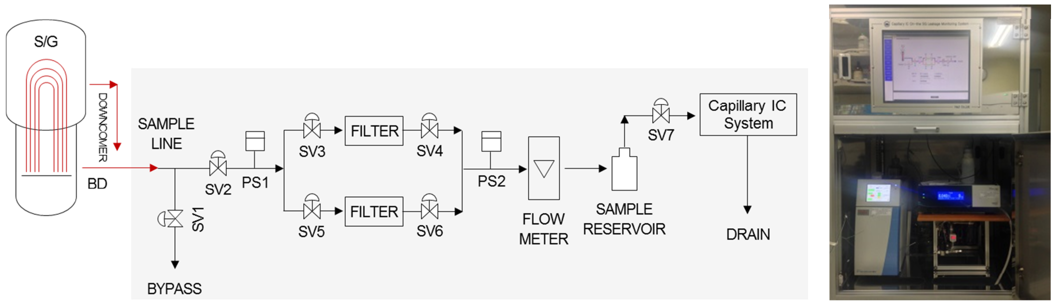

Fig. 1. Flow chart of on-line SG tube monitoring system using capillary IC and SG tube leakage monitoring system

3.2 Boron 5, 50 ppb Simulated sample

Figure 2 and 3 shows the simulated sample as the secondary water system was used B 5, 50 ppb by mixture with the same chemicals in there. The result showed that the standard deviation was obtained 1.966, 1.024 ppb, respectively. And each of the recovery rates was 98.33 and 100.97% (Table IV,V). These measured values were automatically converted to a leakage rate in the front screen of the SG tube leakage monitoring system by an algorithm in the PLC.

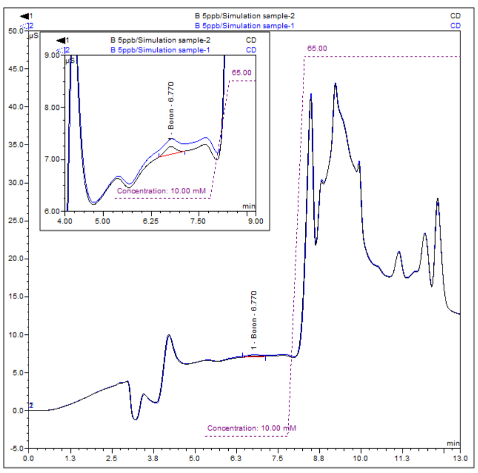

Fig. 2. Chromatogram of B 5 ppb/simulated sample analysis by using capillary IC with capillary anion exchange column

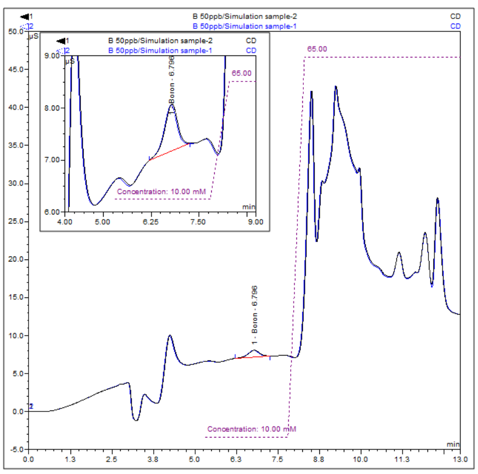

Fig. 3. Chromatogram of B 50 ppb/simulated sample analysis by using capillary IC with capillary anion exchange column

Table IV: Reproducibility test of B 5 ppb/simulated sample

Simulated Sample	Time (min)	Area (µS*min)	Amount (ppb)
B 5 ppb #1	6.793	0.0491	4.9004
B 5 ppb #2	6.770	0.0482	4.7660
Sum	13.564	0.097	9.666
Average	6.781	0.049	4.833
Rel.Std.Dev.	0.245%	1.283%	1.966%

Table V: Reproducibility test of B 50 ppb/simulated sample

Simulated Sample	Time (min)	Area (µS*min)	Amount (ppb)
B 50 ppb #1	6.773	0.3490	50.6053
B 50 ppb #2	6.796	0.3539	51.3431
Sum	13.569	0.703	101.948
Average	6.785	0.351	50.974
Rel.Std.Dev.	0.235%	0.974%	1.024%

4. Conclusions

The reproducibility test with simulated samples was obtained a high reliability within 2% standard deviation. The concentration of B 5 ppb means that it can monitor the 0.8 L/h leak rate of SG tube leakage, when the concentration of boron in RCS is more than 200 ppm. Besides, the measurement technique using capillary tube is possible to reduce the waste solution about 1/100 in comparison with the conventional IC, due to demanding a very small amount of sample. This SG tube leakage monitoring system was expected to be reliable and effective method allowing to monitor in despite of the low reactor power and abnormal conditions.

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