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Reactor Coolant Chemistry Behavior during Flexible Reactor Operation

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1. Introduction

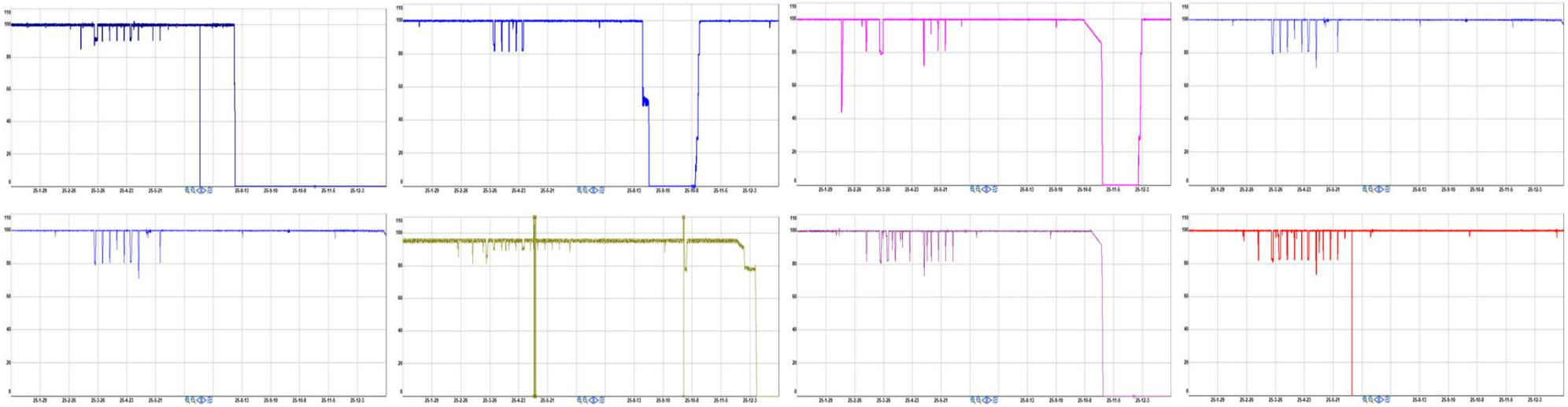
Definition

FRO(Flexible Reactor Operation) : Operation at constant power for significant periods of time (12 hours or greater) at a set power levels

Load Following : (include flexible operations) fast (on the order of seconds to minutes) changes in power to stabilize grid frequency, as well as less frequent (15 minutes to hours) adjustments to accommodate grid power demand

국내 원전현황

원자로출력 100 → 80% 탄력운전 / 경부하 기간(주말 등)



1. Introduction

Gap Analysis Contents

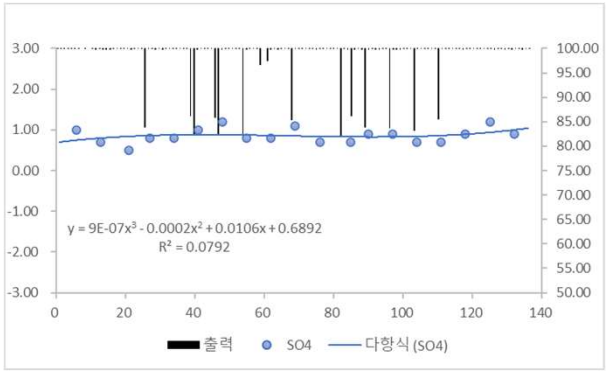
- RCS Boration 및 Dilution에 따른 pHt와 리튬농도 변화
- RCS 용존산소 및 용존수소 변화
- RCS Boration 및 Dilution에 따른 용존질소 영향
- RCS 방사선 핵종농도 변화
- 원자로냉각재계통 관리항목(Control parameter) 영향
- 원자로냉각재계통 진단항목(Diagnostic parameter) 영향
- 주급수계통 관리항목(Control parameter) 영향
- 주급수계통 진단항목(Dianostic parameter) 영향
- 증기발생기 슬러지 축적 및 틈새방출(Hideout) 변화
- 이온교환수지 부하변화

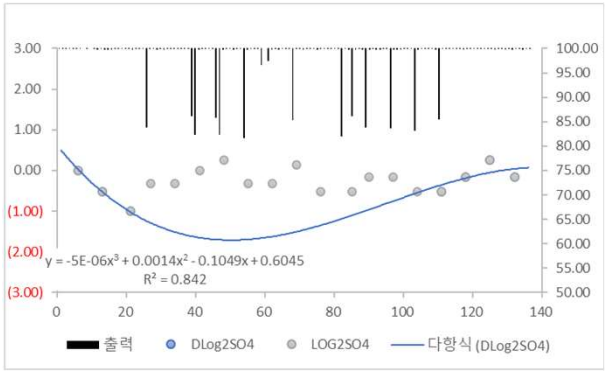
2. Gap Analysis Method

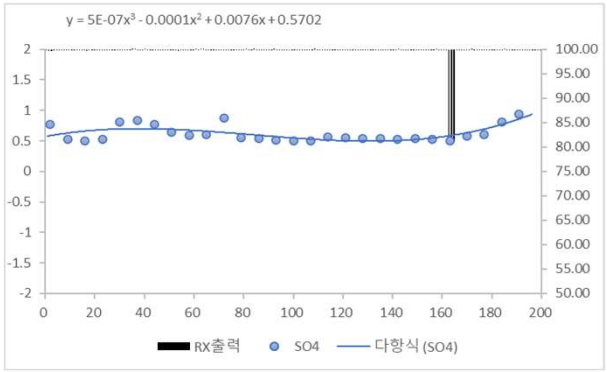
Trend Analysis and Correlation Analysis

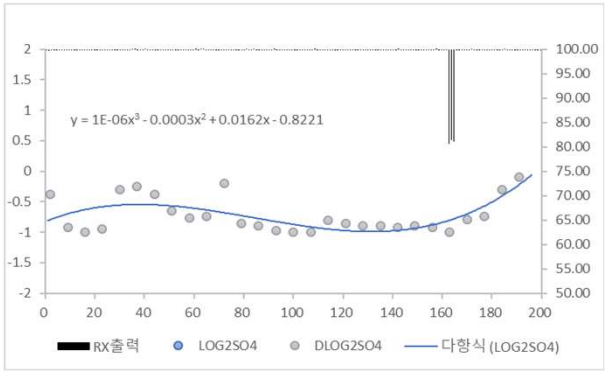
- Trend Analysis : (Original data - Trend)
- D-Trend Analysis : Log2-Data – Trend (3차방정식)
- Pearson Correlation : 출력 – 화학/방사능 분석값 상관성 확인
- Calculation : 출력변동에 따른 붕산수/희석수 사용량

  (B 농도, Li 농도, pH_T, NH_3 생성량, DO/DH 변화)







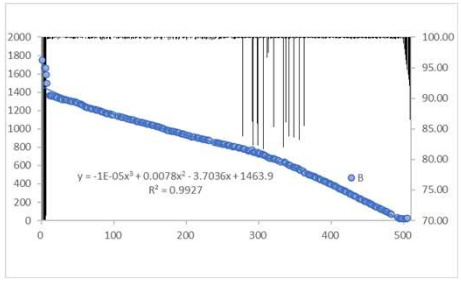


3. Gap Analysis Result

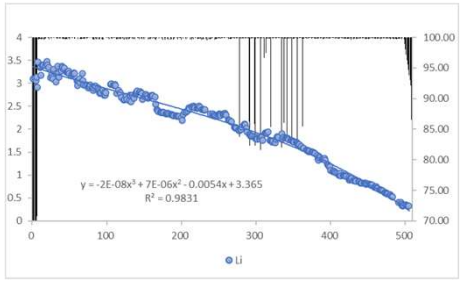
Trend Analysis : (Original data)

▪ Long Term(Cycle) Trend : 다양한 요소에 의한 변동성 때문에 출력 상관성 확인 어려움

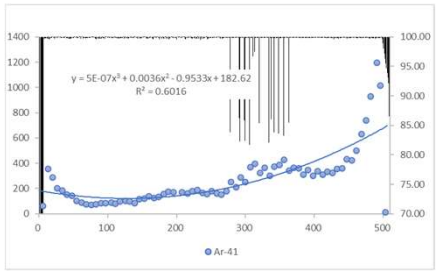
RCS Boron



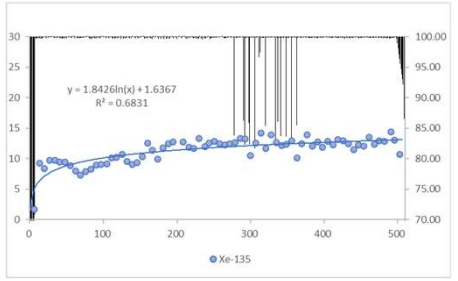
RCS Li

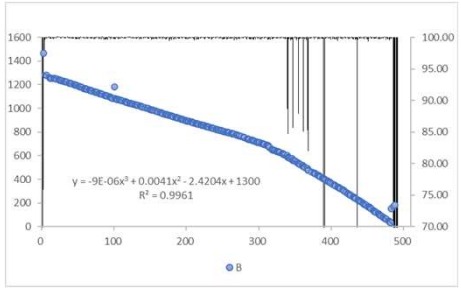


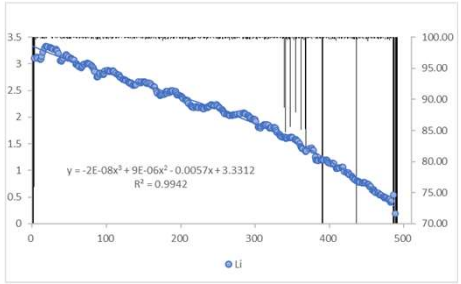
RCS Ar-41

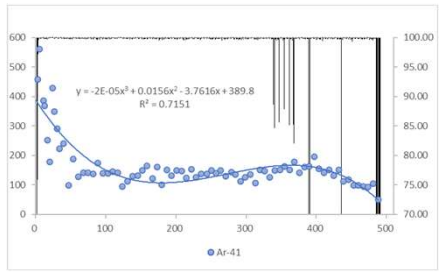


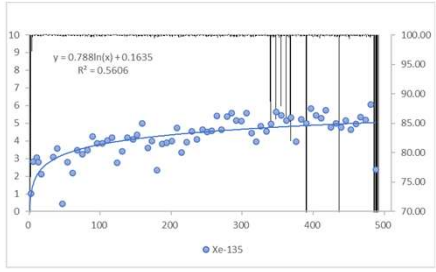
RCS I-135

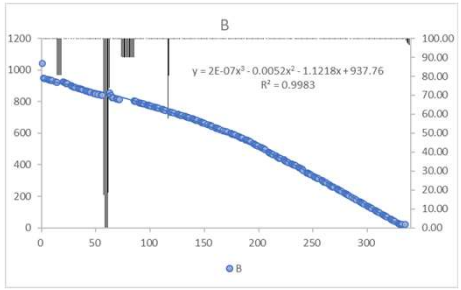


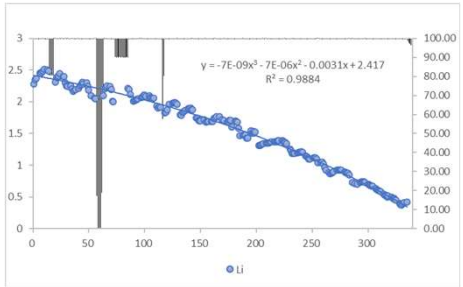


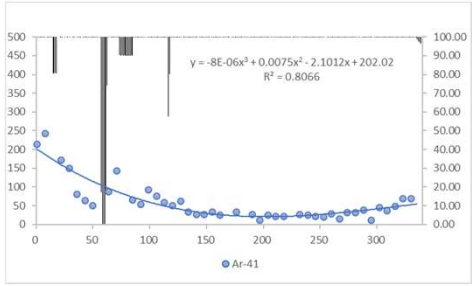


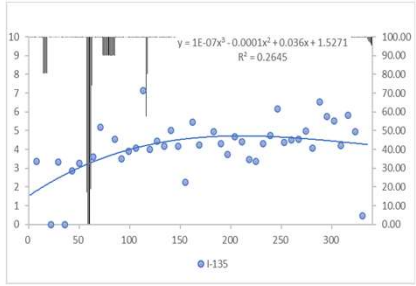










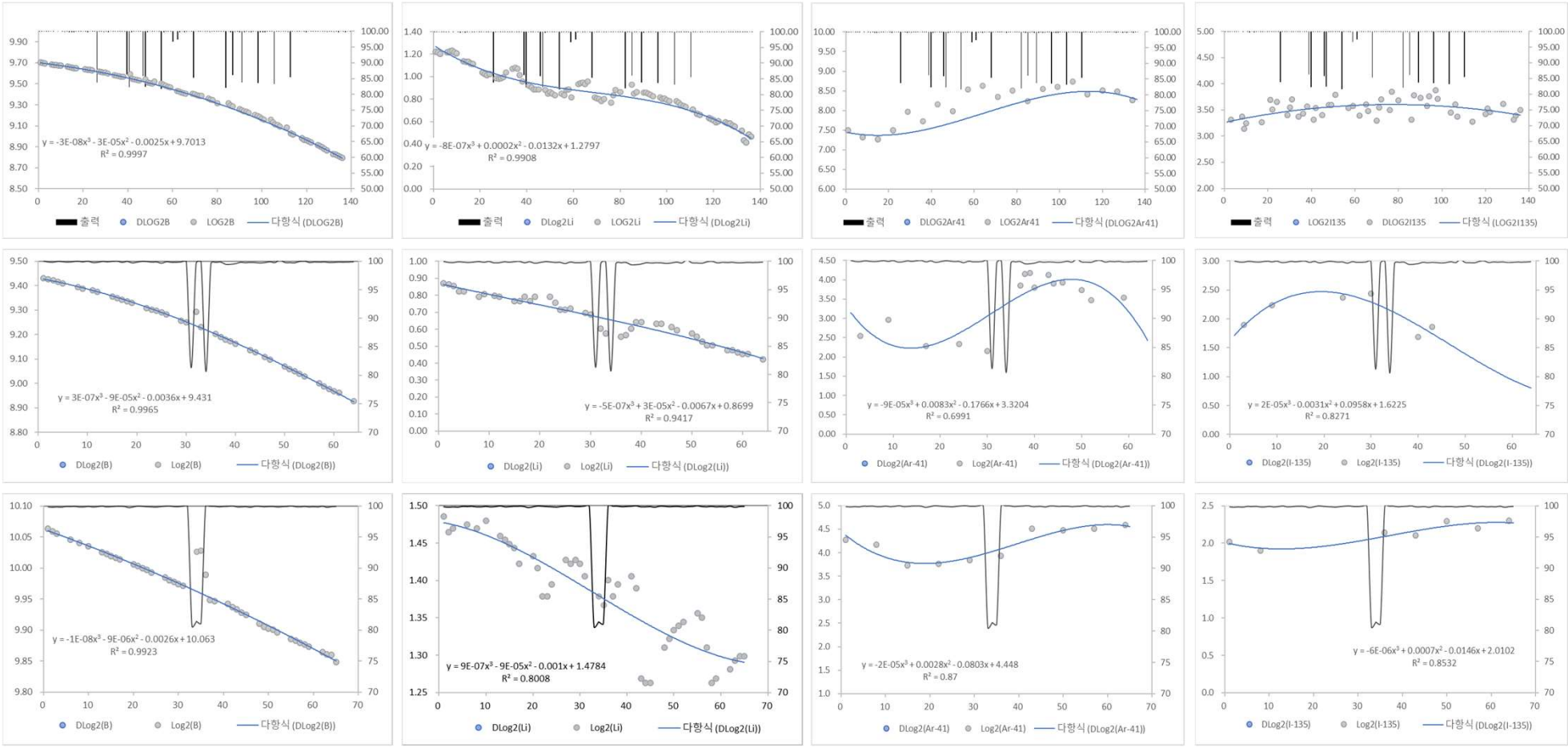


3. Gap Analysis Result

DTrend Analysis : (Log2 data)

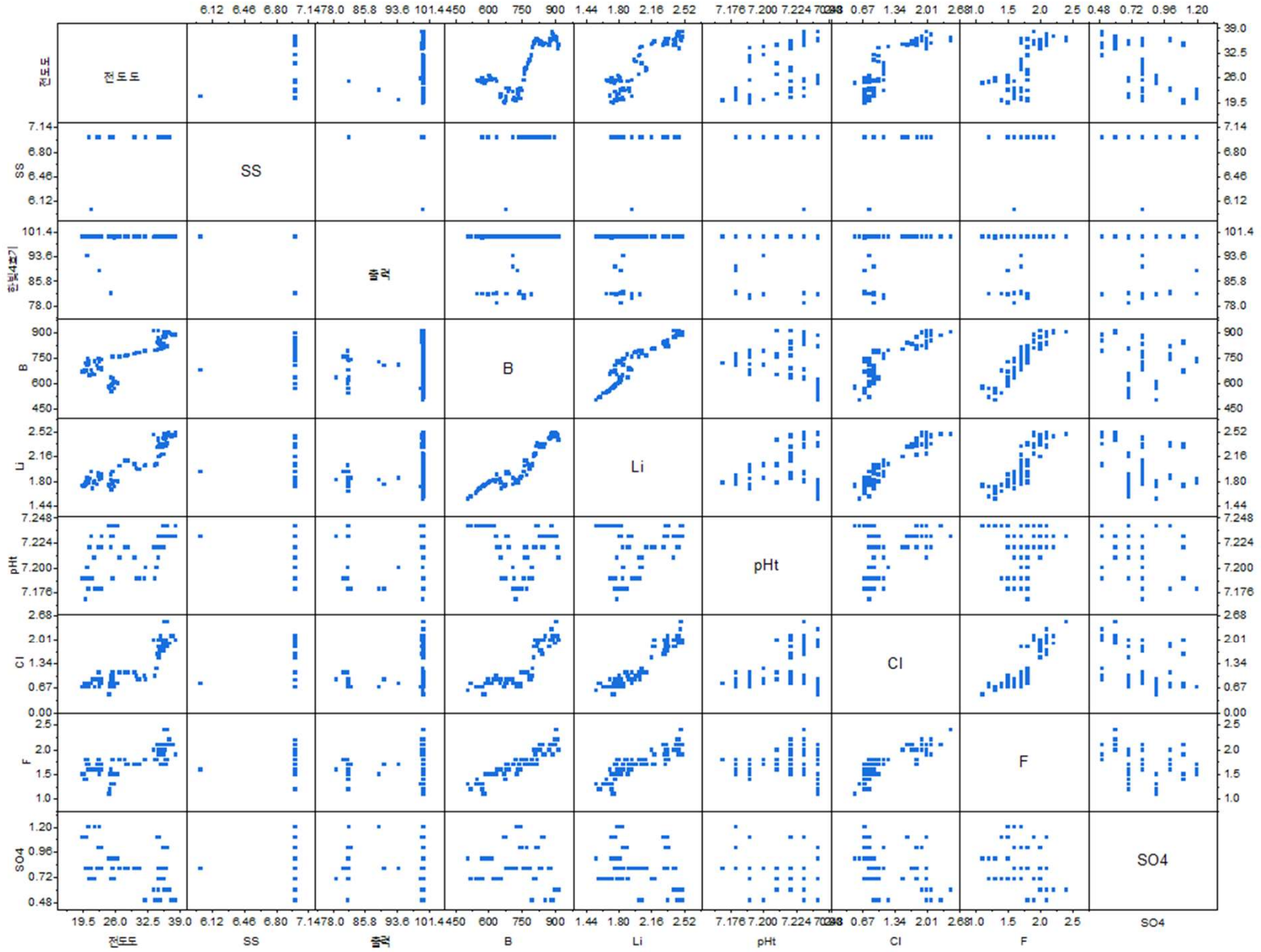
▪ Short Term Trend : 출력변동 Data 제외 Trend 작성 - 시료분석값과 비교

RCS Boron | RCS Li | RCS Ar-41 | RCS I-135



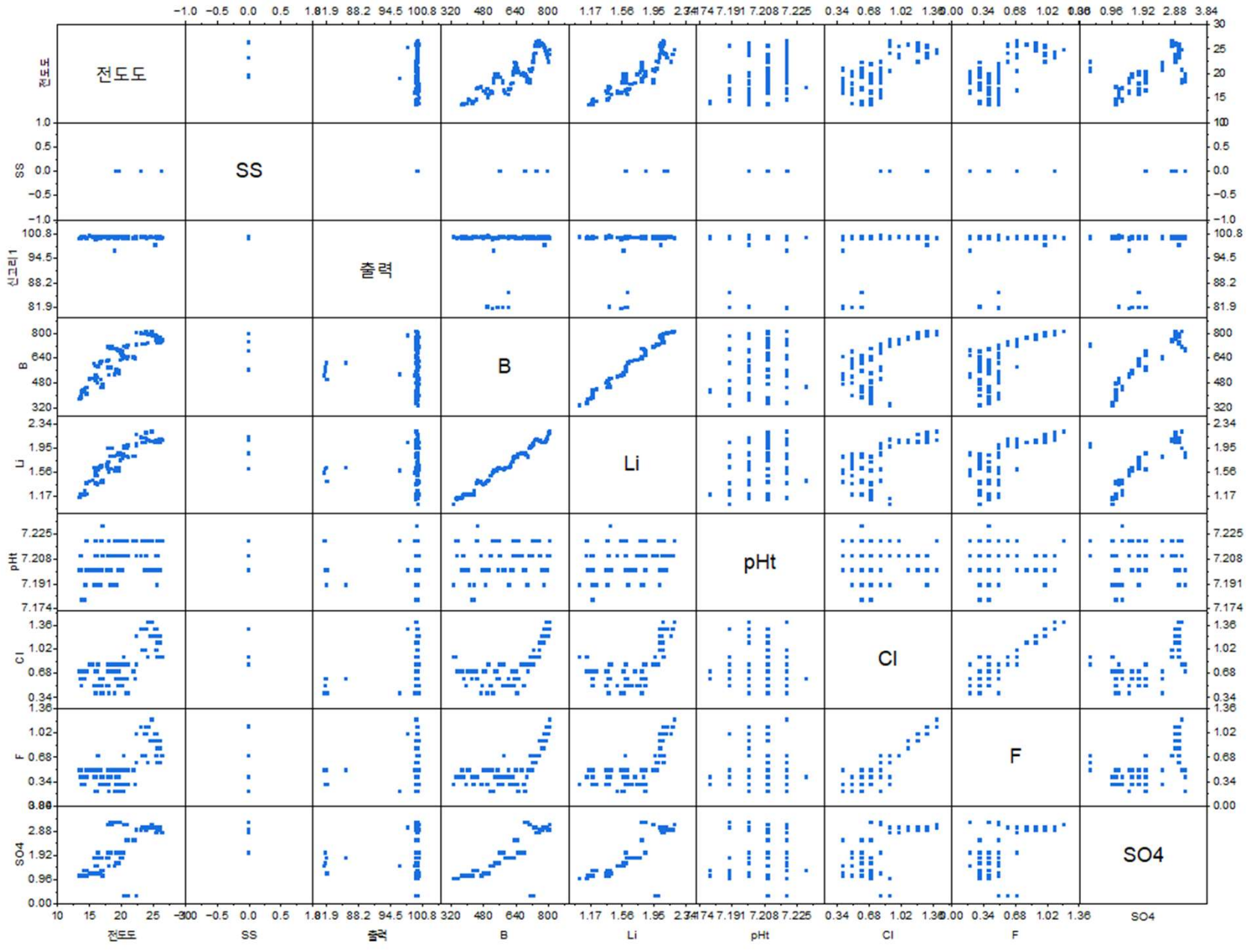
3. Gap Analysis Result

Correlation ▪ 출력-화학변수 상관관계 분석



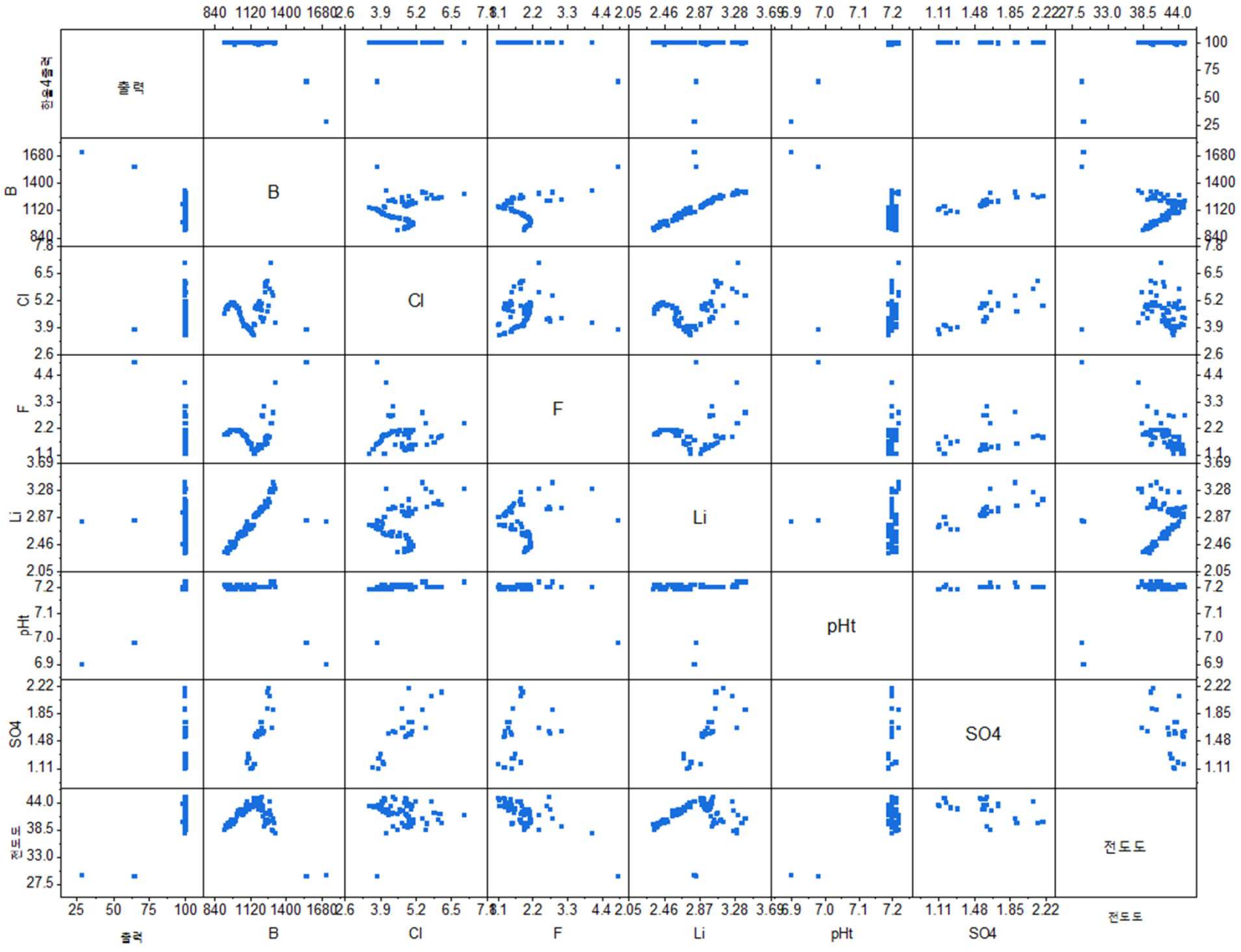
3. Gap Analysis Result

Correlation ▪ 출력-화학변수 상관관계 분석



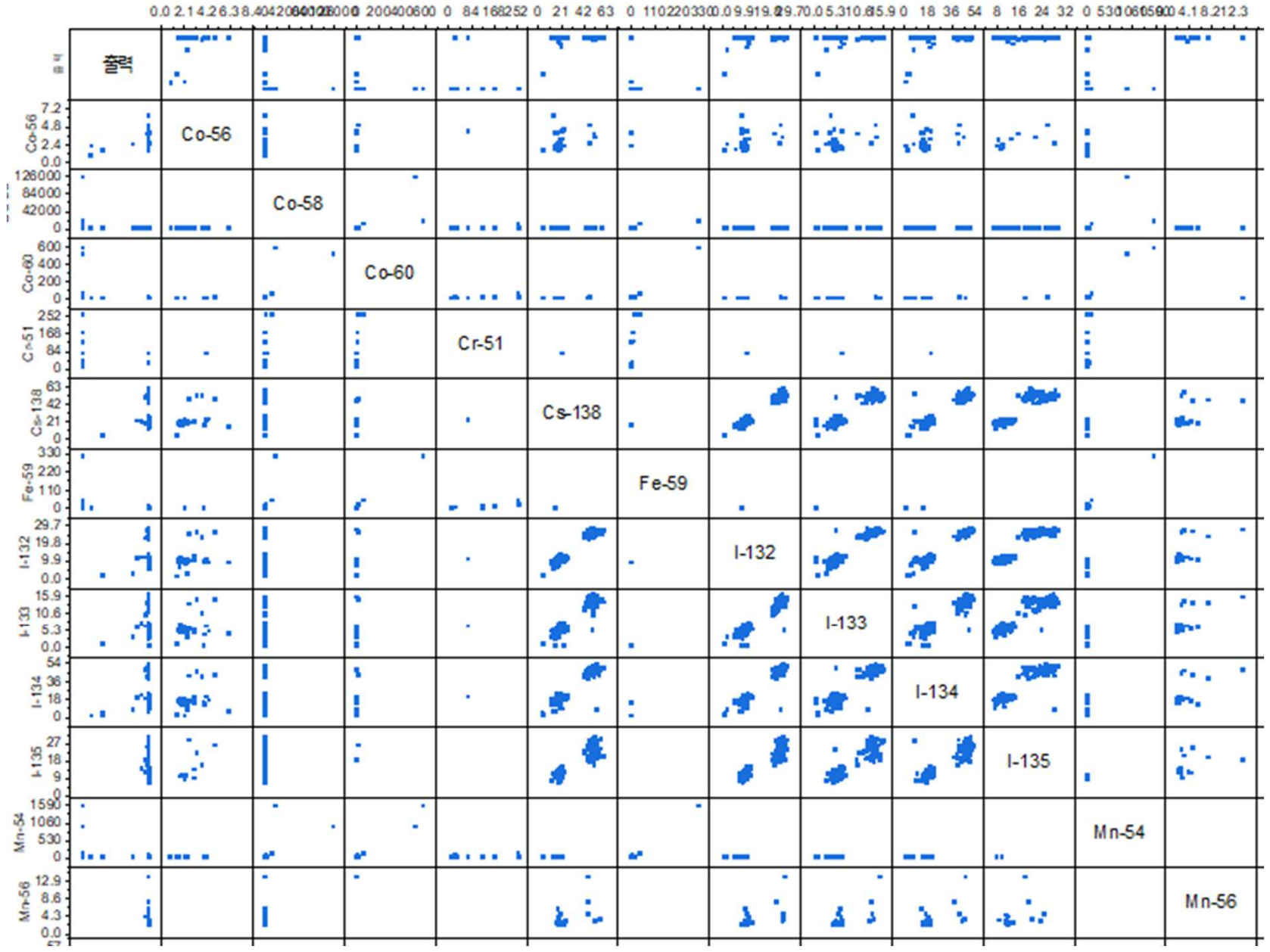
3. Gap Analysis Result

Correlation ▪ 출력-화학변수 상관관계 분석



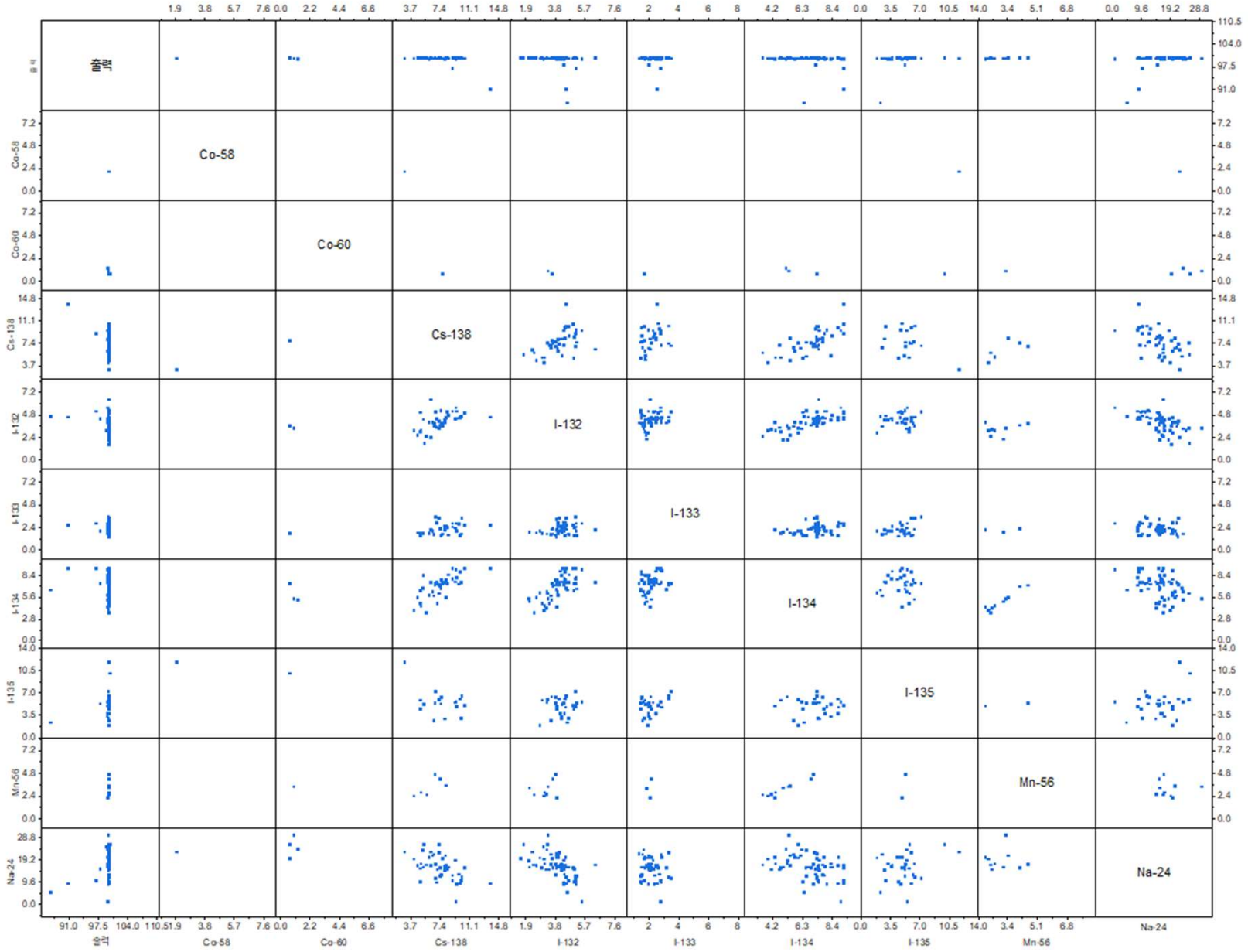
3. Gap Analysis Result

Correlation ▪ 출력-핵종 상관관계 분석



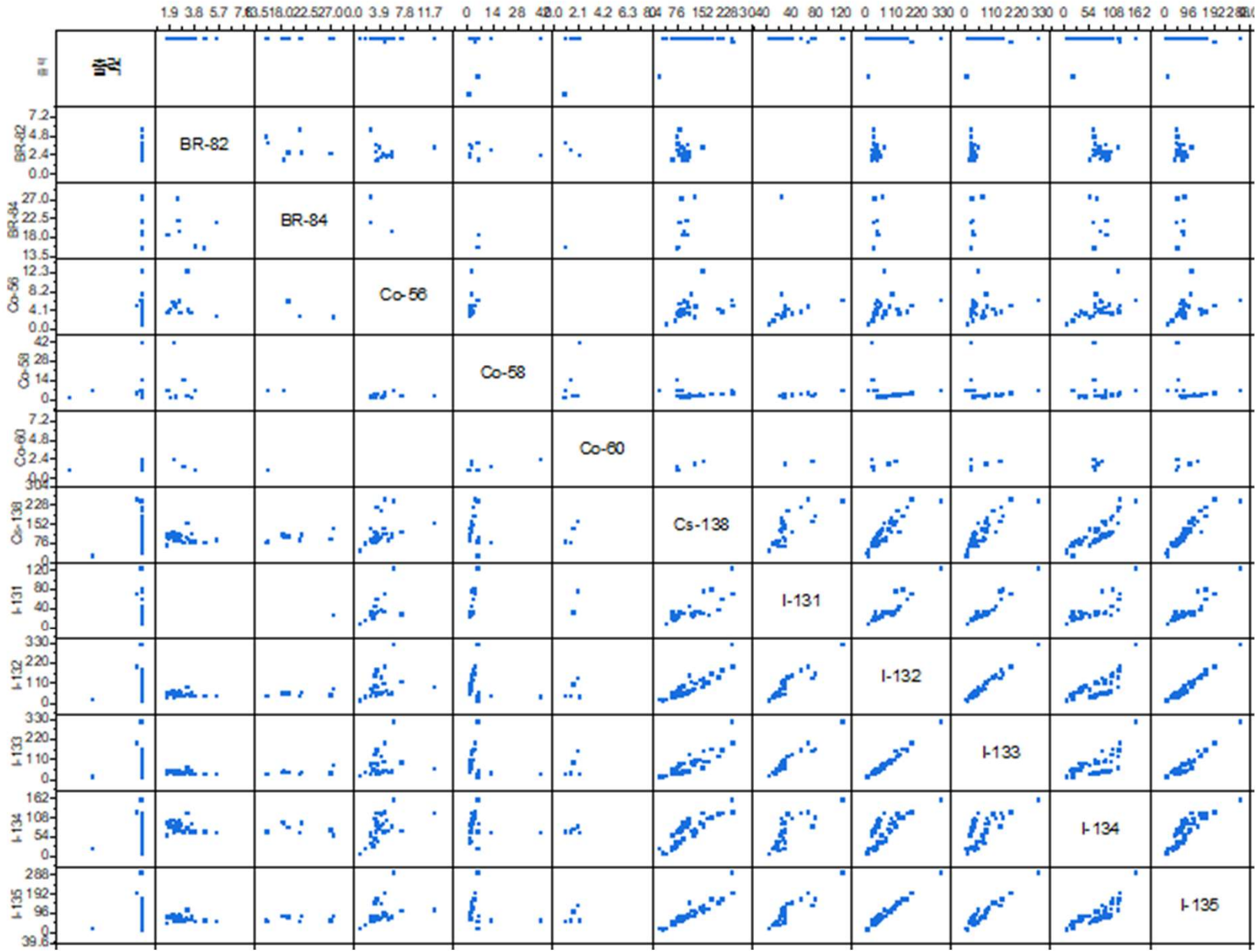
3. Gap Analysis Result

Correlation ▪ 출력-핵종 상관관계 분석



3. Gap Analysis Result

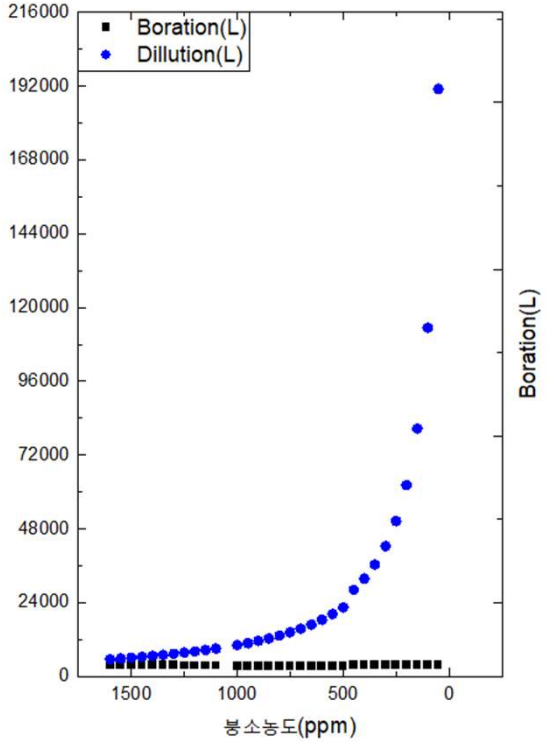
Correlation ▪ 출력-핵종 상관관계 분석

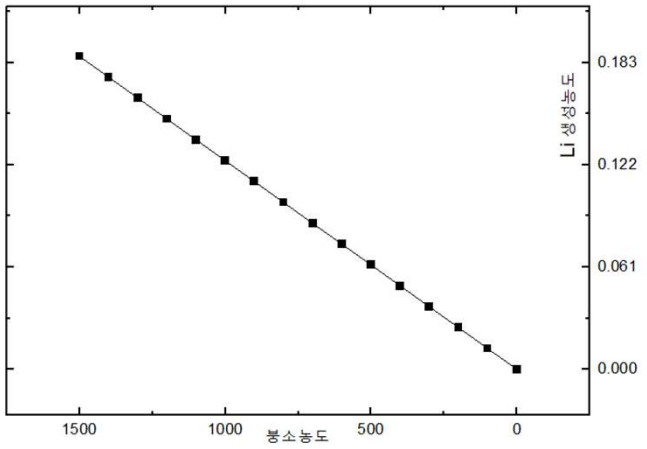


3. Gap Analysis Result

Calculation

- 화학적인 변화 : 붕산수/희석수에 의해 발생
  - 붕산수 : 4,000 ~ 4,400 ppm 붕산수/기체(O_2, Ar, N_2) 용해상태
  - 희석수 : Boron-free / 기체(Ar, N_2) 용해상태
- 출력변동 : 100 → 80 → 100 %
  - 반응도 변화량과 Boron-worth 계산을 통해 붕산수, 희석수 주입량 계산
  - 붕산수, 희석수 주입에 의한 붕소농도, 리튬농도, pH_T 계산
  - 유입되는 기체량 계산

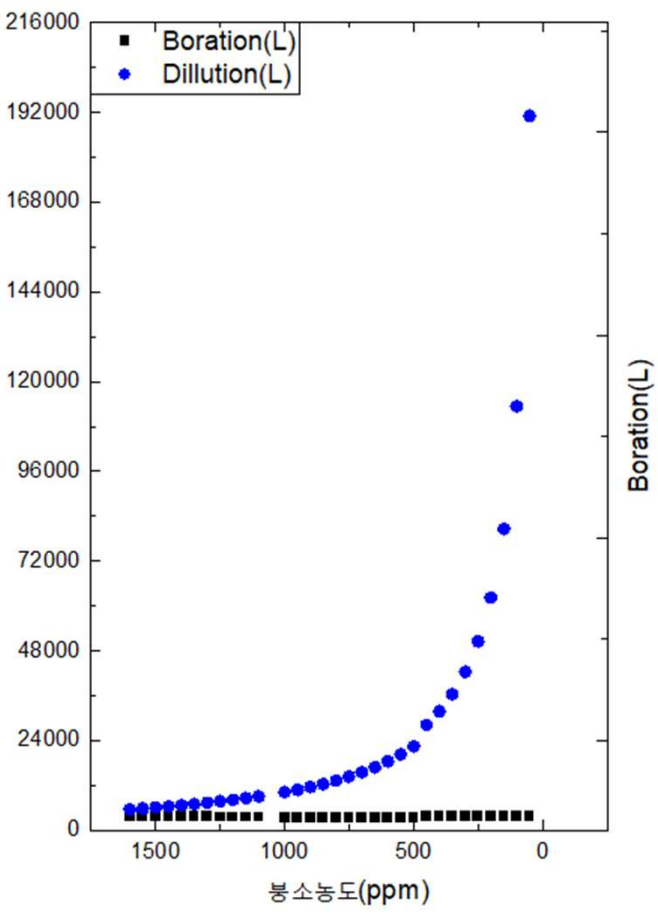


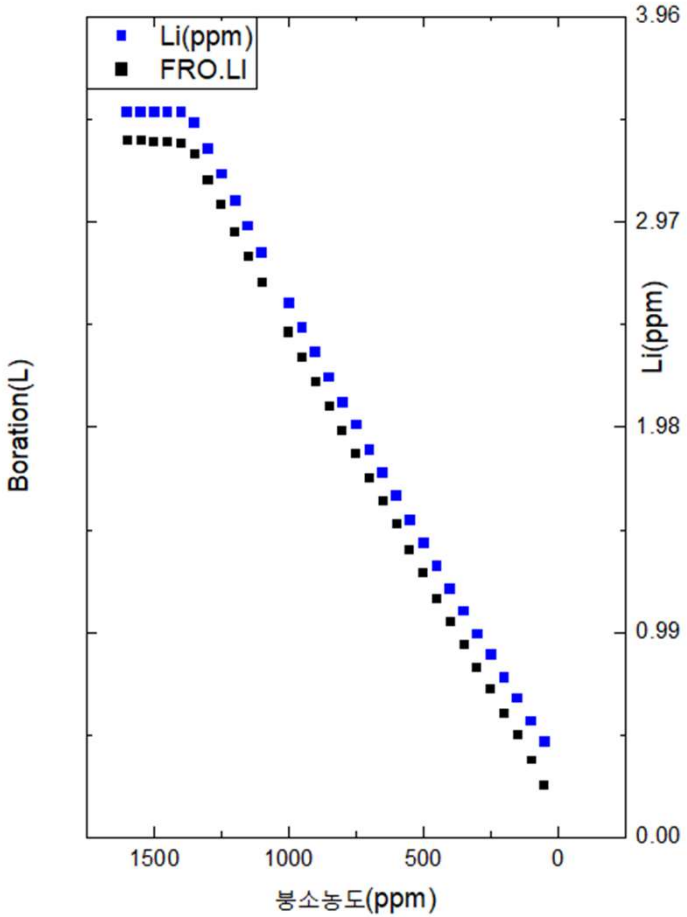


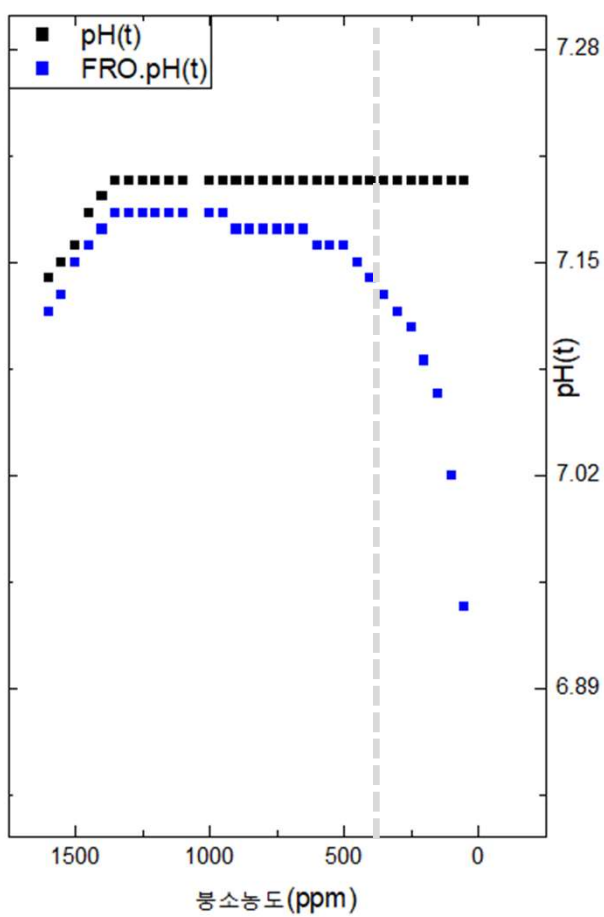
3. Gap Analysis Result

Calculation

- 출력변동 : 100 → 80 → 100 %
  - 반응도 변화량과 Boron-worth 계산을 통해 붕산수, 희석수 주입량 계산
  - 붕산수, 희석수 주입에 의한 붕소농도, 리튬농도, pH_T 계산
  - 유입되는 기체량 계산







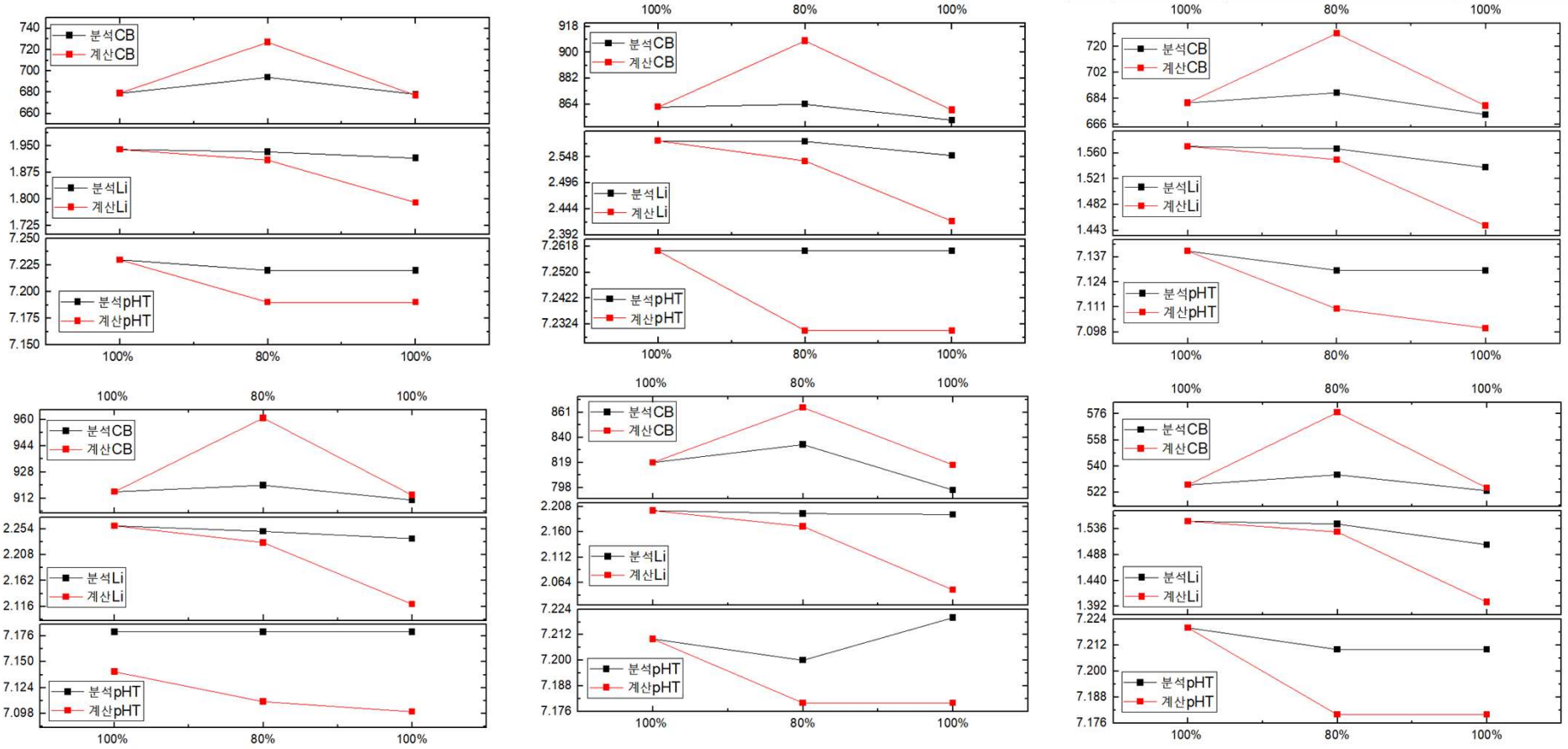
3. Gap Analysis Result

Calculation

▪ 출력변동 : 100 → 80 → 100 %

- 붕산수, 희석수 주입에 의한 붕소농도, 리튬농도, pH_T 계산

구분	Plant-A		Plant-B		Plant-C		Plant-D		Plant-E		Plant-F	
	실적	계산값	실적	계산값	실적	계산값	실적	계산값	실적	계산값	실적	계산값
Boration (L)	850 L	3409.26	100 L	3429.70	600 L	3426.64	580 L	3411.00	1,040 L	3446.00	800 L	3385.00
Dillution (L)	2,180 L	16138.27	2,580 L	12186.27	200 L	12968.50	4,275 L	16092.00	1,350 L	11343.00	5,960 L	21352.00

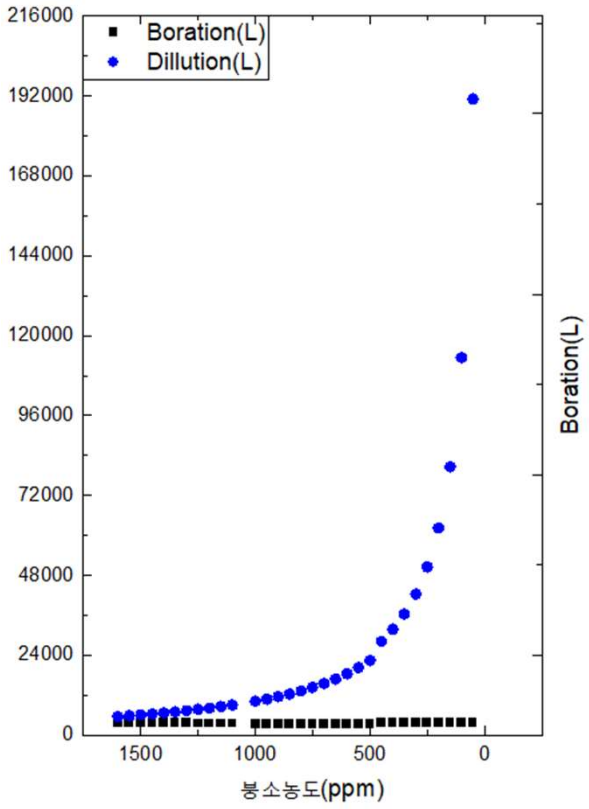


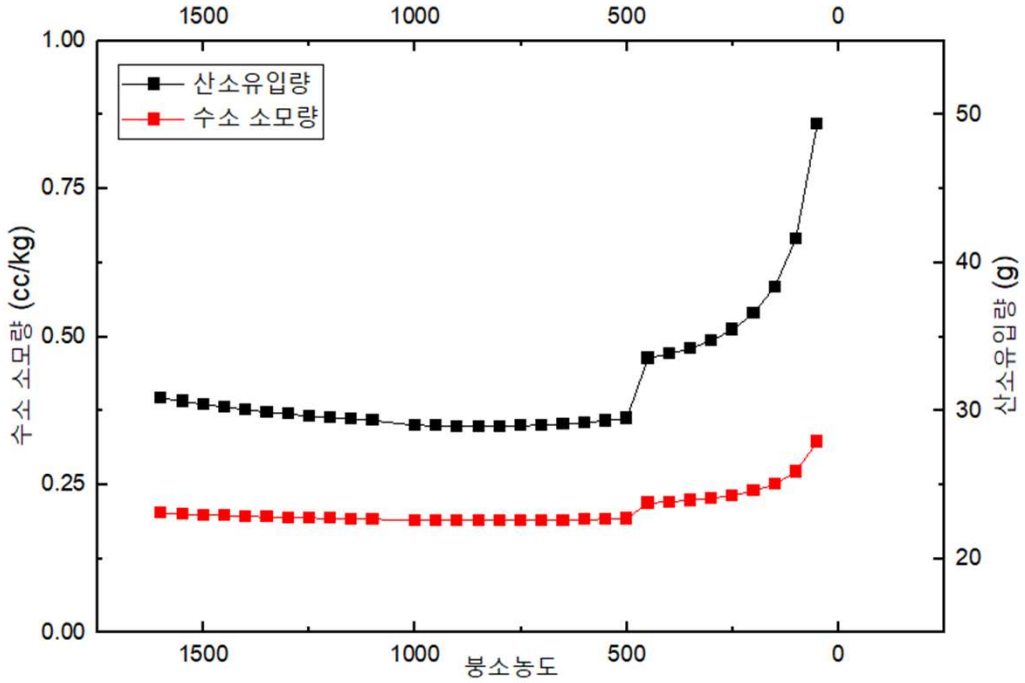
3. Gap Analysis Result

Calculation

▪ 출력변동 : 100 → 80 → 100 %

- O_2 유입량 및 용존수소 농도 변화 (붕산수 : 8 ppm at 25 ℃, 희석수 : 0.1 ppm at 25 ℃)



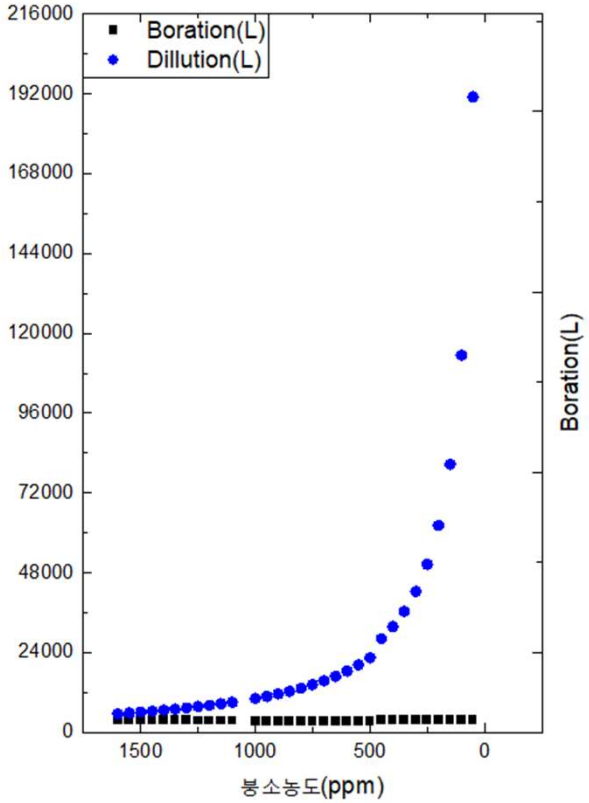


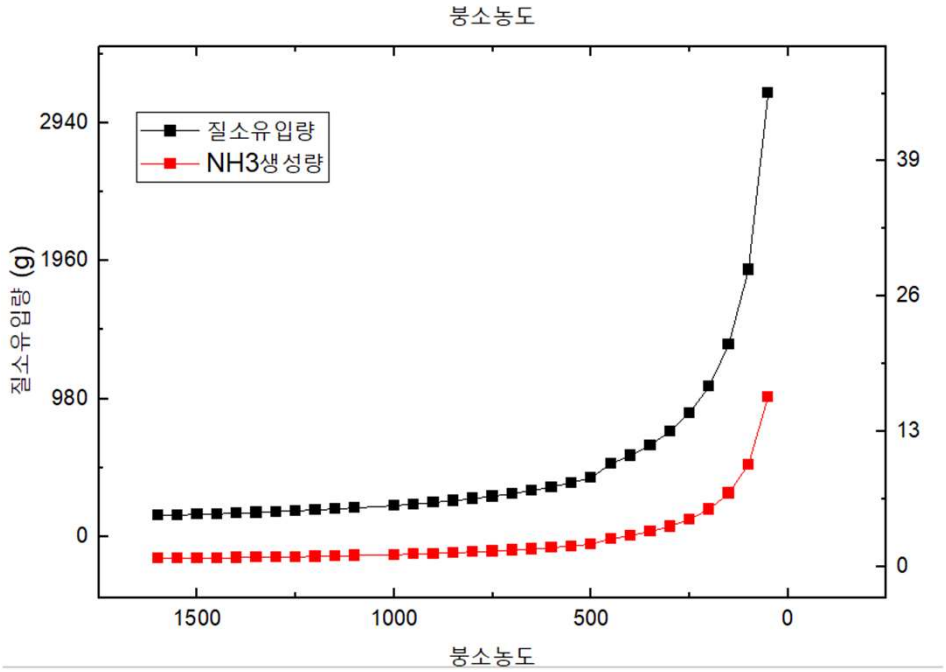
3. Gap Analysis Result

Calculation

▪ 출력변동 : 100 → 80 → 100 %

- N_2 유입량 및 암모니아 생성 (붕산수, 희석수 : 0.000578 mol/kg at 25 ℃)





4. Conclusion

출력변동 시 원자로냉각재 화학적인 영향

- 출력변동에 따른 붕산수, 희석수에 의한 pH_T 변화
- 용해기체(N_2, O_2, Ar) 유입에 의한 암모니아 생성, 용존수소 변화, Ar-41 생성
- 20% 출력변화는 원자로냉각재 수화학적 환경 영향 낮음

출력변동 시 원자로냉각재 방사능 영향

- 핵분열생성물(I,Xe 등)은 출력에 비례
- 낮은 출력변화는 수화학적 영향이 제한적이나,

  → 출력변화가 증가할 경우 수화학적 환경변화에 의한 입자 방사능 증가 가능

  → CRUD 입자 방사능(Co-58, Co-60, Mn-54 등)

경부하 출력변동에 대한 정밀분석

- 출력변동 : 100 → 50 → 100 % 대비 CZT, ISOCS 계측기를 통한 연속진단 예정

THANK YOU

KHNP