Shutdown Hideout Return Chemistry at Browns Ferry-2 and Hatch-2

Technical Report

Shutdown Hideout Return Chemistry at Browns Ferry-2 and Hatch-2

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REPORT SUMMARY

This report describes and analyzes the results of augmented hideout return studies conducted at the Browns Ferry 2 and Hatch 2 BWRs during shutdowns in the spring of 2003. The aim was to provide insights into differences in corrosion of similar fuel cladding materials at the two facilities.

Background

Predicting solution chemistry is important because the chemistry of solutions formed within corrosion product deposits on BWR fuel surfaces may relate to the extent and severity of fuel cladding corrosion. Since techniques employing chemical hideout return data for the prediction of crevice chemistry have shown promise in PWR steam generators, a hideout return study was performed at Susquehanna 2 to assure that the fundamental processes governing hideout and hideout return in BWRs were reasonably well understood. The current report documents augmented hideout return studies conducted in 2003 to provide insights into differences in corrosion of similar fuel cladding materials at Browns Ferry 2 and Hatch 2.

Objective

To conduct hideout return studies at the Browns Ferry 2 and Hatch 2 BWRs.

Approach

In an attempt to provide insights into differences in corrosion of similar fuel cladding materials at Browns Ferry 2 and Hatch 2, the project team conducted augmented hideout return studies during shutdowns in the spring of 2003. The team obtained numerous reactor water samples during the shutdown evolutions and analyzed them for boron, chloride, sulfate, phosphate, fluoride, chrome, iron, copper, zinc, platinum, rhodium, aluminum, calcium, magnesium, sodium, potassium, manganese, vanadium, and silica. Using EPRI's MULTEQ code, the team made predictions of solution chemistry within corrosion deposits during normal operation based on cumulative returns at hot zero power.

Results

Return of highly soluble species such as sodium, potassium, chloride, and fluoride was minimal at both plants reflecting the absence of a tendency to form precipitates at low deposit solution concentration factors relative to the reactor coolant. Silica return was far greater than return of any other species at both plants. Magnesium return was much less than calcium return at both plants due to its four times lower concentration in the condenser cooling water and its tendency to incorporate into spinel type structures. Soluble corrosion product return at Hatch 2, including that of zinc, was generally greater than at Browns Ferry 2 although the core surface area is greater at Browns Ferry 2. This finding could imply a more porous deposit at Hatch 2 leading to faster solubilization kinetics. Lithium return was not detected at Hatch 2. However, limited return was observed at Browns Ferry 2. The lithium source at Browns Ferry 2 is believed to be the control rod blades. Return of platinum and rhodium was negligible at both plants. Return of sulfate was approximately five times greater at Browns Ferry 2 than at Hatch 2. Return of chloride was four times greater. Calcium and silica return at Browns Ferry 2 also was greater than at Hatch 2 reflecting higher impurity source terms for these species. No unusual impurities were detected.

Based on the observation of increased return during cooldown due to precipitate solubilization, concentration factors in the deposit appear to be in the range of several thousand. During normal operation, the pH of predicted deposit solutions at Browns Ferry 2 and Hatch 2 at expected concentration factors is neutral to slightly alkaline. Cladding corrosion is not expected to be accelerated significantly in these solutions compared to corrosion in pure water.

EPRI Perspective

A fraction of the chemical species that concentrate and “hide out” in corrosion deposits will return to the bulk water during a shutdown or power reduction due to void collapse, partial dissolution of precipitates, and diffusion from concentrated liquid solutions to the bulk solution. Concentration measurements made during such evolutions have been used extensively in PWR and was applied to a pair of BWRs. The results showed absence of unusual harmful impurities that may be correlated to the severe corrosion attack of the fuel cladding at Browns Ferry-2 in Cycle 12.

Keywords

BWRs
Chemistry hideout
Fuel cladding corrosion

ABSTRACT

A fraction of the chemical species that concentrate and “hide out” in corrosion deposits in nuclear plants will return to the bulk water during a shutdown or power reduction due to void collapse, partial dissolution of precipitates, and diffusion from concentrated liquid solutions to the bulk solution. Concentration measurements made during such evolutions have been used extensively in PWR systems to estimate hideout and to assess probable chemistry conditions in local regions of the steam generators. This approach is referred to as a hideout return analysis and is routinely employed since concentrations of feedwater and steam borne impurities are very low during normal operation and limitations in analytical sensitivities make it difficult to quantify hideout based on a mass balance approach. This study applied this hideout return analysis to two BWRs, Browns Ferry 2 and Hatch 2, during shutdowns in the spring of 2003. The aim was to provide insights into differences in corrosion of similar fuel cladding materials at the two facilities. Numerous reactor water samples were obtained during the shutdown evolutions and were analyzed for boron, chloride, sulfate, phosphate, fluoride, chrome, iron, copper, zinc, platinum, rhodium, aluminum, calcium, magnesium, sodium, potassium, manganese, vanadium, and silica. Based on these data, EPRI’s MULTEQ code was used to develop predictions of solution chemistry within corrosion deposits during normal operation. The results showed absence of unusual harmful impurities that may be correlated to the severe corrosion attack of the fuel cladding at Browns Ferry-2 in Cycle 12.

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SUMMARY

Because of the possible relation of fuel cladding corrosion to the chemistry of solutions formed within corrosion product deposits on BWR fuel surfaces during normal operation, techniques of predicting solution chemistry were considered. Since application of techniques employing chemical hideout return data for the prediction of crevice chemistry in PWR steam generators (1-11) appeared to offer significant promise, limited hideout return data during shutdowns at 10 BWRs were evaluated (12). Subsequently, a hideout return study was performed at Susquehanna 2 to assure that the fundamental processes governing hideout and hideout return in BWRs were reasonably well understood (13).

In an attempt to provide insights into differences in corrosion of similar fuel cladding materials at Browns Ferry 2 and Hatch 2, augmented hideout return studies were performed during their shutdowns in the spring of 2003. Numerous reactor water samples were obtained during the shutdown evolutions and were analyzed for boron, chloride, sulfate, phosphate, fluoride, chrome, iron, copper, zinc, platinum, rhodium, aluminum, calcium, magnesium, sodium, potassium, manganese, vanadium and silica.

The peak reactor water conductivity during the shutdown evolution at Browns Ferry 2 was approximately 0.52 µS/cm and occurred shortly after reducing temperature to 140°F. The calculated conductivity based on measured impurity concentrations was 0.32 to 0.37 µS/cm. The peak reactor water conductivity at Hatch 2 was approximately 0.34 µS/cm and also occurred shortly after reducing temperature to 140°F. The calculated conductivity based on measured impurity concentrations was 0.25 to 0.29 µS/cm.

Average reactor water impurity concentrations (e.g., chloride and sulfate) at Browns Ferry 2 during the operating period preceding the hideout return study were higher than those at Hatch 2. However, the operating approach (HWC/NMCA), cycle design and circulating water compositions were similar. On this basis, similar hideout return quantities and relative magnitudes were expected assuming the absence of an unidentified impurity source. Although this was the case, (Figure S-1), differences did exist. Results can be summarized as follows:

1. Return of highly soluble species (e.g., sodium, potassium, chloride and fluoride) was minimal at both plants reflecting the absence of a tendency to form precipitates at low deposit solution concentration factors relative to the reactor coolant.

2. Silica return was far greater than return of any other species at both plants. This is attributed to desorption from iron oxide surfaces.

3. A slight increase in the return rate of calcium and sulfate following cooldown was observed at Browns Ferry 2 inferring the presence of a $CaSO_4$ precipitate within the deposit structure, but the quantity was small.

4. Magnesium return was much less than calcium return at both plants due to its four times lower concentration in the condenser cooling water (the source of the hardness elements) and its tendency to incorporate into spinel type structures.

5. Lithium return was not detected at Hatch 2. However, limited return was observed at Browns Ferry 2. The lithium source at Browns Ferry 2 is believed to be the control rod blades.

6. Soluble corrosion product return at Hatch 2, including that of zinc, was generally greater than at Browns Ferry 2 although the core surface area is greater at Browns Ferry 2. This could infer a more porous deposit at Hatch 2 leading to faster solubilization kinetics.

7. Return of Pt and Rh was negligible at both plants. Concentrations remained at or below LLD levels.

8. Return of sulfate was approximately 5 times greater at Browns Ferry 2 than at Hatch 2. Return of chloride was 4 times greater. Calcium and silica return at Browns Ferry 2 also was greater than at Hatch 2 reflecting higher impurity source terms for these species.

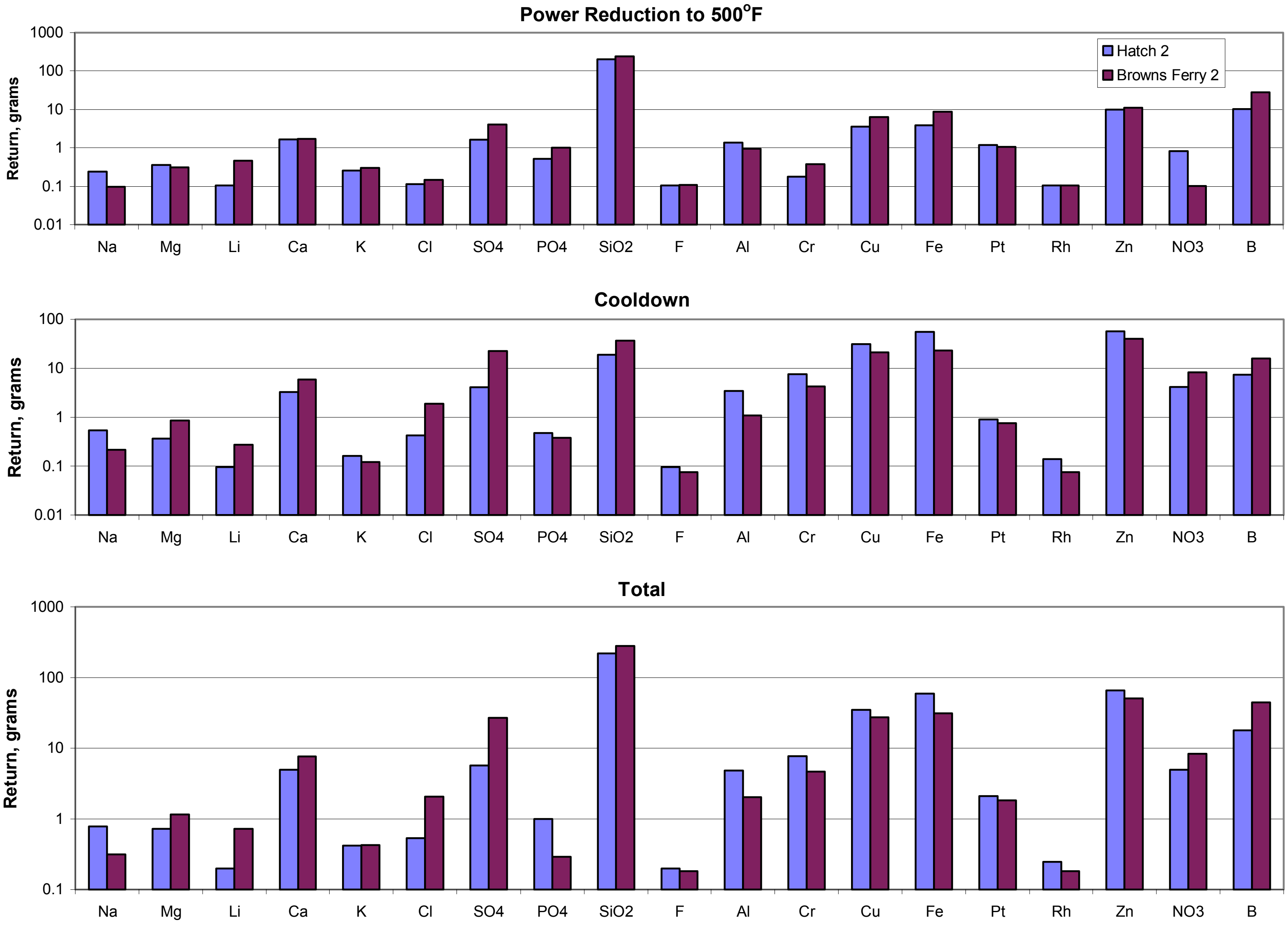
Predictions of solution chemistry within the deposits during normal operation using EPRI's MULTEQ code were developed using the cumulative returns at hot zero power as is the conventional approach for PWR steam generator systems. However, a maximum concentration factor of 10,000 was assumed with more likely values of 100 to 1000 based on theoretical modeling. In partially occluded crevices in PWR steam generators, concentration factors can reach 10^8 to 10^9. Results can be summarized as follows:

1. The pH of the predicted deposit solutions at Browns Ferry 2 and Hatch 2 at expected concentration factors was neutral to slightly alkaline. Cladding corrosion is not expected to be accelerated significantly in these solutions compared to corrosion in pure water.

2. Lithium generally was the major cationic soluble species in the predicted Browns Ferry 2 deposit solutions as a result of precipitation of the hardness elements. However, concentrations were low, i.e., approximately 5 ppm at a concentration factor of 10,000. Note that the observed lithium return was assumed to come from the cladding deposit solutions, i.e., release from control rod blades was assumed to be negligible. Li return was not detected at Hatch 2.

3. At low concentration factors, as anticipated in the porous deposits, concentrations remained relatively low. At higher boiling point elevations, 0.1 to 0.5 molal concentrations are reached. However, these concentration levels are expected only in severely occluded regions where boiling occurs (possibly at spacer to clad contact locations).

4. Based on the observation of increased return during cooldown due to precipitate solubilization, concentration factors in the deposit appear to be in the range of several thousand.


Power Reduction to 500°F

Cooldown

Total

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BACKGROUND

1.1 Hideout in Boiling Systems

During normal power operation, soluble impurities transported by the feedwater to nuclear or fossil boilers either remain in solution in the bulk water or are concentrated, and in some cases precipitate, in partially occluded regions or deposits where boiling is occurring. The latter effect is referred to as “hideout”. If the impurities remain in the boiler water, they can be removed by blowdown or by processing through a recirculating cleanup system.

In fossil boilers, boiling occurs on the inside of low alloy steel tubes and structure related crevices are not present. In this case, hideout predominantly occurs within or under corrosion product deposits on the tube surfaces, and the fraction of a highly soluble impurity (such as sodium or chloride) that hides out in boiling regions generally is small. As a result, corrosion resulting from development of concentrated solutions in local regions normally can be controlled by feedwater chemistry control.

In pressurized water reactor (PWR) recirculating steam generators, boiling occurs on the outside of tubes which pass through tube support plates or grid type support structures. In this case, there is a significant tendency for even highly soluble species to concentrate and in some cases precipitate in the partially occluded regions formed at the junctions of the tubes and support structure (1-3). Development of aggressive chemical solutions in these regions as a result of hideout has led to severe corrosion at many PWRs (4-5). In some cases, steam generator replacement has been required. Although impurities also concentrate within the deposits on the tubes, solution concentrations are not predicted to increase significantly above those in the bulk water. This prediction appears supported by the almost complete absence of significant corrosion of the tubing in free span regions. Because of the impact of chemical hideout on unit availability, hideout in PWR steam generators has been subject to extensive study (6-8).

Tests to quantify hideout in PWR steam generators during normal operation have been performed at several units. Specifically, concentrated chemical solutions containing sodium, potassium, calcium, chloride, sulfate and nitrate have been injected into the feedwater, and steam generator blowdown concentration changes have been monitored to quantify hideout and to develop inferences relative to hideout mechanisms. Results indicate that hideout of sodium, chloride and potassium (highly soluble species) was significantly less than that of calcium, magnesium and sulfate, i.e., species that tend to form precipitates. However, the behavior of the highly soluble species varied. For example, chloride hideout generally was less than that of sodium and potassium with this difference attributed to the volatility of hydrochloric acid formed by hydrolysis reactions during the concentration process. Nevertheless, the behavior of sodium, potassium and chloride is in reasonable agreement with predictions based on a simplistic hideout model which assumes hideout is dependent on the rate of evaporation in crevice regions.

Sulfate behavior differed markedly from that predicted by the crevice evaporation model (9). Specifically, hideout of this species was initially governed by adsorption on oxide coated surfaces until equilibrium was achieved (a period of several days). Thereafter, sulfate hideout appeared to be governed by crevice evaporation.

Calcium and magnesium hideout approached 100%. This was attributed to the tendency for these species to form precipitates such as $Ca(OH)_2$, $CaSO_4$ and a variety of calcium and magnesium silicates when local concentrations increased above the bulk water concentrations by two to four orders of magnitude during the boiling process. In contrast, precipitation of compounds containing sodium, chloride and potassium generally is not predicted to occur until boiling has led to development of solutions with molal concentrations 10^7 to 10^8 times those in the bulk water.

1.2 Application to BWRs

In a boiling water reactor (BWR), boiling occurs on the outside surface of fuel rods which are supported by open grid structures. Velocities of the two phase mixture which passes upward through the bundles are high, and the average core exit quality is only approximately 15%. Although individual bundles can have exit steam qualities approaching 30%, minimal hideout of highly soluble species is expected since 1) crevice regions are limited to the fuel to spacer contact points and 2) concentrations of soluble impurities are not predicted to increase much more than a factor of 1,000 to 10,000 in the porous outer deposit layer or more tenacious but relatively thin inner deposit layer. In addition, reactor water flow distribution is controlled by core design, i.e., the fuel rods are contained within a fuel channel and individual fuel bundles are orificed to distribute the core flow. This minimizes local quality and void fraction variations.

A fraction of the species that concentrates and “hides out” in the deposits will return to the bulk water during a shutdown or power reduction due to void collapse, partial dissolution of precipitates (particularly those with retrograde solubility), and diffusion from concentrated liquid solutions to the bulk solution. As noted above, concentration measurements made during such evolutions have been used extensively in PWR systems to estimate hideout and to assess probable chemistry conditions in local regions of the steam generators (10, 11). This approach is referred to as a hideout return analysis and is routinely employed since concentrations of feedwater and steam borne impurities are very low during normal operation, and limitations in analytical sensitivities make it difficult to quantify hideout based on a mass balance approach.

To develop a preliminary understanding of impurity hideout in BWRs, reactor water chemistry data for ten units during power reduction and shutdown transients were reviewed (12). To complement the routinely collected data on reactor water conductivity and silica, chloride and sulfate concentrations, several utilities provided data on calcium, magnesium, sodium and potassium. Detailed review of these data (12) indicated that conductivity increases observed during the shutdown evolution were mostly attributable to the solubilization of precipitates of hardness elements deposited on the fuel during normal operation, e.g., calcium sulfate, and calcium and magnesium hydroxides and silicates. Return of these precipitates to the reactor water occurs on shutdown when boiling terminates and steam voids collapse. There generally was no significant return of highly soluble species such as sodium and chloride, consistent with the concentration process models developed during the PWR secondary system studies. However, desorption of sulfate from oxide coated surfaces appeared to occur during some shutdowns.

To provide more detailed information on BWR hideout and hideout return processes, a study was performed at Susquehanna-2 during the September 1992 shutdown (13). Observations during this study were consistent with expectations based on the prior review of BWR shutdown data and PWR steam generator hideout and hideout return models:

1. Hideout of species which had little tendency for forming precipitates until very high solution concentrations are reached, i.e., sodium, chloride and potassium, was shown to be minimal (Table 1-1). For these species, concentrations must increase above the bulk water concentrations a minimum of 10^6 times before precipitate formation occurs.

2. Hideout of species such as calcium, magnesium, sulfate and silica, which tend to form precipitates at relatively low concentration factors above the concentrations normally present in the BWR reactor coolant, occurs to a greater extent than hideout of highly soluble species. In this case, precipitation begins at concentration factors of several hundred to several thousand above normal reactor coolant concentrations.

3. During the shutdown evolution when the reactor remains near operating temperature, the relative return of highly soluble species is greater than the relative return of species which readily form precipitates during normal operation. In general, the precipitates exhibit retrograde solubility characteristics which leads to increases in the rate of their return to the reactor coolant when the temperature is decreased.

4. Increases in conductivity observed during and after shutdown were due to solubilization of precipitates with retrograde solubilities.

Similar to the approach used to predict crevice chemistry in PWR steam generators, cumulative hideout return of major impurity species from the beginning of the power reduction to the beginning of the cooldown was used to predict solution chemistry within the fuel deposits during normal operation. In the case of Susquehanna-2, solutions were predicted to be basic at boiling point elevations (BPE) of 5 to 6°C and to contain high concentrations of sodium, potassium, chloride, silica, sulfate, and nitrate (Table 1-2). At lower BPE values consistent with more realistic solution concentration factors, the crevice solution pH was only slightly alkaline, i.e., ~7 at 280°C.

Table 1-1
Cumulative Prompt Hideout Return during the Susquehanna 2 Shutdown (September 12, 1992; 0900H) (13)

	Hideout Return, grams
Sodium	8.6
Magnesium	3.6
Calcium	13.8
Potassium	0.92
Aluminum	11.6
Chromate	5.4
Chloride	0.44
Nitrate	1.7
Silica	252
Sulfate	12.8

Table 1-2
Summary of Predicted Local Solution Chemistry at Susquehanna 2 (September 12, 1992; 0900H) (13)

	All Species		Without Chromium	Without Chromium & Aluminum
	Precipitates Retained	Precipitates Removed	Concentration, molal	
pH	9.4	9.4	9.4	9.3
BPE, °C	6	6	6	5
Na^+	1.86	1.77	1.86	1.46
$NaSO_4^-$	0.13	0.13	0.13	0.13
K^+	0.23	0.23	0.23	0.23
Cl-	0.12	0.12	0.12	0.12
$H_3SiO_4^-$	0.26	0.17	0.26	0.19
SO_4^-	0.33	0.34	0.33	0.37
NO_3^-	0.28	0.28	0.28	0.28
$Al(OH)_4^-$	0.32	0.34	0.32	
OH^-	0.2	0.2	0.2	0.2

2
PLANT FEATURES

In light of the recent fuel cladding corrosion observations at BWRs following Noble Metal Chemical Addition (NMCA), detailed hideout return evaluations were performed at Browns Ferry 2 and Hatch 2 during their Spring 2003 refueling shutdowns. The goal was to assess solution chemistry and the nature of precipitates formed within the deposits present on fuel cladding surfaces. Pertinent design features and chemistry milestones at Browns Ferry 2 and Hatch 2 are summarized in Table 2-1 (14).

Browns Ferry 2 completed Cycle 12 in February 2003. Outages to remove leaking fuel occurred in April/May and October 2002. In addition, frequent power reductions and several other shutdowns occurred during the cycle. NMCA was performed at the end of Cycle 11 on March 18 and 19, 2001. A resin intrusion occurred immediately prior to NMCA application. Following NMCA, the recirculation system was chemically decontaminated between March 25 and 28, 2002. The RHR was decontaminated between March 31 and April 2, 2002. HWC was initiated about 19 months prior to NMCA in August 1999. DZO injection began in October 1997 during Cycle 9.

Hatch 2 completed Cycle 17 in February 2003. One 10 day outage occurred approximately 2 months after the beginning of the cycle. Hydrogen injection was initiated in September 1991; NMCA was performed at the end of Cycle 15 in March 2000. Natural zinc injection began in August 1990 with a change to DZO in December 1993.

Both plants cascade all drains to the condenser and employ full flow precoat filter demineralizers for condensate treatment. RWCU flowrate is 0.8% of feedwater flow at Hatch 2 and 0.9% at Browns Ferry 2. Neither plant employs copper tubed components in the power cycle.

Inleakage of condenser cooling water is normally the major source of impurities such as calcium, magnesium, chloride, sodium and potassium. Although such leakage also can increase reactor water sulfate concentrations, sulfur compound releases from condensate or reactor water demineralizers frequently control reactor water concentrations. Condenser cooling water at Browns Ferry is taken from the Tennessee River (via Wheeler Lake) (Table 2-2). Cooling water at Hatch 2 is taken from the Altamaha River (Table 2-3). Cooling towers which operate at a concentration factor of approximately 2 are employed. The chemistry of the condenser cooling waters is very similar.

Table 2-1
Plant Design and Operating History (EPRI BWR Database)

	HAT2	**BF 2**
Power Rating (MW_{th})	2763	3458
Average Percent Power	98.01	92.77
Condensate Polishing Type	FD	FD
Drains Path	Cascaded	Cascaded
Reheat (Yes/No)	Yes	No
RWCU Flow (% of FW Flow, normal)	0.8	0.9
Copper Source (Low/High)	Low	Low
Iron Addition (None, Iron Oxide or Iron Oxalate)	None	None
Chemistry Milestones		
HWC	Sep-91	Dec-99
NZO	Aug-90	
DZO	Dec-93	Oct-97
NMCA	Mar-00	Mar-01

Table 2-2
Browns Ferry 2 Condenser Cooling Water Chemistry

	Concentration, ppm
Calcium	22
Magnesium	4
Sodium	7
Bicarbonate/Carbonate	49
Chloride	20
Sulfate	17
Silica	5
Conductivity, µS/cm	
K_s (Specific)	220

[*] 1994 Estimates

Table 2-3
Hatch 2 Condenser Cooling Water (May 2001) (15)

ICP - Inductively Coupled Plasma	**Filtered**	**Total**	
Aluminum (Al)	< 0.1	0.3	ppm
Barium (Ba)	< 0.1	< 0.1	ppm
Boron (B)	< 0.1	< 0.1	ppm
Cadmium (Cd)	< 0.01	< 0.01	ppm
Calcium (CaCO3)	32	33	ppm
Calculated Hardness (CaCO3)	40	41	ppm
Chromium (Cr)	< 0.01	< 0.01	ppm
Copper (Cu)	0.01	< 0.01	ppm
Iron (Fe)	0.01	0.63	ppm
Lead (Pb)	< 0.1	< 0.1	ppm
Lithium (Li)	< 0.01	< 0.01	ppm
Magnesium (CaCO3)	7.5	7.5	ppm
Manganese (Mn)	< 0.01	0.06	ppm
Molybdenum (Mo)	< 0.1	< 0.1	ppm
Nickel (Ni)	< 0.1	< 0.1	ppm
Phosphorus (PO4)	< 0.3	< 0.3	ppm
Potassium (K)	2.2	2.3	ppm
Silica (SiO2)	12.0	13.0	ppm
Sodium (CaCO3)	23	23	ppm
Strontium (Sr)	0.05	0.06	ppm
Vanadium (V)	< 0.01	< 0.01	ppm
Zinc (Zn)	0.02	0.04	ppm
IC - Anions by IC			
Bromide (Br)		< 0.20	ppm
Nitrite (NO2)		< 0.20	ppm
Chloride (CaCO3)		7.6	ppm
Nitrate (CaCO3)		0.56	ppm
Sulfate (CaCO3)		17	ppm
ALK - Alkalinity			
Bicarbonate (CaCO3)		50	ppm
Methyl Orange (CaCO3)		50	ppm
Phenolphthalein (CaCO3)		< 1	ppm
Others			
pH		7.8	pH Units
Conductivity		140	mmhos/cm

3

CHEMISTRY VARIATIONS DURING POWER OPERATION

3.1 Ionic Transport

3.1.1 Browns Ferry 2

Condensate, feedwater and reactor water conductivity variations during Cycle 12 at ≥30% power are summarized in Figure 3-1. As shown, the number of power transients during the cycle was significant (Table 3-1). Many transients were related to rod pattern changes. Reactor water sulfate, chloride and conductivity variations are shown in Figure 3-2. Conductivity and zinc variations are shown in Figure 3-3. Average reactor water conductivity and chloride and sulfate concentrations are given in Table 3-2. General comments that can be offered based on these variations are as follows:

- Average concentrations of ionic impurities (sulfate and chloride) were low (Table 3-2). However, significant sulfate, chloride and conductivity increases occurred during startups.
- Reactor water conductivity elevations near the beginning of Cycle 12 are attributed to elevated soluble iron concentrations following NMCA during the refueling outage at the end of Cycle 11.
- Reactor water conductivity during steady-state operation generally was controlled by the soluble zinc concentration. Conductivities of a pure zinc hydroxide solution are illustrated in Figure 3-4. When a strong acid anion is present, the conductivity of the hydroxide solutions initially decreases due to neutralization of the solution (pH decreases) and then increases as the solution goes acidic (e.g., Figure 3-5). Thus, conductivity is not a reliable indicator of a minor intrusion of an anionic species.

3.1.2 Hatch 2

Condensate, feedwater and reactor water conductivity variations during Cycle 17 at ≥30% power are summarized in Figure 3-6. As at Browns Ferry 2, frequent power transients occurred primarily as a result of rod pattern changes (Table 3-1). Reactor water sulfate, chloride and conductivity variations are shown in Figure 3-7. Conductivity and zinc variations are summarized in Figure 3-8. Average reactor water conductivity and chloride and sulfate concentrations are given in Table 3-2. General comments that can be offered based on these variations are as follows:

- Concentrations of ionic impurities (sulfate and chloride) were well controlled during power operation (Table 3-2). Chloride and sulfate concentration excursions were minimal.
- Reactor water conductivity generally was controlled by the soluble zinc concentration.
- The conductivity transient during late February 2002 is attributable to a brief termination of hydrogen flow.

3.2 Corrosion Product Transport

3.2.1 General Considerations

Deposition of corrosion products on BWR fuel cladding surfaces can lead to significant increases in cladding surface temperatures, and correspondingly corrosion rates, if local deposit magnitudes are excessive or deposit densification occurs. The clad temperature also could increase markedly particularly if a gap develops between the deposit and the oxide coated clad surface and steam is formed in the gap. Theoretically, deposit magnitude and structure/composition also could affect tendencies for development of concentrated solutions within the deposit and thus cladding corrosion rates. In light of such considerations, limited consideration was given to approximate deposit formation rates at BF2 and H2 during the cycle preceding the hideout return evaluation. Deposit formation rates and composition were estimated by a mass balance approach. Zinc deposition may be overestimated based on the mass balance approach since incorporation into out-of-core corrosion films could be significant particularly during the restructuring process at Browns Ferry 2.

3.2.2 Browns Ferry 2

Feedwater and reactor water iron, copper, nickel and zinc concentrations for Cycle 12 during operation at ≥30% power are summarized in Figure 3-9 and 3-10, respectively. Average iron, copper, nickel and zinc concentrations are given in Table 3-3.

Feedwater iron transport is compared to RWCU removal and deposition on fuel surfaces (assuming minimal dropout and deposition on other RCS surfaces) in Figure 3-11. Similar results are shown for copper, nickel and zinc in Figures 3-12 to 3-14, respectively. Average deposit formation rates and the average composition of the incremental deposit formed during Cycle 12 are given in Table 3-4. The following observations can be made based on these results:

- Approximately 41% of the amount of iron transported to the RCS was removed by the RWCU system. The remainder deposited primarily on fuel cladding surfaces. However, limited deposition could have occurred on other system surfaces. The low net deposition fraction for iron is attributed to releases due to deposit restructuring following NMCA. Normally, iron deposition fractions are significantly greater, i.e., 80 to 95%. (Note that the net deposition on the fuel and other reactor coolant system surfaces was negligible over the first 100 days of the cycle due to the post-NMCA redistribution effect.)

- Approximately 42% of the copper and 10% of the zinc transported to the RCS were removed by the RWCU system. The remainder is believed to have deposited primarily on fuel cladding surfaces.
- The average incremental deposit composition based on Cycle 12 transport rates was estimated to be 52% Fe, 0.5% Cu, 47% Zn and 1.2% Ni. The high zinc fraction estimate results from the low net iron deposition.

3.2.3 Hatch 2

Feedwater and reactor water iron, copper, nickel and zinc concentrations for Cycle 17 during operation at ≥30% power are summarized in Figures 3-15 and 3-16, respectively. Average iron, copper, nickel and zinc concentrations are given in Table 3-3.

Feedwater iron transport is compared to RWCU removal and deposition on fuel surfaces (assuming minimal dropout and deposition on other RCS surfaces) in Figure 3-17. Similar results are shown for copper, nickel and zinc in Figures 3-18 and 3-20, respectively. Average deposit formation rate and the average composition of the deposit formed during Cycle 17 are given in Table 3-4. The following observations can be made based on these results:

- Approximately 11% of the iron transported to the RCS was removed by the RWCU system. The remainder deposited primarily on fuel cladding surfaces. Limited deposition also could have occurred on other system surfaces.
- Approximately 35% of the copper and 22% of the zinc transported to the RCS were removed by the RWCU system. The remainder is believed to have deposited primarily on fuel cladding surfaces.
- The large fractional deposition of iron corrosion products on fuel surfaces is a result of the iron being primarily in an insoluble form. (Note that NMCA was applied at the end of Cycle 15, and most deposit and film restructuring occurred during Cycle 16.)
- The average incremental fuel deposit composition based on Cycle 17 transport rates was estimated to be 78% Fe, 1.5% Cu, 19% Zn, and 1.8% Ni.

Table 3-1
Number of Power Transients

	To < 90%	To < 80%	To < 50%	Outages
Browns Ferry 2				
Cycle 12	22	11	7	2
Hatch 2				
Cycle 17	15	14	5	1

Table 3-2
Average Reactor Water Chloride and Sulfate Concentrations during Normal Operation (≥30% Power)

Plant	Cycle	Concentration, ppb		Conductivity, µS/cm
		Chloride	Sulfate	
Browns Ferry 2	12	1.0	2.4	0.10
Hatch 2	17	0.15	0.45	0.11

Table 3-3
Average Corrosion Product Concentrations, ppb

	Feedwater	Reactor Water
Browns Ferry 2 (Cycle 12)		
Fe	1.21	59
Zn	0.66	7.9
Cu	0.012	0.60
Ni	0.021	0.53
Hatch 2 (Cycle 17)		
Fe	1.2	4.7
Zn	0.33	5.8
Cu	0.03	0.9
Ni	0.03	0.55

Table 3-4
Deposit Formation at Browns Ferry 2 and Hatch 2

	Browns Ferry 2 Cycle 12[a]	Hatch 2 Cycle 17[b]
Total Feedwater Input		
Fe	248	165
Cu	2.4	4.3
Zn	147	45
Ni	4.4	4.4
Amount Deposited, lbs		
Fe	147	147
Cu	1.4	2.8
Zn	133	35
Ni	3.4	3.3
Total:	285	188
Deposition on cladding/system surfaces, % of FW input		
Fe	59	89
Cu	58	65
Zn	90	78
Ni	77	75
Deposit Composition, %		
Fe	52	78
Cu	0.5	1.5
Zn	47	19
Ni	1.2	1.8

a) NMCA at EOC 11

b) NMCA at EOC 15

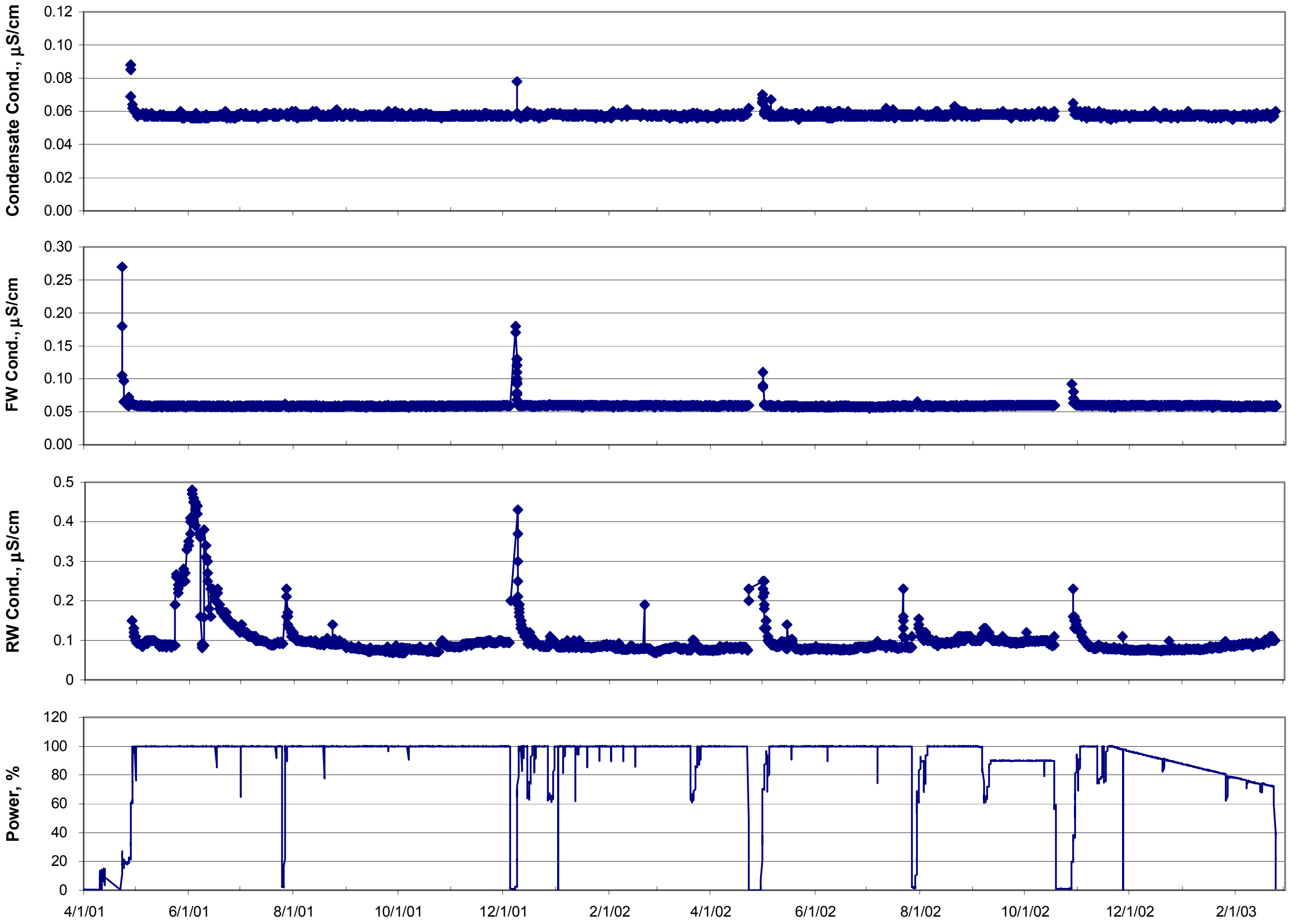

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Figure 3-1
Browns Ferry 2 Cycle 12 Condensate, Feedwater and Reactor Water Conductivity Variations at >30% Power

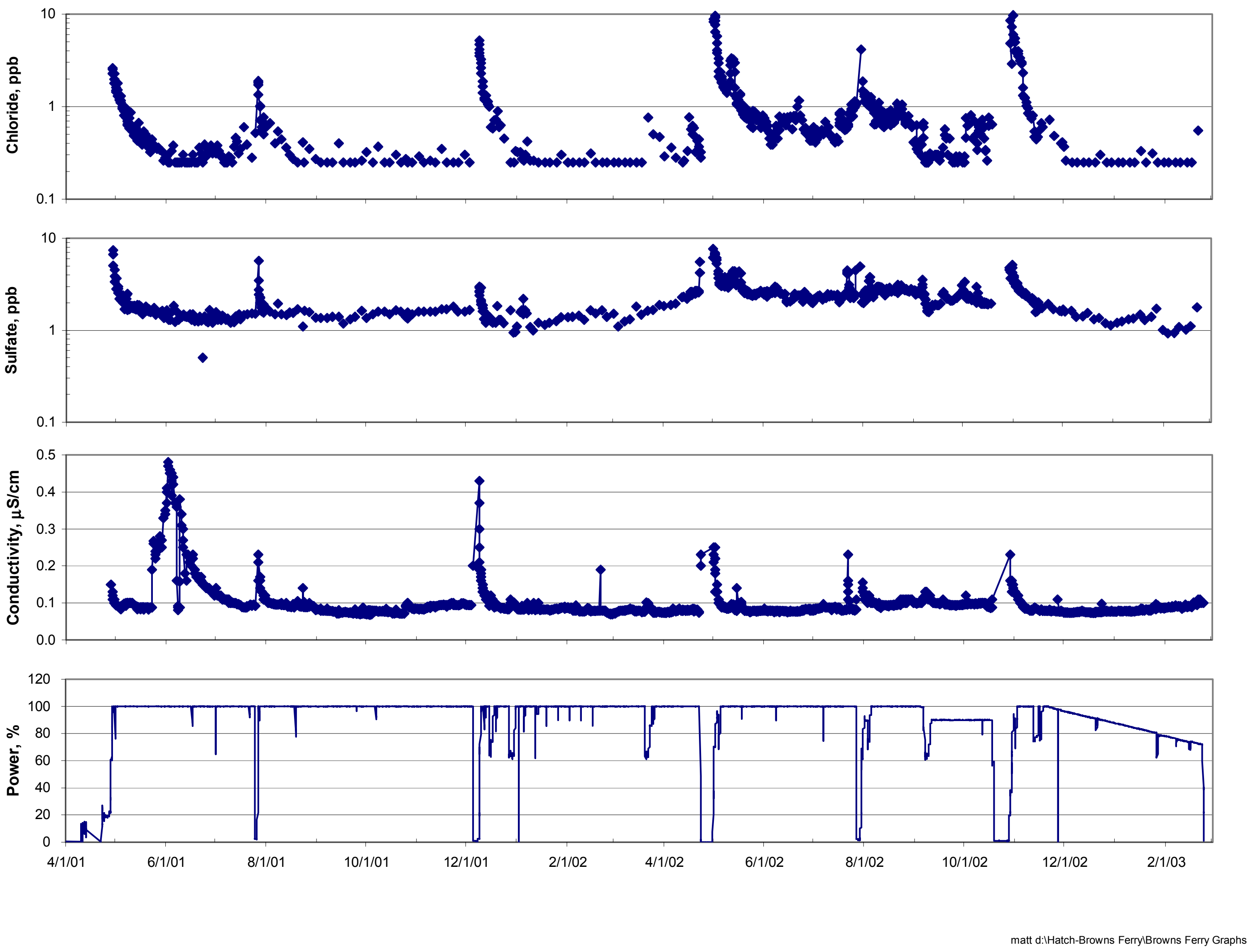

Figure 3-2
Browns Ferry 2 Cycle 12 Reactor Water Chemistry at >30% Power

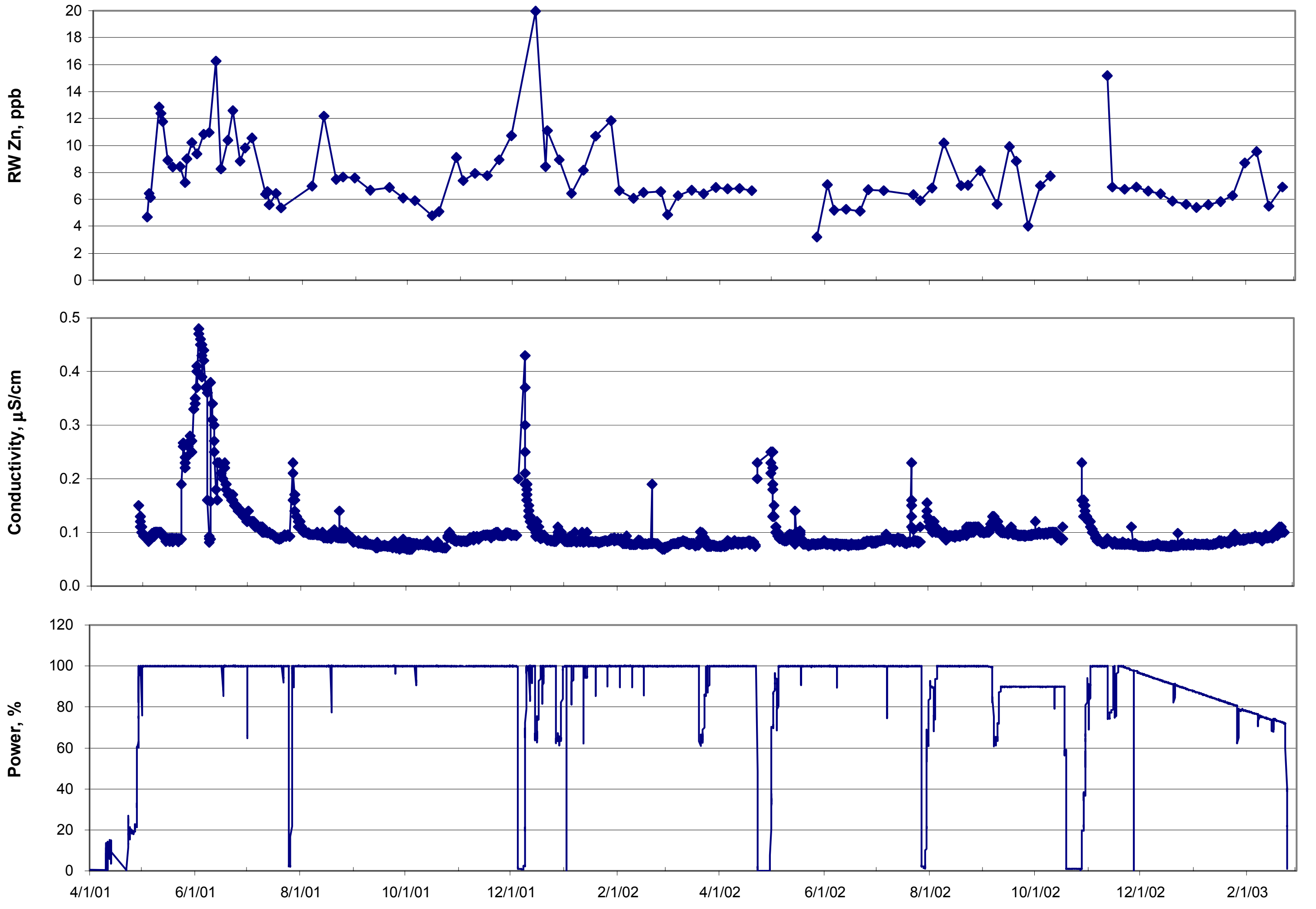

Figure 3-3
Browns Ferry 2 Cycle 12 Reactor Water Conductivity Response to Zinc Concentration Variations

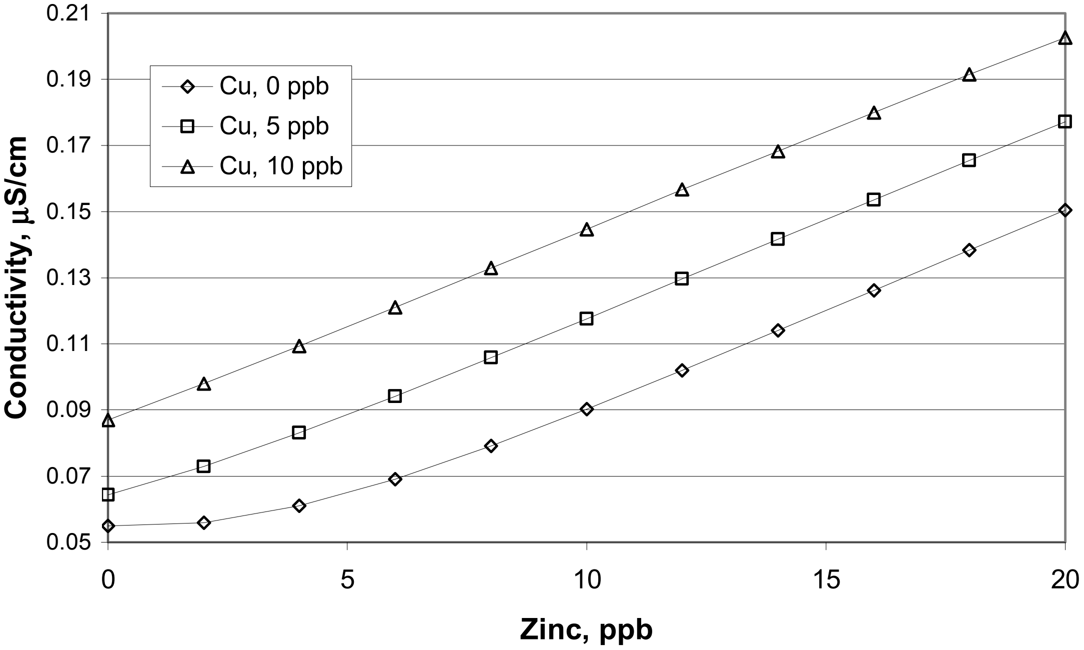

Figure 3-4
Effect of Zinc and Copper Hydroxides on Reactor Water Conductivity

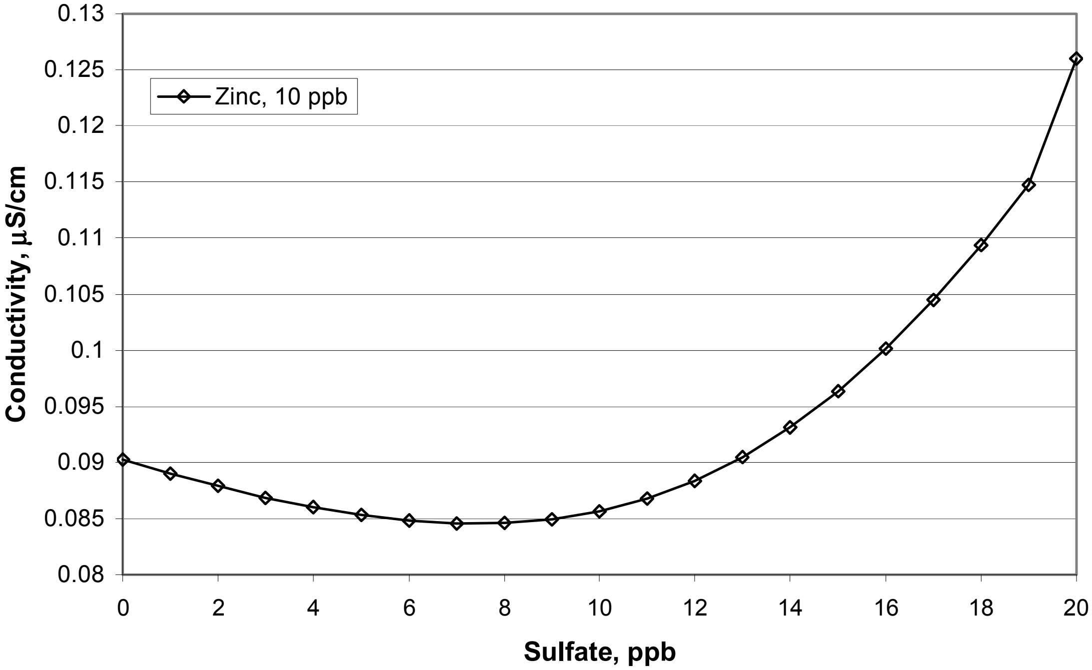

Figure 3-5
Effect of Zinc and Sulfate on Reactor Water Conductivity

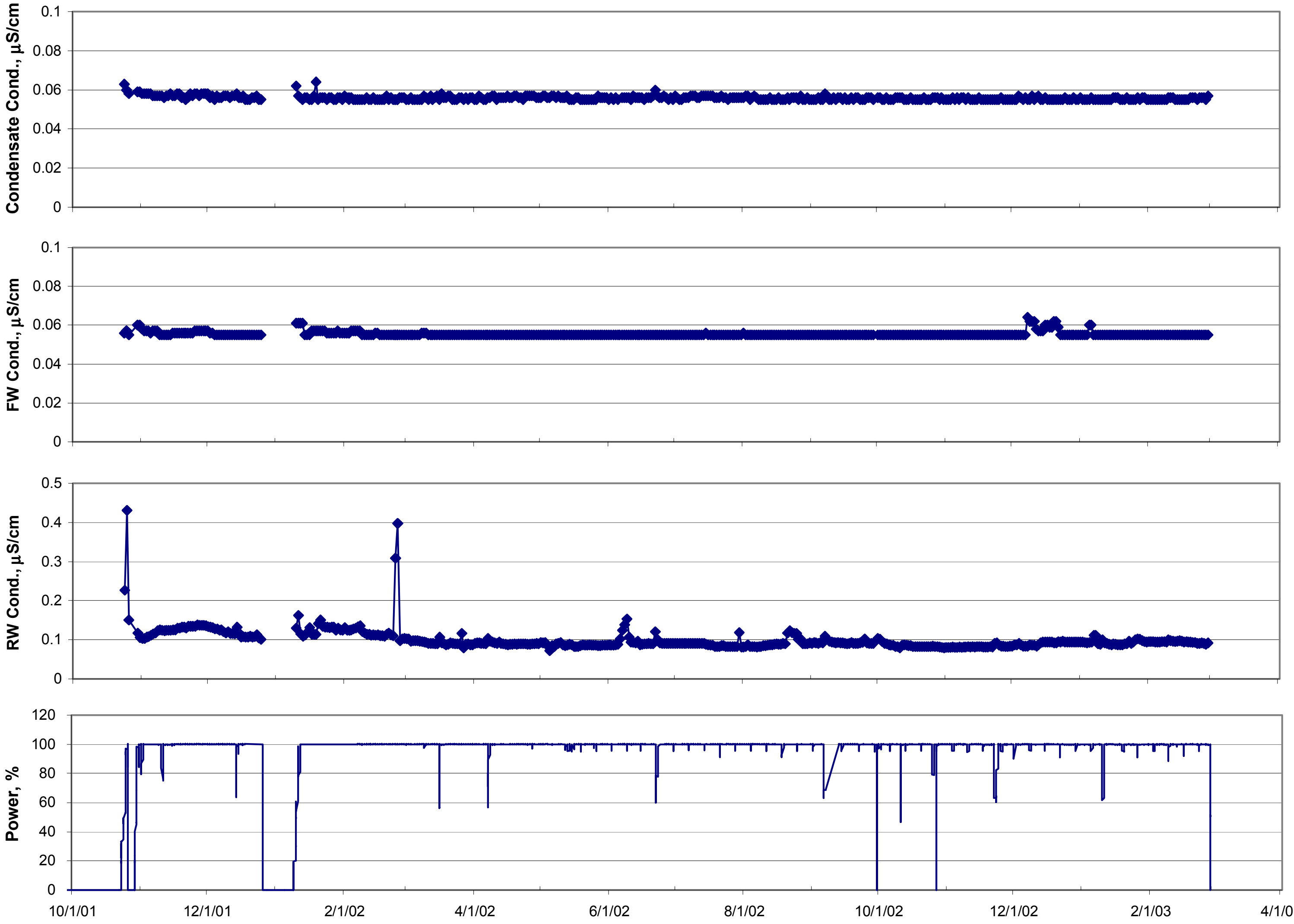

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Figure 3-6
Hatch 2 Cycle 17 Condensate, Feedwater and Reactor Water Conductivity Variations at >30% Power

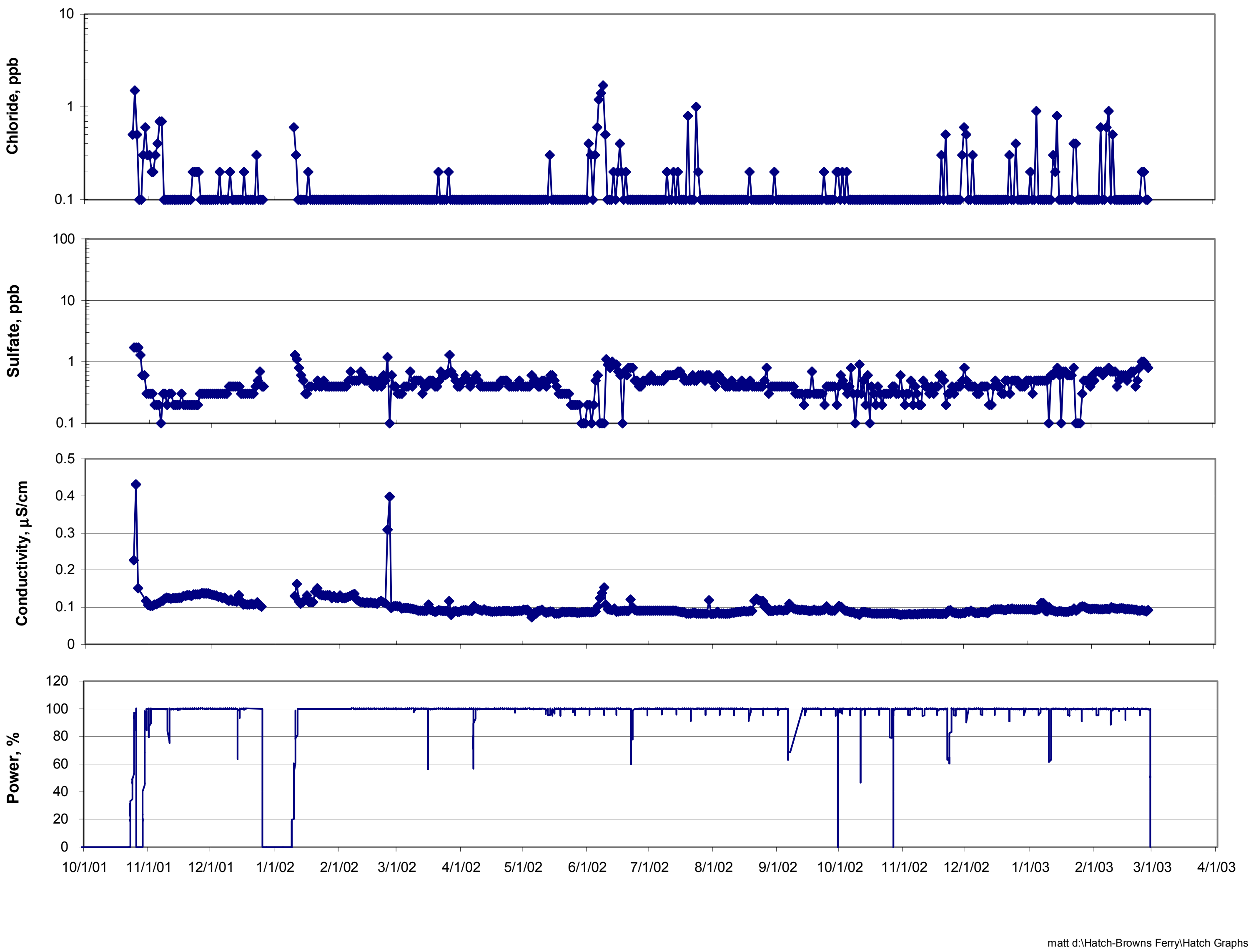

Figure 3-7
Hatch 2 Cycle 17 Reactor Water Chemistry at >30% Power

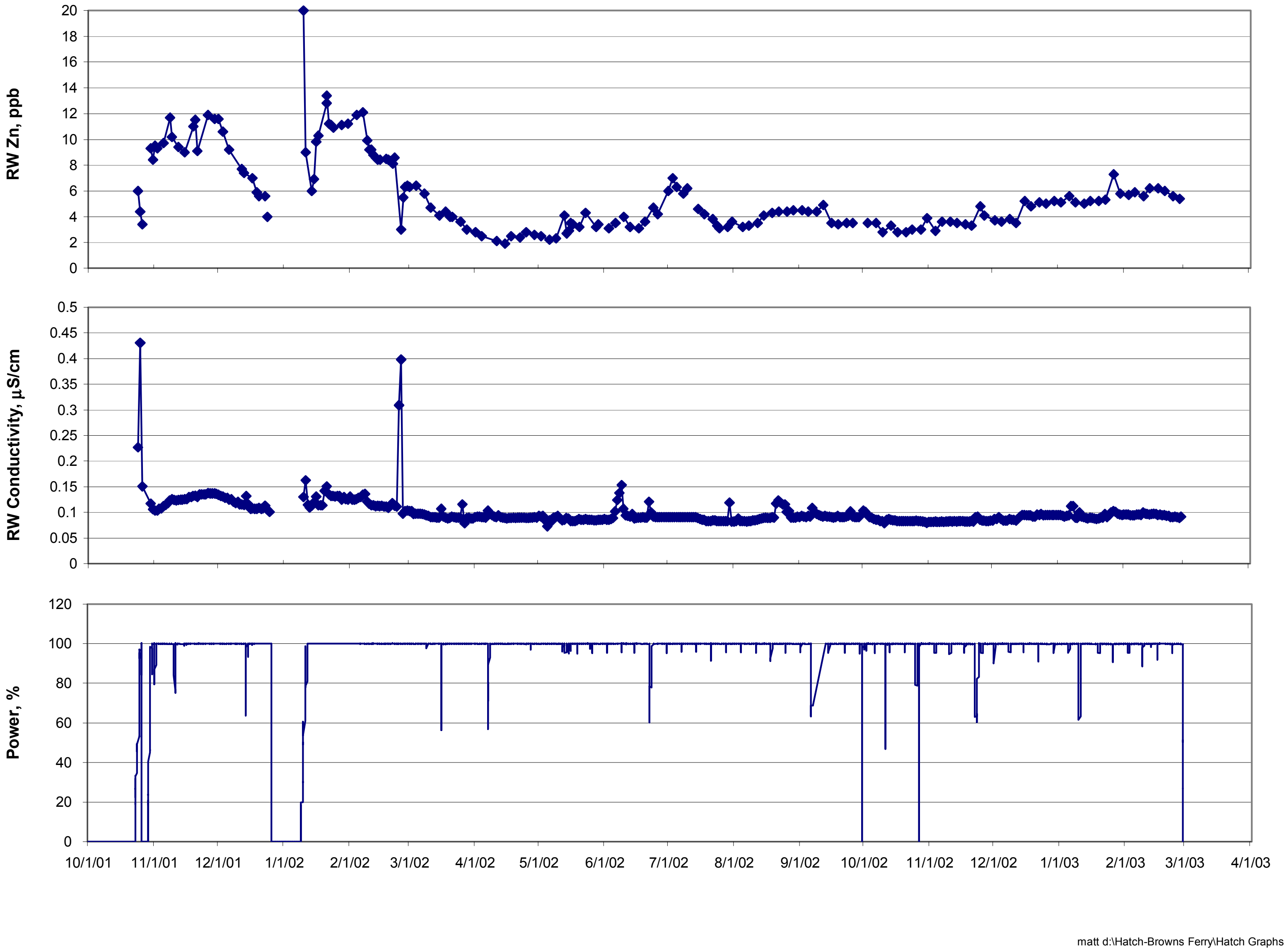

Figure 3-8
Hatch 2 Cycle 17 Reactor Water Conductivity Response to Zinc Concentration Variations

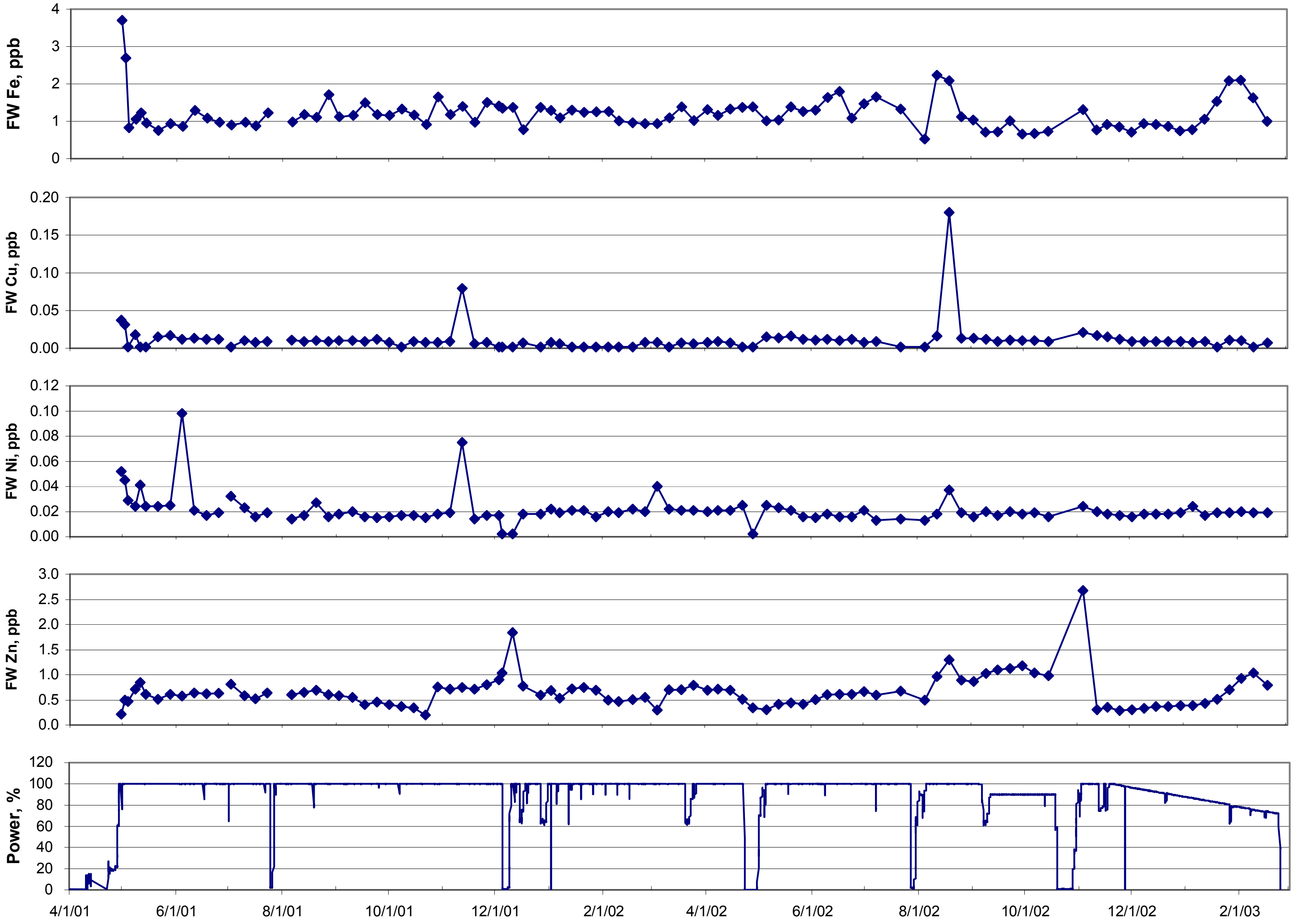

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Figure 3-9
Browns Ferry 2 Cycle 12 Feedwater Corrosion Product Concentrations at >30% Power

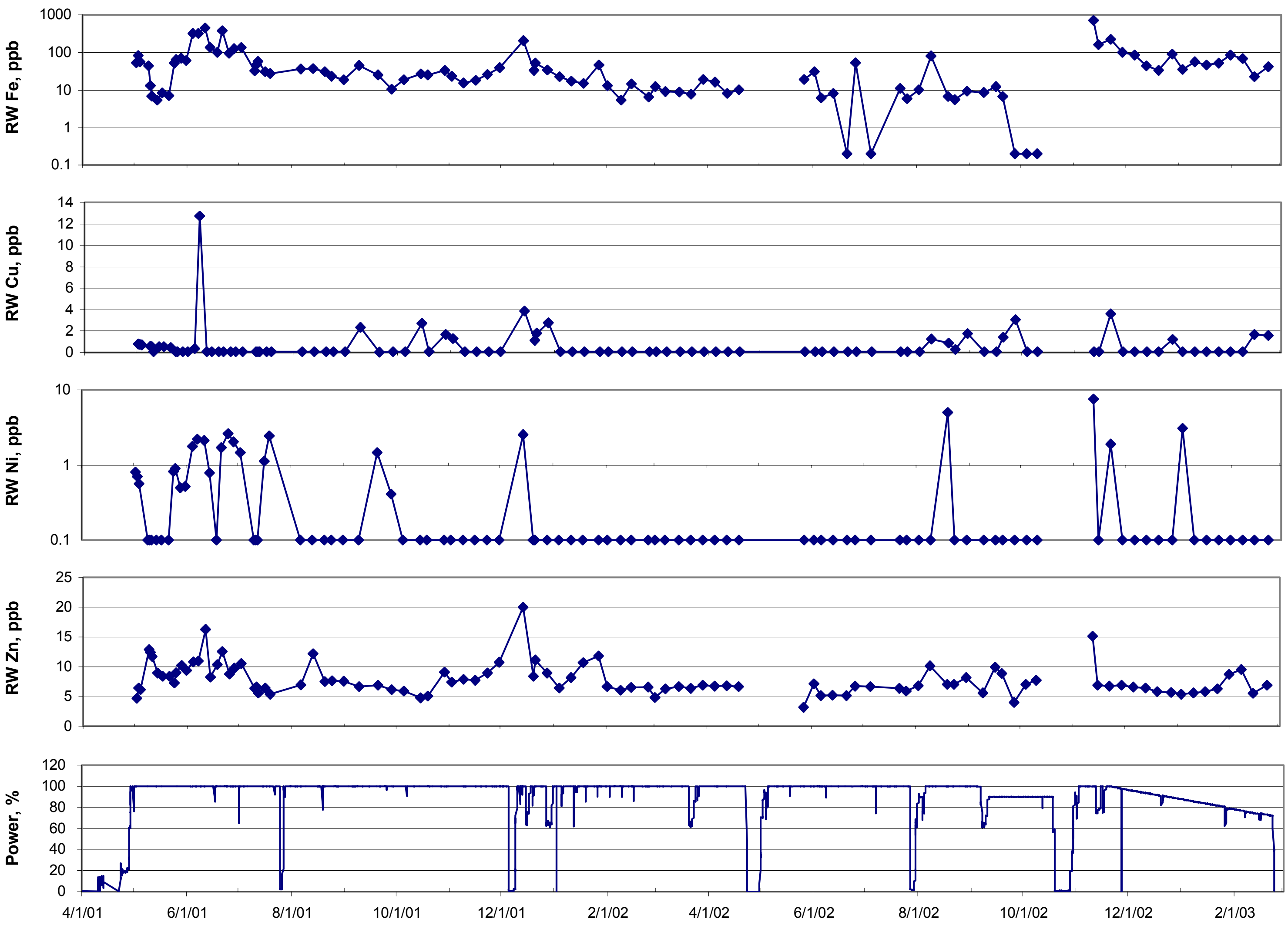

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Figure 3-10
Browns Ferry 2 Cycle 12 Reactor Water Corrosion Product Concentrations at >30% Power

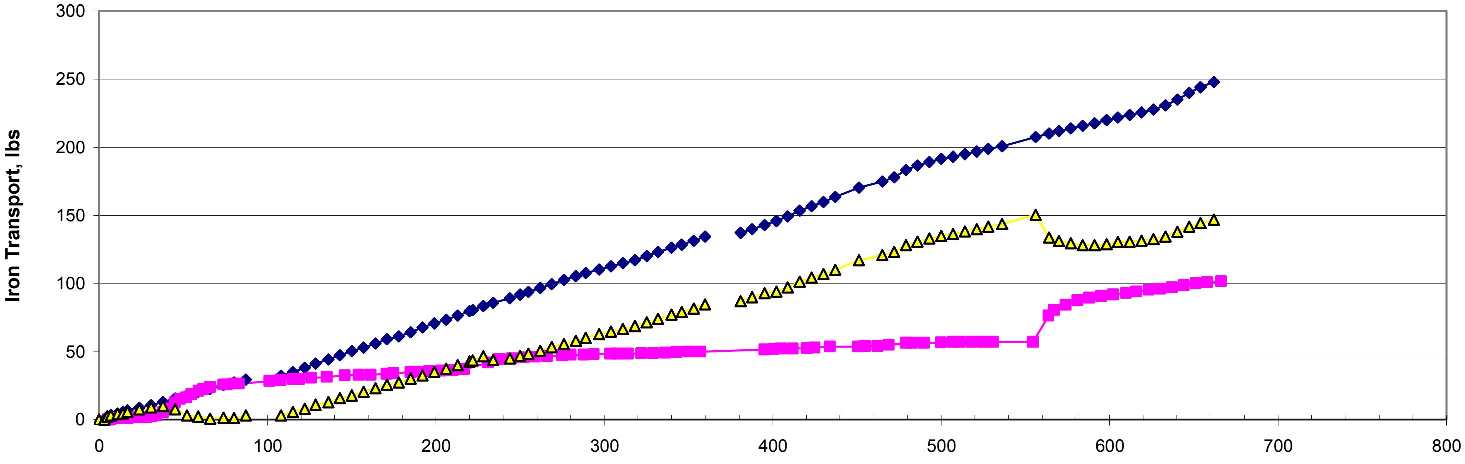

Figure 3-11
Feedwater and RCS Iron Transport during Cycle 12 at Browns Ferry 2

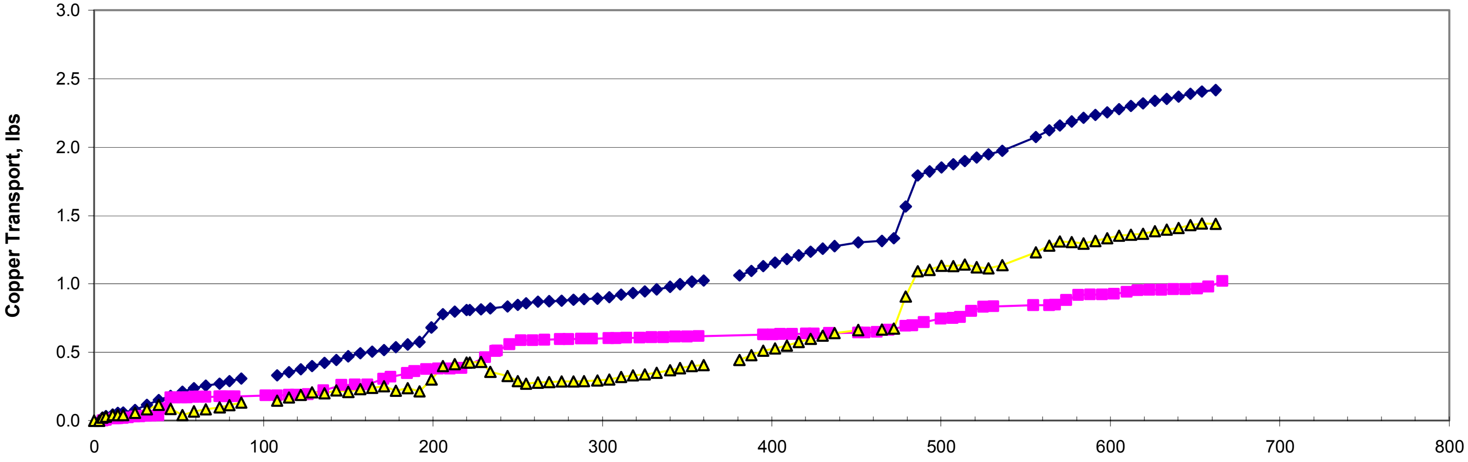

Figure 3-12
Feedwater and RCS Copper Transport during Cycle 12 at Browns Ferry 2

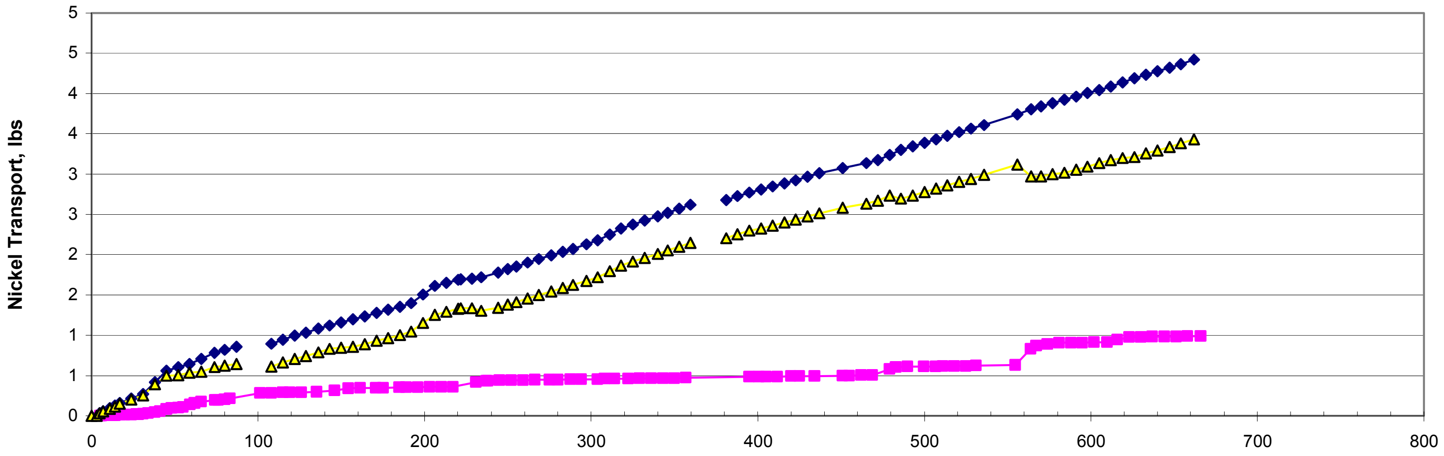

Figure 3-13
Feedwater and RCS Nickel Transport during Cycle 12 at Browns Ferry 2

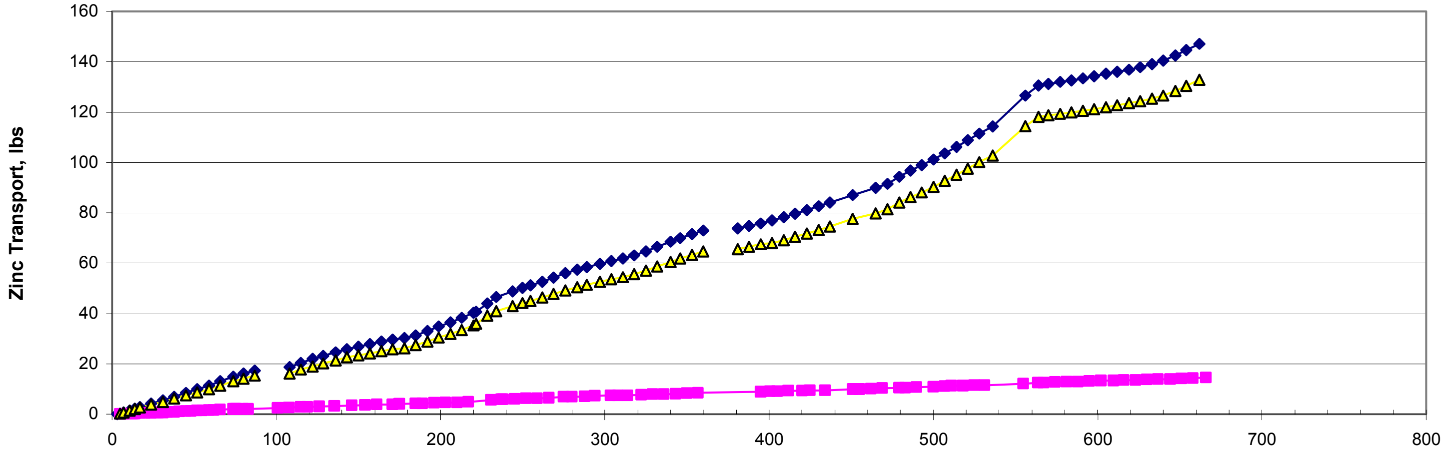

Figure 3-14
Feedwater and RCS Zinc Transport during Cycle 12 at Browns Ferry 2

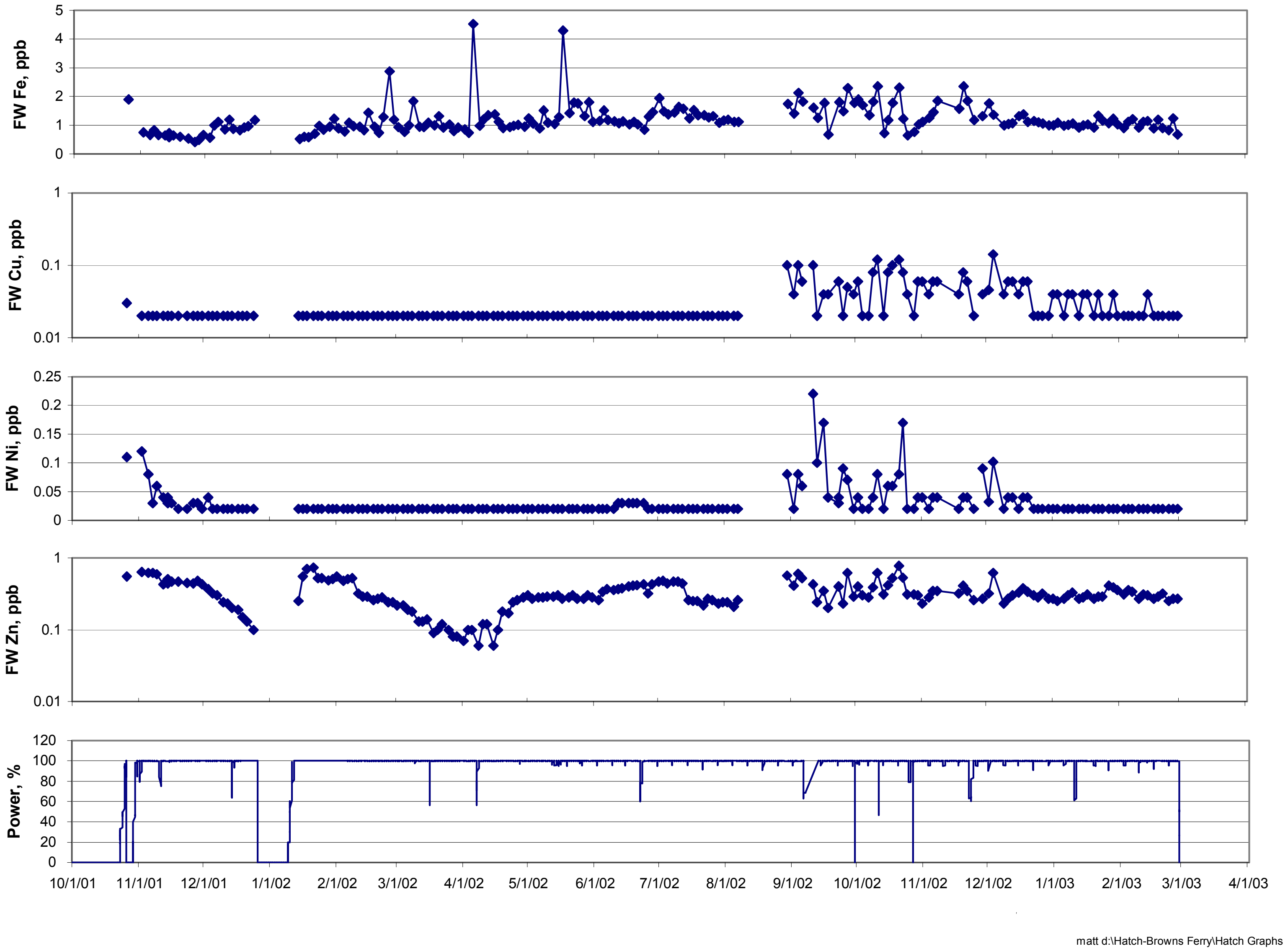

Figure 3-15
Hatch 2 Cycle 17 Feedwater Corrosion Product Concentrations at >30% Power

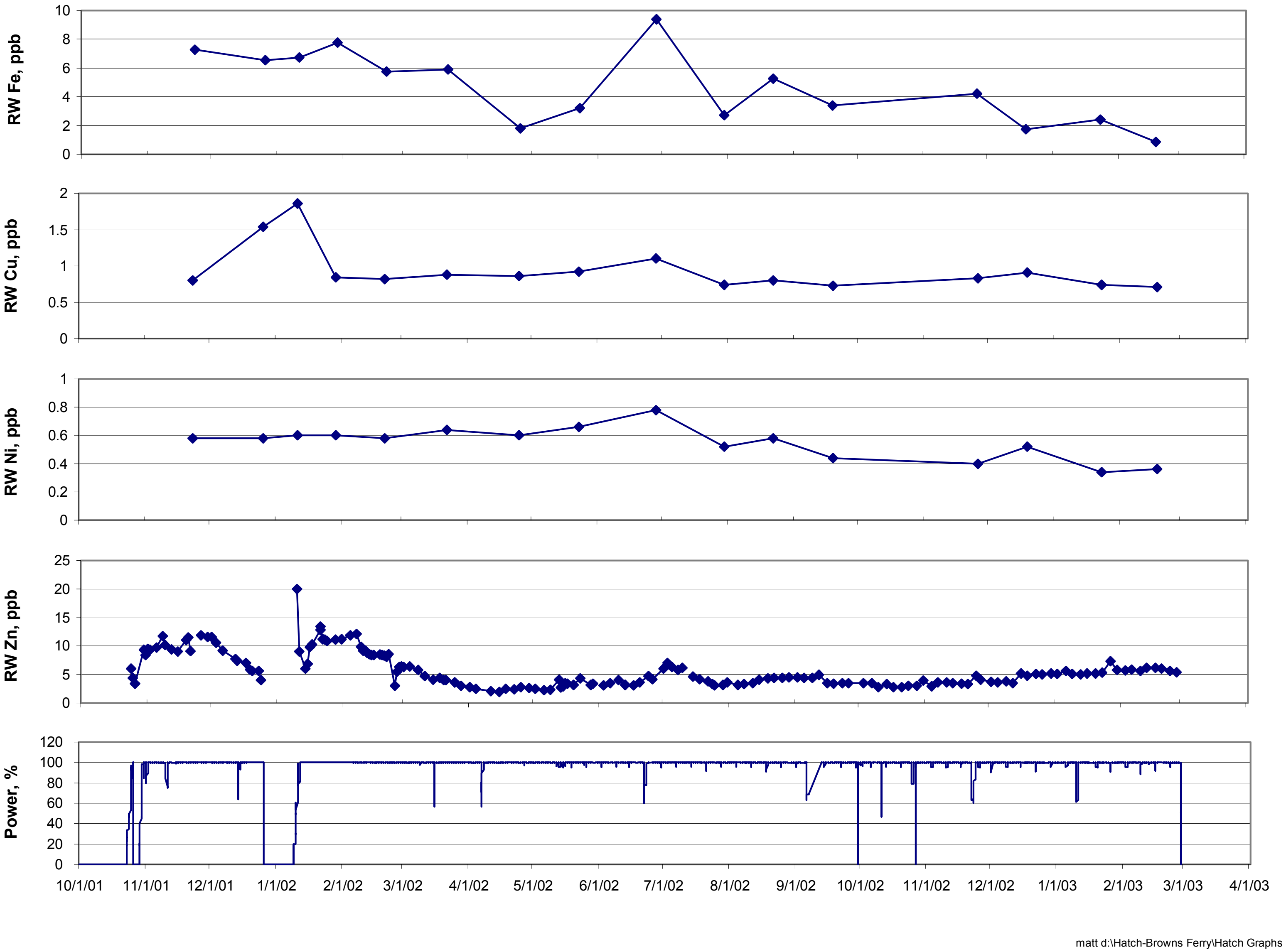

Figure 3-16
Hatch 2 Cycle 17 Reactor Water Corrosion Product Concentrations at >30% Power

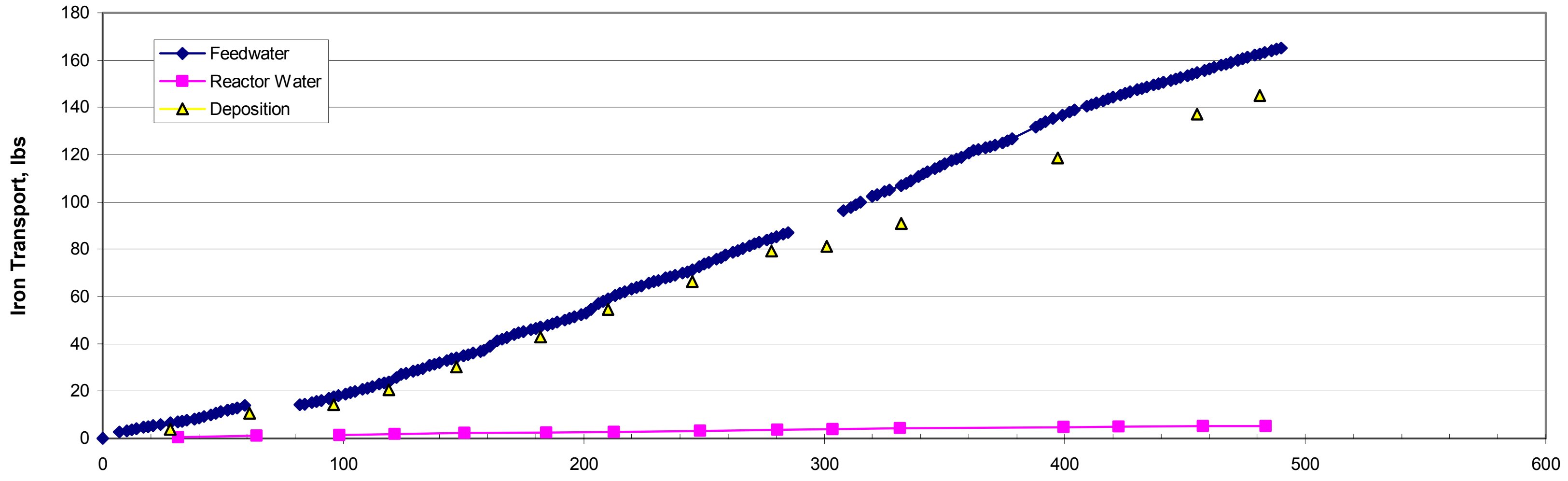

Figure 3-17
Feedwater and RWCU Iron Transport during Cycle 17 at Hatch 2

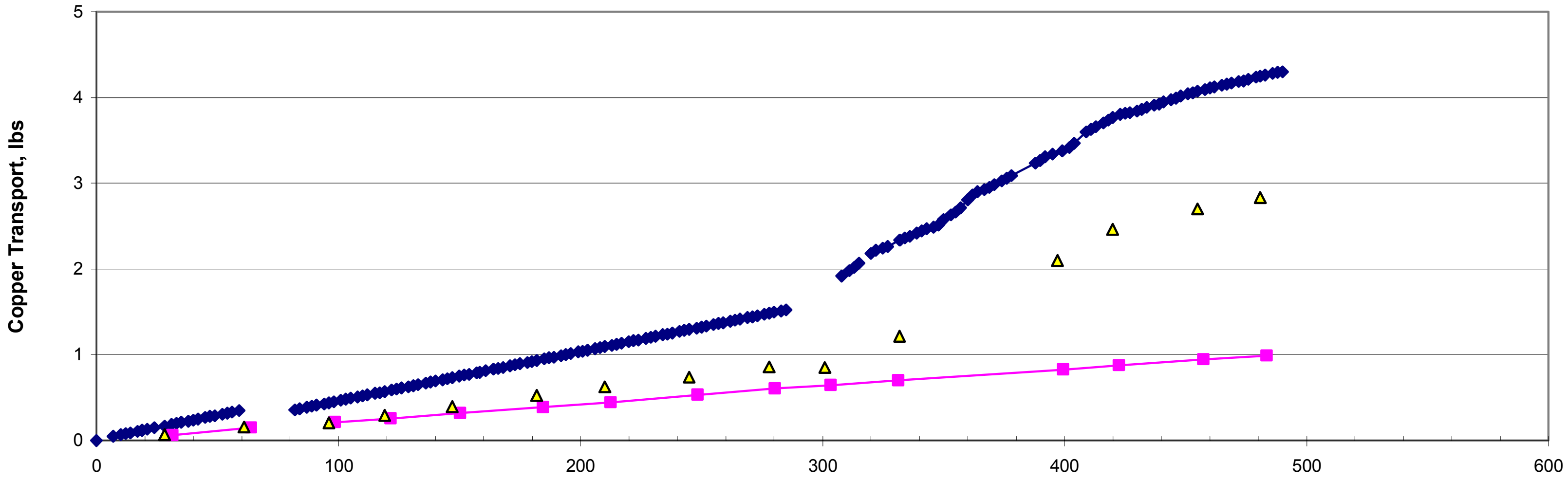

Figure 3-18
Feedwater and RWCU Copper Transport during Cycle 17 at Hatch 2

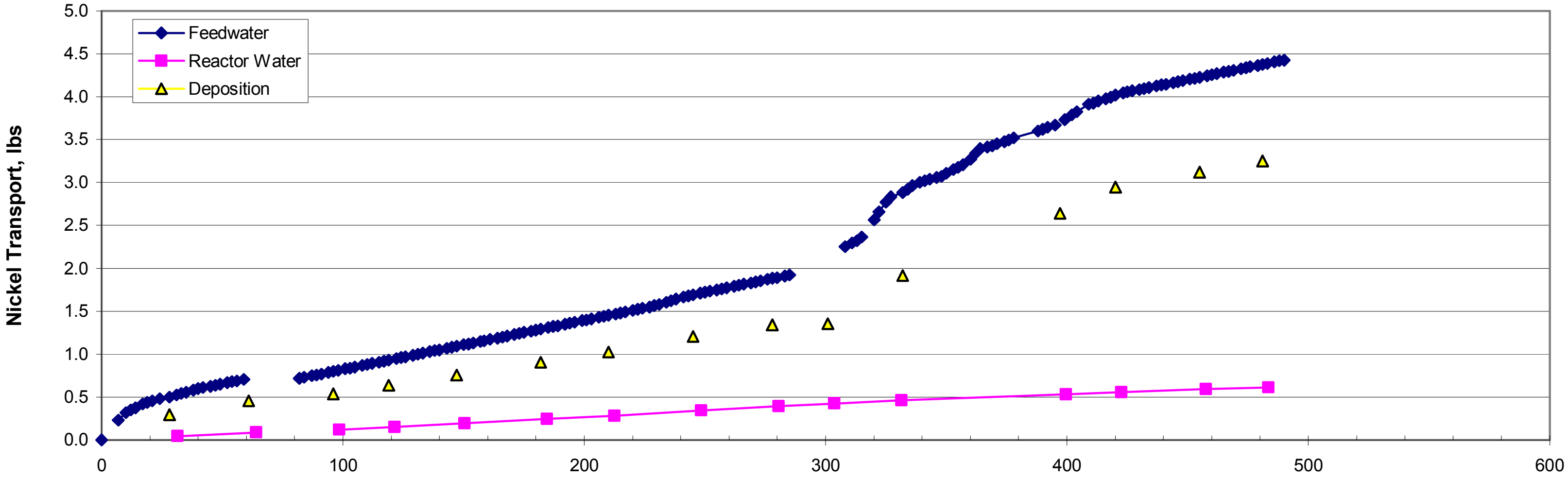

Figure 3-19
Feedwater and RWCU Nickel Transport during Cycle 17 at Hatch 2

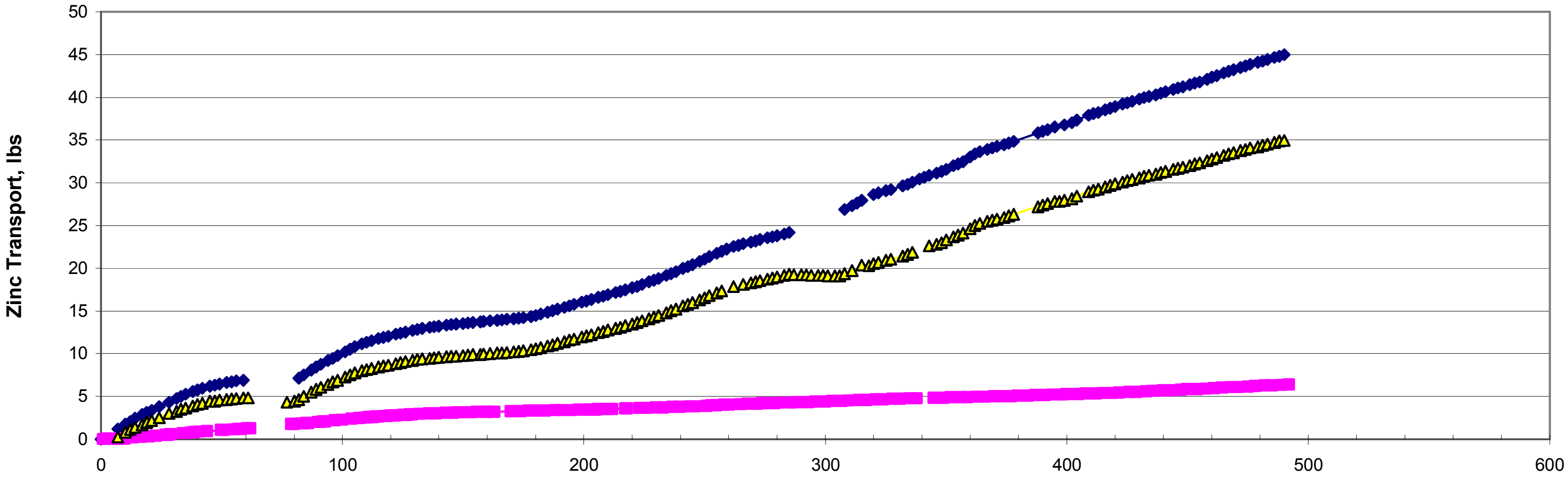

Figure 3-20
Feedwater and RWCU Zinc Transport during Cycle 17 at Hatch 2

4

HIDEOUT RETURN ASSESSMENT

4.1 Background (Technical Basis)

Cumulative hideout return from the beginning of the power reduction until several hours after zero power is reached while the plant is still near operating temperature normally is referred to as "prompt return". Return during this period is believed to be governed by chemical return from concentrated solutions of highly soluble species as well as precipitates from relatively nonoccluded regions. In the authors' opinions, such data provide a reasonable basis for estimating solution chemistry within corrosion product deposits on BWR fuel cladding. Hideout return data obtained during later periods of the shutdown also are of value to identify precipitates and demonstrate consistency with precipitate predictions developed from the prompt return data as well as expectations based on impurity source terms.

4.2 Hideout Return

4.2.1 Browns Ferry 2

The hideout return study at Browns Ferry 2 was performed at the end of Cycle 12. Chronology of the shutdown is given in Table 4-1. Reactor water conductivity during the shutdown evolution is shown in Figure 4-1. Eighteen RCS samples were obtained and shipped to NWT for analysis. Analyses were performed for the following species:

Calcium (0.1)*
Magnesium (0.1)*
Lithium (0.1)*
Potassium (0.1)*
Sodium (0.1)*
Aluminum (1)*
Phosphate (0.5)*
Sulfate (0.1)*
Silica (1)*
Chloride (0.1)*
Fluoride (0.1)*
Copper (0.1)*
Zinc (0.1)*
Platinum (1)*
Rhodium (0.1)*
Iron (0.1)*
Chromium (0.1)*

( )* denotes lower limit of detection (LLD) in ppb

Boron analysis of the Browns Ferry 2 and Hatch 2 samples were performed by TVA personnel at Browns Ferry to improve quantification at the expected concentrations. Limited data were also developed for manganese (0.1) and vanadium (1) at NWT.

The sample bottles were 500-ml polypropylene bottles that had been pretreated at NWT prior to sending them to the site. Sample bottles that were to be used for soluble anions and cations were rinsed several times with high purity water and then presoaked in high purity water for over 24-hours. The sample bottles that were used for metals sampling were acid cleaned by an outside vendor. The sample bottles were prelabeled at NWT.

Site personnel performed all of the sampling and sample acidification. The sampling involved filling and emptying the bottles two times. After the third fill, approximately 10 ml of sample was removed from the bottle before capping. This was done to prevent bottle rupture in case the sample bottles were exposed to sub-freezing temperatures during shipping. The sample bottles labeled with an M were acidified soon after sampling with 0.75 ml of Fisher "TraceMetal" nitric acid (Fisher A509-500, Lot. No. 1102020). The pH in the bottles after the acid addition is estimated to be 1.64. Blank samples were prepared from the site laboratory high purity water system. Three blank samples were acidified. After sampling and the necessary acidification, the bottles were heat sealed inside polyethylene bags and placed in the shipping container.

Along with each set of samples, a 20-ml scintillation vial sample was also taken. Part of this liquid was submitted to the counting room for activity analysis. The objectives were to provide data for sample shipping and to measure the major isotopics released during the shutdown evolution. The site counting results are provided in Appendix A.

Concentrations during the power reduction and cooldown are shown in Figures 4-2 to 4-4. Detailed results are given in Table 4-2. The quantity of impurity return during the shutdown was calculated using the RWCU flowrate, RCS water mass, RCS temperature and impurity concentrations. For concentration values less than the LLD, one half of the LLD value was used in the cumulative return calculation. RWCU removal efficiency was assumed to be 100%. Cumulative returns are shown in Figures 4-5 to 4-7 and Table 4-3. Hideout return during the following periods is summarized in Table 4-4:

- Cumulative return during the power reduction: 100% power to an RCS temperature of 500°F
- Cumulative return from 500°F to end of monitoring period: (T≅ 120°F)
- Total cumulative return

Results can be summarized as follows:

- Return of highly soluble species (e.g., Li, Na, K, Cl, F) was minimal reflecting the absence of a tendency to form precipitates at low solution concentration factors in the deposits relative to the reactor coolant.
- Silica return was far greater than return of any other species and in fact exceeded the return of the sum of the other species. In the authors' opinions, this reflects desorption from iron oxide surfaces rather than dissolution of a precipitate, e.g., a calcium or magnesium silicate. Similar releases from PWR steam generator surfaces are common during shutdowns.
- The increased return of calcium and sulfate following cooldown infers the presence of a $CaSO_4$ precipitate within the deposit structure. Note that the ratio of the sulfate return (~25 grams) to the calcium return (~7 grams) of 3.6 is reasonably consistent with the SO_4 to Ca ratio of 2.4 in $CaSO_4$.

- Mg return is much less than Ca return due to its 5 times lower concentration in the condenser cooling water (the source of the hardness elements) and its tendency to incorporate into spinel structures.
- Fe, Cu and Zn return markedly increased during cooldown inferring solubilization of precipitates with retrograde solubility.
- Return of Pt and Rh was negligible. Concentrations remained at or below LLD levels.

4.2.2 Hatch 2

The hideout return study at Hatch 2 was performed at the end of Cycle 17. Chronology of the shutdown is given in Table 4-5. Reactor water conductivity variations during the shutdown transient are shown in Figure 4-8. Twenty RCS samples were obtained and shipped to NWT for analysis. Analyses were performed for the species listed in Section 4.2.1. Concentrations during the power reduction and cooldown are shown in Figures 4-9 to 4-11. Detailed results are given in Table 4-6. The quantity of impurity return during the shutdown was calculated using the RWCU flowrate, RCS water mass, RCS temperature and impurity concentrations. RWCU removal efficiency was assumed to be 100%. Cumulative returns are shown in Figures 4-12 to 4-14 and Table 4-7. Hideout return during the following periods is summarized in Table 4-8:

- Cumulative return during the power reduction: 100% power to an RCS temperature of 500°F
- Cumulative return from 500°F to end of monitoring period: (T ≅ 120°F)
- Total cumulative return

Results can be summarized as follows. In general, observations were very similar to those at Browns Ferry 2.

- Return of highly soluble species (e.g., Na, K, Cl, F) was minimal reflecting the absence of a tendency to form precipitates at low solution concentration factors in the deposits relative to the reactor coolant. All lithium concentrations were below the LLD of 0.1 ppb.
- Silica return was far greater than return of any other species and in fact exceeded the return of the sum of the other species. As noted above, this is believed to reflect desorption from iron oxide surfaces rather than dissolution of a precipitate.
- A slight increase in the return rate of calcium and sulfate following cooldown infers the presence of a $CaSO_4$ precipitate within the deposit structure but the quantity is small.
- Mg return was much less than Ca return due to its 7 times lower concentration in the condenser cooling water (the source of the hardness elements) and its tendency to incorporate into spinel type structures.
- Fe, Cu and Zn return markedly increased at reduced temperature inferring the presence of compounds exhibiting retrograde solubility.
- Return of Pt and Rh was negligible during the shutdown. Concentrations remained at or below LLD levels.

4.2.3 Conductivity Transient Assessment

Conductivity calculations were performed based on observed solution concentrations at the peak of the conductivity profile at Browns Ferry 2 and Hatch 2 using the MULTEQ conductivity option (Version 2.24; database 1396) for the following cases:

- Redox Potential = 0.1 Volt SHE
- Redox Potential = -0.4 Volt SHE

Results are summarized in Table 4-9. At 0.1 volt SHE, effectively all of the iron, copper and chrome are predicted to be precipitated as Fe_3O_4, Cu_2O and Cu_2O_3. At -0.4 volt SHE, the precipitates are Fe_3O_4, Cu and Cu_2O_3, but only 80 to 87% of the iron is predicted to precipitate at equilibrium. As shown, there is a high side bias in the measured values which could reflect the presence of a low concentration of an unmonitored species (e.g., carbonate/bicarbonate or ammonia) or the lack of achieving thermodynamic equilibrium relative to precipitation of a species such as ferrous iron. The bias is more significant at Browns Ferry 2. If the iron is assumed to remain soluble as a ferrous species, the bias is reversed, i.e., the predicted conductivity significantly exceeds the measured value at both plants.

4.2.4 Summary

Hideout return quantities at Browns Ferry 2 and Hatch 2 are summarized in Figure 4-15. The similarity of the return profiles is generally striking. For impurities entering the system as a result of condenser cooling water leakage (Na, Cl, Ca, and Mg), which is generally the major impurity ingress path at BWRs, this is not surprising. However, several differences did exist:

1. Return of sulfate was approximately 5 times greater at Browns Ferry 2 than at Hatch 2. Return of chloride was 4 times greater. The greater return at Browns Ferry 2 is consistent with the higher average reactor water concentrations at Browns Ferry during power operation. As discussed below, this difference did not result in a major difference in predicted solution pH within the deposit.

2. Aluminum, calcium and silica return at Browns Ferry 2 was greater than at Hatch 2 reflecting higher impurity source terms for these species.

3. Return of lithium was considerably greater at Browns Ferry 2. The Li concentration in all Hatch 2 samples was below the LLD of 0.1 ppb. Note that the source of the lithium release to the reactor water could be fuel cladding deposit solutions or leaking control rod blades.

4. Soluble corrosion product return at Hatch 2, including that of zinc, was generally greater than at Browns Ferry 2 although the core surface area is greater at Browns Ferry 2.

4.3 Deposit Solution Chemistry

To predict deposit solution chemistry during normal operation from the hideout return data, EPRI's MULTEQ code (16) was employed. The hideout return option of MULTEQ Version 2.27 with Species File Version 3.2 was used. It is believed that the hideout return quantities during the power reduction and prior to cooldown are representative of the ratios of highly soluble species present in the deposits prior to shutdown. MULTEQ calculates the composition and pH of a solution as it is concentrated by evaporation. The program considers equilibrium relations including combinations of species, precipitation reactions, and activity coefficients to calculate concentration variations in the liquid phase as boiling proceeds. Calculations were performed with the precipitates in equilibrium with the liquid phase.

Return during the power reduction prior to cooldown below 500°F and also the total cumulative return (Tables 4-4 and 4-8) were used in the MULTEQ calculations. The boiling temperature was estimated as 285°C. MULTEQ results were calculated for boiling point elevations up to 5°C, consistent with limits imposed by the heat transfer process assuming thermodynamics limit the concentration process. However, this boiling point elevation can only be reached at very high deposit concentration factors relative to the coolant (e.g., 10^6 to 10^8), and such values are not expected to be reached within porous deposits. In general, deposit concentration factors of 10 to 1000 are considered more reasonable.

The MULTEQ code currently is limited to consideration of 44 primary species and 100 total species. When the hideout return values of Tables 4-4 and 4-8 are entered as primary species and the code is run in a redox mode at a fixed ECP, approximately 150 possible species are identified. To allow the code to be run, the following approach was used:

1. Since iron is predicted to precipitate almost quantitatively in the crevice solutions at a redox potential of +100 mV and -400 mV, it was not considered in the MULTEQ assessments of deposit solution chemistry. Although it is possible that solubilization in highly acidic crevices could occur, formation of acidic crevice solutions is considered unlikely in the presence of zinc particularly at the low chloride returns and with the expected precipitation of sulfate as calcium sulfate.

2. Fluoride (and all but one phosphate) concentration remained below LLD levels at both Hatch 2 and Browns Ferry 2. Platinum and rhodium returns were also minimal with most concentrations below LLD levels. These species were not considered in the MULTEQ assessment. Similarly, lithium concentrations at Hatch 2 were all below the LLD of 0.1 ppb, and this species was not considered in the Hatch 2 assessment.

3. The major corrosion product species present at +100 to 300 mV over a range of pH were identified. Species present at negligible concentrations were eliminated during the calculation.

4. Since magnesium return was minimal, and the behavior of calcium and magnesium is generally similar, the effect of magnesium was assessed by increasing the amount of calcium return on an equivalent basis.

5. Since a large number of metal chloride complexes are considered in MULTEQ, the tendency to form such complexes at relevant boiling point elevations and pH ranges was assessed. Only those complexes shown to be present at significant concentrations were retained in the hideout return assessment.

Normally, the authors recommend that return at hot zero power (HZP) prior to cooldown be used as the primary basis for predicting deposit solution chemistry. Predicted deposit solution pH values based on HZP return are shown in Figures 4-16 and 4-17. Results based on the total cumulative return are also shown. Neutral to slightly caustic deposit solutions, pH 5.5 to 7.2, were predicted based on the HZP and total hideout return data at Browns Ferry 2 and Hatch 2 at BPE values of 0.01 to 0.02 °C, consistent with concentration factors of 10^2 to 10^4 above the reactor water concentration. Even at the thermodynamic BPE limit of several °C, the pH variation from neutral was minimal, and no significant pH related corrosion acceleration would be expected.

Predicted solution composition and precipitates are shown in Tables 4-10 and 4-11 for Browns Ferry 2 and Hatch 2, respectively. Comments on these results are as follows:

1. The pH of the predicted deposit solutions at Browns Ferry 2 and Hatch 2 at expected concentration factors was neutral to slightly alkaline. Cladding corrosion is not expected to be accelerated significantly in these solutions compared to corrosion in pure water.

2. At Browns Ferry 2, deposit solutions contained primarily sodium, potassium, lithium, chloride and sulfate. Lithium was the major cationic soluble species in the solutions. Note that at Hatch 2, solutions contained primarily sodium, calcium and chloride. Li return was not detected at Hatch 2.

3. At low concentration factors, as anticipated in the porous deposits, concentrations remain relatively low. At higher BPE values, 0.1 to 0.5 molal concentrations are reached. However, these concentration levels are expected only in occluded regions where boiling occurs (possibly at spacer to clad contact locations).

4. Based on the observation of increased return during cooldown and the result of the MULTEQ crevice chemistry assessment, concentration factors in the deposit appear to be in the range of several thousand (or greater).

Table 4-1
Browns Ferry Unit 2 Shutdown Events

Date	Time	Event
2/23/03	12:00	
Sunday	12:24	U2-OPS returned RWCU Demin. "B" to service
	13:00	
	14:00	
	15:00	
	16:00	
	16:14	Sample BF-1 taken
	17:00	
	18:00	
	19:00	Sample BF-2 taken
	20:00	
	21:00	
	21:20	U2-OPS placed 2D cond demin in service
	22:00	Sample BF-3 taken
	22:18	Initiate reactor shutdown. Insert control rods to reduce power to 50%.
	23:00	Reactor at 50% power.
	23:02	Sample BF-4 taken
	23:22	U2-OPS removed 2D cond demin due to power reduction
2/24/03	0:00	
Monday	0:45	U2-OPS removed 2H cond. Demin. Due to power reduction
	1:00	Insert control rods to reduce power to 30%.
	1:04	Sample BF-5 taken
	1:06	U-2 feedwater heaters removed from service
	1:21	U2-OPS commenced flushing RHR loop for shutdown cooling
	1:36	Completed flush of RHR loop.
	2:00	Reactor at 30% power. Initiate power reduction to 23%.
	2:03	Sample BF-6 taken
	2:10	U-2 RHR Loop I sample flush results = 0.49 uS/cm
	2:30	U-2 reactor power reduced to approx. 35%
	3:00	
	3:04	U-2 reactor power is at 27%
	3:05	U-2 HWC tripped
	3:30	Sample BF-7 taken
	4:00	Reactor at 23% power. Maintain reactor power at 23% for approximately 5 hours.
	4:14	U2-OPS commenced flushing RHR Loop II for shutdown cooling.
	4:30	U-2 Loop II RHR sample flush results = 0.72 uS/cm.
	4:45	Sample BF-8 taken
	5:00	
	6:00	%PWR: 21.6
	6:02	Sample BF-9 taken
	7:00	
	8:00	
	8:57	U2 - placed all 9 demins in service with "E" valves full open

Table 4-1 (continued)
Browns Ferry Unit 2 Shutdown Events

Date	Time	Event
2/24/03	9:00	Turbine trip. Initiate manual reactor scram. Initiate reactor cooldown at <90F/hr.
Monday	9:15	Sample BF-10 taken
	9:16	U2 - rolled out Con. Demins., left 2A, 2D, 2F and 2J in-service.
	9:23	Isolated O2 injection to Unit-2
	9:37	Isolated DZO injection to Unit-2
	10:00	Sample BF-19 taken (CDE)
	10:02	Sample BF-11 taken
	11:00	
	11:05	Sample BF-12 taken
	11:17	U2 - Reactor scram due to low water level.
	11:43	U2 - Returned RWCU to service. Both "A" and "B" in service.
	12:00	
	12:10	Sample BF-13 taken
	12:25	Sample BF-20 taken (CDE)
	13:00	
	13:10	Sample BF-14 taken
	13:20	Removed RWCU from service to place in service Shutdown Cooling
	14:00	Placed RHR Loop II in S/D cooling at approx. 8900 gpm using 2"B" RHR pump.
	14:28	U2 - Placed RWCU back in service.
	14:40	Sample BF-15 taken
	15:00	
	15:15	Reactor in cold shutdown. Enter Mode 4.
	15:38	Sample BF-16 taken
	16:00	
	17:00	
	17:13	U2 - Placed 2"D" RHR pump in S/D cooling.
	18:00	
	18:10	Sample BF-17 taken
	19:00	
	20:00	
	21:00	
	22:00	Sample BF-18 taken
	23:00	

Table 4-2
Reactor Water Concentrations during the February 2003 Shutdown at Browns Ferry 2

		POWER	TEMP	RWCU Flow	RCS Mass	Blowdown Concentration, ppb										
DATE	TIME	%	°F	Klb/hr	KLBS	Na	Mg	Li	Ca	K	Cl	SO4	PO4	SiO2	F	B
2/23/03	16:14	72.3	532	124	603.9	0.23	<0.1	0.33	0.6	0.10	0.2	1.3	3.7	84	<0.1	33
2/23/03	19:05	72.2	532	125	603.9	0.10	<0.1	0.23	0.7	0.17	<0.1	1.5	<0.5	72	<0.1	30
2/23/03	22:02	72.2	532	124	603.9	0.10	<0.1	0.21	0.4	<0.1	0.2	1.2	<0.5	62	<0.1	30
2/23/03	23:02	60.6	528	127	609.7	0.10	<0.1	0.17	0.9	0.16	<0.1	1.5	<0.5	69	<0.1	29
2/24/03	1:04	39.0	525	128	620.5	0.22	0.14	0.19	0.6	0.16	0.2	1.4	<0.5	120	<0.1	27
2/24/03	2:03	40.7	515	129	619.7	0.13	0.15	0.20	1.3	0.12	<0.1	1.8	<0.5	150	<0.1	26
2/24/03	3:30	27.1	520	129	626.5	<0.1	0.20	0.23	0.8	0.23	<0.1	2.7	<0.5	180	<0.1	26
2/24/03	4:45	22.1	523	130	629.0	<0.1	0.23	0.25	0.9	0.10	0.2	3.2	<0.5	220	<0.1	25
2/24/03	6:02	21.9	523	130	629.1	0.11	0.25	0.27	1.2	0.23	<0.1	2.9	<0.5	260	<0.1	25
2/24/03	9:15	0.6	513	129	670.1	0.12	0.35	0.69	1.2	0.23	<0.1	4.8	<0.5	300	<0.1	26
2/24/03	10:02	0.5	502	129	679.2	<0.1	0.50	0.78	3.0	0.49	0.2	6.5	<0.5	340	<0.1	28
2/24/03	11:05	0.5	435	127	726.6	0.21	0.57	0.72	2.9	0.19	<0.1	7.7	<0.5	290	<0.1	27
2/24/03	12:10	0.5	371	127	766.5	<0.1	0.75	0.79	11.3	0.24	<0.1	15.0	<0.5	260	<0.1	26
2/24/03	13:10	0.5	309	128	798.6	0.10	0.87	0.78	12.0	0.38	0.3	23.0	<0.5	220	<0.1	26
2/24/03	14:40	0.5	240	125	827.8	0.33	1.3	0.67	11.3	0.38	1.5	25.0	<0.5	180	<0.1	25
2/24/03	15:38	0.4	194	122	843.4	0.29	1.4	0.60	11.5	0.32	1.6	33.0	<0.5	140	<0.1	21
2/24/03	18:10	0.4	140	122	857.6	0.43	1.3	0.46	9.9	0.30	2.7	29.0	<0.5	96	<0.1	21
2/24/03	22:00	0.4	139	121	857.8	0.18	0.79	0.31	2.7	0.19	2.4	23.0	<0.5	78	<0.1	23

Table 4-2 (continued)
Reactor Water Concentrations during the February 2003 Shutdown at Browns Ferry 2

		POWER	TEMP	RWCU Flow	RCS Mass	Blowdown Concentration, ppb									
DATE	TIME	%	°F	Klb/hr	KLBS	Al	Cr	Cu	Fe	Pt	Rh	Zn	NO$_3$	Mn	V
2/23/03	16:14	72.3	532	124.00	603.9	3.0	<0.1	2.8	3.0	<1.0	0.12	9.6	<0.1		
2/23/03	19:05	72.2	532	125.00	603.9	<1.0	<0.1	1.4	0.4	<1.0	<0.1	6.4	<0.1		
2/23/03	22:02	72.2	532	124.00	603.9	<1.0	<0.1	1.2	0.4	<1.0	<0.1	6.1	<0.1		
2/23/03	23:02	60.6	528	127.00	609.7	2.0	<0.1	1.4	1.7	<1.0	<0.1	6.2	<0.1		
2/24/03	1:04	39.0	525	128.00	620.5	3.0	<0.1	1.1	1.1	<1.0	<0.1	6.9	<0.1		
2/24/03	2:03	40.7	515	129.00	619.7	<1.0	<0.1	1.1	1.6	<1.0	<0.1	7.5	<0.1		
2/24/03	3:30	27.1	520	129.00	626.5	<1.0	<0.1	4.1	2.7	<1.0	<0.1	8.6	<0.1		
2/24/03	4:45	22.1	523	130.00	629.0	<1.0	<0.1	6.0	0.7	<1.0	<0.1	11.0	0.3		
2/24/03	6:02	21.9	523	130.00	629.1	<1.0	0.14	8.9	1.3	<1.0	<0.1	13.0	<0.1		
2/24/03	9:15	0.6	513	129.00	670.1	<1.0	0.21	10.0	0.7	<1.0	0.12	14.0	0.3	0.46	<1.0
2/24/03	10:02	0.5	502	129.00	679.2	<1.0	0.86	9.6	24.6	<1.0	<0.1	14.0	<0.1	2.5	
2/24/03	11:05	0.5	435	127.00	726.6	<1.0	0.48	6.6	15.7	<1.0	<0.1	20.0	<0.1		
2/24/03	12:10	0.5	371	127.00	766.5	3.0	0.45	4.7	41.7	<1.0	<0.1	25.0	0.7	14.0	<1.0
2/24/03	13:10	0.5	309	128.00	798.6	<1.0	0.45	3.3	24.2	<1.0	<0.1	40.0	0.2		
2/24/03	14:40	0.5	240	125.00	827.8	4.0	0.31	4.2	21.5	<1.0	<0.1	35.0	9.8	5.1	
2/24/03	15:38	0.4	194	122.00	843.4	1.0	0.38	4.9	18.3	<1.0	<0.1	28.0	13.0	0.0	
2/24/03	18:10	0.4	140	122.00	857.6	<1.0	10.0	32.0	43.1	<1.0	<0.1	54.0	11.0	7.1	<1.0
2/24/03	22:00	0.4	139	121.00	857.8	<1.0	5.3	33.0	27.4	<1.0	<0.1	47.0	8.8	7.0	

Table 4-3
Cumulative Hideout Return for the February 2003 Shutdown at Browns Ferry 2

		POWER	TEMP	RWCU Flow	RCS Mass	Cumulative Hideout Return, grams									
DATE	**TIME**	**%**	**°F**	**Klb/hr**	**KLBS**	**Na**	**Mg**	**Li**	**Ca**	**K**	**Cl**	**SO_4**	**SiO_2**	**F**	B
2/23/03	16:14	72.3	531.8	124.0	603.9	0	0	0	0	0	0	0	0	0	0
2/23/03	19:05	72.2	531.8	125.0	603.9	-0.01	0.01	0.02	0.13	0.04	-0.02	0.28	9.3	0.01	4
2/23/03	22:02	72.2	531.9	124.0	603.9	0.01	0.02	0.05	0.14	0.03	0.04	0.42	17.7	0.02	10
2/23/03	23:02	60.6	527.5	127.0	609.7	0.01	0.02	0.05	0.32	0.06	0.01	0.59	23.5	0.02	11
2/24/03	01:04	39	524.7	128.0	620.5	0.07	0.06	0.08	0.33	0.08	0.06	0.74	49.4	0.03	14
2/24/03	02:03	40.7	515.2	129.0	619.7	0.05	0.07	0.09	0.58	0.08	0.03	0.94	65.5	0.03	15
2/24/03	03:30	27.1	520	129.0	626.5	0.04	0.10	0.12	0.53	0.13	0.03	1.4	88.5	0.03	17
2/24/03	04:45	22.1	523	130.0	629.0	0.04	0.12	0.14	0.62	0.10	0.09	1.8	115	0.04	19
2/24/03	06:02	21.9	523.4	130.0	629.1	0.06	0.15	0.17	0.79	0.15	0.05	1.9	144	0.04	21
2/24/03	09:15	0.6	513.2	129.0	670.1	0.09	0.24	0.39	1.04	0.20	0.06	3.3	214	0.05	26
2/24/03	10:02	0.5	501.5	129.0	679.2	0.07	0.30	0.45	1.69	0.30	0.11	4.1	243	0.05	28
2/24/03	11:05	0.5	435.2	127.0	726.6	0.13	0.37	0.50	1.90	0.23	0.08	5.0	253	0.06	30
2/24/03	12:10	0.5	370.6	127.0	766.5	0.09	0.48	0.58	5.32	0.26	0.08	8.4	265	0.06	32
2/24/03	13:10	0.5	309.1	128.0	798.6	0.11	0.59	0.64	6.42	0.34	0.18	12.6	268	0.06	34
2/24/03	14:40	0.5	240.2	125.0	827.8	0.22	0.85	0.67	7.32	0.37	0.71	15.8	273	0.07	36
2/24/03	15:38	0.4	193.8	122.0	843.4	0.22	0.97	0.68	8.09	0.37	0.85	20.6	268	0.07	36
2/24/03	18:10	0.4	139.5	122.0	857.6	0.33	1.13	0.70	9.04	0.41	1.59	23.6	268	0.08	39
2/24/03	22:00	0.4	138.7	121.0	857.8	0.30	1.16	0.73	7.57	0.42	2.01	26.7	279	0.09	44

Table 4-3 (continued)
Cumulative Hideout Return for the February 2003 Shutdown at Browns Ferry 2

		POWER	TEMP	RWCU Flow	RCS Mass	Cumulative Hideout Return, grams							
DATE	TIME	%	°F	Klb/hr	KLBS	Al	Cr	Cu	Fe	Pt	Rh	Zn	NO_3
2/23/03	16:14	72.3	531.8	124.0	603.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2/23/03	19:05	72.2	531.8	125.0	603.9	-0.2	0.0	0.0	-0.4	0.1	0.0	0.4	0.0
2/23/03	22:02	72.2	531.9	124.0	603.9	-0.1	0.0	0.1	-0.4	0.2	0.0	1.4	0.0
2/23/03	23:02	60.6	527.5	127.0	609.7	0.3	0.0	0.2	0.0	0.2	0.0	1.8	0.0
2/24/03	01:04	39	524.7	128.0	620.5	0.9	0.1	0.3	0.1	0.3	0.0	2.8	0.0
2/24/03	02:03	40.7	515.2	129.0	619.7	0.4	0.1	0.4	0.3	0.3	0.0	3.3	0.0
2/24/03	03:30	27.1	520	129.0	626.5	0.5	0.1	1.5	0.8	0.3	0.0	4.4	0.0
2/24/03	04:45	22.1	523	130.0	629.0	0.6	0.1	2.4	0.3	0.4	0.0	5.8	0.1
2/24/03	06:02	21.9	523.4	130.0	629.1	0.7	0.1	3.8	0.6	0.4	0.0	7.3	0.1
2/24/03	09:15	0.6	513.2	129.0	670.1	0.9	0.2	6.1	0.6	0.5	0.1	10.4	0.2
2/24/03	10:02	0.5	501.5	129.0	679.2	0.9	0.4	6.4	8.6	0.5	0.0	11.1	0.1
2/24/03	11:05	0.5	435.2	127.0	726.6	1.0	0.3	6.1	7.4	0.6	0.1	14.4	0.1
2/24/03	12:10	0.5	370.6	127.0	766.5	1.9	0.3	5.9	18.5	0.6	0.1	17.9	0.4
2/24/03	13:10	0.5	309.1	128.0	798.6	1.3	0.4	5.7	14.7	0.6	0.1	25.6	0.2
2/24/03	14:40	0.5	240.2	125.0	827.8	2.6	0.4	6.4	16.0	0.7	0.1	27.5	4.2
2/24/03	15:38	0.4	193.8	122.0	843.4	1.7	0.4	7.0	16.0	0.7	0.1	26.7	6.2
2/24/03	18:10	0.4	139.5	122.0	857.6	1.8	4.9	20.2	30.0	0.8	0.1	42.8	7.1
2/24/03	22:00	0.4	138.7	121.0	857.8	2.0	4.7	27.4	31.4	0.9	0.1	50.7	8.4

Table 4-4
Cumulative Hideout Return during Different Phases of the February 2003 Shutdown at Browns Ferry 2

	Power Reduction to 500°F	Cooldown	Total
Na	0.07	0.23	0.30
Mg	0.30	0.85	1.16
Li	0.45	0.27	0.73
Ca	1.69	5.88	7.57
K	0.30	0.12	0.42
Cl	0.11	1.90	2.01
SO_4	4.06	22.7	26.7
PO_4[a]	-0.40	0.19	-0.21
SiO_2	243	37	279
F[a, b]	0.05	0.04	0.09
Al[a]	0.40	0.82	1.22
Cr	0.35	4.29	4.65
Cu	6.42	21.00	27.42
Fe	8.56	22.83	31.39
Pt[a, b]	0.53	0.38	0.91
Rh[a]	0.05	0.04	0.09
Zn	11.1	39.7	50.7
NO_3	0.10	8.28	8.39
B	28.2	16.0	44.2

a) Caution should be exercised in considering the cumulative return estimates since a significant fraction of the relevant concentration data were below the lower limit of detection (LLD). In these cases, a value of one-half the LLD was used to estimate return.

b) All concentration data below LLD.

Table 4-5
Hatch Unit 2 Shutdown Events

Date	**Time**	**Sample**	Event
2/28/03	0:00		
	1:00		
	2:00		
	3:00	1	Start reduction of power to 50%.
	4:00		
	5:00		
	6:00		
	7:00	1	Reactor power at 50%. Terminate zinc injection.
	8:00	1	Remove hydrogen injection from service.
	9:00	1	
	10:00		
	11:00	1	
	12:00		
	13:00		
	14:00		
	15:00	1	
	16:00		
	17:00		
	18:00		
	19:00	1	
	20:00		
	21:00		
	22:00		
	23:00		
3/1/03	0:00	1	Generator off line.
	1:00	1	Manual scram of reactor.
	2:00	1	Start decrease of reactor pressure to <375#.
	3:00	1	Start decrease of reactor pressure to <100#.
	4:00	1	
	5:00	1	"B" RHR in SDC.
	6:00	1	
	7:00	1	Plant in cold shutdown - Mode 4
	8:00		
	9:00		
	10:00	1	
	11:00		
	12:00		
	13:00		
	14:00	1	
	15:00		
	16:00		
	17:00		
	18:00	1	
	19:00		
	20:00		

Table 4-5 (continued)
Hatch Unit 2 Shutdown Events

Date	Time	Sample	*Event*
3/1/03	21:00		
	22:00	1	
	23:00		
3/2/03	0:00		
	1:00		
	2:00	1	
	3:00		
	4:00		
	5:00		
	6:00		
	7:00		
	8:00		
	9:00		Plant in Mode 5 - Low water level.
	Total # Samples:	20	

Table 4-6
Reactor Water Concentrations during the February 2003 Shutdown at Hatch 2

		POWER	TEMP	RWCU Flow	RCS Mass	Blowdown Concentration, ppb										
DATE	TIME	%	°F	Klb/hr	KLBS	Na	Mg	Li	Ca	K	Cl	SO4	PO4	SiO2	F	B
2/28/03	1:00	100	550	93.0	441	0.4	<0.1	<0.1	0.7	0.2	0.1	1.1	<0.5	37	<0.1	15
2/28/03	3:00	85	550	93.0	448	0.3	<0.1	<0.1	0.7	0.4	0.2	1.2	<0.5	37	<0.1	14
2/28/03	5:00	60	550	93.0	461	0.4	0.1	<0.1	0.8	0.3	0.1	1.2	<0.5	62	<0.1	13
2/28/03	7:00	51	550	93.0	465	0.3	0.2	<0.1	1.3	0.3	0.1	1.2	<0.5	120	0.1	10
2/28/03	9:00	50	526	93.0	465	0.3	0.2	<0.1	1.4	0.3	0.1	2.4	<0.5	150	<0.1	9
2/28/03	11:00	51	526	92.0	465	0.2	0.3	<0.1	1.3	0.4	0.1	1.6	<0.5	160	<0.1	10
2/28/03	15:00	52	524	93.0	465	0.2	0.2	<0.1	1.0	0.2	0.1	1.5	<0.5	160	<0.1	10
2/28/03	19:00	52	523	92.0	464	0.2	0.3	<0.1	4.0	0.2	0.1	1.6	<0.5	140	<0.1	10
2/28/03	21:25	37	522	94.0	472	0.3	0.3	<0.1	0.9	<0.1	0.1	0.6	<0.5	170	<0.1	10
3/1/03	0:00	18	521	99.0	481	0.2	0.5	<0.1	1.2	0.1	0.1	2.1	<0.5	280	<0.1	9
3/1/03	0:45	1	507	99.0	517	0.2	0.5	<0.1	1.5	0.3	0.1	1.6	<0.5	280	<0.1	12
3/1/03	2:00	0	436	93.0	556	0.3	1.0	<0.1	1.7	0.4	0.2	1.6	<0.5	290	<0.1	10
3/1/03	3:00	0	405	49.0	571	0.4	1.0	<0.1	1.8	0.2	0.1	2.1	<0.5	280	0.1	10
3/1/03	5:00	0	240	75.0	634	0.4	0.9	<0.1	4.7	0.4	0.7	3.6	<0.5	190	<0.1	10
3/1/03	7:00	0	170	74.0	651	0.4	0.6	<0.1	2.2	0.1	0.6	3.1	<0.5	130	<0.1	8
3/1/03	10:00	0	147	73.0	655	0.9	0.5	<0.1	2.5	0.3	0.7	4.6	<0.5	88	<0.1	9
3/1/03	14:00	0	118	80.0	660	1.2	0.8	<0.1	13.0	0.2	0.7	5.6	<0.5	49	<0.1	8
3/1/03	18:00	0	113	80.0	661	0.6	0.3	<0.1	1.5	0.3	0.4	4.5	<0.5	32	<0.1	9
3/1/03	22:00	0	116	82.0	660	0.3	0.2	<0.1	0.8	0.3	0.1	2.9	<0.5	15	<0.1	7
3/2/03	2:00	0	119	81.0	660	0.3	0.1	<0.1	1.2	<0.1	0.2	3.6	<0.5	15	<0.1	9

Table 4-6 (continued)
Reactor Water Concentrations during the February 2003 Shutdown at Hatch 2

		POWER	TEMP	Avg BD	RCS Mass	Blowdown Concentration, ppb									
DATE	TIME	%	°F	Klb/hr	KLBS	Al	Cr	Cu	Fe	Pt	Rh	Zn	NO_3	Mn	V
2/28/03	1:00	100	550	93.00	441	<1.0	<0.1	0.21	2.2	<1.0	<0.1	4.6	0.8		
2/28/03	3:00	85	550	93.00	448	1.4	<0.1	0.42	4.1	<1.0	<0.1	8.2	0.8		
2/28/03	5:00	60	550	93.00	461	<1.0	<0.1	0.32	3.0	<1.0	<0.1	4.8	1.3		
2/28/03	7:00	51	550	93.00	465	1.4	<0.1	0.42	4.4	<1.0	<0.1	4.7	0.7		
2/28/03	9:00	50	526	93.00	465	1.4	<0.1	0.42	2.6	<1.0	<0.1	5.6	<0.1		
2/28/03	11:00	51	526	92.00	465	<1.0	<0.1	0.53	2.8	<1.0	<0.1	7.9	1.1		
2/28/03	15:00	52	524	93.00	465	1.4	<0.1	0.32	2.3	<1.0	<0.1	8.8	0.3		
2/28/03	19:00	52	523	92.00	464	<1.0	<0.1	0.53	6.9	<1.0	<0.1	9.5	0.9		
2/28/03	21:25	37	522	94.00	472	1.4	<0.1	0.53	2.3	<1.0	<0.1	12.0	<0.1		
3/1/03	0:00	18	521	99.00	481	<1.0	0.2	10.00	2.3	<1.0	<0.1	9.5	1.0		
3/1/03	0:45	1	507	99.00	517	1.4	0.4	9.80	3.8	1.6	<0.1	12.0	1.3	0.16	<1.0
3/1/03	2:00	0	436	93.00	556	2.0	1.1	27.00	15.4	<1.0	<0.1	16.0	1.1	1.9	
3/1/03	3:00	0	405	49.00	571	7.0	0.8	4.00	8.1	1.6	<0.1	17.0	0.8	3.7	
3/1/03	5:00	0	240	75.00	634	3.7	1.8	32.00	106.1	<1.0	0.2	43.0	6.1		
3/1/03	7:00	0	170	74.00	651	3.2	3.3	27.00	72.1	1.6	0.3	56.0	6.1	3.2	<1.0
3/1/03	10:00	0	147	73.00	655	1.4	10.0	36.00	90.1	<1.0	0.2	75.0	5.2		
3/1/03	14:00	0	118	80.00	660	8.0	12.0	66.00	94.4	<1.0	0.2	82.0	4.2	4.8	<1.0
3/1/03	18:00	0	113	80.00	661	<1.0	7.8	21.00	52.6	<1.0	0.2	54.0	4.3		
3/1/03	22:00	0	116	82.00	660	7.0	6.1	25.00	36.1	<1.0	<0.1	45.0	1.6		
3/2/03	2:00	0	119	81.00	660	<1.0	6.0	18.00	13.3	<1.0	<0.1	39.0	3.6		

Table 4-7
Cumulative Hideout Return for the February 2003 Shutdown at Hatch 2

		POWER	TEMP	RWCU Flow	RCS Mass	Cumulative Hideout Return, grams									
DATE	**TIME**	**%**	**°F**	**Klb/hr**	**KLBS**	**Na**	Mg	**Li**	**Ca**	**K**	**Cl**	**SO_4**	**SiO_2**	**F**	B
2/28/03	01:00	100	550	93.0	441	0	0	0	0	0	0	0	0	0	0.0
2/28/03	03:00	85	550	93.0	448	0	0	0	0	0	0	0	0	0	1.1
2/28/03	05:00	60	550	93.0	461	0.02	0.00	0.00	0.06	0.06	0.04	0.12	3.25	0.00	2.0
2/28/03	07:00	51	550	93.0	465	0.06	0.03	0.01	0.16	0.06	0.03	0.23	12.86	0.01	2.5
2/28/03	09:00	50.4	525.661	93.0	465	0.07	0.05	0.01	0.35	0.09	0.03	0.33	32.91	0.03	3.1
2/28/03	11:00	51.3	525.58	92.0	465	0.10	0.08	0.02	0.49	0.11	0.03	0.74	50.67	0.02	3.9
2/28/03	15:00	51.6	524.284	93.0	465	0.11	0.11	0.02	0.58	0.16	0.04	0.74	65.76	0.03	5.6
2/28/03	19:00	52.2	523.392	92.0	464	0.15	0.14	0.03	0.71	0.16	0.05	0.98	92.63	0.03	7.2
2/28/03	21:25	36.6	522.257	94.0	472	0.18	0.20	0.04	1.76	0.21	0.06	1.26	113.60	0.04	8.2
3/1/03	00:00	17.7	521.041	99.0	481	0.22	0.23	0.04	1.35	0.19	0.06	1.16	136.35	0.05	9.3
3/1/03	00:45	0.5	507.285	99.0	517	0.22	0.33	0.05	1.54	0.21	0.07	1.65	186.72	0.05	10.3
3/1/03	02:00	0.4	435.626	93.0	556	0.24	0.36	0.05	1.68	0.26	0.07	1.62	200.64	0.06	10.6
3/1/03	03:00	0.3	404.599	49.0	571	0.27	0.52	0.06	1.84	0.31	0.11	1.74	223.71	0.06	11.1
3/1/03	05:00	0.3	239.904	75.0	634	0.31	0.55	0.06	1.94	0.28	0.08	1.94	232.36	0.08	12.0
3/1/03	07:00	0.3	169.857	74.0	651	0.36	0.61	0.06	3.02	0.34	0.30	2.60	227.11	0.07	12.0
3/1/03	10:00	0.3	147.236	73.0	655	0.37	0.57	0.07	2.55	0.30	0.31	2.71	221.69	0.07	13.2
3/1/03	14:00	0.3	118.45	80.0	660	0.59	0.61	0.07	2.88	0.35	0.41	3.54	220.37	0.08	14.0
3/1/03	18:00	0.3	113.455	80.0	661	0.83	0.78	0.08	7.14	0.38	0.51	4.56	218.27	0.08	15.4
3/1/03	22:00	0.3	116.39	82.0	660	0.79	0.72	0.09	4.75	0.44	0.50	4.97	219.07	0.09	15.9
3/2/03	02:00	0.3	119.424	81.0	660	0.75	0.71	0.09	4.72	0.48	0.43	5.03	217.41	0.10	17.8

Table 4-7 (continued)
Cumulative Hideout Return for the February 2003 Shutdown at Hatch 2

		POWER	**TEMP**	**RWCU Flow**	**RCS Mass**	**Cumulative Hideout Return, grams**							
DATE	**TIME**	**%**	**°F**	**Klb/hr**	**KLBS**	**Al**	**Cr**	**Cu**	**Fe**	**Pt**	**Rh**	**Zn**	**NO_3**
2/28/03	01:00	100	550	93.0	441.0	0	0	0	0	0	0	0	0
2/28/03	03:00	85	550	93.0	448.4	0.27	0.00	0.07	0.66	0.04	0.00	1.29	0.07
2/28/03	05:00	60	550	93.0	460.6	0.16	0.01	0.08	0.75	0.09	0.01	1.17	0.27
2/28/03	07:00	51	550	93.0	465.0	0.44	0.01	0.14	1.37	0.13	0.01	1.56	0.23
2/28/03	09:00	50.4	525.661	93.0	465.3	0.55	0.02	0.17	1.28	0.17	0.02	2.19	0.12
2/28/03	11:00	51.3	525.58	92.0	464.9	0.44	0.02	0.23	1.55	0.22	0.02	3.24	0.39
2/28/03	15:00	51.6	524.284	93.0	464.7	0.79	0.03	0.26	1.87	0.30	0.03	4.83	0.34
2/28/03	19:00	52.2	523.392	92.0	464.4	0.76	0.04	0.38	3.61	0.38	0.04	6.51	0.57
2/28/03	21:25	36.6	522.257	94.0	472.1	1.06	0.04	0.43	3.12	0.44	0.04	8.18	0.44
3/1/03	00:00	17.7	521.041	99.0	481.3	0.97	0.08	3.11	3.39	0.50	0.05	8.90	0.71
3/1/03	00:45	0.5	507.285	99.0	516.6	1.22	0.14	3.56	3.88	0.80	0.05	10.00	0.83
3/1/03	02:00	0.4	435.626	93.0	556.1	1.49	0.37	9.07	7.39	0.61	0.06	11.98	0.87
3/1/03	03:00	0.3	404.599	49.0	571.4	2.92	0.32	3.90	6.02	0.92	0.06	12.88	0.83
3/1/03	05:00	0.3	239.904	75.0	633.9	2.45	0.72	13.25	38.24	0.70	0.12	22.69	2.60
3/1/03	07:00	0.3	169.857	74.0	651.0	2.57	1.35	14.02	35.05	1.10	0.16	30.21	3.06
3/1/03	10:00	0.3	147.236	73.0	655.3	2.27	4.01	19.90	48.66	0.89	0.14	42.52	3.37
3/1/03	14:00	0.3	118.45	80.0	659.9	4.92	6.17	36.14	62.97	0.96	0.16	55.70	3.74
3/1/03	18:00	0.3	113.455	80.0	660.6	3.29	6.35	28.99	61.14	1.03	0.18	57.21	4.38
3/1/03	22:00	0.3	116.39	82.0	660.2	5.80	6.86	33.57	62.69	1.10	0.16	61.78	4.01
3/2/03	02:00	0.3	119.424	81.0	659.8	4.41	7.72	34.65	59.52	1.18	0.17	66.19	4.99

Table 4-8
Cumulative Hideout Return during Different Phases of the February 2003 Shutdown at Hatch 2

	Power Reduction to 500°F	Cooldown	Total
Na	0.24	0.54	0.78
Mg	0.36	0.37	0.72
Li[a, b]	0.05	0.05	0.10
Ca	1.68	3.30	4.98
K	0.26	0.18	0.43
Cl[a]	0.07	0.42	0.49
SO_4	1.62	4.10	5.72
PO_4[a, b]	0.26	0.24	0.50
SiO_2	201	19	220
F[a, b]	0.06	0.05	0.11
Al	1.22	3.19	4.41
Cr	0.14	7.58	7.72
Cu	3.56	31.09	34.65
Fe	3.88	55.64	59.52
Pt[a]	0.80	0.38	1.18
Rh[a]	0.05	0.12	0.17
Zn	10.0	56.2	66.2
NO_3	0.83	4.16	5.0
B	10.3	7.43	17.8

a) Caution should be exercised in considering the cumulative return estimates since a significant fraction of the relevant concentration data were below the lower limit of detection (LLD). In these cases, a value of one-half the LLD was used to estimate return.

b) All concentration data below LLD.

Table 4-9
Conductivity Resolution

	Browns Ferry 2	**Hatch 2**
Peak Value, µS/cm	0.52	0.35
Plant Condition	140°F	140°F
Calculated Values		
Redox 0.1 Volt	0.32	0.25
Redox -0.4 Volt	0.37	0.29

Table 4-10
Summary of Predicted Crevice Chemistry at Browns Ferry 2 Based on Cumulative Return

	Return From Power Reduction to 500°F				**Total Return**			
Conc. Factor	100	1,000	10,000	3.2E+07	100	1,000	10,000	1.0E+07
pH	6.16	6.8	7.19	7.1	5.77	5.86	6.13	6.03
BPE, °C	0	0.01	0.02	2.74	0	0.01	0.02	2.04
	Concentration, molal							
Li[a]	6.52E-06	6.50E-05	6.29E-04	1.56	1.06E-05	1.05E-04	1.02E-03	0.90
K^+	1.20E-06	1.20E-05	2.74E-05	0.01	2.43E-06	2.43E-05	1.32E-04	0.00
Cl-	4.21E-07	4.23E-06	4.22E-05	0.13	5.64E-06	5.69E-05	5.75E-04	0.56
SO_4^{2-}	1.38E-06	6.24E-06	1.14E-04	0.27	4.35E-06	2.12E-05	1.33E-04	0.07
$HCrO_4^-$	7.29E-07	7.23E-06	7.08E-05	0.03	4.62E-06	1.16E-05	1.88E-04	0.02
$LiSO_4^-$	3.05E-09	1.29E-07	1.97E-05	0.49	1.52E-08	6.97E-07	3.43E-05	0.15
CrO_4^{2-}	1.69E-09	7.82E-08	2.19E-06	0.18	4.44E-09	1.46E-08	5.48E-07	0.01
$Cr_2O_7^{2-}$	3.08E-13	3.13E-11	3.24E-09	0.01	1.25E-11	8.12E-11	2.36E-08	4.13E-03
OH^-	7.41E-06	3.36E-05	8.90E-05	1.09E-03	3.04E-06	3.87E-06	8.08E-06	6.30E-05
H^+	6.956E-07	1.59E-07	6.44E-08	7.97E-08	1.71E-06	1.39E-06	7.40E-07	9.41E-09
	Precipitates[b]				**Precipitates**[b]			
	Fe_2O_3	Fe_2O_3	$CaSO_4$	$CaSO_4$	Fe_2O_3	$CaSO_4$	$CaSO_4$	$CaSO_4$
	CuO	CuO	$CaSiO_3$	$CaSiO_3$	Cr_2O_3	$Ca_3(PO_4)_2$	$Ca_3(PO_4)_2$	$Ca_3(PO_4)_2$
	ZnO	ZnO	Fe_2O_3	Fe_2O_3	CuO	Fe_2O_3	Fe_2O_3	Fe_2O_3
			CuO	CuO	ZnO	Cr_2O_3	Cr_2O_3	Cr_2O_3
			ZnO	ZnO	AlOH	CuO	CuO	CuO
			SiO_2	SiO_2		ZnO	ZnO	ZnO
			$KAl_2(SiAl)O_{10}(OH)_2$	$KAl_2(SiAl)O_{10}(OH)_2$		AlOH	$ZnSO_4$	$ZnSO_4$
							SiO_2	SiO_2
							$KAl_2(SiAl)O_{10}(OH)_2$	$KAl_2(SiAl)O_{10}(OH)_2$
							$Al_2Si_4O_{10}(OH)_2$	$Al_2Si_4O_{10}(OH)_2$

a) 10^{-6} molal corresponds to 7 ppb Li and 10^{-3} molal corresponds to 7 ppm

b) Precipitate accounts for ≥ 5% of one of the component species

Table 4-11
Summary of Predicted Crevice Chemistry at Hatch 2 based on Cumulative Return

	Return from Power Reduction to 500°F				**Total Return**			
Conc. Factor	100	1,000	10,000	1.0E+08	100	1,000	10,000	3.16E+07
pH	6.09	6.68	6.77	6.97	5.9	6.52	6.26	1.83
BPE, °C	0	0	0.02	2.24	0	0.01	0.02	6.19
	Concentration, molal							
Li	1.45E-06	1.45E-05	1.44E-04	1.25	2.90E-06	2.89E-05	2.89E-04	0.91
K^+	1.69E-06	1.69E-05	3.06E-05	0.02	4.48E-06	4.48E-05	9.94E-05	0.00
Cl-	3.08E-07	3.10E-06	3.10E-05	0.31	1.39E-06	1.41E-05	1.40E-04	0.44
SO_4^{2-}	4.62E-07	1.52E-06	1.34E-05	0.11	9.32E-07	2.55E-06	1.58E-06	0.00
$HCrO_4^-$	3.46E-07	3.43E-06	3.42E-05	0.06	1.49E-05	1.48E-04	5.45E-04	0.13
$LiSO_4^-$	2.28E-10	7.04E-09	6.00E-07	0.19	8.98E-10	2.206E-08	1.23E-07	0.00
CrO_4^{2-}	6.84E-10	2.80E-08	3.52E-07	0.21	1.92E-08	8.93E-07	2.00E-06	0.05
$Cr_2O_7^{2-}$	6.91E-14	7.05E-12	7.11E-10	0.03	1.30E-10	1.36E-08	1.94E-07	0.12
OH^-	6.35E-06	2.54E-05	3.15E-05	7.20E-04	4.10E-06	1.81E-05	1.04E-05	9.75E-05
H^+	8.107E-07	2.10E-07	1.71E-07	1.07E-07	1.27E-06	3.03E-07	5.56E-07	6.44E-07
	Precipitates[a]				**Precipitates**[a]			
	Fe_2O_3	$Ca_3(PO_4)_2$	$CaSO_4$	$CaSO_4$	$Ca_3(PO_4)_2$	$Ca_3(PO_4)_2$	$CaSO_4$	$CaSO_4$
	CuO	Fe_2O_3	$Ca_3(PO_4)_2$	$Ca_3(PO_4)_2$	Fe_2O_3	Fe_2O_3	$Ca_3(PO_4)_2$	$Ca_3(PO_4)_2$
	ZnO	CuO	$CaSiO_3$	$CaSiO_3$	CuO	CuO	$CaSiO_3$	$CaSiO_3$
		ZnO	Fe_2O_3	Fe_2O_3	ZnO	ZnO	Fe_2O_3	Fe_2O_3
		AlOH	CuO	CuO	AlOH	AlOH	Cr_2O_3	Cr_2O_3
			ZnO	ZnO			CuO	CuO
			SiO_2	SiO_2			ZnO	ZnO
			$KAl_2(SiAl)O_{10}(OH)_2$	$KAl_2(SiAl)O_{10}(OH)_2$			SiO_2	SiO_2
			$Al_2Si_4O_{10}(OH)_2$				$KAl_2(SiAl)O_{10}(OH)_2$	$KAl_2(SiAl)O_{10}(OH)_2$
							$Al_2Si_4O_{10}(OH)_2$	$Al_2Si_4O_{10}(OH)_2$

a) Precipitate accounts for ≥5% of one of the component species

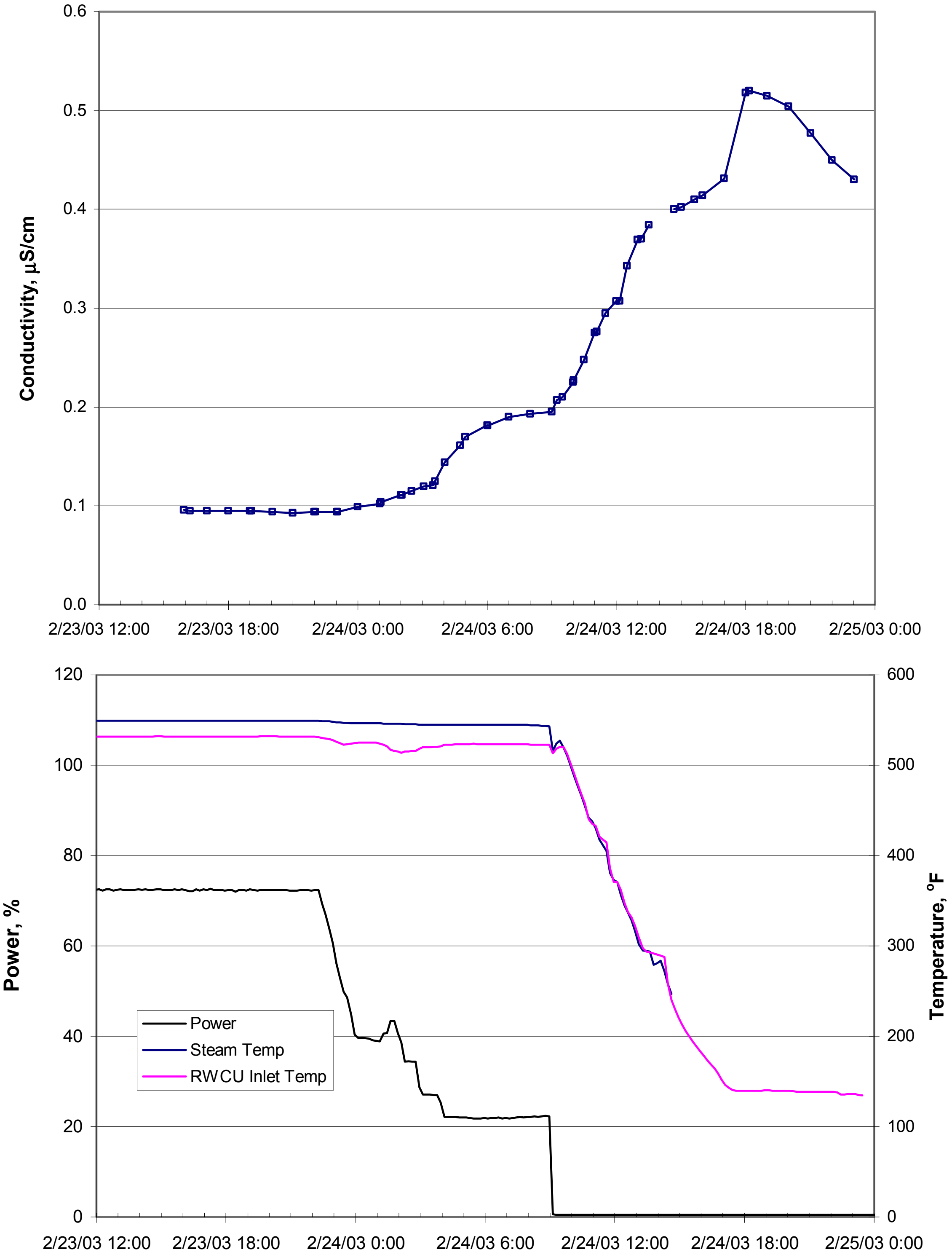

Figure 4-1
Browns Ferry 2 Conductivity during the February 2003 Shutdown Transient

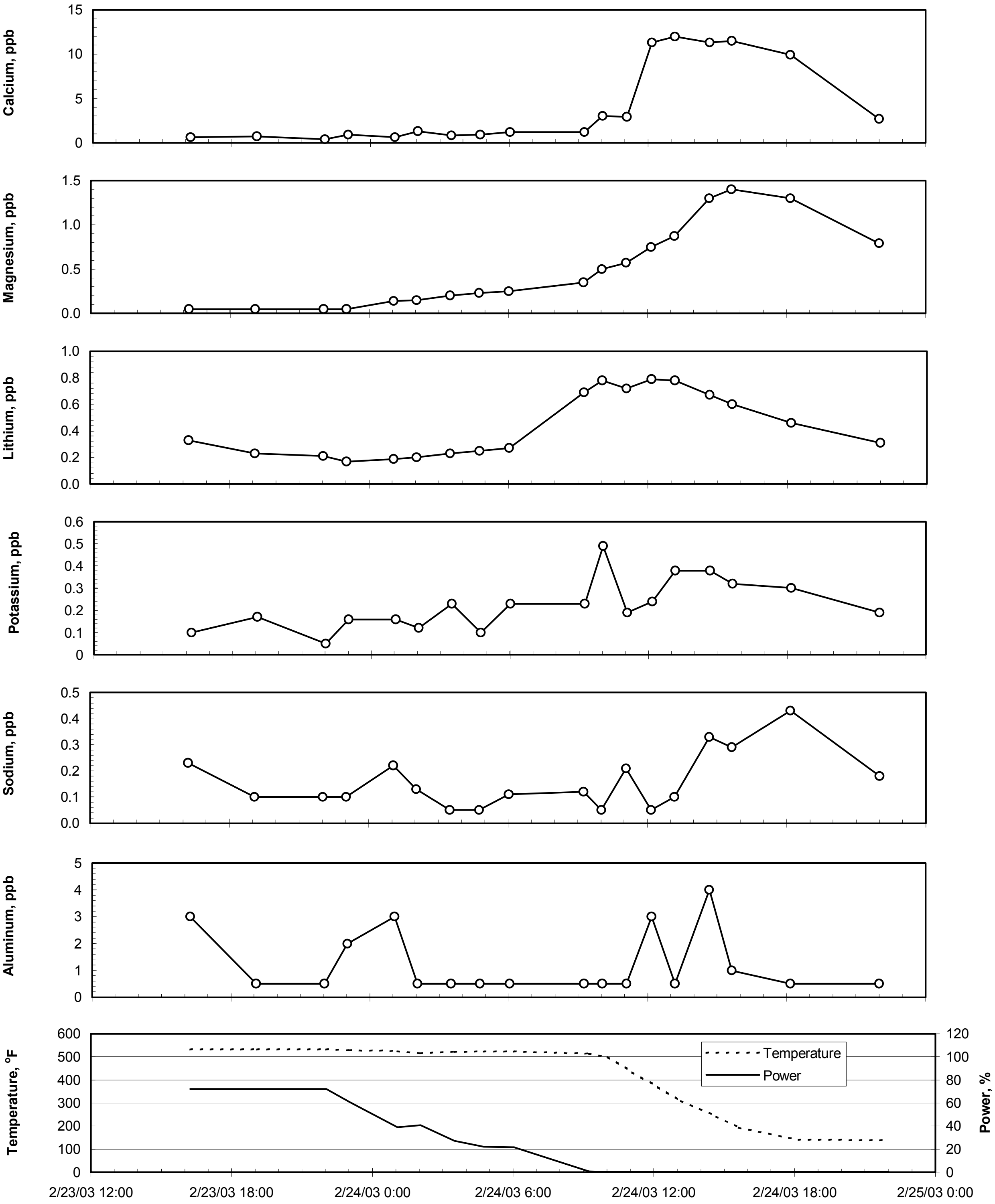

Figure 4-2
Cation Concentration Variations during the February 2003 Shutdown at Browns Ferry Unit 2

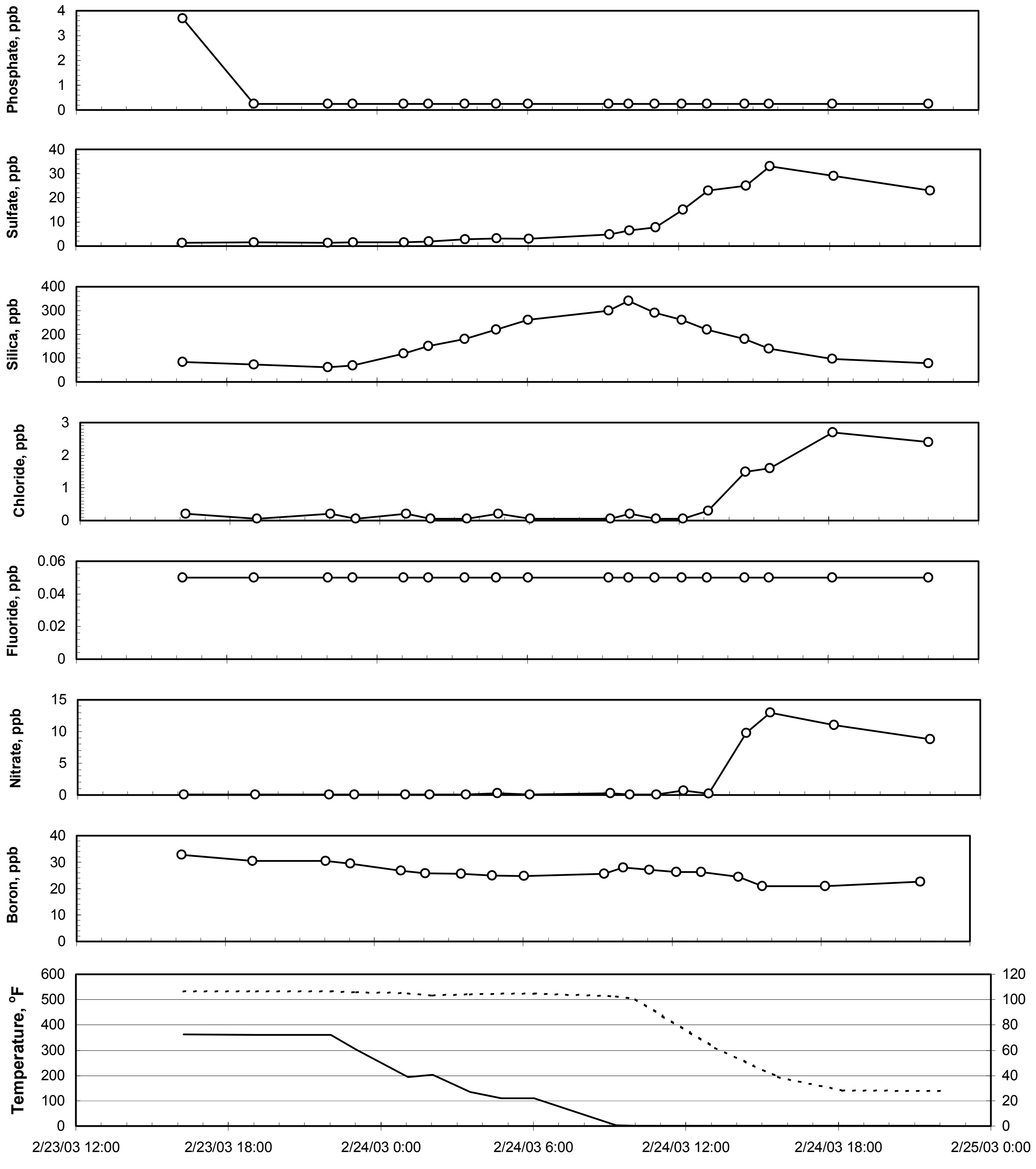

Figure 4-3
Anion Concentration Variations during the February 2003 Shutdown at Browns Ferry Unit 2

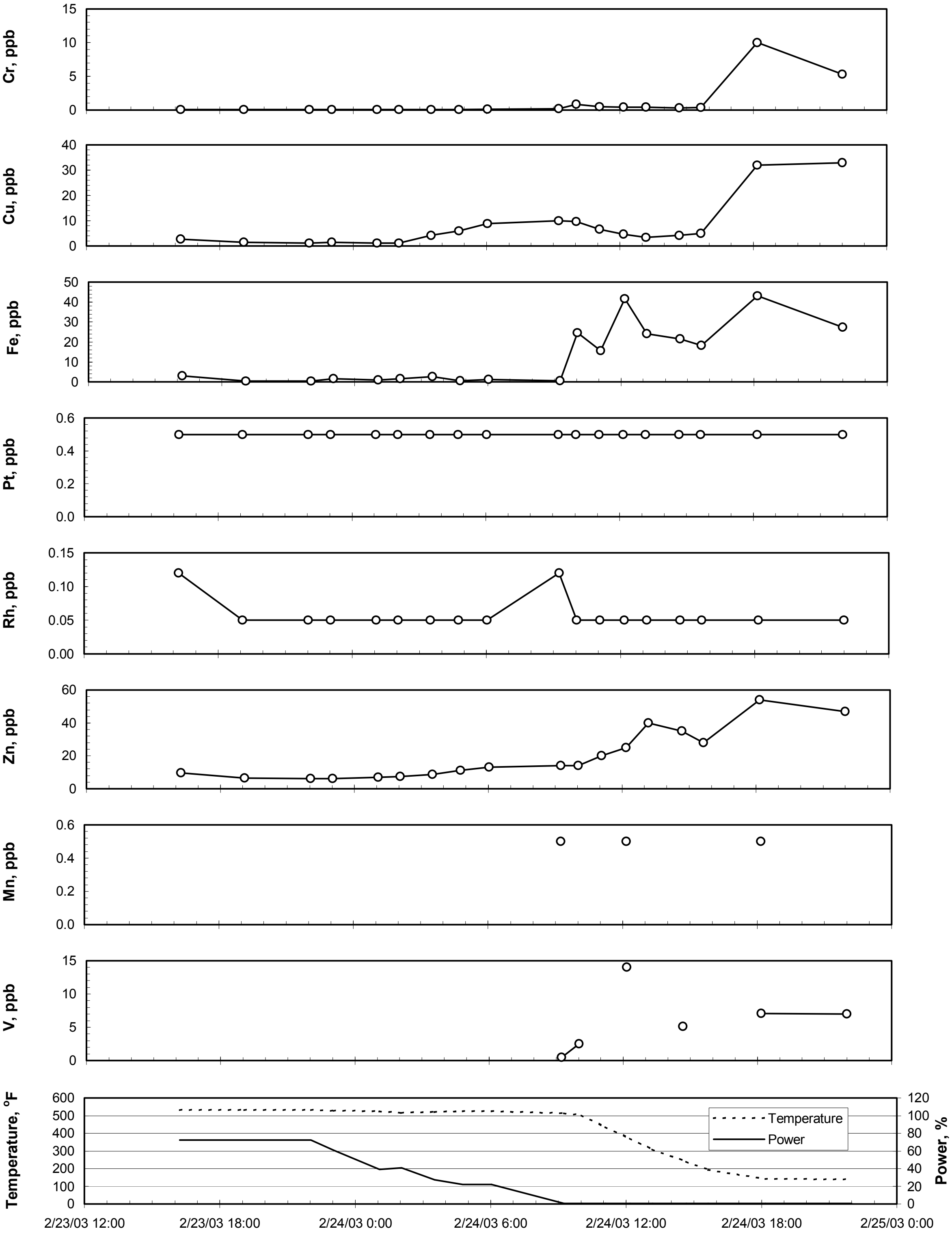

Figure 4-4
Metal Concentration Variations during the February 2003 Shutdown at Browns Ferry Unit 2

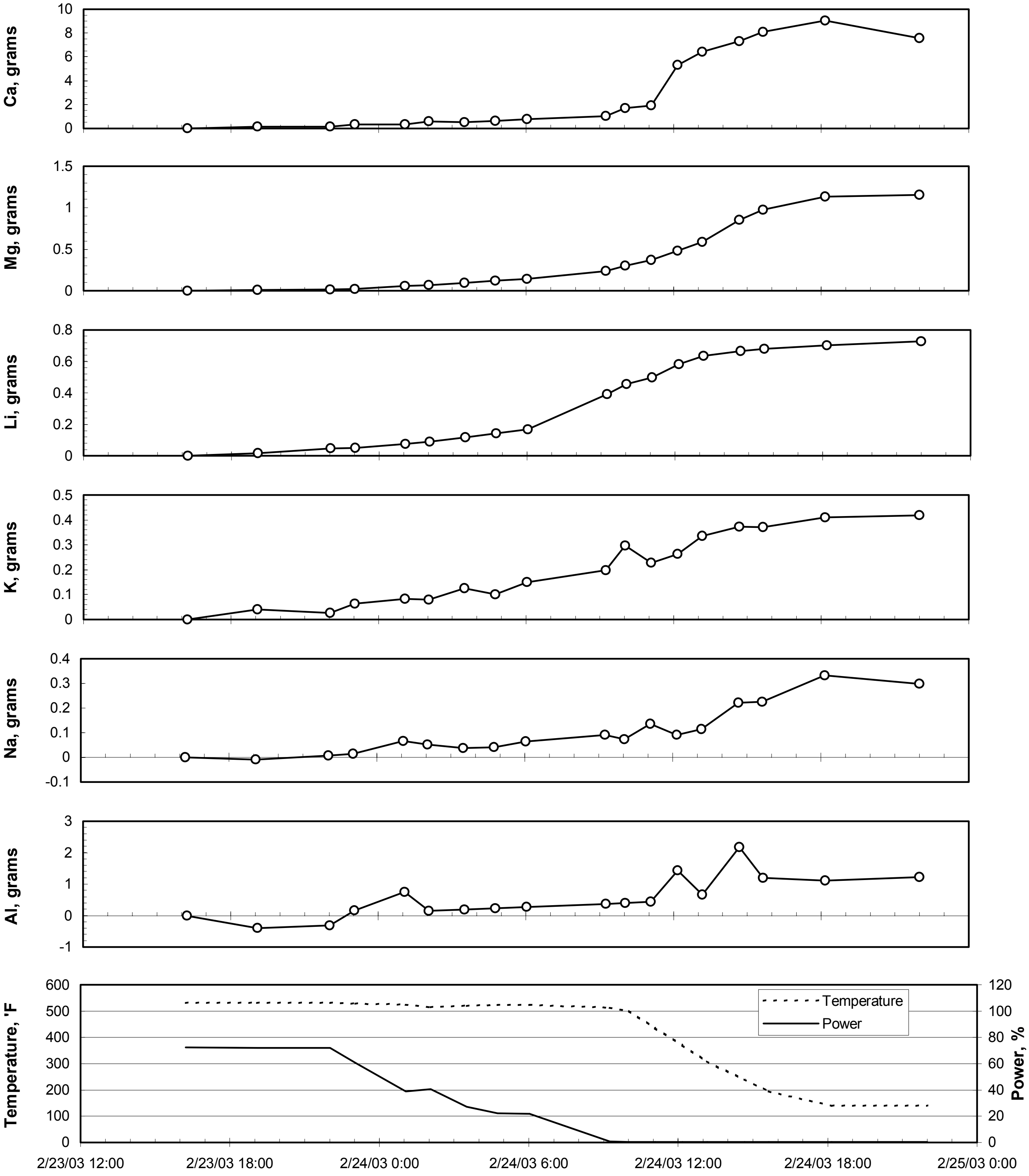

Figure 4-5
Cation Cumulative Returns during the February 2003 Shutdown at Browns Ferry Unit 2

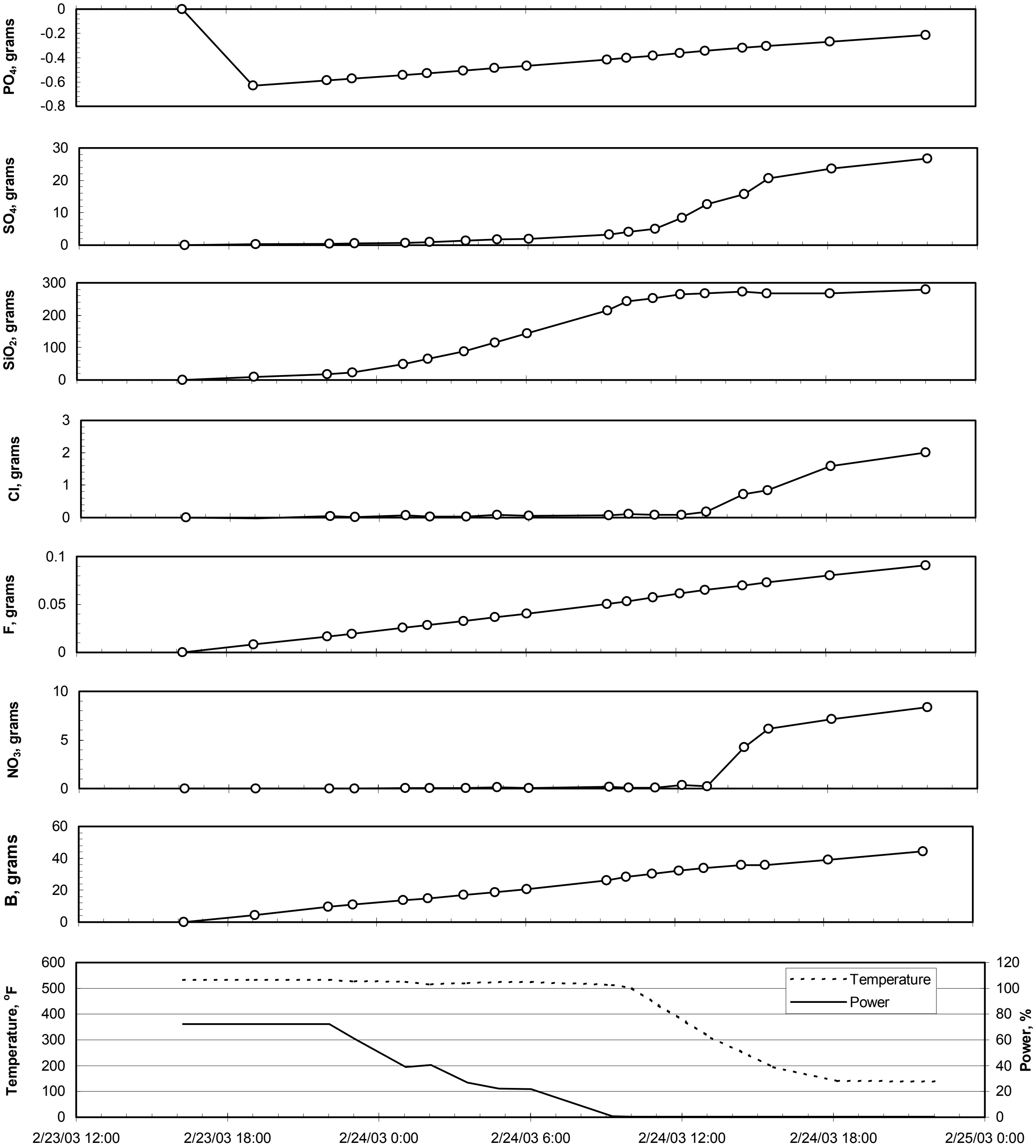

Figure 4-6
Anion Cumulative Returns during the February 2003 Shutdown at Browns Ferry Unit 2

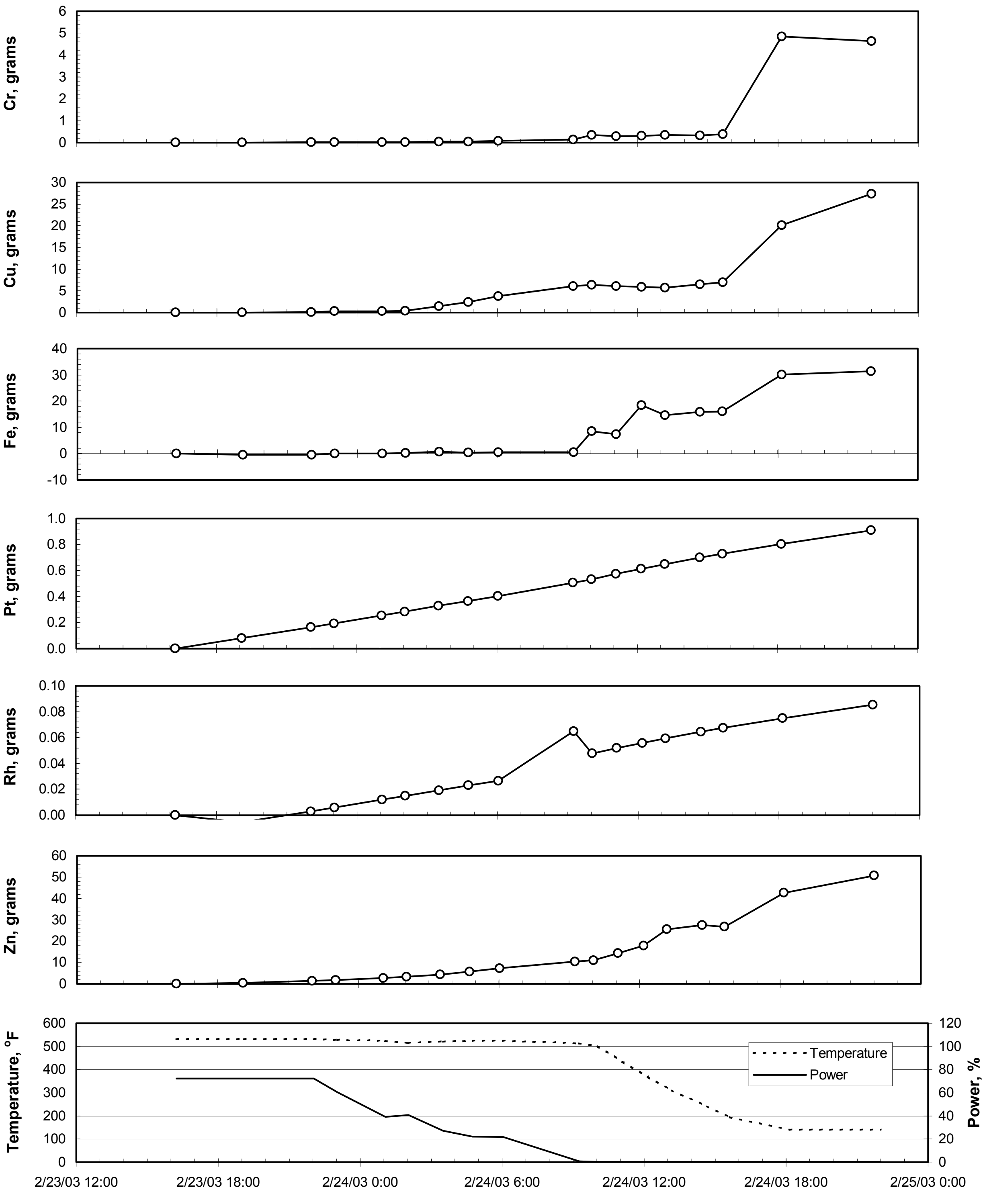

Figure 4-7
Metal Cumulative Returns during the February 2003 Shutdown at Browns Ferry Unit 2

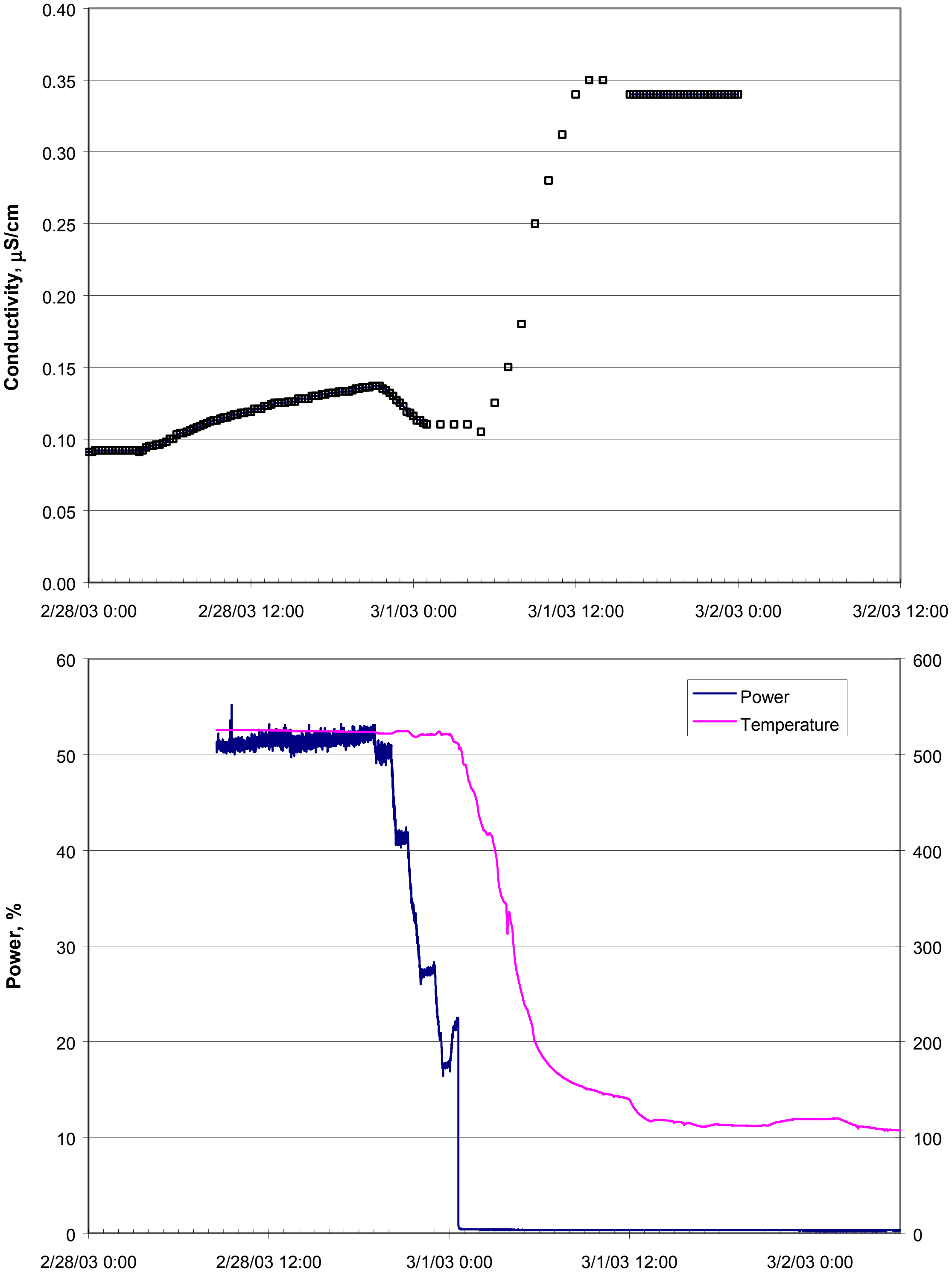

Figure 4-8
Hatch 2 Conductivity Variations during the February 2003 Shutdown Evolution

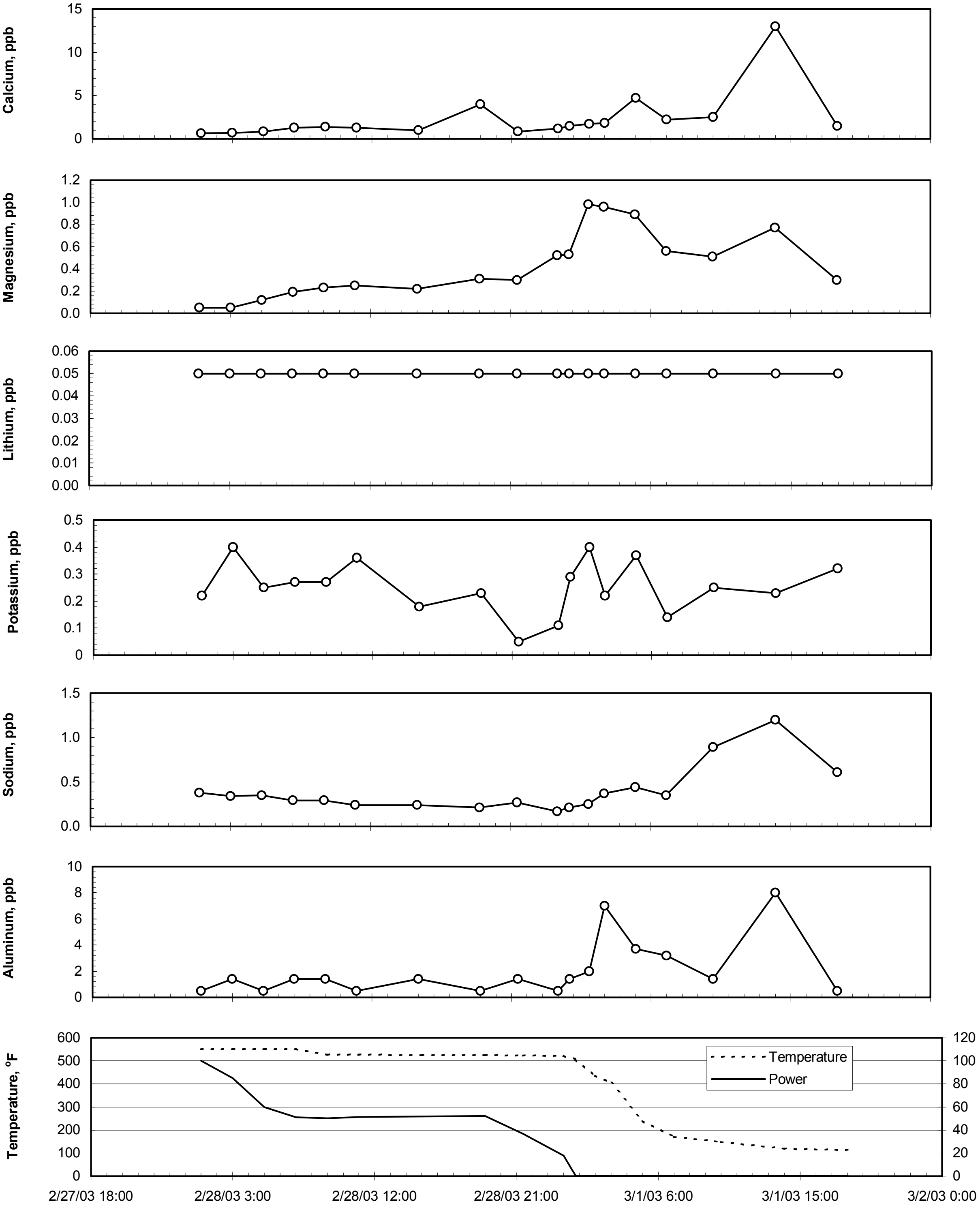

Figure 4-9
Cation Concentration Variations during the February 2003 Shutdown at Hatch Unit 2

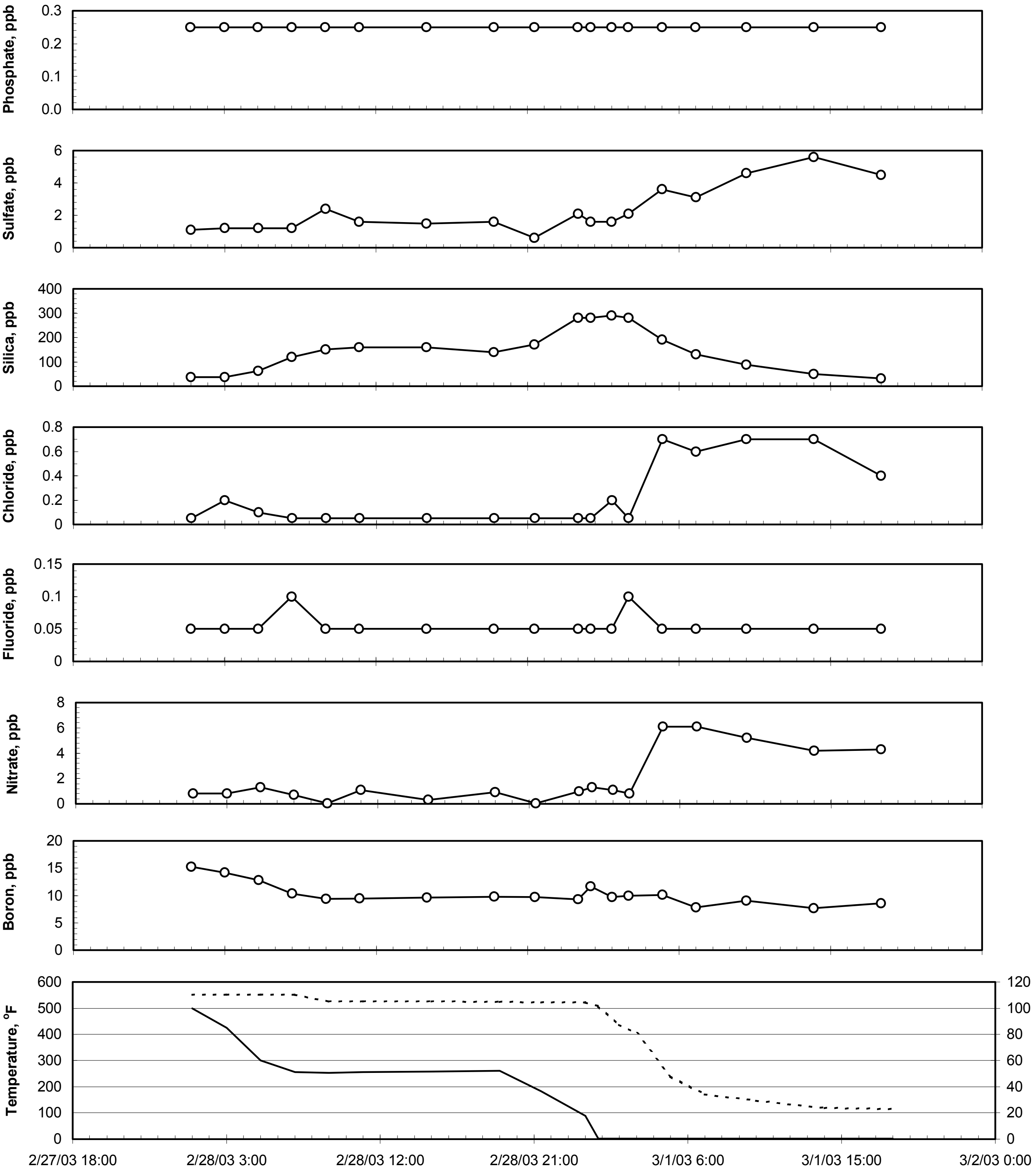

Figure 4-10
Anion Concentration Variations during the February 2003 Shutdown at Hatch Unit 2

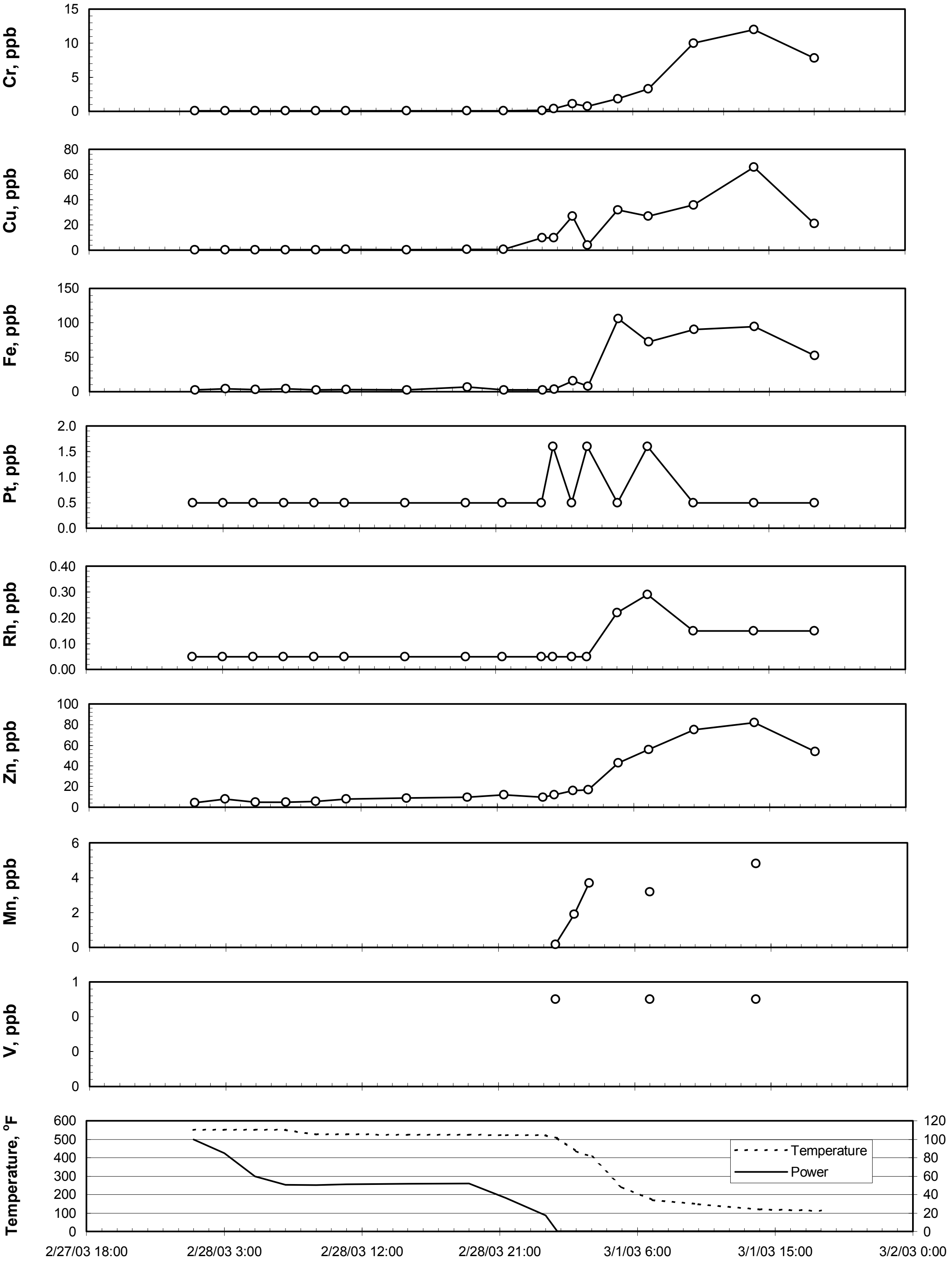

Figure 4-11
Metal Concentration Variations during the February 2003 Shutdown at Hatch Unit 2

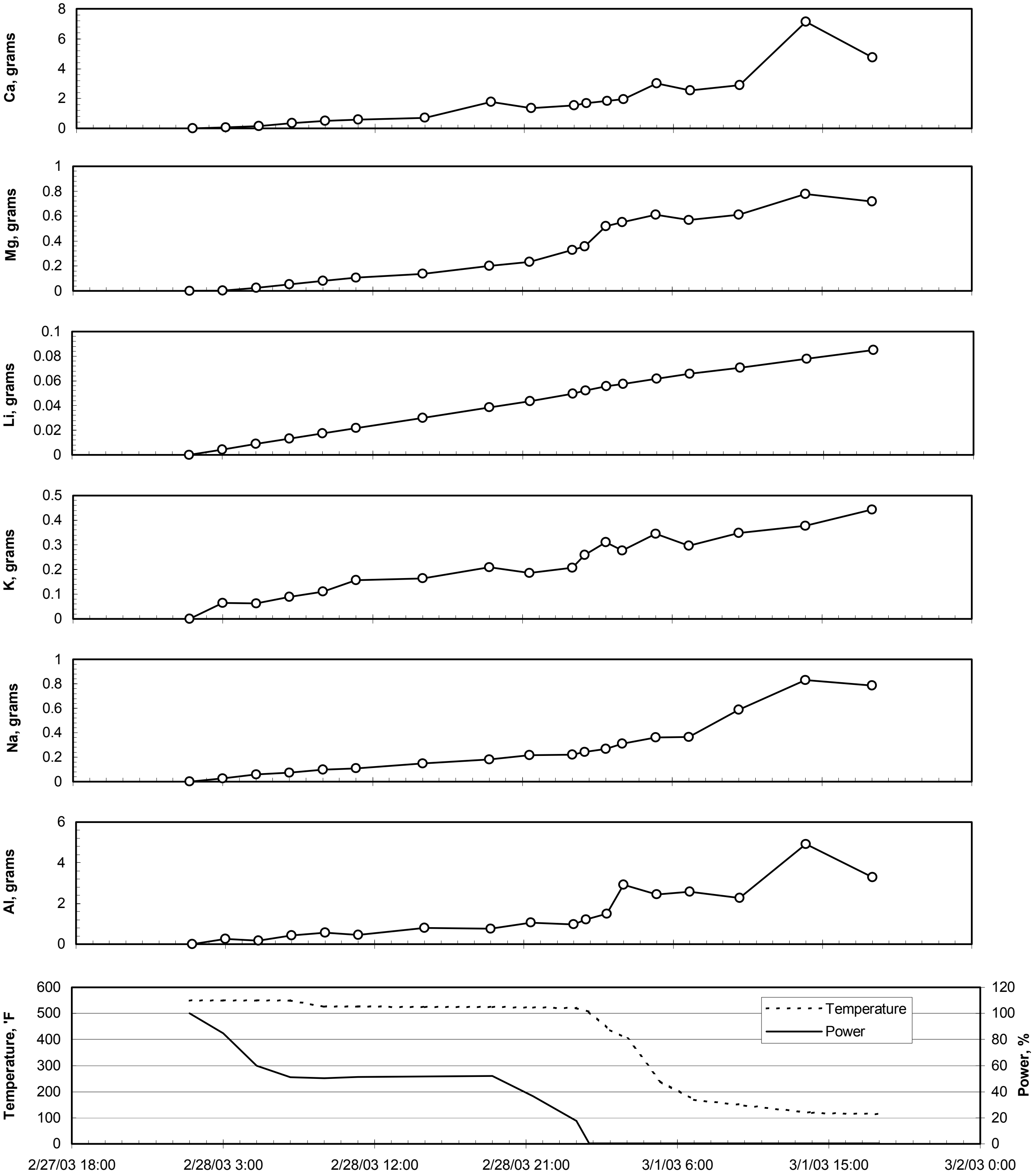

Figure 4-12
Cation Cumulative Returns during the February 2003 Shutdown at Hatch Unit 2

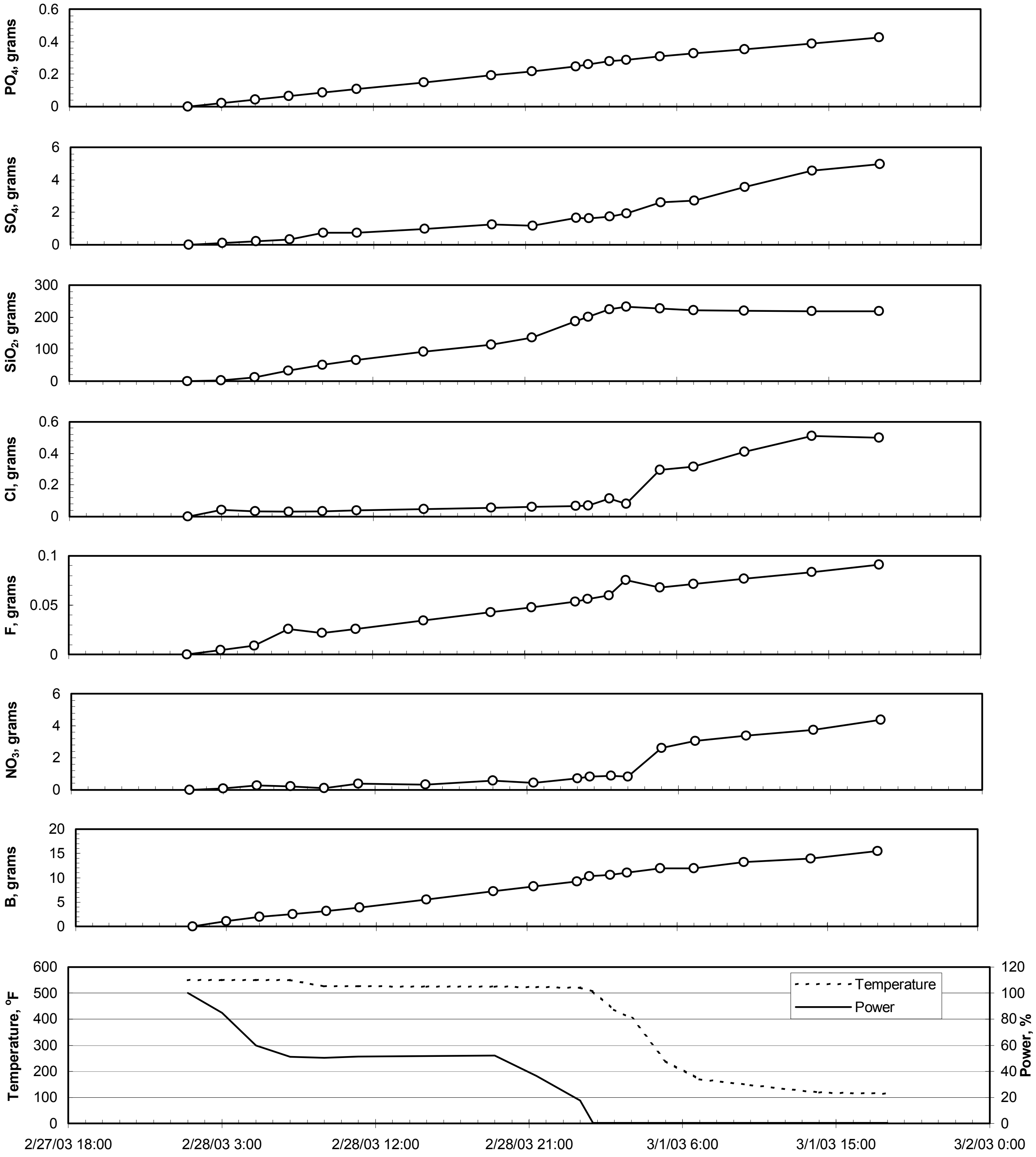

Figure 4-13
Anion Cumulative Returns during the February 2003 Shutdown at Hatch Unit 2

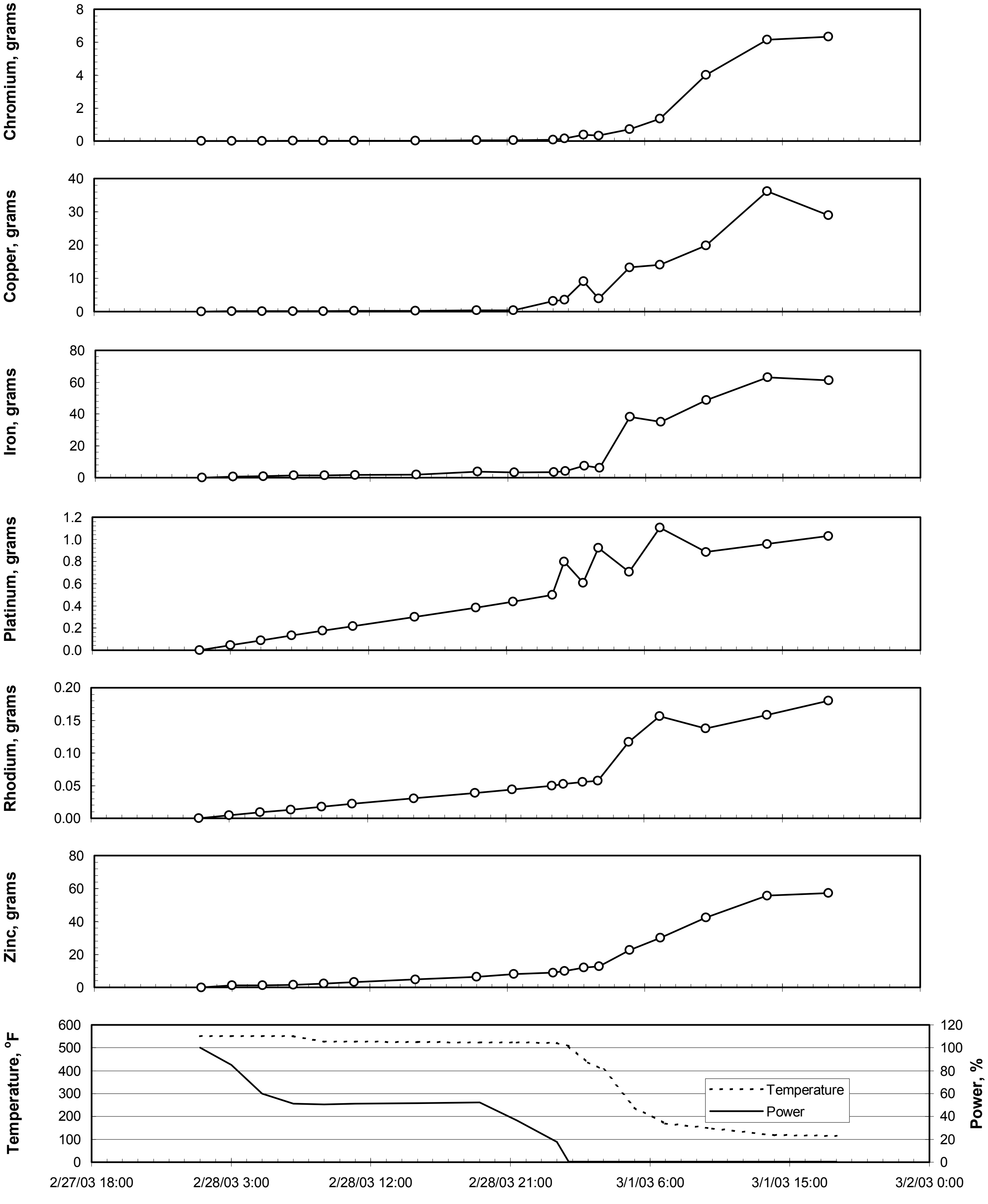

Figure 4-14
Metal Cumulative Returns during the February 2003 Shutdown at Hatch Unit 2

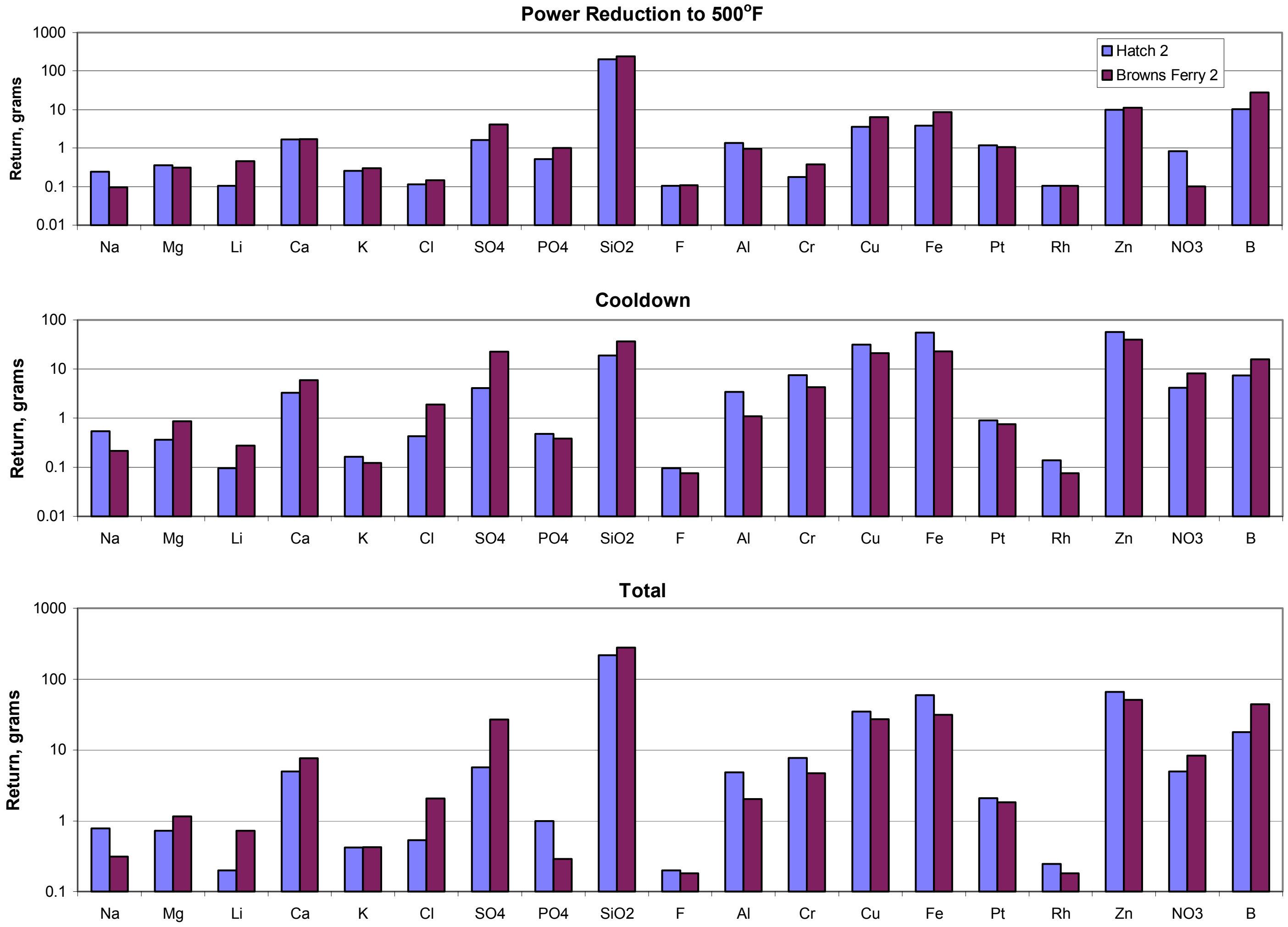

Figure 4-15
Hideout Return at Browns Ferry 2 and Hatch 2

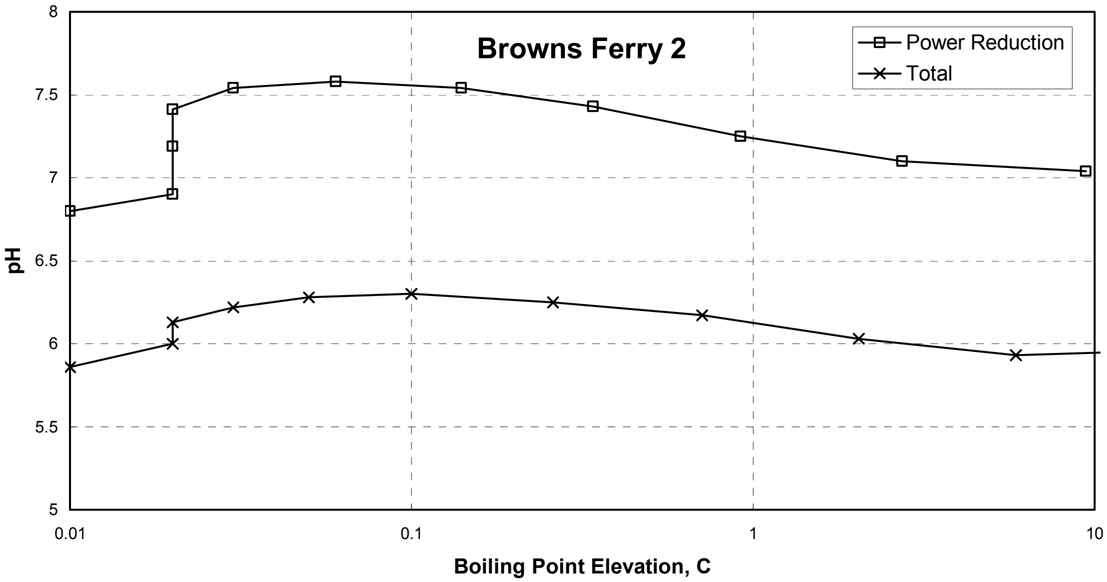

Figure 4-16
Predicted Solution pH as a Function of Boiling Point Elevation at Browns Ferry 2

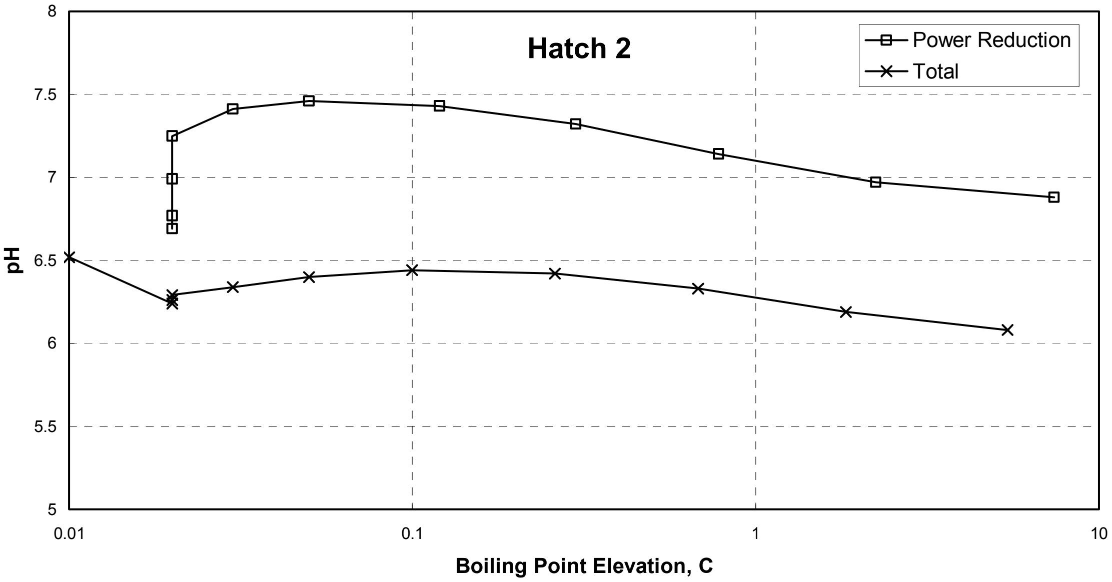

Figure 4-17
Predicted Solution pH as a Function of Boiling Point Elevation at Hatch 2

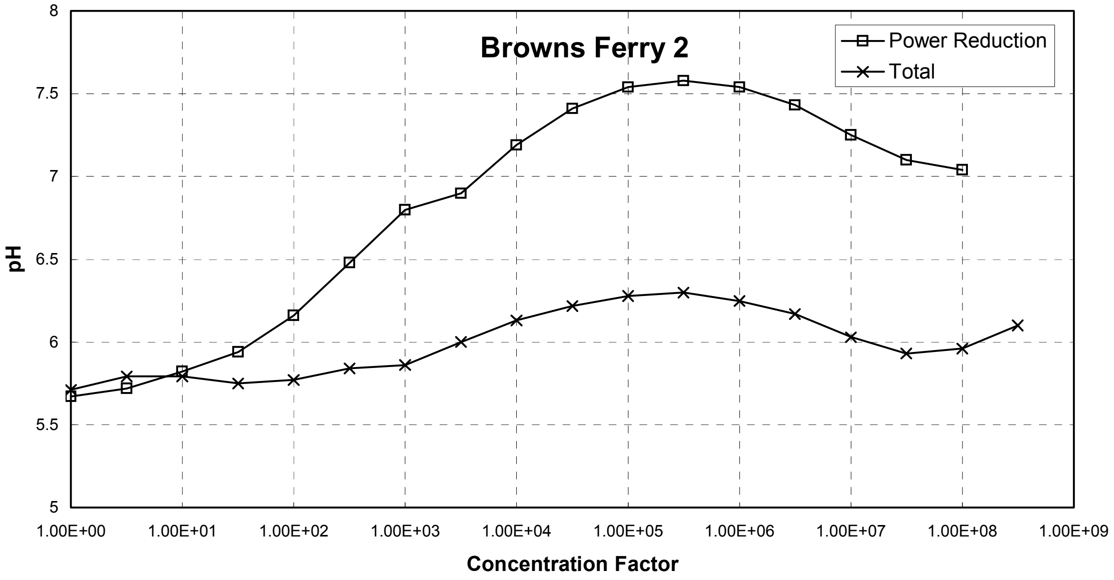

Figure 4-18
Predicted Solution pH as a Function of Concentration Factor at Browns Ferry 2

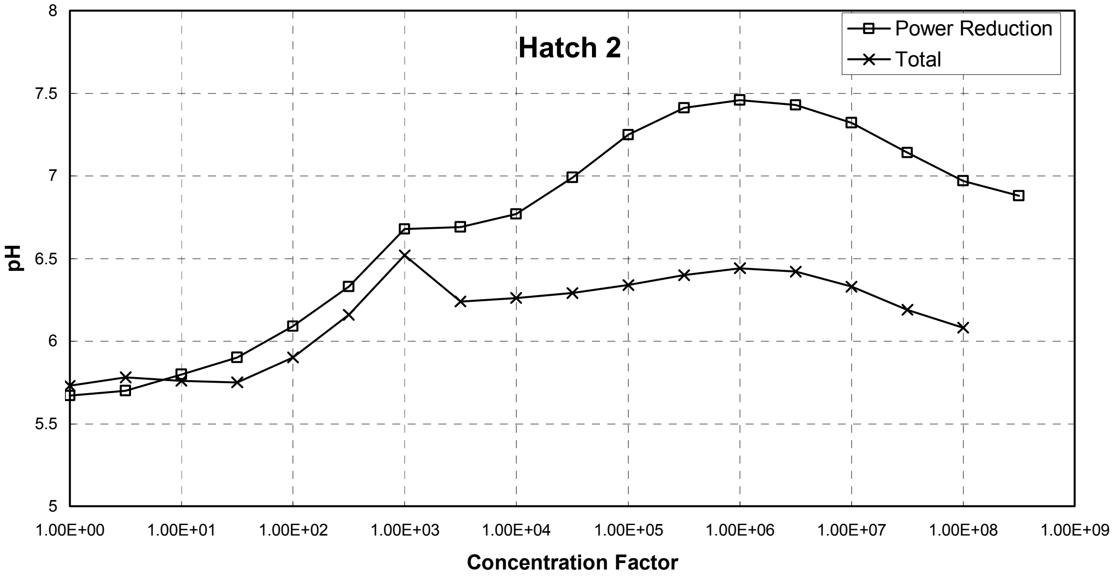

Figure 4-19
Predicted Solution pH as a Function of Concentration Factor at Hatch 2

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A

SAMPLE ISTOPICS

Table A-1
Browns Ferry Unit 2 Counting Results (Corrected to Sample Time)

System Sampled		**RWCU**	**RWCU**	**RWCU**	**RWCU**	**RWCU**	**RWCU**	**RWCU**	**RWCU**	**RWCU**	**RWCU**	**RWCU**	**RWCU**	**RWCU**	**RWCU**		**RWCU**	**RWCU**	**RWCU**	**CDE**	**CDE**
Sample I.D.		**BF-1**	**BF-2**	**BF-3**	**BF-4**	**BF-5**	**BF-6**	**BF-7**	**BF-8**	**BF-9**	**BF-10**	**BF-11**	**BF-12**	**BF-13**	**BF-14**	**BF-15**	**BF-16**	**BF-17**	**BF-18**	**BF-19**	**BF-20**
Sample Date		2/23/03	2/23/03	2/23/03	2/23/03	2/24/03	2/24/03	2/24/03	2/24/03	2/24/03	2/24/03	2/24/03	2/24/03	2/24/03	2/24/03	2/24/03	2/24/03	2/24/03	2/24/03	2/25/03	2/25/03
Sample Time		16:14	19:00	22:00	23:02	1:04	2:03	3:30	4:45	6:02	9:15	10:02	11:05	12:10	13:10	14:40	15:38	18:10	22:00	10:18	12:25
Isotope	**Half-life**	**Activity Concentration, (µCi/ml)**																			
Co-60	1925.2	1.643E-03	4.564E-04	4.651E-04	1.523E-03	9.116E-04	1.081E-03	8.420E-04	5.931E-04	6.303E-04	2.134E-03	1.737E-02	5.783E-03	6.675E-02	7.846E-02	1.741E-02	2.961E-02	4.360E-02	2.376E-02	0.000E+00	6.086E-07
Cr-51	27.7	2.146E-03	0.000E+00	3.972E-04	3.225E-03	1.472E-03	2.118E-03	1.763E-03	8.863E-04	1.168E-03	0.000E+00	1.235E-01	3.856E-02	2.257E-01	2.271E-01	3.230E-02	5.619E-02	7.882E-02	3.183E-02	0.000E+00	0.000E+00
Mn-54	312.2	1.275E-03	3.962E-04	4.222E-04	1.429E-03	1.136E-03	1.564E-03	9.077E-04	5.603E-04	5.656E-04	1.123E-03	1.325E-02	1.439E-02	7.166E-02	8.122E-02	1.212E-02	1.973E-02	3.270E-02	1.405E-02	0.000E+00	0.000E+00
Mn-56	0.10742	1.599E-02	1.267E-02	1.250E-02	4.347E-02	3.411E-02	3.733E-02	1.586E-02	8.746E-03	6.296E-03	1.149E-02	1.309E-01	1.649E-01	2.967E-01	2.409E-01	3.058E-02	2.932E-02	2.184E-02	3.783E-03	0.000E+00	0.000E+00
Fe-59	44.51	7.005E-04	1.602E-04	1.972E-04	9.908E-04	5.465E-04	6.959E-04	5.031E-04	3.634E-04	3.557E-04	1.049E-03	1.306E-02	3.771E-03	4.410E-02	5.099E-02	5.566E-03	1.134E-02	1.925E-02	6.838E-03	0.000E+00	0.000E+00
Co-58	70.88	3.990E-04	1.267E-04	1.124E-04	4.050E-04	0.000E+00	3.450E-04	3.131E-04	1.964E-04	1.891E-04	0.000E+00	3.875E-03	2.341E-03	2.227E-02	0.000E+00	4.022E-03	8.228E-03	8.512E-03	4.870E-03	0.000E+00	0.000E+00
Zn-65	243.8	1.993E-04	8.779E-05	7.721E-05	1.544E-04	0.000E+00	1.769E-04	0.000E+00	0.000E+00	2.262E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	4.331E-03	9.828E-04	1.334E-03	2.130E-03	0.000E+00	0.000E+00	0.000E+00
Zn-69m	0.5733	5.591E-04	5.036E-04	5.055E-04	1.021E-03	8.544E-04	9.044E-04	1.028E-03	1.309E-03	1.386E-03	0.000E+00	8.029E-03	3.318E-03	1.366E-02	1.760E-02	6.265E-03	7.359E-03	9.929E-03	5.246E-03	0.000E+00	0.000E+00
W-187	69.4	0.000E+00	0.000E+00	0.000E+00	6.110E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	4.201E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.395E-02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Zr-95/Nb-95	64.02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.398E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Ru-103	39.27	3.708E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Na-24	0.62625	1.259E-03	1.054E-03	1.006E-03	9.705E-04	9.637E-04	9.256E-04	8.799E-04	6.972E-04	6.822E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Mo-99/Tc-99	2.7476	1.529E-04	1.730E-04	1.772E-04	2.519E-04	2.280E-04	1.379E-04	1.606E-03	1.071E-03	9.272E-04	1.431E-02	2.858E-02	1.067E-02	1.329E-02	1.545E-02	1.329E-02	1.182E-02	5.141E-02	5.203E-02	0.000E+00	0.000E+00
Zr-97/Nb-97	0.7	3.774E-05	0.000E+00	0.000E+00	4.901E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.061E-04	1.346E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.980E-03	0.000E+00	0.000E+00	0.000E+00
As-76	1.09583	0.000E+00	0.000E+00	0.000E+00	1.048E-04	1.741E-04	0.000E+00	1.293E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	5.448E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Ag-110m	249.8	5.310E-04	0.000E+00	0.000E+00	5.740E-05	0.000E+00	0.000E+00	6.631E-05	7.298E-04	2.128E-03	3.315E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.828E-03	5.075E-02	1.726E-02	0.000E+00	0.000E+00
Au-199	3.14	0.000E+00	0.000E+00	0.000E+00	5.774E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.553E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Ce-141	32.5	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.639E-06	0.000E+00
Sr-91/Y-91m	0.395	1.547E-03	1.514E-03	1.627E-03	1.343E-03	1.586E-03	1.722E-03	1.281E-03	1.316E-03	1.105E-03	5.709E-03	5.980E-03	6.572E-03	0.000E+00	5.034E-03	3.655E-03	3.487E-03	2.809E-03	1.789E-03	0.000E+00	0.000E+00
Sr-92/Y-92	0.11292	4.444E-03	4.358E-03	4.624E-03	5.018E-03	4.176E-03	3.620E-03	3.088E-03	2.713E-03	2.124E-03	1.674E-03	0.000E+00	1.709E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
I-131	8.04	5.437E-04	3.326E-04	2.891E-04	3.121E-04	5.268E-04	6.663E-04	1.066E-03	1.809E-04	1.856E-04	1.540E-02	8.049E-02	9.651E-02	4.892E-02	2.012E-02	1.842E-02	1.554E-02	0.000E+00	5.788E-03	0.000E+00	1.666E-06
I-132	0.095	0.000E+00	0.000E+00	4.321E-05	0.000E+00	0.000E+00	0.000E+00	2.515E-04	0.000E+00	0.000E+00	9.493E-03	3.692E-02	3.532E-02	1.188E-02	4.881E-03	4.566E-03	4.033E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
I-133/Xe-133	0.8666	1.975E-04	1.663E-04	1.467E-04	1.658E-04	2.695E-04	2.266E-04	6.597E-04	7.445E-05	1.025E-04	9.897E-03	5.915E-02	7.297E-02	3.115E-02	1.493E-02	1.504E-02	1.036E-02	1.190E-03	3.090E-03	0.000E+00	0.000E+00
I-134	3.65E-02	0.000E+00	2.555E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.556E-02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
I-135/Xe-135	0.27375	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	5.903E-03	3.109E-02	2.955E-02	1.298E-02	0.000E+00	4.478E-03	0.000E+00	6.814E-03	0.000E+00	0.000E+00	0.000E+00
Cs-136	13.1	0.000E+00	1.538E-04	1.227E-04	1.287E-04	0.000E+00	0.000E+00	2.071E-04	1.924E-04	2.191E-04	8.120E-02	7.483E-02	6.524E-02	5.881E-02	6.201E-02	6.318E-02	0.000E+00	4.142E-02	4.208E-02	0.000E+00	0.000E+00
Sb-122	2.72	5.217E-05	0.000E+00	4.427E-05	1.662E-04	7.496E-05	6.691E-05	1.207E-04	0.000E+00	7.133E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.681E-02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
La-142	0.064167	0.000E+00	7.622E-04	6.376E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Ba-140/La-140	12.75	5.433E-04	4.901E-04	4.962E-04	4.426E-04	6.411E-04	6.024E-04	5.688E-04	5.166E-04	4.534E-04	0.000E+00	2.451E-02	2.172E-02	1.856E-02	7.434E-03	3.259E-03	4.978E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Cs-134	754.2	1.155E-03	8.627E-04	6.947E-04	6.991E-04	9.072E-04	1.091E-03	1.225E-03	1.285E-03	1.215E-03	3.975E-01	3.935E-01	3.694E-01	3.780E-01	3.077E-01	3.302E-01	3.248E-01	2.310E-01	2.303E-01	0.000E+00	0.000E+00
Cs-137	11019.5	7.602E-04	5.988E-04	4.623E-04	5.184E-04	5.340E-04	5.703E-04	6.124E-04	8.370E-04	8.184E-04	2.438E-01	2.469E-01	2.185E-01	2.289E-01	2.192E-01	2.075E-01	1.950E-01	1.450E-01	1.417E-01	0.000E+00	0.000E+00
Ba-139	0.05817	0.000E+00	4.440E-03	4.468E-03	4.374E-03	3.717E-03	3.983E-03	0.000E+00	2.615E-03	2.271E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	7.759E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Np-239	2.35	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.237E-03	1.734E-03	1.969E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	5.642E-03	3.669E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Ce-144	284.6	2.667E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	6.260E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	8.204E-03	0.000E+00	0.000E+00	0.000E+00

Table A-2
Hatch Unit 2 Counting Results (Corrected to Sample Time)

Sample I.D.		H-1	H-2	H-3	H-4	H-5	H-6	H-7	H-8	H-9	H-10	H-11	H-12	H-13	H-14	H-15	H-16	H-17	H-18	H-19	H-20
Sample Date		2/28/03	2/28/03	2/28/03	2/28/03	2/28/03	2/28/03	2/28/03	2/28/03	2/28/03	3/1/03	3/1/03	3/1/03	3/1/03	3/1/03	3/1/03	3/1/03	3/1/03	3/1/03	3/1/03	3/2/03
Sample Time		1:00	3:00	5:00	7:00	9:00	11:00	15:00	19:00	21:25	0:00	0:45	2:00	3:00	5:00	7:00	10:00	14:00	18:00	22:00	2:00
Isotope	**Half-life**	**Activity Concentration (uCi/ml)**																			
Co-60	1925.2	6.159E-05	6.847E-05	1.344E-04	9.119E-05	8.708E-05	1.996E-04	2.660E-04	3.685E-04	6.781E-04	3.759E-04	7.373E-03	6.269E-02	3.214E-02	5.902E-02	2.518E-01	7.724E-02	4.642E-02	5.747E-03	2.933E-03	1.872E-03
Cr-51	27.7	0.000E+00	0.000E+00	2.988E-04	0.000E+00	0.000E+00	5.665E-04	1.543E-03	1.853E-03	5.806E-03	3.961E-03	8.715E-02	7.735E-01	3.856E-01	5.807E-01	2.511E+00	7.008E-01	4.055E-01	4.323E-02	1.655E-02	9.104E-03
Mn-54	312.2	1.692E-04	1.574E-04	3.569E-04	3.063E-04	4.706E-04	9.868E-04	1.062E-03	1.228E-03	2.213E-03	8.466E-04	1.631E-02	1.399E-01	6.960E-02	1.240E-01	6.365E-01	1.804E-01	9.185E-02	1.153E-02	5.217E-03	3.322E-03
Mn-56	0.10742	7.342E-03	7.153E-03	1.310E-02	1.639E-02	1.933E-02	3.117E-02	2.012E-02	1.764E-02	2.501E-02	4.892E-03	8.742E-02	4.432E-01	1.861E-01	1.651E-01	4.216E-01	5.663E-02	1.072E-02	9.880E-04	0.000E+00	0.000E+00
Fe-59	44.51	0.000E+00	0.000E+00	1.175E-04	0.000E+00	0.000E+00	1.855E-04	3.364E-04	4.844E-04	1.352E-03	7.338E-04	1.635E-02	1.328E-01	6.106E-02	1.076E-01	5.234E-01	1.557E-01	7.112E-02	8.224E-03	3.171E-03	1.628E-03
Co-58	70.88	6.758E-05	5.647E-05	1.538E-04	1.059E-04	1.119E-04	2.023E-04	2.352E-04	2.893E-04	4.792E-04	2.735E-04	4.453E-03	3.587E-02	1.909E-02	3.025E-02	1.384E-01	3.835E-02	2.327E-02	3.450E-03	1.704E-03	1.219E-03
Zn-65	243.8	1.151E-04	1.287E-04	1.731E-04	1.515E-04	1.679E-04	3.070E-04	4.334E-04	4.052E-04	7.031E-04	6.343E-04	4.574E-03	3.578E-02	1.766E-02	3.258E-02	1.295E-01	4.154E-02	2.103E-02	3.251E-03	2.167E-03	1.422E-03
Zn-69m	0.5733	2.105E-04	1.930E-04	2.630E-04	2.405E-04	2.981E-04	1.333E-03	1.619E-03	1.857E-03	2.371E-03	1.722E-03	8.903E-03	5.626E-02	2.990E-02	3.826E-02	1.385E-01	3.710E-02	2.088E-02	5.012E-03	3.235E-03	2.330E-03
Cu-64	0.52921	0.000E+00	0.000E+00	0.000E+00	0.000E+00	6.715E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Zr-95/Nb-95	64.02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Ru-103	39.27	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Na-24	0.62625	1.430E-03	1.434E-03	1.687E-03	1.407E-03	1.108E-03	8.995E-04	5.230E-04	4.696E-04	4.426E-04	4.414E-04	3.182E-04	0.000E+00	0.000E+00	3.109E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Mo-99/Tc-99	2.7476	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Sc-46	83.81	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
As-76	1.09583	2.770E-04	2.370E-04	2.655E-04	3.641E-04	4.851E-04	5.582E-05	7.179E-05	1.738E-04	1.118E-03	3.269E-04	1.559E-03	1.229E-02	5.783E-03	9.401E-03	3.449E-02	9.097E-03	3.925E-03	3.775E-04	0.000E+00	0.000E+00
Ag-110m	249.8	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Au-199	3.14	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	3.852E-05	8.960E-05	1.647E-04	1.142E-03	1.064E-02	5.445E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	4.628E-04	1.567E-04	0.000E+00
Sb-124	60.2	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	8.407E-04	6.722E-03	3.232E-03	5.625E-03	3.043E-02	7.894E-03	3.394E-03	4.503E-04	1.827E-04	1.009E-04
I-131	8.04	1.725E-05	1.749E-05	1.557E-05	1.638E-05	1.746E-05	1.405E-05	2.045E-05	2.067E-05	3.533E-05	2.284E-05	1.140E-04	5.295E-04	3.563E-04	3.166E-04	3.606E-03	3.479E-04	3.324E-04	8.744E-05	6.477E-05	5.062E-05
I-132	0.095	3.136E-05	3.151E-05	3.338E-05	4.850E-05	0.000E+00	5.060E-05	4.558E-05	4.413E-05	7.484E-05	4.067E-05	2.530E-04	1.128E-03	7.504E-04	8.389E-04	1.095E-02	8.235E-04	7.190E-04	1.863E-04	1.406E-04	1.095E-04
I-133	0.8666	2.816E-05	3.479E-05	3.487E-05	3.743E-05	5.729E-05	3.736E-05	1.879E-05	3.308E-05	4.394E-05	2.410E-05	1.147E-04	6.656E-04	4.487E-04	4.088E-04	4.711E-03	4.432E-04	4.167E-04	1.101E-04	8.067E-05	6.269E-05
I-134	3.65E-02	1.117E-04	1.172E-04	1.181E-04	1.191E-04	0.000E+00	1.765E-04	1.313E-04	1.299E-04	2.540E-04	1.203E-03	2.873E-03	2.116E-02	3.138E-03	6.238E-03	1.000E-01	1.598E-02	1.719E-02	9.604E-03	1.009E-02	9.307E-04
I-135	0.27375	6.500E-05	6.184E-05	6.824E-05	7.019E-05	0.000E+00	8.405E-05	7.611E-05	7.534E-05	1.199E-04	6.846E-05	3.403E-04	1.465E-03	9.663E-04	8.096E-04	1.009E-02	7.674E-04	7.381E-04	1.999E-04	1.523E-04	1.052E-04
Sn-121	1.128	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Sn-123	129.2	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Sn-125	9.63	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Ba-140/La-140	12.75	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Cs-134	754.2	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Cs-137	11019.5	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Ce-141	32.5	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Ce-143	1.38	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Ce-144	284.6	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	4.281E-04	0.000E+00	1.672E-03	3.773E-02	1.526E-02	2.386E-02	1.085E-01	2.953E-02	1.328E-02	1.294E-03	3.708E-04	0.000E+00

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