Electro Chemical Recovery of Sodium Hydroxide from Alkaline Salt Solution

by

D. T. Hobbs

Westinghouse Savannah River Company

Savannah River Site

Aiken, South Carolina 29808

T. B. Edwards

MASTER

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Westinghouse Savannah River Company
P.O. Box 616
Aiken, SC 29802

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Samuel D. Fink, Group Mgr.
Authorized Reviewing Official

Savannah River Technology Center
Westinghouse Savannah River Company
Aiken, SC 29802

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SUMMARY

A statistically designed set of tests determined the effects of current density, temperature, and the concentrations of nitrate/nitrite, hydroxide and aluminate on the recovery of sodium as sodium hydroxide (caustic) from solutions simulating those produced from the Savannah River Site (SRS) In-Tank Precipitation process. These tests included low nitrate and nitrite concentrations which would be produced by electrolytic nitrate/nitrite destruction. The tests used a two compartment electrochemical cell with a Nafion® Type 324 ion-exchange membrane. Caustic was successfully recovered from the waste solutions. Evaluation of the testing results indicated that the transport of sodium across the membrane was not significantly affected by any of the varied parameters. The observed variance in the sodium flux is attributed to experimental errors and variations in the performance characteristics of individual pieces of the organic-based Nafion® membrane. Additional testing is recommended to determine the maximum current density, to evaluate the chemical durability of the organic membrane as a function of current density and to compare the durability and performance characteristics of the organic-based Nafion® membrane with that of other commercially available organic membranes and the inorganic class of membranes under development by Ceramtec® and PNNL.

INTRODUCTION

High-level waste (HLW) stored at the Hanford and Savannah River sites contain large amounts of sodium salts that can, in principle, be recovered as sodium hydroxide for recycling. For example, the sodium ions can be separated from the other components in the HLW by electrochemical salt splitting. In the electrochemical salt splitting process, sodium ions migrate across a cation-selective membrane under the influence of an applied electrical potential. In a two compartment cell in which the membrane separates the two electrodes, the HLW waste stream is fed into the anolyte compartment (see Figure 1). Sodium ions migrate across the membrane into the catholyte. Hydroxide is produced at the cathode by the reduction of water. The catholyte product is thus a sodium hydroxide solution. Anionic species such as nitrate, aluminate, and sulfate do not pass through the membrane, and therefore, are retained in the feed stream compartment of the electrochemical cell.

A number of ion-selective membranes have been developed for industrial electrochemical processes including chlorine/caustic production, production of drinking water from brine, and advanced batteries. Organic and inorganic membranes are potential candidates for this application. Organic membranes such as the Nafion® type of membranes have been used in salt splitting applications including the production of sodium hydroxide from sodium sulfate solutions. These membranes exhibit excellent chemical stability over a wide range of pH values. A statistically designed set of tests were conducted to determine the effects of key operating parameters and variation in the waste composition for the evaluation of the salt splitting process in treating Savannah River Site low-level waste streams[1].

Figure 1. Diagram of Electrochemical Salt Splitting Process for the Recovery of Sodium Hydroxide from Alkaline Salt Solutions

EXPERIMENTAL

The electrochemical salt splitting tests used a MP electrolyzer manufactured by ElectroCell AB (Sweden) equipped with a nickel cathode, platinized titanium anode and Nafion[®] Type 324 membrane. The test equipment included the electrochemical reactor, two rotameters (PVDF shell with EPPM) sealing O-rings, two March model #AC-3C-MD centrifugal pumps (PVD-lined) and two 2.0 liter polyethylene reservoirs equipped with glass condensers. Electrical power to the cell and the pumps was provided by a BOSS electrochemical controller model #710 manufactured by the Electrosynthesis Company (Lancaster, NY).

Temperature was controlled by circulating water through a 0.25 inch ID stainless steel coil located in each reservoir using a Endocal Refrigerated Circulation Bath, model #RTE-5. Reservoir temperatures were measured using a thermistor thermometer, Omega model

#5831 equipped with thermister probes, Omega model # OL-703. Current and voltage were recorded from the Boss electrochemical controller readouts. Current was confirmed by measuring the voltage across a shunt using a Fluke model 25 multimeter. Figure 2 provides a schematic diagram of the test equipment. Figure 3 gives photograph of the test equipment.

Reagent grade chemicals and deionized, distilled (DDI) water were used for all salt solution preparations. The initial catholyte solution for all tests was a 1.0 molar sodium hydroxide solution. The anolyte solution was one of eight different salt solutions having the composition indicated in Table I.

Table I. Initial Composition of Anolyte Salt Solutions*

Solution ID	Concentration (molar)			
	NaNO ₃	NaNO ₂	NaOH	NaAlO ₂
000	1.19	0.365	2.05	0.255
+++	2.29	0.706	3.50	0.500
++	0.0765	0.0235	3.50	0.500
+-	2.29	0.706	0.60	0.010
+	0.0765	0.0235	3.50	0.010
++	2.29	0.706	0.60	0.500
+	0.0765	0.0235	0.60	0.500
+-	2.29	0.706	0.60	0.010
---	0.0765	0.0235	0.60	0.010

* All solutions contained the following salts (concentrations): sodium carbonate (0.16 M), sodium silicate (0.0038 M), sodium phosphate (0.0085 M), sodium chloride (0.022 M), sodium fluoride (0.015 M) and sodium chromate (0.0033 M).

The following experimental procedure was used for each test. The electrochemical cell was assembled and installed in the testing system. Prior to the first usage and between each test, each piece of Nafion® membrane was heated for 1 hour at 80 °C in a diluted sulfuric acid solution, rinsed with DDI water, and then allowed to stand in DDI prior to initial use. Between tests, the membrane was allowed to stand in a 1.0 M sodium hydroxide solution. The catholyte reservoir was charged with 1.5 L of a 1.0 M sodium hydroxide solution and the anolyte reservoir charged with 1.5 L of the simulated waste solution. The centrifugal pumps and the refrigerated bath were turned on, the solutions circulated through the system and heated to the desired temperature. After reaching the test temperature, the DC power supply in the BOSS electrochemical controller was activated and current supplied to the cell at the desired current density.

The temperature of the refrigerated bath liquid was adjusted to maintain the temperature of the solutions in each reservoir to within ± 2 °C. Voltage, current, temperature, flowrate, solution volumes and charge were recorded periodically during each test. Liquid samples from each reservoir were taken periodically during each test. A test was stopped after 6 hours, when solids were observed in the anolyte or when a large increase in the cell voltage occurred. After shutting off the power supply, the anolyte and catholyte were allowed to

cool to room temperature. Both reservoirs were drained and sampled for analysis. The DDI water was introduced and circulated through the cell to flush out each compartment. The rinse solutions were discarded and cell disassembled for inspection. After inspection, the cell components were rinsed and stored until reassembled for the next test.

Liquid samples were analyzed for sodium, aluminum, chromium, silicon and phosphorus by atomic absorption spectroscopy (AAS). Free hydroxide, aluminate and carbonate were determined titrimetrically. Nitrate, nitrite, sulfate, phosphate, fluoride and chloride were determined by ion chromatography (IC).

Figure 2. Schematic Diagram of Electrochemical Caustic Recovery Bench-Scale Test Equipment

Figure 3. Photograph of Electrochemical Caustic Recovery Bench-Scale Test Equipment

RESULTS AND DISCUSSION

A fractional factorial design was used to evaluate the effects of current density, temperature and the concentrations of nitrate/nitrite, hydroxide and aluminate on the recovery of sodium hydroxide from simulated waste solutions. To reduce the size of the design matrix, the concentrations of nitrate and nitrite were kept a fixed ratio of 3.26:1. Nitrate/nitrite and hydroxide concentrations were varied to reflect feed solutions with and without nitrate/nitrite destruction prior to caustic recovery. A total of four center point tests were conducted, two at the start and two at the conclusion, to evaluate the experimental variability. Minimum, center point and maximum values for the five test parameters are provided in Table II.

Table II. Range of Parameter Values in Test Matrix

	<u>Minimum (-)</u>	<u>Center Point (0)</u>	<u>Maximum (+)</u>
Temperature (° C)	30	50	70
Current Density (amp/m ²)	1000	2500	4000
Total NO ₃ ⁻ & NO ₂ ⁻ Conc. (M)	0.100	1.56	3.00
OH ⁻ Concentration (M)	0.600	2.05	3.50
AlO ₂ ⁻ Concentration (M)	0.010	0.255	0.500

Table III provides the test ID, run order and parameter key for the 12 experiments. An uncontrolled variable that developed during the course of the testing was the use of three different pieces of membrane. Single pieces of membrane were used for tests CR3 through CR9, CR10 and CR11 through CR14. All three pieces of membrane were cut from a single larger piece of membrane. Pretreatment and storage were identical for all pieces of the membrane.

Originally CR11 was to be run immediately after CR10. However, during the setup prior to turning on the power supply, a leak in the membrane developed resulting in the mixing of the anolyte and catholyte solutions. There was no visible signs of a hole or tear in the membrane and, therefore, the leak was attributed to improper assembly of the cell. A new piece of membrane was inserted into the cell and the next test, CR12, performed. Test CR11 was performed after preparing fresh salt solution.

Table III. Matrix Test Run Order, ID and Conditions

Run Order	Test ID	FFDesign Row No.	NO ₃ ⁻ +NO ₂ ⁻ Conc.	OH ⁻ Conc.	Temp.	Current Density	AlO ₂ ⁻ Conc
1	CR3*	1	0	0	0	0	0
2	CR4	2	0	0	0	0	0
3	CR5	5	+	+	+	+	+
4	CR6	10	-	+	+	-	+
5	CR7	3	+	-	+	-	-
6	CR8	4	-	+	-	+	-
7	CR9	6	+	-	-	+	+
8	CR10*	7	-	-	-	-	+
9	CR12*	9	+	+	-	-	-
10	CR11	8	-	-	+	+	-
11	CR13	11	0	0	0	0	0
12	CR14	12	0	0	0	0	0

*new sheet of membrane installed in electrochemical cell

The changes in moles of sodium ion and hydroxide in the catholyte and anolyte with total charge passed were determined for each test. Plots of moles of sodium and hydroxide versus charge passed are provided in Figures 4-15. Transport of sodium and hydroxide out of the anolyte is a loss and, therefore, has a negative sign. Transport of sodium and hydroxide into the catholyte is a gain and, therefore, has a positive sign. In theory, the moles of sodium transferred out of the anolyte should equal that into the catholyte, and assuming 100 % electrical efficiency, the absolute value of the flux is 1.04E-05 mole/coulomb of charge.

The sodium ion and hydroxide fluxes (moles/coulomb) were determined as the slope of the linear fit of the data from a plot of the total moles of sodium or hydroxide in the respective compartments versus the charge passed (see Figures 4 - 15). Table IV presents a summary of the fluxes for each compartment in the test matrix.

Table V presents a summary of the electrical efficiency for each test determined from the flux data reported in Table IV. The electrical efficiency (%) is determined by dividing the sodium or hydroxide flux by the theoretical flux ($\pm 1.04\text{E-}05$ mole/coulomb) and multiplying the result by 100.

$$\text{Electrical Efficiency (\%)} = (F_m/F_t) * 100$$

where F_m = measured sodium or hydroxide flux (mole/coulomb),
 F_t = theoretical sodium or hydroxide flux (mole/coulomb).

Table IV. Sodium Ion and Hydroxide Fluxes in Catholyte and Anolyte Solutions

<u>Test ID</u>	<u>Flux (mole/coulomb)</u>			
	<u>Catholyte</u>		<u>Anolyte</u>	
	<u>Sodium</u>	<u>Hydroxide</u>	<u>Sodium</u>	<u>Hydroxide</u>
CR3	1.10E-05	9.89E-06	-1.24E-05	-1.05E-05
CR4	9.98E-06	1.06E-05	-1.12E-05	-8.80E-06
CR5	9.95E-06	8.24E-06	-1.13E-05	-8.25E-06
CR6	7.80E-06	8.13E-06	-1.88E-05	-1.17E-05
CR7	1.05E-05	8.37E-06	-1.49E-05	-6.57E-06
CR8	9.86E-06	6.85E-06	-6.08E-06	-9.63E-06
CR9	1.07E-05	7.07E-06	-1.20E-05	-6.83E-06
CR10	7.49E-06	7.76E-06	-1.02E-05	-9.33E-06
CR12	8.67E-06	1.15E-05	-1.57E-05	-1.61E-05
CR11	7.43E-06	4.36E-06	-9.07E-06	-6.08E-06
CR13	7.43E-06	5.84E-06	-8.70E-06	-7.92E-06
CR14	6.38E-06	6.63E-06	-8.52E-06	-6.01E-06

Analysis of the sodium and hydroxide flux data indicated that none of the varied parameters were statistically significant in affecting the transport of sodium from the anolyte into the catholyte. That is, the transport of sodium across the Nafion® membrane was not affected over the range of salt solution compositions, current densities (1000-4000 amp/m²) and temperatures (30-70 °C) tested. There is considerable spread in the data attributed to experimental errors associated with sampling and analytical measurements as well as the performance characteristics of different pieces of membrane.

Table V. Electrical Efficiencies for Transport of Sodium and Hydroxide

<u>Test ID</u>	Electrical Efficiency (%)			
	Catholyte		Anolyte	
	<u>Sodium</u>	<u>Hydroxide</u>	<u>Sodium</u>	<u>Hydroxide</u>
CR3	106	95.1	119	101
CR4	96.0	102	108	84.6
CR5	95.7	79.2	109	79.3
CR6	75.0	78.1	181	112
CR7	101	80.5	143	63.2
CR8	94.8	65.9	58.5	92.6
CR9	103	68.0	115	65.7
CR10	72.0	74.6	98.1	89.7
CR12	83.4	111	151	155
CR11	71.4	41.9	87.2	58.5
CR13	71.4	56.2	83.7	76.2
CR14	61.3	63.7	81.9	57.8

Table VI lists the current density, temperature cell voltage and whether precipitation of solids occurred during a test. There was no evidence that exposure of the membrane to the higher cell voltages for short periods of time significantly affect the transport characteristics of the membrane. However, the membrane vendor recommends removal of solids in feed streams to membrane cell to minimize the possibility of fouling or physical attack of the membrane by the solids.

The increase in the cell voltage is attributed to the depletion of hydroxide and nitrite in the anolyte solution. Upon depletion of these species, the anodic reactions switch from that of hydroxide and nitrite oxidation to water oxidation. The standard potential for water oxidation is -1.229 volts compared to -0.401 volts for hydroxide and -0.01 volts for nitrite[2]. Thus, for the cell to continue to operate at the same current density, the potential must increase.

Upon depletion of the hydroxide in the anolyte, aluminum and silicon will precipitate as hydrous oxides. Typically, alumina and silica precipitate when the pH falls below 12 (hydroxide concentration of 0.01 molar). The quantity of solids will depend on the concentration of aluminum, silicon and the hydroxide. Although solids were produced during most of the tests, there was no visible signs of attack or fouling of the membrane as a result of the solids formation.

Table VI. Test Conditions and Selected Findings of Matrix Tests

<u>Test ID</u>	<u>Temp.</u> <u>(°C)</u>	<u>Current Density</u> <u>(amp/m²)</u>	<u>Cell Voltage*</u> <u>(V)</u>	<u>Solids</u> <u>Formation**</u>
CR3	50	2500	5.7-6.0, 7.4	yes
CR4	50	2500	5.5-6.0, 8.4	no
CR5	70	4000	6.4-6.5, 8.1	yes
CR6	70	1000	3.2-3.3, 3.3	no
CR7	70	1000	3.3-3.7, 3.7	trace
CR8	30	4000	7.9-8.2, 9.4	no
CR9	30	4000	9.2-10.1, 9.6	yes
CR10	30	1000	4.5-5.0, 5.8	yes
CR12	30	1000	3.8-4.0, 4.0	no
CR11	70	4000	7.1-10.2, 10.2	yes
CR13	50	2500	5.4-5.8, 7.8	yes
CR14	50	2500	5.4-5.7, 6.4	yes

* The first values are the range of cell voltages during test until latter stage when sharp rise in potential was observed; the latter value is the potential at the conclusion of the test.

** yes = solids found on electrode and throughout frame

no = no solids found throughout cell

trace = small amount of solids found on anode, no solids in frame

Analysis of the anolyte samples for nitrate and nitrite content indicated that during a test, nitrite is oxidized to nitrate. Since this reaction competes with the predominant reaction, hydroxide oxidation, additional sodium hydroxide can be recovered without exhausting available hydroxide resulting in precipitation of alumina and silica. After caustic removal, the anolyte solution is a more corrosive solution due to the depletion of hydroxide and nitrite.

The catholyte samples were also analyzed for the other components the anolyte compartment. Since the majority of these components are anionic, transport across the Nafion® membrane should be very small. This information is important, however, to determine the chemical purity of the recovered caustic. The flux of these species into the catholyte was very small. Appendix I provides a table of the fluxes for each component. The fluxes were determined by dividing the product of the final measured concentrations and the final catholyte volume by the total charge passed (equation 1).

$$\text{Flux (mole/coulomb)} = (C_f \times V_f) / Q_t$$

where C_f = final concentration (mole/L) of j species
 V_f = final catholyte volume (L)
and Q_t = total charge (coulombs) passed during experiment

In general, the fluxes of the anionic species were 10000 times or more lower than that measured for sodium. Exceptions to this were carbonate and nitrate and aluminum at high

salt concentrations, where the fluxes were approximately 100 to 1000 times lower than that for sodium. The high carbonate flux is attributed to the transport of carbonate across the membrane and adsorption of atmospheric carbon dioxide which reacts with hydroxide to produce carbonate. No attempt was made during the test to prevent the exposure of the catholyte solution to air. The relatively high aluminum flux may be result of the presence of cationic aluminum species (Al^{3+} , $\text{Al}(\text{OH})^{2+}$ and $\text{Al}(\text{OH})_2^+$) in equilibrium with $\text{Al}(\text{OH})_4^-$ in the strongly alkaline solution.

CONCLUSIONS AND RECOMMENDATIONS

A statistically designed set of tests determined the effects of current density, temperature, and the concentrations of nitrate/nitrite, hydroxide and aluminate on the recovery of sodium as sodium hydroxide (caustic) from solutions simulating those produced from the Savannah River Site (SRS) In-Tank Precipitation process. These tests included low nitrate and nitrite concentrations which would be produced by electrolytic nitrate/nitrite destruction. Evaluation of the testing results indicated that the transport of sodium across the membrane was not significantly affected by any of the varied parameters. The observed variance in the sodium flux is attributed to experimental errors and variations in the performance characteristics of individual pieces of membrane. It is recommended that the process be designed to maintain a high pH (>12) to ensure that alumina and silica do not precipitate. Additional testing is recommended to determine the maximum current density, to evaluate the chemical durability of the organic membrane as a function of current density and to compare the durability and performance characteristics of the organic based Nafion[®] membrane with that of other commercially available organic membranes and the inorganic class of membranes under development by Ceramtec[®] and PNNL.

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Figure 4. Change in Moles of Sodium and Hydroxide in Catholyte and Anolyte for Test CR3

Figure 5. Change in Moles of Sodium and Hydroxide in Catholyte and Anolyte for Test CR4

Figure 6. Change in Moles of Sodium and Hydroxide in Catholyte and Anolyte for Test CR5

Figure 7. Change in Moles of Sodium and Hydroxide in Catholyte and Anolyte for Test CR6

Figure 8. Change in Moles of Sodium and Hydroxide in Catholyte and Anolyte for Test CR7

Figure 9. Change in Moles of Sodium and Hydroxide in Catholyte and Anolyte for Test CR8

Figure 10. Change in Moles of Sodium and Hydroxide in Catholyte and Anolyte for Test CR9

Figure 11. Change in Moles of Sodium and Hydroxide in Catholyte and Anolyte for Test CR10

Figure 12. Change in Moles of Sodium and Hydroxide in Catholyte and Anolyte for Test CR11

Figure 13. Change in Moles of Sodium and Hydroxide in Catholyte and Anolyte for Test CR12

Figure 14. Change in Moles of Sodium and Hydroxide in Catholyte and Anolyte for Test CR13

Figure 15. Change in Moles of Sodium and Hydroxide in Catholyte and Anolyte for Test CR14

Appendix 1
Calculated Species Fluxes into Catholyte
(Caustic Product Solution)

Test ID	CR3	CR4	CR5	CR6	CR7	CR8	CR9	CR10	CR11	CR12	CR13	CR14	Average	Std. Dev.	% RSD
Element/Species	(mole/C)	(mole/C)	(mole/C)	(mole/C)	(mole/C)	(mole/C)	(mole/C)	(mole/C)	(mole/C)	(mole/C)	(mole/C)	(mole/C)	(mole/C)	(mole/C)	
CO3	1.50E-06	bdl	bdl	4.81E-07	2.32E-07	1.56E-08	2.49E-08	3.01E-07	1.08E-07	9.81E-08	6.62E-07	1.45E-08	3.43E-07	4.59E-07	133.76
Al	1.99E-09	1.27E-08	4.31E-08	3.74E-08	5.33E-09	1.44E-09	3.56E-08	4.70E-08	4.44E-09	4.36E-09	7.31E-09	7.53E-09	1.74E-08	1.77E-08	102.28
Cr	2.07E-10	2.32E-10	1.66E-10	3.67E-10	5.54E-10	1.50E-10	4.79E-10	6.98E-10	4.61E-10	3.02E-10	1.58E-10	1.40E-10	3.26E-10	1.85E-10	56.76
P	2.43E-09	2.72E-09	2.22E-09	4.31E-09	6.51E-09	3.77E-10	1.21E-09	3.51E-09	2.32E-09	1.27E-09	1.46E-09	3.52E-10	2.39E-09	1.75E-09	73.28
Si	5.75E-10	6.43E-10	4.60E-10	1.02E-09	2.56E-09	1.94E-09	6.21E-09	9.04E-09	5.97E-09	3.91E-09	2.05E-09	1.81E-09	3.02E-09	2.73E-09	90.47
NO3	2.80E-08	9.18E-09	3.98E-09	2.43E-09	7.52E-08	1.88E-09	bdl	3.51E-09	bdl	9.67E-08	bdl	bdl	2.76E-08	3.74E-08	135.59
NO2	4.29E-09	8.08E-09	9.36E-10	bdl	6.26E-09	1.69E-09	6.82E-08	1.97E-09	1.30E-09	bdl	bdl	bdl	1.16E-08	2.30E-08	198.62
Total NOx	3.23E-08	1.73E-08	4.91E-09	2.43E-09	8.14E-08	3.57E-09	6.82E-08	5.48E-09	1.30E-09	9.67E-08	bdl	bdl	3.14E-08	3.68E-08	117.47
SO4	2.29E-09	3.13E-10	2.90E-10	6.79E-10	bdl	4.05E-10	bdl	1.13E-09	bdl	2.70E-09	bdl	bdl	1.12E-09	9.92E-10	88.92
PO4	5.53E-10	6.18E-10	4.42E-10	9.78E-10	bdl	7.99E-10	bdl	9.31E-10	bdl	1.61E-09	bdl	bdl	8.48E-10	3.91E-10	46.07
F	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl		
Cl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl		
Ratio of Flux to Na Flux													Average	Std. Dev.	% RSD
CO3	9.59E-02			2.66E-02	8.71E-03	1.06E-03	1.06E-03	1.13E-02	5.61E-03	5.43E-03	5.93E-02	1.47E-03	2.16E-02	3.16E-02	146.13
Al	1.28E-04	7.76E-04	2.58E-03	2.07E-03	2.01E-04	9.83E-05	1.51E-03	1.77E-03	2.31E-04	2.41E-04	6.55E-04	7.64E-04	9.19E-04	8.54E-04	92.99
Cr	1.33E-05	1.41E-05	9.94E-06	2.03E-05	2.08E-05	1.02E-05	2.03E-05	2.63E-05	2.40E-05	1.67E-05	1.42E-05	1.42E-05	1.70E-05	5.27E-06	30.97
P	1.56E-04	1.66E-04	1.33E-04	2.38E-04	2.45E-04	2.57E-05	5.11E-05	1.32E-04	1.21E-04	7.01E-05	1.31E-04	3.57E-05	1.25E-04	7.15E-05	57.02
Si	3.68E-05	3.92E-05	2.76E-05	5.63E-05	9.64E-05	1.32E-04	2.63E-04	3.41E-04	3.11E-04	2.17E-04	1.83E-04	1.84E-04	1.57E-04	1.10E-04	69.96
NO3	1.80E-03	5.60E-04	2.39E-04	1.34E-04	2.83E-03	1.28E-04		1.32E-04		5.35E-03			1.40E-03	1.88E-03	134.52
NO2	2.75E-04	4.93E-04	5.61E-05		2.35E-04	1.15E-04	2.89E-03	7.42E-05	6.78E-05				5.26E-04	9.67E-04	183.87
Total NOx	2.07E-03	1.05E-03	2.95E-04	1.34E-04	3.06E-03	2.43E-04	2.89E-03	2.06E-04	6.78E-05	5.35E-03			1.54E-03	1.77E-03	115.41
SO4	1.47E-04	1.91E-05	1.74E-05	3.75E-05		2.76E-05		4.27E-05		1.49E-04			6.29E-05	5.89E-05	93.54
PO4	3.54E-05	3.77E-05	2.65E-05	5.41E-05		5.45E-05		3.51E-05		8.92E-05			4.75E-05	2.11E-05	44.40

Distribution:

D. W. Geiser, DOE-HQ
P. McGinnis, ORNL
W. C. Laveille, 703-A
D. Kurath, PNNL
W. E. Lawrence, PNNL
W. L. Kuhn, PNNL
R. E. White, University of South Carolina
J. W. Van Zee, University of South Carolina
J. W. Weidner, University of South Carolina
L. M. Papauchado, 773-A
C. R. Wolf, 773-A
W. L. Tamosaitis, 773-A
S. D. Fink, 773-A
S. T. Wach, 773-43A
J. L. Steimke, 786-5A
J. P. Morin, 719-4A
R. W. Brandon, 719-4A
B. L. Lewis, 703-H
J. R. Fowler, 704-Z
T. B. Edwards, 773-42A
D. T. Hobbs, 773-A
IWT-LWP File, 773-A
TIM, 773-52A