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SOLVENT REFINED COAL (SRC) PROCESS: TRACE ELEMENTS

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TABLE OF CONTENTS

TABLE OF CONTENTS (cont'd)

LIST OF TABLES

LIST OF TABLES (cont'd)

LIST OF FIGURES

ABSTRACT

Results are presented on a study of the distribution and fate of 34 trace elements in the Solvent Refined Coal Process at the pilot plant located at Fort Lewis, Washington, and operated by the Pittsburg & Midway Coal Mining Co. under contract with the U. S. Department of Energy. Neutron activation analysis was used to determine Ti, V, Ca, Mg, Al, Cl, Mn, As, Sb, Se, Hg, Br, Co, Ni, Cr, Fe, Na, Rb, Cs, K, Sc, Tb, Eu, Sm, Ce, La, Sr, Ba, Th, Hf, Ta, Ga, Zr, and Cu in feed coals, process solvent, Solvent Refined Coal (SRC), mineral residues, wet filter cake, by-product solvents, process and effluent waters and by-product sulfur. The sample points were chosen such that the major process streams were adequately described and that the major input and output materials were included. Atomic absorption spectrophotometry was used to measure the toxic elements Pb, Cd, and Be in plant-derived solvents, effluent water and Hamer Marsh water. Specific methods were developed for analysis of a wide range of material compositions. The neutron activation analysis procedures were divided into short and long irradiation procedures for elements with short half lives (less than 3 hours) and intermediate to long half lives (8 hours to 5.2 years).

Data are presented for preliminary SRC I process materials and also for a set of materials taken during operation of the pilot plant but not under equilibrium conditions.

Two separate sets of samples were taken when the pilot plant had operated continuously for seven days and composite samples were collected for each process fraction over a 24-hour period. These are designated Equilibrium Sets 1 and 2. A material balance (or budget) was calculated for each element from the concentration data and the yields of each process fraction for each equilibrium set in the SRC process. The SRC and insoluble residue account for more than 95% of the input of each element (except for Hg and Co in Equilibrium Set 1) with other process fractions contributing little to the trace element balance. Except for Cl, Br, and Ti, each element was substantially lower in the SRC compared to the original feed coal.

I. INTRODUCTION

Coal conversion is a means of producing low sulfur, low ash fuels from coal which is a relatively dirty fuel compared to residual fuel oil and other petroleum based products. In order to reduce dependence on petroleum, the future energy needs of the United States will be met in large part by coal and coal-derived products, and coal conversion will play a large role in future energy generation. Coal gasification, coal cleaning and coal liquefaction processes are now under development and are at various stages of commercialization. Coal liquefaction is expected to provide chemical and refinery feedstock materials in addition to boiler fuels for energy generation, although this aspect of coal conversion is at present less attractive economically than the production of fuels for power generation.

The Solvent Refined Coal Process developed by the Pittsburg & Midway Coal Mining Co. under contract with the U. S. Department of Energy is presently at an advanced stage and a 50 ton/day pilot plant is operating at Fort Lewis, Washington. This pilot plant has undergone extensive testing and production runs of solvent refined coal (SRC) have been made for power plant burning studies of the solid SRC I product.

The widespread development and use of coal conversion plants requires an evaluation of the environmental hazards associated with each process and plant. Among such hazards is the problem of emissions of trace elements. An important objective of liquefaction processes is to remove much of the sulfur and the ash content of coal so that the resulting fuel can be burned without expensive stack gas scrubbers. Removal of a large fraction of the ash content will result in removal of a fraction of the trace element content of the coal. It is thus important that the fate and distribution of trace elements in the SRC I process be determined to assess the pollution potential of the product fuel (SRC), the environmental effects of emissions, and the effects of waste disposal. The distribution of trace elements during the liquefaction process is also important in determining the trace element material balances of the process and in evaluating the effects of such variables as coal type, autocatalytic effects, temperature, pressure, solvent composition and degree of hydrogenation on the material balance.

The objective of this study was to apply the techniques of neutron activation analysis (NAA) and atomic absorption spectroscopy (AAS) to the determination of trace elements in the SRC I process. Neutron activation analysis was chosen as the main method of trace element analysis because of the high sensitivity for many elements, good precision and accuracy, the multielement nature of the technique, and the capability of analyzing very different matrix types. The ability to analyze different matrix types is significant for the SRC I process where very diverse materials are encountered; e.g. coal, SRC, mineral residues, process waters and volatile solvents. Atomic absorption spectroscopy was used for Pb, Be and Cd which cannot be determined by thermal neutron activation analysis.

Material balances have been measured for the elements Ti, V, Ca, Mg, Al, Cl, Mn, As, Sb, Se, Hg, Br, Co, Ni, Cr, Fe, Na, Rb, Cs, K, Sc, Tb, Eu, Sm, Ce, La, Sr, Ba, Th, Hf, Ta, Ga, Zr and Cu. A preliminary study was carried out when the SRC I Pilot Plant was operating at non-steady-state conditions, and the data from this study were reported at the 1976 International Conference on Modern Trends in Activation Analysis, Munich, Germany, September 1976 (1,2). The trace element material balances obtained in that study do not truly represent the coal analyzed but did provide preliminary data for future guidance. Later, two sets of materials were collected after the pilot plant had operated continuously for at least seven days, and these are referred to as equilibrium or steady state sets (1 and 2).

A. The Solvent Refined Coal (SRC I) Process

A schematic diagram of the SRC I process is shown in Figure 1. In this process, coal is crushed, ground and dried and is then mixed with a hydrogen-donor solvent (recycled in the process) to form a slurry. Hydrogen is introduced and the coal is hydrogenated in a reactor at 850°F and 1500 psig. After the reactor, product gases (C_1-C_4 hydrocarbons, CO_2, H_2S, CO, H_2, etc.) are flashed off and the liquid is filtered through a pre-coated rotary drum filter to remove unreacted coal and mineral matter. Light oils and process solvent are flashed off the liquid to give a solid product, SRC, and the solvent is recycled back into the system. In this process, the coal is dissolved in the solvent and depolymerized to give smaller molecules, which are stabilized by hydrogen transfer from the process solvent.

In this process, some of the organic sulfur is converted to H_2S and most of the FeS_2 is converted to FeS + H_2S;

i.e. $$FeS_2 + H_2 \longrightarrow FeS + H_2S$$

$$R\text{-}S\text{-}R' + 2H_2 \longrightarrow H_2S + R\text{-}H + R'\text{-}H$$

where R-S-R' represents organically bound sulfur.

Approximate daily rates of production of trace elements in the 50 ton/day pilot plant are shown in Table 1. The amounts of each trace element produced daily have been calculated assuming 50 tons coal converted per day and concentrations of each trace element taken as those values for coals used in Equilibrium Sets 1 and 2.

The fate of trace elements present in the coal is dependent on: a) the element, b) the chemical bonding of the element, i.e., organically or inorganically, and c) the nature of the mineral species if inorganically bound. Under the reducing process conditions (high H_2 pressure, 850°F, 1500 psig), several elements may be volatile or form volatile inorganic species; e.g., Hg^0, H_2Se, AsH_3, $AsCl_3$, SbH_3, HBr, $Fe(CO)_5$, and $Ni(CO)_4$, among others. Whether these inorganic species will be formed will depend largely

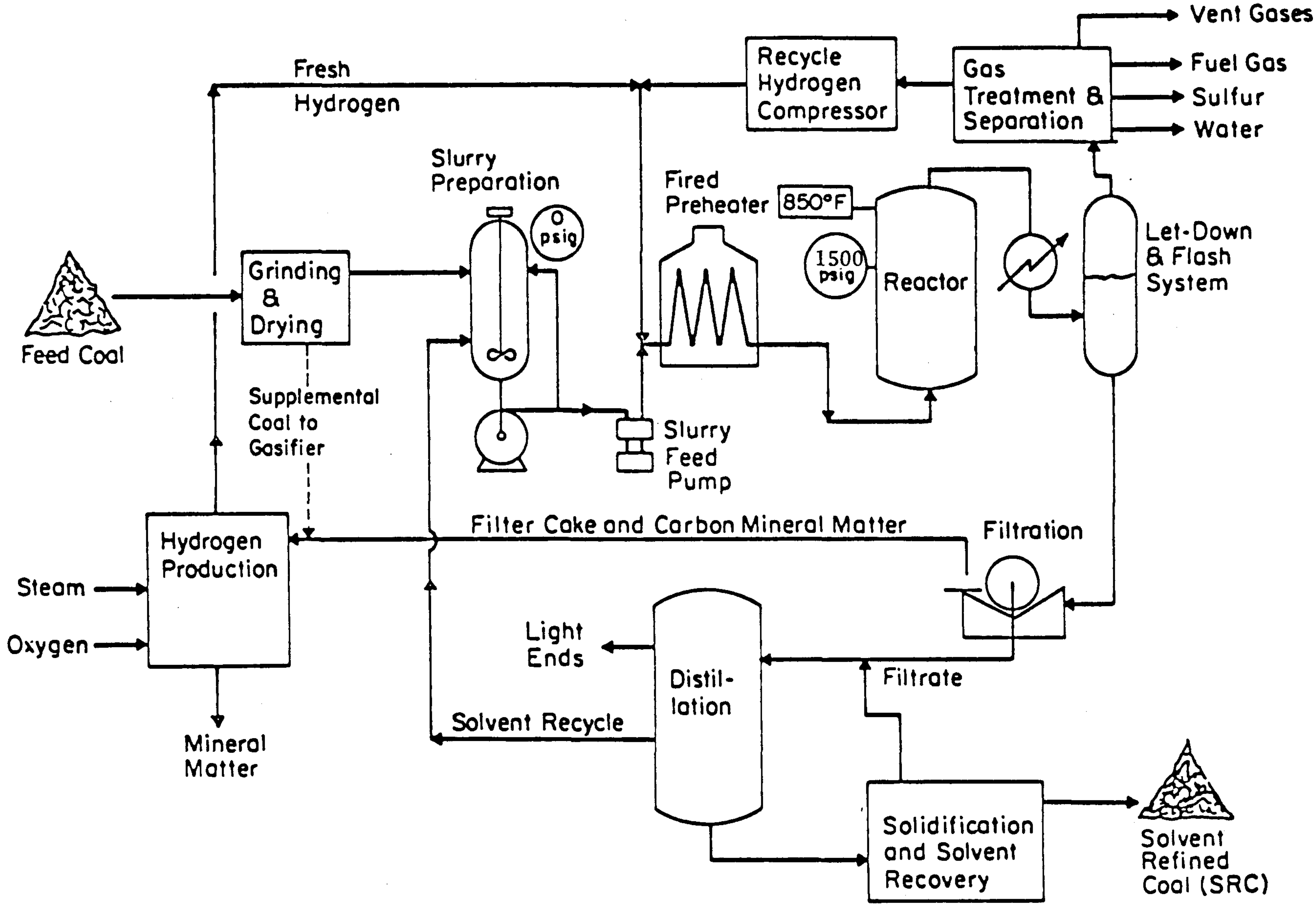

Figure 1: SCHEMATIC DIAGRAM OF SRC I PROCESS

TABLE 1

PRODUCTION OF TRACE ELEMENTS IN KG/DAY FOR
50 TON/DAY SRC PILOT PLANT: EQUILIBRIUM CONDITIONS

Minor Elements	Concentration in Coal (Eq. Set 1)	Kg/day	Concentration in Coal (Eq. Set 2)	Kg/day
Fe (%)	2.40	1200	2.90	1500
Al (%)	1.07	540	1.24	630
Ti (ppm)	547	28	660	34
V (ppm)	25.2	1.3	29.2	1.5
Ca (ppm)	633	32	658	33
Mg (ppm)	858	44	--	--
Cl (ppm)	286	15	250	13
Mn (ppm)	32.8	1.7	34.8	1.8
Trace Elements				
As (ppm)	11.6	0.6	21.2	1.1
Sb (ppm)	0.98	<0.1	1.13	<0.1
Se (ppm)	2.18	0.1	2.24	0.11
Hg (ppb)	113.0	5.7×10^{-3}	114	5.7×10^{-3}
Br (ppm)	5.79	0.3	3.24	0.2
Ni (ppm)	18.0	0.9	12.4	0.6
Co (ppm)	5.25	0.3	6.0	0.3
Cr (ppm)	10.4	0.5	14.9	0.8
Na (ppm)	124	6.3	144	7.3
Rb (ppm)	3.57	0.2	11.9	0.6
Cs (ppm)	0.75	<0.1	1.03	<0.1
K (ppm)	1260	64	1840	88

TABLE 1 (cont'd)

PRODUCTION OF TRACE ELEMENTS IN KG/DAY FOR

50 TON/DAY SRC PILOT PLANT: EQUILIBRIUM CONDITIONS

Trace Elements	Concentration in Coal (Eq. Set 1)	Kg/day	Concentration in Coal (Eq. Set 2)	Kg/day
Sc (ppm)	2.10	0.1	2.71	0.1
Tb (ppm)	0.43	<0.1	0.29	<0.1
Eu (ppm)	0.26	<0.1	0.24	<0.1
Sm (ppm)	2.59	0.1	2.29	0.1
Ce (ppm)	24.2	1.2	30.5	1.6
La (ppm)	7.52	0.4	8.0	0.4
Sr (ppm)	97.2	4.9	134	6.8
Ba (ppm)	31.0	1.6	53.2	2.7
Th (ppm)	1.51	<0.1	2.16	0.1
Hf (ppm)	0.34	<0.1	0.57	<.01
Ta (ppm)	0.10	<0.1	0.10	<0.1
Ga (ppm)	2.69	0.1	2.27	0.1
Zr (ppm)	66.5	3.4	57.3	2.9
Cu (ppm)	22.4	1.1	13.2	0.8

on the nature of the host mineral and whether this mineral is reactive under the liquefaction/hydrogenation conditions. In addition to the volatile inorganic species that might escape in gaseous emissions or condense with distillate products, there is the possibility of reaction with the organic matrix to form organometallic compounds, many of which are volatile and extremely toxic. Most of the transition metals (e.g., Ti, Fe, Mn, Ni, Co, etc.) form a large number of stable organometallic compounds with hydrocarbons or hydrocarbon-like molecules; for example, the cyclopentadienyl compounds (e.g., ferrocene $Fe(C_5H_5)_2$, titanocene $Ti(C_5H_5)_2$) and the many derivatives of the metallocenes (e.g., carbonyls, hydrides, salts, etc.) Many of these are toxic and many are relatively volatile species so that these compounds may present an environmental hazard - examples are shown in Table 2.

Unfortunately, we have very little information on the fate of the trace elements present in coal during liquefaction, although it is obvious that the final molecular species may be quite different from those originally present in coal because of the highly reactive conditions and the complex chemical system of the dissolution/hydrogenation process. It is pertinent, therefore, to briefly discuss the form of trace elements in coals before some predictions of the fate of these elements in coal conversion can be made.

B. Trace Elements in Coals

There are a large number of data on trace elements in coals although many of the data are suspect because they were obtained on coal ashes using spectrochemical analysis techniques. Losses of volatile elements during ashing of the coals and matrix effects in the spectrochemical procedure account for many of the erroneous values. Reviews of the occurrence of trace elements in coals have been published by Zubovic (4), Swaine (5), Mackowsky (6) and Magee, Hall and Varga (7). Ruch, Gluskoter and Shimp (8) and Gluskoter et al., (9) have investigated the occurrence of trace elements in coals of the Illinois Basin and have discussed chemical forms of some elements. Recently, the U. S. Geological Survey (10) has begun a comprehensive program of coal analysis for U. S. coals and Swanson et al., (11) have collected and evaluated the data obtained in this program up to 1976.

Although there is a large body of data on trace elements in coal, there is much less known about the forms in which such trace elements occur and such knowledge is important for an understanding of trace element behavior during coal conversion. Trace elements can occur in coal basically in either organic or inorganic forms and most trace elements are probably found in both combinations. Possible forms are shown in Table 3.

Elements such as Fe, Ca, Zn, Mg, Si, etc., may occur predominantly in mineral species of these elements; e.g., FeS_2, $CaCO_3$, ZnS, etc. However, for many elements such as Hg, As, Sb, Pb, Cd, Co, Ni,

TABLE 2

POSSIBLE ENVIRONMENTALLY IMPORTANT FORMS OF SOME TRACE ELEMENTS DURING LIQUEFACTION

Element	Volatile Species	Organic Species*
As	AsH_3, $AsCl_3$, $AsBr_3$	$RAsH_2$, RR'AsH
Sb	SbH_3, $SbCl_3$, $SbBr_3$, SbOCl	R_3Sb, $R_4Sb^+X^-$
Hg	Hg°, $HgBr_2$	R_2Hg, RHg^+X^-
Se	H_2Se, Se°	R-Se-R'; $R\text{-}SeO_3H$
Fe	$Fe(CO)_5$	$Fe(C_5H_5)_2(CO)_x$
Ni	$Ni(CO)_4$	Ni-asphaltene bonds
Ti	$TiCl_4$	$Ti(C_5H_5)_2$

*R and R' represent organic moieties without regard to composition or structure

TABLE 3

POSSIBLE FORMS OF TRACE ELEMENTS IN COALS

Organic Forms (Macerals)	Inorganic Forms (Minerals)
Vitrinite	Clay Minerals: Illite, montmorillonite, kaolinite, chlorite
Semi vitrinite	Sulfides: Galena PbS, pyrite FeS_2, marcasite FeS_2, sphalerite ZnS
Fusinite	Carbonates: Calcite $CaCO_3$, ankerite, siderite $FeCO_3$
Semi fusinite	Sulfates: Gypsum $CaSO_4 2H_2O$
Micrinite	Oxides: Quartz SiO_2, hematite Fe_2O_3, rutile TiO_2

Se, etc., no specific mineral of the element may be present but the element may be distributed among several mineral species. Several authors (4, 5) have discussed the organic versus inorganic occurrence of trace elements in coals. Ruch et al., (8) and Gluskoter et al., (9) used float-sink specific gravity separations of coal to determine organic versus inorganic affinity of trace elements in four Illinois coals. Zubovic (4) has determined similar affinities for coals. Their general conclusions are summed up in Table 4.

Filby and Brown (12) in this laboratory have used Factor Analysis to determine "factors" that explain the distribution of elements in the suite of Illinois coals reported by Ruch et al., (8). The tentative results of this statistical study are shown in Table 5, which lists the factors extracted interpreted as mineral species. Details of the Factor Analysis technique are outside the scope of this work and will be published elsewhere (12). In general, these conclusions support those of Gluskoter et al., (9) but also provide information about species with which elements are associated. Particularly important for the SRC process is the observation that Ti appears in coal associated with a silicate fraction, which is contrary to the results of Gluskoter et al., (9) and Zubovic (4).

There is thus no concensus on the nature of trace elements in coal and further research is badly needed.

C. Trace Element Balances in Liquefaction

Very little information is available on the distribution of trace elements in coal conversion processes, although a number of preliminary studies have been made for gasification processes. Forney et al., (13) have studied the distribution of trace elements around the SYNTHANE gasifier at the Pittsburgh Energy Research Center (PERC) using mass spectroscopy. The results ranged from 218% recovery for F to 1103% for Pb and no reliable mass balances could be derived. Jahnig and Magee (14) presented some limited data on trace elements in SRC and related coals, but no mass balances were calculated nor were other process streams analyzed. Schultz et al., (15) have made a preliminary study on the distribution of Cu, Cr, Mn, Ni, Cd and Pb in the 1/2 ton per day SYNTHOIL Pilot Plant and trace element material balances ranging from 100% to 124% were obtained, although the authors noted that the process run was not to be regarded as typical of the SYNTHOIL process.

This work, therefore, is the first attempt at calculating trace element balances in the SRC process.

II. ANALYTICAL METHODOLOGY

A. Sample Collection and Preparation

The sample collection procedure is very critical in order to correctly evaluate the fate of various elements in the coal

TABLE 4

ORGANIC-INORGANIC AFFINITIES OF SOME METALS IN COALS

Form	Zubovic (4)	Gluskoter et al., (9)
Predominantly Organic	Ge, Be, Ga, Ti, B, V, Ni	B, Ga, Ge, Be Ti, Sb, V, P
Predominantly Inorganic	Zn, La, Sn, Cu, Mo	Zn, Pb, As, Hg, Cd, Mo, V, Zr, Cu

Many exceptions have been noted in the above general relationships.

TABLE 5

ASSOCIATION OF TRACE ELEMENTS IN ILLINOIS COALS

Factors and Possible Species	Elements Associated with Factor
Silicate Factor (clay minerals)	K, Al, Si, Ti, V, Mg
Sulfide Factor (PbS)	Pb, As, Sb, Ge
Sulfide Factor (pyrite)	Fe, Mo, Ge
Sulfide Factor (sphalerite)	Zn, Cd
Sulfide Factor (NiS)	Ni, Co, Be, Ga, Sb
Carbonate Factor ($CaCO_3$)	Ca, Mn, B
Phosphate Factor (apatite)	Ca, P, F, Mo

liquefaction process. Sampling of an operating pilot plant is, in itself, a difficult operation because of the problem of obtaining a representative sample of the stream and, at the same time, avoiding contamination of the sample during the sampling procedure. The samples collected should not only evaluate various important process streams, effluents and products but also be truly representative of the material sampled. After discussion with Mr. Russell E. Perrussel at the pilot plant, twelve different points in the pilot plant were selected as the sample collection points. These points (see Table 6) covered effectively all input, output and other important process streams and were accessible to on-line sampling. Table 7 is a list of other laboratory prepared samples. These samples were necessary to check any process contamination of plant products by the process.

A representative sample was essential for this study. It was necessary that all samples be collected when the plant was operating under a 'steady state' condition. Although this is very difficult to achieve, it was decided that a close approximation to steady-state conditions would be achieved when the plant had been operating for at least seven days with no shutdown. In order to nullify the effects of momentary fluctuations of the process conditions, all samples were collected for a period of 24 hours (every four hours) from each collection point. Final composites of samples were prepared by mixing samples collected during the 24-hour collection period for each point. Run conditions for Equilibrium Sets 1 and 2 are shown in Tables 8 and 9.

Samples collected for elemental analysis were divided into three groups depending upon matrix type. These were: a) solids, b) organic solvents, and c) aqueous samples. Each matrix required different procedures for the sample preparation, storage, and analysis. These procedures are discussed below:

a) Solid Samples: Solid samples, such as SRC, ground coal, pyridine insolubles, mineral residues, etc., were collected in cleaned glass or polyethylene containers. These containers were soaked in dilute nitric acid for about four hours and then cleaned with double distilled water. The procedure was necessary to remove any surface contamination.

b) Organic solvents were collected in pre-cleaned brown glass containers (see Section a) to prevent decomposition of organic compounds.

c) Collection and shipping of aqueous samples required special attention. It is known that many elements are readily adsorbed on the walls of containers (plastic or glass) from aqueous solution. The rate and extent of adsorption varies from element to element and is dependent on the pH of the solution, presence of

TABLE 6
PILOT PLANT SAMPLE COLLECTION POINTS

No.	Description	Matrix
1.	Raw coal	solid
2.	Dried/pulverized coal	solid
3.	Dust collector	solid
4.	Recycle solvent	organic solvent
5.	Solvent refined coal	solid
6.	Mineral residue	solid
7.	Elemental sulfur by-product	solid
8.	Light ends	organic solvent
9.	Filter-aid	solid
10.	Process water	aqueous
11.	Treated process water	aqueous
12.	Fresh wash solvent	organic solvent

TABLE 7
LAB MAKEUP SAMPLES

No.	Description	Matrix
1.	Wet filter cake	solid
2.	Pyridine insolubles	solid
3.	Light ends	organic solvent
4.	Wash solvent	organic solvent
5.	Vacuum bottoms	solid
6.	Ash of pyridine insolubles	solid
7.	Process solvent	organic solvent
8.	Water phases	aqueous

TABLE 8

RUN CONDITIONS AND YIELDS FOR EQUILIBRIUM SET 1

Run Conditions (3/1/76 1900 to 3/1/76 2100 hrs.)	Amount	
Raw coal feed	3422	lb/hr
Water removed from coal	233	lb/hr
Net dehumidified coal feed	3188	lb/hr
Moisture free coal feed	3129	lb/hr
Solvent feed	4635	lb/hr
Slurry recycle feed	0	lb/hr
Slurry feed to preheater	7823	lb/hr
Solv. & rec. slurry to deh. coal ratio	1.45	
Percent slurry recycle	0.0	%
Recycle/total feed ratio	0.00	
Hydrogen-rich gas feed	201	lb/hr
Gas feed purity - mol. % H_2	97.6	
Hydrogen feed	164	lb/hr
Hydrogen feed	30855	SCFW
Slurry preheater inlet pressure	1623	PSIG
Slurry preheater outlet temperature	742°	F
Dissolver A pressure	1545	PSIG

Dissolver Temperatures (°F)

Ft from inlet	0	4	8	12
Dissolver A	571	836	840	844

Unit	Yield(lb/hr)	Yield %MFC
H_2	-36.02	-2.75
N_2	0.57	0.02
C_1	79.39	2.54
CO	0.57	0.02
C_2	49.96	1.69
CO_2	43.05	1.38

TABLE 8 (cont'd)

RUN CONDITIONS AND YIELDS FOR EQUILIBRIUM SET 1

Unit	Yield (lb/hr)	Yield %MFC
C_3	36.32	1.16
C_4	16.74	0.54
H_2S	51.49	1.65
Light oil	79.17	2.53
H_2O	156.40	5.00
Wash solvent	242.93	7.77
Process solvent	-278.30	-8.90
SRC	2173.36	69.48
Ash	371.72	11.88
Unreacted coal	101.49	6.12
Coal	-3128.79	-100.03
Total	0.05	0.00

TABLE 9

RUN CONDITIONS FOR EQUILIBRIUM SET 2

Run Conditions (5/14/76 1600 - 5/14/76 1800 hrs.)	Amount	
Raw coal feed	3488	lb/hr
Water removed from coal	219	lb/hr
Net dehumidified coal feed	3269	lb/hr
Moisture free coal feed	3241	lb/hr
Solvent feed	4240	lb/hr
Slurry recycle feed	0	lb/hr
Slurry feed to preheater	7509	lb/hr
Solv. & rec. slurry to deh. coal ratio	1.30	
Percent slurry recycle	0.0	%
Recycle/total feed ratio	0.00	
Hydrogen-rich gas feed	162	lb/hr
Gas feed purity - mol. % H_2	93.7	
Hydrogen feed	140	lb/hr
Hydrogen feed	26306	SCFH
Slurry preheater inlet pressure	1631	PSIG
Slurry preheater outlet temperature	752	°F
Dissolver A pressure	1498	PSIG

Dissolver Temperatures (°F)

Ft from inlet	0	4	8	12
Dissolver	567	832	835	842

Unit	Yield (lb/hr)	Yield %MFC
H_2	-62.35	-1.92
N_2	0.02	0.00
C_1	61.73	1.91
CO	25.72	0.79
C_2	24.60	0.76

TABLE 9 (Cont'd)

RUN CONDITIONS FOR EQUILIBRIUM SET 2

Unit	Yield (lb/hr)	Yield %MFC
CO_2	53.34	1.65
C_3	29.89	0.92
C_4	15.65	0.48
H_2S	62.27	1.92
Light oil	93.86	2.90
H_2O	162.00	5.00
Wash solvent	100.85	3.11
Process solvent	-224.39	-6.93
SRC-I	2304.53	71.13
Ash	308.76	12.31
Unreacted coal	194.37	6.00
Coal	-3240.77	-100.02
Total	0.07	0.00

complexing agents, etc. As the adsorption is often an irreversible process, it was necessary to collect the samples to minimize adsorption.

It has been found that, if the aqueous samples are frozen immediately after the collection and kept frozen until analysis, adsorption can be kept to a minimum (16). It is also necessary that aqueous samples be free of any suspended matter. Since the concentrations of most elements in water, particularly treated effluents, are very low, any suspended matter will bias the total analysis. In order to prevent adsorption on container walls and remove particulate matter, a special sample collection procedure was developed. Immediately after sampling an aqueous process stream, the sample was filtered through clean Nucleopore (General Electric) 0.4 μm filter in a hand-pumped Teflon filter assembly. The filtered water was collected in high purity polyethylene bags and quickly frozen. The frozen samples were then stored on dry ice for shipment. As the aqueous samples were analyzed by both neutron activation and atomic absorption, the aqueous filtered samples were collected in cleaned 200 ml polyethylene bottles (for AAS) and in four different 50 ml thin walled polyethylene bags (for NAA). All samples were shipped to the Nuclear Radiation Center at Washington State University. The frozen aqueous samples were shipped in dry ice-containing boxes.

B. Neutron Activation Analysis

Neutron activation analysis was used to determine a total of 36 elements, Ti, V, Mg, Ca, Al, Cl, Mn, I, As, Br, Na, K, Sm, La, Ga, Cu, Sb, Se, Hg, Ni, Co, Cr, Fe, Rb, Cs, Sc, Tb, Eu, Ce, Sr, Ba, Th, Hf, Ta, Zr, and Zn in these samples. Neutron activation analysis is a multi-element method and the procedure requires only two neutron irradiations of varying time to determine these elements. Detailed descriptions of the procedures have been published elsewhere (17-19). These irradiation periods and the elements determined are shown in Table 10. Additional information on the transitions which occur, the energy levels of emitted gamma rays and detection limits is reported in Table 11.

1. Preparation of Samples for Irradiation

Solid samples (about 75-200 mg) were weighed into 2/5 dram polyethylene (Olympic Plastic Co.) vials. These vials were cleaned by soaking in dilute nitric acid for at least four hours and subsequently cleaned with double distilled water followed by acetone. This was necessary to remove surface contamination from the vials. All pre-irradiation sample preparation was performed in a clean-air hood (Agnew-Higgins Model 43) to minimize the contamination from airborne dust.

The low concentrations of many elements in the aqueous sample and organic solvents required larger sample volumes

TABLE 10

IRRADIATION PROCEDURES

Irradiation Time	Decay Time	Elements Determined
5-10 minutes	a) 1 minute	Ti, V, Mg, Ca, Al
	b) 30 minutes	Cl, Mn, I
8 hours	a) 14 hours	As, Br, Na, K, Sm, La
	b) 17 days	Ga, Cu, Sb, Se, Hg, Ni, Co, Cr, Fe, Rb, Cs, Sc, Tb, Eu, Ce, Sr, Ba, Th, Hf, Ta, Zr, and Zn.

TABLE 11
NUCLEAR DATA ON NUCLIDES MEASURED

Element	Nuclear Reaction and Product	Half Life	$\sigma_{th} f$[1] (barns)	γ-Rays[2] Measured (keV)	Approx. Detection Limit (ng/g)[3]
Mg	$^{26}Mg(n,\gamma)^{27}Mg$	9.5 m	0.0031	1013	10000
Ca	$^{48}Ca(n,\gamma)^{49}Ca$	8.8 m	0.002	3084	10^5
Cl	$^{37}Cl(n,\gamma)^{38}Cl$	37 m	0.105	1643	100
V	$^{51}V(n,\gamma)^{52}V$	3.8 m	4.8	1452	100
Ti	$^{50}Ti(n,\gamma)^{51}Ti$	5.79	0.007	320	10^4
Al	$^{27}Al(n,\gamma)^{28}Al$	2.3 m	0.24	1779	1.0
I	$^{127}I(n,\gamma)^{128}I$	25 m	6.40	443	10^5
S	$^{36}S(n,\gamma)^{37}S$	5.07 m	.000014	3105	10^6
Mn	$^{55}Mn(n,\gamma)^{56}Mn$	2.56 h	13.3	847	0.05
Br	$^{81}Br(n,\gamma)^{82}Br$	35.3 h	1.58	777	0.1
Na	$^{23}Na(n,\gamma)^{24}Na$	15.0 h	0.53	1368	0.1
K	$^{41}K(n,\gamma)^{42}K$	12.4 h	0.08	1525	10
Rb	$^{85}Rb(n,\gamma)^{86}Rb$	18.7 d	0.72	1079	1
Sm	$^{152}Sm(n,\gamma)^{153}Sm$	46.8 h	56.0	103	10
La	$^{139}La(n,\gamma)^{140}La$	40.2 h	8.9	1597	10
Ga	$^{71}Ga(n,\gamma)^{72}Ga$	14.1 h	2.1	834	100

TABLE 11 (cont'd)

NUCLEAR DATA ON NUCLIDES MEASURED

Element	Nuclear Reaction and Product	Half Life	σ_{th} f[1] (barns)	γ-Rays[2] Measured (keV)	Approx. Detection Limit (ng/g)[3]
Ni	$^{58}Ni(n,p)^{58}Co$	71.3 d	--	811	1000
Cu	$^{63}Cu(n,\gamma)^{64}Cu$	12.8 h	3.1	511	500
Zn	$^{64}Zn(n,\gamma)^{65}Zn$	243 d	0.23	1116	10^4
Fe	$^{58}Fe(n,\gamma)^{59}Fe$	45.6 d	0.003	1292	100
Co	$^{59}Co(n,\gamma)^{60}Co$	5.26 y	37.0	1333	0.1
Cr	$^{50}Cr(n,\gamma)^{51}Cr$	27.8 d	0.73	320	10
Hg	$^{202}Hg(n,\gamma)^{203}Hg$	46.9 d	1.19	279	100
As	$^{75}As(n,\gamma)^{76}As$	26.3 h	5.0	559	10
Sb	$^{123}Sb(n,\gamma)^{124}Sb$	60.3 d	1.41	1691	200
Se	$^{74}Se(n,\gamma)^{75}Se$	120 d	0.26	265	50
Cs	$^{133}Cs(n,\gamma)^{134}Cs$	2.05 y	28.0	797	50
Sc	$^{45}Sc(n,\gamma)^{46}Sc$	83.9 d	13.0	889	1
Tb	$^{159}Tb(n,\gamma)^{160}Tb$	72.1 d	46.0	879	10
Eu	$^{151}Eu(n,\gamma)^{152}Eu$	12.7 y	2820+	1408	1
Ce	$^{140}Ce(n,\gamma)^{141}Ce$	32.5 d	0.53	145	10
Sr	$^{84}Sr(n,\gamma)^{85}Sr$	64.0 d	0.004	514	104
Ba	$^{130}Ba(n,\gamma)^{131}Ba$	12.0 d	0.009	496	10^4

TABLE 11 (cont'd)

NUCLEAR DATA ON NUCLIDES MEASURED

Element	Nuclear Reaction and Product	Half Life	σ_{th} f[1] (barns)	γ-Rays[2] Measured (keV)	Approx. Detection Limit (ng/g)[3]
Th	$^{232}Th(n,\gamma)^{233}Th \rightarrow ^{233}Pa$	27.0 d	7.4	312	100
Hf	$^{180}Hf(n,\gamma)^{181}Hf$	42.5 d	3.52	482	100
Ta	$^{181}Ta(n,\gamma)^{182}Ta$	115.0 d	21.0	1121	10
Zr	$^{94}Zr(n,\gamma)^{95}Zr$	64.0 d	0.014	757	1000

NOTES:

1: σ_{th} f - product of thermal neutron (n,γ) capture cross section (barns) and isotopic fraction of target nuclide. All reactions involved are (n,γ) reactions except the fast-neutron reaction, $^{58}Ni(n,p)^{58}Co$ used to measure Ni

2: Energies in keV taken from Filby et al. (29)

3: Approximate detection limits are given for SRC type matrix. These detection limits are very matrix dependent.

in order to obtain sufficient sensitivity and precision. Irradiation positions in the Washington State University TRIGA reactor core are of limited size (cylinder of 2.5 inch diameter and 10 inches long), which created a problem. Reactor neutron flux variations over small distances was also of concern with large samples. Concentration of samples by either controlled evaporation (for organic solvents), whenever practical, or by vacuum freeze-drying (aqueous samples) was necessary. Aqueous samples (50-100 g) were freeze-dried in thin walled polyethylene bags in a Virtis freeze-dryer and each sample bag and its contents were transferred to a pre-cleaned 2/5 dram polyethylene vial and heat sealed. All 2/5 dram vials were transferred to 2 dram snap-top vials and again heat sealed.

Preparation of organic solvents for irradiation was dependent on irradiation time. For shorter irradiation times (5 to 10 minutes) organic solvents were weighed carefully in a 2/5 dram cleaned polyethylene vial as described for solid samples. For longer irradiation times (8 hours), about 2-3 gm of organic solvent samples were transferred carefully with disposable syringes to specially prepared open quartz vials (approximately 3cc). The quartz vials had been previously soaked in technical grade nitric acid to remove any surface contamination. These quartz vials were prepared in the same manner as described earlier for 2/5 dram polyethylene vials. Each quartz vial containing solvents was carefully inserted into a 2 dram snap-top polyethylene vial and heat sealed. Special precautions were taken to prevent any tipping of the vials containing solvents.

Several elemental standards were used, depending upon the element of interest. These are described in Table 12. All samples with the appropriate standards were irradiated in the Washington State University TRIGA Mark-III fueled research reactor. A thermal neutron flux of approximately 8×10^{12} neutrons cm^{-2} sec^{-1} was used. After irradiation samples and standards were allowed to decay to allow unwanted short-lived nuclides to decay. The decay times depended on the half lives of the nuclides and are shown in Table 10.

2. <u>Gamma-Ray Spectroscopy Procedures</u>

Gamma-ray spectroscopy was used for all radionuclide activity determinations. A typical γ-ray spectrometer system used consisted of a coaxial Ge(Li) detector (Princeton Gamma-Tech; volume, 60 cm^3), Princeton Gamma-Tech Preamplifier (Model RG-11), Tennelec 203 BLR amplifier, Nuclear Data Model 2200-4096 channel analyzer and a Kennedy 3112 7-track magnetic tape unit. The system resolution was 2.9 keV measured at the ^{60}Co 1333 keV line and a peak/Compton ratio 30:1. For short irradiations, the samples and appropriate standards were irradiated for a total integrated neutron flux of 3.6×10^{15} neutrons cm^{-2} on a rotator assembly. The rotator

TABLE 12

ELEMENTAL STANDARDS FOR ACTIVATION ANALYSIS

Type of Standards	Element
Aliquots of multi-element standard solutions dried on high purity BioSil	Ti, V, Al, Cl, I, As, Br, Na, K, La, Ga, Cu, Sb, Se, Ni, Co, Cr, Fe, Rb, Cs, Sc, Tb, Eu, Sr, Ba, and Zn
U.S. Geological Survey Standards - GSP-1, AGV-1, G-2	Sm, Ce, Th, Hf, Ta, and Zr
National Bureau of Standards Orchard Leaves (SRM 1571)	Hg and Mn
Specpure Compounds	Ca and Mg

assembly rotated at the rate of 1 RPM to obtain a homogeneous horizontal neutron distribution flux. After irradiation, the polyethylene vials (2/5 dram) containing samples and standards were immediately transferred to clean 2 dram polyethylene counting vials. For the determination of Ca, Mg, Al, V, and Ti, the samples and standards were counted as soon as possible (decay time varied from 0 to 10 minutes) for 300 seconds on the gamma-ray spectrometer to record 0-4096 keV γ-ray spectra. The γ-ray spectra were stored on IBM compatible 7-track magnetic tape. For the determination of Cl, Mn, and I, the samples and corresponding standards were counted for at least 1000 seconds to collect 0-2048 keV gamma-ray spectra. These spectra were also recorded on 7-track magnetic tape. Typical gamma-ray spectra obtained for coal and SRC are shown in Figures 2 and 3.

For long irradiations, the samples, corresponding standards and Fe standard solutions as flux monitors were mounted on a specially prepared rotator and irradiated to an integrated flux of 2.5 x 10^{17} neutrons cm^{-2}. The samples and standards were rotated about a vertical axis at 1 RPM during irradiation. Samples were allowed to 'cool' for 14 hours so that nuclides with short half life, such as ^{38}Cl, ^{28}Al, etc., decayed. For solid and aqueous samples, the samples and standards in 2/5 dram vials were transferred to new 2-dram counting vials. The irradiated organic solvents required special preparation for counting. Each solvent sample was carefully transferred from the quartz vial to a clean glass petri dish (5 cm diameter). The quartz vials were rinsed with the minimum amount of benzene to remove any remaining sample. Powdered silica was slowly added to the petri dish containing solvent and mixed carefully to form a homogeneous gel. The glass petri dish was sealed and then stored in a refrigerator. Standards were prepared for counting in similar manner except water was used instead of benzene in making the silica gel.

After transferring all samples and standards to appropriate counting vials or dishes, they were counted for approximately 4000 seconds to measure the radionuclides ^{24}Na, ^{42}K, ^{82}Br, ^{153}Sm, ^{64}Cu, ^{72}Ga, ^{76}As, and ^{140}La. The γ-ray spectra were recorded on magnetic tape. After the decay period of not less than 17 days, the samples and standards were counted for 10,000 to 80,000 seconds to measure ^{60}Co, ^{51}Cr, ^{65}Zn, ^{58}Co (for Ni), ^{75}Se, ^{86}Rb, ^{46}Sc, ^{134}Cs, ^{160}Tb, ^{152}Eu, ^{141}Ce, ^{85}Sr, ^{131}Ba, ^{233}Pa (for Th), ^{181}Hf, ^{182}Ta, ^{95}Zr, and ^{203}Hg. For most elements, reduction of gamma-ray spectra and calculation of concentrations was carried out on the W.S.U. IBM 360/67 computer using previously developed computer programs for gamma-ray spectrum analysis.

C. Atomic Absorption Spectrophotometry (AAS)

Atomic absorption spectrophotometry was used to measure Pb, Cd, and Be as these three elements are not easily determined by

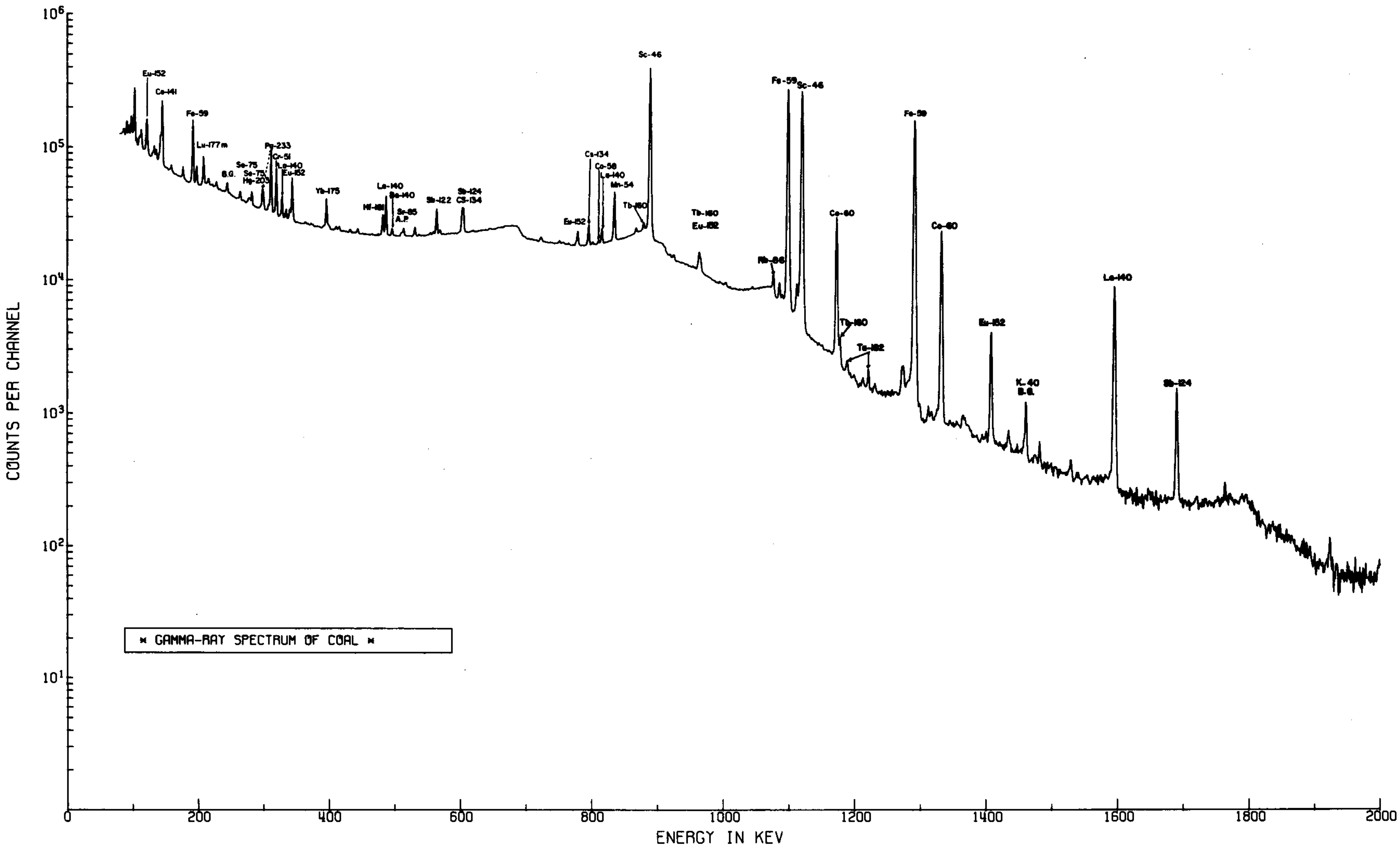

Figure 2: Gamma-Ray Spectrum of Coal

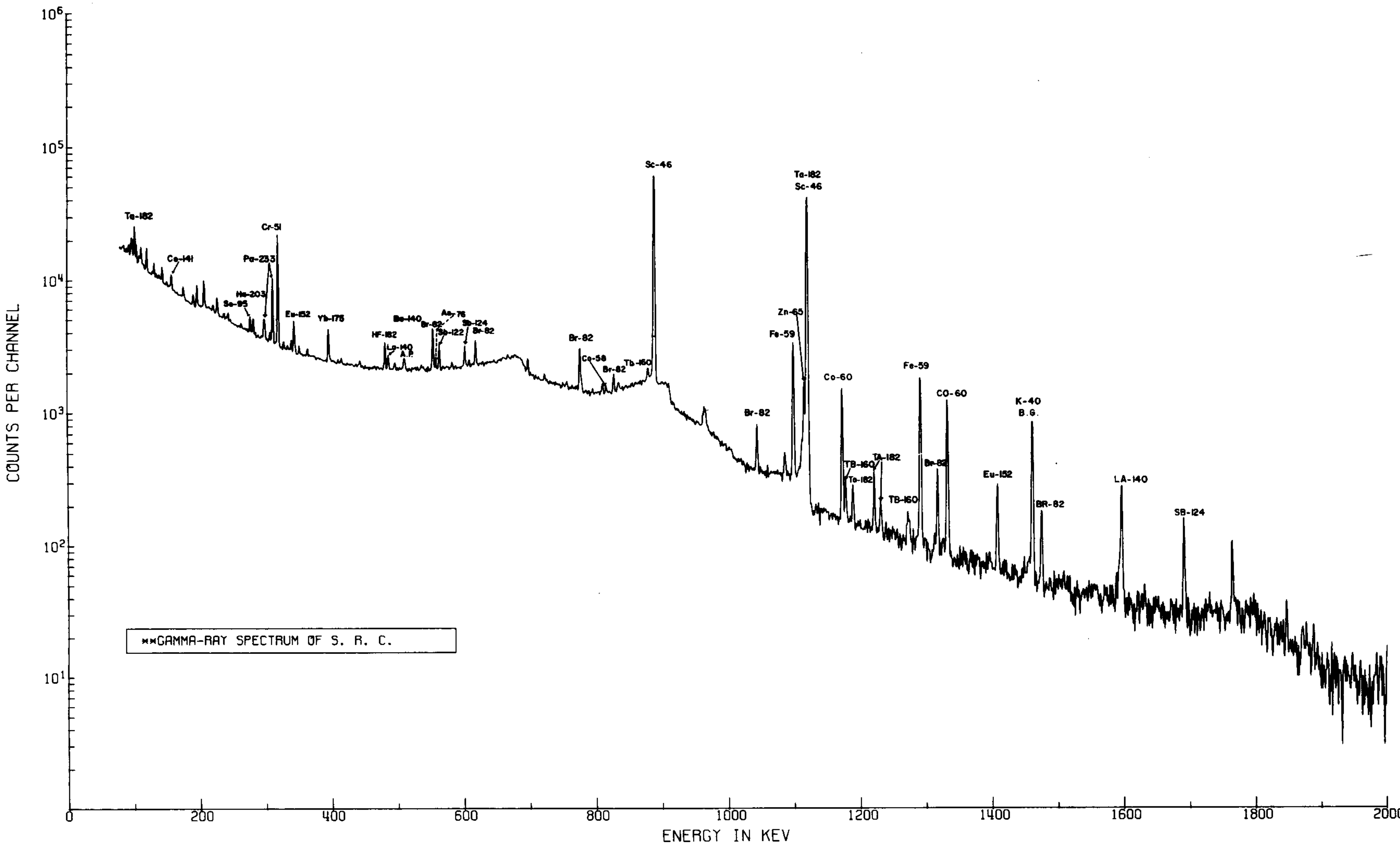

Figure 3: Gamma-Ray Spectrum of SRC

instrumental neutron activation analysis. The atomic absorption spectrometer used in this work was a Varian-Techtron Model AA-5. As AAS is not a multi-element method, the procedure for each element will be described separately. The method used was also dependent on the sample matrix. First, the method used for organic solvents will be discussed.

1. Method for Organic Solvents

Lead was analyzed by modifying the method developed by Bratzel and Chakrabarti (20). The organic solvent sample, (approximately & gms), was weighed into a 25 ml volumetric flask and dissolved in re-distilled xylene which contained 0.1 mg/ml dithizone (Kodak). Three milliliters of the xylene-dithizone solution was transferred to a 50 ml Pyrex screw-cap centrifuge tube. The oil solution was extracted with 3 ml of 40% v/v HNO_3 by shaking for 30 minutes and then centrifuged for 15 minutes. The lower aqueous layer was then withdrawn with a capillary transfer pipette. A blank was prepared by extracting 3 ml of the xylene-dithizone solution with 40% v/v HNO_3.

The Pb content of the oil extract was measured by flameless atomic absorption spectroscopy using a Varian Model AA-5 with a Model M-63 carbon rod atomizer (CRA). Table 13 shows the pertinent instrument settings used in the analysis of Pb, Cd, and Be. Argon was used as the sheathing gas. Three microliters of the extract solution were used for the analysis.

Data were recorded on a Hewlett-Packard strip chart recorder, Moseley Model 7100BM, operated at a speed of 5 cm/min. The dual input Model 17501A allowed for simultaneous recording of the absorbance peak at atomization and the integrated form of the peak. Either or both measurements can be used for analytical work. The results reported in the present study are generally based on the integrated peak mode. Background measurements were made using a hydrogen continuum lamp and corrections were made where necessary.

Because absorbance showed a marked dependence on matrix in the case of Pb, an internal standard was necessary (method of standard additions). The procedure used was as follows: Two milliliters of the 40% v/v - dithizone HNO_3 extract (or a dilution of this extract), the absorbance of which did not exceed 0.2, was pipetted into a 10 ml Erlenmeyer flask. The absorbance was measured by a minimum of three firings of the CRA. If the agreement was poor (deviation greater than 10%), more measurements were made. Next, 25 μl (to minimize the volume correction) of a freshly diluted standard solution of Pb $(NO_3)_2$ (Pb conc. 2.4 μg/ml) sufficient to increase absorbance by about 0.1 was added and the atomization measurements repeated. A second addition of 25 μl of Pb

TABLE 13

INSTRUMENT SETTINGS (AA-5) FOR ORGANIC SOLVENT ANALYSIS

Setting	Pb	Cd	Be
Lamp Current (mA)	7	4	7
Slit Width (μm)	300	300	150
Slit Height (mm)	4	4	4
Special Band Width (nm)	0.99	0.99	0.50
Dry Cycle (Voltage-time)	7 volts-30 sec	7 volts-30 sec	7 volts-30 sec
Ash Cycle (Voltage-time)	8 volts-20 sec	7 volts-20 sec	8 volts-20 sec
Atomize Cycle (Voltage Time)	9 volts-3 sec	9 volts-3 sec	10 volts-3 sec
Wave Length (nm)	217.0	228.8	234.9

standard was made to give a final maximum absorbance of not greater than 0.4. Corrections were made for the volume changes due to removal of solution for AAS and addition of Pb-containing solvent. The Pb content of the original extract was determined by a linear extrapolation of the three points using a procedure designed to reveal any significant deviation of the data from linearity.

When the level of Pb in the extract was below the limit of reliable measurement, only one standard addition (at the 0.2 absorbance level) was used. This standard addition then served to detect (if it should occur) an apparent absence of Pb arising from a severe depression of Pb absorbance (or loss of Pb) due to the oil matrix.

The efficiency of the extraction procedure for the transfer of Pb from oil to an aqueous solution was tested with lead tetraphenyl in xylene solution alone and in the presence of a crude oil and was found to be satisfactory.

The Pb content of dithizone and AR grade HNO_3 was found to be negligible, and the Pb content of xylene and deionized water were reduced to negligible levels by distillation of the solvents. However, Pb contamination from the Pyrex containers was noted, particularly during the extraction step. A cleaning procedure, which included soaking all glassware at least 24 hours in 40% v/v HNO_3, succeeded in reducing this Pb contamination to a relatively low and consistent level but did not remove it completely. The Pb blank for the aqueous extracts was between 6 and 11 ng/ml.

The 40% HNO_3-dithizone extracts of oil samples prepared for Pb measurement were also used for the measurement of Cd. Instrument settings used for these two elements are given in Table 13. Absorbing substances (including dithizone products) cannot be completely removed at the low ashing temperature required to avoid the loss of the volatile element Cd. Thus, background measurements are important in this work. These measurements were performed using a hydrogen continuum lamp. Although measureable quantities of Cd were found in the organic solvents, the use of an internal standard of $CdSO_4$ solution (as described for Pb) helped to assure that Cd, if present in the extract, would be detected by AAS. Calculated detection limits of Cd are based on actual measurements of the standards in the aqueous extracts. As expected, these limits vary from sample to sample but were approximately 4 ppb for Cd, based on the actual sample.

Using the internal standard method (Standard $BeSO_4$ solution), Be was also determined in the previously prepared 40% HNO_3-dithizone extract of the oil samples. Instrument settings for these measurements are given in Table 13. No detectable amount of Be was found in any of the aqueous extracts analyzed. As for Cd and Pb, the external standard method was used to calculate the detection limits for Be. The detection limit for beryllium is approximately 5 ppb for organic solvents and light oils.

2. Method for Aqueous Samples

The procedure followed for the determination of Pb, Cd, and Be in aqueous samples is as follows: the 100 ml frozen water sample was allowed to partially thaw, then was acidified with 2 ml concentrated HNO_3. Flameless atomic absorption measurements using the CRA were taken by adding 3 μl of the sample directly to the graphite tube.

Severe matrix effects were observed for the measurement of Pb and Be in the aqueous sample and the standard addition method was used throughout to attempt to account for this effect. However, since it is known that Pb, Cd, and Be can be "lost" in flameless AAS under certain unfavorable conditions, an investigation was made to ascertain that this did not occur. Further research needs to be carried out on the determination of Pb, Cd, and Be. This effort is continuing.

III. RESULTS AND DISCUSSION

A. Accuracy and Precision of Analysis

The first six months of the contract period were devoted to the development of analytical methods for the determination of trace elements in materials from the SRC I process. These materials have been listed in Tables 6 and 7. The neutron activation analysis procedures previously developed for other materials (17-19) were modified where necessary for use with SRC materials. The principal differences were in sample preparation (see Section II), particularly where applied to light organic solvents and aqueous process streams and effluents.

Naturally, there was concern to obtain accurate and precise analyses of each process stream because of the need to close material balances for the SRC I process. It was, therefore, decided to routinely analyze the National Bureau of Standards (NBS) Standard Reference Materials (SRM's) Coal (SRM 1632), Coal Fly Ash (SRM 1633) and Orchard Leaves (SRM 1571) with each analytical run of SRC samples. For some elements the SRM's were used as primary standards. These elements were those that were difficult to maintain in solution or were difficult to get into solution. These are shown in Table 12. An indication of the accuracy and precision of the analyses made in the project can be obtained from the data obtained in this laboratory on the NBS Coal and Fly Ash SRM's before they were certified. This laboratory, with approximately 40 other laboratories, participated in the round-robin study in which the SRM's were analyzed as unknowns.

The results for many elements presented at an Environmental Protection Agency, National Bureau of Standards conference in Research

Triangle Park, N.C., 1973, show the superiority of activation analysis over other techniques (21). This was further emphasized by comparing the results obtained by NAA by four laboratories with those obtained by other techniques (22,23). Summaries of these results are shown for Coal (SRM 1632) in Table 14, for Fly Ash (SRM 1633) in Table 15, and compared to NBS Certified Values in Table 16. Except for As, the results agree very well with the other laboratories and with NBS values. The data for As resulted from using an erroneous NBS certified value for As in Orchard Leaves (SRM 1571). It can be concluded that the methods used in this study have satisfactory accuracy and precision.

B. Preliminary Studies

After development of the neutron activation analysis procedures, it was decided to apply the techniques to actual SRC process materials and to check the validity of the trace element data for SRC and coal reported by Jahnig and Magee of Exxon (14), since these authors had noted the high concentration of Ti in SRC and the relatively high concentrations of Be, Cu, Co, Ni, Mn, V, and Na. Both feed coal and SRC were analyzed. The SRC was actually a vacuum bottoms sample obtained from the P&M Laboratory, Merriam, Kansas. The results are shown in Table 17. It should be noted that there are wide discrepancies between our results and those of the Exxon study (14), particularly for Mg, V, Sb, Se, Cr and Ni in coal and for Na, As, Se, Ba and Fe in SRC. However, differences in input coal and process conditions between the two sets of samples may be responsible for the discrepancies. Table 18 shows the results of the first set of analyses of the Fort Lewis pilot plant samples. It should be emphasized that these analyses were performed on laboratory work-up samples and no effort was made to obtain truly representative samples since the objective of these experiments was to test the analytical procedures on SRC process samples.

A comprehensive set of samples from the pilot plant taken on January 26 and 28 and March 5, 1975, was received and analyzed by neutron activation analysis. These samples included SRC I, vacuum bottoms (equivalent to SRC), solvents, residues and process waters. Some of these samples were laboratory work-ups and some were obtained directly from pilot plant streams. The detailed analyses of these materials are given in Appendix A. A summary of the results for 22 trace elements in the feed coal, SRC, pyridine insolubles (PI), recycle process solvent (PS), light ends (LE) and process water (PW) is given in Table 19. Although these analyses represent the SRC process adequately, it should be emphasized that they do not represent steady-state operation and the data were used to obtain preliminary information on a full range of SRC I process samples. These data have been recently reported in the literature (1,2).

C. Equilibrium Set Data

It was decided that, in order to obtain information about steady-state operation of the SRC I process, samples should only be

TABLE 14

ELEMENTAL CONCENTRATIONS IN NBS STANDARD COAL (SRM 1632)

		University of Maryland	Battelle Northwest Richland	Lawrence Livermore Laboratory	Washington State University	Average
Na	(ppm)	399 ± 20	420 ± 30	313 ± 22	424 ± 19	414 ± 19
K	(ppm)		0.28 ± 0.01	0.226 ± 0.0076	0.33 ± 0.11	0.28 ± 0.03
Rb	(ppm)	20 ± 2[a]	19 ± 2		23 ± 2	21 ± 2
Cs	(ppm)	1.4 ± 0.1	1.4 ± 0.1			1.4 ± 0.1
Mg	(%)	0.16 ± 0.02	0.23 ± 0.07		0.436 ± 0.053	0.28 ± 0.11
Ca	(%)	0.41 ± 0.05 0.47 ± 0.06[a]		0.422 ± 0.067		0.43 ± 0.05
Ba	(ppm)	330 ± 20	390 ± 20	327 ± 19	366 ± 35	353 ± 25
Sr	(ppm)		170 ± 10		142 ± 20	156 ± 14
Cl	(ppm)	970 ± 140	800 ± 200	758 ± 62	1020 ± 90	890 ± 110
Br	(ppm)	20 ± 4	17 ± 2	18.6 ± 2.4	21.4 ± 0.7	19.3 ± 1.6
Al	(%)	1.78 ± 0.18	1.78 ± 0.08	2.00 ± 0.11		1.85 ± 0.10
Sc	(ppm)	3.7 ± 0.15	3.4 ± 0.3	3.94 ± 0.19	3.98 ± 0.38	3.8 ± 0.2
Ti	(%)	0.096 ± 0.01 0.089 ± 0.02[a]	0.111 ± 0.02	0.106 ± 0.012	0.114 ± 0.006	0.107 ± 0.006
V	(ppm)	37.0 ± 3.3	33.0 ± 4	38.3 ± 3.3	40 ± 5	37.1 ± 3.3
Cr	(ppm)	19.7 ± 0.8	19 ± 2	19.3 ± 0.97	21.4 ± 2	19.8 ± 0.8
Mn	(ppm)	41 ± 1.6	41 ± 6	47.6 ± 3.4		43 ± 3
Fe	(%)	0.86 ± 0.06	0.81 ± 0.07	0.818 ± 0.037	0.892 ± 0.004	0.85 ± 0.03
Co	(ppm)	5.6 ± 0.2	5.2 ± 0.4	6.04 ± 0.29	6.1 ± 0.4	5.7 ± 0.3
Ni	(ppm)		16 ± 4		21 ± 3	18 ± 3

TABLE 14 (cont'd)

ELEMENTAL CONCENTRATIONS IN NBS STANDARD COAL (SRM 1632)

		University of Maryland	Battelle Northwest Richland	Lawrence Livermore Laboratory	Washington State University	Average
Zn	(ppm)	30 ± 10				30 ± 10
Ag	(ppm)		0.06 ± 0.03			0.06 ± 0.03
As	(ppm)	5.7 ± 0.02 8 ± 2[a]	5.7 ± 0.5	5.04 ± 0.66	11.2 ± 0.36	5.5 ± 0.4
Se	(ppm)	3.1 ± 0.3	3.3 ± 0.4	3.53 ± 0.42	3.66 ± 0.40	3.4 ± 0.2
Sb	(ppm)	4.3 ± 3.0	3.7 ± 2.0	4.1 ± 5.3	3.2 ± 1.3	3.8 ± 1.3
In	(ppm)			0.196 ± 0.12		0.196 ± 0.12
Hf	(ppm)	0.95 ± 0.05	0.97 ± 0.1	0.724 ± 0.06	0.74 ± 0.08	0.85 ± 0.12
Ta	(ppm)	0.21 ± 0.02	0.23 ± 0.05		0.33 ± 0.05	0.22 ± 0.02
W	(ppm)			0.62 ± 0.27		0.62 ± 0.27
La	(ppm)	11.3 ± 0.5	10.5 ± 0.5	9.1 ± 0.38	11.9 ± 0.5	10.7 ± 0.5
Ce	(ppm)	20.4 ± 0.8		18.5 ± 0.65		19.5 ± 1
Sm	(ppm)	1.83 ± 0.07	1.7 ± 0.3	1.48 ± 0.07		1.7 ± 0.1
Eu	(ppm)	0.38 ± 0.03	0.28 ± 0.01	0.321 ± 0.011	0.33 ± 0.04	0.31 ± 0.02
Tb	(ppm)	0.22 ± 0.05	0.23 ± 0.06			0.23 ± 0.05
Lu	(ppm)	0.14 ± 0.01				0.14 ± 0.01
Yb	(ppm)	0.7 ± 0.1				0.7 ± 0.1
Th	(ppm)	3.0 ± 0.21	3.4 ± 0.6 3.45 0.10[b]	2.97 ± 0.17	3.3 ± 0.2	3.2 ± 0.2
U	(ppm)	1.41 ± 0.07[b]				1.41 ± 0.07

[a] Determined by instrumental photon activation analysis

[b] Determined by direct γ-ray counting of natural radioactivity

TABLE 15
ELEMENTAL CONCENTRATIONS IN NBS STANDARD FLY ASH (SRM 1633)

		University of Maryland	Battelle Northwest Richland	Lawrence Livermore Laboratory	Washington State University	Average
Na	(%)	0.34 ± 0.02	0.37 ± 0.02	0.280 ± 0.021	0.297 ± 0.005	0.32 ± 0.03
K	(%)		1.71 ± 0.03	1.384 ± 0.064	1.73 ± 0.08	1.72 ± 0.03
Rb	(ppm)	126 ± 10[a]	124 ± 10		125 ± 15	125 ± 10
Cs	(ppm)	7.9 ± 0.9	9.9 ± 0.8			8.9 ± 1.0
Mg	(%)	1.50 ± 0.16	2.08 ± 0.43		3.26 ± 0.21	1.8 ± 0.3
Ca	(%)	4.2 ± 0.4[a] 5.3 ± 0.5[a]		4.48 ± 0.26		4.7 ± 0.6
Ba	(%)	0.27 ± 0.02 0.26 ± 0.02	0.34 ± 0.04	0.261 ± 0.017	0.293 ± 0.044	0.27 ± 0.02
Sr	(%)		0.19 ± 0.02		0.140 ± 0.009	0.17 ± 0.03
Cl	(ppm)	42 ± 10	<500			42 ± 10
Br	(ppm)		12 ± 4			12 ± 4
I	(ppm)	2.9 ± 1.2[a]				2.9 ± 1.2[a]
Al	(%)	13.2 ± 0.5	12.6 ± 0.4	12.3 ± 0.63		12.7 ± 0.4
Si	(%)	21 ± 2[a]				21 ± 2[a]
Sc	(ppm)	27 ± 1.1	27 ± 1	28.0 ± 1.7	27.1 ± 1.3	27.3 ±1.0
Ti	(%)	0.73 ± 0.04 0.73 ± 0.04[a]	0.76 ± 0.08	0.722 ± 0.067	0.755 ± 0.025	0.74 ± 0.03
V	(ppm)	251 ± 26	220 ± 15	244 ± 24	223.6 ± 12.3	235 ± 15
Cr	(ppm)	130 ± 6	131 ± 8	126 ± 10	126.2 ± 4.5	128 ± 5
Mn	(ppm)	509 ± 20	489 ± 11	506 ± 23	480 ± 12	496 ± 12
Fe	(%)	6.2 ± 0.3	6.51 ± 0.31	5.80 ± 0.30	6.51 ± 0.53	6.25 ± 0.3
Co	(ppm)	41.2 ± 1.6	40 ± 2	42 ± 1.9	43.8 ± 1.3	41.8 ± 1.3
Ni	(ppm)	92 ± 6[a]				92 ± 6

[a]Determined by instrumental photon activation analysis

[b]Determined by direct γ-ray counting of natural radioactivity

TABLE 15 (cont'd)

ELEMENTAL CONCENTRATIONS IN NBS STANDARD FLY ASH (SRM 1633)

	University of Maryland	Battelle Northwest Richland	Lawrence Livermore Laboratory	Washington State University	Average
Zn (ppm)	216 ± 25[a]				216 ± 25
As (ppm)	59.6 ± 2.4[a] 61.5 ± 3.0[a]	61 ± 5	51.7 ± 3.3	78.7 ± 4.3	60.7 ± 2.4
Se (ppm)	10.3 ± 1.4	8.8 ± 1.2	11.5 ± 1.4		10.2 ± 1.3
Zr (ppm)	301 ± 20[a]				301 ± 20
Sb (ppm)	7.8 ± 0.7 7.0 ± 1.1[a]	7.2 ± 0.8	6.38 ± 0.41	6.3 ± 0.4	6.9 ± 0.5
In (ppm)			0.321 ± 0.100		0.32 ± 0.10
Hf (ppm)	7.9 ± 0.4	8.2 ± 0.8	5.79 ± 0.38	5.9 ± 0.5	7.0 ± 1.1
Ta (ppm)	1.64 ± 0.13	1.72 ± 0.3		2.5 ± 0.9	1.67 ± 0.13
Pb (ppm)	75 ± 5[a]				75 ± 5
W (ppm)			3.5 ± 1.1		3.5 ± 1.1
Y (ppm)	62 ± 10[a]				62 ± 10
La (ppm)	82 ± 3	82 ± 4	65.0 ± 6.6	82 ± 2	82 ± 2
Ce (ppm)	156 ± 12		135 ± 7		146 ± 10
Sm (ppm)	13.8 ± 0.6	12.4 ± 0.5	11.1 ± 0.7		12.4 ± 0.9
Eu (ppm)	2.9 ± 0.2	2.3 ± 0.1	2.22 ± 0.20		2.3 ± 0.1
Tb (ppm)	1.7 ± 0.25	2.0 ± 0.3			1.9 ± 0.3
Lu (ppm)	1.01 ± 0.10				1.01 ± 0.10
Yb (ppm)	5.1 ± 0.8	8.9 ± 0.9			7 ± 2
Th (ppm)	23.5 ± 1.0	28 ± 2 26.2 ± 1.3[b]	23.3 ± 1.3	25.8 ± 1.4	25.4 ± 1.5
U (ppm)		12.0 ± 0.5[b]			12.0 ± 0.5

TABLE 16

COMPARISON OF NBS VALUES WITH 4-LABORATORY AVERAGE FOR COAL AND FLY ASH

SRM 1632 COAL			SRM 1633 FLY ASH		
Element	4-Laboratory Average	NBS Values	Element	4-Laboratory Average	NBS Values
Ti (%)	0.107 ± 0.006	0.08*	K (%)	1.72 ± 0.03	1.72*
V (ppm)	37.1 ± 3.3	35 ± 3	Rb (ppm)	125 ± 10	112*
Cr (ppm)	19.8 ± 0.8	20.5 ± 0.5	Sr (%)	0.17 ± 0.03	0.138*
Mn (ppm)	43 ± 3	40 ± 3	V (ppm)	235 ± 15	214 ± 8
Fe (%)	0.85 ± 0.03	0.87 ± 0.30	Cr (ppm)	128 ± 5	131 ± 2
Co (ppm)	5.7 ± 0.3	6*	Mn (ppm)	496 ± 12	493 ± 7
Ni (ppm)	18 ± 3	15 ± 1	Co (ppm)	41.8 ± 1.3	38*
Zn (ppm)	30 ± 10	37 ± 4	Ni (ppm)	92 ± 6	98 ± 3
As (ppm)	5.5 ± 0.4	5.9 ± 0.6	Zn (ppm)	216 ± 25	210 ± 20
Se (ppm)	3.4 ± 0.2	2.9 ± 0.3	As (ppm)	60.7 ± 2.4	61 ± 6
U (ppm)	1.41 ± 0.07	1.4 ± 0.1	Se (ppm)	10.2 ± 1.3	9.4 ± 0.5
			Th (ppm)	25.4 ± 1.5	24*
			U (ppm)	12.0 ± 0.5	11.6 ± 0.2

* Non-certified NBS values

TABLE 17

COMPARISON OF EXXON SRC DATA WITH W.S.U. DATA FOR SRC I MATERIALS

Element	Pyridine Insolubles	Coal (This Study)	Coal (Exxon)	Vacuum Bottoms (W.S.U.)	SRC (Exxon)
Ti (ppm)		388,415	460		74, 300
Mn (ppm)		30.2 - 31.2	39	2.8 - 3.2	1, 3
Mg (ppm)		1980	550	<10	
Cl (ppm)		388, 403, 393		36 - 42	
Na (ppm)		108, 131, 135	166	6.2 - 9.4	25, 45
Ca (%)		0.43	0.34	0.016, 0.019	0.007, 0.018
S (%)		3.3		1.1, 1.2%	
K (%)		0.09. 0.11	0.13. 0.18	< 0.005	0.0005, 0.0017
V (ppm)		16	175		
La (ppm)	11, 12. 13	2.5, 2.6, 2.7		0.052. 0.093. 0.17	
Sb (ppm)	1.6, 1.6	0.5, 0.6	11	0.058, 0.62, 0.091	0.25, 0.30
As (ppm)		22,32	19	6.0, 6.9	0.5, 1.4
Br (ppm)	2.6, 4.5, 4.7	3.3 - 4.2	7.2	4.8 - 5.1	3.8, 3.9

NOTES: More than one concentration represents either different gamma rays used or independent values.
Materials analyzed were obtained from Pittsburg & Midway Coal Mining Co., Merriam, KS.

TABLE 17 (cont'd)

COMPARISON OF EXXON SRC DATA WITH W.S.U. DATA FOR SRC I MATERIALS

		Vacuum Bottoms (WSU)	SRC (Exxon)	Coal (WSU)	Coal (Exxon)	Filter Cake (WSU)	Pyridine Insolubles Ash (WSU)	Pyridine Insolubles (WSU)
Ce	(ppm)	0.32		11		26	112	74
Se	(ppm)	0.22	2.0	2.8	7	6.3	1.8	13.6
Th	(ppm)	0.22		1.3		2.8	18	6.6
Cr	(ppm)	1.3	1.3	12.8	31, 38	30		73
Hf	(ppm)	0.08		0.47		1.0	5.1	2.3
Ba	(ppm)	2.4	0.2, 0.5	28	50	89	240	161
Sr	(ppm)	5.0	0.5	24	20	43	165	100
Zr	(ppm)	7.0	5.4, 2.0	54	6.3, 35	99	366	210
Cs	(ppm)			0.49		1.2	4.7	2.6
Ni	(ppm)	1.9	4.0, 2.5	6.8	29	8.9	46	15
Tb	(ppm)	0.02		0.16				1.2
Sc	(ppm)	0.30		1.7		3.4	16	7.7
Rb	(ppm)			15		43	130	84
Fe	(%)	0.0043	0.0098, 0.016	1.3	2.4	3.1	12.4	7.1
Ta	(ppm)	0.05		0.16		0.27	0.85	0.57
Co	(ppm)	0.26	0.23, 0.35	9.6	17, 6.0	23	90	51
Eu	(ppm)	0.015		0.14		0.31	1.2	0.65

TABLE 18

ELEMENTAL CONCENTRATIONS IN PRELIMINARY SRC MATERIALS
(PILOT PLANT MATERIALS - NON-EQUILIBRIUM CONDITIONS)

	Vacuum Bottoms	Coal	Filter Cake	Ash	Pyridine Insolubles
Br (ppm)	6.6	7.0	10.0		11
As (ppm)	0.7	12	23	70	55
Na (ppm)	5.8	230	673	2200	1400
K (%)	<0.0001	0.19	0.67	2.4	1.5
La (ppm)	0.10	9	27	93	58
Ce (ppm)	0.48	23	53	201	118
Lu (ppm)	0.04	0.25	0.55	1.9	1.3
Se (ppm)	0.12	2.8	7.4		14
Th (ppm)	0.32	1.9	4.9	19	11
Cr (ppm)	2.6	44	84	310	177
Hf (ppm)	0.10	0.50	1.2	5.0	2.7
Ba (ppm)	9.0	77	186	578	455
Sr (ppm)		198	353	1100	833
Zr (ppm)	7.5	53	139	348	267
Cs (ppm)		1.2	3.8	12.5	8.0
Ni (ppm)	1.4	30	54	202	84
Tb (ppm)	0.06	0.52	1.2		0.48
Sc (ppm)	0.68	3.1	7.2	23	14
Rb (ppm)		24	79	240	157
Fe (%)	0.0066	3.3	7.3	24.7	1.6
Ta (ppm)	0.05	0.15	0.3	1.3	0.80
Co (ppm)	0.46	6.9	18	63	39
Eu (ppm)	0.04	0.43	1.0	3.6	2.3

TABLE 19

ELEMENTAL CONCENTRATION DATA FOR NON-EQUILIBRIUM RUN FROM SRC PILOT PLANT*

Element	Process Fraction**						
	Coal	SRC	FC	PI	PS	LE	PW
As(ppm)	13.6	1.39	33.3	52.0	0.13	0.005	0.008
Sb(ppm)	0.50	0.074	1.3	2.9	0.011	<0.01	<0.01
Se(ppm)	1.53	0.148	8.1	20.0	0.044	0.16	0.19
Hg(ppm)	0.436	0.025	0.447	1.50	0.010	0.012	0.053
Br(ppm)	3.51	3.95	6.22	7.67	0.75	0.018	0.044
Ni(ppm)	20.0	2.7	51.5	156	0.42	<0.1	<0.1
Co(ppm)	3.7	0.31	12.8	22.7	0.031	0.035	0.012
Cr(ppm)	14.0	2.68	56.4	122	3.67	0.053	<0.1
Fe(%)	1.73	0.068	5.70	12.0	0.0022	0.0001	ND
Na(ppm)	148	9.55	473	865	0.405	0.63	11.5
K (ppm)	1500	40	4800	11000	3.49	<1.0	4.57
Rb(ppm)	22.4	0.57	74.7	175	0.196	<0.1	<0.1
Cs(ppm)	0.89	0.023	2.74	6.26	0.003	0.002	0.002
Sc(ppm)	2.8	0.13	7.8	18.1	0.005	<0.001	<.001
Tb(ppm)	0.437	0.014	0.992	2.46	0.001	-	-
Eu(ppm)	0.292	0.013	1.10	2.47	0.006	0.009	0.005
Sm(ppm)	1.37	0.040	4.53	10.2	0.004	<.001	<.001
Ce(ppm)	17.0	0.553	59.0	140	-	-	-
Lu(ppm)	0.125	0.004	0.416	0.832	-	-	-
Sr(ppm)	152	4.4	348	789	-	-	-
Ba(ppm)	62.6	2.48	169	349	-	-	-
Th(ppm)	1.66	0.055	5.31	11.8	0.004	-	-

Note: *Error terms are not given in order to reduce space. Data from Reference (2).

**Abbreviations:

SRC: Solvent Refined Coal
FC: Filter Cake
PI: Pyridine insolubles
PS: Recycled process solvent
LE: Light ends
PW: Process water

collected after the pilot plant had operated continuously for at least seven days and that composite samples over a 24-hour period should be collected.

Optimum conditions for sample collection were attained on March 1, 1976, and 24 samples were collected for a 24-hour period. The samples collected are referred to in this report as Equilibrium Set 1. A second set of 23 samples was taken for a 24-hour period on May 3, 1976, and is hereby referred to as Equilibrium Set 2. The elements determined by neutron activation analysis were: Ti, V, Ca, Mg, Al, Cl, Mn, As, Sb, Se, Hg, Br, Ni, Co, Fe, Cr, Na, Rb, Cs, K, Sc, Tb, Eu, Sm, Ce, La, Sr, Ba, Th, Hf, Ta, Ga, Zr, and Cu; whereas, Pb, Cd and Be were determined in solvents and aqueous phases by atomic absorption spectroscopy. This gives a total of 37 elements. The sample descriptions and the analytical data are shown in Appendix B for Equilibrium Set 1 and in Appendix C for Equilibrium Set 2. The pilot plant run conditions are shown in Tables 8 and 9 in the Analytical Methodology section (Section II). The error terms listed for each determination made by neutron activation analysis are those obtained from the counting statistics of the measurement and are standard deviations for a single measurement. The larger errors (over 20% relative standard deviation) are those associated with measurements close to the detection limit for the measurements. Less-than values were computed for some elements and do not represent the actual sensitivities of the method for the elements in question but are often the result of high background in the region of the gamma-ray peak used for the determination. Summaries of the data are given in Tables 20 and 21.

D. Trace Elements in Solvent Refined Coal (SRC)

Table 22 compares trace element levels in the feed coal and the corresponding solvent refined coal (SRC) to indicate the decrease in trace element levels in SRC, resulting primarily from the removal of mineral matter from the coal during the liquefaction process. Data for both equilibrium sets are shown. Table 23 shows the ratio of each trace element in SRC relative to feed coal (SRC/coal) and the percentage reduction in SRC compared to the coal. All elements, except Br, show a reduction when SRC is compared to coal. In both equilibrium sets there is an increase in Br relative to the feed coal, and this has been true for the preliminary runs previously discussed. The reason for the increase is not clear. The relatively large increases (70% for Equilibrium Set 1 and 73% for Set 2) rule out a simple concentration effect due to removal of mineral matter, assuming that all the Br in the original coal is organically bound and remains so in SRC. The relatively low concentrations of Br in the process solvents (1.0 ppm and 0.75 ppm for Sets 1 and 2, respectively) also indicate that this not a source of Br in the process. Further work is obviously needed to determine the behavior of Br in the SRC I process.

Another exceptional element is Ti. In both equilibrium sets, the Ti contents of the SRC are only marginally lower than in the feed

TABLE 20

SUMMARY OF TRACE ELEMENT DATA IN SRC I STREAMS
(EQUILIBRIUM SET 1)

Element	GC	SRC	PI	WFC	LO	PRS	WS	S	PW	EW
Ti (ppm)	530	465	3350	1490	2.04	19.1	0.92	<90.0	<0.2	<0.1
V (ppm)	30.1	4.63	195	141	0.050	0.445	0.052	8.2	<0.002	0.02
Ca (ppm)	330	72.8	6300	3020	<10	<10	<5	<600.0	<1.0	4.4
Mg (ppm)	1160	89.0	4000	4350	<10	<10	<7	<300.0	<2	1.9
Mn (ppm)	34.0	20.3	185	140	0.18	2.09	0.2	8.0	0.02	0.01
Al (%)	1.18	0.02	7.72	5.5	50**	43.9**	11.6**	<6**	0.54**	0.25**
Cl (ppm)	260	160	760	1640	16.9	127	92.2	<40.0	32.4	1.7
As (ppm)	12.5	2.00	85.7	62.1	0.011	0.24	0.011	<2.0	0.006	<0.001
Sb (ppm)	0.76	0.06	7.21	5.35	<0.4*	8.2*	<0.4*	<0.1	0.66*	2.0*
Se (ppm)	2.0	0.12	16.5	11.3	0.052	0.024	0.014	<1.5	0.16	0.0012
Hg (ppb)	113	39.6	508	346	18.5	1.45	10.5	<100	106	3.2
Br (ppm)	4.56	7.74	12.0	20.7	0.015	1.0	0.02	<3.0	15.6 *	31.8 *
Ni (ppm)	14.9	<3.0	142	82.4	<0.03	0.4	<0.03	<28.0	<0.004	0.013
Co (ppm)	5.88	0.22	40.7	26.5	<3.0*	40.7*	1.43*	110	0.2*	0.41*
Cr (ppm)	13.7	1.64	106	69.2	0.037	3.59	0.041	<2.0	0.007	0.15
Fe (%)	2.11	0.03	16.8	11.7	2.90**	211**	11.2**	<0.1	0.30**	1.25**
Na (ppm)	137	4.23	1020	623	0.60	0.50	0.45	3120	0.70	8.3

TABLE 20 (cont'd)

SUMMARY OF TRACE ELEMENT DATA IN SRC I STREAMS
(EQUILIBRIUM SET 1)

Element	GC	SRC	PI	WFC	LO	PRS	WS	S	PW	EW
Rb (ppm)	<4.0	<0.5	66.5	37.1	<0.01	0.02	<0.01	<9.0	0.78*	0.52*
Cs (ppm)	0.75	0.02	5.08	3.20	1.06*	<1.2*	0.91*	<0.2	0.04*	0.02*
K (ppm)	1550	4.72	11100	6660	<0.1	0.25	<0.1	179	0.2	1.26
Sc (ppm)	2.59	0.57	14.8	9.26	0.15*	32.8*	0.19*	<0.02	0.13*	0.01*
Tb (ppm)	0.39	0.045	2.06	1.34	<0.13*	3.75*	<0.13*	<0.1	0.01*	0.01*
Eu (ppm)	0.26	0.055	1.48	0.96	<0.01	<0.01	<0.01	<0.01	0.01*	0.01*
Sm (ppm)	2.62	0.29	16.9	8.16	<0.01	0.02	<0.01	0.61	0.08*	<0.06*
Ce (ppm)	20.9	0.45	156.0	102	<0.004	<0.004	<0.003	<2.0	<0.2*	<0.2*
La (ppm)	7.55	0.13	59.8	35.2	<0.01	0.01	<0.01	1.80	0.27*	0.5*
Sr (ppm)	88.6	<6.0	456.0	453	<0.6	<0.2	0.74	<45.0	<0.01	<0.04
Ba (ppm)	53.0	5.75	347.0	185.0	<0.1	1.14	<0.07	<39.0	<0.02	<0.04
Th (ppm)	2.00	0.22	12.8	7.70	<0.001	0.012	<0.001	<0.2	0.05*	<0.01*
Hf (ppm)	0.51	0.084	3.30	2.20	<0.001	0.003	<0.001	<0.2	0.02*	<0.01*
Ta (ppm)	0.14	0.046	0.71	0.42	<0.4*	2.53*	<0.3*	<0.2	0.02*	0.01*
Ga (ppm)	3.56	1.79	19.4	11.3	<0.01	0.06	<0.01	<1.5	<1*	<4*
Zr (ppm)	62.9	16.0	500.0	246	0.07	0.71	<0.1	<61.0	0.02	0.04
Cu (ppm)	19.9	2.07	189	138	0.03	0.68	0.03	<1.0	<12*	<10*

NOTES: *Values in ppb
**Values in ppm

GC - Ground Coal
WFC - Wet Filter Cake
PRS - Process Recycle Solvent
PW - Process Water
PI - Pyridine Insolubles
LO - Light Oil
WS - Wash Solvent
S - Sulfur
EW - Effluent Water

TABLE 21

SUMMARY OF TRACE ELEMENT DATA IN SRC I STREAMS
(EQUILIBRIUM SET 2)

Element	GC	SRC	PI	WFC	LO	PRS	WS	PW	EW
Ti(ppm)	660†	490	4480	<1500	2.50	15.0	1.8	<0.3	<0.2
V (ppm)	29.2†	13.7	226	103	0.44	0.80	0.32	<0.001	0.009
Ca(ppm)	660†	123	10200	10300	<12	9.7	<6	<10	9.6
Mg(ppm)	<2400	96.0	5290	4550	10.5	<8	7.2	<17	4.2
Mn(ppm)	35.7	14.2	219	147	<0.1	1.27	0.16	0.04	0.03
Al(%)	1.58	0.042	6.84	2.84	74**	41.6**	56.4**	0.40**	0.25**
Cl(ppm)	289	99.0	668	147	300	38.9	115	17.0	3.70
As(ppm)	20.1	2.27	388	3.24	2.85*	243*	68.6*	10.7*	<5*
Sb(ppm)	1.43	0.06	9.05	6.38	1.86*	9.20*	--	1.0*	0.66*
Se(ppm)	3.03	0.080	14.1	8.64	0.023	0.036	0.012	914*	0.37*
Hg(ppb)	114	46.7	497	33.8	3.40	<1	10.2	20.7	5.5
Br(ppm)	3.72	4.93	10.1	12.3	0.018	0.752	0.048	18.3*	<10*
Ni(ppm)	12.4	<2	170	142	0.04	0.22	<0.04	14.0*	10.0*
Co(ppm)	5.20	0.25	32.2	24.4	1.8*	37.6*	1.20*	0.43*	0.36*
Cr(ppm)	14.8	5.50	200	141	<5*	2.42	0.018	11.3*	10.1*
Fe(%)	2.38	0.026	13.7	9.37	0.30**	57.5**	7.0**	1.34**	0.41**
Na(ppm)	173	6.30	1040	710	0.04	1.18	0.33	5.10	<10

TABLE 21 (cont'd)

SUMMARY OF TRACE ELEMENT DATA IN SRC I STREAMS
(EQUILIBRIUM SET 2)

Element	GC	SRC	PI	WFC	LO	PRS	WS	PW	EW
Rb(ppm)	11.8	0.21	76.7	54.1	<0.01	<0.02	<0.01	0.77*	1.36*
Cs(ppm)	0.91	<0.2	4.93	3.34	0.84*	1.53*	1.02*	0.04*	0.06*
K (ppm)	2030	2.27	11200	7600	0.20	<0.5	0.22	0.73	<1
Sc(ppm)	2.48	0.36	18.5	12.3	0.13*	24.5*	0.10*	0.12*	0.12*
Tb(ppm)	0.32	0.030	2.41	1.64	<0.1*	1.7*	<0.2*	<0.01*	<0.01*
Eu(ppm)	0.20	0.027	1.06	0.77	<0.001	<0.001	<0.001	0.012*	0.015*
Sm(ppm)	1.65	0.117	10.4	7.47	<0.01*	10.1*	0.15*	<0.1*	<0.1*
Ce(ppm)	20.8	0.36	131	94.6	<0.005	0.03	<0.004	<0.2*	6.5*
La(ppm)	6.56	0.09	37.4	25.9	<0.001*	9.30*	<0.001*	<0.7*	<0.01*
Sr(ppm)	158	<4	<74	271	<0.1	<0.2	<0.1	<0.02	<0.01
Ba(ppm)	62.5	<2	409	390	<0.1	0.18	<0.1	<0.02	<0.01
Th(ppm)	1.90	0.19	12.6	9.30	<0.001	0.015	<0.001	<0.04*	0.09*
Hf(ppm)	0.59	0.069	4.32	3.0	<0.001	0.004	<0.001	0.04*	0.02*
Ta(ppm)	0.17	0.05	1.07	0.81	<0.5*	3.20*	<0.4*	0.02*	<0.2*
Ga(ppm)	3.26	<1.5	13.1	10.3	<0.1*	34.3*	<0.1*	<0.004	<0.004
Zr(ppm)	79.0	6.4	422	373	<0.1	0.34	<0.1	0.02	0.02
Cu(ppm)	14.3	1.15	93.0	93.7	0.02	0.23	0.02	0.24	0.025

*Values in ppb
**Values in ppm
† Values for raw coal

GC - Ground Coal
WFC - Wet Filter Cake
PRS - Process Recycle Solvent
PW - Process Water
PI - Pyridine Insolubles
LO - Light Oil
WS - Wash Solvent
S - Sulfur
EW - Effluent Water

TABLE 22

COMPARISON OF TRACE ELEMENTS IN INPUT COAL AND SRC I

		Equilibrium Set 1		Equilibrium Set 2	
		Coal	SRC	Coal	SRC
Ti	(ppm)	530	465	660*	490
V	(ppm)	30.1	4.63	29.2*	13.7
Ca	(ppm)	633*	72.8	660*	123
Mg	(ppm)	1160	89	ND	96.0
Al	(%)	1.18	0.02	1.58	0.042
Cl	(ppm)	260	160	290	99
Mn	(ppm)	34.0	20.3	35.7	14.2
As	(ppm)	12.5	2.00	20.1	2.27
Sb	(ppm)	0.76	0.060	1.43	0.06
Se	(ppm)	2.00	0.12	3.03	0.08
Hg	(ppb)	113	39.6	114	46.7
Br	(ppm)	4.56	7.74	3.72	4.93
Ni	(ppm)	14.9	<3.0	12.4	<2.0
Co	(ppm)	5.88	0.22	5.20	0.25
Cr	(ppm)	13.7	1.64	14.8	5.50
Fe	(%)	2.11	0.030	2.38	0.026
Na	(ppm)	137	4.23	173	6.30
Rb	(ppm)	3.57*	<0.5	11.8	0.21**
Cs	(ppm)	0.75	0.02	0.91	<0.2
K	(ppm)	1550	4.72	2030	2.27
Sc	(ppm)	2.59	0.57	2.48	0.36

TABLE 22 (cont'd)

COMPARISON OF TRACE ELEMENTS IN INPUT COAL AND SRC I

	Equilibrium Set 1		Equilibrium Set 2	
	Coal	SRC	Coal	SRC
Tb (ppm)	0.39	0.045	0.32	0.03
Eu (ppm)	0.26	0.055	0.20	0.027
Sm (ppm)	2.62	0.29	1.65	0.117
Ce (ppm)	20.9	0.45	20.9	0.34
La (ppm)	7.55	0.13	6.56	0.09
Sr (ppm)	88.6	<5	158	<6
Ba (ppm)	53.0	5.75	62.5	<2
Th (ppm)	2.00	0.22	1.90	0.19
Hf (ppm)	0.51	0.084	0.59	0.069
Ta (ppm)	0.14	0.046	0.17	0.05
Ga (ppm)	3.56	1.79	3.26	0.61**
Zr (ppm)	62.9	16.0	79.0	6.4
Cu (ppm)	19.9	2.07	14.3	1.15

* Value for raw coal
** Value for Vacuum Bottoms
ND = not determined

TABLE 23

TRACE ELEMENT REDUCTION IN SRC COMPARED TO COAL

Equilibrium Set No. 1			Equilibrium Set No. 2		
Element	SRC/Coal	% Reduction	Element	SRC/Coal	% Reduction
Ti	0.88	12	Ti	0.74	16
V	0.15	85	V	0.47	53
Ca	0.22	78	Ca	0.22	78
Mg	0.08	92	Mg		
Al	0.02	98	Al	0.03	97
Cl	0.61	39	Cl	0.34	66
Mn	0.60	40	Mn	0.40	60
As	0.16	84	As	0.07	93
Sb	0.08	92	Sb	0.04	96
Se	0.06	94	Se	0.03	97
Hg	0.35	65	Hg	0.41	59
Br	1.70	+70	Br	1.33	+33
Ba	0.11	89	Ba		
Th	0.11	89	Th	0.10	90
Hf	0.16	84	Hf	0.12	88
Ta	0.39	61	Ta	0.29	71
Ga	0.50	50	Ga	0.19	81
Zr	0.25	75	Zr	0.08	92
Cu	0.10	90	Cu	0.08	92
Na	0.03	97	Na	0.04	96
Rb			Rb	0.02	98
Cs	0.03	97	Cs		
K	0.003	100	K	0.001	99.9
Co	0.04	96	Co	0.05	95
Cr	0.12	88	Cr	0.37	63
Fe	0.01	99	Fe	0.01	99
Sc	0.22	78	Sc	0.15	85
Tb	0.12	88	Tb	0.09	91
Eu	0.21	79	Eu	0.14	86
Sm	0.11	89	Sm	0.07	93
Ce	0.02	98	Ce	0.02	98
La	0.02	98	La	0.01	99

coal (12% and 16% for Sets 1 and 2, respectively). The high Ti content of SRC has been confirmed by other workers (24) and Ti shows relatively little variation from SRC run to run (see Section III-BI on SRC trace element variability). In this respect, Ti is a unique element and the nature of Ti in SRC is discussed further in Section H.

Table 23 indicates that most elements in both sets of data are reduced in SRC relative to coal by 75% or more. Exceptions are Ta, Hg, Mn, and Cl in both sets of data, Ga in Set 1 and V and Cr in Set 2. These differences in behavior are presumably related to the forms in which these elements exist in coal and/or possible mineral transformations during liquefaction. For many elements the reduction in concentration is greater than 90%.

E. Comparison of Trace Element Data with Other Laboratories

Although no comparisons of analytical data on SRC among different laboratories on identical samples have been made, sufficiently similar samples have been analyzed by this laboratory, Battelle-Northwest, Richland, Washington, and the Illinois State Geological Survey (25). The results are summarized in Table 24. For most elements the agreement among the three sets of data is excellent, given that the samples analyzed were not taken during the same periods.

F. Comparison of Trace Element Contents of SRC and Other Fuels

Table 25 compares trace element contents of SRC (average of Equilibrium Sets 1 and 2 values) with average feed coal (Equilibrium Sets 1 and 2), crude shale oil data obtained by Fruchter et al (24), and average values for trace elements in U. S. East Coast residual fuel oils measured by Cahill (26). It should be noted that shales oil values are single determinations and the residual fuel oil values are means of 13 residual fuel oils. The residual fuel oil data should be regarded as orders of magnitude because the relative standard deviations for each element range from approximately 50 to 300%.

When SRC is compared to other boiler fuels (or potential boiler fuels), it is obvious that the major difference is the much higher Ti content of SRC relative to shale oil and residual fuel oil. In general, both shale oil and residual fuel oil show much lower contents of most trace elements. Important exceptions are the high Na, Ni and V in residual fuel, and the high As and Na in shale oil relative to SRC.

G. Materials Balance Calculations

One of the main objectives of this study was to determine the fate of trace elements in the SRC I process and to determine a material balance for each element, particularly those elements known or suspected of being toxic. To do this, it is necessary to know the element concentration of each process fraction and the weight yield as a percentage of the original coal of each

TABLE 24

COMPARISON OF ANALYTICAL DATA ON SRC AND FEED COAL
OBTAINED BY THREE LABORATORIES

		COAL			SRC	
	W.S.U.	BNW(24)	ISGS(25)	W.S.U.	BNW(24)	ISGS(25)
As (ppm)	16.3	19	14.2	2.14	2.1	2.7
Sb (ppm)	1.10	1.4	2.43	0.060	0.066	0.12
Se (ppm)	2.52	3.6	2.77	0.10	0.17	0.20
Hg (ppb)	114	160	-	43.2	20	-
Br (ppm)	4.14	3.6	4.67	6.34	4.7	6.75
Ni (ppm)	13.7	21	23	<3	<6	<5
Co (ppm)	5.54	5.2	6.7	0.24	0.26	0.36
Cr (ppm)	14.3	18	19	3.6	7.5	4.1
Fe (%)	2.25	2.29	2.3	0.028	0.027	0.035
Na (ppm)	155	180	158	5.27	8.8	9
Rb (ppm)	7.69	13	13.2	0.21	-	<5
Cs (ppm)	0.83	0.95	1.1	0.02	0.012	.12
K (ppm)	1790	-	1590	3.50	-	5

*For this laboratory, values given are means of equilibrium sets 1 and 2 samples. For ISGS, values are means of 3 values for coal and 2 values for SRC.

**X-ray fluorescence value. All others neutron activation analysis.

BNW: Battelle - Northwest, Richland, Washington
ISGS: Illinois State Geological Survey

TABLE 24 (cont'd)

COMPARISON OF ANALYTICAL DATA ON SRC AND FEED COAL
OBTAINED BY THREE LABORATORIES

	Coal			SRC		
	W.S.U.	BNW(24)	ISGS(25)	W.S.U.	BNW(24)	ISGS(25)
Sc (ppm)	2.54	2.6	4.0	0.47	0.45	0.65
Tb (ppm)	0.36	0.26	0.44	0.038	0.026	0.14
Eu (ppm)	0.23	0.36	0.49	0.041	0.025	0.09
Sm (ppm)	2.14	1.76	2.3	0.20	0.1-	0.33
Ce (ppm)	20.9	17	19	0.40	0.4	0.53
La (ppm)	7.06	8.9	16.9	0.11	0.10	0.22
Sr (ppm)	123	59	52	<5	0.96	-
Ba (ppm)	57.8	45	42	<2	0.14	<20
Th (ppm)	1.95	1.9	2.2	0.21	0.19	0.41
Hf (ppm)	0.55	0.44	0.59	0.077	0.054	0.16
Ta (ppm)	0.16	0.14	0.15	0.05	0.043	0.07
Ga (ppm)	3.41	3**	3.2	1.2	0.4**	1.1
Zr (ppm)	142	-	-	11	-	-
Cu (ppm)	17.1	10**	-	1.61	0.6**	-

TABLE 25

COMPARISON OF TRACE ELEMENT CONTENTS OF SRC
WITH COAL, SHALE OIL, AND RESIDUAL FUEL OIL

	SRC	COAL	CRUDE SHALE OIL (24)	RESIDUAL FUEL OIL (26)
As (ppm)	2.14	16.3	15.6*	0.055
Sb (ppm)	0.060	1.10	0.008	0.004
Se (ppm)	0.10	2.52	0.86	0.09
Hg (ppb)	43.2	114	200	4*
Br (ppm)	6.34	4.14	0.079	0.22
Cl (ppm)	130	275	-	40
V (ppm)	9.17	29.7	-	87
Ni (ppm)	<3	13.7	0.88*	12.5*
Co (ppm)	0.24	5.54	0.37	0.32
Cr (ppm)	3.6	14.3	0.04	0.070
Fe (%)	0.028	2.25	0.003	0.0005
Ti (ppm)	478	595	<10	<10
S (%)	0.74	4.34	-	1.1
Na (ppm)	5.27	155	19.4	33
Rb (ppm)	0.21	7.69	-	-
Cs (ppm)	0.02	0.83	<0.002	-
K (ppm)	3.50	1790	-	-

* Values obtained in this laboratory.

TABLE 25 (cont'd)

COMPARISON OF TRACE ELEMENT CONTENTS OF SRC
WITH COAL, SHALE OIL, AND RESIDUAL FUEL OIL

	SRC	COAL	CRUDE SHALE OIL (24)	RESIDUAL FUEL OIL (26)
Sc (ppm)	0.47	2.54	<0.0002	0.0002
Tb (ppm)	0.038	0.36	0.00006	
Eu (ppm)	0.041	0.23	<0.0002	0.0002
Sm (ppm)	0.20	2.14	0.00009	0.00007
Ce (ppm)	0.40	20.9	<0.009	0.00001
La (ppm)	0.11	7.06	0.0009	0.0002
Sr (ppm)	<5	123	<0.09	-
Ba (ppm)	<2	58	<0.014	-
Th (ppm)	0.21	1.95	-	-
Hf (ppm)	0.077	0.55	<0.004	-
Ta (ppm)	0.05	0.16	-	-
Ga (ppm)	1.2	3.41	-	-
Zr (ppm)	11	142	-	-
Cu (ppm)	1.6	17.1	-	-

fraction. The equilibrium run data shown in the sample collection section (Section II) provide information on the yields of SRC, light oil (LO), wash solvent (WS), recycle process water (RPW), and sulfur (from H_2S yields). These are shown in Tables 8 and 9. However, as the recycle process solvent yields are negative (to force material balance) and some make-up solvent has to be added during the process, a value of 5% has been assigned for this fraction. It should also be pointed out that, as this solvent recycles, some build-up of trace elements is to be expected, and it is difficult to assign a yield per unit mass of coal. However, in quantitative terms, the recycle process solvent contributes little to the overall material balances because the trace element contents are very low and the uncertainty associated with the assigned yield is small.

A more difficult problem concerns the contribution of the filtered residue to the material balance. Several residues were analyzed viz: pyridine insolubles (PI), mineral residue, filter cake (FC) and ash of pyridine insolubles. The mineral residue comprises material collected on the rotary drum filters after washing with wash solvent. The mineral residue, however, still contains some soluble material and a significant amount of filter-aid. This is indicated by the high Na contents of the mineral residues compared to pyridine insolubles (Tables 20 and 21). All of the filter-aid materials contain very high Na concentrations (up to 3.2% Na), and contamination of the mineral residue with soluble material and filter-aid made this residue unsuitable for use in material balance calculations. We have chosen to base the "residue" component of the materials balance on the pyridine insolubles because a) solvent-soluble material has been washed out, in contrast to the filter cake, b) no elements have been lost by ashing (very important for Hg, Se, and As) compared to the ash of the pyridine insolubles, and c) the PI are not contaminated with filter-aid. However, we did not have data on the fractional yields of the pyridine insolubles (compared to input coal). Consequently, the PI contribution was computed by assuming that 100% of K from the coal is found in the PI. When computed in this way, the PI yield per unit of coal is 13.9% for Equilibrium Set 1 and 18.1% for Equilibrium Set 2. The proportions of each fraction (coal = 1.0), and the weighted contributions of each element in each fraction are shown in Tables 26 and 27 for Equilibrium Sets 1 and 2, respectively. The contributions are shown graphically in Figure 4. The material balance for each element in percent of input from coal are given in the last column of Table 26 and 27. A comparison of the material balances for each element in both equilibrium sets is shown in Table 28. In these calculations we have assumed that the only contribution to the trace element input is the coal. This assumption naturally does not take into account contributions from the recycle process solvent (small), H_2 gas (small) or from corrosion and erosion of the construction materials (possibly important for some elements). The data from Tables 26 and 27 are also illustrated graphically for As, Sb, Se, Hg, Br, Ni, Co, Cr, Fe, Na, K, Sc, Ga, Cu, Ce, and La in Figures 5 and 6 for Equilibrium Sets 1 and 2, respectively. In these

TABLE 26

MATERIAL BALANCE FOR TRACE ELEMENTS (EQUILIBRIUM SET 1) IN SRC PROCESS

MATERIAL	SRC	PI	PRS	LO	WS	SULFUR	RPW	TOTAL	COAL	MATERIAL BALANCE
FRACTION	0.695	0.139	0.05	0.023	0.05	0.016	0.05	1.02	1.00	(PERCENT)
Ti (ppm)	323	465	-*	-	-	-		788	530	149
V (ppm)	3.22	27.1	-	-	0.01	0.13		30.5	30.1	101
Ca (ppm)	50.6	876	-	-	-	-		927	633	146
Mg (ppm)	61.9	556	-	-	-	-		618	1160	53.3
Al (%)	0.014	1.07	-	-	-	-		1.08	1.18	91.9
Cl (ppm)	111	106	2.3	1.6	-	-		221	260	85.0
Mn (ppm)	14.1	29.7	-	-	-	0.13		43.8	34.0	129

Values for each element are contributions for each Process fraction weighted for yield (Coal = 1)

* - = indicates insignificant contribution.

TABLE 26 (cont'd)

MATERIAL BALANCE FOR TRACE ELEMENTS (EQUILIBRIUM SET 1) IN SRC PROCESS

MATERIAL	SRC	PI	PRS	LO	WS	SULFUR	RPW	TOTAL	COAL	MATERIAL BALANCE
FRACTION	0.695	0.139	0.05	0.023	0.05	0.016	0.05	1.02	1.00	(PERCENT)
As (ppm)	1.39	11.9	0.012	-	-	-	-	13.3	12.5	106
Sb (ppm)	0.042	1.00	-	-	-	-	-	1.04	0.76	137
Se (ppm)	0.083	2.30	0.001	0.001	-	-	-	2.38	2.0	119
Hg (ppb)	13.8	35.3	0.072	0.43	0.53	-	5.3	55.4	56.5	98.0
Br (ppm)	5.38	1.66	0.05	-	-	-	0.78	7.87	4.56	172
Ni (ppm)	< 2	19.8	0.07	-	-	-	-	19.9	14.9	133
Co (ppm)	0.15	5.65	0.002	-	-	1.76	-	7.56	5.88	129
Cr (ppm)	1.14	14.7	0.18	-	0.002	-	-	16.0	13.7	117
Fe (%)	0.021	2.34	0.001	-	-	-	-	2.36	2.11	112
Na (ppm)	2.94	142	0.03	0.01	0.022	50	0.04	195	137	142
Rb (ppm)	0.3	9.24	-	-	-	-	-	9.54	3.57	259
Cs (ppm)	0.014	0.71	-	-	-	-	-	0.724	0.75	96.5
K (ppm)	3.28	1540	-	-	-	2.8	-	1546	1546	100

Values for each element are contributions for each Process fraction weighted for yield (Coal = 1)

TABLE 26 (cont'd)

MATERIAL BALANCE FOR TRACE ELEMENTS (EQUILIBRIUM SET 1) IN SRC PROCESS

MATERIAL	SRC	PI	PRS	LO	WS	SULFUR	RPW	TOTAL	COAL	MATERIAL BALANCE
FRACTION	0.695	0.139	0.05	0.023	0.05	0.016	0.05	1.02	1.00	(PERCENT)
Sc (ppm)	0.396	2.05	0.002	-	-	-	-	2.45	2.59	94.5
Tb (ppm)	0.031	0.286	-	-	-	-	-	0.32	0.39	81.3
Eu (ppm)	0.038	0.206	-	-	-	-	-	0.244	0.26	93.9
Sm (ppm)	0.202	2.35	-	-	-	0.010	-	2.55	2.62	97.4
Ce (ppm)	0.313	21.7	-	-	-	-	-	22.0	20.9	105
La (ppm)	0.090	8.31	-	-	-	0.029	-	8.43	7.55	112
Sr (ppm)	-	63.4	-	-	-	-	-	63.4	88.6	71.6
Ba (ppm)	4.00	48.2	0.06	-	-	-	-	52.3	53.0	98.6
Th (ppm)	0.153	1.78	-	-	-	-	-	1.93	2.00	96.7
Hf (ppm)	0.058	0.459	-	-	-	-	-	0.517	0.51	101
Ta (ppm)	0.032	0.099	-	-	-	-	-	0.131	0.14	93.6
Ga (ppm)	1.24	2.69	0.003	-	-	-	-	3.93	3.56	110
Zr (ppm)	11.1	69.5	-	-	-	-	-	80.6	62.9	128
Cu (ppm)	1.44	26.3	0.34	-	-	-	-	27.8	19.9	140

Values for each element are contributions for each Process fraction weighted for yield (Coal = 1)

TABLE 27

MATERIAL BALANCE FOR TRACE ELEMENTS (EQUILIBRIUM SET 2) IN SRC PROCESS

MATERIAL	SRC	PI	PRS	LO	WS	SULFUR	RPW	TOTAL	COAL	MATERIAL BALANCE
FRACTION	0.711	0.187	0.05	0.03	0.05	0.016	0.05	1.09	1.00	(PERCENT)
Ti (ppm)	348	811	1.0	-*	-	-	-	1160	660	176
V (ppm)	9.71	40.8	0.04	0.01	-	-	-	51.6	29.2	177
Ca (ppm)	87.5	1843	-	-	-	-	-	1931	658	293
Mg (ppm)	68.3	957	-	-	-	-	-	1025	1160	88.4
Al (%)	0.0299	1.24	0.002	-	-	-	-	1.27	1.24	102
Cl (ppm)	70.4	121	1.95	9.00	3.5	-	-	206	250	82.3
Mn (ppm)	10.1	39.6	0.064	-	0.005	-	-	49.8	34.8	143

* - = insignificant contribution

TABLE 27 (cont'd)

MATERIAL BALANCE FOR TRACE ELEMENTS (EQUILIBRIUM SET 2) IN SRC PROCESS

MATERIAL	SRC	PI	PRS	LO	WS	SULFUR	RPW	TOTAL	COAL	MATERIAL BALANCE
FRACTION	0.711	0.187	0.05	0.03	0.05	0.016	0.05	1.09	1.00	(PERCENT)
As (ppm)	1.61	70.2	0.012	-	0.002	-	-	71.8	20.1	357
Sb (ppm)	0.043	1.64	0.001	-	-	-	-	1.68	1.43	118
Se (ppm)	0.057	2.55	0.002	0.001	-	-	0.046	2.66	3.03	87.7
Hg (ppb)	33.2	89.9	-	-	0.31	-	1.04	124	114.3	109
Br (ppm)	3.51	1.84	0.04	0.001	0.001	-	-	5.39	3.72	145
Ni (ppm)	1.42	30.7	0.011	-	-	-	-	30.71	12.4	248
Co (ppm)	0.178	5.82	0.002	-	-	-	-	6.00	5.20	115
Cr (ppm)	3.91	36.2	0.12	-	-	-	-	40.2	14.8	272
Fe (%)	0.0185	2.48	-	-	-	-	-	2.50	2.38	105
Na (ppm)	4.48	189	-	-	-	-	0.26	194	173	112
Rb (ppm)	0.149	13.9	-	-	-	-	-	14.0	11.8	119
Cs (ppm)	-	0.89	-	-	-	-	-	0.89	0.91	97.8
K (ppm)	1.61	2020	-	-	-	-	-	2030	2030	100

TABLE 27 (cont'd)

MATERIAL BALANCE FOR TRACE ELEMENTS (EQUILIBRIUM SET 2) IN SRC PROCESS

MATERIAL	SRC	PI	PRS	LO	WS	SULFUR	RPW	TOTAL	COAL	MATERIAL BALANCE
FRACTION	0.711	0.187	0.05	0.03	0.05	0.016	0.05	1.09	1.00	(PERCENT)
Sc (ppm)	0.256	3.35	0.001	-	-	-	-	3.61	2.48	145
Tb (ppm)	0.021	0.436	-	-	-	-	-	0.457	0.32	143
Eu (ppm)	0.019	0.192	-	-	-	-	-	0.211	0.20	105
Sm (ppm)	0.083	1.88	-	-	-	-	-	1.96	1.65	119
Ce (ppm)	0.24	23.7	-	-	-	-	-	23.9	20.8	115
La (ppm)	0.064	6.78	-	-	-	-	-	6.84	6.56	104
Sr (ppm)	-	-	-	-	-	-	-	-	158	-
Ba (ppm)	-	74.0	-	-	-	-	-	74	62.5	118
Th (ppm)	0.135	2.28	-	-	-	-	-	2.42	1.40	127
Hf (ppm)	0.049	0.78	-	-	-	-	-	0.82	0.59	141
Ta (ppm)	0.036	0.194	-	-	-	-	-	0.23	0.17	135
Ga (ppm)	0.43	2.37	0.002	-	-	-	-	2.80	3.26	85.9
Zr (ppm)	4.55	76.4	-	-	-	-	-	81.0	79.0	102
Cu (ppm)	0.818	16.8	0.011	-	-	-	0.012	17.6	14.3	123

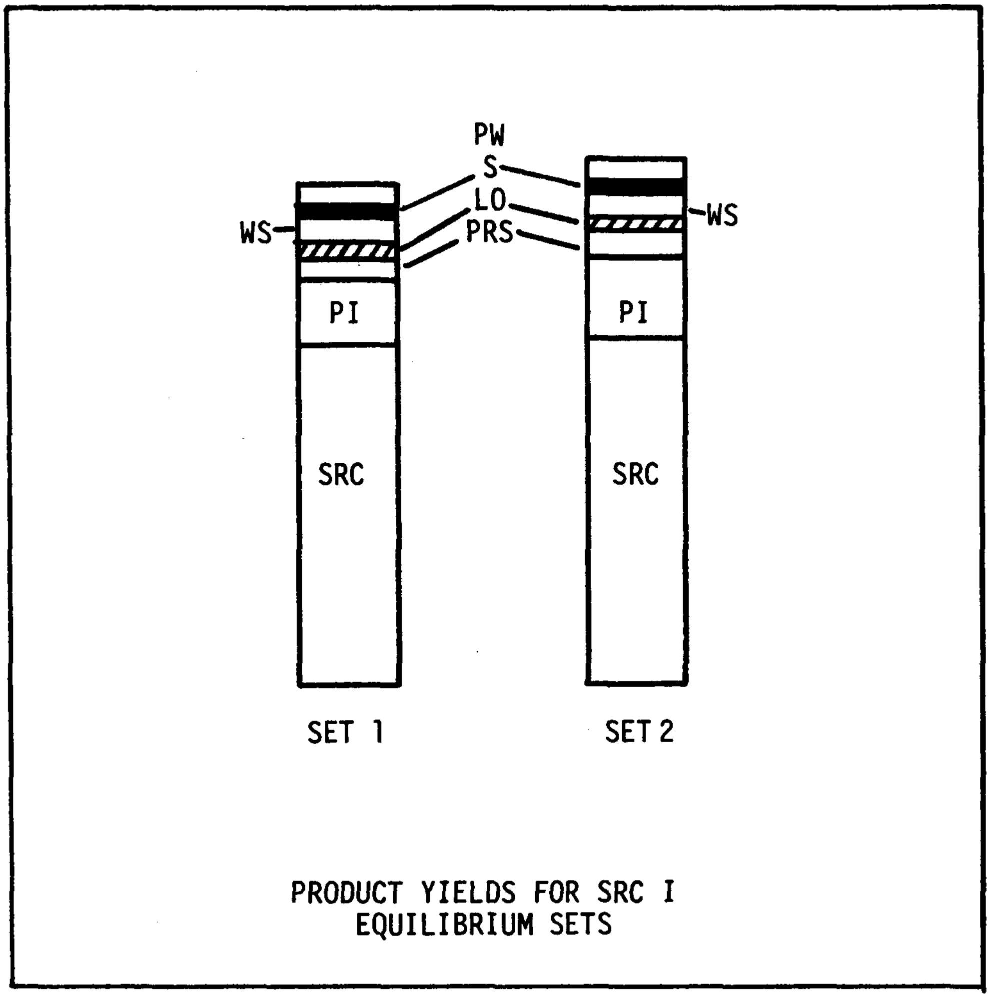

Figure 4: SCHEMATIC DIAGRAM OF SRC EQUILIBRIUM SET PRODUCT YIELDS

TABLE 28

MATERIAL BALANCES FOR EQUILIBRIUM SETS

Element	Set 1(%)	Set 2(%)	Element	Set 1(%)	Set 2(%)
Ti	149	176	Na	142	112
V	101	177	Rb	259	119
Ca	146	293	Cs	97	98
Mg	53	88	K	100	100
Al	92	102	Sc	95	145
Cl	85	82	Tb	81	143
Mn	129	143	Eu	94	105
As	106	357	Sm	97	119
Sb	137	118	Ce	105	115
Se	119	88	La	112	104
Hg	98	109	Ba	99	118
Br	172	145	Th	97	127
Ni	133	248	Hf	101	141
Co	129	115	Ta	94	135
Cr	117	272	Ga	110	86
Fe	112	105	Zr	128	102
			Cu	140	123

figures the relative contributions of each process fraction are shown relative to coal = 1.0. For Equilibrium Set 2 the balances range from a low value of 82.3% (Cl) to a high of 293% (Ca). Except for Ca, Ni, Ti, V, and Cr, all balances lie within the range 83 - 145%, which may be regarded as excellent given the assumptions made and the errors associated with obtaining representative samples of the process streams. For Equilibrium Set 1, the values range from 53% (Mg) to 259% (Rb). Except for Mg (53%), Rb (259%) and Br (172%), all values lie within the range 85 - 150%, which may be considered excellent. Figure 7 shows graphically the range of the material balance for each element in Equilibrium Sets 1 and 2.

Of particular significance are the material balances for Hg, As, Se, Sb and Br. For Hg, a volatile element, the material balances are 98% and 109% for Sets 1 and 2, and this shows that all the Hg in the process is accounted for within the limits of experimental error. It should be noted that the recycle process water of Equilibrium Set 1 accounts for 10% of the total and Hg is the only element for which the RPW accounts for more than 1% of the total. Arsenic, antimony and selenium in Equilibrium Set 1 all balance well. For Set 2, the As could not be balanced (359%) because of an erroneous value for As in the PI. The As content of all the laboratory prepared samples (WFC, PI, Ash of PI) are all much higher than As in the mineral residue (PI As = 388 ppm, MR As = 81.2 ppm). If the materials balance for As in Set 2 is based on the mineral residue rather than the PI, a material balance of 83.6% is obtained. Evidently the wet filter cake was not representative for As when the sample was taken. For Sb and Se the balance is again good. For both sets, Br is high and there may be an external source of Br (solvents probably). Titanium is also high, 149% and 176% for Sets 1 and 2, respectively. The reasons for the high balance on titanium has not yet been determined. The high values for Set 2 for Cr, Ni, and V may be due to equipment corrosion. These three elements balance normally for Equilibrium Set 1.

H. Nature of Titanium in SRC

Examination of the trace element data in Tables 22 and 23 show that SRC contains 84-88% of the Ti present in the original coal. In this respect Ti does not behave like any other metal present in the coal, including those which may be considered volatile and which may be released from mineral species into the organic matrix of SRC, e.g., Hg, Se, As or Sb. It is not yet clear why Ti behaves differently from other metals but possible explanations are:

a) Ti is present in the original coal as an extremely finely divided oxide, TiO_2, which passes through the filtration system whereas other minerals do not.

b) Ti minerals present in the coal (probably rutile, TiO_2) are converted to finely divided forms in the SRC I reactor.

c) Ti is present as an organometallic species in the coal and this species is soluble in the process solvent.

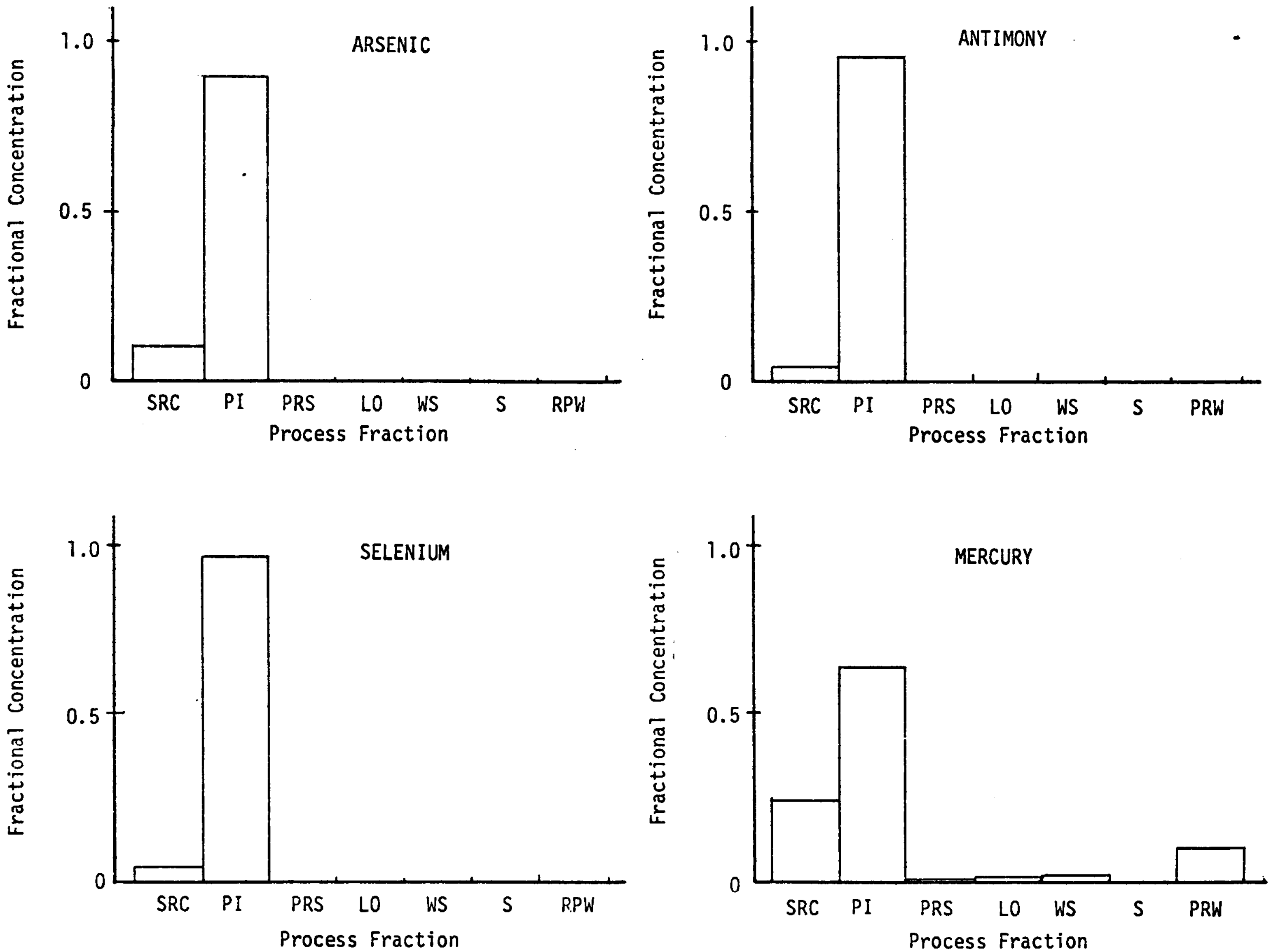

Figure 5: ELEMENTAL DISTRIBUTIONS IN SRC I PROCESS
(EQUILIBRIUM SET 1)

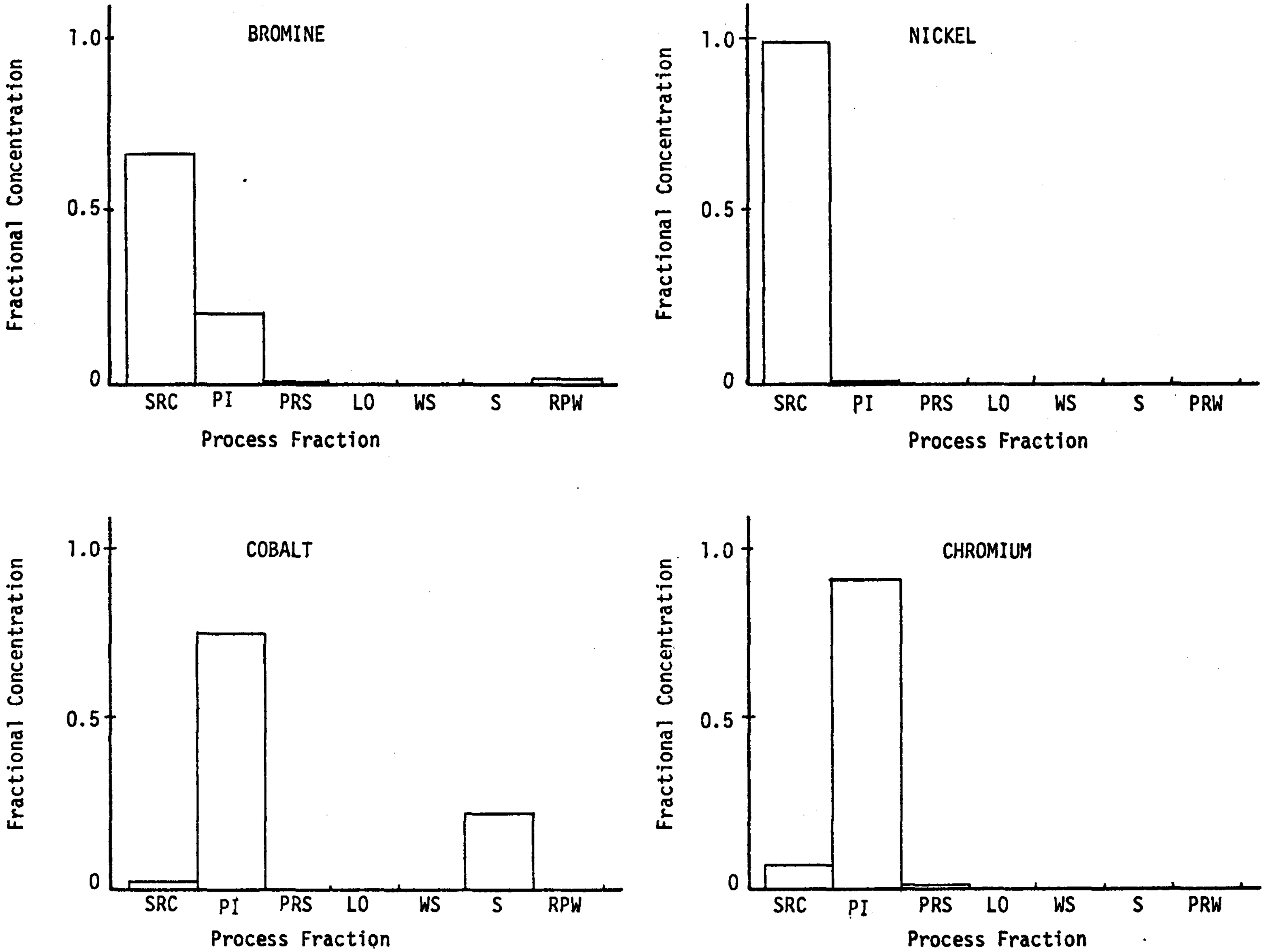

Figure 5: ELEMENTAL DISTRIBUTIONS IN SRC I PROCESS
(EQUILIBRIUM SET 1)

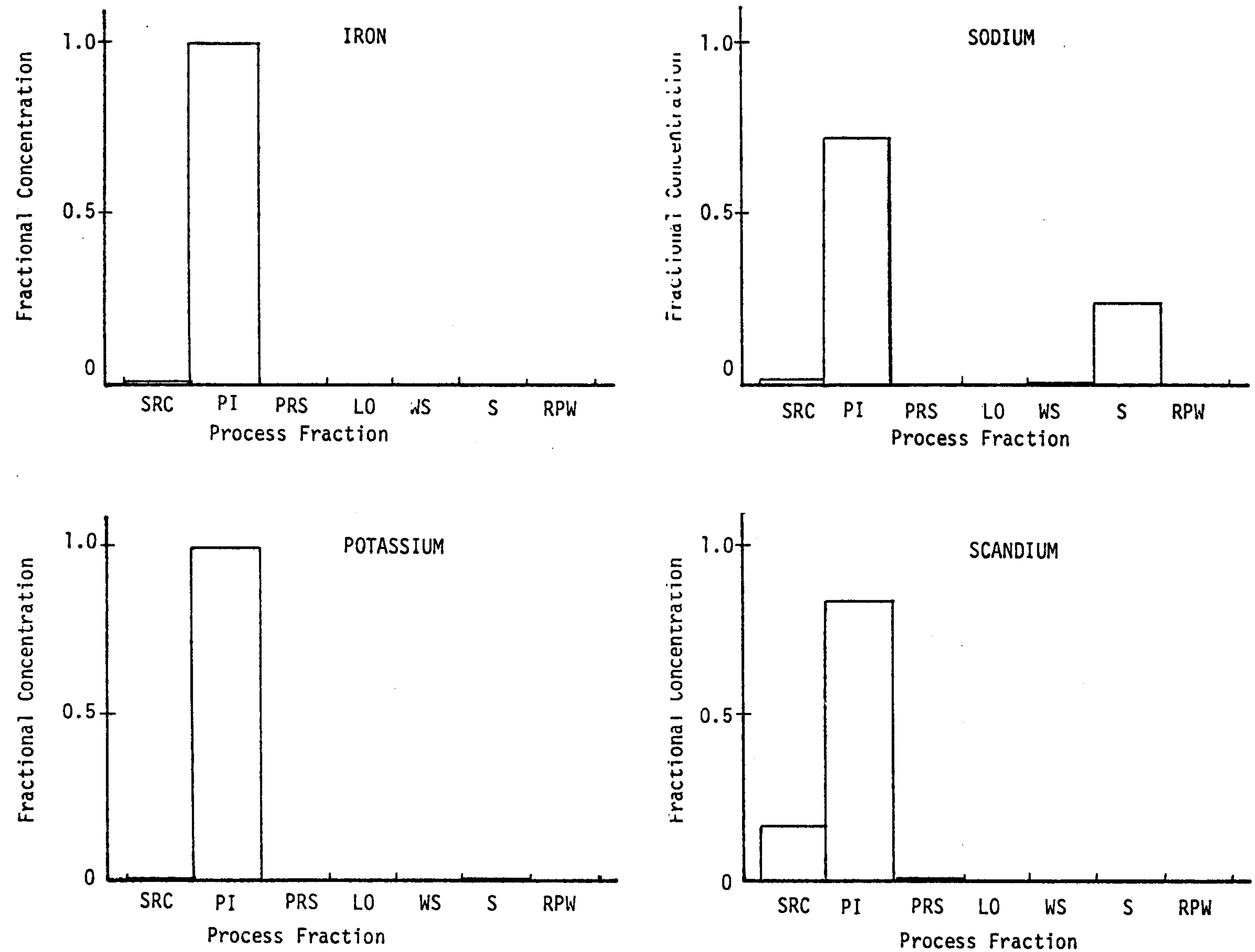

Figure 5: ELEMENTAL DISTRIBUTIONS IN SRC I PROCESS
(EQUILIBRIUM SET 1)

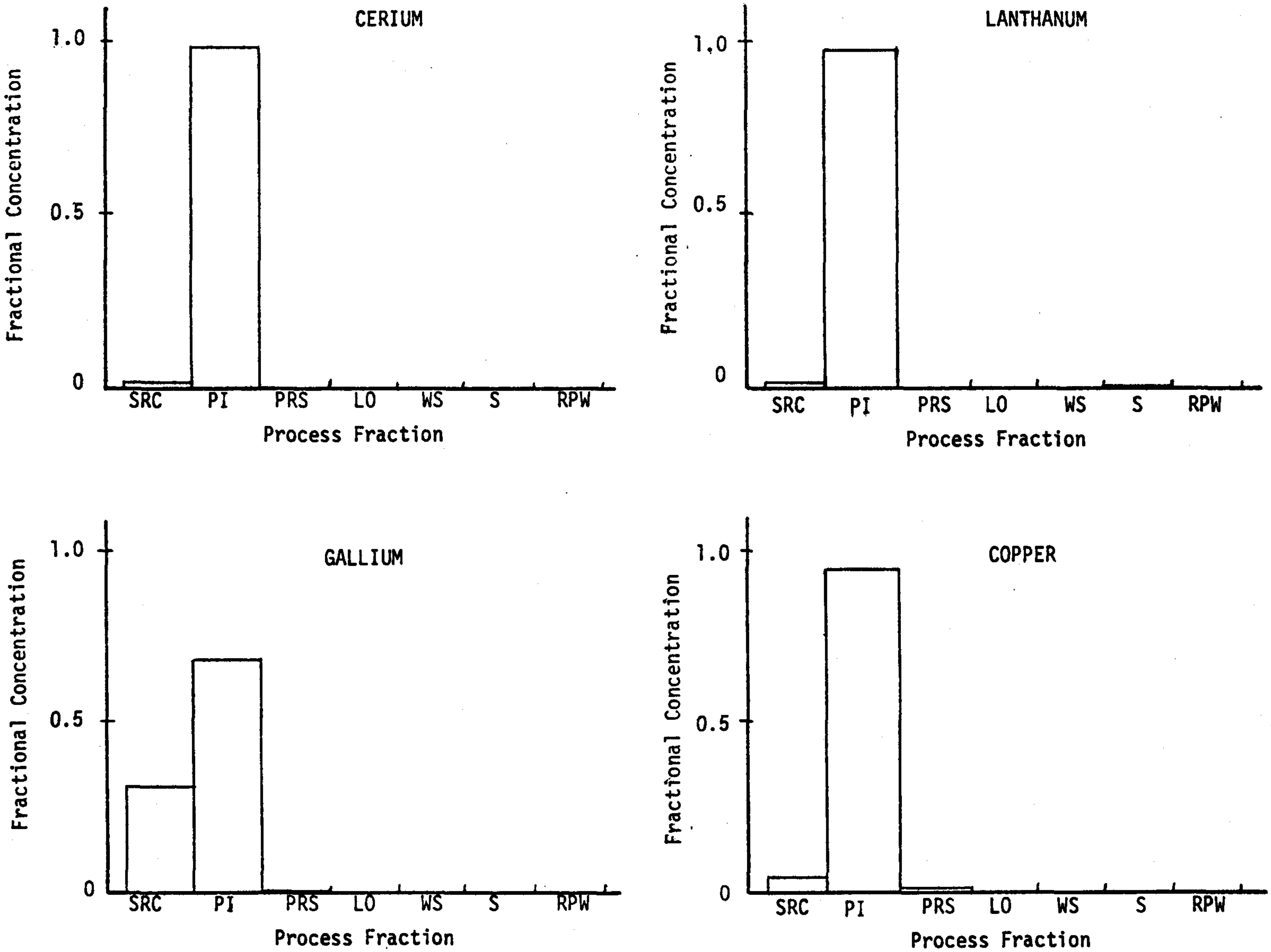

Figure 5: ELEMENTAL DISTRIBUTIONS IN SRC I PROCESS
(EQUILIBRIUM SET 1)

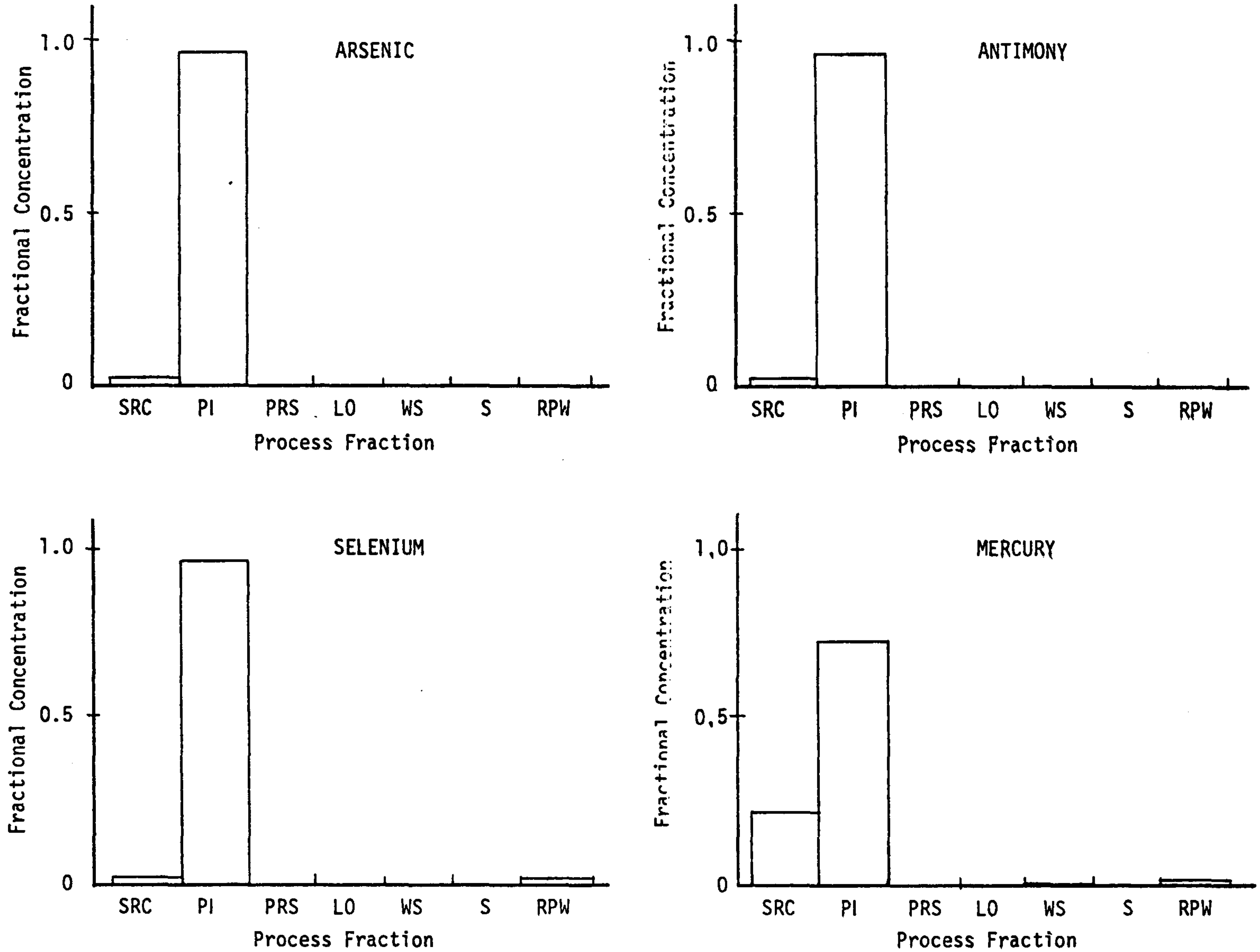

Figure 6: ELEMENTAL DISTRIBUTIONS IN SRC PROCESS (EQUILIBRIUM SET 2)

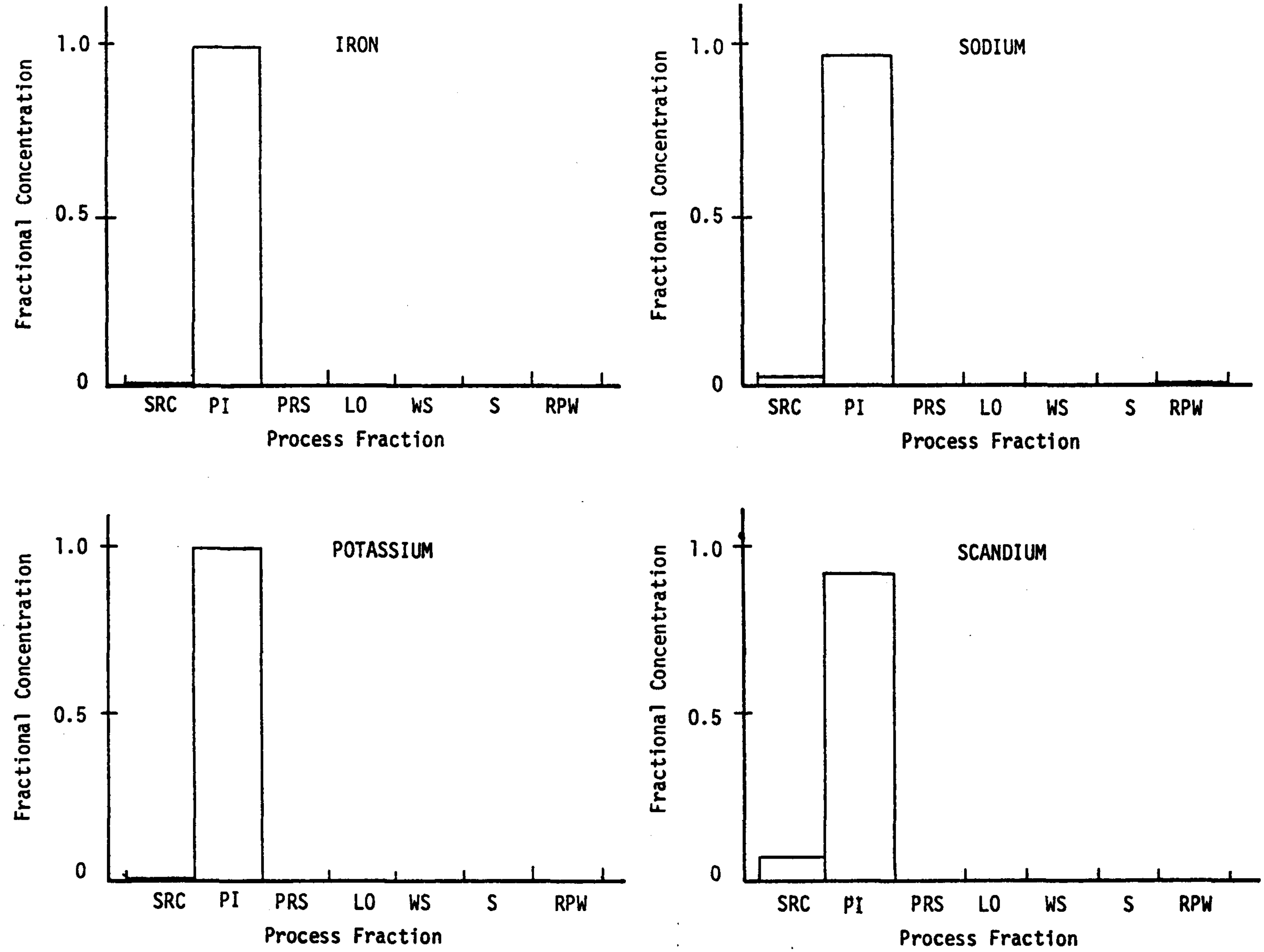

Figure 6: ELEMENTAL DISTRIBUTIONS IN SRC I PROCESS
(EQUILIBRIUM SET 2)

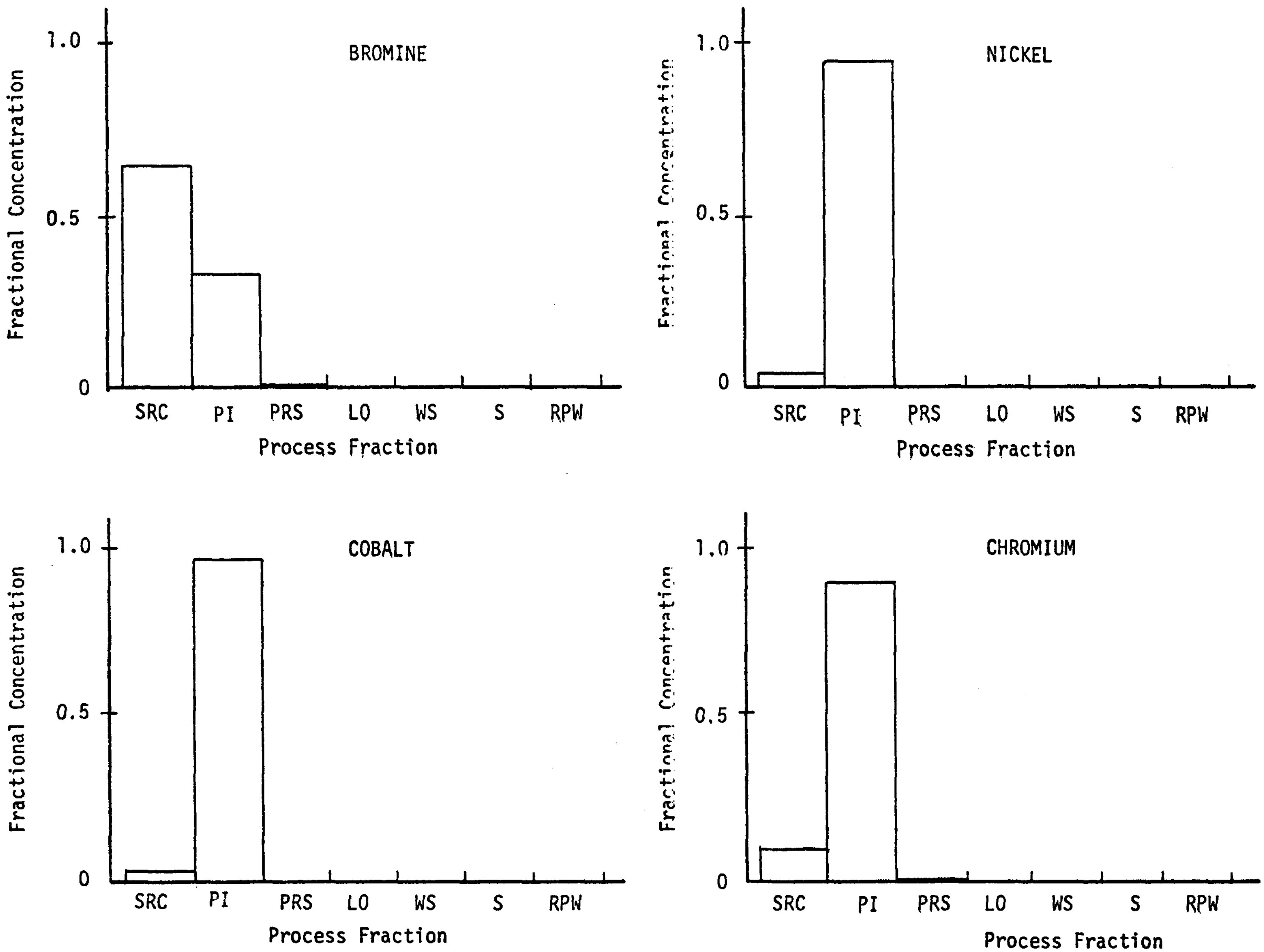

Figure 6: ELEMENTAL DISTRIBUTIONS IN SRC I PROCESS
(EQUILIBRIUM SET 2)

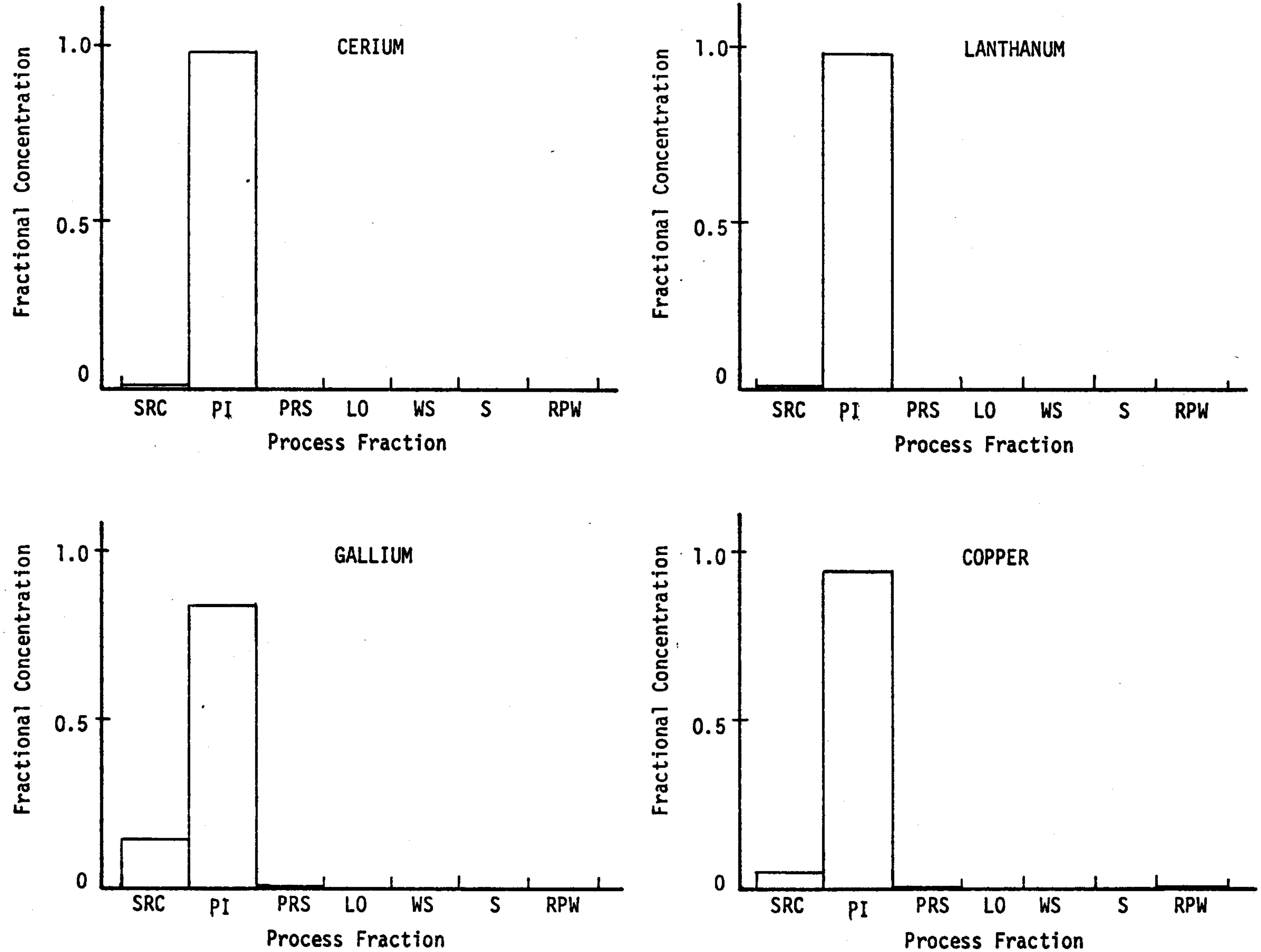

Figure 6: ELEMENTAL DISTRIBUTIONS IN SRC I PROCESS
(EQUILIBRIUM SET 2)

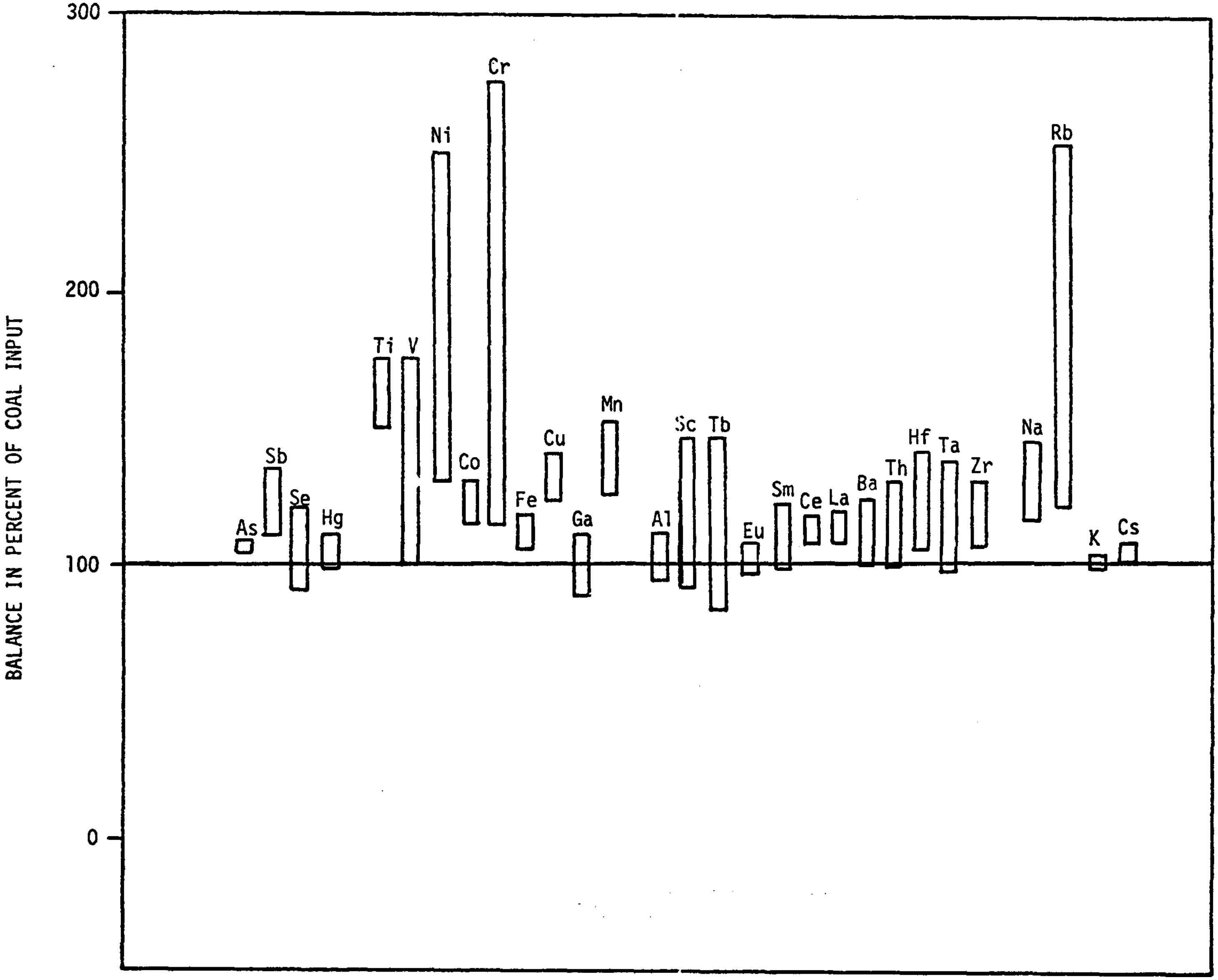

Figure 7: RANGES OF MATERIAL BALANCES
FOR TWO EQUILIBRIUM SETS, SRC I PROCESS

d) Ti is present as an inorganic mineral species, i.e., rutile (TiO_2), which reacts to form soluble organo-titanium species during the hydrogenation reaction.

Although there is some evidence (27) that Ti can exist in coal partly as an organo-titanium species, it appears that explanations a and d are most likely since recent work on Ti forms in coal (25, 28) indicates a predominantly inorganic association of Ti. Also, it is known that under reducing conditions and in the presence of Cl_2, TiO_2 can form reactive $TiCl_4$ at temperatures as low as 500°C. If $TiCl_4$ is produced, reactions with aromatic hydrocarbon species could produce organo-titanium compounds such as titanocene, $(C_5H_5)_2$ Ti, titanocene derivatives or other "sandwich" type compounds. Further study of Ti forms in SRC is under way.

I. Variability of Trace Element Content of SRC

During the period January - October 1976, production runs of SRC were made primarily for the purpose of burning tests subsequently conducted at the Georgia Power Co., Plant Mitchell, Albany, Georgia. This SRC material was made under the standard production conditions of 1410 psig hydrogen, a solvent: coal ratio of 1.6:1 and a temperature of 850°F. Each railroad car of SRC shipped was sampled to determine product homogeneity. A total of 35 SRC shipments were sampled and SRC samples have been analyzed for trace elements by the procedures listed in this report. The complete data are included in Appendix D, together with the appropriate shipment numbers. A summary of the data is given in Table 29. In this table the mean concentration ($\bar{X}$) for each element in ppm (except Fe in percent), the standard deviation, S, in ppm, the relative standard deviation, $100(s/\bar{x})$, expressed as a percentage of the mean, and the number of samples for which numerical concentrations were obtained. Not included were those concentrations listed as "less than". Also included in Table 29 are the trace element concentrations in SRC from Equilibrium Sets 1 and 2, which are listed for comparison purposes.

The results indicate that SRC produced over a 10-month period with variations in the input coal is remarkably homogeneous. The largest variation is for Na with a relative standard deviation of 74.9%. This value indicates that even for an ubiquitous element such as Na the variability of the product is not great. Several interesting differences are apparent in the data. The lowest relative standard deviations (greatest homogeneity) are those associated with the transition metals Ti (23.2%), Mn (23.5%), Cu (25.5%), V (27.8%), Ni (34.3%), and Co (31.2%) and the volatile elements As (22.7%), Cl (36.2%), Br (29.7%), Ga (33.8%), and Se (39.4%). The rare earths plus Hf, Ta, Zr, Sc and Th (i.e., refractory elements) range from 40.4% (Eu) to 65.2% (Tb). The highest inhomogeneity is shown by Na (74.9%), K (69.4%) and Al (67.6%) which are important contaminants in the SRC.

A comparison of the mean SRC trace element contents with the SRC product of Equilibrium Sets 1 and 2 shows that good agreement exists and that elemental values for both equilibrium sets fall within the

TABLE 29

VARIABILITY OF TRACE ELEMENTS IN 35 PRODUCTION RUN

SRC I SAMPLES

Element[a]	SRC EQ. Set 1	SRC EQ. Set 2	Mean Value All SRC ($\bar{x}$)	Standard Deviation s	Relative St. Deviation(s/$\bar{x}$)100	n
Ti	465	490	326	75.9	23.2	34
V	4.63	13.7	9.51	2.64	27.8	35
Ca	72.9	123	150	54.0	35.7	28
Al	200	420	326	220	67.6	35
Cl	160	99	129	46.8	36.2	35
Mn	20.3	14.2	14.3	3.36	23.5	34
As	2.00	2.27	2.10	0.477	22.7	35
Sb	0.060	0.060	0.136	0.0668	49.1	32
Se	0.12	0.080	0.122	0.0482	39.4	28
Br	7.74	4.93	5.69	1.69	29.7	35
Ba	5.75	< 2	9.31	6.37	68.3	21
Th	0.22	0.19	0.270	0.148	50.9	35
Hf	0.084	0.069	0.0848	0.042	49.5	34
Ta	0.046	0.050	0.0511	0.0223	41.7	34
Ga	1.79	0.61	1.05	0.355	33.8	33
Zr	16.0	6.4	8.99	4.69	52.1	28
Cu	2.07	1.15	2.07	0.528	25.5	28
Na	4.23	6.3	13.5	10.1	74.9	35
K	4.72	2.27	8.44	5.85	69.4	28
Ni	< 3	< 2	1.82	0.624	34.3	17
Co	0.22	0.25	0.314	0.098	31.2	34
Cr	1.64	5.50	4.19	2.01	48.0	35
Fe (%)	0.030	0.026	0.0438	0.02	57.1	35
Sc	0.57	0.36	0.605	0.289	47.8	35
Tb	0.045	0.03	0.0365	0.0238	65.2	32
Eu	0.055	0.027	0.033	0.014	40.4	35
Sm	0.29	0.117	0.27	0.12	44	21
Ce	0.45	0.34	0.602	0.288	47.8	35
La	0.13	0.09	0.236	0.124	52.5	35

a) Concentrations in ppm except as indicated.

range $\bar{x} \pm s$, except for Ti. Both Equilibrium Set SRC samples are significantly higher in Ti than the production run SRC samples. Values for Hg in the production runs have not been given because most of the SRC samples were below the detection limit for Hg in these analyses.

J. Concentrations of Pb, Cd, and Be in Plant Solvents

Lead, cadmium and beryllium were determined by atomic absorption spectrophotometry (see Section II-C) in the light ends, wash solvent, and process solvent in both equilibrium sets. The values obtained are shown in Table 30. All elements were below detection limits for the solvents analyzed. The detection limit for each element varies from solvent to solvent because of background and matrix effects during the analysis (described in Section II-C).

K. Trace Elements in Aqueous Phases and Effluents

An important effluent of environmental concern is water produced in the process or used at various stages for cooling, etc. In order to assess the trace element pollution potential of water effluents, process water, effluent water (after water treatment) and Hamer Marsh water were analyzed for trace elements by neutron activation analysis and by atomic absorption spectrophotometry (for Pb, Cd and Be) as described in Section II. The values obtained for samples of both equilibrium sets are shown in Table 31. Also shown in Table 31 is a sample of biosludge from the water treatment process during the period that Equilibrium Set 2 was being taken. Examination of the data reveals that high concentrations of Se, Hg, As, Cl and Cu (Set 2 only) are found in the process water but that after water treatment these high concentrations are reduced to essentially background levels in the effluent water. It appears from the high Se, Hg and Cu in the biosludge that the biotreatment process is effectively removing these elements from the process water.

In order to compare the quality of the effluent water with natural waters, the trace element data obtained in this study are compared with median trace element concentrations for U. S. rivers (30), mean trace element levels for Pacific Northwest rivers (31) and with 1975 Environmental Protection Agency Drinking Water Standards (Table 32). There is remarkably close agreement between the plant effluent water and the median concentrations for U.S. river. The exceptions are Pb, Be and Cd for which the effluent water concentrations are considerably lower than those reported for U. S. rivers. It should be stressed that the U. S. river data were obtained using less sensitive methods than those employed in this study.

A comparison of trace element levels in effluent water with EPA Drinking Water Standards (Table 32) reveals that only Al and Fe exceed EPA levels. All other elements measured in this study are below EPA levels, and for some elements (e.g., Pb, Cd, Be, As, Se, Sb, Hg, etc.) the effluent water values are orders of magnitude lower than the EPA limits.

TABLE 30

CONCENTRATIONS OF Pb, Cd, AND Be IN PLANT SOLVENTS

	Equilibrium Set 1			Equilibrium Set 2		
	Light Ends	Process Recycle Solvent	Wash Solvent	Light Ends	Process Recycle Solvent	Wash Solvent
Pb (ppb)	<17	<63	<53	<20	<24	<8
Cd (ppb)	<9	<32	<17	<6	<36	<12
Be (ppb)	<3	<4	<4	<2	<9	<2

TABLE 31

TRACE ELEMENTS IN PROCESS WATERS, EFFLUENTS, HAMER MARSH WATER AND BIOSLUDGE

	Equilibrium Set 1			Equilibrium Set 2			
	Process Water	Effluent Water	Hamer Marsh Water	Process Water	Effluent Water	Hamer Marsh Water	Biosludge
Ti (ppm)	<0.20	<0.08	<0.06	<0.3	<0.2	<0.3	<10
V (ppm)	<0.002	0.02	0.01	<0.001	0.009	0.008	595.6
Ca (ppm)	<1.0	4.4	4.6	<1.0	9.6	5.0	1964
Mg (ppm)	<2.0	1.9	1.4	<1.7	4.2	2.4	
Be (ppb)	--	<0.4	<0.4	--	<0.8	<1	
Al (ppm)	0.54	0.25	0.2	0.4	0.25	0.73	213,000
Cl (ppm)	32.4	1.7	2.6	17.0	3.7	3.1	562.3
Mn (ppm)	0.02	0.01	0.012	0.04	0.03	0.02	20.74
Pb (ppb)	--	<7	<10	--	<10	<10	
Cd (ppb)	--	2.2	<0.3	--	0.09	0.15	

TABLE 31 (cont'd)

TRACE ELEMENTS IN PROCESS WATERS, EFFLUENTS, HAMER MARSH WATER AND BIOSLUDGE

	Equilibrium Set 1			Equilibrium Set 2			
	Process Water	Effluent Water	Hamer Marsh Water	Process Water	Effluent Water	Hamer Marsh Water	Biosludge
As (ppb)	6.3	<1	<1	10.7	<5	<5	<12000
Sb (ppb)	0.66	2.0	2.6	1.0	0.64	0.5	1210
Se (ppb)	159.0	1.20	0.9	914.3	0.37	0.45	6280
Hg (ppb)	106.3	3.2	1.0	20.7	5.5	0.38	8750
Br (ppb)	15.6	31.8	22.9	18.3	<10	28.1	8570
Ni (ppb)	4	13.0	12	14.0	16.0	7.0	12000
Co (ppb)	0.2	0.41	0.34	0.43	0.36	0.26	4480
Cr (ppb)	7.4	153.3	137.3	11.30	10.1	6.2	47330
Fe (ppm)	0.30	1.25	0.82	1.34	0.41	0.36	12000
Na (ppm)	0.70	8.3	6.7	5.1	<10	42.4	9630
Rb (ppb)	0.78	0.52	0.31	0.77	1.36	0.91	2660
Cs (ppb)	0.04	0.022	0.03	0.04	0.06	0.05	190
K (ppm)	0.2	1.26	0.93	0.73	<1	<8	<200

TABLE 31 (cont'd)

TRACE ELEMENTS IN PROCESS WATERS, EFFLUENTS, HAMER MARSH WATER AND BIOSLUDGE

	Equilibrium Set 1			Equilibrium Set 2			
	Process Water	Effluent Water	Hamer Marsh Water	Process Water	Effluent Water	Hamer Marsh Water	Biosludge
Sc (ppb)	0.13	0.01	0.02	0.12	0.12	0.11	800
Tb (ppb)	0.01	0.01	<0.005	<0.01	<0.01	<0.01	120
Eu (ppb)	0.01	0.008	0.006	0.012	0.015	0.013	60
Sm (ppb)	0.08	<0.06	<0.06	<0.1	<0.1	<0.1	<150
Ce (ppb)	<0.2	<0.2	1.5	<0.2	6.5	0.40	3210
La (ppb)	0.27	<0.5	<0.5	<0.7	<0.01	<1.2	<200
Sr (ppm)	<0.01	0.04	<0.01	<0.02	<0.01	<0.01	<10
Ba (ppm)	<0.02	<0.04	<0.04	<0.02	<0.01	<0.01	29.0
Th (ppb)	0.05	<0.01	<0.01	<0.04	0.09	0.09	1800
Hf (ppb)	0.02	<0.01	0.01	0.04	0.02	0.02	340
Ta (ppb)	0.02	0.01	<0.02	0.02	<0.02	<0.01	40
Ga (ppb)	<1	<4	<4	<4	<4	<10	9300
Zr (ppm)	0.02	0.04	0.06	0.02	0.02	0.01	41.5
Cu (ppb)	<12	<10	<10	243.5	<25	<25	103000
Zn (ppm)	0.02	0.02	0.06	0.3	0.06	0.09	309

TABLE 32

COMPARISON OF TRACE ELEMENTS IN PLANT EFFLUENT WATER WITH U. S. RIVER WATERS AND EPA DRINKING WATER STANDARDS*

Element	Plant Effluent	Median U.S. Rivers	Mean Pacific NW Rivers	EPA Drinking Water
Ti	<0.2	0.009	0.009	0.1
V	0.009	0.001	0.013	0.1
Ca	9.6	15	--	--
Mg	4.2	4.1	--	10
Al	0.25	0.24	0.03	0.01
Cl	3.7	7.8	--	--
Mn	0.03	0.012	0.0028	0.05
As	<0.005	0.0004	0.0007	0.05
Sb	0.0006	--	--	0.05
Se	0.0004	<0.02	--	0.01
Hg	0.00055	0.00008	--	0.002
Br	<0.01	0.021	--	3
Ba	0.01	0.054	0.027	1.0
Th(μg/l)	0.09	0.02	--	--
Zn	0.06	0.01	0.04	5
Ga	<0.004	<0.001	--	--
Zr	0.02	0.003	--	1
Cu	<0.025	0.01	0.009	0.1
Na	8.3	6.3	--	--
Rb	0.0014	0.0015	--	5
Cs	0.0006	0.0002	--	--
K	<1	2.3	--	--
Co	0.00036	0.0009	0.008	0.05
Cr	0.010	0.0002	0.006	0.05
Fe	0.41	0.67	0.032	0.3
Pb(μg/l)	<0.01	5	15	50
Be(μg/l)	0.8	1	0.02	1000
Cd(μg/l)	0.09	80	5	10

* Data in Mg/l except Th, Pb, Be and Cd μg/l

Source of data: Plant Effluent - Equilibrium Set 2; Median U.S. Rivers (Cited in Bowen (30)); PNW Rivers (Kopp and Kroner (31)); EPA Drinking Water (1975)

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APPENDIX A

TRACE ELEMENT DATA FOR NON-EQUILIBRIUM SRC PILOT PLANT MATERIALS

The data listed in Appendix A were collected on the dates shown

a) 1/26-28/75

Input Coal: Coal 1 and Coal 2

SRC I: Vacuum Bottoms 1 and 2 (laboratory prepared)

Pyridine Insolubles: Pyridine Insolubles 1
Pyridine Insolubles 2

Ash of Pyridine Insolubles: Ash 1
Ash 2

Wet Filter Cake: Filter Cake 1
Filter Cake 2

b) 3/3/75 (Sample descriptions as for previous set.) Additional samples analyzed:

SRC - Solvent Refined Coal 1 and 2 (plant)

Light Ends

Wash Solvent

Recycle Process Solvent

Filter Feed Surge Vessel, Recirculator #15922

Filtrate (plant product)

Filtrate 2 (laboratory filtered)

Flare K. O. Drum #15911

Process Water #12538

Process Water #16983

PRELIMINARY SRC PRODUCT DATA
(1/26 - 28/75)

	PYRIDINE INSOLUBLES-1	PYRIDINE INSOLUBLES-2	ASH-1	ASH-2	COAL-1	COAL-2
As (ppm)	57.9 ± 1.3	52.6 ± 1.2	76.9 ± 2.1	65.7 ± 1.7		11.8 ± 0.3
Sb (ppm)	3.2 ± 0.2	2.99 ± 0.14	2.9 ± 0.3	3.0 ± 0.2		0.517 ± 0.03
Se (ppm)	14.5 ± 0.4	13.6 ± 0.4			2.63 ± 0.07	3.003 ± 0.08
Hg (ppb)						
Br (ppm)	10.7 ± 0.8	11.2 ± 0.8				6.93 ± 0.2
Ni (ppm)	71 ± 12	97.6 ± 11	247 ± 26	158 ± 22	24.1 ± 2	35.5 ± 3
Co (ppm)	41.1 ± 0.4	36.8 ± 0.3	63.9 ± 0.6	62.1 ± 0.6	6.09 ± 0.05	7,73 ± 0.07
Cr (ppm)	188.3 ± 1.6	167 ± 1.4	307 ± 3	313 ± 2.7	39.6 ± 0.3	49.4 ± 0.4
Fe (%)	16.4 ± 0.3	15.1 ± 0.3	25.0 ± 0.5	24.3 ± 0.4	3.0 ± 0.05	3.6 ± 0.07
Na (ppm)	1470 ± 25	1330 ± 23	2263 ± 43	2210 ± 40		231 ± 4.3
Rb (ppm)	163 ± 6	151 ± 5	300 ± 9	181 ± 7	27.7 ± 1	20.7 ± 1
Cs (ppm)	8.2 ± 0.2	7.83 ± 0.2	12.8 ± 0.3	12.4 ± 0.2	1.10 ± 0.03	1.34 ± 0.03
K (ppm)	1575 ± 575	14558 ± 560	2444 ± 127	23260 ± 913		1874 ± 91

PRELIMINARY SRC PRODUCT DATA
(1/26-28/75)

	PYRIDINE INSOLUBLES-1	PYRIDINE INSOLUBLES-2	ASH-1	ASH-2-3	COAL-1	COAL-2
Sc (ppm)	14.7 ± 0.05	13.1 ± 0.05	23.0 ± 0.08	23.0 ± 0.08	2.75 ± 0.01	3.57 ± 0.01
Tb (ppm)	0.42 ± 0.04	0.539 ± 0.05	0.80 ± 0.08	2.38 ± 0.1	0.418 ± 0.02	0.616 ± 0.03
Eu (ppm)	2.4 ±	<2.13	3.7 ±	<3.46	0.383 ± 0.007	<0.488
Sm (ppm)						
Ce (ppm)	125.6 ± 0.43	111 ± 0.4	205 ± 0.6	197 ± 0.7	20.0 ± 0.07	25.6 ± 0.08
La (ppm)	60.5 ± 1.3	54.9 ± 1.2	94.5 ± 2.3	91 ± 2		8.82 ± 0.2
Lu (ppm)	1.17 ± 0.02	1.36 ± 0.02	1.8 ± 0.03	1.92 ± 0.04	0.210 ± 0.003	0.285 ± 0.006
Sr (ppm)	896 ± 60	770 ± 49	1181 ± 68	1072 ± 73	172 ± 9	224 ± 12
Ba (ppm)	437 ± 32	452 ± 30	556 ± 40	604 ± 61	53.5 ± 4	99.9 ± 8
Th (ppm)	11.3 ± 0.06	10.1 ± 0.05	20 ± 1	19.0 ± 0.1	1.69 ± 0.01	2.14 ± 0.01
Hf (ppm)	2.9 ± 0.07	2.44 ± 0.06	4.5 ± 0.1	5.47 ± 0.1	0.419 ± 0.01	0.589 ± 0.01
Ta (ppm)	0.87 ± 0.08	0.765 ± 0.08	1.3 ± 0.1	1.20 ± 0.1	0.128 ± 0.01	0.166 ± 0.02
Ga (ppm)						
Zr (ppm)	341 ± 35	193 ± 20	381 ± 41	316 ± 35	44.7 ± 5	61.5 ± 5
Cu (ppm)						

PRELIMINARY SRC PRODUCT DATA
(1/26-28/75)

	VACUUM BOTTOMS-1	VACUUM BOTTOMS-2	FILTER CAKE-2	FILTER CAKE-1
As (ppm)		0.67 ± 0.04	18.6 ± 0.5	28.2 ± 0.7
Sb (ppm)			0.46 ± 0.05	1.7 ± 0.1
Se (ppm)	0.14 ± 0.03	0.08 ± 0.02	7.1 ± 0.2	7.9 ± 0.2
Hg (ppb)				
Br (ppm)		6.6 ± 0.2	8.2 ± 0.4	12.4 ± 0.5
Ni (ppm)	1.4 ± 0.4		45 ± 6	64 ± 7
Co (ppm)	0.51 ± 0.01	0.42 ± 0.006	16.1 ± 0.1	19.8 ± 0.2
Cr (ppm)	2.67 ± 0.04	2.5 ± 0.04	76.0 ± 0.7	92 ± 1
Fe (%)	0.005 ± 0.0003	0.008 ± 0.0003	6.7 ± 0.07	8.0 ± 0.1
Na (ppm)		5.8 ± 0.3	615 ± 11	730 ± 13
Rb (ppm)			67 ± 2	92 ± 3
Cs (ppm)			3.4 ± 0.07	4.1 ± 0.08
K (ppm)			145 ± 55	7300 ± 304

PRELIMINARY SRC PRODUCT DATA

(1/26-28/75)

	VACUUM BOTTOMS-1	VACUUM BOTTOMS-2	FILTER CAKE-2	FILTER CAKE-1
Sc (ppm)	0.73 ± 0.003	0.64 ± 0.002	6.3 ± 0.02	8.1 ± 0.03
Tb (ppm)	0.07 ± 0.004	0.06 ± 0.003	1.0 ± 0.05	1.4 ± 0.06
Eu (ppm)	0.05 ± 0.01	0.04 ± 0.01	0.94 ± 0.02	1.2 ± 0.02
Sm (ppm)				
Ce (ppm)	0.53 ± 0.01	0.43 ± 0.01	47.9 ± 0.2	59.3 ± 0.2
La (ppm)		0.13 ± 0.02	24.0 ± 0.6	30.0 ± 0.7
Lu (ppm)	0.05 ± 0.001	0.04 ± 0.001	0.51 ± 0.01	0.61 ± 0.01
Sr (ppm)			338 ± 19	370 ± 21
Ba (ppm)	10.1 ± 1.4	8.4 ± 1.3	177 ± 13	195 ± 13
Th (ppm)	0.34 ± 0.003	0.30 ± 0.002	4.6 ± 0.03	5.3 ± 0.03
Hf (ppm)	0.11 ± 0.004	0.08 ± 0.002	1.1 ± 0.02	1.4 ± 0.03
Ta (ppm)	0.06 ± 0.005	0.05 ± 0.004	0.31 ± 0.03	0.36 ± 0.04
Ga (ppm)				
Zr (ppm)	8.4 ± 1.2	6.6 ± 1.1	132 ± 13	146 ± 13
Cu (ppm)				

PRELIMINARY SRC PRODUCT DATA
(3/5/75)

	COAL-1	COAL-2	FILTER CAKE-1	FILTER CAKE-2
As (ppm)	13.6 ± 0.1	14.3 ± 0.1	36.5 ± 0.3	29.3 ± 0.3
Sb (ppm)	0.5 ± 0.02	0.6 ± 0.02	1.3 ± 0.03	1.4 ± 0.03
Se (ppm)	2.8 ± 0.1	2.9 ± 0.1	7.4 ± 0.2	8.2 ± 0.2
Hg (ppb)				
Br (ppm)	3.51 ± 0.05	3.46 ± 0.05	6.22 ± 0.12	5.21 ± 0.12
Ni (ppm)	20 ± 3	14 ± 3	51 ± 7	57 ± 6
Co (ppm)	3.7 ± 0.03	3.7 ± 0.04	13.0 ± 0.1	13.0 ± 0.1
Cr (ppm)	14.1 ± 0.1	14.4 ± 0.2	56.4 ± 0.4	60.0 ± 0.4
Fe (%)	1.7 ± 0.02	1.8 ± 0.03	5.7 ± 0.1	5.8 ± 0.1
Na (ppm)	148 ± 2	149 ± 2	473 ± 6	492 ± 7
Rb (ppm)	22.0 ± 0.7	23 ± 1	74 ± 2	57 ± 2
Cs (ppm)	0.9 ± 0.02	0.8 ± 0.03	2.7 ± 0.1	2.9 ± 0.05
K (ppm)	1480 ± 52	1530 ± 50	4810 ± 180	5240 ± 210

PRELIMINARY SRC PRODUCT DATA
(3/5/75)

	COAL-1	COAL-2	FILTER CAKE-1	FILTER CAKE-2
Sc (ppm)	2.8 ± 0.01	2.8 ± 0.01	7.8 ± 0.03	8.1 ± 0.03
Tb (ppm)	0.4 ± 0.01	0.4 ± 0.02	1.0 ± 0.03	1.3 ± 0.03
Eu (ppm)	0.30 ± 0.007	0.31 ± 0.01	1.1 ± 0.02	1.1 ± 0.02
Sm (ppm)				
Ce (ppm)	17.0 ± 0.1	18.0 ± 0.1	59.0 ± 0.2	59.0 ± 0.2
La (ppm)				
Lu (ppm)	0.13 ± 0.001	0.14 ± 0.003	0.42 ± 0.005	0.43 ± 0.005
Sr (ppm)		153 ± 16	348 ± 21	420 ± 21
Ba (ppm)	65 ± 4	69 ± 6	164 ± 10	166 ± 9
Th (ppm)	1.7 ± 0.01	1.7 ± 0.01	5.3 ± 0.03	5.3 ± 0.03
U (ppm)	32.7 ± 0.5	10.5 ± 0.4	50 ± 1	43 ± 1
Hf (ppm)	0.5 ± 0.01	0.5 ± 0.02	1.4 ± 0.03	1.3 ± 0.03
Ta (ppm)	0.16 ± 0.02	0.20 ± 0.03	0.35 ± 0.05	0.40 ± 0.05
Ga (ppm)				
Zr (ppm)	62 ± 7	47 ± 7	143 ± 16	120 ± 13
Cu (ppm)				

PRELMINARY SRC PRODUCT DATA
(3/5/75)

	PYRIDINE INSOLUBLES-1	PYRIDINE INSOLUBLES-2	SOLVENT REFINED COAL-1	SOLVENT REFINED COAL-2
As (ppm)	52.0 ± 0.1	54.5 ± 0.1	1.39 ± 0.03	1.48 ± 0.04
Sb (ppm)	2.9 ± 0.1	3.0 ± 0.1	0.07 ± 0.003	0.08 ± 0.004
Se (ppm)	19.7 ± 0.4	21.1 ± 0.5	0.12 ± 0.01	0.12 ± 0.01
Hg (ppb)	7.67 ± 0.23	5.78 ± 0.21	3.95 ± 0.04	4.12 ± 0.04
Br (ppm)				
Ni (ppm)	157 ± 15	120 ± 15	2.8 ± 0.4	2.8 ± 0.5
Co (ppm)	23.0 ± 0.2	22.2 ± 0.2	0.31 ± 0.005	0.30 ± 0.005
Cr (ppm)	122 ± 1	124 ± 1	2.7 ± 0.02	2.7 ± 0.02
Fe (%)	12.0 ± 0.2	12.0 ± 0.2	0.07 ± 0.001	0.07 ± 0.001
Na (ppm)	866 ± 12	975 ± 14	8.67 ± 0.16	10.3 ± 0.21
Rb (ppm)	174 ± 4	184 ± 5	0.57 ± 0.08	0.35 ± 0.08
Cs (ppm)	6.3 ± 0.1	6.2 ± 0.1	0.02 ± 0.003	0.02 ± 0.003
K (ppm)	10800 ± 600	11000 ± 400	31.5 ± 3	45.4 ± 5

PRELIMINARY SRC PRODUCT DATA
(3/5/75)

	PYRIDINE INSOLUBLES-1	PYRIDINE INSOLUBLES-2	SOLVENT REFINED COAL-1	SOLVENT REFINED COAL-2
Sc (ppm)	18.1 ± 0.06	17.3 ± 0.06	0.13 ± 0.001	0.13 ± 0.001
Tb (ppm)	2.5 ± 0.06	1.8 ± 0.06	0.01 ± 0.002	0.01 ± 0.002
Eu (ppm)	2.5 ± 0.05	2.4 ± 0.05	0.013 ± 0.001	0.01 ± 0.001
Sm (ppm)				
Ce (ppm)	14.1 ± 0.6	141.0 ± 0.6	0.60 ± 0.01	0.55 ± 0.01
La (ppm)				
Lu (ppm)	0.83 ± 0.007	0.90 ± 0.01	0.004 ± 0.0002	0.004 ± 0.0002
Sr (ppm)	787 ± 43	806 ± 45	--	4.4 ± 1.2
Ba (ppm)	350 ± 17	340 ± 20	2.5 ± 0.6	--
Th (ppm)	11.8 ± 0.06	11.9 ± 0.06	0.06 ± 0.001	0.06 ± 0.001
U (ppm)	314 ± 4	256 ± 3	0.84 ± 0.04	0.66 ± 0.04
Hf (ppm)	3.2 ± 0.07	3.3 ± 0.07	0.03 ± 0.002	0.03 ± 0.002
Ta (ppm)	0.9 ± 0.1	1.0 ± 0.1	0.01 ± 0.002	0.02 ± 0.003
Ga (ppm)				
Zr (ppm)	267 ± 31	303 ± 35	4.3 ± 0.8	3.6 ± 0.6
Cu (ppm)				
Zn (ppm)			11.0 ± 0.2	17.3 ± 0.2

PRELIMINARY SRC PRODUCT DATA
(3/5/75)

	FILTER FEED SURGE VESSEL, RECIRC. #15922	FILTRATE	FILTRATE (LAB FILTERED)-2
As (ppm)	3.1 ± 0.02	0.76 ± 0.006	0.50 ± 0.01
Sb (ppm)	0.50 ± 0.006	0.04 ± 0.002	0.01 ± 0.002
Se (ppm)	0.93 ± 0.02	0.097 ± 0.02	0.11 ± 0.01
Hg (ppb)			
Br (ppm)	0.9 ± 0.01	1.7 ± 0.01	1.0 ± 0.01
Ni (ppm)	8.68 ± 0.81	0.96 ± 0.25	1.0 ± 0.3
Co (ppm)	1.31 ± 0.01	0.12 ± 0.01	0.11 ± 0.01
Cr (ppm)	7.45 ± 0.07	0.32 ± 0.001	0.22 ± 0.01
Fe (ppm)	5400 ± 100	28.1 ± 1.0	27.4 ± 1.1
Na (ppm)	120 ± 1	1.40 ± 0.03	1.1 ± 0.03
Rb (ppm)	5.55 ± 0.18	<0.1	<0.1
Cs (ppm)	0.30 ± 0.01	<0.1	<0.1
K (ppm)	730 ± 18	2.2 ± 0.6	<5

PRELIMINARY SRC PRODUCT DATA

(3/5/75)

	FILTER FEED SURGE VESSEL RECIRC. #15922	FILTRATE	FILTRATE (LAB FILTERED)-2
Sc (ppm)	0.75 ± 0.04	0.32 ± 0.02	0.27 ± 0.01
Tb (ppm)	0.050 ± 0.002	0.021 ± 0.0001	0.029 ± 0.02
Eu (ppm)	0.096 ± 0.002	0.021 ± 0.001	0.020 ± 0.001
Sm (ppm)	0.77 ± 0.002	0.152 ± 0.0005	0.15 ± 0.001
Ce (ppm)	6.81 ± 0.03	0.279 ± 0.007	0.25 ± 0.01
La (ppm)	3.3 ± 0.02	0.07 ± 0.002	0.07 ± 0.003
Sr (ppm)	22.0 ± 1	<5	<5
Ba (ppm)	20.5 ± 2	3.57 ± 0.5	3.60 ± 0.6
Th (ppm)	0.63 ± 0.003	0.20 ± 0.01	0.16 ± 0.02
Hf (ppm)	0.15 ± 0.003	0.04 ± 0.001	0.034 ± 0.001
Ta (ppm)	--	--	--
Ga (ppm)	1.0 ± 0.3	0.30 ± 0.04	0.28 ± 0.05
Zr (ppm)	19.2 ± 1.6	5.59 ± 0.71	3.76 ± 0.61
Cu (ppm)	13.7 ± 0.3	2.0 ± 0.04	0.52 ± 0.04

PRELIMINARY SRC PRODUCT DATA
(3/5/75)

	LIGHT ENDS	WASH SOLVENT	RECYCLE PROCESS SOLVENT
As (ppm)	0.005 ± 0.0003	0.013 ± 0.0001	0.13 ± 0.002
Sb (ppm)	<0.01	<0.01	0.01 ± 0.001
Se (ppm)	0.159 ± .005	0.038 ± 0.003	0.044 ± 0.004
Hg (ppb)	<10	<10	<10
Br (ppm)	0.02 ± 0.001	0.011 ± 0.002	0.75 ± 0.005
Ni (ppm)	<1	<1	0.42 ± 0.11
Co (ppm)	0.035 ± 0.001	0.039 ± 0.001	0.031 ± 0.001
Cr (ppm)	0.045 ± .004	0.037 ± .003	3.48 ± 0.034
Fe (ppm)	10.3 ± 0.5	6.24 ± 0.29	220 ± 4.6
Na (ppm)	0.63 ± 0.01	0.07 ± 0.001	0.40 ± 0.01
Rb (ppm)	<0.1	<0.1	0.20 ± 0.04
Cs (ppm)	0.002 ± 0.0004	0.002 ± .0003	0.003 ± 0.001
K (ppm)	<0.1	0.04 ± 0.001	3.5 ± 0.3

PRELIMINARY SRC PRODUCT DATA

(3/5/75)

	LIGHT ENDS	WASH SOLVENT	RECYCLE PROCESS SOLVENT
Sc (ppm)	<0.001	<0.001	0.005 ± 0.0001
Tb (ppm)	<0.001	<0.001	0.001 ± 0.0003
Eu (ppm)	0.009 ± 0.0004	0.007 ± 0.0003	0.006 ± 0.0003
Sm (ppm)	<0.001	<0.001	0.004 ± 0.0001
Ce (ppm)	<0.1	<0.1	<0.1
La (ppm)	<0.001	<0.001	0.020 ± 0.0006
Sr (ppm)	<1	<1	<1
Ba (ppm)	<1	<1	<1
Th (ppm)	<0.001	<0.001	0.004 ± 0.0005
Hf (ppm)	<0.1	<0.1	<0.1
Ta (ppm)	<0.1	<0.1	<0.1
Ga (ppm)	<0.01	<0.01	0.04 ± 0.01
Zr (ppm)	--	--	--
Cu (ppm)	0.06 ± 0.003	0.016 ± 0.0003	0.40 ± 0.01

PRELIMINARY SRC PRODUCT DATA
(3/5/75)

	PROCESS WATER, SAMPLE #12538	PROCESS WATER, SAMPLE #16983	FLARE K.O. DRUM #15911
As (ppm)	<0.01	0.01 ± 0.001	1.76 ± 0.01
Sb (ppm)	<0.01	<0.01	1.23 ± 0.01
Se (ppm)	0.21 ± 0.004	0.39 ± 0.007	0.923 ± 0.024
Hg (ppb)	1042 ± 100	--	--
Br (ppm)	0.04 ± 0.003	0.01 ± 0.002	0.82 ± 0.01
Ni (ppm)	<1	<1	11.2 ± 0.8
Co (ppb)	12.0 ± 0.6	11.0 ± 0.6	917 ± 10
Cr (ppm)	<0.1	<0.1	12.8 ± 0.1
Fe (ppm)	0.73 ± 0.08	<1	4100 ± 80
Na (ppm)	11.5 ± 0.1	4.0 ± 0.04	88 ± 1
Rb (ppm)			4.69 ± 0.20
Cs (ppm)		0.002 ± 0.0004	0.27 ± 0.006
K (ppm)	4.6 ± 0.7	<5	551 ± 16
Zn (ppm)	0.11 ± 0.006	0.05 ± 0.01	--

PRELIMINARY SRC PRODUCT DATA
(3/5/75)

	PROCESS WATER, SAMPLE #12538	PROCESS WATER, SAMPLE #16983	FLARE K.O. DRUM #15911
Sc (ppm)	<0.01	<0.01	0.72 ± 0.004
Tb (ppm)	<0.01	<0.01	0.061 ± 0.0023
Eu (ppm)	0.005 ± 0.0002	0.004 ± 0.0002	0.086 ± 0.002
Sm (ppm)	<0.01	<0.01	0.60 ± 0.001
Ce (ppm)	<0.1	<0.1	6.0 ± 0.03
La (ppm)	<0.01	<0.01	2.7 ± 0.02
Sr (ppm)	<1	<1	22.1 ± 1.7
Ba (ppm)	<1	<1	12.8 ± 1.2
Th (ppm)	<0.1	<0.1	0.541 ± .004
Hf (ppm)	<0.1	<0.1	0.14 ± 0.004
Ta (ppm)	<0.1	<0.1	0.039 ± .004
Ga (ppm)	<1	<1	1.2 ± 0.3
Zr (ppm)	--	--	--
Cu (ppm)	0.34 ± 0.01	0.12 ± 0.006	18.2 ± 0.3

APPENDIX B

TRACE ELEMENT DATA FOR EQUILIBRIUM SET 1

EQUILIBRIUM SET 1

Plant Samples - Description

(composite of the period 3-1-76, 1000 hrs.
through 3-2-76, 1000 hrs.)

No.	Description
1.	Raw coal
2.	Ground coal
3.	Solvent refined coal
4.	Mineral residue
5.	Sulfur
6.	Speedex filteraid
7.	Speed plus filteraid
8.	Celite 6000
9.	Fibra Flo
10.	Celite 545
11.	Process recycle solvent
12.	Light oil
13.	Wash solvent
14.	Process water
15.	Plant effluent water
16.	Hamer Marsh water (3-2-76, 1100 hrs.)
17.	Wet filter cake, Lab.

EQUILIBRIUM SET 1 (continued)

Laboratory Prepared Samples

Sample No.	Description	Sample Dates
18.	Wet filter cake	2/27 - 2/29
19.	Pyridine insolubles	2/26 - 3/1
20.	Ash of pyridine insolubles	2/27
21.	Vacuum bottoms	3/1
22.	Light oil-water phase composite	2/19 - 3/1
23.	Wash solvent	2/16 - 3/1
24.	Process solvent	2/17 - 3/1

SRC PILOT PLANT, EQUILIBRIUM SET 1, RAW MATERIALS & PRODUCTS

	Raw Coal	Ground Coal	Solvent Refined Coal	Mineral Residue	Sulfur
Ti (ppm)	546.5 ± 122.3	530.1 ± 55.3	465.0 ± 16.0	2600 ± 334.7	<90.0
V (ppm)	25.23 ± 1.14	30.1 ± 0.82	4.63 ± 0.08	225.3 ± 4.70	8.2 ± 0.1
Ca (ppm)	632.9 ± 264	--	72.8 ± 22.3	4900 ± 800	<600.0
Mg (ppm)	858.3 ± 150.0	1160 ± 200	89.0 ± 25.0	5200 ± 600	<300.0
Al (%)	1.07 ± 0.02	1.18 ± 0.04	0.02 ± 0.001	7.47 ± 0.29	<6 ppm
Cl (ppm)	285.6 ± 6.02	260.1 ± 6.93	159.5 ± 3.0	987.8 ± 78.4	<40.0
Mn (ppm)	32.8 ± 0.4	34.0 ± 0.41	20.3 ± 0.20	174.0 ± 1.85	8.0 ± 0.31

SRC PILOT PLANT, EQUILIBRIUM SET 1, RAW MATERIALS & PRODUCTS

	Raw Coal	Ground Coal	Solvent Refined Coal	Mineral Residue	Sulfur
As (ppm)	11.60 ± 0.10	12.5 ± 0.11	2.00 ± 0.03	97.62 ± 1.37	<2.0
Sb (ppm)	0.98 ± 0.06	0.76 ± 0.04	0.06 ± 0.009	5.84 ± 0.20	<0.1
Se (ppm)	2.18 ± 0.19	2.0 ± 0.10	0.12 ± 0.03	14.80 ± 0.51	<1.5
Hg (ppb)	<130	113.0 ± 14.6	39.6 ± 4.0	540 ± 70	<160
Br (ppm)	5.79 ± 0.14	4.56 ± 0.14	7.74 ± 0.10	5.67 ± 1.33	<3.0
Ni (ppm)	18.0 ± 4.0	14.9 ± 2.62	<3.0	89.2 ± 11.3	<28.0
Co (ppm)	5.25 ± 0.075	5.88 ± 0.064	0.22 ± 0.007	38.81 ± 0.32	109.6 ± 0.7
Cr (ppm)	10.40 ± 0.31	13.70 ± 0.20	1.64 ± 0.04	116.9 ± 1.18	<2.0
Fe (%)	2.40 ± 0.12	2.11 ± 0.09	0.03 ± 0.001	15.45 ± 0.69	<0.1
Na (ppm)	123.9 ± 0.70	136.9 ± 0.74	4.23 ± 0.09	1833.6 ± 14.8	3115.0 ± 24.0
Rb (ppm)	3.57 ± 0.80	<4.0	<0.5	62.2 ± 4.20	<9.0
Cs (ppm)	<0.2	0.75 ± 0.03	0.02 ± 0.006	4.93 ± 0.13	<0.2
K (ppm)	1258.2 ± 17.4	1546.0 ± 19.9	4.72 ± 0.95	10178.0 ± 185.0	179.1 ± 6.60

SRC PILOT PLANT, EQUILIBRIUM SET 1, RAW MATERIALS & PRODUCTS

	Raw Coal	Ground Coal	Solvent Refined Coal	Mineral Residue	Sulfur
Sc (ppm)	2.10 ± 0.011	2.59 ± 0.01	0.57 ± 0.002	14.30 ± 0.04	<0.02
Tb (ppm)	0.43 ± 0.021	0.39 ± 0.013	0.045 ± 0.003	2.41 ± 0.06	<0.1
Eu (ppm)	0.26 ± 0.008	0.26 ± 0.006	0.055 ± 0.002	1.41 ± 0.024	<0.01
Sm (ppm)	2.59 ± 0.015	2.62 ± 0.016	0.29 ± 0.004	13.10 ± 0.25	0.61 ± 0.15
Ce (ppm)	24.20 ± 0.24	20.85 ± 0.14	0.45 ± 0.024	139.3 ± 0.63	<2.0
La (ppm)	7.52 ± 0.09	7.55 ± 0.11	0.13 ± 0.012	52.30 ± 1.0	1.80 ± 0.31
Sr (ppm)	97.2 ± 19.4	88.64 ± 12.4	<6.0	808.5 ± 70.1	<45.0
Ba (ppm)	31.0 ± 8.14	53.0 ± 7.74	5.75 ± 1.23	259.3 ± 31.7	<39.0
Th (ppm)	1.51 ± 0.028	2.00 ± 0.018	0.22 ± 0.004	11.82 ± 0.082	<0.2
Hf (ppm)	0.34 ± 0.03	0.51 ± 0.018	0.084 ± 0.006	2.73 ± 0.082	<0.2
Ta (ppm)	0.10 0.02	0.14 ± 0.017	0.046 ± 0.005	0.71 ± 0.088	<0.2
Ga (ppm)	2.69 ± 0.07	3.56 ± 0.086	1.79 ± 0.041	17.72 ± 0.79	<1.5
Zr (ppm)	66.5 ± 11.1	62.9 ± 7.94	16.0 ± 3.34	441.6 ± 41.5	<61.0
Cu (ppm)	22.4 ± 2.20	19.9 ± 1.56	2.07 ± 0.20	175.8 ± 12.5	<1.0

SRC PILOT PLANT, EQUILIBRIUM SET 1, LAB PREPARED SAMPLES

	Wet Filter Cake	Pyridine Insolubles	Ash of Pyridine Insolubles	Vacuum Bottoms
Ti (ppm)	1490 ± 162.0	3350 ± 409	4465 ± 417	449.7 ± 9.7
V (ppm)	140.6 ± 4.3	195.2 ± 5.0	375.7 ± 8.4	4.0 ± 0.07
Ca (ppm)	3015 ± 568	6300 ± 1000	10500 ± 1300	63.7 ± 24.5
Mg (ppm)	4345 ± 61.6	4000 ± 800	7490 ± 1160	56.2 ± 28.5
Al (%)	5.5 ± 0.52	7.72 ± 0.75	20.2 ± 0.65	0.043 ± 0.001
Cl (ppm)	1641.0 ± 267	759.6 ± 67.4	<400.0	17.8 ± 1.60
Mn (ppm)	140.0 ± 1.16	185.0 ± 2.1	254.0 ± 2.4	7.2 ± 0.11

SRC PILOT PLANT, EQUILIBRIUM SET 1, LAB PREPARED SAMPLES

	Wet Filter Cake	Pyridine Insolubles	Ash of Pyridine Insolubles	Vacuum Bottoms
As (ppm)	62.07 ± 1.02	85.70 ± 1.63	119.3 ± 1.93	1.30 ± 0.03
Sb (ppm)	5.35 ± 0.24	7.21 ± 0.29	11.70 ± 0.44	<0.2
Se (ppm)	11.33 ± 0.76	16.53 ± 1.05	<4.2	<0.2
Hg (ppb)	346 ± 30	508 ± 65	-	<90
Br (ppm)	20.74 ± 1.04	11.95 ± 1.63	<7.0	1.15 ± 0.054
Ni (ppm)	82.4 ± 18.2	142.3 ± 21.5	-	<3.0
Co (ppm)	26.53 ± 0.30	40.67 ± 0.40	61.52 ± 0.56	0.29 ± 0.01
Cr (ppm)	69.20 ± 1.30	106.10 ± 1.74	146.9 ± 2.35	1.34 ± 0.09
Fe (%)	11.67 ± 0.57	16.81 ± 0.82	22.25 ± 1.10	0.011 ± 0.001
Na (ppm)	623.1 ± 6.06	1023.6 ± 10.7	1723.9 ± 15.6	23.30 ± 0.24
Rb (ppm)	37.13 ± 4.20	66.50 ± 5.51	106.7 ± 8.37	<0.5
Cs (ppm)	3.20 ± 0.16	5.08 ± 0.22	7.54 ± 0.30	<0.04
K (ppm)	6,656 ± 140	11,124 ± 255	17,851 ± 344	<6.0

SRC PILOT PLANT, EQUILIBRIUM SET 1, LAB PREPARED SAMPLES

	Wet Filter Cake	Pyridine Insolubles	Ash of Pyridine Insolubles	Vacuum Bottoms
Sc (ppm)	9.26 ± 0.04	14.78 ± 0.06	25.45 ± 0.10	0.82 ± 0.004
Tb (ppm)	1.34 ± 0.075	2.06 ± 0.09	4.07 ± 0.13	0.084 ± 0.005
Eu (ppm)	0.96 ± 0.025	1.48 ± 0.03	2.42 ± 0.05	0.055 ± 0.002
Sm (ppm)	8.16 ± 0.16	16.94 ± 0.34	29.2 ± 0.53	0.37 ± 0.004
Ce (ppm)	102.4 ± 0.85	156.0 ± 1.08	249.3 ± 1.50	0.87 ± 0.051
La (ppm)	35.2 ± 0.67	59.8 ± 1.30	103.5 ± 1.73	0.14 ± 0.014
Sr (ppm)	452.6 ± 59.5	456.0 ± 77.9	646.3 ± 88.7	<6,0
Ba (ppm)	185.0 ± 37.3	347.0 ± 74.7	524.3 ± 78.6	6.53 ± 1.92
Th (ppm)	7.70 ± 0.11	12.82 ± 0.14	21.11 ± 0.20	0.45 ± 0.009
Hf (ppm)	2.20 ± 0.12	3.30 ± 0.15	4.40 ± 0.22	0.155 ± 0.010
Ta (ppm)	0.42 ± 0.085	0.71 ± 0.122	1.02 ± 0.16	0.066 ± 0.007
Ga (ppm)	11.27 ± 0.55	19.41 ± 1.17	31.90 ± 1.31	1.15 ± 0.05
Zr (ppm)	245.6 ± 44.7	500.0 ± 72.5	714.0 ± 100.9	<8.0
Cu (ppm)	138.2 ± 6.75	189.1 ± 10.2	290.7 ± 12.7	1.42 ± 0.10

SRC PILOT PLANT, EQUILIBRUM SET 1, PLANT SOLVENTS

	Light Oil	Process Recycle Solvent	Wash Solvent
Ti (ppm)	2.04 ± 0.53	19.1 ± 1.19	0.92 ± 0.31
V (ppm)	0.050 ± 0.003	0.445 ± 0.008	0.052 ± 0.0028
Ca (ppm)	<9	<8	<5
Mg (ppm)	<10	<10	<7
Al (ppm)	50 ± 1	43.9 ± 0.75	11.6 ± 0.47
Cl (ppm)	16.9 ± 0.18	127 ± 1.15	92.2 ± 0.41
Mn (ppm)	0.18 ± 0.005	2.09 ± 0.2	<0.2
I (ppm)	0.05 ± 0.004	0.076 ± 0.0095	<0.01

SRC PILOT PLANT EQUILIBRUM, SET 1, PLANT SOLVENTS

	Light Oil	Process Recycle Solvent	Wash Solvent
As (ppm)	0.011 ± 0.0003	0.24 ± 0.002	0.011 ± 0.0003
Sb (ppm)	<0.4	8.2 ± 0.38	<0.4
Se (ppb)	51.6 ± 1.1	24.0 ± 1.3	14.4 ± 0.8
Hg (ppb)	18.5 ± 0.77	1.45 ± 0.20	10.5 ± 0.5
Br (ppm)	0.015 ± 0.001	1.0 ± 0.006	0.02 ± 0.001
Ni (ppm)	<0.03	0.4 ± 0.03	<0.03
Co (ppb)	<3.0	40.7 ± 0.4	1.43 ± 0.11
Cr (ppb)	37.3 ± 1.3	3,589 ± 10.3	41.3 ± 1.05
Fe (ppm)	2.9 ± 0.09	211.3 ± 3.5	11.21 ± 0.22
Na (ppm)	0.60 ± 0.004	0.50 ± 0.004	0.45 ± 0.004
Rb (ppm)	<0.01	0.02 ± 0.005	<0.01
Cs (ppb)	1.06 ± 0.12	<1.2	0.91 ± 0.09
K (ppm)	<1	0.25 ± 0.05	<1

SRC PILOT PLANT, EQUILIBRUM SET 1, PLANT SOLVENTS

	Light Oil	Process Recycle Solvent	Wash Solvent
Sc (ppb)	0.15 ± 0.006	32.8 ± 0.07	0.19 ± 0.007
Tb (ppb)	<0.13	3.75 ± 0.15	<0.13
Eu (ppm)	<0.001	<0.001	<0.001
Sm (ppm)	<0.01	0.02 ± 0.001	<0.01
Ce (ppm)	<0.004	<0.004	<0.003
La (ppm)	<0.001	0.01 ± 0.0006	<0.001
Sr (ppm)	<0.6	<0.2	0.74 ± 0.03
Ba (ppm)	<0.1	1.14 ± 0.04	<0.07
Th (ppm)	<0.001	0.012 ± 0.0001	<0.001
Hf (ppm)	<0.001	0.003 ± 0.0001	<0.001
Ta (ppb)	<0.4	2.53 ± 0.20	<0.3
Ga (ppm)	<0.1	0.06 ± 0.001	<0.1
Zr (ppm)	0.07 ± 0.02	0.71 ± 0.09	<0.1
Cu (ppm)	0.03 ± 0.001	0.68 ± 0.004	0.03 ± 0.001

SRC PILOT PLANT, EQUILIBRUM SET 1, LABORATORY SOLVENTS

	Light Oil - Water Phase	Wash Solvent	Process Solvent
Ti (ppm)	<25	<2	<2
V (ppm)	<0.2	0.21 ± 0.05	<0.02
Ca (ppm)	<87	14.5 ± 5	<8
Mg (ppm)	<118	<8	<8
Al (ppm)	<15.2	15.1 ± 3.1	1.2 ± 0.2
Cl (ppm)	<69	2.15 ± 0.14	58. ± 0.6
Mn (ppm)	<0.4	<0.2	<0.02
I (ppm)	<8	<0.03	<0.02

SRC PILOT PLANT, EQUILIBRUM SET 1, LABORATORY SOLVENTS

	Light Oil - Water Phase	Wash Solvent	Process Solvent
As (ppm)	<0.1	0.01 ± 0.001	0.1 ± 0.007
Sb (ppb)	2.6 ± 0.32	0.52 ± 0.16	<0.2
Se (ppb)	7.8 ± 1.6	12.0 ± 1.14	-
Hg (ppb)	151.6 ± 7.1	2.53 ± 0.23	0.6 ± 0.04
Br (ppm)		0.021 ± 0.003	0.06 ± 0.001
Ni (ppm)	1.88 ± 0.05	<0.03	<0.02
Co (ppb)	47.1 ± 0.6	<3.0	1.88 ± 0.08
Cr (ppb)	3,681 ± 13.2	9.5 ± 1.1	3.07 ± 0.60
Fe (ppm)	162.2 ± 2.8	0.18 ± 0.05	0.5 ± 0.08
Na (ppm)	<1	5.0 ± 0.02	0.23 ± 0.002
Rb (ppm)	0.15 ± 0.014	<0.008	<0.005
Cs (ppb)	2.70 ± 0.40	0.70 ± 0.10	0.94 ± 0.06
K (ppm)	<1	<1	0.04 ± 0.01

SRC PILOT PLANT, EQUILIBRUM SET 1, LABORATORY SOLVENTS

	Light Oil - Water Phase	Wash Solvent	Process Solvent
Sc (ppb)	1.18 ± 0.03	0.02 ± 0.005	0.011 ± 0.003
Tb (ppb)	<0.6	<0.2	<0.1
Eu (ppm)	<0.001	<0.001	<0.001
Sm (ppm)	<0.01	<0.01	<0.01
Ce (ppm)	<0.01	<1.0	<0.02
La (ppm)	<0.001	<0.001	<0.001
Sr (ppm)	<0.3	1.0 ± 0.04	0.3 ± 0.1
Ba (ppm)	0.43 ± 0.09	<0.05	<0.06
Th (ppm)	<0.001	<0.001	<0.001
Hf (ppm)	<0.001	<0.001	<0.001
Ta (ppb)	<0.7	0.35 ± 0.08	<0.2
Ga (ppm)	<0.1	<0.1	<0.1
Zr (ppm)	<0.3	<0.1	<0.06
Cu (ppm)	<0.1	0.15 ± 0.005	0.02 ± 0.001

SRC PILOT PLANT, EQUILIBRIUM SET 1, AQUEOUS SAMPLES

	Process Water	Plant Effluent Water	Hamer Marsh Water
Ti (ppm)	<0.20	<0.08	<0.06
V (ppm)	<0.002	0.02 $\pm$ 0.001	0.01 $\pm$ 0.0003
Ca (ppm)	<1.0	4.4 $\pm$ 0.3	4.6 $\pm$ 0.3
Mg (ppm)	<2.0	1.9 $\pm$ 0.3	1.4 $\pm$ 0.3
Al (ppm)	0.54 $\pm$ 0.02	0.25 $\pm$ 0.005	0.2 $\pm$ 0.004
Cl (ppm)	32.4 $\pm$ 0.42	1.7 $\pm$ 0.05	2.6 $\pm$ 0.04
Mn (ppm)	0.02 $\pm$ 0.002	0.01 $\pm$ 0.001	0.012 $\pm$ 0.001
I (ppm)	<0.01	<0.01	< 0.01

SRC PILOT PLANT, AQUEOUS SAMPLES, EQU. SET 1

	Process Water	Plant Effluent Water	Hamer Marsh Water
As (ppb)	6.3 ± 0.12	<1.0	<1.0
Sb (ppb)	0.66 ± 0.02	2.0 ± 0.03	2.6 ± 0.04
Se (ppb)	159.0 ± 2.2	1.20 ± 0.04	0.9 ± 0.03
Hg (ppb)	106.3 ± 2.5	3.2 ± 0.08	1.0 ± 0.03
Br (ppb)	15.6 ± 0.28	31.8 ± 0.6	22.9 ± 0.5
Ni (ppb)	4 ± 0.5	13.0 ± 0.5	12 ± 0.5
Co (ppb)	0.2 ± 0.01	0.41 ± 0.007	0.34 ± 0.006
Cr (ppb)	7.4 ± 0.11	153.3 ± 1.3	137.3 ± 1.2
Fe (ppm)	0.30 ± 0.007	1.25 ± 0.02	0.82 ± 0.015
Na (ppm)	0.70 ± 0.003	8.3 ± 0.04	6.7 ± 0.03
Rb (ppb)	0.78 ± 0.2	0.52 ± 0.13	0.31 ± 0.08
Cs (ppb)	0.04 ± 0.004	0.022 ± 0.004	0.03 ± 0.003
K (ppm)	0.2 ± 0.02	1.26 ± 0.11	0.93 ± 0.07

SRC PILOT PLANT, AQUEOUS SAMPLES, EQU. SET 1

	Process Water	Plant Effluent Water	Hamer Marsh Water
Sc (ppb)	0.13 ± 0.001	0.01 ± 0.0004	0.02 ± 0.001
Tb (ppb)	0.01 ± 0.002	0.01 ± 0.002	<0.005
Eu (ppb)	0.01 ± 0.002	0.008 ± 0.003	0.006 ± 0.001
Sm (ppb)	0.08 ± 0.01	<0.06	<0.06
Ce (ppb)	<0.2	<0.2	1.5 ± 0.04
La (ppb)	0.27 ± 0.05	<0.5	<0.5
Sr (ppm)	<0.01	0.04 ± 0.002	<0.01
Ba (ppm)	<0.02	<0.04	<0.04
Th (ppb)	0.05 ± 0.006	<0.01	<0.01
Hf (ppb)	0.02 ± 0.005	<0.01	0.01 ± 0.003
Ta (ppb)	0.02 ± 0.004	0.01 ± 0.003	<0.02
Ga (ppb)	<1	<4	<4
Zr (ppm)	0.02 ± 0.001	0.04 ± 0.002	0.06 ± 0.002
Cu (ppb)	<12	<10	<10
Zn (ppm)	0.02 ± 0.003	0.02 ± 0.003	0.06 ± 0.004

SRC PILOT PLANT, EQUILIBRIUM SET 1, FILTERAID MATERIALS

	Celite-545 Basecoat	Fibra Flo 11C Basecoat	Celite 6000	Speed Plus	Speedex
Ti (ppm)	1544.4 ± 225.0	1516.0 ± 295.4	1449 ± 246		750 ± 250
V (ppm)	157.9 ± 3.90	197.4 ± 5.20	447.9 ± 5.3		391.3 ± 4.3
Ca (ppm)	3480 ± 868.9	3657 ± 943	35480 ± 1800	-	23100 ± 1820
Mg (ppm)	6427 ± 1168	14287 ± 1392	4660 ± 828		3400 ± 990
Al (%)	2.83 ± 0.102	2.98 ± 0.112	2.61 ± 0.048	-	3.45 ± 0.111
Cl (ppm)	-	-	-		201.5 ± 75.3
Mn (ppm)	72.1 ± 3.28	91.5 ± 3.10	57.9 ± 2.5	50.5 ± 2.3	87.3 ± 2.0

SRC PILOT PLANT, EQUILIBRIUM SET 1, FILTERAID MATERIALS

	Celite-545 Basecoat	Fibra Flo 11C Basecoat	Celite 6000	Speed Plus	.Speedex
As (ppm)	<17.0	<25.0	<20.0	<20.0	<18.0
Sb (ppm)	1.57 ± 0.045	1.74 ± 0.06	3.0 ± 0.06	2.73 ± 0.06	2.73 ± 0.09
Se (ppm)	0.78 ± 0.12	1.62 ± 0.13	2.11 ± 0.10	0.60 ± 0.10	
Hg (ppb)	-	-	-	272 ± 40	-
Br (ppm)	<30.0	<30.0	<30.0	<30.0	<30.0
Ni (ppm)	29.60 ± 2.13	146.2 ± 14.5	77.2 ± 2.50	73.0 ± 2.5	71.90 ± 4.40
Co (ppm)	2.82 ± 0.034	8.43 ± 0.077	2.92 ± 0.03	3.47 ± 0.036	2.81 ± 0.04
Cr (ppm)	67.1 ± 0.52	167.6 ± 1.43	105.6 ± 0.76	107.5 ± 0.77	107.3 ± 1.0
Fe (%)	1.20 ± 0.053	1.31 ± 0.064	1.10 ± 0.05	1.13 ± 0.05	1.24 ± 0.06
Na (ppm)	31227 ± 243	32117 ± 254	24715 ± 195	22837 ± 180	25757 ± 203
Rb (ppm)	28.0 ± 0.72	34.50 ± 1.17	28.73 ± 0.78	20.81 ± 0.60	20.60 ± 1.0
Cs (ppm)	1.80 ± 0.03	1.90 ± 0.04	1.58 ± 0.024	1.45 ± 0.024	1.48 ± 0.045
K (ppm)	5672 ± 700	7090 ± 980	5976 ± 764	2263 ± 478	4462 ± 585

SRC PILOT PLANT, EQUILIBRIUM SET 1, FILTERAID MATERIALS

	Celite-545 Basecoat	Fibra Flo 11C Basecoat	Celite 6000	Speed Plus	Speedex
Sc (ppm)	4.51 ± 0.013	4.51 ± 0.018	3.51 ± 0.01	4.40 ± 0.012	3.82 ± 0.016
Tb (ppm)	0.41 ± 0.011	0.28 ± 0.015	0.34 ± 0.009	0.41 ± 0.009	0.39 ± 0.018
Eu (ppm)	0.32 ± 0.005	0.22 ± 0.005	0.34 ± 0.005	0.22 ± 0.004	0.24 ± 0.04
Sm (ppm)	4.69 ± 0.61	2.04 ± 0.36	<2.0	<2.0	4.56 ± 0.61
Ce (ppm)	23.10 ± 0.11	25.6 ± 0.19	21.07 ± 0.10	25.41 ± 0.11	24.0 ± 0.20
La (ppm)	4.91 ± 1.44	16.5 ± 3.05	<7.0	11.54 ± 2.28	9.46 ± 2.10
Sr (ppm)	88.1 ± 11.0		258.0 ± 7.9	170.0 ± 9.7	
Ba (ppm)	296.4 ± 8.1	293.0 ± 11.8	415.0 ± 7.65	318.3 ± 6.5	301.5 ± 13.0
Th (ppm)	4.74 ± 0.02	3.86 ± 0.03	3.20 ± 0.016	4.05 ± 0.017	3.84 ± 0.03
Hf (ppm)	1.30 ± 0.02	1.28 ± 0.03	1.11 ± 0.017	1.10 ± 0.018	1.06 ± 0.03
Ta (ppm)	0.32 ± 0.02	0.35 ± 0.03	0.28 ± 0.016	0.27 ± 0.016	0.25 ± 0.025
Ga (ppm)	<25.0	<25.0	<25.0	<25.0	<25.0
Zr (ppm)	129.0 ± 8.3	144.0 ± 14.5	203.0 ± 7.9	210.0 ± 10.3	161.0 ± 15.0
Cu (ppm)	113.5 ± 27.8	139.0 ± 18.3	85.6 ± 13.2	104.1 ± 23.2	148.0 ± 27.0

APPENDIX C

TRACE ELEMENT DATA FOR EQUILIBRIUM SET 2

EQUILIBRIUM SET 2

Plant Samples - Description

(composite of the period 5/13/76, 1600 hrs.
through 5/14/76, 1600 hrs.)

Sample No.	Description
1	Solvent Refined Coal
2	Feed coal
3	Ground coal
4	Mineral residue
5	Coal dust from Scavenger
6	Speedex Filteraid
7	Fibra Flow 11C basecoat
8	Speed Plus Filteraid
9	Dicalite 6000 basecoat
10	Sludge from Bio-Unit aeration section
11	Light oil
12	Wash solvent
13	Process solvent
14	Process water
15	Plant effluent water
16	Hamer Marsh water

EQUILIBRIUM SET 2 (continued)

Laboratory Prepared Samples - Description

Sample No.	Description	Composite Dates
17	Pyridine insolubles	3/5/76 - 5/13/76
18	Ash of pyridine insolubles	" "
19	Wet filter cake	" "
20	Vacuum bottoms	" "
21	Process solvent	" "
22	Wash solvent	" "
23	Light oil/water composite	" "

SRC PILOT PLANT, EQUILIBRIUM SET 2

	Raw Coal	Ground Coal	Solvent Refined Coal	Mineral Residue	Vacuum Bottom
Ti (ppm)	659.9 ± 165.9	<700.0	489.9 ± 33.0	2117.8 ± 717.5	282.3 ± 21.70
V (ppm)	29.2 ± 1.51	< 27.0	13.65 ± 0.21	160.3 ± 6.45	6.78 ± 0.16
Ca (ppm)	657.8 ± 182	<1200.0	122.9 ± 48.2	10676 ± 1477	<95.0
Mg (ppm)	<2300.0	<2400.0	96.0 ± 39.2	4780.0 ± 1044.0	<100.0
Al (%)	1.242 ± 0.17	1.58 ± 0.22	0.042 ± 0.008	3.864 ± 0.371	0.052 ± 0.010
Cl (ppm)	249.7 ± 7.3	289.4 ± 6.65	99.0 ± 3.68	975.7 ± 47.54	18.6 ± 1.05
Mn (ppm)	34.8 ± 0.37	35.7 ± 0.40	14.2 ± 0.16	143.5 ± 1.50	1.146 ± 0.28

SRC PILOT PLANT, EQUILIBRIUM SET 2, RAW MATERIALS AND PRODUCTS

	Raw Coal	Ground Coal	Solvent Refined Coal	Mineral Residue
As (ppm)	21.2 ± 0.015	20.10 ± 0.17	2.27 ± 0.03	81.2 ± 1.65
Sb (ppm)	1.13 ± 0.06	1.43 ± 0.047	0.06 ± 0.006	6.10 ± 0.12
Se (ppm)	2.24 ± 0.21	3.03 ± 0.13	0.08 ± 0.015	10.94 ± 0.26
Hg (ppb)	--	114.3 ± 15.6	46.7 ± 12.5	1182 ± 135
Br (ppm)	3.24 ± 0.12	3.72 ± 0.14	4.93 ± 0.065	5.28 ± 1.57
Ni (ppm)	<18.0	12.44 ± 2.51	<2.0	118.3 ± 7.81
Co (ppm)	6.0 ± 0.07	5.20 ± 0.05	0.25 ± 0.006	23.2 ± 0.17
Cr (ppm)	14.9 ± 0.31	14.80 ± 0.20	5.50 ± 0.055	107.9 ± 0.86
Fe (%)	2.90 ± 0.14	2.38 ± 0.11	0.026 ± 0.001	11.0 ± 0.49
Na (ppm)	144.0 ± 0.83	172.6 ± 0.94	6.30 ± 0.08	2882.0 ± 22.1
Rb (ppm)	11.90 ± 1.1	11.80 ± 0.63	<0.3	74.72 ± 2.16
Cs (ppm)	1.03 ± 0.05	0.91 ± 0.03	<0.02	4.26 ± 0.067
K (ppm)	1736.0 ± 22.0	2028.0 ± 23.9	2.27 ± 0.61	11121 ± 226

SRC PILOT PLANT, EQUILIBRIUM SET 2, RAW MATERIALS AND PRODUCTS

	Raw Coal	Ground Coal	Solvent Refined Coal	Mineral Residue
Sc (ppm)	2.71 ± 0.012	2.48 ± 0.008	0.36 ± 0.001	9.00 ± 0.02
Tb (ppm)	0.29 ± 0.02	0.32 ± 0.016	0.03 ± 0.002	0.23 ± 0.015
Eu (ppm)	0.24 ± 0.007	0.20 ± 0.005	0.027 ± 0.001	0.75 ± 0.011
Sm (ppm)	2.29 ± 0.013	1.65 ± 0.01	0.117 ± 0.002	7.73 ± 0.17
Ce (ppm)	30.54 ± 0.25	20.8 ± 0.12	0.34 ± 0.015	93.2 ± 0.31
La (ppm)	8.0 ± 0.10	6.56 ± 0.09	0.09 ± 0.007	36.3 ± 1.0
Sr (ppm)	134.0 ± 14.6	158.0 ± 17.0	<4.0	316.0 ± 20.0
Ba (ppm)	53.2 ± 7.45	62.5 ± 4.73	<2.0	294.0 ± 15.8
Th (ppm)	2.16 ± 0.03	1.90 ± 0.015	0.19 ± 0.003	8.58 ± 0.04
Hf (ppm)	0.57 ± 0.03	0.59 ± 0.017	0.069 ± 0.003	2.51 ± 0.043
Ta (ppm)	0.10 ± 0.02	0.17 ± 0.015	0.05 ± 0.004	0.59 ± 0.042
Ga (ppm)	2.27 ± 0.06	3.26 ± 0.074	<1.6	13.51 ± 1.09
Zr (ppm)	57.3 ± 11.2	79.0 ± 8.4	6.4 ± 1.2	328.0 ± 20.4
Cu (ppm)	13.2 ± 1.75	14.3 ± 2.0	1.15 ± 0.20	84.0 ± 8.25

SRC PILOT PLANT, EQUILIBRIUM SET 2, LABORATORY SAMPLES

	Pyridine Insolubles	Ash of Pyridine Insolubles	Wet Filter Cake	Coal Dust	Biosludge
Ti (ppm)	4480 ± 1051	<4200.0	<1500.0	<500.0	--
V (ppm)	225.5 ± 7.91	376.5 ± 20.7	102.6 ± 4.85	35.9 ± 2.36	595.6 ± 10.5
Ca (ppm)	10183 ± 2523	19437 ± 2125.5	10271 ± 1071	19283 ± 1387	1964 ± 702.4
Mg (ppm)	5288 ± 1816	13675 ± 2022	4550 ± 2045	<5400	--
Al (%)	6.836 ± 0.65	10.36 ± 1.85	2.84 ± 0.408	1.602 ± 0.230	2.13 ± 0.38
Cl (ppm)	668.3 ± 35.4	<400.0	970.2 ± 25.0	152.6 ± 9.13	562.3 ± 25.9
Mn (ppm)	218.8 ± 2.1	308.7 ± 2.5	146.6 ± 1.42	72.0 ± 0.75	20.74 ± 0.66

SRC PILOT PLANT, EQUILIBRIUM SET 2, LAB PREPARED SAMPLES

	Pyridine Insolubles	Ash of Pyridine Insolubles	Wet Filter Cake	Vacuum Bottom	Biosludge
Sc (ppm)	18.5 ± 0.067	22.0 ± 0.08	12.3 ± 0.05	0.24 ± 0.001	0.80 ± 0.003
Tb (ppm)	2.41 ± 0.06	--	1.64 ± 0.06	0.02 ± 0.002	0.12 ± 0.006
Eu (ppm)	1.06 ± 0.018	1.48 ± 0.025	0.77 ± 0.021	0.015 ± 0.001	0.06 ± 0.002
Sm (ppm)	10.37 ± 0.19	14.45 ± 0.22	7.47 ± 0.12	0.047 ± 0.002	<1.50
Ce (ppm)	130.7 ± 0.63	177.6 ± 0.83	94.6 ± 0.70	0.40 ± 0.024	3.21 ± 0.06
La (ppm)	37.44 ± 0.88	56.62 ± 1.06	25.85 ± 0.55	0.064 ± 0.007	<2.0
Sr (ppm)	<74.0	<300.0	270.5 ± 49.6	<6.0	<10.0
Ba (ppm)	409.0 ± 28.4	545.6 ± 37.5	390.0 ± 31.6	<2.0	29.0 ± 2.24
Th (ppm)	12.58 ± 0.076	18.06 ± 0.11	9.30 ± 0.085	0.14 ± 0.004	1.80 ± 0.009
Hf (ppm)	4.32 ± 0.10	4.99 ± 0.12	3.0 ± 0.10	0.09 ± 0.007	0.34 ± 0.009
Ta (ppm)	1.07 ± 0.09	1.71 ± 0.14	0.81 ± 0.09	0.034 ± 0.005	0.04 ± 0.006
Ga (ppm)	13.10 ± 0.75	21.51 ± 0.74	10.31 ± 0.44	0.61 ± 0.02	9.30 ± 2.33
Zr (ppm)	422.0 ± 40.0	471.0 ± 51.6	373.4 ± 43.8	4.0 ± 1.0	41.5 ± 3.51
Cu (ppm)	93.0 ± 7.45	130.2 ± 8.7	93.70 ± 4.35	33.4 ± 4.35	103.3 ± 17.6
Zn (ppm)	<8.0	<20.0	<10.0	<0.4	308.7 ± 1.52

SRC PILOT PLANT, EQUILIBRUM SET 2, PLANT SOLVENTS

	Light Oil	Process Recycle Solvent	Wash Solvent
Ti (ppm)	2.5 ± 0.67	15.0 ± 1.0	1.8 ± 0.5
V (ppm)	0.44 ± 0.007	0.80 ± 0.008	0.32 ± 0.006
Ca (ppm)	<12	9.7 ± 2.6	<6
Mg (ppm)	10.5 ± 2.4	<8	7.2 ± 2.3
Al (ppm)	74 ± 1.6	41.6 ± 0.78	56.4 ± 2.24
Cl (ppm)	300 ± 1.1	38.9 ± 0.49	115 ± 0.5
Mn (ppm)	<0.09	1.27 ± 0.2	0.16 ± 0.015
I (ppm)	<0.03	<0.07	<0.03

SRC PILOT PLANT EQUILIBRUM, SET 2, PLANT SOLVENTS

	Light Oil	Process Recycle Solvent	Wash Solvent
As (ppb)	2.83 ± 0.22	243.1 ± 1.9	68.4 ± 0.32
Sb (ppb)	1.84 ± 0.19	9.2 ± 0.71	
Se (ppb)	23.4 ± 0.9	33.5 ± 1.4	12.4 ± 0.7
Hg (ppb)	3.4 ± 0.22	<1	10.2 ± 0.5
Br (ppb)	18.2 ± 1.0	752.0 ± 7.0	47.7 ± 1.4
Ni (ppm)	0.04 ± 0.009	0.22 ± 0.023	<0.04
Co (ppb)	1.8 ± 0.13	37.6 ± 0.4	1.20 ± 0.10
Cr (ppb)	<5	2,415 ± 7	11.8 ± 0.74
Fe (ppm)	0.3 ± 0.05	57.5 ± 1.0	7.0 ± 0.15
Na (ppm)	0.04 ± 0.004	1.18 ± 0.09	0.33 ± 0.004
Rb (ppm)	<0.012	<0.02	<0.008
Cs (ppb)	0.84 ± 0.1	1.53 ± 0.4	1.02 ± 0.11
K (ppm)	0.20 ± 0.03	<0.5	0.22 ± 0.04

SRC PILOT PLANT, EQUILIBRUM SET 2, PLANT SOLVENTS

	Light Oil	Process Recycle Solvent	Wash Solvent
Sc (ppb)	0.13 ± 0.008	24.5 ± 0.07	0.10 ± 0.06
Tb (ppb)	<0.13	1.7 ± 0.11	<0.2
Eu (ppm)	<0.001	<0.001	<0.001
Sm (ppb)	<0.01	10.1 ± 0.15	0.15 ± 0.04
Ce (ppm)	<0.005	0.03 ± 0.001	<0.004
La (ppb)	<0.001	9.3 ± 0.77	<0.001
Sr (ppm)	<0.09	<0.2	<0.1
Ba (ppm)	<0.1	0.18 ± 0.04	<0.06
Th (ppm)	<0.001	0.015 ± 0.0002	<0.001
Hf (ppm)	<0.001	0.004 ± 0.0002	<0.001
Ta (ppb)	<0.5	3.20 ± 0.23	<0.4
Ga (ppb)	<0.1	34.3 ± 0.9	<0.1
Zr (ppm)	<0.1	0.34 ± 0.07	<0.1
Cu (ppm)	0.02 ± 0.001	0.23 ± 0.003	0.02 ± 0.001

SRC PILOT PLANT, EQUILIBRUM SET 2, LABORATORY SOLVENTS

	Light Oil - Water Phase	Wash Solvent	Process Solvent
Ti (ppm)	<2.4	3.1 ± 0.43	<2
V (ppm)	0.05 ± 0.003	0.20 ± 0.005	0.27 ± 0.008
Ca (ppm)	20.9 ± 2.8	14.4 ± 4	7.4 ± 2.2
Mg (ppm)	<12	16.6 ± 2.8	<9
Al (ppm)	6.3 ± 0.28	13.5 ± 0.3	43.3 ± 1.0
Cl (ppm)	14.2 ± 0.71	6.5 ± 0.15	51.4 ± 0.62
Mn (ppm)	<0.3	<0.2	0.027 ± 0.0073
I (ppm)	7.76 ± 0.16	1.98 ± 0.013	0.125 ± 0.017

SRC PILOT PLANT, EQUILIBRUM SET 2, LABORATORY SOLVENT

	Light Oil - Water Phase	Wash Solvent	Process Solvent
As (ppb)	<0.1	13.8 $\pm$ 1.5	60.7 $\pm$ 0.9
Sb (ppb)	<0.1	<0.1	0.7 $\pm$ 0.2
Se (ppb)	<3.6	29.9 $\pm$ 1.6	30.3 $\pm$ 1.3
Hg (ppb)	79.6 $\pm$ 2.8	18.3 $\pm$ 0.9	2.3 $\pm$ 0.17
Br (ppb)	<0.1	40.0 $\pm$ 6.8	10.9 $\pm$ 0.7
Ni (ppm)	0.07 $\pm$ 0.009	0.14 $\pm$ 0.03	0.09 $\pm$ 0.009
Co (ppb)	4.3 $\pm$ 0.10	10.3 $\pm$ 0.31	6.30 $\pm$ 0.22
Cr (ppb)	16.0 $\pm$ 0.8	21.2 $\pm$ 0.8	17.5 $\pm$ 1.2
Fe (ppm)	0.22 $\pm$ 0.025	0.8 $\pm$ 0.01	0.7 $\pm$ 0.3
Na (ppm)	<0.01	14.8 $\pm$ 0.05	0.17 $\pm$ 0.004
Rb (ppm)	0.013 $\pm$ 0.004	<0.03	<0.009
Cs (ppb)	2.06 $\pm$ 0.09	3.0 $\pm$ 0.35	4.06 $\pm$ 0.16
K (ppm)	<1	0.80 $\pm$ 0.22	<1

SRC PILOT PLANT, EQUILIBRUM SET 2, LABORATORY SOLVENTS

	Light Oil - Water Phase	Wash Solvent	Process Solvent
Sc (ppb)	0.092 ± 0.006	0.31 ± 0.03	0.14 ± 0.006
Tb (ppb)	<0.14	<0.7	<0.2
Eu (ppm)	<0.001	<0.001	<0.001
Sm (ppb)	<0.01	<0.01	<0.01
Ce (ppm)	<0.003	<0.005	<0.005
Sr (ppm)	<0.07	<0.2	<0.1
Ba (ppm)	0.17 ± 0.02	0.3 ± 0.07	<0.09
Th (ppm)	<0.001	<0.0001	<0.0001
Hf (ppm)	<0.001	<0.001	<0.001
Ta (ppb)	<0.3	<0.5	<0.4
Ga (ppb)	<0.1	<0.1	<0.1
Zr (ppm)	<1	<0.4	<0.1
Cu (ppm)	<0.1	0.44 ± 0.005	0.07 ± 0.001

SRC PILOT PLANT, EQUILIBRIUM SET 2, AQUEOUS SAMPLES

	Process Water	Plant Effluent Water	Hamer Marsh Water
Ti (ppm)	<0.3	<0.2	<0.3
V (ppm)	<0.001	0.009 ± 0.001	0.008 ± 0.001
Ca (ppm)	<1.0	9.6 ± 0.7	5.0 ± 0.7
Mg (ppm)	<1.7	4.2 ± 0.7	2.4 ± 0.7
Al (ppm)	0.4 ± 0.01	0.25 ± 0.01	0.73 ± 0.09
Cl (ppm)	17.0 ± 0.2	3.7 ± 0.2	3.1 ± 0.07
Mn (ppm)	0.04 ± 0.002	0.03 ± 0.003	0.02 ± 0.002
I (ppm)	<0.01	<0.06	<0.01

SRC PILOT PLANT, AQUEOUS SAMPLES, EQU. SET 2

	Process Water	Plant Effluent Water	Hamer Marsh Water
As (ppb)	10.7 ± 0.36	<5	<5.0
Sb (ppb)	1.0 ± 0.02	0.64 ± 0.02	0.5 ± 0.02
Se (ppb)	914.3 ± 13.0	0.37 ± 0.04	0.45 ± 0.03
Hg (ppb)	20.7 ± 0.5	5.5 ± 0.14	0.38 ± 0.01
Br (ppb)	18.3 ± 0.75	<10	28.1 ± 1.4
Ni (ppb)	14.0 ± 1.1	16.0 ± 0.9	7.0 ± 0.5
Co (ppb)	0.43 ± 0.008	0.36 ± 0.008	0.26 ± 0.005
Cr (ppb)	11.30 ± 0.16	10.1 ± 0.12	6.2 ± 0.07
Fe (ppm)	1.34 ± 0.02	0.41 ± 0.009	0.36 ± 0.007
Na (ppm)	5.1 ± 0.03	<10	42.4 ± 0.23
Rb (ppb)	0.77 ± 0.18	1.36 ± 0.2	0.91 ± 0.12
Cs (ppb)	0.04 ± 0.006	0.06 ± 0.005	0.05 ± 0.003
K (ppm)	0.73 ± 0.10	<1	<8

SRC PILOT PLANT, AQUEOUS SAMPLES, EQU. SET 2

	Process Water	Plant Effluent Water	Hamer Marsh Water
Sc (ppb)	0.12 ± 0.001	0.12 ± 0.001	0.11 ± 0.001
Tb (ppb)	<0.01	<0.01	<0.01
Eu (ppb)	0.012 ± 0.002	0.015 ± 0.002	0.013 ± 0.001
Sm (ppb)	<0.1	<0.1	<0.1
Ce (ppb)	<0.2	6.5 ± 0.11	0.40 ± 0.02
La (ppb)	<0.7	<0.01	<1.2
Sr (ppm)	<0.02	<0.01	<0.01
Ba (ppm)	<0.02	<0.01	<0.01
Th (ppb)	<0.04	0.09 ± 0.004	0.09 ± 0.003
Hf (ppb)	0.04 ± 0.008	0.02 ± 0.004	0.02 ± 0.002
Ta (ppb)	0.02 ± 0.005	<0.02	<0.01
Ga (ppb)	<4	<4	<10
Zr (ppm)	0.02 ± 0.002	0.02 ± 0.001	0.01 ± 0.001
Cu (ppb)	243.5 ± 2.3	<25	<25
Zn (ppm)	0.3 ± 0.002	0.06 ± 0.001	0.09 ± 0.001

SRC PILOT PLANT, EQUILIBRIUM SET 2, FILTERAID MATERIALS

	Speedex Filteraid	Fibra Flo 11C Basecoat	Speed plus Filteraid	Dicalite 6000 basecoat
Ti (ppm)	-	-	1270.0 ± 516.1	1396.0 ± 632.0
V (ppm)	456.6 ± 7.90	194.0 ± 6.15	247.5 ± 4.94	244.8 ± 5.94
Ca (ppm)	--	17708 ± 1895	24776 ± 1944	49563 ± 2953
Mg (ppm)	3468 ± 1109	7253 ± 1352	-	2902 ± 954.0
Al (%)	2.98 ± 0.15	3.47 ± 0.17	1.51 ± 0.30	1.52 ± 0.303
Cl (ppm)	182.7 ± 34.1	912.3 ± 23.9	117.8 ± 32.8	352.6 ± 51.0
Mn (ppm)	50.2 ± 1.64	105.1 ± 2.9	52.2 ± 1.48	74.9 ± 1.76

SRC PILOT PLANT, EQUILIBRIUM SET 2, FILTERAID MATERIALS

	Speedex Filteraid	Fibra Flo 11C Basecoat	Speed plus Filteraid	Dicalite 6000 Basecoat
As (ppm)	12.80 ± 3.20	<25.0	<18.0	<20.6
Sb (ppm)	2.85 _ 0.08	1.51 ± 0.045	2.236 ± 0.041	2.94 ± 0.07
Se (ppm)	1.00 ± 0.12	1.36 ± 0.11	0.63 ± 0.073	1.74 ± 0.14
Hg (ppb)	103.4 ± 12.5	138.7 ± 16.6	277.0 ± 9.50	<250.0
Br (ppm)	<25.0	<25.0	<30.0	<25.0
Ni (ppm)	74.4 ± 3.44	121.0 ± 3.40	60.0 ± 1.8	72.8 ± 3.0
Co (ppm)	2.50 ± 0.04	6.44 ± 0.06	3.11 ± 0.03	2.62 ± 0.03
Cr (ppm)	94.5 ± 0.72	120.2 ± 1.02	90.9 ± 0.64	91.4 ± 0.8
Fe (%)	0.90 ± 0.04	1.114 ± 0.055	0.88 ± 0.04	1.05 ± 0.051
Na (ppm)	22518 ± 164	28254 ± 207	20993 ± 157	22497 ± 165
Rb (ppm)	20.50 ± 0.77	26.24 ± 0.76	20.02 ± 0.50	20.3 ± 0.7
Cs (ppm)	1.38 ± 0.031	1.64 ± 0.032	1.11 ± 0.02	1.52 ± 0.031
K (ppm)	4969 ± 499	8008 ± 955	3515 ± 548	4560 ± 564

SRC PILOT PLANT, EQUILIBRIUM SET 2, FILTERAID MATERIALS

	Speedex Filteraid	Fibra Flo 11C Basecoat	Speed Plus Filteraid	Dicalite 6000 Basecoat
Sc (ppm)	3.54 ± 0.011	3.76 ± 0.014	3.85 ± 0.01	3.0 ± 0.01
Tb (ppm)	0.31 ± 0.012	0.28 ± 0.013	0.34 ± 0.007	0.32 ± 0.011
Eu (ppm)	0.22 ± 0.006	0.17 ± 0.004	0.30 ± 0.004	0.18 ± 0.004
Sm (ppm)	<4.2	<2.0	<2.0	2.70 ± 0.33
Ce (ppm)	19.06 ± 0.11	21.0 ± 0.14	20.53 ± 0.10	18.76 ± 0.13
La (ppm)	7.14 ± 1.27	7.55 ± 1.41	<10.0	9.76 ± 1.61
Sr (ppm)	<29.0	<19	132.0 ± 7.2	206.4 ± 11.4
Ba (ppm)	332.0 ± 10.0	238.3 ± 8.0	253.0 ± 4.5	324.6 ± 8.04
Th (ppm)	3.53 ± 0.02	3.34 ± 0.02	3.10 ± 0.012	2.75 ± 0.02
Hf (ppm)	0.97 ± 0.02	1.10 ± 0.02	0.83 ± 0.012	1.00 ± 0.02
Ta (ppm)	0.23 ± 0.02	0.28 ± 0.023	0.21 ± 0.012	0.24 ± 0.02
Ga (ppm)	<25.0	<25.0	<25.0	<25.0
Zr (ppm)	151 ± 10.2	126 ± 13.0	171.0 ± 7.9	137.0 ± 11.0
Cu (ppm)	110.0 ± 12.5	88.0 ± 6.3	93.2 ± 8.5	102.8 ± 19.5

APPENDIX D

TRACE ELEMENT DATA FOR 35 SRC RAILCAR SHIPMENTS

Description of Samples

Various SRC

Sample No.	Description
393	SRC Car No. UP 18595, ash = 0.15%
394	SRC Car No. UP 18609, ash = 0.14%
395	SRC Car No. UP 39003, ash = 0.10%
396	SRC Car No. UP 39004L, ash = 0.26%
397	SRC Car No. UP 39005, ash = 0.29%
398	SRC Car No. UP 39006, ash = 0.16%
399	SRC Car No. UP 73116, ash = 0.46%
400	SRC Car No. BN 522549, ash = 0.54%
401	SRC Sample No. 109801 ash = 0.31%
412	Raw coal, Jan + Feb.composite, ash = 11.19%
413	SRC 39707 - Car No. UP 18609, ash = 0.14%
414	SRC 36390 - Car No. UP 18579, ash = 0.14%
415	SRC 36372 - Car No. UP 18595, ash = 0.16%
416	SRC 39711 - Car No. UP 38979, ash = 0.17%
417	SRC 39467 - Car No. UP 18711, ash = 0.17%
418	SRC 39797 - Car No. UP 18481, ash = 0.14%
419	SRC 39710 - Car No. UP 18396, ash = 0.14%
477	SRC Car No. UP 38796, ash = 0.19%
478	SRC Car No. UP 37802, ash = 0.16%
479	SRC Car No. 36772, ash = 0.14%
480	SRC Car No. 18155, ash = 0.15%
551	Railroad Car No. 522549, ash = 0.25%
552	Railroad Car No. 522112, ash = 0.17%
553	Railroad Car No. 73548, ash = 0.14%
554	Railroad Car No. 73279, ash = 0.17%
555	Railroad Car No. 160850, ash = 0.16%
556	Railroad Car No. 160599, ash = 0.16%
621	Railroad Car No. WP 10280, ash = 0.10%
622	Railroad Car No. WP 10151, ash = 0.09%

Description of Samples (continued)
Various SRC

Sample No.	Description
623	Railroad Car No. WP 10110, ash = 0.15%
624	Railroad Car No. WP 10247, ash = 0.20%
625	Railroad Car No. WP 10235, ash = 0.12%
626	Railroad Car No. WP 10101, ash = 0.16%
627	Railroad Car No. WP 10123, ash = 0.14%
628	Railroad Car No. WP 10138, ash = 0.12%
629	Railroad Car No. BN 522171, ash = 0.16%

SRC PILOT PLANT, VARIOUS CARLOADS SRC

	UP-18595 (393)	UP-18609 (394)	UP-39003 (395)	UP-39005 (397)	UP-39006 (398)
Ti (ppm)	315.4 ± 10.2	329.2 ± 11.2	219.4 ± 8.9	258.4 ± 8.24	323.6 ± 9.2
V (ppm)	8.55 ± 0.13	7.94 ± 0.14	7.65 ± 0.11	7.0 ± 0.10	8.7 ± 0.12
Ca (ppm)	124.6 ± 27.9	147.0 ± 33.0	146.8 ± 29.0	139.7 ± 30.6	147.0 ± 30.8
Mg (ppm)	62.3 ± 34.7	<80.0	69.8 ± 23.4	<90.0	102.2 ± 40.0
Al (ppm)	391.3 ± 7.6	426.0 ± 7.9	376.3 ± 13.8	214.5 ± 3.90	405.8 ± 7.21
Cl (ppm)	113.6 ± 3.6	177.5 ± 7.3	159.0 ± 9.44	128.4 ± 4.32	85.6 ± 2.4
Mn (ppm)	14.1 ± 0.20	19.4 ± 0.27	14.3 ± 0.20	11.9 ± 0.2	9.20 ± 0.16
I (ppm)	1.50 ± 0.18	2.08 ± 0.40	<1.4	1.34 ± 0.20	1.36 ± 0.09

SRC PILOT PLANT, VARIOUS CARLOADS SRC

	UP-73116 (399)	BN-522549 (400)	109801 (401)	UP-39004L (396)
Ti (ppm)	317.2 ± 8.70	343.8 ± 9.5	99.7 ± 8.35	334.2 ± 10.4
V (ppm)	10.8 ± 0.10	16.2 ± 0.20	7.83 ± 0.15	7.47 ± 0.10
Ca (ppm)	167.4 ± 29.2	215.6 ± 28.0	59.0 ± 20.5	193.5 ± 32.0
Mg (ppm)	<90.0	74.2 ± 40.2	<85.0	<100.0
Al (ppm)	613.9 ± 21.5	835.9 ± 33.0	616.3 ± 25.4	590.5 ± 12.9
Cl (ppm)	135.7 ± 6.75	147.0 ± 3.3	48.0 ± 2.7	90.8 ± 3.20
Mn (ppm)	14.9 ± 0.20	15.3 ± 0.2	11.2 ± 0.17	9.0 ± 0.11
I (ppm)	1.45 ± 0.50	1.08 ± 0.09	1.80 ± 0.13	1.27 ± 0.2

SRC PILOT PLANT, VARIOUS CARLOADS SRC

	Raw Coal (412)	SRC-39707 (413)	SRC-36390 (414)	SRC-36372 (415)
Ti (ppm)	509.1 ± 92.1	292.7 ± 17.7	325.7 ± 9.62	304.7 ± 11.32
V (ppm)	33.7 ± 1.40	7.41 ± 0.22	7.89 ± 0.11	8.78 ± 0.15
Ca (ppm)	1631 ± 233.8	143.8 ± 33.6	290.0 ± 45.2	182.2 ± 46.6
Mg (ppm)	1355 ± 128.3	<100.0	<125.0	155.8 ± 44.8
Al (ppm)	11600 ± 200	170.0 ± 13.4	168.0 ± 3.2	427.0 ± 8.4
Cl (ppm)	277.0 ± 11.3	137.0 ± 4	117.2 ± 3.5	118.9 ± 5.13
Mn (ppm)	37.0 ± 0.5	18.2 ± 0.3	14.0 ± 0.2	15.0 ± 0.22
I (ppm)	1.0 ± 0.8	1.52 ± 0.13	1.24 ± 0.16	1.28 ± 0.33

SRC PILOT PLANT, VARIOUS CARLOADS SRC

	SRC-39711 (416)	SRC-39467 (417)	SRC-39797 (418)	SRC-39710 (419)
Ti (ppm)	346.7 $\pm$ 10.0	243.0 $\pm$ 10.8	294.8 $\pm$ 11.9	217.6 $\pm$ 11.40
V (ppm)	10.3 $\pm$ 0.11	9.60 $\pm$ 0.13	7.75 $\pm$ 0.11	9.3 $\pm$ 0.14
Ca (ppm)	199.3 $\pm$ 33.8	125.6 $\pm$ 26.6	<50.0	<50.0
Mg (ppm)	65.5 $\pm$ 30.5	<70.0	<70.0	<80.0
Al (ppm)	90.6 $\pm$ 2.8	158.0 $\pm$ 5.5	362 $\pm$ 6.9	351.0 $\pm$ 7.4
Cl (ppm)	105.8 $\pm$ 2.8	98.0 $\pm$ 3.54	113.6 $\pm$ 3.52	72.1 $\pm$ 3.62
Mn (ppm)	10.25 $\pm$ 0.19	18.3 $\pm$ 0.24	17.88 $\pm$ 0.23	9.32 $\pm$ 0.17
I (ppm)	1.28 $\pm$ 0.09	1.23 $\pm$ 0.16	1.77 $\pm$ 0.17	1.06 $\pm$ 0.22

SRC PILOT PLANT, VARIOUS CARLOADS SRC

	UP-38796 (477)	UP-37802 (478)	36772 (479)	18155 (480)
Ti (ppm)	329.3 ± 18.5	445.0 ± 26.2	434.6 ± 22.0	132.5 ± 9.5
V (ppm)	7.54 ± 0.11	12.2 ± 0.2	9.94 ± 0.15	3.0 ± 0.05
Ca (ppm)	232 ± 40	198 ± 45	138 ± 25	82.0 ± 16.0
Mg (ppm)	<108.0	<130.0	<80.0	<110.0
Al (ppm)	180.0 ± 5.0	180.0 ± 7.0	184.0 ± 10	90.0 ± 4.0
Cl (ppm)	144.0 ± 3.3	331.0 ± 5.6	142.2 ± 3.8	63.7 ± 1.61
Mn (ppm)	18.3 ± 0.20		17.6 ± 0.20	10.2 ± 0.12
I (ppm)	1.37 ± 0.15	2.21 ± 0.30	2.0 ± 0.26	0.70 ± 0.09

SRC PILOT PLANT, VARIOUS CARLOADS SRC

	RRCN-1650599 (556)	WP-10280 (621)	WP-10151 (622)	WP-10110 (623)	WP-10247 (624)
Ti (ppm)	271 ± 19	275 ± 9	299 ± 10	232 ± 9	415 ± 9
V (ppm)	9.4 ± 0.2	8.2 ± 0.1	7.2 ± 0.09	4.3 ± 0.07	12.2 ± 0.13
Ca (ppm)	115 ± 39	84 ± 20	<77	<80	84 ± 23
Mg (ppm)	<130	<114	<196	<131	<200
Al (ppm)	260 ± 7	87.7 ± 1.9	80 ± 1	40 ± 1	215 ± 2.4
Cl (ppm)	104.4 ± 2.5	127.0 ± 2.9	142.2 ± 2.5	141.3 ± 3.5	132.0 ± 2.9
Mn (ppm)	11.7 ± 0.2	13.5 ± 0.15	16.8 ± 0.2	18.5 ± 0.20	13.34 ± 0.35
I (ppm)	1.84 ± 0.13	2.2 ± 0.14	1.6 ± 0.13	2.0 ± 0.23	1.10 ± 0.14

SRC PILOT PLANT, VARIOUS CARLOADS SRC

	RRCN-5522549 (551)	RRCN-5522112 (552)	RRCN-73548 (553)	RRCN-73279 (554)	RRCN-160850 (555)
Ti (ppm)	356.4 ± 16.7	496.0 ± 25.9	292.0 ± 18.8	324.0 ± 15.4	444.8 ± 22.1
V (ppm)	13.4 ± 0.15	13.7 ± 0.20	11.0 ± 0.14	12.4 ± 0.13	11.0 ± 0.12
Ca (ppm)	<110	197 ± 41	123 ± 35	148 ± 54	184 ± 38
Mg (ppm)	183.0 ± 26.8	193.0 ± 65.0	<95	230.0 ± 44.4	<140
Al (ppm)	550 ± 18	760 ± 32	680 ± 11	780 ± 25	220 ± 90
Cl (ppm)	155.1 ± 2.8	116.1 ± 2.2	116.7 ± 2.3	112.8 ± 2.1	116.5 ± 2.9
Mn (ppm)	14.3 ± 0.14	19.7 ± 0.15	12.6 ± 0.2	15.9 ± 0.14	19.4 ± 0.14
I (ppm)	1.57 ± 0.16	1.22 ± 0.11	0.88 ± 0.08	1.02 ± 0.10	1.26 ± 0.21

SRC PILOT PLANT, VARIOUS CARLOADS SRC

	RRCN WP-10235 (625)	WP-10101 (626)	WP-10123 (627)	WP-10138 (628)	BN-522171 (629)
Ti (ppm)	319 ± 10	346 ± 9.4	405 ± 11	419 ± 14.7	396 ± 15.2
V (ppm)	8.5 ± 0.12	10.0 ± 0.12	11.54 ± 0.12	12.4 ± 0.5	11.7 ± 0.5
Ca (ppm)	<59	<60	176 ± 26	60 ± 16	105 ± 27
Mg (ppm)	<175	<175	<175	<200	<200
Al (ppm)	149 ± 3	161 ± 3	212 ± 2	322 ± 2.8	222 ± 3.5
Cl (ppm)	180 ± 4	137 ± 2.7	191 ± 4.3	96.3 ± 4.1	128.0 ± 5.5
Mn (ppm)	10.54 ± 0.13	16.0 ± 0.17	9.4 ± 0.14	14.5 ± 0.2	10.9 ± 0.2
I (ppm)	1.7 ± 0.11	1.60 ± 0.12	1.37 ± 0.22	1.36 ± 0.3	1.52 ± 0.5

SRC PILOT PLANT, VARIOUS CARLOADS SRC

	UP-18595 (393)	UP-18609 (394)	UP-39003 (395)	UP-39005 (397)	UP-39006 (398)
As (ppm)	1.711 ± 0.032	1.750 ± 0.034	1.67 ± 0.02	1.81 ± 0.022	1.70 ± 0.031
Sb (ppm)	0.087 ± 0.012	0.074 ± 0.010	0.095 ± 0.009	0.13 ± 0.01	0.09 ± 0.013
Se (ppm)	0.20 ± 0.05	<0.15	0.05 ± 0.013	0.072 ± 0.020	<0.12
Hg (ppb)	<45.0	<45.0	<50.0	<45.0	<50.0
Br (ppm)	5.3 ± 0.08	6.01 ± 0.091	5.63 ± 0.062	5.56 ± 0.063	4.37 ± 0.072
Ni (ppm)	<3.0	<3.0	<3.0	2.19 ± 0.43	<3.0
Co (ppm)	0.274 ± 0.010	0.266 ± 0.009	0.30 ± 0.007	0.376 ± 0.008	0.29 ± 0.010
Cr (ppm)	2.33 ± 0.08	2.60 ± 0.08	1.61 ± 0.035	3.13 ± 0.043	2.02 ± 0.078
Fe (%)	0.047 ± 0.004	0.042 ± 0.004	0.023 ± 0.001	0.101 ± 0.003	0.032 ± 0.003
Na (ppm)	6.87 ± 0.10	4.26 ± 0.072	4.82 ± 0.06	13.25 ± 0.11	8.53 ± 0.12
Rb (ppm)	<0.6	0.58 ± 0.16	<0.8	<0.7	<0.8
Cs (ppm)	<0.07	<0.07	<0.07	0.021 ± 0.005	<0.08
K (ppm)	5.78 ± 1.10	<7.0	<10.0	17.5 ± 1.23	6.71 ± 1.44

SRC PILOT PLANT, VARIOUS CARLOADS SRC

	UP-73116 (399)	BN-522549 (400)	SRC-109801 (401)	UP-39004L (396)
As (ppm)	2.04 ± 0.023	2.07 ± 0.025	1.155 ± 0.017	1.63 ± 0.020
Sb (ppm)	0.028 ± 0.006	0.25 ± 0.013	0.11 ± 0.008	0.12 ± 0.011
Se (ppm)	0.047 ± 0.013	0.141 ± 0.02	0.114 ± 0.015	0.15 ± 0.036
Hg (ppb)	< 82.0	76.20 ± 3.8	16.0 ± 2.0	7.17 ± 1.3
Br (ppm)	5.02 ± 0.06	4.80 ± 0.06	4.80 ± 0.056	4.86 ± 0.06
Ni (ppm)	1.06 ± 0.30	1.59 ± 0.37	1.81 ± 0.33	<1.5
Co (ppm)	0.033 ± 0.004	0.415 ± 0.007	0.26 ± 0.006	0.27 ± 0.007
Cr (ppm)	0.07 ± 0.022	4.44 ± 0.045	2.78 ± 0.032	3.51 ± 0.044
Fe (%)	0.01 ± 0.0009	0.096 ± 0.003	0.082 ± 0.003	0.046 ± 0.002
Na (ppm)	17.40 ± 0.13	43.27 ± 0.21	7.04 ± 0.07	18.05 ± 0.12
Rb (ppm)	<0.37	0.26 ± 0.076	<0.4	<0.5
Cs (ppm)	0.012 ± 0.002	<0.05	0.03 ± 0.004	0.021 ± 0.004
K (ppm)	24.12 ± 1.54	47.76 ± 2.07	39.44 ± 1.39	18.33 ± 1.20

SRC PILOT PLANT, VARIOUS CARLOADS SRC

	Raw Coal (412)	SRC-39707 (413)	SRC-36390 (414)	SRC-36372 (415)
As (ppm)	19.80 ± 0.10	2.266 ± 0.032	2.47 ± 0.022	1.61 ± 0.037
Sb (ppm)	1.55 ± 0.035	0.094 ± 0.008	0.117 ± 0.013	0.103 ± 0.009
Se (ppm)	3.06 ± 0.092	0.090 ± 0.0162	<0.10	0.095 ± 0.017
Hg (ppb)	< 60.0	< 60.0	<75.0	<75.0
Br (ppm)	4.89 ± 0.114	4.67 ± 0.074	4.64 ± 0.053	5.33 ± 0.075
Ni (ppm)	23.36 ± 2.68	<3.0	<3.0	<2.5
Co (ppm)	6.33 ± 0.057	0.327 ± 0.006	0.330 ± 0.011	0.266 ± 0.006
Cr (ppm)	15.40 ± 0.22	2.74 ± 0.039	1.87 ± 0.068	2.51 ± 0.038
Fe (%)	2.97 ± 0.24	0.037 ± 0.0013	0.031 ± 0.003	0.057 ± 0.002
Na (ppm)	188.0 ± 1.0	22.0 ± 0.17	5.80 ± 0.062	5.60 ± 0.09
Rb (ppm)	16.0 ± 0.84	<0.9	<1.0	<0.9
Cs (ppm)	0.92 ± 0.019	<0.08	<0.10	<0.10
K (ppm)	1987.3 ± 26.1	3.77 ± 0.91	2.81 ± 0.55	6.19 ± 0.87

SRC PILOT PLANT, VARIOUS CARLOADS SRC

	SRC-39711 (416)	SRC-39467 (417)	SRC-39797 (418)	SRC-39710 (419)
As (ppm)	2.29 ± 0.037	2.26 ± 0.028	1.57 ± 0.024	2.28 ± 0.022
Sb (ppm)	0.079 ± 0.011	0.15 ± 0.012	<0.10	0.072 ± 0.008
Se (ppm)	<0.1	<0.1	0.078 ± 0.017	0.12 ± 0.018
Hg (ppb)	<50	<60	<50	<45
Br (ppm)	4.51 ± 0.083	4.13 ± 0.062	5.39 ± 0.069	3.84 ± 0.049
Ni (ppm)	<2.0	<2.5	<2.0	2.14 ± 0.51
Co (ppm)	0.362 ± 0.01	0.388 ± 0.010		0.329 ± 0.007
Cr (ppm)	2.64 ± 0.004	5.55 ± 0.096	3.23 ± 0.036	3.16 ± 0.04
Fe (%)	0.04 ± 0.003	0.107 ± 0.009	0.026 ± 0.001	0.041 ± 0.001
Na (ppm)	7.96 ± 0.102	8.43 ± 0.091	6.54 ± 0.08	7.95 ± 0.08
Rb (ppm)	<1.0	<1.0	<1.0	<1.0
Cs (ppm)	<0.1	<0.1	<0.1	<0.1
K (ppm)	4.18 ± 0.85	19.44 ± 1.35	7.55 ± 1.03	10.12 ± 0.87

SRC PILOT PLANT, VARIOUS CARLOADS SRC

	UP-38796 (477)	UP-37802 (478)	36772 (479)	18155 (480)
As (ppm)	2.39 ± 0.03	2.500 ± 0.033	2.115 ± 0.03	2.35 ± 0.032
Sb (ppm)	<0.25	0.177 ± 0.016	0.161 ± 0.014	0.178 ± 0.018
Se (ppm)	0.22 ± 0.04	<0.5	0.103 ± 0.028	0.136 ± 0.038
Hg (ppb)	<50.0	<50.0	<40.0	<45.0
Br (ppm)	5.51 ± 0.075	6.09 ± 0.087	5.80 ± 0.08	14.1 ± 0.125
Ni (ppm)	3.41 ± 0.74	1.85 ± 0.50	<3.5	<3.0
Co (ppm)	0.37 ± 0.008	0.34 ± 0.01	0.311 ± 0.008	0.40 ± 0.012
Cr (ppm)	4.26 ± 0.053	3.56 ± 0.08	4.05 ± 0.054	3.82 ± 0.102
Fe (%)	0.060 ± 0.002	0.046 ± 0.004	0.030 ± 0.0011	0.032 ± 0.0028
Na (ppm)	9.83 ± 0.11	42.1 ± 0.30	7.07 ± 0.11	7.90 ± 0.10
Rb (ppm)	<1.0	<1.0	<1.0	<1.0
Cs (ppm)	< 0.1	<0.1	<0.1	<0.1
K (ppm)	11.05 ± 1.14	7.28 ± 1.28	4.24 ± 0.77	10.38 ± 1.60

SRC PILOT PLANT, VARIOUS CARLOADS SRC

	RRCN-1650599 (556)	WP-10280 (621)	WP-10151 (622)	WP-10110 (623)	WP-10247 (624)
As (ppm)	3.06 ± 0.05	2.40 ± 0.02	1.53 ± 0.01	2.04 ± 0.01	2.20 ± 0.02
Sb (ppm)	0.21 ± 0.007	0.11 ± 0.007	0.09 ± 0.005	0.12 ± 0.007	0.10 ± 0.01
Se (ppm)	0.170 ± 0.013	0.06 ± 0.01	0.06 ± 0.01	0.73 ± 0.13	0.11 ± 0.03
Hg (ppb)	< 50	2.6 ± 0.75	< 50	4.6 ± 1.4	< 50
Br (ppm)	5.17 ± 0.11	6.62 ± 0.06	6.74 ± 0.03	6.74 ± 0.05	5.44 ± 0.05
Ni (ppm)	1.71 ± 0.28	<1.0	1.4 ± 0.28	1.0 ± 0.3	<2.87
Co (ppm)	0.43 ± 0.004	0.17 ± 0.004	0.20 ± 0.003	0.23 ± 0.004	0.29 ± 0.007
Cr (ppm)	7.0 ± 0.07	2.4 ± 0.03	5.5 ± 0.04	4.2 ± 0.04	6.19 ± 0.06
Fe (ppm)	341 ± 5.2	140 ± 3	280 ± 4	300 ± 4	288 ± 5.6
Na (ppm)	11.27 ± 0.17	8.7 ± 0.09	6.90 ± 0.04	9.45 ± 0.08	17.4 ± 0.16
Rb (ppm)	<1.15	<0.22	<0.23	<0.26	<0.47
Cs (ppm)	<0.010	0.10 ± 0.002	<0.01	0.02 ± 0.002	0.02 ± 0.005
K (ppm)	11.9 ± 1.9	3.7 ± 0.54	3.13 ± 0.38	3.53 ± 0.45	6.5 ± 1.0

SRC PILOT PLANT, VARIOUS CARLOADS SRC

	RRCN-522549 (551)	RRCN-522112 (552)	RRCN-73548 (553)	RRCN-73279 (554)	RRCN-160850 (555)
As (ppm)	2.23 ± 0.06	2.53 ± 0.05	2.94 ± 0.06	3.14 ± 0.06	2.86 ± 0.06
Sb (ppm)	0.27 ± 0.008	0.20 ± 0.001	0.21 ± 0.007	0.28 ± 0.007	0.28 ± 0.008
Se (ppm)	0.19 ± 0.02	0.23 ± 0.04	0.13 ± 0.012	0.14 ± 0.015	0.14 ± 0.015
Hg (ppb)	<50	<50	<50	<50	<50
Br (ppm)	5.87 ± 0.15	5.54 ± 0.14	5.64 ± 0.14	5.10 ± 0.12	5.14 ± 0.13
Ni (ppm)	0.86 ± 0.23		2.07 ± 0.37	2.6 ± 0.41	1.34 ± 0.28
Co (ppm)	0.45 ± 0.005	0.40 ± 0.008	0.43 ± 0.004	0.51 ± 0.004	0.48 ± 0.005
Cr (ppm)	5.53 ± 0.053	7.16 ± 0.09	5.35 ± 0.05	8.38 ± 0.06	8.23 ± 0.06
Fe (ppm)	1000 ± 12.3	396 ± 9.3	336 ± 4.6	538 ± 6.9	507 ± 6.6
Na (ppm)	41.8 ± 0.41	20.4 ± 0.25	13.1 ± 0.22	15.5 ± 0.21	13.3 ± 0.21
Rb (ppm)	0.32 ± 0.09	<0.4	<0.4	<0.5	<0.4
Cs (ppm)	0.03 ± 0.004	0.055 ± 0.007	<0.01	<0.01	0.011 ± 0.003
K (ppm)	61.9 ± 4.3	8.7 ± 1.7	<10	18.6 ± 2.4	<12

SRC PILOT PLANT, VARIOUS CARLOADS SRC

	WP-10235 (625)	WP-10101 (626)	WP-10123 (627)	WP-10138 (628)	BN-522171 (629)
As (ppm)	1.47 ± 0.008	1.70 ± 0.009	2.10 ± 0.015	1.5 ± 0.014	2.13 ± 0.03
Sb (ppm)	0.07 ± 0.005	0.10 ± 0.007	<0.02	0.08 ± 0.006	0.12 ± 0.007
Se (ppm)	0.10 ± 0.02	0.12 ± 0.02	0.11 ± 0.02	0.14 ± 0.02	0.11 ± 0.02
Hg (ppb)	7.6 ± 2.0	28.9 ± 8.7	< 50	25.6 ± 6.1	< 50
Br (ppm)	5.55 ± 0.02	5.90 ± 0.03	5.43 ± 0.04	5.62 ± 0.05	8.44 ± 0.09
Ni (ppm)	2.01 ± 0.44	2.15 ± 0.44	<3.0	1.75 ± 0.36	<2.3
Co (ppm)	0.20 ± 0.004	0.25 ± 0.005	0.25 ± 0.006	0.23 ± 0.004	0.25 ± 0.004
Cr (ppm)	4.9 ± 0.04	8.5 ± 0.06	5.0 ± 0.06	4.3 ± 0.04	4.2 ± 0.04
Fe (ppm)	220 ± 3	370 ± 5	310 ± 6	200 ± 3	230 ± 4
Na (ppm)	6.43 ± 0.04	8.52 ± 0.05	12.7 ± 0.10	18.4 ± 0.14	14.5 ± 0.20
Rb (ppm)	0.24 ± 0.07	<0.32	<0.50	<0.30	<0.35
Cs (ppm)	<0.01	0.02 ± 0.004	0.02 ± 0.004	<0.02	<0.02
K (ppm)	1.85 ± 0.35	3.54 ± 0.56	4.8 ± 0.54	6.3 ± 0.6	4.9 ± 1.3

SRC PILOT PLANT, VARIOUS CARLOADS SRC

	UP-18595 (393)	UP-18609 (394)	UP-39003 (395)	UP-39005 (397)	UP-39006 (398)
Sc (ppm)	0.57 ± 0.003	0.66 ± 0.003	0.38 ± 0.002	0.56 ± 0.002	0.65 ± 0.003
Tb (ppm)	0.037 ± 0.004	0.05 ± 0.004	0.03 ± 0.002	0.03 ± 0.002	0.04 ± 0.004
Eu (ppm)	0.023 ± 0.001	0.03 ± 0.002	0.024 ± 0.001	0.03 ± 0.011	0.03 ± 0.002
Sm (ppm)	<0.2	<0.22	0.142 ± 0.002	0.22 ± 0.003	<0.25
Ce (ppm)	0.44 ± 0.044	0.62 ± 0.045	0.39 ± 0.018	0.57 ± 0.018	0.55 ± 0.05
La (ppm)	0.18 ± 0.018	0.20 ± 0.018	0.18 ± 0.012	0.24 ± 0.014	0.17 ± 0.014
Sr (ppm)	<25.0	<24.0	<22.0	9.93 ± 2.30	13.5 ± 3.7
Ba (ppm)	<12.0	<10.0	5.2 ± 1.2	<11.0	<11.0
Th (ppm)	0.14 ± 0.004	0.19 ± 0.004	0.19 ± 0.003	0.25 ± 0.004	0.15 ± 0.004
Hf (ppm)	0.05 ± 0.004	0.06 ± 0.004	0.055 ± 0.003	0.10 ± 0.004	0.07 ± 0.005
Ta (ppm)	0.03 ± 0.004	0.03 ± 0.003	0.04 ± 0.004	0.05 ± 0.004	0.034 ± 0.004
Ga (ppm)	<1.0	1.21 ± 0.028	0.74 ± 0.016	0.78 ± 0.018	0.81 ± 0.028
Zr (ppm)	<15.0	4.90 ± 1.40	4.80 ± 1.20	10.3 ± 1.40	3.6 ± 1.04
Cu (ppm)	2.30 ± 0.11	2.10 ± 0.12	1.51 ± 0.12	3.00 ± 0.35	1.85 ± 0.10

SRC PILOT PLANT, VARIOUS CARLOADS SRC

	UP-73116 (399)	BN-522549 (400)	SRC-109801 (401)	UP-39004L (396)
Sc (ppm)	0.007 ± 0.0003	0.90 ± 0.003	0.10 ± 0.0007	0.49 ± 0.002
Tb (ppm)	0.004 ± 0.001	0.066 ± 0.003	0.006 ± 0.001	0.03 ± 0.002
Eu (ppm)	0.016 ± 0.0011	0.04 ± 0.001	0.016 ± 0.0007	0.03 ± 0.001
Sm (ppm)	0.32 ± 0.003	0.37 ± 0.003	0.06 ± 0.002	0.17 ± 0.002
Ce (ppm)	0.08 ± 0.016	1.29 ± 0.021	0.544 ± 0.017	0.49 ± 0.02
La (ppm)	0.29 ± 0.014	0.43 ± 0.019	0.255 ± 0.014	0.21 ± 0.014
Sr (ppm)	53.51 ± 2.69	<30.0	<25.0	<15.0
Ba (ppm)	45.70 ± 1.34	7.26 ± 1.17	2.1 ± 0.60	<15.0
Th (ppm)	0.06 ± 0.002	0.46 ± 0.004	0.052 ± 0.002	0.22 ± 0.003
Hf (ppm)	0.008 ± 0.001	0.140 ± 0.004	0.022 ± 0.002	0.09 ± 0.004
Ta (ppm)	0.012 ± 0.002	0.073 ± 0.005	<0.08	0.05 ± 0.004
Ga (ppm)	0.89 ± 0.02	0.89 ± 0.022	<1.0	0.20 ± 0.009
Zr (ppm)	<25.0	13.0 ± 1.64	3.60 ± 0.82	7.56 ± 1.25
Cu (ppm)	2.00 ± 0.12	2.10 ± 0.12	<3.0	2.22 ± 0.14

SRC PILOT PLANTS, VARIOUS CARLOADS SRC

	Raw Coal (412)	SRC-39707 (413)	SRC-36390 (414)	SRC-36372 (415)
Sc (ppm)	2.89 ± 0.009	0.59 ± 0.002	0.662 ± 0.003	0.63 ± 0.002
Tb (ppm)	0.33 ± 0.009	0.037 ± 0.002	0.048 ± 0.004	0.048 ± 0.002
Eu (ppm)	0.21 ± 0.003	0.029 ± 0.001	0.026 ± 0.0014	0.027 ± 0.001
Sm (ppm)	2.65 ± 0.011	<0.4	0.235 ± 0.002	<0.4
Ce (ppm)	28.80 ± 0.122	0.58 ± 0.021	0.68 ± 0.046	0.49 ± 0.022
La (ppm)	11.70 ± 0.132	0.23 ± 0.018	0.24 ± 0.013	0.16 ± 0.013
Sr (ppm)	157.0 ± 13.0	6.45 ± 1.67	<25.0	<30.0
Ba (ppm)	48.7 ± 6.27	7.47 ± 1.3	10.7 ± 2.63	5.56 ± 1.35
Th (ppm)	1.40 ± 0.008	0.30 ± 0.003	0.21 ± 0.004	0.25 ± 0.003
Hf (ppm)	0.34 ± 0.008	0.105 ± 0.004	0.078 ± 0.005	0.087 ± 0.004
Ta (ppm)	0.11 ± 0.007	0.062 ± 0.004	0.043 ± 0.004	0.053 ± 0.004
Ga (ppm)	3.30 ± 0.09	0.87 ± 0.03	0.81 ± 0.014	1.00 ± 0.027
Zr (ppm)	50.43 ± 3.57	8.81 ± 1.50	<20.0	7.64 ± 1.37
Cu (ppm)	20.5 ± 1.0	1.41 ± 0.15	1.38 ± 0.14	2.10 ± 0.19

SRC PILOT PLANT, VARIOUS CARLOADS SRC

	SRC-39711 (416)	SRC-39467 (417)	SRC-39797 (418)	SRC-39710 (419)
Sc (ppm)	0.794 ± 0.003	0.420 ± 0.002	0.102 ± 0.007	0.303 ± 0.0014
Tb (ppm)	0.053 ± 0.004	0.021 ± 0.003	<0.05	0.020 ± 0.0017
Eu (ppm)	0.032 ± 0.018	0.018 ± 0.001	0.004 ± 0.0004	0.021 ± 0.0001
Sm (ppm)	<0.2	<0.2	<0.2	0.11 ± 0.002
Ce (ppm)	0.98 ± 0.048	0.69 ± 0.045	0.28 ± 0.013	0.39 ± 0.02
La (ppm)	0.26 ± 0.019	0.22 ± 0.014	0.15 ± 0.013	0.169 + 0.010
Sr (ppm)	<25.0	<25.0	<25.0	<25.0
Ba (ppm)	<18.0	<15.0	<13.0	4.87 ± 1.24
Th (ppm)	0.27 ± 0.004	0.14 ± 0.003	0.17 ± 0.003	0.14 ± 0.003
Hf (ppm)	0.083 ± 0.004	0.047 ± 0.004	<0.10	0.054 ± 0.003
Ta (ppm)	0.06 ± 0.004	0.029 ± 0.003	<0.05	0.032 ± 0.003
Ga (ppm)	0.837 ± 0.024	0.217 ± 0.012	0.839 ± 0.020	0.858 ± 0.018
Zr (ppm)	4.77 ± 1.41	7.03 ± 1.14	<10.0	6.18 ± 1.30
Cu (ppm)	2.0 ± 0.22	2.21 ± 0.20	3.15 ± 0.23	1.80 ± 0.12

SRC PILOT PLANT, VARIOUS CARLOADS SRC

	UP-38796 (477)	UP-37802 (478)	36772 (479)	18155 (480)
Sc (ppm)	0.68 ± 0.003	0.32 ± 0.002	0.733 ± 0.003	0.741 ± 0.004
Tb (ppm)	0.045 ± 0.003	0.009 ± 0.002	0.044 ± 0.003	0.060 ± 0.005
Eu (ppm)	0.035 ± 0.001	0.016 ± 0.001	0.030 ± 0.001	0.03 ± 0.002
Sm (ppm)	0.27 ± 0.003	0.13 ± 0.003	0.27 ± 0.003	0.28 ± 0.003
Ce (ppm)	0.794 ± 0.026	0.41 ± 0.048	0.74 ± 0.03	1.02 ± 0.055
La (ppm)	0.25 ± 0.014	0.17 ± 0.017	0.19 ± 0.013	0.25 ± 0.016
Sr (ppm)	7.60 ± 2.0	<15.0	13.33 ± 2.54	<25.0
Ba (ppm)	4.79 ± 1.20	<12.0	9.80 ± 1.84	15.0
Th (ppm)	0.378 ± 0.004	0.112 ± 0.003	0.38 ± 0.005	0.25 ± 0.005
Hf (ppm)	0.103 ± 0.004	0.03 ± 0.003	0.14 ± 0.005	0.072 ± 0.005
Ta (ppm)	0.070 ± 0.005	0.03 ± 0.003	0.09 ± 0.006	0.050 ± 0.004
Ga (ppm)	1.03 ± 0.025	1.14 ± 0.033	1.14 ± 0.028	0.92 ± 0.024
Zr (ppm)	12.80 ± 1.66	<15.0	<20.0	<20.0
Cu (ppm)	1.90 ± 0.22	1.77 ± 0.18	1.36 ± 0.11	1.48 ± 0.13

SRC PILOT PLANT, VARIOUS CARLOADS SRC

	RRCN-1650599 (556)	WP-10280 (621)	WP-10151 (622)	WP-10110 (623)	WP-10247 (624)
Sc (ppm)	0.97 ± 0.003	0.11 ± 0.001	0.32 ± 0.001	0.24 ± 0.001	0.82 ± 0.002
Tb (ppm)	0.07 ± 0.002	0.004 ± 0.0005	0.01 ± 0.001	0.01 ± 0.001	<0.005
Eu (ppm)	0.05 ± 0.001	0.02 ± 0.001	0.03 ± 0.001	0.04 ± 0.001	0.05 ± 0.002
Sm (ppm)	0.42 ± 0.007	<0.003	0.17 ± 0.001	<21.1	<66.2
Ce (ppm)	0.72 ± 0.015	0.09 ± 0.006	0.27 ± 0.008	0.26 ± 0.01	0.55 ± 0.02
La (ppm)	0.34 ± 0.03	0.113 ± 0.01	0.10 ± 0.002	0.14 ± 0.008	0.27 ± 0.01
Sr (ppm)	<6	<2.3	<2.8	<3.0	<6.5
Ba (ppm)	62.6 ± 8.2	<2.5	5.3 ± 1.2	<3.4	10.4 ± 1.7
Th (ppm)	0.47 ± 0.004	0.05 ± 0.001	0.12 ± 0.002	0.09 ± 0.002	0.33 ± 0.004
Hf (ppm)	0.15 ± 0.004	0.02 ± 0.001	0.04 ± 0.002	0.03 ± 0.002	0.12 ± 0.005
Ta (ppm)	0.08 ± 0.004	0.02 ± 0.002	0.03 ± 0.002	0.03 ± 0.003	0.07 ± 0.007
Ga (ppm)	1.19 ± 0.04	1.41 ± 0.021	0.74 ± 0.02	1.23 ± 0.01	1.44 ± 0.026
Zr (ppm)	17.0 ± 1.3	2.9 ± 0.5	4.9 ± 0.7	4.3 ± 0.7	13.7 ± 2.2
Cu (ppm)	<2	1.62 ± 0.03	1.48 ± 0.02	2.02 ± 0.02	2.09 ± 0.04
Zn (ppm)	<0.3	6.9 ± 0.1	<0.2	<0.2	<0.3

SRC PILOT PLANT, VARIOUS CARLOADS SRC

	RRCN-5522549 (551)	RRCN- 522112 (552)	RRCN-73548 (553)	RRCN-73279 (554)	RRCN-160850 (555)
Sc (ppm)	1.0 ± 0.003	1.10 ± 0.005	0.88 ± 0.003	0.99 ± 0.003	0.97 ± 0.003
Tb (ppm)	0.082 ± 0.002	0.072 ± 0.003	0.071 ± 0.002	0.082 ± 0.002	0.082 ± 0.002
Eu (ppm)	0.056 ± 0.001	0.047 ± 0.002	0.05 ± 0.001	0.058 ± 0.001	0.056 ± 0.001
Sm (ppm)	0.45 ± 0.008	0.40 ± 0.007	0.37 ± 0.007	0.48 ± 0.007	0.39 ± 0.007
Ce (ppm)	1.16 ± 0.015	1.06 ± 0.03	0.79 ± 0.01	0.92 ± 0.012	0.92 ± 0.011
La (ppm)	0.80 ± 0.05	0.30 ± 0.03	0.32 ± 0.03	0.38 ± 0.03	0.26 ± 0.03
Sr (ppm)	<7	<8	<5	<6	<6
Ba (ppm)	14.3 ± 1.8	26.10 ± 3.3	20.0 ± 2.0	19 ± 2	13 ± 1.3
Th (ppm)	0.51 ± 0.003	0.55 ± 0.006	0.47 ± 0.003	0.54 ± 0.003	0.51 ± 0.003
Hf (ppm)	0.14 ± 0.003	0.15 ± 0.006	0.13 ± 0.002	0.15 ± 0.003	0.14 ± 0.003
Ta (ppm)	0.071 ± 0.004	0.098 ± 0.005	0.080 ± 0.004	0.087 ± 0.004	0.087 ± 0.004
Ga (ppm)	1.61 ± 0.07	1.36 ± 0.05	1.37 ± 0.06	1.47 ± 0.05	1.30 ± 0.05
Zr (ppm)	15.0 ± 1.3	16.0 ± 2.0	14.0 ± 1.0	16 ± 1.2	17.0 ± 1.3
Cu (ppm)	<2	<2	<2	<2	<2
Zn (ppm)	<0.3	<0.4	<0.4	<0.2	<0.3

SRC PILOT PLANT, VARIOUS CARLOADS SRC

	WP-10235 (625)	WP-10101 (626)	WP-10123 (627)	WP-10138 (628)	BN-522171 (629)
Sc (ppm)	0.52 ± 0.001	0.56 ± 0.002	0.76 ± 0.002	0.77 ± 0.002	0.88 ± 0.002
Tb (ppm)	0.01 ± 0.001	0.02 ± 0.001	0.02 ± 0.001	0.02 ± 0.001	0.02 ± 0.001
Eu (ppm)	0.02 ± 0.001	0.04 ± 0.001	0.05 ± 0.002	0.04 ± 0.001	0.04 ± 0.001
Sm (ppm)	0.23 ± 0.001	0.24 ± 0.001			
Ce (ppm)	0.31 ± 0.009	0.48 ± 0.01	0.52 ± 0.02	0.48 ± 0.01	0.52 ± 0.01
La (ppm)	0.10 ± 0.002	0.13 ± 0.003	0.19 ± 0.008	0.20 ± 0.01	0.17 ± 0.01
Sr (ppm)	<3.6	<4.5	<6.9	<4.3	<4.9
Ba (ppm)	5.7 ± 1.0	4.2 ± 1.0	7.6 ± 1.4	11.9 ± 1.5	13.0 ± 1.4
Th (ppm)	0.24 ± 0.002	0.23 ± 0.002	0.31 ± 0.004	0.34 ± 0.003	0.37 ± 0.003
Hf (ppm)	0.06 ± 0.002	0.07 ± 0.002	0.09 ± 0.004	0.10 ± 0.003	0.10 ± 0.003
Ta (ppm)	0.04 ± 0.003	0.05 ± 0.004	0.06 ± 0.005	0.06 ± 0.004	0.07 ± 0.004
Ga (ppm)	0.94 ± 0.03	0.87 ± 0.03	1.27 ± 0.01	1.57 ± 0.02	1.77 ± 0.04
Zr (ppm)	2.7 ± 0.8	6.6 ± 1.2	7.8 ± 1.4	8.4 ± 1.3	10.7 ± 1.3
Cu (ppm)	3.33 ± 0.03	2.47 ± 0.03	2.9 ± 0.03	2.11 ± 0.02	2.2 ± 0.06
Zn (ppm)	<0.2	<0.2	<0.3	<0.2	<0.2

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