TRACE ELEMENT MATERIAL BALANCE

for

HAT CREEK COAL TEST BURN

Prepared for:

B.C. HYDRO & POWER AUTHORITY

Prepared by:

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Expiry Date Oct. 8, 197

May 1978

WR&D Ref 3463-R1

604H-E016

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SCOPE

Western Research & Development conducted a series of tests for trace elements for British Columbia Hydro and Power Authority (B.C. Hydro) during a test burn of Hat Creek coal. The test program included the determination of:

- vapour and solids emission rates for:
  - mercury
  - fluoride
  - arsenic
  - selenium
- pulverized coal, flyash and bottom ash trace element analyses and material balance calculations for:
  - mercury
  - fluoride
  - arsenic
  - selenium
  - beryllium
  - boron
  - cadmium
  - chromium
  - copper
  - lead
  - manganese
  - nickel
  - strontium
  - uranium
  - vanadium
  - zinc

LOCATION

Outlet duct of Unit No. 2 electrostatic precipitator at the Alberta Power Limited, Battle River Generating Station.

TEST PERIOD

August 14, 20 and 21, 1977

RESULTS

Detailed results of measurements, analyses and calculations made for this study have been organized into three sections. They are:

- Appendix 1 Trace Element Emission Rate Determinations
- Appendix 2 Laboratory Analyses
- Appendix 3 Material Balance

Appendix 1 contains all of the results of the field stack sampling including the tests to determine solid and vapour phase emission rates for selected elements. A summary of all the emission rate tests is contained in Table 1.

Appendix 2 presents the analytical results that were supplied to WR&D by Environmental Research & Technology Inc. for all of the samples that they analysed. Table 2 presents a summary of theanalyses.

The results for Flyash Emitted were corrected to the mean coal analysis. Thus for the coal fired on the three days of testing for trace elements the values presented represent a mean composition for each flow stream.

Appendix 3 presents material balance calculations and is divided into four parts.

Part 1 outlines the ash material balance reconciliation made by WR&D for purposes of making component material balances.

Part 2 contains the component material balances for each test and the results are contained in tables 3-2, 3-3 and 3-4. Due to the complexity of the tables they have not been summarized. The component material balances for the six trace element tests show in some instances, serious imbalances.

In Part 3 a mean value trace element composition is established for each flow stream based on the data collected for the six trace element tests.

In Part 4 a typical material balance for a firing rate of 50,000 Kg/Hr was prepared using the mean value trace element composition of each stream and assuming the following parameters:

- Coal - 28% moisture
  - 32.5 % ash (wet basis)
  - 50,000 Kg/hr (wet basis)

- Bottom ash - 15% of total ash
  - 2437.5 Kg/hr

- Flyash to precip - 85% of total ash
  - 13812.5 Kg/hr
- Flyash emitted - 99.7% efficient precipitator
  - 41.4 Kg/hr

- Vapour phase emitted - Scaled up from test burn results based on coal flow rates and mean composition.

Table 3 contains the typical material balance. The standard deviation of each stream flow rate is indicated.

DISCUSSION

Establishing emission rates for trace elements is a difficult task as is evidenced by other published material balances for coal fired boilers (1) (2). For the tests conducted as part of this study the following factors must be taken into consideration.

- Total test duration was three hours allowing a total sample time of approximately 108 minutes. This factor limited the quantity of sample collected.

- Duplicate tests were not possible due to factors beyond the control of WR&D or the test burn crew. These included boiler stability, boiler firing rate and precipitator efficiency variations. In addition the tests had to be conducted simultaneously with precipitator efficiency and flyash particle size determination tests.

- Cyclic operation of the boiler during the entire test period, including variations in start-up and shut-down may have affected trace element retention and subsequent release from the boiler.

- Quantities of sample availiable for analysis did not allow for duplicate sample analyses. In many cases lower detectability limits controlled the analytical results.

Based on reviews of the information contained in Appendicies 1, 2 and 3 the following comments are made.

- The emission rates for mercury, selenium and arsenic are all maximum values. For each test the sample collected was distributed over the probe, filter, first impinger, and second and third impingers (together). The analytical results for the filter, and all impingers for mercury were less than the minimum detectible amount. For selenium and arsenic quantities in all portions of the train were less than the minimum detectible amount.

- For the majority of the elements a large standard deviation is associated with each mean. When the material balances are examined considering the standard deviation only fluoride does not balance.

RECOMMENDATION

- *In the application of the results of these tests it is recommended that the mean value composition of each stream and the typical material balance be used rather than the individual results of each test.*

REFERENCES

(1) Klein, D.H. et al, Pathways of Thirty-seven Trace Elements Through Coal-Fired Power Plant, Environmental Science & Technology Vol 9, No 10, 1975.

(2) Block, C and R Dams, Study of Fly Ash Emissions During Combustion of Coal, Environmental Science & Technology Vol 10, No 10, 1976.

Table 1

B.C. HYDRO TRACE ELEMENT STUDY

SUMMARY OF STACK EMISSIONS

	Morning Tests			Afternoon Tests		
	Solids Kg/hr	Gaseous Kg/hr	Total Kg/hr	Solids Kg/hr	Gaseous Kg/hr	Total Kg/hr
August 14, 1977						
Arsenic	<0.00225	<0.00375	<0.00600	<0.00064	<0.00107	<0.00171
Beryllium	<0.00039		<0.00039	<0.00005		<0.00005
Lead	0.00552		0.00552	<0.00058		<0.00058
Aug 20, 1977						
Fluoride	<0.01735	0.14690	0.16425	<0.02187	0.25150	<0.27337
Aug 21, 1977						
Mercury	<0.00010	0.00023	<0.00033	<0.00089	0.00134	<0.00223
Selenium	<0.00045	<0.00135	<0.00180	<0.00052	<0.00263	<0.00315
Boron	0.00108		0.00108	0.00250		0.00250
Cadmium	<0.00011		<0.00011	0.00050		0.00050
Chromium	0.00013		0.00013	0.00110		0.00110
Copper	0.00031		0.00031	0.00190		0.00190
Manganese	0.00325		0.00325	0.01840		0.01840
Molybdenum	<0.00015		<0.00015	0.00080		0.00080
Nickel	0.00042		0.00042	0.00340		0.00340
Strontium	0.00014		0.00014	0.00290		0.00290
Vanadium	<0.00011		<0.00011	0.00020		0.00020
Zinc	0.00699		0.00699	0.00610		0.00610

Table 2

B.C. HYDRO TRACE ELEMENT STUDY
MEAN COMPOSITION OF TRACE ELEMENTS
mg/Kg

	Element	Hg	F	As	Se	Be	B	Cd	Cr	Cu	Pb	Mn	Mo	Ni	Sr	U	V	Zn
Coal	n	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
	mean	0.08	123	10.3	10.0	0.43	12.2	1.03	46	>557	13.2	>483	3.8	34.8	176	5.8	172	56
	Std Dev	0.02	39	7.3	10.6	0.27	8.3	0.50	17	369	3.7	432	0.41	33.4	100	2.6	116	23
Bottom Ash	n	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
	mean	0.14	73	5.4	13.2	0.96	29	0.74	164	>678	12.6	>854	8.2	55	380	9.6	>564	58
	Std Dev	0.16	32	2.7	9.5	0.63	27	0.23	158	443	5.0	213	7.4	22	213	6.0	416	36
A Field	n	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Hopper Catch	mean	0.04	50	27.0	18.3	1.7	41	0.68	179	>958	31.0	>560	10.8	68	415	13.8	>697	136
	Std Dev	0.01	38	7.7	11.7	1.2	18	0.16	92	102	7.3	385	3.5	23	180	3.7	228	82
B Field	n	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Hopper Catch	mean	0.09	75	87	24	2.0	117	1.0	266	>893	60	>767	14.8	105	>557	18.3	>660	393
	Std Dev	0.10	52	56	12	0.6	76	0.5	158	261	19	379	9.7	129	260	6.2	292	208
C Field	n	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Hopper Catch	mean	0.04	201	201	14.2	2.0	109	1.9	319	>1000	86	>760	16.2	156	>544	17.4	>762	>604
	Std Dev	0.01	122	296	12.2	1.2	62	1.3	144	0.0	67	329	6.2	198	345	15.3	264	366
Composite	n	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17
A, B & C	mean	0.06	104	99	19.1	1.9	88	1.1	251	>948	57	>692	13.8	107	>503	16.5	>703	>364
Hopper Catch	Std Dev	0.06	97	168	11.9	1.0	65	0.9	138	163	42	358	7.0	129	256	8.9	249	295
Flyash	n	2	2	2	2	2	2	2	2	2	2	2	2	2	2	0	1	2
Emitted (1)	mean	<67.8	500.1	<220.4	<76.2	<3.1	189.8	<28.1	85.4	>160.5	<38.1	>2992.4	<67.9	92.9	73.5		<30.4	231.3
	Std Dev	16.6	32.3	288.8	6.8	2.5	98.0	1.3	22.7	105.4	9.6	3540.6	34.5	19.5	61.4		37.0	52.2

(1) Total front half of EPA Train (probe wash plus filter)

Table 3

B.C. HYDRO TRACE ELEMENT STUDY
TYPICAL MATERIAL BALANCE

	ELEMENT INPUT		ELEMENT OUTPUT								TOTAL OUTPUT
Trace Element	Element Input Kg/hr		Bottom Ash Kg/hr		Flyash Kg/hr		Flyash Emitted Kg/hr		Vapour Phase Mat'l Kg/hr		Kg/hr**
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	
Hg	0.004	± 0.001	0.0003	± 0.0004	0.0008	± 0.0008	<0.002	± 0.00002	<0.0037	± 0.0027	<0.007 ± 0.004
F	6.17	± 1.93	<0.180	± 0.080	1.430	± 1.340	0.030	± 0.004	0.4000	± 0.1393	<2.040 ± 1.563
As	0.52	± 0.37	0.010	± 0.007	1.370	± 2.320	<0.001	± 0.0008	<0.0353	± 0.0207	<1.390 ± 2.349
Se	0.50	± 0.53	0.030	± 0.020	0.260	± 0.160	<0.005	± 0.005	<0.0129	± 0.0146	<0.308 ± 0.200
Be	0.02	± 0.01	0.002	± 0.0015	0.030	± 0.010	<0.0001	± 0.00003			<0.032 ± 0.01
B	0.61	± 0.42	0.070	± 0.0065	1.210	± 0.890	0.014	± 0.011			1.294 ± 0.908
Cd	0.05	± 0.03	0.002	± 0.0006	0.020	± 0.010	<0.002	± 0.0009			<0.024 ± 0.012
Cr	2.31	± 0.83	0.400	± 0.390	3.460	± 1.900	0.003	± 0.00002			3.860 ± 2.290
Cu	>27.84	± 18.44	>1.650	± 1.080	>13.080	± 2.250	0.005	± 0.0014			>14.735 ± 3.331
Pb	0.66	± 0.19	0.030	± 0.010	0.790	± 0.580	<0.0014	± 0.0002			<0.821 ± 0.590
Mn	>24.14	± 21.60	2.080	± 0.520	>9.550	± 4.940	0.054	± 0.017			>11.684 ± 5.477
Mo	0.19	± 0.02	0.020	± 0.018	0.190	± 0.100	<0.0024	± 0.0008			<0.212 ± 0.119
Ni	1.74	± 1.67	0.130	± 0.050	1.470	± 1.770	0.008	± 0.0006			1.608 ± 1.821
Sr	8.79	± 5.02	0.930	± 0.520	>6.940	± 3.530	0.005	± 0.0026			>7.875 ± 4.053
U	0.29	± 0.03	0.020	± 0.010	0.230	± 0.120	0.0007	± 0.0004*			0.2507 ± 0.1304
V	8.62	± 5.78	>1.380	± 1.010	>9.700	± 3.440	<0.0013	± 0.0013			>11.081 ± 4.451
Zn	2.78	± 1.16	0.140	± 0.090	>5.030	± 4.070	0.014	± 0.0002			> 5.184 ± 4.160

Parameters:
Coal Flow = 50,000 Kg/hr (Wet Basis)
Bottom Ash = 2437.5 Kg/hr
Flyash = 13812.5 Kg/hr
Flyash Emitted = 41.4 Kg/hr

* Value for uranium based on mean value of uranium in composite A, B and C hopper catch (Table 3-5 Appendix 3)

** Values are sum of stream output means or standard deviations

APPENDIX 1

TRACE ELEMENT EMISSION RATE DETERMINATIONS

RESULTS

Two solid phase/vapour phase emission rate tests were conducted at the precipitator outlet for each of the following trace elements

- mercury
- fluoride
- arsenic
- selenium

A detailed summary of results of the solid phase/vapour phase test program for each of the four elements is presented in Table 1-1.

On August 14 arsenic emission rates were determined using the concentration and flue gas flow rate determined using the EPA sample train.

On August 20 and 21 the trace element tests were conducted during the same time periods that the Precipitator Study(1) was conducted. For the Precipitator Study inlet and outlet gas volumes were measured and because of the favourable agreement between the inlet and outlet values the gas volumes determined for the precipitator study were used to calculate the trace element emission rates. The volumes determined by the trace element sample train were consistently low with respect to the Precipitator Study.

The coal flow rate for each test period was determined by others and supplied to WR&D by B.C. Hydro.

REFERENCES

(1) Precipitator Study for Hat Creek Coal Test Burn. Western Research & Development. November 1977 (WR&D Job 3462)

B.C. HYDRO
HAT CREEK COAL TEST BURN

TABLE 1 - 1

TRACE CONTAMINANTS - SOLID PHASE/VAPOR PHASE

Contaminant		Mercury (Hg)		Fluoride (F-)		Arsenic (As)		Selenium (Se)	
Test Number		Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
Test Date		Aug 21/77	Aug 21/77	Aug 20/77	Aug 20/77	Aug 14/77	Aug 14/77	Aug 21/77	Aug 21/77
Coal Flow Rate (Dry)	Kg/hr	9,890	14,170	16,700	19,490	11,720**	10,980**	9,890	14,170
Flue Gas	SCFM (Dry)	54,617	84,936	95,660	96,587	42,174	36,866	54,617	84,936
	M^3/MIN (Dry)	1,547	2,406	2,709	2,735	1,194	1,044	1,547	2,406
Total Particulate	mg/M^3*	22.0	125.9	139.6	208.8	2502.3	247.8	22.0	125.9
Contaminant Concentration:									
Solid	mg/M^3	<0.0011	<0.0062	0.1068	0.1296	<0.0314	<0.0102	<0.0048	<0.0036
Gaseous	mg/M^3	<0.0025	<0.0093	0.9047	1.5379	<0.0524	<0.0170	<0.0146	<0.0182
Total	mg/M^3	<0.0036	<0.0155	1.0115	1.6675	<0.0838	<0.0272	<0.0194	<0.0218
Contaminant Emission Rate									
Solid	g/hr	<0.102	<0.895	17.360	21.270	<2.249	<0.639	<0.445	<0.518
Gaseous	g/hr	<0.232	<1.343	147.040	252.370	<3.754	<1.065	<1.358	<2.627
Total	g/hr	<0.334	<2.238	164.400	273.640	<6.003	<1.704	<1.803	<3.145
Total Contaminant / Total Particulate		0.000164	0.000123	0.007250	0.007980	0.000033	0.000110	0.000883	0.000173
Average		0.000144		0.007620		0.000072		0.000528	
Gaseous fraction of Contaminant / Total Contaminant		0.694	0.600	0.894	0.922	0.625	0.625	0.753	0.835
Average		0.647		0.908		0.625		0.794	
Total Contaminant / Total Coal (Dry basis)		$0.034x10^{-6}$	$0.158x10^{-6}$	$9.837x10^{-6}$	$14.027x10^{-6}$	$0.512x10^{-6}$	$0.155x10^{-6}$	$0.182x10^{-6}$	$0.222x1^{-6}$
Average		$0.096x10^{-6}$		$11.932x10^{-6}$		$0.334x10^{-6}$		$0.202x10^{-6}$	

* Total Particulate Concentration by EPA Train
** Percent Ash in Coal on Wet Basis Taken as Average Value of Aug 20 and 21, 1977.

TEST METHODS

Trace element emission rates were determined at the precipitator outlet by means of a standard EPA type sampling train as shown in Figure 1-1.

An integrated gas sample was obtained by isokinetic sampling at pre-selected traverse points through a sharp-edged nozzle. The probe and filter temperatures were maintained above the stream dew point. The appropriate sampling train parameters were monitored and recorded at regular intervals during the sampling.

The H_2O content of the stream was calculated from the volume increase of the impinger solutions. The vapour leaving impinger 3 and absorbed by the desiccant was computated by a method that assumes saturation of the sample stream at impinger 3 outlet conditions.

The particulate concentration of the stream was based upon the total mass of particulates collected by the probe and filter (front-end). Quantitative recovery of the particulate from the probe and front-end glassware was achieved by washing and allowing subsequent evaporation. The filter catch was determined by the mass gain of the filter after it was dried to a constant mass.

IMPINGER SOLUTIONS

The procedure for each test was specified by Environmental Research & Technology, Inc.

- Mercury and Selenium

  The apparatus and method correspond to EPA Reference method 01-01-01-05. The impinger solutions used were:

  IMPINGER 1. 6M hydrogen peroxide

  IMPINGER 2. 0.2M ammonium persulfate + 0.2M silver nitrate

  IMPINGER 3. 0.2M ammonium persulfate + 0.2M silver nitrate

  IMPINGER 4. silica gel

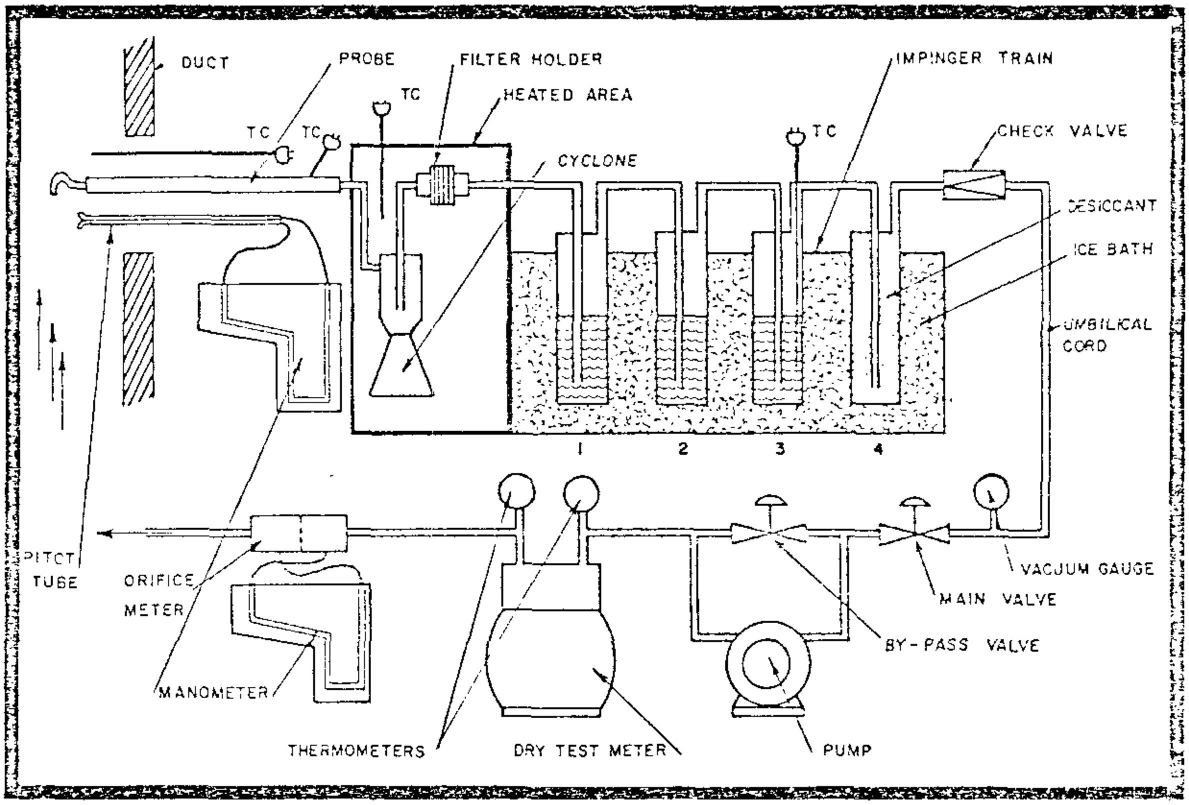

FIG 1-1 CONCENTRATION OF PARTICULATE MATTER IN A GAS STREAM.

- Arsenic:

  The reference method is UNPUBLISHED[2] and the impinger solutions were:

  IMPINGER 1. 10% hydrogen peroxide
  IMPINGER 2. 10% hydrogen peroxide
  IMPINGER 3. 0.1 N sodium hydroxide
  IMPINGER 4. silica gel

- Fluoride:

  The reference method is EPA METHOD 13-B and the impinger solutions were:

  IMPINGER 1. distilled water
  IMPINGER 2. distilled water
  IMPINGER 3. empty
  IMPINGER 4. silica gel

EQUIPMENT WASHING SOLUTIONS

Probe and Front-End Glassware Washing

The probe and front-end glassware were washed with distilled water after each test.

Impinger Washing

Each impinger was rinsed with a clean batch of the same solution that it contained for the test in question.

EMISSION CALCULATIONS

Western Research & Development's computer programs were used to calculate the following for each mass emission test:

- moisture content
- average velocity of flue gas
- total flue gas flow rate

The total particulate concentration and trace element concentrations were calculated manually.

The following pages present the computer printout and manual calculations.

REFERENCE

(2) Test method for arsenic furnished by Jim Steiner of Aerotherm Corporation (Aerotherm Corporation presently under contract to EPA to develop testing and analytical methods for various trace elements)

BATTLE RIVER UNIT 2 B.C. HYDRO TEST BURN MERCURY AND SELENIUM

EMISSION CALCULATIONS

PAGE 1 Test #1 DATE AUG. 21,1977

LOCATION OF SAMPLING POINT	20 FROM PRECIP. OUT
DEPTH OF RECTANGULAR DUCT	6.94 FT.
WIDTH OF RECTANGULAR DUCT	11.00 FT.
BAROMETRIC PRESSURE	27.87 IN. HG
AMBIENT TEMPERATURE	61. DEG.F

CARBON DIOXIDE ANALYSIS
FYRITE INDICATOR 11.60 PERCENT-DRY BASIS
OXYGEN ANALYSIS
FYRITE INDICATOR 8.20 PERCENT-DRY BASIS

AVERAGE COMPOSITION OF FLUE GAS

	DRY BASIS PERCENT	WET BASIS PERCENT
O2	8.20	7.11
CO2	11.60	10.06
N2 *	80.20	69.57
H2O		13.25

* BY DIFFERENCE

SPECIFIC GRAVITY OF FLUE GAS-(AIR=1.00) .987

BATTLE RIVER UNIT 2 B.C. HYDRO TEST BURN MERCURY AND SELENIUM

EMISSION CALCULATIONS

PAGE 2 DATE AUG. 21,1977

PARTICULATE LOADING DETERMINATION

SAMPLE DURATION	108.00	MIN.
GAS SAMPLE METERED	52.32	CU.FT.
GAS SAMPLE TEMPERATURE	532.	DEG.R.
VACUUM AT METER	.00	IN.HG.
VACUUM AT CONDENSER	3.60	IN.HG.
VOLUME OF WATER COLLECTED	128.00	CC.
WT OF DUST BY EVAPORATION	.00000	GM.
TOTAL VOL OF GAS SAMPLED	60.32	CU.FT. (METER CONDITIONS)

BATTLE RIVER UNIT 2 B.C. HYDRO TEST BURN MERCURY AND SELENIUM

EMISSION CALCULATIONS

PAGE 3 DATE AUG. 21,1977

FLUE GAS FLOW RATE

SECTOR	PROBE TIP FROM WALL-FT.	VELOCITY HEAD - IN. H20 TRAVERSE NUMBER 1	2	3
1	.578	.090	.080	.060
2	1.735	.115	.095	.060
3	2.892	.115	.100	.050
4	4.048	.110	.100	.030
5	5.205	.105	.100	.050
6	6.362	.105	.095	.065
AV. SQ. ROOT		.326	.308	.228

SECTOR	PROBE TIP FROM WALL-FT.	VELOCITY HEAD - IN. H20 TRAVERSE NUMBER 4	5	6
1	.578	.045	.050	.060
2	1.735	.045	.075	.060
3	2.892	.030	.075	.060
4	4.048	.015	.050	.040
5	5.205	.030	.070	.060
6	6.362	.040	.070	.060
AV. SQ. ROOT		.182	.254	.237

AVERAGE STATIC PRESSURE	-1.80	IN. H20
AVERAGE FLUE GAS TEMPERATURE	352.	DEG.F
PITOT TUBE CALIBRATION FACTOR	.852	
OVERALL AVERAGE SQUARE ROOT	.256	
AVERAGE VELOCITY OF FLUE GAS SAMPLE LEVEL	18.8	FT./SEC - MEAS.
TOTAL FLUE GAS FLOW RATE	870.3	SCFS*
	52217.7	SCFM*
	75.2	MMCFD*
	8095.8	MOLS/HR

* VOLUMES EXPRESSED AT 70 F AND 14.7 PSIA

BATTLE RIVER UNIT 2 H.C. HYDRO TEST BURN MERCURY AND SELENIUM

EMISSION CALCULATIONS

PAGE 1 Test #2 DATE AUG. 21,1977

LOCATION OF SAMPLING POINT	20 FROM PRECIPITATO
DEPTH OF RECTANGULAR DUCT	6.94 FT.
WIDTH OF RECTANGULAR DUCT	11.00 FT.
BAROMETRIC PRESSURE	27.87 IN. HG
AMBIENT TEMPERATURE	55. DEG.F

CARBON DIOXIDE ANALYSIS
FYRITE INDICATOR 11.60 PERCENT-DRY BASIS
OXYGEN ANALYSIS
FYRITE INDICATOR 8.00 PERCENT-DRY BASIS

AVERAGE COMPOSITION OF FLUE GAS

	DRY,BASIS PERCENT	WET BASIS PERCENT
O2	8.00	6.96
CO2	11.60	10.09
N2 *	80.40	69.96
H2O		12.98

* BY DIFFERENCE

SPECIFIC GRAVITY OF FLUE GAS-(AIR=1.00) .988

BATTLE RIVER UNIT 2 B.C. HYDRO TEST BURN MERCURY AND SELENIUM

EMISSION CALCULATIONS

PAGE 2 DATE AUG. 21,1977

PARTICULATE LOADING DETERMINATION

SAMPLE DURATION	108.00	MIN.
GAS SAMPLE METERED	36.43	CU.FT.
GAS SAMPLE TEMPERATURE	524.	DEG.R.
VACUUM AT METER	.00	IN.HG.
VACUUM AT CONDENSER	3.20	IN.HG.
VOLUME OF WATER COLLECTED	95.00	CC.

TOTAL VOL OF GAS SAMPLED 41.86 CU.FT. (METER CONDITIONS)

BATTLE RIVER UNIT 2 B.C. HYDRO TEST BURN MERCURY AND SELENIUM

EMISSION CALCULATIONS

PAGE 3 DATE AUG. 21,1977

FLUE GAS FLOW RATE

SECTOR	PROBE TIP FROM WALL-FT.	VELOCITY HEAD - IN. H2O TRAVERSE NUMBER 1	2	3
1	.578	.200	.165	.140
2	1.735	.230	.205	.100
3	2.892	.230	.205	.075
4	4.048	.220	.210	.060
5	5.205	.220	.210	.100
6	6.362	.210	.210	.145
AV. SQ. ROOT		.467	.448	.318

SECTOR	PROBE TIP FROM WALL-FT.	VELOCITY HEAD - IN. H2O TRAVERSE NUMBER 4	5	6
1	.578	.115	.150	.165
2	1.735	.105	.165	.205
3	2.892	.075	.190	.200
4	4.048	.050	.115	.175
5	5.205	.080	.190	.205
6	6.362	.135	.200	.205
AV. SQ. ROOT		.302	.409	.438

AVERAGE STATIC PRESSURE	-4.60 IN. H2O
AVERAGE FLUE GAS TEMPERATURE	366. DEG.F
PITOT TUBE CALIBRATION FACTOR	.852
OVERALL AVERAGE SQUARE ROOT	.397
AVERAGE VELOCITY OF FLUE GAS SAMPLE LEVEL	29.6 FT./SEC - MEAS.
TOTAL FLUE GAS FLOW RATE	1332.6 SCFS*
	79956.3 SCFM*
	115.1 MMCFD*
	12396.3 MOLS/HR

* VOLUMES EXPRESSED AT 70 F AND 14.7 PSIA

BATTLE RIVER UNIT 2 B.C. HYDRO TEST BURN FLUORIDES

EMISSION CALCULATIONS

TEST NUMBER 1 PAGE 1 DATE AUG. 20,1977

LOCATION OF SAMPLING POINT	20 FROM PRECIP. OUT
DEPTH OF RECTANGULAR DUCT	6.94 FT.
WIDTH OF RECTANGULAR DUCT	11.00 FT.
BAROMETRIC PRESSURE	27.84 IN. HG
AMBIENT TEMPERATURE	64. DEG.F

CARBON DIOXIDE ANALYSIS
FYRITE INDICATOR 11.10 PERCENT-DRY BASIS
OXYGEN ANALYSIS
FYRITE INDICATOR 8.50 PERCENT-DRY BASIS

AVERAGE COMPOSITION OF FLUE GAS

	DRY BASIS PERCENT	WET BASIS PERCENT
O2	8.50	7.18
CO2	11.10	9.38
N2 *	80.40	67.91
H2O		15.54

* BY DIFFERENCE

SPECIFIC GRAVITY OF FLUE GAS-(AIR=1.00) .975

BATTLE RIVER UNIT 2 B.C. HYDRO TEST BURN FLUORIDES

EMISSION CALCULATIONS

TEST NUMBER 1 PAGE 2 DATE AUG. 20,1977

PARTICULATE LOADING DETERMINATION

SAMPLE DURATION	180.00	MIN.
GAS SAMPLE METERED	65.73	CU.FT.
GAS SAMPLE TEMPERATURE	557.	DEG.R.
VACUUM AT METER	.00	IN.HG.
VACUUM AT CONDENSER	6.40	IN.HG.
VOLUME OF WATER COLLECTED	150.00	CC.

TOTAL VOL OF GAS SAMPLED 77.81 CU.FT. (METER CONDITIONS)

BATTLE RIVER UNIT 2 B.C. HYDRO TEST BURN FLUORIDES

EMISSION CALCULATIONS

TEST NUMBER 1 PAGE 3 DATE AUG. 20,1977

FLUE GAS FLOW RATE

SECTOR	PROBE TIP FROM WALL-FT.	VELOCITY HEAD - IN. H2O TRAVERSE NUMBER 1	2	3
1	.578	.230	.210	.175
2	1.735	.275	.250	.180
3	2.892	.285	.255	.120
4	4.048	.280	.255	.080
5	5.205	.275	.255	.110
6	6.362	.220	.255	.185
AV. SQ. ROOT		.510	.496	.372

SECTOR	PROBE TIP FROM WALL-FT.	VELOCITY HEAD - IN. H2O TRAVERSE NUMBER 4	5	6
1	.578	.100	.190	.195
2	1.735	.106	.205	.235
3	2.892	.050	.225	.230
4	4.048	.030	.150	.205
5	5.205	.055	.235	.245
6	6.362	.130	.225	.230
AV. SQ. ROOT		.272	.452	.472

AVERAGE STATIC PRESSURE	-5.70 IN. H2O
AVERAGE FLUE GAS TEMPERATURE	382. DEG.F
PITOT TUBE CALIBRATION FACTOR	.852
OVERALL AVERAGE SQUARE ROOT	.429
AVERAGE VELOCITY OF FLUE GAS SAMPLE LEVEL	32.5 FT./SEC - MEAS.
TOTAL FLUE GAS FLOW RATE	1433.3 SCFS*
	85997.8 SCFM*
	123.8 MMCFD*
	13333.0 MOLS/HR

* VOLUMES EXPRESSED AT 70 F AND 14.7 PSIA

BATTLE RIVER UNIT 2 B.C. HYDRO TEST BURN FLUORIDES

EMISSION CALCULATIONS

TEST NUMBER 2 PAGE 1 DATE AUG. 20,1977

LOCATION OF SAMPLING POINT	20 FROM PRECIP. OUT
DEPTH OF RECTANGULAR DUCT	6.94 FT.
WIDTH OF RECTANGULAR DUCT	11.00 FT.
BAROMETRIC PRESSURE	27.84 IN. HG
AMBIENT TEMPERATURE	73. DEG.F

CARBON DIOXIDE ANALYSIS
FYRITE INDICATOR 11.70 PERCENT-DRY BASIS
OXYGEN ANALYSIS
FYRITE INDICATOR 8.10 PERCENT-DRY BASIS

AVERAGE COMPOSITION OF FLUE GAS

	DRY BASIS PERCENT	WET BASIS PERCENT
O2	8.10	6.99
CO2	11.70	10.10
N2 *	80.20	69.24
H2O		13.67

* BY DIFFERENCE

SPECIFIC GRAVITY OF FLUE GAS-(AIR=1.00) .985

BATTLE RIVER UNIT 2 B.C. HYDRO TEST BURN FLUORIDES

EMISSION CALCULATIONS

TEST NUMBER 2 PAGE 2 DATE AUG. 20,1977

PARTICULATE LOADING DETERMINATION

SAMPLE DURATION	120.00 MIN.
GAS SAMPLE METERED	46.61 CU.FT.
GAS SAMPLE TEMPERATURE	548. DEG.R.
VACUUM AT METER	.00 IN.HG.
VACUUM AT CONDENSER	6.40 IN.HG.
VOLUME OF WATER COLLECTED	109.00 CC.

TOTAL VOL OF GAS SAMPLED 54.00 CU.FT. (METER CONDITIONS)

BATTLE RIVER UNIT 2 B.C. HYDRO TEST BURN FLUORIDES

EMISSION CALCULATIONS

TEST NUMBER 2 PAGE 3 DATE AUG. 20,1977

FLUE GAS FLOW RATE

SECTOR	PROBE TIP FROM WALL-FT.	VELOCITY HEAD - IN. H2O TRAVERSE NUMBER 1	2	3
1	.578	.275	.240	.195
2	1.735	.300	.290	.180
3	2.892	.300	.300	.100
4	4.048	.290	.290	.085
5	5.205	.290	.290	.140
6	6.362	.260	.300	.210
AV. SQ. ROOT		.534	.533	.384

SECTOR	PROBE TIP FROM WALL-FT.	VELOCITY HEAD - IN. H2O TRAVERSE NUMBER 4	5	6
1	.578	.110	.180	.225
2	1.735	.130	.210	.265
3	2.892	.100	.240	.250
4	4.048	.060	.150	.215
5	5.205	.100	.250	.260
6	6.362	.175	.240	.275
AV. SQ. ROOT		.331	.458	.498

AVERAGE STATIC PRESSURE	-5.90 IN. H2O
AVERAGE FLUE GAS TEMPERATURE	387. DEG.F
PITOT TUBE CALIBRATION FACTOR	.852
OVERALL AVERAGE SQUARE ROOT	.457
AVERAGE VELOCITY OF FLUE GAS SAMPLE LEVEL	34.6 FT./SEC - MEAS.
TOTAL FLUE GAS FLOW RATE	1512.3 SCFS*
	90740.7 SCFM*
	130.7 MMCFD*
	14068.3 MOLS/HR

* VOLUMES EXPRESSED AT 70 F AND 14.7 PSIA

BATTLE RIVER UNIT 2 B.C. HYDRO TEST RUN ARSENIC

EMISSION CALCULATIONS

TEST NUMBER 1 PAGE 1 DATE AUG. 14,1977

LOCATION OF SAMPLING POINT	20 FROM PRECIP OUTL
DEPTH OF RECTANGULAR DUCT	6.94 FT.
WIDTH OF RECTANGULAR DUCT	11.00 FT.
BAROMETRIC PRESSURE	27.96 IN. HG
AMBIENT TEMPERATURE	64. DEG.F

CARBON DIOXIDE ANALYSIS
FYRITE INDICATOR 10.00 PERCENT-DRY BASIS
OXYGEN ANALYSIS
FYRITE INDICATOR 9.30 PERCENT-DRY BASIS

AVERAGE COMPOSITION OF FLUE GAS

	DRY BASIS PERCENT	WET BASIS PERCENT
O2	9.30	8.14
CO2	10.00	8.75
N2 *	80.70	70.62
H2O		12.49

* BY DIFFERENCE

SPECIFIC GRAVITY OF FLUE GAS-(AIR=1.00) .984

BATTLE RIVER UNIT 2 B.C. HYDRO TEST BURN ARSENIC

EMISSION CALCULATIONS

TEST NUMBER 1 PAGE 2 DATE AUG. 14,1977

PARTICULATE LOADING DETERMINATION

SAMPLE DURATION	72.00 MIN.
GAS SAMPLE METERED	14.83 CU.FT.
GAS SAMPLE TEMPERATURE	545. DEG.R.
VACUUM AT METER	.00 IN.HG.
VACUUM AT CONDENSER	1.70 IN.HG.
VOLUME OF WATER COLLECTED	29.50 CC.
TOTAL VOL OF GAS SAMPLED	16.94 CU.FT. (METER CONDITIONS)

BATTLE RIVER UNIT 2 B.C. HYDRO TEST BURN ARSENIC

EMISSION CALCULATIONS

TEST NUMBER 1 PAGE 3 DATE AUG. 14,1977

FLUE GAS FLOW RATE

SECTOR	PROBE TIP FROM WALL-FT.	VELOCITY HEAD - IN. H2O TRAVERSE NUMBER 1	2	3	4
1	.578	.050	.090	.065	.050
2	1.735	.030	.090	.060	.030
3	2.892	.045	.075	.070	.040
4	4.048	.045	.085	.075	.045
5	5.205	.065	.055	.020	.040
6	6.362	.075	.060	.035	.050
AV. SQ. ROOT		.225	.274	.228	.205

AVERAGE STATIC PRESSURE	-2.00	IN. H2O
AVERAGE FLUE GAS TEMPERATURE	336.	DEG.F
PITOT TUBE CALIBRATION FACTOR	.852	
OVERALL AVERAGE SQUARE ROOT	.233	
AVERAGE VELOCITY OF FLUE GAS SAMPLE LEVEL	17.0	FT./SEC - MEAS.
TOTAL FLUE GAS FLOW RATE	803.2	SCFS*
	48193.4	SCFM*
	69.4	MMCFD*
	7471.9	MOLS/HR

* VOLUMES EXPRESSED AT 70 F AND 14.7 PSIA

BATTLE RIVER UNIT 2 O.C. HYDRO TEST BURN ARSENIC

EMISSION CALCULATIONS

TEST NUMBER 2 PAGE 1 DATE AUG. 14,1977

LOCATION OF SAMPLING POINT	20 FROM PRECIP. OUT.
DEPTH OF RECTANGULAR DUCT	6.95 FT.
WIDTH OF RECTANGULAR DUCT	11.00 FT.
BAROMETRIC PRESSURE	27.98 IN. HG
AMBIENT TEMPERATURE	64. DEG.F

CARBON DIOXIDE ANALYSIS
FYRITE INDICATOR 10.50 PERCENT-DRY BASIS
OXYGEN ANALYSIS
FYRITE INDICATOR 9.60 PERCENT-DRY BASIS

AVERAGE COMPOSITION OF FLUE GAS

	DRY BASIS PERCENT	WET BASIS PERCENT
O2	9.60	8.34
CO2	10.50	9.12
N2 *	79.90	69.44
H2O		13.10

* BY DIFFERENCE

SPECIFIC GRAVITY OF FLUE GAS-(AIR=1.00) .984

BATTLE RIVER UNIT 2 B.C. HYDRO TEST BURN ARSENIC

EMISSION CALCULATIONS

TEST NUMBER 2 PAGE 2 DATE AUG. 14,1977

PARTICULATE LOADING DETERMINATION

SAMPLE DURATION	102.00 MIN.
GAS SAMPLE METERED	44.32 CU.FT.
GAS SAMPLE TEMPERATURE	529. DEG.R.
VACUUM AT METER	.00 IN.HG.
VACUUM AT CONDENSER	3.10 IN.HG.
VOLUME OF WATER COLLECTED	98.00 CC.

TOTAL VOL OF GAS SAMPLED 51.00 CU.FT. (METER CONDITIONS)

BATTLE RIVER UNIT 2 B.C. HYDRO TEST BURN ARSENIC

EMISSION CALCULATIONS

TEST NUMBER 2 PAGE 3 DATE AUG. 14,1977

FLUE GAS FLOW RATE

SECTOR	PROBE TIP FROM WALL-FT.	VELOCITY HEAD - IN. H20 TRAVERSE NUMBER 1	2	3	4	5
1	.579	.071	.065	.048	.048	.0
2	1.737	.070	.060	.040	.038	.0
3	2.896	.070	.065	.038	.025	.0
4	4.054	.070	.065	.028	.025	.0
5	5.212	.070	.065	.038	.025	.0
6	6.371	.070	.065	.048	.048	.0
AV. SQ. ROOT		.265	.253	.199	.185	.2

SECTOR	PROBE TIP FROM WALL-FT.	VELOCITY HEAD - IN. H20 TRAVERSE NUMBER 7	8	9	*	*
1	.579	.000	.080	.075	.025	.0
2	1.737	.000	.080	.075	.015	.0
3	2.896	.000	.080	.080	.035	.0
4	4.054	.000	.080	.080	.045	.0
5	5.212	.065	.060	.040	.035	.0
6	6.371	.080	.070	.030	.030	.0
AV. SQ. ROOT		.090	.273	.248	.173	.1

AVERAGE STATIC PRESSURE	-2.50 IN. H20
AVERAGE FLUE GAS TEMPERATURE	370. DEG.F
PITOT TUBE CALIBRATION FACTOR	.852
OVERALL AVERAGE SQUARE ROOT	.209
AVERAGE VELOCITY OF FLUE GAS SAMPLE LEVEL	15.6 FT./SEC - MEAS.
TOTAL FLUE GAS FLOW RATE	707.1 SCFS*
	42423.7 SCFM*
	61.1 MMCFD*
	6577.3 MOLS/HR

* VOLUMES EXPRESSED AT 70 F AND 14.7 PSIA

Western Research & Development
Division of Bow Valley Resource Services Ltd

SUBJECT: BCH - Trace Contaminants
Aug 21/77 Mercury

JOB NUMBER 3463
DATE 12/11/77
BY DGC
SHEET 1 OF 1

Mercury		TEST 1		TEST 2		AVERAGE
Solid	probe wash	0.001	mg	.0055	mg	
	filter	<0.0005	mg	<.0005	mg	
	Total	<0.0015	mg	<.0060	mg	
Gaseous		<0.0035	mg	< .009	mg	
Total Solids	filter	27.57	mg	103.26	mg	
	residue	02.60	mg	13.22	mg	
	Total	30.17	mg	122.26	mg	
Gas Volume Sampled						
	DSCF	48.50		34.29		
	M^3 Dry	1.374		0.971		
Concentration						
Solid	Hg	<0.0011	mg/M^3	<0.0062	mg/M^3	
Gaseous	Hg	<0.0025	mg/M^3	<0.0093	mg/M^3	
Total	Hg	<0.0036	mg/M^3	<0.0155	mg/M^3	
Total particulate		22.0	mg/M^3	125.91	mg/M^3	
Ratio	Total Hg / Total particulate	<0.000164		<0.000123		<0.000143
Ratio	Gaseous Hg / Total Hg	0.694		0.60		0.647
Boiler Effluent (Precipitator Study)		54617	DSCFM	94936	DSCFM	
		1547	DM^3/M	2406	DM^3/M	
		181	°C	185	°C	
Emission						
Solid	Hg	<0.102	g/hr	<0.895	g/hr	
Gaseous	Hg	<0.232	g/hr	<1.343	g/hr	
Total	Hg	<0.334	g/hr	<2.238	g/hr	
Coal Rate (Dry)		9,890	Kg/hr	14,170	Kg/hr	
Ratio	Total Hg / UNIT WT COAL	0.034×10^{-6}		0.158×10^{-6}		0.096×10^{-6}

Note Hg content in Sample 1 - blank reading for impinger solution.
An error was assumed, thus, calculations disregarded figure.

Western Research & Development
Division of Bow Valley Resource Services Ltd

SUBJECT: BCH Trace Contaminants
Aug 20/77 Fluoride

JOB NUMBER 3463
DATE 12/11/77
BY DGC
SHEET 1 OF 1

		TEST 1	TEST 2	AVERAGE
Fluoride				
Solid	probe wash	0.173 mg	0.153 mg	
	filter	0.003 mg	0.001 mg	
	Total	0.176 mg	0.154 mg	
Gaseous		1.491 mg	1.827 mg	
Total Solids				
	filter	212.0 mg	184.1 mg	
	residue	18.0 mg	64.0 mg	
	Total	230.0 mg	248.1 mg	
Gas Volume Sampled				
	DSCF	58.196	41.945	
	M^3(Dry)	1.648	1.188	
Concentration				
	Solid F	0.1068 mg/M^3	0.1296 mg/M^3	0.1182 mg/M^3
	Gaseous F	0.9047 mg/M^3	1.5379 mg/M^3	1.2213 mg/M^3
	Total F	1.0115 mg/M^3	1.6675 mg/M^3	1.3395 mg/M^3
	Total Particulate	139.6 mg/M^3	208.8 mg/M^3	174.2 mg/M^3
Ratio	Total F / Total particulate	0.00725	0.00798	0.0076
Ratio	Gaseous F / Total	.8944	0.9223	0.908
Boiler Effluent		95660 DSCFM	96587 DSCFM	
(Precipitator Study)		2709 DM^3/M	2735 DM^3/M	
		194 °C	197 °C	
Emission				
Solid F		17.36 g /hr	21.27 g /hr	
Gaseous F		147.04 g /hr	252.37 g /hr	
Total		164.4 g /hr	273.64 g /hr	
Coal Rate		16,700 Kg/hr	19,490 Kg/hr	
Ratio	Total F / UNIT WT COAL	9.837×10^{-6}	14.027×10^{-6}	11.932×10^{-6}

Western Research & Development
Division of Bow Valley Resource Services Ltd

SUBJECT: BCH - Trace Contaminants
Aug 14/77 - Arsenic

JOB NUMBER 3463
DATE Dec 12/77
BY GMS
SHEET 1 OF 1

Arsenic		TEST 1		TEST 2		AVERAGE
Solids	probe wash	<0.010	mg	<0.010	mg	
	filter	<0.002	mg	<0.002	mg	
	Total	<0.012	mg	<0.012	mg	
Gaseous		<0.020	mg	<0.012	mg	
Total Solids	filter	15.87	mg	48.19	mg	
	residue	940	mg	243	mg	
	Total	955.87	mg	291.19	mg	
Gas volume sampled						
	DSCF	13.484		41.518		
	M^3 Dry	0.382		1.175		
Concentration	solid As	<0.0314	mg/M^3	<0.0102	mg/M^3	
	gaseous As	<0.0524	mg/M^3	<0.0170	mg/M^3	
	Total As	<0.0838	mg/M^3	<0.0272	mg/M^3	
Total Particulate (Dry)		2502.28	mg/M^3	247.82	mg/M^3	
Ratio	Total As / Total Particulate	<0.000033		<0.000110		
Ratio	Gaseous As / Total As	0.6253		0.625		
Boiler Effluent (Trace element test)		42,174	DSCFM	36,866	DSCFM	
		1194	DM^3/min	1044	DM^3/min	
		169	°C	188	°C	
Emission						
Solid As		<2.249	g/hr	<0.639	g/hr	
Gaseous As		<3.754	g/hr	<1.065	g/hr	
Total As		<6.003	g/hr	<1.704	g/hr	
Coal Rate		11,720	Kg/hr	10,980	Kg/hr	
Ratio	Total As / UNIT WT COAL	$<0.512x10^{-6}$		$<0.155x10^{-6}$		Avg. = $<0.334x10^{-6}$

Western Research & Development
Division of Bow Valley Resource Services Ltd

SUBJECT: BCH - Trace Contaminants
Aug 21/77 - Selenium

JOB NUMBER 3463
DATE Dec 12/77
BY GMS
SHEET 1 OF 1

Selenium		TEST 1		TEST 2		AVERAGE
Solid	probe wash	<0.00618	mg	< 0.00309	mg	
	filter	< 0.0004	mg	< 0.0004	mg	
	Total	<0.00658	mg	< 0.00349	mg	
Gaseous		<0.0201	mg	<0.0177	mg	
Total Solids	filter	27.57	mg	109.26	mg	
	residue	2.60	mg	13.00	mg	
	Total	30.17	mg	122.26	mg	
Gas Volume Samples						
	DSCF	48.50		34.29		
	M^3 Dry	1.374		0.971		
Concentration						
	solid Se	<0.00479	mg/M^3	<0.00359	mg/M^3	
	gaseous Se	<0.01463	mg/M^3	< 0.0182	mg/M^3	
	Total Se	<0.01942	mg/M^3	<0.02179	mg/M^3	
Total Particulate		22.0	mg/M^3	125.91	mg/M^3	
Ratio	Total Se / Total Particulate	<0.000883		<0.000173		
Ratio	Gaseous Se / Total Se	0.75334		0.83525		
Boiler Effluent (Precipitator Study)		54617	DSCFM	84936	DSCFM	
		1547	DM^3/M	2406	DM^3/M	
		181	°C	185	°C	
Emission						
	Solid Se	<0.445	g/hr	<0.518	g/hr	
	Gaseous Se	<1.358	g/hr	<2.627	g/hr	
	Total Se	<1.803	g/hr	<3.145	g/hr	
Coal Rate		9,890	Kg/hr	14,170	Kg/hr	
Ratio	Total Se / UNIT WT COAL	$<0.182 \times 10^{-6}$		$<0.222 \times 10^{-6}$		Avg. = $<0.202 \times 10^{-6}$

APPENDIX 2

LABORATORY ANALYSES

LABORATORY ANALYSES

Subcontractor

All sample train, coal, flyash and bottom ash samples were analysed by Environmental Research & Technology, Inc., Concord, Massachusetts.

Sample Train Catch

Table 2-1 gives a description of each sample analysed, including blank filters and solutions. The samples were analyses for

- mercury
- fluorides
- arsenic
- selenium

The results are given in Table 2-2. Filter and probe wash samples for August 21, 1977 were analysed for all trace elements covered by this study.

Coal Samples

Pulverized coal sample analyses are given in Table 2-3a to 2-3c for August 14, 20, and 21, 1977.

Bottom Ash

Bottom ash analyses for each test day are listed in Tables 2-3a to 2-3c.

Flyash

Flyash analyses for each test day are listed in Tables 2-3a to 2-3c.

Precipitator Inlet

Four samples of flyash collected in the precipitator inlet duct while conducting tests for the Precipitator Study on August 20 and 21 were analysed for trace elements. The results are shown in Table 2-4.

Discussion

Due to sample size and component concentrations some analyses resulted in concentrations that were less than the detectable limit of the measurement instrument. These analyses are noted with < signs and the material balances carry these signs. Similarly, some analyses for major components resulted in concentrations above the range of the measurement instrument and the values are noted with > signs.

TABLE 2 - 1

B.C. HYDRO TRACE ELEMENT STUDY

SAMPLES FOR LABORATORY ANALYSES

Sample Number	Description
1	Blank for Mercury & Selenium, 50/50 $AgNO_3/(NH_4)_2 \cdot S_2O_4$
2	Blank for Mercury, Selenium, & Arsenic Double distilled water
3	Blank for Mercury & Selenium, 6M H_2O_2
4	Blank for Arsenic, 0.1 N NaOH
5	1st impinger wash Test 1 (Hg/Se)
6	1st impinger wash Test 2 (Hg/Se)
7	2nd & 3rd impinger wash Test 1 (Hg/Se)
8	2nd & 3rd impinger wash Test 2 (Hg/Se)
9	Probe wash Test 1 (Hg/Se)
10	Probe wash Test 2 (Hg/Se)
11	Probe wash Test 1 (Arsenic)
12	Probe wash Test 2 (Arsenic)
13	1st & 2nd impinger Test 1 (Arsenic)
14	1st & 2nd impinger Test 2 (Arsenic)
15	3rd impinger Test 1 (Arsenic)
16	3rd impinger Test 2 (Arsenic)
17	Probe wash Test 1 (Fluorine)
18	Probe wash Test 2 (Fluorine)
19	Impinger wash Test 1 (Fluorine)
20	Impinger wash Test 2 (Fluorine)
21	Blank Whatman filter paper
22	Blank Gelman glass fiber paper
23	Filter #1 - Fluorine Test 1
24	Filter #2 - Fluorine Test 2
25	Filter #54 - Arsenic Test 1
26	Filter #55 - Arsenic Test 2
27	Filter #57 - Hg/Se Test 1
28	Filter #58 - Hg/Se Test 2.

TABLE 2 - 2

B.C. HYDRO TRACE ELEMENT STUDY

LABORATORY ANALYSES OF SAMPLED EMISSIONS

SAMPLE NUMBER

		1	2	3	4	5	6	7	8	9	10	11	12	13
Sample Volume	ml	172	172	90	327	250	225	420	365	206	103	407	186	510
Mercury	ug	133.0	< 1.0	2.3		2.5	7.9	1.0	1.1	1.0	5.5			
Fluoride	ug		<17.0											
Arsenic	ug		<10.0	<10.0	<10.0							<10.0	<10.0	<10.0
Selenium	ug	< 5.16	< 5.16	< 2.70		<7.50	<6.75	<12.60	<10.95	< 6.18	< 3.09			
Beryllium	ug		< 0.86	0.45	< 1.64							< 2.04	< 0.93	< 2.55
Boron	ug		15.48							24.72	5.15			
Cadmium	ug		< 0.86							< 1.03	1.34			
Chromium	ug		< 0.86							1.44	5.97			
Copper	ug		1.72							4.94	8.76			
Lead	ug		< 8.60	4.50	16.35							28.49	< 9.30	<25.50
Manganese	ug		< 0.34							26.57	79.93			
Molybdenum	ug		< 1.72							< 2.06	4.53			
Nickel	ug		< 1.72							6.18	21.63			
Strontium	ug		< 0.34							1.65	3.09			
Uranium	ug		1376							< 206	299			
Vanadium	ug		< 0.86							< 1.03	1.13			
Zinc	ug		< 1.72							8.24	37.29			
Residue	mg		< 1.0							2.6	13.0	940.0	243.0	

TABLE 2 - 2 (CONTINUED)

B.C. HYDRO TRACE ELEMENT STUDY

LABORATORY ANALYSES OF SAMPLED EMISSIONS

SAMPLE NUMBER

		14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Sample Volume	ml	440	208	254	230	232	645	610	NA	NA	NA	NA	NA	NA	NA	NA
Mercury	ug														<0.50	< 0.50
Fluoride	ug				173.0	153.0	1491.0	1827.0	6.0		9.0	7.0				
Arsenic	ug	<10.0	<10.0	<10.0									<2.0	<2.0		
Selenium	ug								<0.60						< 0.40	< 0.40
Beryllium	ug	< 2.2	< 1.04	< 1.27					<0.07				<0.07	<0.07		
Boron	ug								1.0						10.8	17.9
Cadmium	ug								<0.1						0.67	1.87
Chromium	ug								1.10						1.52	2.67
Copper	ug								0.32						2.09	6.51
Lead	ug	<22.0	<10.4	66.04					<0.67				0.93	1.60		
Manganese	ug								2.96						24.5	46.7
Molybdenum	ug								0.22						0.36	1.29
Nickel	ug								0.86						0.61	1.73
Strontium	ug								0.10						0.56	16.5
Uranium	ug															
Vanadium	ug								0.12						0.68	
Zinc	ug								1.84						3.87	5.31
Residue	mg				18.0	64.0										

TABLE 2 - 3a
B.C. HYDRO TRACE ELEMENT STUDY

ANALYSES OF PULVERIZED COAL, BOTTOM ASH, AND FLYASH
mg/kg BY WEIGHT

AUGUST 14, 1977

ELEMENT	Pul. Coal AM	Bott. Ash	Ash-A Field AM	Ash-B Field AM	Pul. Coal PM	Ash-A Field PM	Ash-B Field PM	Ash-C Field PM
Mercury	0.10	0.07	0.04	0.04	0.11	0.04	0.05	0.05
Fluoride	100	44	36	100	120	24	44	300
Arsenic	8	13	18	55	1	32	63	79
Selenium	2	9	10	13	1	19	21	14
Beryllium	0.7	1	1	2	0.3	3	3	4
Boron	0.4	37	32	66	7	59	140	130
Cadmium	0.8	0.5	0.6	0.6	0.6	0.6	2	4
Chromium	72	120	64	27	36	220	430	430
Copper	140	>1000	750	360	420	>1000	>1000	>1000
Lead	13	13	20	48	11	35	69	200
Manganese	530	>1000	110	120	160	640	>1000	>1000
Molybdenum	4	7	8	12	4	9	17	25
Nickel	29	25	77	37	6	78	350	500
Strontium	110	250	180	680	84	300	>1000	>1000
Uranium	2	11	7	12	6	17	27	44
Vanadium	79	>1000	420	800	240	570	>1000	430
Zinc	41	230	55	460	41	100	620	>1000

TABLE 2 - 3b
B.C. HYDRO TRACE ELEMENT STUDY

ANALYSES OF PULVERIZED COAL, BOTTOM ASH, AND FLYASH
mg/kg BY WEIGHT

AUGUST 20, 1977

ELEMENT	Pul. Coal AM	Bott. Ash AM	Ash-A Field AM	Ash-B Field AM	Ash-C Field AM	Pul. Coal PM	Bott. Ash PM	Ash-A Field PM	Ash-B Field PM	Ash-C Field PM
Mercury	0.08	0.42	0.03	0.05	0.03	0.06	0.02	0.05	0.06	0.03
Fluoride	180	76	110	160	140	160	72	84	92	130
Arsenic	11	2	32	70	78	12	7	28	59	75
Selenium	19	23	10	20	9	7	19	40	43	13
Beryllium	1	1	3	1	1	0.4	2	2	2	2
Boron	15	71	40	52	110	12	37	50	260	200
Cadmium	0.8	0.9	0.6	0.8	1	1	0.5	1	0.7	2
Chromium	40	430	220	380	380	60	120	130	320	310
Copper	530	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000
Lead	13	5	35	60	40	9	19	40	64	88
Manganese	>1000	>1000	960	>1000	430	66	>1000	510	480	370
Molybdenum	4	21	17	8	19	4	8	13	16	12
Nickel	11	40	78	35	40	13	86	90	16	43
Strontium	110	610	680	360	540	170	560	540	570	580
Uranium	6	17	17	15	15	5	14	15	22	13
Vanadium	120	>1000	950	840	840	65	>1000	630	350	540
Zinc	46	17	280	250	280	38	41	110	300	>1000

TABLE 2 - 3c
B.C. HYDRO TRACE ELEMENT STUDY

ANALYSES OF PULVERIZED COAL BOTTOM ASH, AND FLYASH
mg/kg BY WEIGHT

AUGUST 21, 1977

ELEMENT	Pul. Coal AM	Bott. Ash AM	Ash-A Field AM	Ash-B Field AM	Ash-C Field AM	Pul. Coal PM	Bott. Ash PM	Ash-A Field PM	Ash-B Field PM	Ash-C Field PM
Mercury	0.05	0.12	0.03	0.3	0.04	0.07	0.02	0.05	0.05	0.03
Fluoride	84	≤20	24	28	360	96	≤20	≤20	28	76
Arsenic	23	3	35	72	45	7	3	17	200	730
Selenium	27	18	21	13	1	4	8	10	34	34
Beryllium	0.8	0.8	0.9	2	1	0.3	0.5	0.2	2	2
Boron	25	23	53	97	60	14	60	10	88	44
Cadmium	2	0.5	0.6	0.8	0.5	1	0.5	0.7	1	2
Chromium	41	170	320	120	74	28	120	120	320	400
Copper	>1000	>1000	>1000	>1000	>1000	250	>1000	>1000	>1000	>1000
Lead	20	13	31	30	40	13	20	25	86	64
Manganese	140	740	140	>1000	>1000	>1000	>1000	>1000	>1000	>1000
Molybdenum	3	4	9	4	9	4	7	9	32	16
Nickel	90	60	27	42	45	60	45	56	150	150
Strontium	350	390	450	280	28	230	350	340	450	570
Uranium	10	9	13	12	5	6	23	14	22	10
Vanadium	160	370	>1000	260	>1000	370	≥500	>610	710	>1000
Zinc	71	96	180	110	430	96	53	90	620	310

Table 2 - 4
B.C. HYDRO TRACE ELEMENT STUDY

ANALYSES OF PRECIPITATOR INLET ASH
mg/Kg BY WEIGHT

DATE	AUG 20, 1977		Aug 21, 1977	
TIME	AM	PM	AM	PM
SAMPLE NO.	M93	M76	M96	M92
ELEMENT				
Mercury	0.19	0.19	0.44	0.29
Fluoride	<20	<20	<20	<20
Arsenic	15	65	38	99
Selenium	7	19	6	23
Beryllium	0.9	2.0	0.8	3.0
Boron	51	49	46	71
Cadmium	0.4	0.8	0.5	1.0
Chromium	210	360	170	430
Copper	>1000	>1000	660	>1000
Lead	13	64	27	77
Manganese	550	>1000	>740	>1000
Molybdenum	6	13	5	21
Nickel	150	87	75	520
Strontium	120	500	230	>1000
Uranium	6	13	9	4
Vanadium	820	470	180	>1000
Zinc	71	410	120	830

APPENDIX 3

MATERIAL BALANCE

Part 1 - Ash Reconciliation

METHODOLOGY

Coal flow on a dry basis was determined from the coal flow (wet basis) multiplied by the ratio of percent ash on a wet basis to percent ash on a dry basis. Coal flow (wet basis) was supplied by B.C. Hydro (P. Willis) in lb/hr and converted to Kg/hr.

The flyash produced during combustion was measured at the precipitator inlet by WR&D during the precipitator efficiency tests. The values were used to obtain total flyash and bottom ash flow rates based on an 85/15 split of flyash to bottom ash as measured by the combustion test crew during the test burn.

EXAMPLES

The ash reconciliation calculation for the morning test of August 21, 1977 is included to illustrate the methodology:

- Coal
  coal flow (wet basis) = 15,067 Kg/hr
  % ash (wet basis) = 31.7%
  % ash (dry basis) = 48.31%
  coal flow (dry basis) = $15{,}067 \times \frac{0.317}{0.4831}$
  = 9,886 Kg/hr

- Ash
  measured flyash flow into precipitator (ASTM tests)
  = 4309 Kg/hr

  using 85/15 spilt of flyash to bottom ash:

  total ash = $4309 \times \frac{100}{85}$
  = 5069 Kg/hr

  bottom ash = 5069 - 4309
  = 760 Kg/hr

- Check
  calculated based on coal burned

  - 9886 Kg/hr coal x 48.31% ash = 4776 Kg/hr

    Determined from ASTM precipitator inlet test and an 85/15 split

  - total ash is 5069 Kg/hr

    difference

  - 5069 - 4776 = 293 Kg/hr
    Difference as a percent of input = 6%

On August 14, 1977 no precipitator efficiency tests were conducted, therefore a number of assumptions were made in order to determine the ash reconciliation. The following example for the morning tests of August 14 illustrate the methodology.

- coal flow (wet basis) = 16,308 Kg/hr
- % ash (wet basis) = average of ash content for Aug 20 and 21

  $$= \frac{31.8 + 37.6 + 31.7 + 29.8}{4}$$

  = 32.2%

- % ash (dry basis) = 44.82%
- coal flow (dry basis) = 16,308 x 0.332
  = 11,716 Kg/hr

- total ash = 11,716 x 0.4482
  = 5251 x Kg/hr

- assuming on 85/15 flyash to bottom ash split:

  total flyash = 5251 x 0.85
  = 4463 Kg/hr

  bottom ash = 5251 - 4463
  = 788 Kg/hr

RESULTS

The results of the ash reconciliation for August 14, 20 and 21, 1977 are given in Table 3-1. Except for August 21, 1977 PM the ash reconciliation is reasonable. Explanations for August 21, 1977 PM may be found in the coal ash content wet basis.

TABLE 3 - 1

B.C. HYDRO TRACE ELEMENT STUDY

ASH RECONCILIATION

		August 14		August 20		August 21	
		AM	PM	AM	PM	AM	PM
Coal Flow (Kg/hr)	Wet	16,308	16,749	25,120	27,107	15,067	22,585
Ash in Coal (%)	Wet	32.20	32.20	31.80	35.60	31.70	29.80
Coal Flow (Kg/hr)	Dry	11,716	10,977	16,698	19,491	9,886	14,169
Ash in Coal (%)	Dry	44.82	49.13	47.84	49.51	48.31	47.50
Total Ash (Kg/hr)	Dry	5,251	5,393	8,974	10,273	5,069	8,917
Bottom Ash (Kg/hr)	Dry	788	809	1,346	1,541	760	1,338
Flyash (Kg/hr)	Dry	4,463	4,584	7,628	8,732	4,309	7,579
Total Ash / Coal flow (wet) x % Ash (wet)		1.0	1.0	1.12	1.06	1.06	1.32
COMMENT	No Flyash Measurements			OK	OK	OK	Poor

Part 2 - Material Balance Calculations for Each Test

METHODOLOGY

A material balance for each of the elements

- mercury
- fluorides
- arsenic
- selenium
- beryllium
- boron
- cadmium
- chromium
- copper
- lead
- manganese
- molybdenum
- nickel
- strontium
- uranium
- vanadium
- zinc

was calculated for each test conducted on August 14, 20, and 21, 1977.

The material balance calculation is illustrated by the following simplified flow diagram:

[1]	[2]	+	[3]	+	[4]	=	[5]
ELEMENT IN	BOTTOM ASH		FLYASH		STACK EMISSIONS		TOTAL EMISSIONS

August 14, 1977

A complete material balance for arsenic was calculated. The stack emissions for arsenic were split into solid and vapour fractions since the trace element sampling on this date was specifically for arsenic.

Additionally, ERT analysed the arsenic samples for beryllium and lead and material balance calculations were made (solid phase only).

The material balances for all other elements do not include stack emissions since no analyses for these elements are available from the stack emission tests.

August 20, 1977

Trace element testing was specifically for fluoride. Consequently a complete material balance was calculated for fluoride including the solid and vapour phase fractions of the stack emissions.

The material balances for all other elements do not include stack emissions as no laboratory data on stack emissions for these elements was available.

August 21, 1977

Trace element testing was specifically for mercury and selenium. Consequently a complete material balance was calculated for these elements including the solid and vapour phase fractions of the stack emissions.

The filter catch and probe washings were also analysed for the following:

- boron
- cadmium
- chromium
- copper
- manganese
- molybdenum
- nickel
- strontium
- uranium (reported values were judged invalid)
- vanadium (AM test only)
- zinc

Consequently, the material balance calculations include the stack emissions in the solid phase for these elements.

The material balance calculations for

- fluoride
- arsenic
- beryllium
- lead

do not include stack emissions since no analyses for these elements were conducted.

EXAMPLE

Material balance calculations were done by a programmable calculator. The following example illustrates the calculation technique:

Material balance for cadmium, for August 21, 1977, AM test

1 Cd input = coal flow x cadmium in coal

$= 9,886 \times 2 \times 10^{-6}$

= 0.0198 Kg/hr

2 Cd in bottom ash = bottom ash flow rate x cadmium in bottom ash

$= 760 \times 0.5 \times 10^{-6}$

= 0.00038 Kg/hr

3 Cd in flyash = flyash flow rate x cadmium in flyash

$= 4309 \times 0.63 \times 10^{-6}$

= 0.00272 Kg/hr

4 Cd in stack emissions (solid phase only)

Cd on filter paper and probe washings = <1.697 ug

gas sample (dry) = 1.374 M^3

Cd concentration $= \frac{<1.697}{1.374}$

$= <1.235 \frac{ug}{M^3}$

boiler effluent = 1547 M^3/Min (Dry)

Cd emission rate = <1.235 x 1547 x 60

= <0.00012 Kg/hr

5 total Cd emissions = 2 + 3 + 4

= <0.00321 Kg/hr

Cd output/Cd input = 16%

RESULTS

August 14, 1977

The material balance results are given in Tables 3-2a and 3-2b.

August 20, 1977

The material balance results are given in Tables 3-3a and 3-3b.

August 21, 1977

The material balance results are given in Tables 3-4a and 3-4b.

CONCLUSIONS

These material balances point to the fact that the individual trace element concentration determinations are not accurate or that the composition is highly variable.

For this reason the six sets of data (two for the stack emission ash) are averaged in Part 3 and a typical material balance for coal firing rate of 50000 Kg/hr is presented in Part 4.

TABLE 3 - 2a

B.C. HYDRO TRACE ELEMENT STUDY
MASS BALANCE

Coal Flow (Dry Basis) = 11,716 Kg/hr

DATE: AUGUST 14 (MORNING TEST)

	(1)	(2)		(3)		(4)				(5)	
						Amount in Stack Emissions				Output Sum of (2)+ (3)+(4)	Element Output(5)/ Input(1)
	Input	Amount in Bottom Ash		Amount in Flyash		Solids		Gaseous			
Element	Kg/hr	Kg/hr	(2)/(5)%	Kg/hr	(3)/(5)%	Kg/hr	(4)/(5)%	Kg/hr	(4)/(5)%	Kg/hr	%
Mercury	0.0012	0.0005	20.0	0.0002	80.0	No Data				0.00025	20
Fluorides	1.1716	0.0347	10.2	0.3035	89.8	No Data				0.3382	29
Arsenic	0.0937	0.0103	5.7	0.1629	91.0	<0.00225	<1.2	<0.00375	2.1	<0.1755	191
Selenium	0.0235	0.0071	12.1	0.0513	87.9	No Data				0.0584	249
Beryllium	0.0082	0.0008	9.8	0.0067	85.2	<0.00039	<5.0			<0.0079	96
Boron	0.0047	0.0292	11.8	0.2187	88.2	No Data				0.2479	5289
Cadmium	0.0094	0.0004	13.2	0.0027	86.8	No Data				0.0031	33
Chromium	0.8436	0.0945	31.8	0.2031	68.2	No Data				0.2976	35
Copper	1.6403	>0.7879	>22.9	2.6557	77.1	No Data				>3.4436	210
Lead	0.1523	0.0103	6.1	0.1518	90.6	0.00552	3.3			0.1676	110
Manganese	6.2096	>0.7879	>60.6	0.5133	39.4	No Data				>1.3012	21
Molybdenum	0.0469	0.0055	11.0	0.0446	89.0	No Data				0.0501	107
Nickel	0.3398	0.0197	7.2	0.2544	92.8	No Data				0.2741	81
Strontium	1.2888	0.1970	9.3	1.9192	90.7	No Data				2.1162	164
Uranium	0.0235	0.0087	17.0	0.0424	83.0	No Data				0.0511	218
Vanadium	0.9256	>0.7879	>22.4	2.7226	77.6	No Data				>3.5105	379
Zinc	0.4804	0.1812	13.6	1.1493	86.4	No Data				1.3305	277

TABLE 3 - 2b
B.C. HYDRO TRACE ELEMENT STUDY
MASS BALANCE

Coal Flow (Dry Basis) = 10,977 Kg/hr

DATE: AUGUST 14, 1977 (AFTERNOON TEST)

	(1)	(2)		(3)		(4)				(5)	
						Amount in Stack Emissions				Output Sum of (2)+(3)+(4)	Element Output(5)/Input(1)
	Input	Amount in Bottom Ash		Amount in Flyash		Solids		Gaseous			
Element	Kg/hr	Kg/hr	(2)/(5)%	Kg/hr	(3)/(5)%	Kg/hr	(4)/(5)%	Kg/hr	(4)/(5)%	Kg/hr	%
Mercury	0.0012	0.0005	16.7	0.00023	83.3	No Data				0.00028	22
Fluorides	1.3183	0.0356	6.1	0.5477	93.9	No Data				0.5832	44
Arsenic	0.0110	0.0105	3.8	0.2659	95.6	<0.000640	<0.2	<0.00107	<0.4	<0.2781	2534
Selenium	0.0110	0.0073	8.3	0.0803	91.7	No Data				0.0876	798
Beryllium	0.0033	0.0008	5.1	0.0153	94.6	<0.00005	<0.3			<0.0161	490
Boron	0.0768	0.0299	5.7	0.4910	94.3	No Data				0.5209	678
Cadmium	0.0066	0.0004	4.0	0.0098	96.0	No Data				0.0102	155
Chromium	0.3952	0.0971	5.7	1.6068	94.3	No Data				1.7039	431
Copper	4.6105	0.8088	15.3	>4.4633	>84.7	No Data				>5.2721	114
Lead	0.1207	0.0105	2.2	0.4644	97.5	<0.00058	<0.12			<0.4755	394
Manganese	1.7564	0.8088	17.1	>3.9277	>82.9	No Data				4.7365	270
Molybdenum	0.0439	0.0057	7.0	0.0759	93.0	No Data				0.0816	186
Nickel	0.0659	0.0202	1.4	1.3792	98.6	No Data				1.3994	2125
Strontium	0.9221	0.2022	5.6	>3.4234	>94.4	No Data				>3.6255	393
Uranium	0.0659	0.0089	6.4	0.1295	93.6	No Data				0.1383	210
Vanadium	2.6345	0.8088	21.4	>2.9770	>78.6	No Data				>3.7858	144
Zinc	0.4501	0.1860	6.8	>2.5575	>93.2	No Data				>2.7435	610

TABLE 3 - 3a

B.C. HYDRO TRACE ELEMENT STUDY
MASS BALANCE

Coal Flow (Dry Basis) = 16,698 Kg/hr
Precipitator Efficiency = 99.65%

DATE: AUGUST 20 (MORNING TEST)

Element	(1) Input Kg/hr	(2) Amount in Bottom Ash Kg/hr	(2)/(5)%	(3) Amount in Flyash Kg/hr	(3)/(5)%	(4) Amount in Stack Emissions Solids Kg/hr	(4)/(5)%	Gaseous Kg/hr	(4)/(5)%	(5) Output Sum of (2)+(3)+(4) Kg/hr	Element Output(5)/Input(1) %
Mercury	0.0013	0.0006	68.4	0.00027	31.6					0.00087	63
Fluorides	3.006	0.1023	7.8	1.0450	79.7	0.01735	1.3	0.1469	11.2	1.3116	44
Arsenic	0.1837	0.0026	5.8	0.4577	94.2					0.4603	251
Selenium	0.3172	0.0310	23.8	0.0992	76.2					0.1301	41
Beryllium	0.0167	0.0014	9.5	0.0130	90.5					0.0143	86
Boron	0.2505	0.0956	15.8	0.5111	84.2					0.6066	242
Cadmium	0.0134	0.0012	16.8	0.0060	83.2					0.0073	55
Chromium	0.6679	0.5789	18.8	2.4942	81.2					3.0731	460
Copper	8.8497	>1.3463	>15.0	>7.6276	85.0					>8.9738	101
Lead	0.2171	0.0067	1.9	0.3432	98.1					0.3500	161
Manganese	>16.6976	>1.3463	>18.1	6.0792	81.9					>7.4254	>44
Molybdenum	0.0668	0.0283	19.8	0.1144	80.2					0.1427	214
Nickel	0.1837	0.0538	12.2	0.3890	87.8					0.4428	241
Strontium	1.8367	0.8212	17.0	4.0197	83.0					4.8409	264
Uranium	0.1002	0.0229	15.8	0.1221	84.2					0.1449	145
Vanadium	2.0037	>1.3463	>16.8	6.6894	83.2					>8.0356	401
Zinc	0.7681	0.0229	1.1	2.0594	98.9					2.0823	271

TABLE 3 - 3b

B.C. HYDRO TRACE ELEMENT STUDY
MASS BALANCE

Coal Flow (Dry Basis) = 19,491 Kg/hr
Precipitator Efficiency = 99.52%

DATE: AUGUST 20 (AFTERNOON TEST)

Element	(1) Input Kg/hr	(2) Amount in Bottom Ash Kg/hr	(2)/(5)%	(3) Amount in Flyash Kg/hr	(3)/(5)%	(4) Amount in Stack Emissions Solids Kg/hr	(4)/(5)%	Gaseous Kg/hr	(4)/(5)%	(5) Output Sum of (2)+(3)+(4) Kg/hr	Element Output(5)/Input(1) %
Mercury	0.0012	0.000032	6.8	0.00044	93.2	No Data				0.000467	40
Fluorides	3.1185	0.1109	8.7	0.8908	69.9	0.02187	1.7	0.2515	19.7	1.2750	41
Arsenic	0.2339	0.0108	2.2	0.4716	97.8	No Data				0.4823	206
Selenium	0.1364	0.0293	9.5	0.2794	90.5	No Data				0.3087	226
Beryllium	0.0078	0.0031	15.0	0.0175	85.0	No Data				0.0205	264
Boron	0.2339	0.0570	3.7	1.4845	96.3	No Data				1.5415	659
Cadmium	0.0195	0.00077	6.9	0.0105	93.1	No Data				0.0112	58
Chromium	1.1694	0.1849	7.7	2.2092	92.3	No Data				2.3941	205
Copper	>19.4908	>1.5408	>15.0	>8.7321	85.0	No Data				>10.2729	53
Lead	0.1754	0.0293	5.0	0.5589	95.0	No Data				0.5881	335
Manganese	1.2864	>1.5408	>28.0	3.9556	72.0	No Data				>5.4965	427
Molybdenum	0.0780	0.0123	9.2	0.1222	90.8	No Data				0.1346	173
Nickel	0.2534	0.1325	23.3	0.4366	76.7	No Data				0.5691	225
Strontium	3.3134	0.8629	14.9	4.9161	85.1	No Data				5.7790	174
Uranium	0.0975	0.0216	12.7	0.1485	87.3	No Data				0.1700	174
Vanadium	1.2669	>1.5408	>25.8	4.4272	74.2	No Data				>5.9680	471
Zinc	0.7407	0.0623	1.5	4.1041	98.5	No Data				4.1673	563

TABLE 3 - 4a

B.C. HYDRO TRACE ELEMENT STUDY
MASS BALANCE

Coal Flow (Dry Basis) = 9,886 Kg/hr
Precipitator Efficiency = 99.92%

DATE: AUGUST 21 (MORNING TEST)

	(1)	(2)		(3)		(4)				(5)	
	Input	Amount in Bottom Ash		Amount in Flyash		Amount in Stack Emissions Solids		Amount in Stack Emissions Gaseous		Output Sum of (2)+(3)+(4)	Element Output(5)/Input(1)
Element	Kg/hr	Kg/hr	(2)/(5)%	Kg/hr	(3)/(5)%	Kg/hr	(4)/(5)%	Kg/hr	(4)/(5)%	Kg/hr	%
Mercury	0.00050	0.000091	16.3	0.00014	24.4	<0.000103	<18.5	<0.000230	40.8	<0.00057	115
Fluorides	0.8305	<0.0152	<2.5	0.5917	97.5					<0.6069	73
Arsenic	0.2274	0.0023	1.0	0.2185	99.0					0.2208	97
Selenium	0.2669	0.0137	20.8	0.0503	76.4	<0.000450	<0.7	<0.001351	<2.1	<0.0659	25
Beryllium	0.0079	0.0006	9.5	0.0056	90.5					0.0062	79
Boron	0.2472	0.0175	5.5	0.3016	94.1	0.00108	0.3			0.3202	130
Cadmium	0.0198	0.0004	11.6	0.0027	86.8	<0.00011	<3.4			<0.0032	16
Chromium	0.4053	0.1292	14.9	0.7382	85.1	0.00013	<0.1			0.8674	214
Copper	>9.8864	<0.7602	<15.0	<4.3091	>85.0	0.00031	<0.1			5.0696	51
Lead	0.1977	0.0099	6.4	0.1452	93.6					0.1551	78
Manganese	1.3841	0.5625	15.1	>3.1499	>84.8	0.00325	<0.1			>3.7150	268
Molybdenum	0.0297	0.0030	8.8	0.0316	91.1	<0.00015	<0.4			<0.0347	117
Nickel	0.8898	0.0456	21.8	0.1637	78.1	0.00042	0.2			0.2098	24
Strontium	3.4603	0.2965	21.4	1.0889	78.6	0.00014	<0.1			1.3857	40
Uranium	0.0989	0.0068	13.7	0.0431	86.3					0.0499	51
Vanadium	1.5818	0.2813	8.0	>3.2448	92.0	<0.00011	<0.1			3.5261	223
Zinc	0.7019	0.0730	6.6	1.0342	93.3	0.00699	0.6			1.1142	159

TABLE 3 - 4b

B.C. HYDRO TRACE ELEMENT STUDY
MASS BALANCE

Coal Flow (Dry Basis) = 14,169 Kg/hr
Precipitator Efficiency = 99.72%

DATE: AUGUST 21 (AFTERNOON TEST)

	(1)	(2)		(3)		(4)				(5)	
						Amount in Stack Emissions				Output Sum of (2)+(3)+(4)	Element Output(5)/Input(1)
	Input	Amount in Bottom Ash		Amount in Flyash		Solids		Gaseous			
Element	Kg/hr	Kg/hr	(2)/(5)%	Kg/hr	(3)/(5)%	Kg/hr	(4)/(5)%	Kg/hr	(4)/(5)%	Kg/hr	%
Mercury	0.00099	0.000027	1.1	0.00033	12.6	<0.00089	<34.5	<0.00134	<51.8	<0.00259	261
Fluorides	1.3602	<0.0268	<7.9	<0.3130	92.1					<0.3398	25
Arsenic	0.0992	0.0040	0.2	2.3927	99.8					2.3967	2416
Selenium	0.0567	0.0107	5.1	0.1970	93.5	<0.00052	<0.2	<0.00263	<1.2	<0.2109	372
Beryllium	0.0043	0.0007	6.0	0.0106	94.0					0.0113	265
Boron	0.1987	0.0802	18.2	0.3585	81.6	0.0025	0.6			0.4413	222
Cadmium	0.0142	0.0007	6.7	0.0091	90.0	0.00050	4.9			0.0103	72
Chromium	0.3967	0.1605	7.0	2.1221	92.9	0.0011	<0.1			2.2838	576
Copper	3.5422	>1.3376	15.0	>7.5790	85.0	0.0019	<0.1			>8.9186	252
Lead	0.1842	0.0268	5.7	0.4418	94.3					0.4686	254
Manganese	14.1688	>1.3376	>15.0	>7.5790	84.8	0.0184	0.2			>8.9350	63
Molybdenum	0.0567	0.0093	6.1	0.1440	93.5	0.0008	0.5			0.1542	272
Nickel	0.8501	0.0602	6.3	0.8997	93.4	0.0034	0.4			0.9632	113
Strontium	3.2588	0.4682	12.0	3.4356	88.0	0.0029	<0.1			3.9067	120
Uranium	0.0850	0.0308	21.0	0.1159	79.0					0.1467	173
Vanadium	5.2425	>0.6688	>10.2	>5.8609	89.8	0.0002	0.1			>6.5299	125
Zinc	1.3602	0.0709	2.7	2.5769	97.1	0.0061	0.2			2.6539	195

Part 3 - Mean Value Trace Element Composition

PURPOSE

The material balance calculations for each of the six tests indicated wide variations in trace element composition and flow rate, and in many cases large imbalances in the component material balance. Consequently, it was determined that mean values and standard deviations should be calculated for the trace element composition of each flow stream and that a typical material balance based on the mean values be calculated.

ASSUMPTIONS

To determine the mean value and standard deviation of an element in each flow stream the following assumptions were made:

- The coal fired in the boiler was considered to be one uniformly mixed sample.
- Boiler operation, including firing rate and temperature, did not alter the trace element composition of any stream.
- Precipitator efficiency did not alter the trace element composition of the ash emitted to the atmosphere.
- Concentrations of trace elements in the ash emitted from the precipitator can be corrected based on the trace element concentration in the coal during the test and the mean value of the trace element in all coal samples.

MEAN VALUE

Each mean value was calculated using the formula

$$\overline{X} = \frac{\sum_{i=1}^{N} X_i}{N}$$

where X_i = value of datum point i

N = total number of data points

STANDARD DEVIATION

The standard deviation of each mean value was calculated using the formula

$$\text{S. Dev} = \left[\frac{\sum_{i=1}^{N} X_i^2 - \frac{\left(\sum_{i=1}^{N} X_i\right)^2}{N}}{N-1} \right]^{1/2}$$

CORRECTION FACTORS

The concentration of any trace element in the mean ash emitted from the precipitator was calculated in the following manner:

- By test the following were determined
  - concentration of element in ash emitted during test. (1)
  - concentration of element in coal fired during test. (2)
- By calculation the mean value of the element in all coal samples was determined. (3)
- By calculation the composition of the emitted ash corrected to the mean coal was determined [(1) ÷ (2) X (3)]

RESULTS

Mean values and standard deviations were determined for the trace element composition of

- Coal
- Bottom ash
- Precipitator inlet Flyash
- A-Field, B-Field and C-Field hopper ash
- Precipitator emission.

In addition, the samples of flyash from each hopper were grouped without weighting, to give a composite sample mean value and standard deviation for each component.

The results for all flow streams are presented in Table 3-5. The number of datum points for each data set is indicated.

CONCLUSIONS

The calculated standard deviation for the majority of the samples is large, confirming the observations of Part 2.

The data for A-Field, B-Field and C-Field shows that there is a substantial difference in composition of the flyash collected by each field. Secondly, the standard deviation of each B-Field and C-Field mean is generally larger than the deviation of each A-Field means.

RECOMMENDATION

For calculating a general material balance the coal, bottom ash, composite hopper catch and flyash emitted stream compositions should be used. Material balance calculations using the individual hopper analyses are not warranted due to lack of flow rate data for ash collected by each field.

Table 3-5

B.C. HYDRO TRACE ELEMENT STUDY
MEAN COMPOSITION OF TRACE ELEMENTS
mg/Kg

	Element	Hg	F	As	Se	Be	B	Cd	Cr	Cu	Pb	Mn	Mo	Ni	Sr	U	V	Zn
Coal	n	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
	mean	0.08	123	10.3	10.0	0.43	12.2	1.03	46	>557	13.2	>483	3.8	34.8	176	5.8	172	56
	Std Dev	0.02	39	7.3	10.6	0.27	8.3	0.50	17	369	3.7	432	0.41	33.4	100	2.6	116	23
Bottom Ash	n	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
	mean	0.14	73	5.4	13.2	0.96	29	0.74	164	>678	12.6	>854	8.2	55	380	9.6	>564	58
	Std Dev	0.16	32	2.7	9.5	0.63	27	0.23	158	443	5.0	213	7.4	22	213	6.0	416	36
Precipitator Inlet	n	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
	mean	0.3	<20	54	13.8	1.7	54	0.7	293	<915	45	>823	11.3	208	>463	14.5	>618	358
	Std Dev	0.1	0.0	36	8.5	1.0	11	0.3	123	170	30	219	7.4	211	392	10.7	365	349
A Field Hopper Catch	n	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
	mean	0.04	<50	27.0	18.3	1.7	41	0.68	179	>958	31.0	>560	10.8	68	415	13.8	>697	136
	Std Dev	0.01	38	7.7	11.7	1.2	18	0.16	92	102	7.3	385	3.5	23	180	3.7	228	82
B Field Hopper Catch	n	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
	mean	0.09	75	87	24	2.0	117	1.0	266	>893	60	>767	14.8	105	>557	18.3	>660	393
	Std Dev	0.10	52	56	12	0.6	76	0.5	158	261	19	379	9.7	129	260	6.2	292	208
C Field Hopper Catch	n	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
	mean	0.04	201	201	14.2	2.0	109	1.9	319	>1000	86	>760	16.2	156	>544	17.4	>762	>604
	Std Dev	0.01	122	296	12.2	1.2	62	1.3	144	0.0	67	329	6.2	198	345	15.3	264	366
Composite A, B & C Hopper Catch	n	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17
	mean	0.06	<104	99	19.1	1.9	88	1.1	251	>948	57	>692	13.8	107	>503	16.5	>703	>364
	Std Dev	0.06	97	168	11.9	1.0	65	0.9	138	163	42	358	7.0	129	256	8.9	249	295
Flyash Emitted(1)	n	2	2	2	2	2	2	2	2	2	2	2	2	2	2	0	1	2
	mean	<67.8	500.1	<220.4	<76.2	<3.1	189.8	<28.1	85.4	>160.5	<38.1	>2992.4	<67.9	92.9	78.5		<30.4	231.3
	Std Dev	16.6	32.3	288.8	6.8	2.5	98.0	1.3	22.7	105.4	9.6	3540.6	34.5	19.5	61.4		37.0	52.2

(1) Total front half of EPA Train (probe wash plus filter)

Part 4 - Typical Material Balance

PURPOSE

A typical material balance was completed to assist in the evaluation of the disposition of ash and trace contaminants contained in the Hat Creek coal as fired at the Battle River Generating Station.

ASSUMPTIONS

The following assumptions were made:

- The coal flow rate was 50,000 Kg/hr.
- The ash content (wet basis) was taken to be 32.5% based on a 28% moisture content in the raw coal.
- The ash distribution is: Bottom ash 15%
Flyash 85%
- The electrostatic precipitator efficiency is assumed to be 99.7%.

RESULTS

The typical material balance is listed in Table 3-6.

Except for the vapour phase emissions of mercury, fluoride, arsenic and selenium the entries are the direct multiplication of the mean values of each element in a flow stream (Table 3-5) times the flow rates indicated in Table 3-6. The precipitator emission rates are corrected to the mean coal as outlined in Part 3.

Vapour phase emission rates are the measured rates at Battle River scaled up to 50,000 Kg/hr and corrected for the mean coal as outlined in Part 3.

Table 3 - 6

B.C. HYDRO TRACE ELEMENT STUDY
TYPICAL MATERIAL BALANCE

	ELEMENT INPUT		ELEMENT OUTPUT								TOTAL OUTPUT
Trace Element	Element Input Kg/hr		Bottom Ash Kg/hr		Flyash Kg/hr		Flyash Emitted Kg/hr		Vapour Phase Mat'l Kg/hr		Kg/hr**
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	
Hg	0.004	± 0.001	0.0003	± 0.0004	0.0008	± 0.0008	<0.002	± 0.00002	<0.0037	± 0.0027	<0.007 ± 0.004
F	6.17	± 1.93	<0.180	± 0.080	1.430	± 1.340	0.030	± 0.004	0.4000	± 0.1393	<2.040 ± 1.563
As	0.52	± 0.37	0.010	± 0.007	1.370	± 2.320	<0.001	± 0.0008	<0.0353	± 0.0207	<1.390 ± 2.349
Se	0.50	± 0.53	0.030	± 0.020	0.260	± 0.160	<0.005	± 0.005	<0.0129	± 0.0146	<0.308 ± 0.200
Be	0.02	± 0.01	0.002	± 0.0015	0.030	± 0.010	<0.0001	± 0.00003			<0.032 ± 0.01
B	0.61	± 0.42	0.070	± 0.0065	1.210	± 0.890	0.014	± 0.011			1.294 ± 0.908
Cd	0.05	± 0.03	0.002	± 0.0006	0.020	± 0.010	<0.002	± 0.0009			<0.024 ± 0.012
Cr	2.31	± 0.83	0.400	± 0.390	3.460	± 1.900	0.003	± 0.00002			3.860 ± 2.290
Cu	>27.84	± 18.44	>1.650	± 1.080	>13.080	± 2.250	0.005	± 0.0014			>14.735 ± 3.331
Pb	0.66	± 0.19	0.030	± 0.010	0.790	± 0.580	<0.0014	± 0.0002			<0.821 ± 0.590
Mn	>24.14	± 21.60	2.080	± 0.520	>9.550	± 4.940	0.054	± 0.017			>11.684 ± 5.477
Mo	0.19	± 0.02	0.020	± 0.018	0.190	± 0.100	<0.0024	± 0.0008			<0.212 ± 0.119
Ni	1.74	± 1.67	0.130	± 0.050	1.470	± 1.770	0.008	± 0.0006			1.608 ± 1.821
Sr	8.79	± 5.02	0.930	± 0.520	>6.940	± 3.530	0.005	± 0.0026			>7.875 ± 4.053
U	0.29	± 0.03	0.020	± 0.010	0.230	± 0.120	0.0007	± 0.0004*			0.2507 ± 0.1304
V	8.62	± 5.78	>1.380	± 1.010	>9.700	± 3.440	<0.0013	± 0.0013			>11.081 ± 4.451
Zn	2.78	± 1.16	0.140	± 0.090	>5.030	± 4.070	0.014	± 0.0002			>5.184 ± 4.160

Parameters:
Coal Flow = 50,000 Kg/hr (Wet Basis)
Bottom Ash = 2437.5 Kg/hr
Flyash = 13812.5 Kg/hr
Flyash Emitted = 41.4 Kg/hr

* Value for uranium based on mean value of uranium in composite A, B and C hopper catch (Table 3-5)

** Values are sum of stream output means or standard deviations