United States
Environmental Protection
Agency

Office of Air Quality
Planning and Standards
Research Triangle Park NC 27711

EMB Report 86-SPB-2
March 1986

Air

EPA

Fluidized Bed Boiler Emission Test Report

Canadian Forces Base Summerside, Prince Edward Island Canada

TRC-A87-192(1)

Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air Quality Planning and Standards
Emissions Measurement Branch
Research Triangle Park, NC

Contract No. 68-02-3851
Work Assignment No. 11

George Walsh - Project Officer
Dennis Holzschuh - Task Manager

EMISSION TEST REPORT
CANADIAN FORCES BASE
PRINCE EDWARD ISLAND, CANADA
VOLUME I

Final Report

EMB No. 86-SPB-2

May 1987

Prepared by

John M. Foley
Howard Schiff

ALLIANCE TECHNOLOGIES CORPORATION
213 Burlington Road
Bedford, Massachusetts 01730
(617) 275-9000

DISCLAIMER

This Final Report was furnished to the Environmental Protection Agency by the Alliance Technologies Corporation, Bedford, Massachusetts 01730, in fulfillment of Contract No. 68-02-3851, Work Assignment No. 11. The opinions, findings, and conclusions expressed are those of the authors and not necessarily those of the Environmental Protection Agency or the cooperating agencies. Mention of company or product names is not to be considered as an endorsement by the Environmental Protection Agency.

CONTENTS

Figures iv
Tables v

1.0 Introduction 1
2.0 Summary and Discussion of Results 2
3.0 Process Description and Operation 8
3.1 General Information 8
3.2 Design Information 8
3.3 Operating Information 10
3.4 Operating Procedures 15
3.5 Process Operation 16
3.6 Process Data 18
4.0 Sampling Location 25
5.0 Sampling and Analytical Procedures 28
5.1 Overview 28
5.2 Measurement of Flue Gas Emissions 28
6.0 Program Quality Assurance 36
6.1 Introduction 36
6.2 Precision, Accuracy and Completeness 36

Appendices

A. 30-Day Hourly CEM Emissions Summary A-1
B. 30-Day Coal Analyses Results B-1
C. 30-Day Limestone Analyses Results C-1
D. Process Generated Materials' Analytical Results D-1
E. Hourly Field Coal Analysis Lob E-1
F. Relative Accuracy Field and Reduced Data Sheets F-1
G. Zero and Calibration Drift Data Sheets G-1
H. Field Team's Daily Log H-1
I. Daily Calibration Log I-1
J. Calibration Gas Certification Reports J-1
K. 30-Day Digistrip Data Log (Volume II) K-1

FIGURES

Number		Page
3-1	Foster Wheeler boiler at Prince Edward Island	9
3-2	Flow diagrams for coal, wood and limestone	12
3-3	FBC layout	14
3-4	Emission source test summary	21
4-1	Schematic of Sampling Locations	26
4-2	Stack sample traverse point locations	27
5-1	CEMS program schedule	29
5-2	EMR Continuous Emissions Monitor	30

TABLES

Number		Page
2-1A	Results of CEM Relative Accuracy Tests	3
2-1B	Summary of Measurement Values	4
2-2	Summary of Analysis Procedures Performed on Samples Obtained During 30-Day CEM Program	6
2-3	Summary of Sieve Analyses	7
3-1	Baghouse Design Data	11
3-2	Operating Anomalies During FBC Emissions Tests at Prince Edward Island	19
3-3	Daily Average Process Flow Rates	23
3-4	Daily Average Process Parameters and Emission Results	24
5-1	Analyzer Specifications	31
5-2	Calibration Gas Concentrations	31
5-3	CEMS System--Monitor Response Time Results (Seconds)	33
5-4	Analytical Procedures	35
6-1	Performance Specification Requirements	37
6-2	Results of CEM Relative Accuracy Tests	38
6-3	Results of EPA Cylinder Gas Audit	40
6-4	Results of EPA Reference Method 6 Audit	40

SECTION 1.0

INTRODUCTION

The objective of this test program was to demonstrate the sulfur dioxide (SO_2) and nitrogen oxide (NO_x) control capabilities of a fluidized bed combustion (FBC) unit over an extended period of time (30 days). The data presented in this report will be used to develop and support New Source Performance Standards for small steam-generating units (100 million Btu/hr or less heat input).

The test program was conducted at an FBC facility located at the Canadian Forces Base (CFB), Summerside, Prince Edward Island, Canada. The facility has two FBC boilers that generate a maximum of 40,000 lb steam/hr each. These boilers supply space heating to the base and are operated as peak load units from September through May. One of the boilers was used for testing purposes.

Emissions from the unit were characterized utilizing a Continuous Emissions Monitoring System (CEMS) provided by Energy Mines and Resources (EMR)/Canada. Oxygen, carbon dioxide, carbon monoxide, oxides of nitrogen, and sulfur dioxide were monitored at the stack location for 30 consecutive days.

In addition to gaseous emissions monitoring, coal and limestone samples were obtained from the unit's solids handling systems on a regular basis. These samples were analyzed by Spotts, Stevens & McCoy Laboratories, Reading, PA. These data, in conjunction with the CEMS data and process logs, will allow a comprehensive evaluation of the operational characteristics of the FBC unit.

This report summarizes the emissions test program conducted by Alliance Technologies Corporation (formerly GCA Technology Division, Inc.) on the FBC facility from February 17 through March 28, 1986. In addition to the data base generated by 30 days of CEMS data, the results of coal and limestone analyses, pertinent field logs, and data related to CEMS certification are included in this report.

SECTION 2.0

SUMMARY AND DISCUSSION OF RESULTS

The fluidized bed combustion unit (FBC) located at the Canadian Forces Base at Summerside, Prince Edward Island, Canada, underwent a 30-day continuous emission monitoring (CEM) period during February and March, 1986. Sulfur dioxide, oxides of nitrogen, carbon monoxide, carbon dioxide, and oxygen concentrations were monitored by the CEM system in the flue gas stream at the final emission point downstream of the baghouse.

The 30-day CEM data summaries are found in Appendix A. These data result from the raw data obtained and stored by the Kaye Digistrip III in the field. Due to the volume of this raw data, only the summary tables are included in this report. The raw data file, also containing operational data, is found in Volume II, Appendix K of this report. Certification of the CEM system was performed both prior to and following completion of the 30-day test program in accordance with procedures outlined in 40 CFR Part 60 Appendices A, B, Da, and F (proposed). Certification results can be found in Section 6 of this report and are summarized in Table 2-1A.

Concurrent with the continuous monitoring, coal and limestone feed lines to the FBC were also sampled during three 8-hour shifts. The coal samples were taken every half-hour during the 24-hour period. These samples were composited over an 8-hour period to form three composite samples for each calendar day. The limestone samples taken during the 24-hour period were composited to form a single, daily composite sample for each calendar day. In addition to the CEM and coal and limestone sampling, ash samples were obtained from the FBC unit at various points in the emission control device system (i.e., bed drains, cyclone reinjection point, and baghouse). The ash samples were collected at least once a week at selected intervals during the 30-day period. Analytical results for the coal, limestone, and ash can be found in Appendices B through D.

The data sets presented in Appendices A through E will be utilized by others in computing pollutant emission rates, sulfur capture efficiency of the unit, and a correlation of the emissions with fuel sulfur content and process operating conditions. A summary of these average values will be presented in this section, as well as, the ranges of sulfur content in the coal limestone and ash, and the SO_2, NO_x, CO, CO_2, and O_2 concentrations in the flue gas are given in Table 2-1B.

TABLE 2-1A. RESULTS OF CEM RELATIVE ACCURACY[a] TESTS

	Specification (percent)	Initial set (percent) 9 runs	Final set[b] (percent) 3 runs
O_2	0.5	0.45 O_2 [c]	0.30 O_2 [d]
CO_2	1.0	0.39 CO_2 [c]	0.07 CO_2 [d]
CO	10.0	5.4[a]	13.5[b]
NO_x	20.0	7.8[a]	8.1[b]
SO_2	20.0	10.4[a]	20.4[b]

[a] $RA = \frac{|\bar{d}| + cc}{RM} \times 100$

[b] $RA = \frac{|\bar{d}|}{RM} \times 100$

[c] $AA = |\bar{d}| + cc$

[d] $AA = |\bar{d}|$

Where: RA = Relative accuracy.

AA = Absolute accuracy.

$\bar{d}$ = Algebraic average of differences between CEMS value and Reference Method value.

cc = 95% confidence coefficient.

RM = Reference Method value.

TABLE 2-1B. SUMMARY OF MEASUREMENT VALUES

Parameter	Value Range	Mean Value
Coal, sulfur content, % dry basis	5.34 - 7.62	
% wet basis	4.74 - 7.10	5.89
Limestone, purity	96.4 - 98.5	97.7
sulfur content, %	<0.01	<0.01
Ash, sulfur content		
Bed material	11.1 - 14.4	13.00
Bed drain material	7.08 - 18.34	7.70
Multicyclone ash for reinjection	7.02 - 9.46	8.38
Baghouse ash	5.73 - 7.31	6.90
Ash silo material	7.23 - 7.78	7.51
Flue gas		
Sulfur dioxide, ppm SO_2	2 - 1,658	226
Oxides of nitrogen, ppm NO_x	180 - 340	270
Carbon monoxide, ppm CO	330 - 1,060	481
Carbon dioxide, % CO_2	4.1 - 12.5	9.4
Oxygen, % O_2	9.7 - 12.9	10.7

A single limestone sample was tested for reactivity by Westinghouse Electric Corporation, Research and Development Center, located in Pittsburgh, PA. In the Westinghouse thermogravimetric reactivity test, the limestone was found to be highly reactive with SO_2. The Fluidized Bed Combustor sulfur capture model estimates that 90 percent sulfur removal would be achieved with a calcium to sulfur ratio of 3:1. Information and correspondence relating to the analysis, as well as results, are provided in Appendix C-3. The analyses of the ash samples showed a relatively high percentage of sulfur present, as shown in Table 2-1B. The overall results of the ash analyses can be found in Appendix D.

In addition to the emissions data, results of coal and limestone analyses are provided. Coal and limestone samples were composited over three 8-hour intervals/day (t = 0000-0800; t = 0800-1600; t = 1600-2400). Samples were bagged, labelled, and prepared for shipment onsite. Analyses were conducted by Spotts, Stevens & McCoy, Inc. of Reading, PA.

Daily coal samples obtained during the first 8-hour interval (t = 1600-2400) were subjected to moisture, higher heating value, and sulfur analyses (see Appendix B-3). Also, on a weekly basis (days 1, 7, 14, 24, and 29 of the CEM program), a single coal sample for the t = 0000-0800 composite sample was subjected to proximate, ultimate, higher heating value, sieve, and ash speciation analyses. These data are provided in Appendix B-1.

The three 8-hour limestone samples generated per day were composited to create a single sample for each day of testing. These samples were subjected to calcium carbonate and sulfur analyses; results of the analyses are provided in Appendix C-2. One daily composite sample/week was selected to undergo calcium carbonate, sulfur, and sieve analyses. These data are provided in Appendix C-1.

Finally, samples of bed material, bed drain material, multicyclone ash for reinjection, baghouse ash, and ash silo material were obtained at various times during the test program. These samples provide additional information regarding the combustion characteristics. The samples underwent ultimate analysis, and the results are located in Appendix D. Table 2-2 provides a breakdown of the analyses procedures performed on all samples obtained during the 30-day test program. Samples of coal, limestone and ash material were subjected to sieve analyses which are summarized in Table 2-3.

TABLE 2-2. SUMMARY OF ANALYSIS PROCEDURES PERFORMED ON SAMPLES OBTAINED DURING 30 DAY CEM PROGRAM

	Sample Description									
Analysis Type	Daily Coal	Daily Limestone	Weekly Coal	Weekly Limestone	Bed Material	Bed Drain Material	Cyclone Ash	Multicyclone Ash for Reinjection	Baghouse Ash	Ash Silo Material
Proximate	1		1							
Ultimate	1		1		5	5	5	5	5	5
HHV[a]	1,2,3		1					c	c	
Sieve			1	4[b]						
Ash Speciation			1							
Moisture	2,3									
Sulfur	2,3	4[d]		4[b]						
$CaCO_3$		4[d]		4[b]						
Reactivity	4[e]		4[e]							

1 - Samples obtained over the t - 0000-0800 composite interval.

2 - Samples obtained over the t - 0800-1600 composite interval.

3 - Samples obtained over the t - 1600-2400 composite interval.

4 - Samples are a composite of the three daily composite samples; effective sample interval t = 0000-2400.

5 - Miscellaneous grab samples.

[a]Higher heating value, Btu/lb

[b]Note exceptions: 3/21/86 t = 1600-2400 composite analyzed.

[c]One sample.

[d]Note exceptions: 3/07/86 t = 0000-0800 composite analyzed.
3/08/86 t = 0800-2400 composite analyzed.
3/18/86 t = 0000-2400 composite analyzed.

[e]Indicates that a single 24-hour composite sample (3/5/86) underwent the reactivity test.

TABLE 2-3. SUMMARY OF SIEVE ANALYSES

		Mean value	Value Range
Coal			
Retained on:	3/4", %	21.2	13.8 - 31.0
	1/2", %	26.7	8.9 - 45.0
	3/8", %	14.6	8.9 - 18.4
	1/4", %	12.7	9.2 - 17.3
	4 mesh (0.185"), %	5.0	2.0 - 8.8
	8 mesh (0.09"), %	8.5	1.5 - 23.6
Passing:	8 mesh (0.09"), %	11.4	2.8 - 2.4
Limestone			
Retained on:	3.320 mm - 6 mesh, %	7.3	2.3 - 23.3
	2.000 mm - 9 mesh, %	44.2	40.0 - 49.8
	1.397 mm - 12 mesh, %	32.9	16.3 - 38.4
	1.190 mm - 14 mesh, %	7.3	2.7 - 10.1
	0.133 mm - 20 mesh, %	3.6	2.4 - 5.3
	0.595 mm - 28 mesh, %	7.1	0.4 - 3.1
Passing:	0.595 mm - 28 mesh, %	3.6	1.0 - 10.5
Ash[a]		Multicyclone ash for reinjection	Baghouse ash
Retained on:	4 mesh (0.185") (4.7 mm), %	0.0	0.0
	8 mesh (0.093") (2.362 mm), %	0.0	0.0
	10 mesh (0.065") (1.65 mm), %	0.0	0.0
	20 mesh (0.0328") (0.833 mm), %	0.0	0.0
	50 mesh (0.0117") (0.297 mm), %	5.8	0.8
	100 mesh (0.0058") (0.147 mm), %	14.7	13.9
Passing:	100 mesh (0.0058") (0.147 mm), %	79.5	85.3

[a]Single sample of multiclone ash and baghouse ash underwent sieve analysis.

SECTION 3.0

PROCESS DESCRIPTION AND OPERATION

This section presents a process description of the fluidized bed combustion (FBC) test unit. Included are characterizations of the boiler/ auxiliary equipment design and operation, discussions of the boiler operating history, control procedures, and process test conditions.

3.1 GENERAL INFORMATION

The two FBC boilers located at the Summerside, Prince Edward Island site were built to provide 40,000 lb/hr of steam each for space heating at the Canadian Forces Base , and are operated as full-scale demonstration units by the Canadian government. The two identical FBC boilers (Unit Nos. 1 and 2) are field-erected, bubbling bed units manufactured by Foster Wheeler (FW) Canada Ltd. The emission test data were gathered on Unit No. 2.

Two 25+ year old dump and grate stoker boilers are also located at the Summerside site. The two stoker units have a combined steam production capacity of 35,000 lb/hr. The two FBC units were purchased to meet the additional steam needed for Base heating and are operated as peak load units. Fluidized bed combustion was chosen because the Canadian government wanted to demonstrate on a commercial scale that FBC is a viable, clean, "off oil" technology.

During early operation of the FBC units, attention was drawn to the great amount of make-up water required by the boilers. This concern led to a steam leak repair program in the steam tunnels of the Base, resulting in a significant reduction in the steam demand. The reduction was so large that typically, only one FBC unit is needed on-line to accommodate the additional steam demand.

3.2 DESIGN INFORMATION

A side view of one of the FBC boiler units located at the site is shown in Figure 3-1. Each of the atmospheric fluidized bed (ABF) boilers is designed to produce 40,000 lb/hr of saturated steam at 110 to 140 lb/in^2 (psi). The heat input capacity of each unit is rated at 50 million Btu/hr. The fluidized beds are operated at temperatures near 1560°F (850°C). The units were guaranteed by FW Canada Ltd. to achieve greater than or equal to 80 percent boiler efficiency. In actual testing, the boiler efficiency has been measured at 83 percent. Each FBC boiler consists of two combustion beds, A and B, each fed by its own overbed spreader stoker. In Figure 3-1,

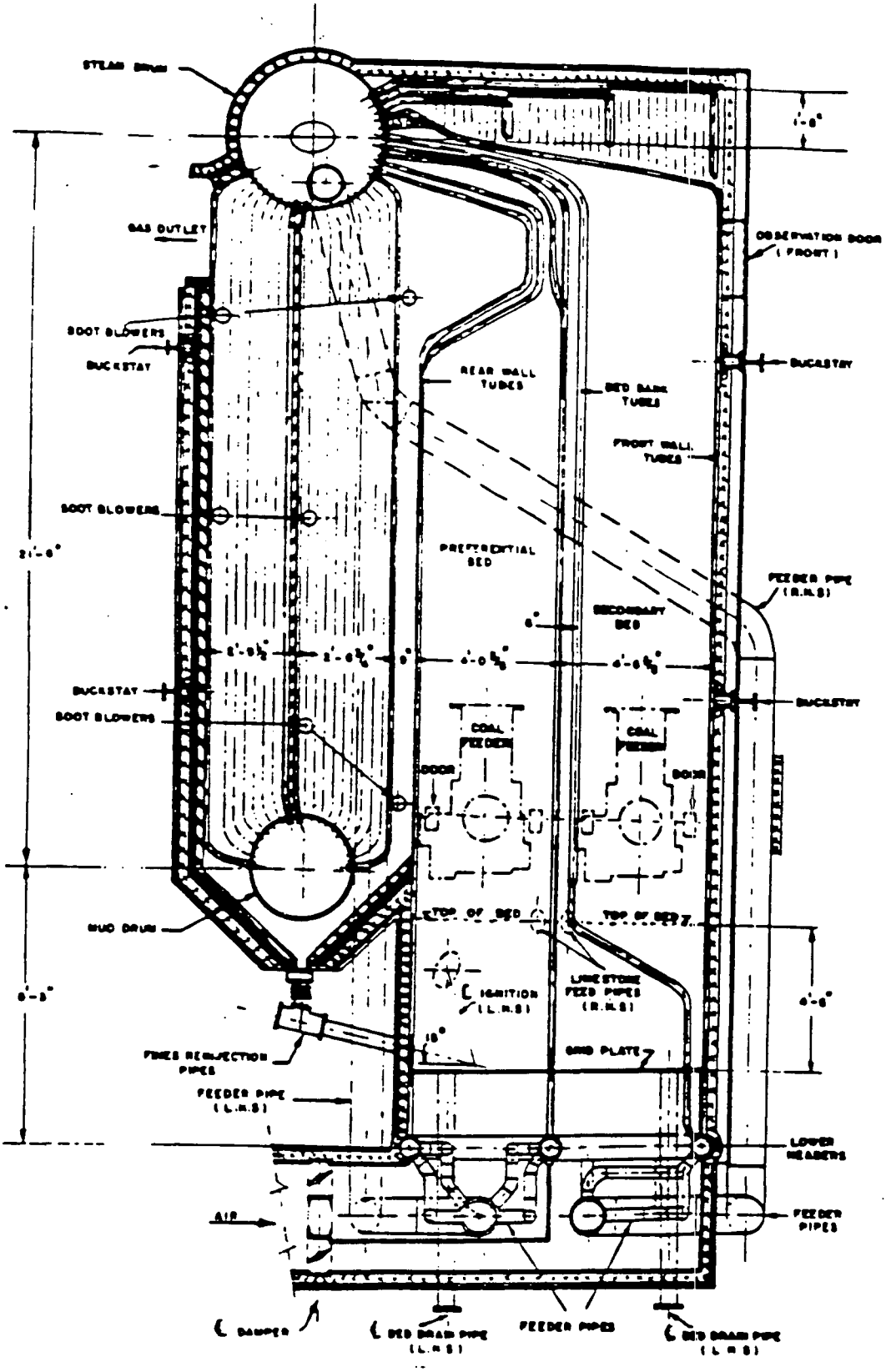


Figure 3-1. Foster Wheeler boiler at Prince Edward Island.

combustion bed A is indicated as the preferential bed, while combustion bed B is indicated as the secondary bed. The two beds are divided by a waterwall which has a 1 ft^2 opening located at the bottom center of the wall. This opening allows bed material to circulate between the two beds when both are in operation. This two-bed system allows for greater flexibility in turndown. A turndown ratio of 8:1 has been achieved during regular operation by taking bed B off-line.

As shown in Figure 3-1, tubes are located both in and above the bed. The total heating surface is 9,930 ft^2. In-bed tubes are mounted vertically along the walls and then diagonally across the unit. Above-bed tubes are mounted vertically along the wall. When fluidized, the bed depth is approximately 4.5 ft and the freeboard extends 22 ft above the bed. The slumped (non-fluidized) bed height is 2 ft. Bed A is 4 ft wide and 9.5 ft long, while bed B is 4.5 ft wide and 9.5 ft long.

Each FBC unit is equipped with a fly ash reinjection system. All of the fly ash collected in the convective tube bank and by the mechanical dust collector is recycled back to bed A. The mechanical dust collector is a multi-tube cyclone, housing five small-diameter cyclone tubes which operate in parallel. The multi-tube cyclone was manufactured by Enviro Systems and Research, and was designed to capture particles greater than 40 microns in diameter.

Each FBC unit is also equipped with a baghouse unit designed to capture nearly all of the particulate matter remaining in the flue gas exiting the cyclone. The baghouse was also manufactured by Enviro Systems and Research. The design data for these units are shown in Table 3-1.

3.3 OPERATING INFORMATION

Annual operation is from early September to late May, and the typical load over this heating period is 75 to 80 percent of maximum design load. During operation of the boiler, coal and limestone are trucked to the facility and dumped into separate underground hoppers as shown in Figure 3-2. The coal and limestone are sifted by screens and the larger sizes are re-crushed before being carried by bucket elevators to onsite storage bunkers. Bucket elevators transport the coal and limestone from the storage bunkers to the respective coal and limestone day bins located above the boiler unit. From the day bins, the coal and limestone flow by gravity to weigh feeders. The coal feed system is equipped with one weigh feeder which delivers the coal to a pant leg, where the coal flows by gravity and is distributed to separate stoker feeders, one feeder for each bed. The limestone feed system is equipped with a separate weigh feeder for each bed. From the weigh feeders, the limestone flows by gravity through separate feed pipes to beds A and B.

The coal normally fired in the FBC units, as well as during the emission testing period, is an unwashed eastern bituminous coal which has been sized to 1 in. x 0. The coal has an average heating value of 11,500 Btu/lb and an average sulfur content of 5.5 percent. This corresponds to potential SO_2 emissions of 9.57/million Btu on an uncontrolled basis. Typical ash,

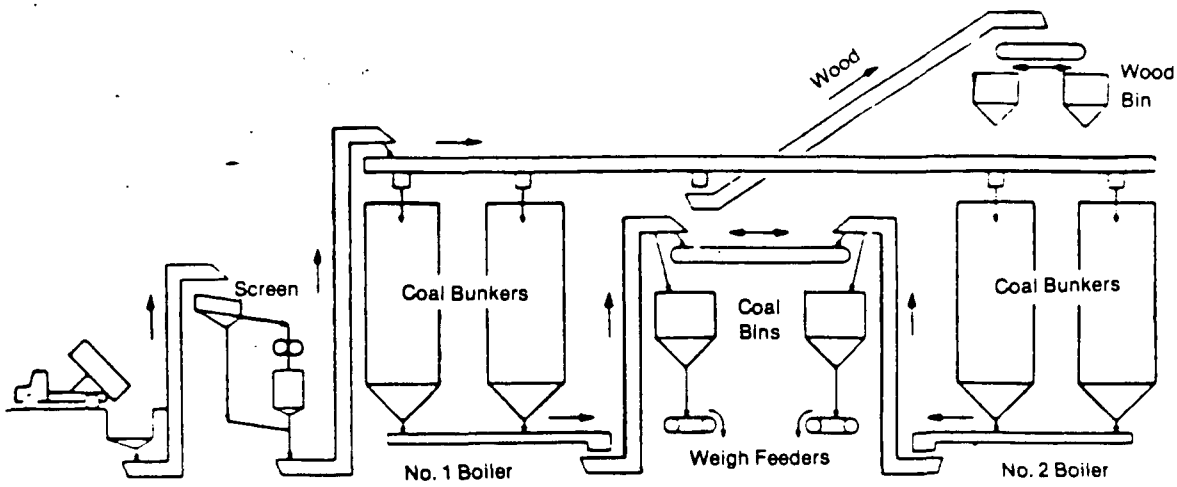
TABLE 3-1. BAGHOUSE DESIGN DATA

Flue Gas	
Inlet gas volume	17,278 ACFM[a] @ 350°F
Inlet gas moisture	8 Wt. Percent
Dust	
Loading	2.4 gr/SCF[b]
Particle size	40 Percent minus 10 microns
Bags	
Number of cells	12/Unit
Number of bags	36/Cell
Total cloth area	4,898 Ft^2
Air-to-cloth ratio	3.52 (All cells on-line)
Operating Information	
Collector design pressure	±20 in. water gauge
Particulate matter emission (Baghouse outlet)	0.02 gr/SCF
Collection efficiency	99.2 Percent[c]

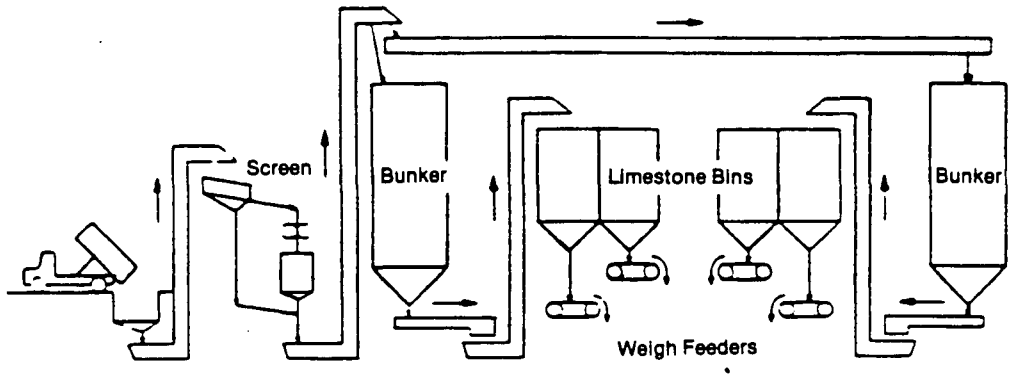
[a]ACFM = actual cubic feet per minute.

[b]gr/SCF = grains per standard cubic foot.

[c]Collection efficiency calculated on the basis of the inlet loading and outlet emissions.



Flow Diagram - Coal and Wood



Flow Diagram - Limestone

MATERIALS HANDLING - RATES AND CAPACITIES FOR EACH FBC UNIT

	COAL	LIMESTONE
Transfer to receiving hoppers to bunkers	25 tons/hour	25 tons/hour
Bunkers capacity	4 x 82.5 tons	2 x 75 tons
Transfer to bins	5 tons/hour	2.5 tons/hour
Bins capacity	2 x 5 tons	2 x 2.5 tons
Burn rate	2.5 tons/hour	1.13 tons/hour

Figure 3-2. Flow diagrams for coal, wood and limestone.

nitrogen, and moisture contents are 19.3, 1.0, and 0 to 10 percent, respectively. The fixed carbon is 47.2 percent and the volatile matter is 33.5 percent.

The limestone normally used at the site is Havelock limestone with a calcium carbonate ($CaCO_3$) content of 94 to 95 percent. Currently, it is sized to 0.0934 in. x 0.0331 in. (8 x 20 mesh) with certain percentages at 10, 12, and 15 mesh. The FBC unit can also utilize a limestone sized to 1/4 in. x 0, which contains a higher percentage of fines than does the 8 x 20 mesh limestone. Limestone is used as the sorbent for purposes of sulfur dioxide (SO_2) removal. As discussed in Section 3.4, limestone is added to the bed as one method to control bed level. During normal operation, the limestone-to-coal feed ratio is maintained near 1 to 5, which corresponds to a calcium-to-sulfur (Ca/S) ratio of approximately 1.1:1 based on a 5.5 percent sulfur coal. SO_2 reductions usually range from about 40 to 50 percent at this operating condition. This unit was designed to achieve 83 percent SO_2 reduction at Ca/S ratios ranging from 2.4 and 4.1, depending on the fuel burned.

The material handling system shown in Figure 3-2 can also handle wood chips. The FBC units can combust wood, but only 50 percent load can be achieved due to size limitations of the wood feed system. (The original design called for 30 percent of the heat input to be from wood chips.)

Screw conveyors are operated under the beds to remove ash and sulfated limestone (i.e., bed material). The desired bed level is maintained by adjusting either the limestone feed rate or the screw conveyor discharge rate. Each bed is equipped with a separate drain pipe which allows bed material to drain by gravity when the screw conveyors are operated.

The FBC layout is shown in Figure 3-3. Combustion air passes through a forced draft (FD) fan and enters the plenum. The air flow is distributed across the two beds at fluidizing velocity by means of distributor nozzles which are uniformly spaced across the base of each bed. Fluidized bed material freely circulates through the door in the water wall which separates beds A and B. This movement of material, as the two beds seek a common level, promotes fuel and sorbent mixing and improves the operational stability of the boiler.

Hot flue gas leaves the bed at approximately 1560°F (850°C), passes through the freeboard section, and flows across the convective tube bank before exiting the boiler. All of the fly ash collected in the convective tube bank is gravity fed back into bed A.

The flue gas exiting the boiler enters the mechanical dust collector where fly ash is captured and gravity fed through a straight leg reinjection system back into bed A. Spargers inject air into the reinjection leg at the reinjection point to assist fly ash recycle and prevent plugging of the reinjection leg.

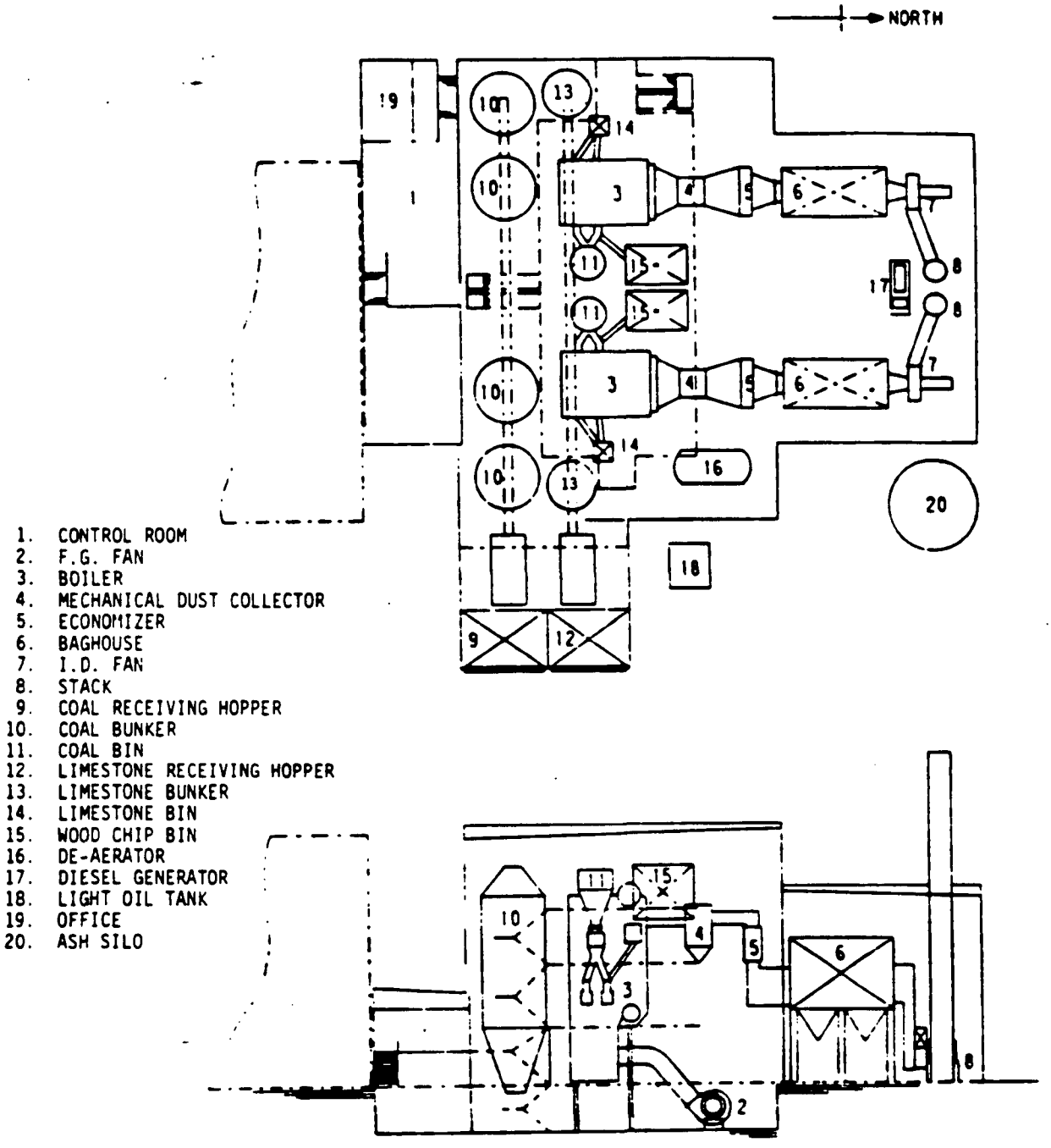


Figure 3-3. FBC layout.

The flue gas then passes through the finned-tube economizer where it is cooled before entering the baghouse. In the economizer, the feed water temperature is raised from 220°F (105°C) to 275°F (135°C). In the baghouse, nearly all remaining particulate matter is removed. From the baghouse, the flue gas is drawn through an induced draft (ID) fan and exhausted to the stack.

The ash which is collected from under the bed and in the baghouse is transported in a vacuum-type pneumatic handling system to the ash silo. From the ash silo, the waste is trucked to disposal trenches located on the Base.

3.4 OPERATING PROCEDURES

During normal operation, the boiler plant master controller operates in the automatic mode and regulates the steam output from the operating boilers. The controller modulates the total steam flow from the boiler plant to maintain constant pressure in the common steam header to the Base. During peak heating periods, when more than one boiler is operating, the control strategy is to operate one unit at constant load conditions while the peak load unit is allowed to track the excess steam demand. This control strategy is accomplished by setting the boiler master controller for the constant load unit in manual mode, and operating the boiler master controller for the peak load unit in automatic mode.

As mentioned earlier, the FBC boilers are normally operated as peak load units. Operating in the automatic mode, the FBC master controller adjusts the coal feed rate to the unit to compensate for swings in the plant steam demand. The combustion air controller, sensing the coal rate change, adjusts the total air flow to the unit to maintain a constant air-to-coal ratio. The total air flow is further adjusted by an oxygen trim controller, as necessary, to maintain the bed at optimum sulfation temperature.

The FBC unit design control scheme calls for the limestone feed controllers to automatically track the stack gas SO_2 concentration and adjust the sorbent feed rates to beds A and B based on an SO_2 emission set-point. However, this loop was never sufficiently tuned to allow fully automatic control and, therefore, has been by-passed as part of the overall FBC unit control scheme. During normal operation, the limestone feed controllers are operated in manual mode, and the limestone feed rates to beds A and B are adjusted by operating personnel to maintain desired bed levels.

The boiler feed water flow responds to the steam output requirements. The boiler feed water flow rate is also subject to control by the steam drum level which is a slower control loop. The steam drum level is controlled at the mid-level height of the drum.

3.5 PROCESS OPERATION

The primary operating objective of the emission source test was to demonstrate long-term FBC system performance of approximately 93 percent SO_2 reduction. Secondary operating objectives of the test were: 1) to obtain system performance data demonstrating the effect of limestone particle size on sulfation capacity, and 2) to determine the maximum SO_2 reduction achievable during stable two-bed unit operation.

During the first 3 weeks of the testing period, the FBC unit was operated at near 70 percent load, and the limestone feed rate was manually adjusted to maintain the SO_2 removal efficiency at the targeted 93 percent level. As discussed in Section 3.4, the control system between the SO_2 outlet flue gas concentration and the limestone feeders was never sufficiently tuned to allow fully-automatic control of SO_2 emissions using the limestone feed rate. As a result, the limestone feeders to beds A and B were controlled manually by plant operators.

A target SO_2 emissions level was established consistent with the feed coal sulfur and heating values and desired SO_2 reduction levels. While it would have been physically possible for the plant operators to adjust the limestone feed rates on a near-continuous basis to match the target SO_2 emissions level and load changes, this would have required an operator to be dedicated to limestone feed adjustments. This was impractical and was inconsistent with normal plant operation in which limestone feed rates were set manually, and only adjusted infrequently.

Another approach was to hold the unit load at a steady level so that a relatively constant Ca/S feed ratio could be maintained. This was the control approach used for all but the last week of the emission source test. It was desired that the FBC unit operate at a high a load as was practicable in order to fully test the capabilities of the limestone feed system, solid waste withdrawal system, and sulfur capture reactions in the bed. Unfortunately, weather conditions during the emissions test period were unseasonably mild, such that Base steam demand was below normal. To operate the FBC system at loads in the range of 80 to 90 percent would have required the venting of steam during much of the test period, at considerable cost to the plant. A unit load at or above 70 percent was selected as a reasonable compromise between the desire to demonstrate FBC system performance under the adverse conditions of relatively high load, and the economic penalties of venting large quantities of steam. During short periods when the steam demand exceeded that available from the FBC unit operating at or above 70 percent load, the dump and grate stokers were quickly brought on-line to meet the extra demand.

The actual steam output of the FBC boiler was not known because the steam flow rate recorder was out of calibration and was considered unreliable for measuring actual flows. However, the recorder was considered reliable for indicating flow trends. The unit load target of 70 percent was maintained on the basis of the coal feed rate, the heating value of the coal, and the known maximum heat input capacity of the FBC boiler.

For these reasons, the control strategy used during emissions testing was to set the coal feed rate to the test unit to a level approximating a 70 percent load condition, and to set the limestone feeders to achieve a target SO_2 emissions level. During the emission testing, the bed level was maintained by adjusting the screw conveyor bed drain discharge rate. The dump and grate stoker load or the steam vent rate was then adjusted as necessary to allow the FBC unit to operate at the steady load condition during the test period. The boiler combustion air and feed water controls were operated in the automatic mode during the test period to ensure smooth boiler operation at the constant load condition.

Variations from the desired load condition during testing were due to fluctuating coal characteristics such as moisture content and bulk density. At constant controller settings, the bulk density affected the coal delivery rate to the unit while increased coal moisture content lowered the effective heat input to the unit. Operating personnel monitored flue gas SO_2 concentration trends during the test period and adjusted the limestone feed rates step-wise, as necessary to maintain desired SO_2 reduction performance.

During the last week of the source testing period, two short-term parametric tests were conducted. During the first parametric test, system performance data were gathered over an 8-hour period, while 1/4 in. x 0 limestone was fed to the unit. The 1/4 in. x 0 limestone evaluated during this period was obtained from the same mine as the 0.0934 in. x 0.0331 in. (8 x 20 mesh) limestone used during the remainder of the source testing. The data gathered during this period were used to compare the SO_2 reduction efficiency of the two limestones at equivalent Ca/S ratios.

During the second parametric test, the unit was operated at high Ca/S ratios (by increasing the limestone feed rate) to determine if mass transfer restrictions would prevent the FBC unit from operating at SO_2 flue gas concentrations in the range of 20 to 40 ppm(v). For a unit firing low sulfur coal (2 percent sulfur), the flue gas SO_2 concentration must be maintained in this range to achieve approximately 93 percent SO_2 reduction. The boiler was operated at near 50 percent load during this 12-hour test to avoid overloading the baghouse at the high Ca/S ratios. The dump and grate stokers were brought on-line as necessary to handle any additional steam demand.

Due to inclement weather conditions, electrical power to the Base was interrupted four times during the source testing period. When a power outage occurred, a diesel-fired generating system at the plant was started and brought on-line to provide electricity for the FBC boiler operation. The switching process from main power to back-up power required a few minutes to execute; as a result, all feed flows to the unit were interrupted during this period. As the back-up power was brought on-line, controller settings were restored to their pre-outage positions. However, the limestone feed was discontinued until the coal and combustion air rates had been adjusted to bring the bed temperatures back within desired operating ranges.

The system operating performance and SO_2 reduction performance were unsteady while the unit was operated on back-up power due to the process upsets (e.g., interruption of feed flows). Also, the electricity generated by

the diesel system was at a slightly different frequency than that of the main power system. This affected the performance and reliability of sensitive electronic equipment such as the feed totalizers.

Once main power was restored to the facility, the same switching process was repeated as the back-up power supply was taken off-line and main power to the boiler was restored. The fuel and combustion air feed flows were again interrupted for a short period, and the limestone feed was discontinued until bed temperatures stabilized within operating ranges. After the return to main power, a period of 8 to 15 hours was normally required for coal and limestone feed rates to stabilize and for the FBC system to return to near steady operation.

Due to the frequency of power outages at this facility during winter storm periods, a more advanced back-up system will be installed in the future to instantaneously provide electricity to the unit during power outage periods. The new back-up system will allow the unit to operate smoothly during the transition from main to back-up power supply.

For these reasons, the data gathered during periods of back-up power generation were not considered to be representative test data. Once the unit was restored to main power and the system performance steadied to set conditions, testing was recommenced. However, the data gathered during process upset periods caused by unavoidable euipment malfunctions and operating anomalies other than power outages, were considered representative test data. Data gathered during these periods were evaluated in order to obtain an accurate estimate of achievable long-term SO_2 reduction performance during normal day-to-day operation. A summary of the operating anomalies encountered during the emissions source test is included in Table 3-2.

A summary of the FBC unit status for the source testing period is shown in Figure 3-4. Power outages occurred on the following dates: March 6, March 9, March 15, and March 18. On March 7, a severe winter storm forced the Base to be closed to all non-essential personnel. The ash hauling trucks, therefore, were not available to transfer waste ash from the ash silos to disposal trenches located on the Base. To avoid overloading the ash silos during this period, the boiler was operated at low limestone feed rates. The unit was returned to test conditions on the morning of March 8. The March 18 power outage resulted in the formation of clinkers in bed B of the test unit. The clinkers prevented fluidization of bed B, making this bed inoperable. The unit was taken off-line and allowed to cool so that operating personnel could remove the clinkers. The test unit was restarted on March 21 and was operating at test conditions by approximately 12:30 p.m. During the week after restart-up, the parametric tests associated with the secondary operating objectives were conducted.

3.6 PROCESS DATA

During the source testing period, process data were logged automatically and printed every 15 minutes. The recorded data reflect the instantaneous process conditions at the time the data were logged. The recorded process

TABLE 3-2. OPERATING ANOMALIES DURING FBC EMISSIONS TEST AT PRINCE EDWARD ISLAND

From:		To:		Duration (Days)	Operating Anomaly
Date	Time	Date	Time		
2/28	2300	2/29	0800	0.38	Operators bypassed flue gas around the baghouse. The baghouse was operating at high differential pressures (6 to 6.5 inches of H_2O). Operators were manually cleaning the ash from the baghouse.
3/5	0900	3/6	0830	0.98	General inspection. Coal rate to the boiler was lowered such that no steam was vented; load was reduced to about 50 percent. During the early morning of March 3, load was at 66 percent.
3/9	1800	3/10	0900	0.63	Limestone feed rate did not respond to increased limestone control settings. Consequently, SO_2 emissions were high (300 to 400 ppm).
3/16	0800	3/16	1045	0.11	One of the pins holding a coal bucket came loose in primary bucket elevator. While switching coal flow to the other bucket elevator, the coal supply was exhausted. Began feeding coal from emergency stockpile. Coal weigh feeder jammed and bed temperature varied more than normal after switching to emergency coal due to high moisture and fines content.
3/16	2200	3/16	2315	0.05	Very wet coal from emergency stockpile extinguished furnace flames. Limestone feed was discontinued until furnace fire was restarted and the bed temperature returned to 1560°F (850°C).

TABLE 3-2 (continued)

From:		To:		Duration (Days)	Operating Anomaly
Date	Time	Date	Time		
3/16	2315	3/18	0945	1.44	Operated with emergency coal until new coal shipment arrived on Base. Operating problems occurred with coal handling and feeding systems.
3/21	1330	3/22	0900	0.81	Discontinued limestone feed due to artifically high baghouse differential pressures (between 7 and 7.5 inches of H_2O). The high differential pressure was caused by plugging in the pneumatic line of the controller.
3/25	1345	3/25	1400	0.01	Replaced faulty electrical board in coal weigh feeder totalizer. Coal feed rate readings from March 21 @ 0945 to March 25 @ 1400 were artifically low.

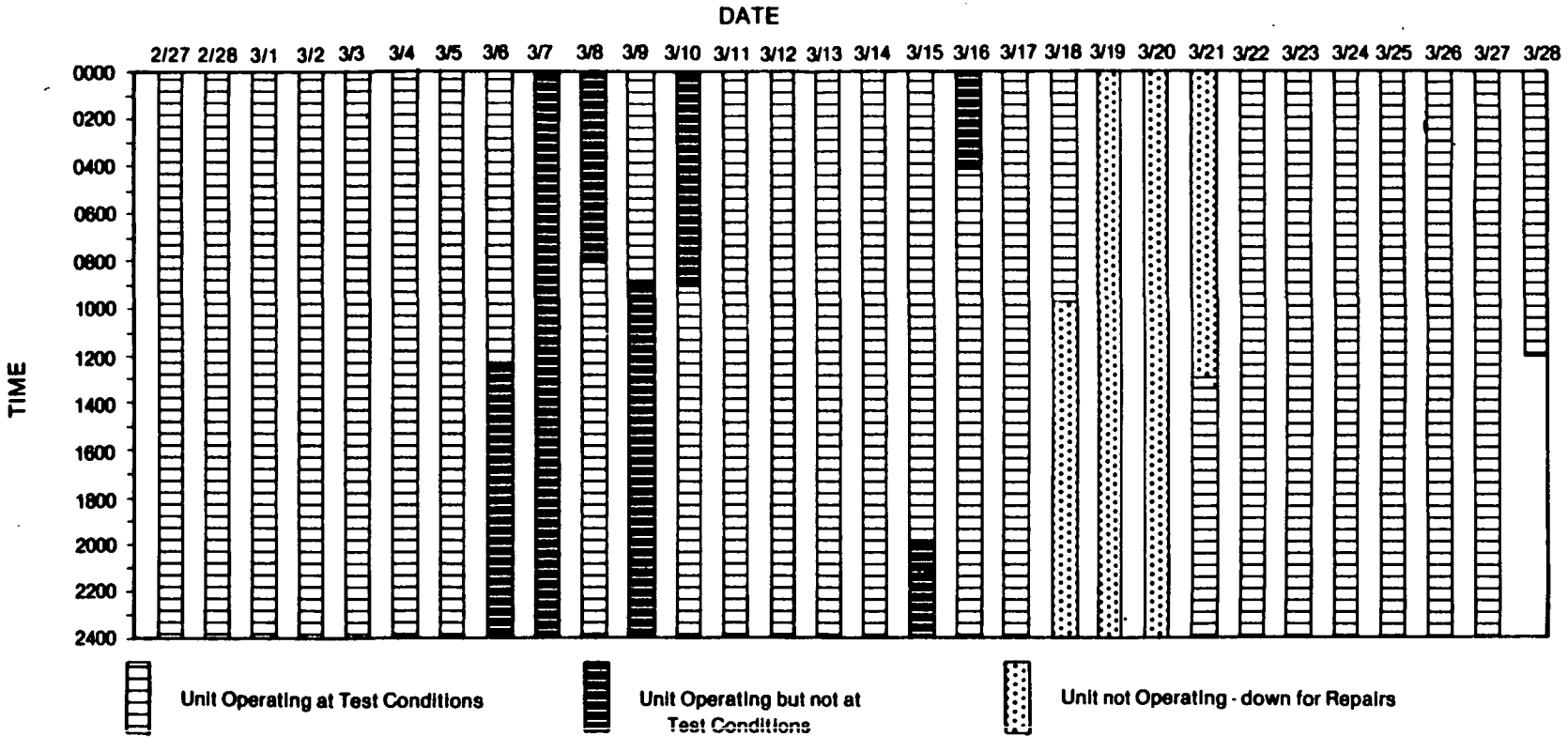


Figure 3-4. Emission source test summary.

parameters included lthe coal feed rate, limestone feed rate, total air flow, bed temperatures, average freeboard temperature, boiler exit gas temperature, stack gas temperature, steam flow and pressure, economizer inlet oxygen content, and pressure drop across the beds. Also included were fan suction and discharge pressures, flue gas operating pressures, boiler feed water temperature and pressure, and steam drum level. A copy of the process data recorded by the plant data logger during the emissions test period is included in Appendix K.

The coal, limestone, and steam flow rates were also indicated by electronic totalizers. Coal and limestone totalizer readings were recorded on an hourly basis during day-shift operation in order to compute average hourly feed rates during these periods. Coal, limestone, and steam totalizer readings were also recorded at approximately midnight each day by operating personnel in order to compute the total flow for the 24-hour period.

The average hourly coal, limestone, and steam flow rates during the testing period are summarized in Table 3-3. The flow rates shown in the table were calculated from the midnight totalizer readings recorded by the operating personnel and, therefore, represent average hourly rates based on total daily flows. On test days interrupted by power outages, the average coal and limestone rates shown in Table 3-3 were computed from the midnight and latest available day-shift readings prior to the power outage. The coal and limestone rates, therefore, represent hourly flow rate averages indicative of test operation. However, the average steam rates computed during test periods interrupted by power outages also include steam output during off-test conditions. These data, therefore, were not included in the Table 3-3 summary.

As mentioned in Section 3.5, the recorded steam rates, although considered inaccurate on an exact rate basis, were useful in determining unit operating trends. Table 3-4 presents the daily average process parameters affecting emissions, as well as the daily average emission results.

TABLE 3-3. DAILY AVERAGE PROCESS FLOW RATES

Date	Daily Hours of Test Operation	Average Coal Feed Rate (lb/hr)	Average Limestone Feed Rate (lb/hr)	Average Steam Production Rate (lb/hr)
2/27	24	3010	2190	37,400
2/28	24	3080	2120	37,600
3/1	24	3180	2280	38,200
3/2	24	3120	2380	38,700
3/3	24	3080	2290	37,900
3/4	24	3160	2290	37,100
3/5	24	2960	1960	35,100
3/6	12.5	3240	2260	-
3/7	0	-	-	-
3/8	16	3080	2120	-
3/9	9	3260	2040	-
3/10	24	3010	2270	36,800
3/11	24	3230	2270	38,100
3/12	24	3150	2150	37,900
3/13	24	3030	2100	38,600
3/14	24	2670	2060	36,900
3/15	20	3280	2010	-
3/16	24	2810	1910	36,900
3/17	24	3040	2010	36,600
3/18	9.5	3120	2070	-
3/19	0[a]	-	-	-
3/20	0[a]	-	-	-
3/21	11.5	2370	1520	-
3/22	24	2380	2230	42,200
3/23	24	2300	2470	35,300
3/24	24	2230	2440	35,400
3/25	24	2740	2680	39,500
3/26	24	2800	2680	36,300
3/27	24	2760	2900	33,000
3/28	12	2460	3290	-

[a]Boiler was shut down.

TABLE 3-4. DAILY AVERAGE PROCESS PARAMETERS AND EMISSION RESULTS

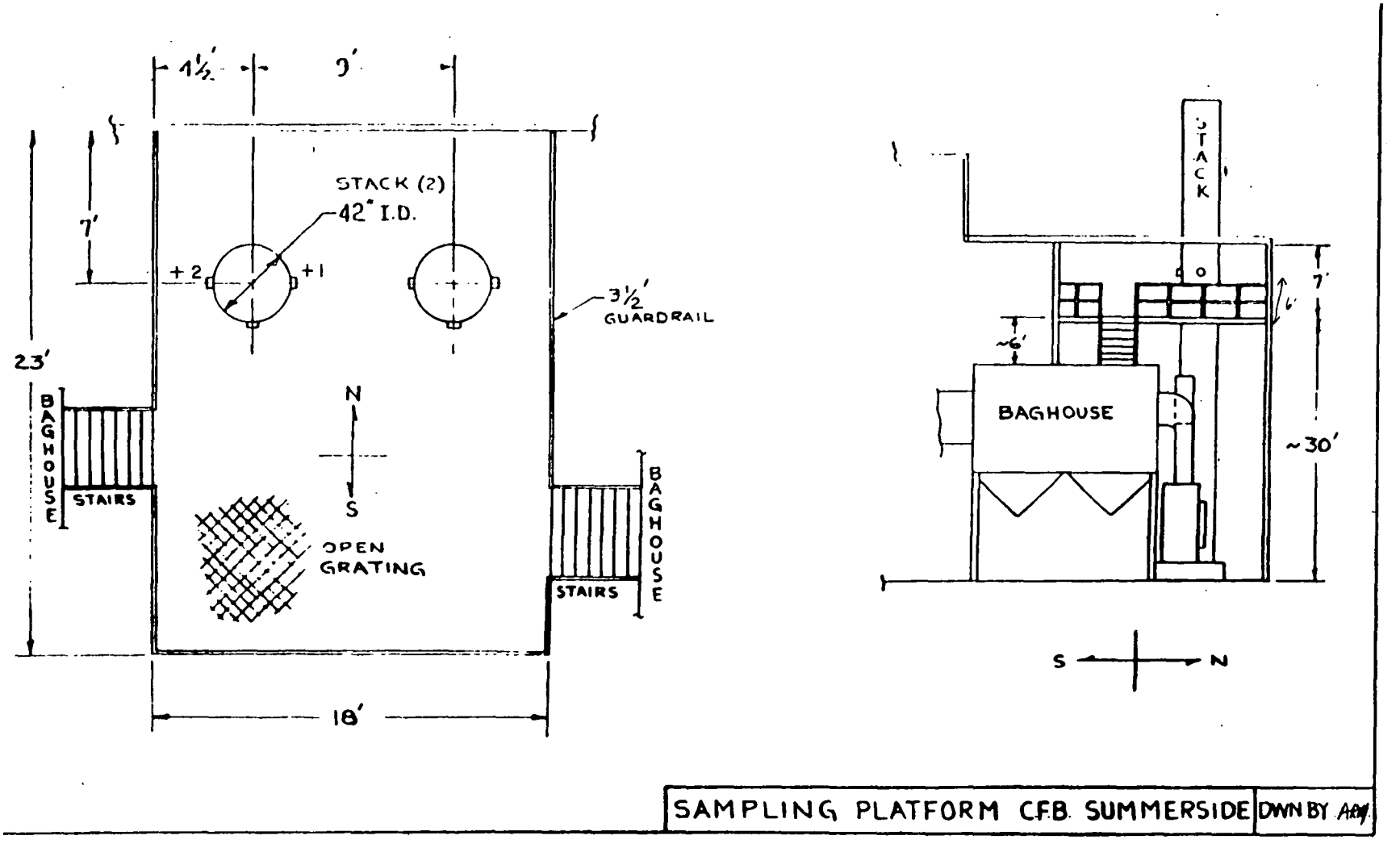
Date	Load, 10^6 Btu/hr	Calcium-to-Sulfur Ratio	SO_2 Reduction, Percent	Outlet SO_2 Emissions, lb/10^6 Btu	Outlet NO_x Emissions, lb/10^6 Btu
2/27	35.6	3.9	94.2	0.58	0.58
2/28	36.4	3.4	93.1	0.71	0.63
3/1	37.4	3.7	93.3	0.66	0.63
3/2	36.5	4.1	95.2	0.48	0.65
3/3	36.0	3.9	94.1	0.61	0.65
3/4	37.1	3.8	95.9	0.42	0.67
3/5	34.0	3.3	93.1	0.75	0.56
3/6	36.1	3.6	91.3	0.88	0.62
3/7	-	-	88.3	3.53	0.66
3/8	36.1	2.7	73.2	2.03	0.67
3/9	35.9	3.4	89.0	1.11	0.74
3/10	35.2	3.9	93.4	0.66	0.71
3/11	37.9	3.6	97.1	0.31	0.65
3/12	37.5	3.7	96.6	0.33	0.65
3/13	36.2	3.6	95.4	0.47	0.62
3/14	31.4	4.4	-	-	-
3/15	36.7	3.3	94.7	0.53	0.59
3/16	32.7	4.0	92.8	0.68	0.59
3/17	35.2	3.6	93.8	0.61	0.61
3/18	36.7	3.3	95.0	0.53	0.62
3/19	-	-	-	-	-
3/20	-	-	-	-	-
3/21	27.6	3.7	-	-	-
3/22	27.8	5.1	94.1	0.57	0.69
3/23	27.7	5.8	95.2	0.47	0.69
3/24	26.5	5.6	95.4	0.48	0.69
3/25	32.2	5.1	93.8	0.62	0.65
3/26	33.3	4.8	89.6	1.08	0.63
3/27	32.3	6.0	95.8	0.40	0.68
3/28	28.1	7.7	-	-	-

SECTION 4.0

SAMPLING LOCATION

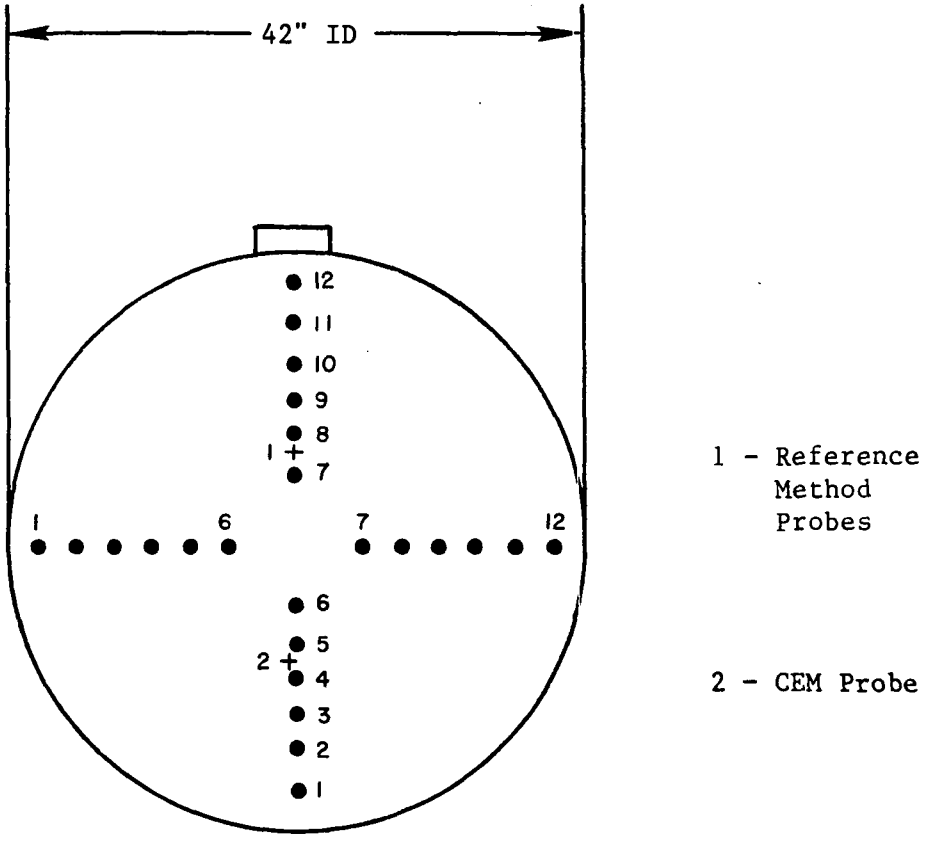
Continuous emissions monitoring and EPA Reference Methods 3, 6, 7E, and 10 were conducted at the stack location. A schematic of the stack location is shown in Figure 4-1.

Figure 4-2 shows the placement of traverse points for stratification testing. The stack is 42 inches in diameter. Traverse points were positioned according to EPA Reference Method 1.



+1 CEM PORT
+2 RM PORT

Figure 4-1. Schematic of Sampling Locations.



Point	Distance from wall (inches)
1	41.1
2	39.2
3	37.0
4	34.6
5	31.5
6	27.0
7	15.0
8	10.5
9	7.4
10	5.0
11	2.8
12	0.9

Figure 4-2. Stack sample traverse point locations.

SECTION 5.0

SAMPLING AND ANALYTICAL PROCEDURES

5.1 OVERVIEW

Alliance conducted the continuous monitoring program over a period of approximately 6 weeks (see Figure 5-1). The first phase of the study required certification of the monitoring instruments according to EPA Performance Specifications 2, 3, and 4. During the initial performance specification tests, zero and calibration drift, instrument response time, and relative accuracy were determined. EPA Reference Methods 3: (O_2/CO_2), 6: (SO_2), 7E: (NO_x), and 10: (CO) were used to determine the accuracy of the monitors in use. Upon successful completion of the relative accuracy tests, the monitoring program commenced. Prior to completion of the monitoring period, the analyzers were again subjected to relative accuracy tests.

5.2 MEASUREMENT OF FLUE GAS EMISSIONS

Flue gas emissions were measured on a dry basis with an Energy Mines and Resources/Canada Continuous Emissions Monitoring System (CEMS). The CEMS, based upon extractive gas sampling principles, consists of three subsystems: sample acquisition/conditioning, sample analysis, and data acquisition (see Figure 5-2).

The Sample Acquisition/Conditioning unit was designed to deliver a sample stream, representative of the stack gas stream, to the sample analysis subsystem. Since the stream must be clean and dry for proper analyzer operation, a filter and condenser were used for particulate and moisture removal. The sample line, which carries the gas from the stack location to the conditioning system, was heat traced to eliminate in-line condensation. Sample was drawn into the system by a vacuum pump, which was also heated to eliminate condensation.

Sample analyses for sulfur dioxide, nitrogen oxides, carbon monoxide, oxygen, and carbon dioxide were achieved with the analyzers specified in Table 5-1. In each case, accurate interpretation of analyzer response required systematic calibration of the instrument against gases of known concentrations (see Table 5-2). A calibration curve was determined from a linear regression of known gas concentrations versus instrument response. The equation used to convert instrument signal to concentration units is as follows:

$$\text{concentration} = m(\text{response}) + b$$

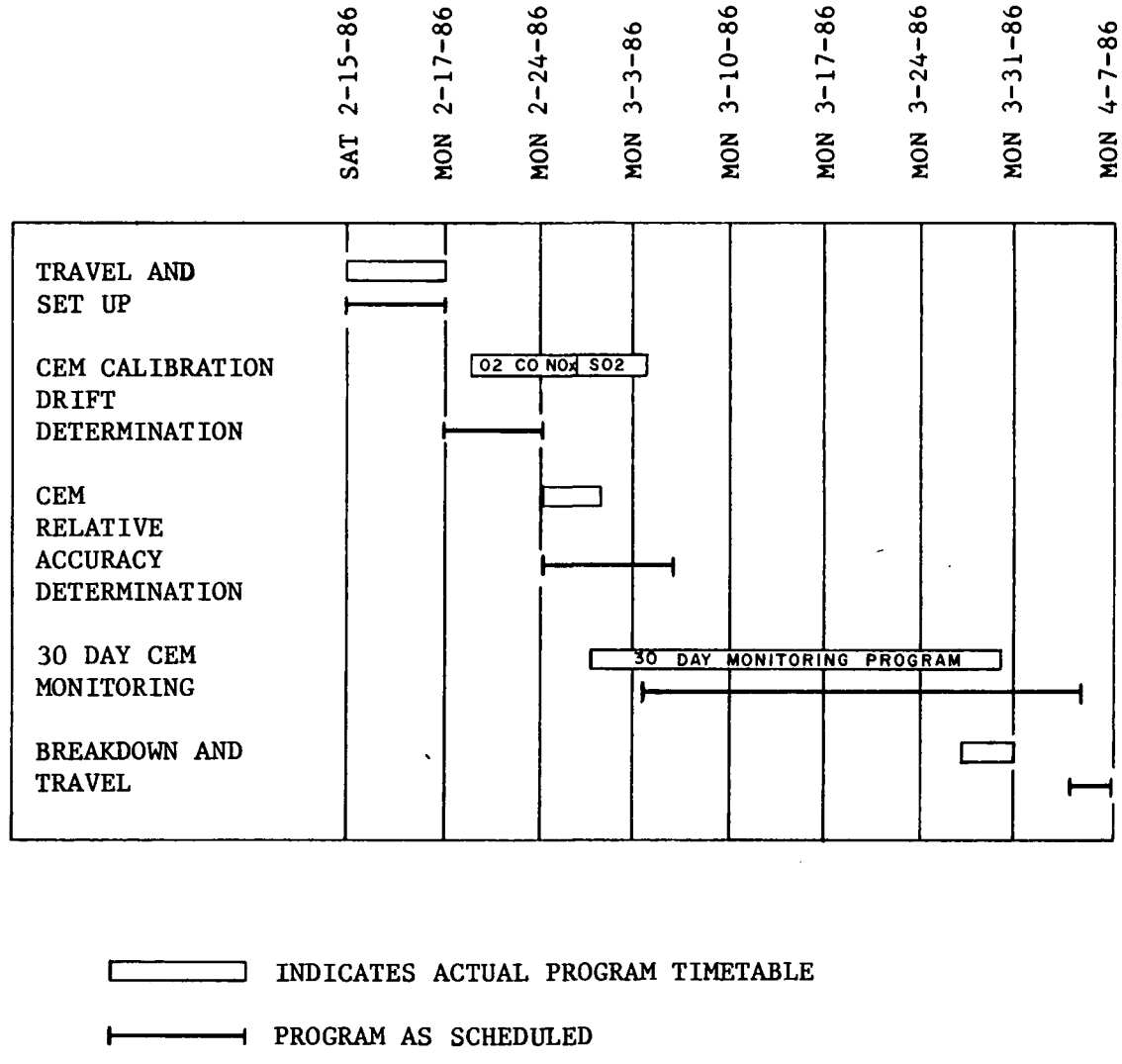


Figure 5-1. CEMS program schedule.

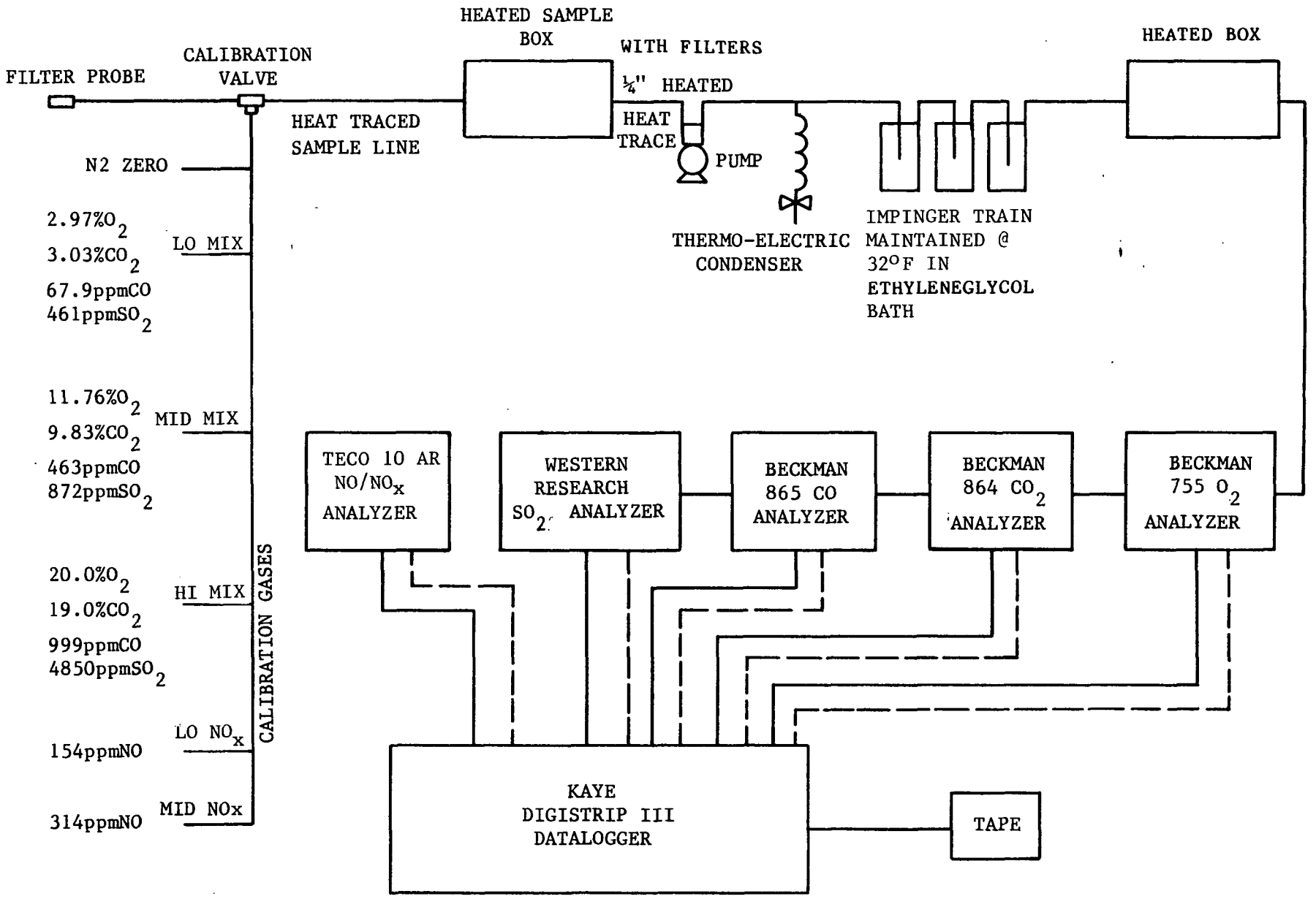


Figure 5-2. EMR Continuous Emissions Monitor

TABLE 5-1. ANALYZER SPECIFICATIONS

Pollutant/diluent	Manufacturer	Model No.	Operating principle
Sulfur dioxide (SO_2)	Western Research	721	NDUV
Oxides of nitrogen (NO_x)	TECO	10AR	Chemiluminescence
Carbon monoxide (CO)	Beckman	865	NDIR
Carbon dioxide (CO_2)	Beckman	864	NDIR
Oxygen (O_2)	Beckman	755	Paramagnetic wind

TABLE 5-2. CALIBRATION GAS CONCENTRATIONS

	Zero	Low	Mid	High
SO_2	N2	461 ppm	872 ppm	4,850 ppm
NO_x	N2	154 ppm	315 ppm	---
CO	N2	67.9 ppm	463 ppm	999 ppm
O_2	N2	2.97%	11.76%	20.0%
CO_2	N2	3.03%	9.83%	19.0%

where: m = slope of calibration curve

response = instrument signal (volts)

b = y - intercept of calibration curve

All calibration gases utilized during this program were obtained from AIRCO with an analytical certification of concentrations (Protocol No. 1; see Appendix J). The Data Acquisition System consisted of a Kaye Digistrip III Data Logger programmed to accept daily calibration data, and to perform the previously mentioned concentration calculation. Average concentration values (derived from the concentration calculation) for each analyzer were logged at 15-minute intervals, on the quarter-hour.

Stratification Check

Before beginning relative accuracy tests, a stratification test was conducted at the sampling location to verify a homogeneous gas stream. The stratification test consisted of measuring the velocity, pollutant, and diluent concentration at each traverse point (see Figure 4-2). Data collected at each traverse point was utilized to define the spatial variation of the flue gas stream. The results of the stratification test indicated a homogeneous stack gas stream and Reference Method sample probes were placed in close proximity to the CEMS probe.

Response Time

Monitor response time was used as a Quality Control check and is reported as the slower of the average of three sets of up-scale and down-scale determinations. The up-scale determination is the time it takes the monitor to respond from a zero calibration gas reading to a stable stack effluent reading. Conversely, the down-scale determination is the time it takes the monitor to respond from a high-level calibration gas concentration to a stable stack effluent reading. The mean up-scale and down-scale response times are determined, with the slower value reported. Reporting the slower value identifies an important operational limitation of the monitor. Results of the monitor response time check are provided in Table 5-3.

Instrument Drift

Instrument drift was determined during the first and second week of the test program according to procedures outlined in Performance Specification Tests 2, 3, and 4. Drift determinations were based upon the routine daily calibration checks conducted at 24-hour intervals. Instrument drift data are included in Appendix G.

Calibration Gas Traceability

All calibration gases used during the test program were obtained from AIRCO Industrial Gases with an analytical certification of concentration (NBS Traceable Protocol No. 1). Appendix J provides copies of the Calibration Gas Analytical Reports.

TABLE 5-3. CEMS SYSTEM -- MONITOR RESPONSE TIME RESULTS (SECONDS)

		O_2	CO_2	CO	NO_x	SO_2
Upscale	1	88	66	64	63	74
	2	89	63	64	62	78
	3	83	64	65	59	70
	$\overline{X}$	87	64	64	61	74
Downscale	1	89	65	68	67	109
	2	93	66	68	63	101
	3	85	65	68	69	105
	$\overline{X}$	89	65	68	66	105
Response Time		89	65	68	66	105

Coal and Limestone Sampling and Analysis

Coal and limestone grab samples were collected and composited (over 8-hour periods: 0000-0800; 0800-1600; 1600-2400, continually throughout the CEMS program. An individual day's sample consisted of three 8-hour composites (total approximate weight - 96 lbs) for both the fuel and sorbent. Prior to bagging, the limestone samples were composited into a single daily sample. These samples were bagged and labelled in the field for shipment to Alliance. Upon arrival at Alliance, the samples were again logged and tagged for shipment to Spotts, Stevens and McCoy (SSM), Reading, PA. SSM was responsible for the analyses summarized in Table 5-4, with the exception of the reactivity test which was conducted by Westinghouse Research and Development Center. Appendices B and C contain the data sheets as received from SSM and Westinghouse.

In addition to the 8-hour composite coal sampling, Alliance personnel analyzed hourly grab samples of coal for moisture and sulfur content at the plant site. This information provided process engineers with the data necessary to determine sulfur emissions on a day-to-day basis. This information was used in conjunction with emissions data to adjust coal and limestone feed rates and, concurrently, the calcium to sulfur ratio.

Coal samples were analyzed on a hourly basis for sulfur content and heating value from February 27 through March 5. For the remainder of the program, 3-hour intervals were composited such that eight 3-hour composites were analyzed per day. The coal analyses involved weighing, drying for 24 hours, and again weighing each sample to determine moisture content. The samples were then pulverized and analyzed in triplicate for sulfur content with a LECO MODEL 10 sulfur analyzer. The hourly coal sample and analysis logs are provided in Appendix E.

Additional samples, obtained periodically throughout the program, were taken to further aid in characterizing FBC operation. They included: Bed Material, Bed Drain Material, Multi-cyclone Ash for Reinjection, Baghouse Ash, and Ash Silo Samples. The analyses of these materials are provided in Appendix D.

TABLE 5-4. ANALYTICAL PROCEDURES

Material	Parameter	ASTM Method	Other Method
Coal	Sieve Analysis	D410	
	Preparation for Analysis	D2013	
	Ultimate Analysis	D3176	
	Carbon and Hydrogen	D3178	
	Sulfur	D4239B	
	Nitrogen	D3179	
	Ash	D3173	
	Moisture	D3173	
	Oxygen	Calculated by Difference	
	Proximate Analysis	D3172	
	Moisture	D3173	
	Ash	D3174	
	Volatile Matter	D3175	
	Fixed Carbon	Calculated by Difference	
	Ash Analysis		
	Calcium	D3682	
	Magnesium	D3682	
	Sodium	D3682	
Limestone	Calcium	C25, E508	
	Sulfur	D423B	
	Sieve Analysis	D410	
	Reactivity		Westinghouse Research & Development Thermogravimetric Analysis
Ash Bed, Multiclone Baghouse Silo	Ultimate Analysis	D3176	
	Carbon and Hydrogen	D3178	
	Sulfur	D4239B	
	Nitrogen	D3179	
	Ash	D3174	
	Moisture	D3173	
	Oxygen	Calculated by Difference	
	Carbonate Carbon	D1756	
	Sieve	D410	

SECTION 6.0

PROGRAM QUALITY ASSURANCE

6.1 INTRODUCTION

A detailed Test and Quality Assurance Plan was written, submitted, and approved for use under this project. This document was intended to serve as a guide for use during the field, laboratory, and data handling segments of the project.

6.2 PRECISION, ACCURACY AND COMPLETENESS

Alliance followed recommended procedures outlined in 40 CFR Part 60, Subpart Da and Appendices A, B, and F (proposed) to assess the precision, accuracy, and completeness of the continuous emissions monitors used during this program. These checks include determination of relative accuracy, precision estimates, tests for instrument drift and response time, and completeness of the data base. Table 6-1 provides Performance Specifications for Relative Accuracy (R.A.) and Calibration Drift as delineated in 40 CFR 60.

Relative Accuracy Tests

Relative accuracy (R.A.) tests were performed to assess the precision and accuracy of the continuous monitors. Reference Methods 3: (O_2, CO_2), 6: (SO_2), 7E: (NO_x), and 10: (CO), outlined in 40 CFR Part 60 Appendix A, were performed to generate information for comparison with CEM data. Reference Method field data sheets and R.A. calculations are presented in Appendix F. All the analyzers surpassed the established criteria during the initial relative accuracy evaluation conducted prior to beginning the 30-day CEM period (February 25-27, 1986). A second abbreviated relative accuracy test (three runs) was conducted during the final week of testing. The analyzers did not fare as well during the second set of tests, as the CO and SO_2 analyzers failed. Failure of the analyzers during the second set of tests can be traced to the extreme ambient temperature fluctuations that occurred as local weather patterns changed.

The analyzers were located within 10 feet of the roof of the boiler building in an uncontrolled temperature environment. On the day of the final relative accuracy and cylinder audit tests the outside ambient temperature was between 60° and 70°F, with the temperature surrounding the analyzers within the building between 100° and 110°F. Prior to this, the outside ambient temperatures were much lower with the temperature surrounding the analyzers between 70° to 80°F. Once a relative accuracy test series commences on a

TABLE 6-1. PERFORMANCE SPECIFICATION REQUIREMENTS

	Relative accuracy (RA)	Calibration drift
SO_2	±20%	±2.5% for 6 of 7 test days
NO_x	±20%	±2.5% for 6 of 7 test days
CO_2*	±1% (CO_2)	±0.5% for 6 of 7 test days
O_2*	±0.5% (O_2)	±0.5% for 6 of 7 test days
CO	±10%	±5% for 6 of 7 test days

*No criteria are designated for individual diluent analyzers. GCA uses these criteria as a basis for judging proper operation.

TABLE 6-2. RESULTS OF CEM RELATIVE ACCURACY[a] TESTS

	Specification (percent)	Initial set (percent) 9 runs	Final set[b] (percent) 3 runs
O_2	0.5	0.45 O_2 [c]	0.30 O_2 [d]
CO_2	1.0	0.39 CO_2 [c]	0.07 CO_2 [d]
CO	10.0	5.4[a]	13.5[b]
NO_x	20.0	7.8[a]	8.1[b]
SO_2	20.0	10.4[a]	20.4[b]

[a] $$RA = \frac{|\bar{d}| + cc}{RM} \times 100$$

[b] $$RA = \frac{|\bar{d}|}{RM} \times 100$$

[c] $$AA = |\bar{d}| + cc$$

[d] $$AA = |\bar{d}|$$

Where: RA = Relative accuracy.

AA = Absolute accuracy.

$\bar{d}$ = Algebraic average of differences between CEMS value and Reference Method value.

cc = 95% confidence coefficient.

RM = Reference Method value.

given day, the analyzers are not recalibrated until the next calendar day. Therefore, any drift due to temperature fluctuation, after initial calibration early in the morning, is not corrected as the temperature fluctuates. In reality, the location of the monitor system was not ideal and it should have been in a controlled temperature environment.

Both the CO and SO_2 analyzers were biased high relative to Reference Methods values. The higher values for SO_2 would, therefore, affect the SO_2 capture efficiency calculations; i.e., showing a lower percent capture than actual. A summary of relative accuracy tests results is provided in Table 6-2.

Calibration Drift

Zero and calibration drift tests were used to indicate an individual analyzer's ability to remain accurately calibrated over an extended period of time. Performance Specifications (Table 6-1) set a level for maximum allowable drift per day. This criteria must be met for seven consecutive days as part of the CEM certification routine. The Alliance field team used the data from daily calibrations to determine individual analyzer drift. The O_2, CO, NO_x, and SO_2 analyzers all eventually passed the tests; the CO_2 did not. Appendix G contains zero and calibration drift field data sheets.

Completeness

The completeness of the emissions monitoring data was determined based upon the 60 minute data file (Appendix A). Excluding 71 hours of FBC unit downtime (unit repair), the CEMS completeness percentage for the test program was 97.5 percent. The analyzers were down only 2.5 percent of the time for maintenance and repair.

Results of EPA Audit

Alliance conducted cylinder gas audits on the SO_2 and NO_x analyzers. The audit gases were introduced to the CEM system, per normal calibration routine at the probe location, thereby eliminating the potential for system bias. The results of the audit are presented in Table 6-3.

Due to relatively high temperatures surrounding the analyzers on the day of the audit, the SO_2 analyzer had drifted positively from the original settings, which had been set earlier in the day, prior to conducting the audit. Once a calibration has been set at the beginning of a 24-hour period, the analyzers are not recalibrated until the start of the next 24-hour period. The differences between the cylinder value and the analyzed values were 18.3 ppm and 28.5 ppm for the 69.4 and 296.1 ppm cylinders, respectively. The higher percent difference for the low cylinder audit is due to its value, as the differences are apparently equal. As the SO_2 monitor was reading in the 200 to 350 ppm range during most of the test period, the cylinder gas audit showed that the concentrations presented by the monitor are fairly accurate.

TABLE 6-3. RESULTS OF EPA CYLINDER GAS AUDIT

Pollutant	Concentration A Cylinder value	Concentration B Analyzed value	$\frac{B-A}{A} \times 100$
NO_x	70.4	69.8	-0.85
	402.6	397.6	-1.24
SO_2	69.4	87.7	26.37
	296.1	324.6	8.78

Two EPA Audit Ampules for SO_2 (Reference Method 6) were analyzed along with the initial Reference Method Runs. Table 6-4 provides the results of the Method 6 Audit.

TABLE 6-4. RESULTS OF EPA REFERENCE METHOD 6 AUDIT

EPA audit sample #	Concentration A Actual concentration	Concentration B Reported value	$\frac{B-A}{A} \times 100$
2478	297.4 mg/dscm	298.2	0.2%
3666	282.2 mg/dscm	294.4	4.3%

Coal Analyses

Four U.S. EPA Quality Assurance coal samples were provided by the Emissions Measurement Branch for auditing the analyses conducted by Spotts, Stevens and McCoy. Each sample was analyzed twice on each of two different days. The results of these analyses are presented in Appendix B-4.

An internal Quality Control sample was also analyzed by Spotts, Stevens and McCoy on four separate days during the analytical program. These results are presented in Appendix B-4.