Air Quality Measurements in the Coal-Fired Power Plant Environment of Colstrip, Montana

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July 1979

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ABSTRACT

A network of up to six air monitoring and sampling stations were operated 4-23 km downwind of the 700 MW coal-fired power plants at Colstrip, Montana. Continuous monitoring identified background SO₂ levels in the surrounding air at approximately 1 ppb (2.3 µg/m³). Average air concentrations measured in 1978 throughout the network increased to about 2 ppb (4.6 µg/m³) as a result of power plant operations. Meteorological and aerosol correlations with SO₂ concentrations helped identify and isolate the major source. The high sensitivity for SO₂ measurement provided resolution of all significant power plant plume fumigations at ground level. The magnitude of SO₂ exposures were higher than predicted in this rough terrain environment.

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1.0 INTRODUCTION

Results are reported from an air sampling and monitoring network operating in the eastern portion of the State of Montana during 1978. This program is an expansion and sophistication of earlier attempts to characterize the air quality downwind of the two coal-fired power plants at Colstrip, Montana (700 MW). A year of continuous operations has yielded data which include significant environmental effects from operation of these power plants 4-23 km downwind. The atmospheric models presently used to estimate pollutant exposures in this rough terrain environment appear to have underestimated the frequency and intensity of power plant emission exposures at the more distant locations.

Long-term studies have been reported concerning the downwind ground level concentration of sulfur dioxide in the coal-fired power plant environment.^(1,2,3,4) In general, these studies have taken place in areas of considerable pollution, where high background levels must be tolerated. Additional problems relating to instrumental sensitivity capabilities in real time have limited the detection of low-level plume fumigation. Lack of instrumental sensitivities may be responsible for high background estimates reported at locations where incoming air appears to have no obvious pollution source.⁽⁵⁾ Long distance transport (100 km) of sulfur dioxide from major industrial regions has been reported, however, and the influence of such sources must be considered in some situations.⁽⁶⁾ In spite of elevated levels of sulfur dioxide in the background, meteorological correlations have helped identify the larger sources in many instances.^(7,8)

The Great Plains contains a vast reservoir of fossilized energy. The most direct purpose for its use is in supplying the power needs of the region it underlies. It is anticipated that the expanded use of coal for supplying electrical power will present environmental problems which must be addressed. In the Colstrip area a consortium of public utilities has site applications

which propose to triple the generating capacity of this area with two additional units. Each of these proposed power plants will have the combined capacity of the two original units. Experimental data such as that reported here, as well as much more, will be necessary to provide accurate siting criteria information on the expected impact of large pollutant emitters. The bulk of the air-monitoring and sampling data reported here includes the entire year of 1978.

A review of the collected data illustrates the sensitivity of the air monitoring stations to assess the sulfur dioxide impact upon the downwind environment. As a result of the success in ambient-level air quality measurements, pertinent data are available to estimate the extent of the power plant impact upon the Class 1 region located adjacent to our more distant monitoring stations.

2.0 MONITORING STATION DESCRIPTION

The relative positions of the air-monitoring stations and the power plant are shown in Figure 1. Not more than four sites were operated simultaneously. The initial site locations selected were based upon a windrose analysis of this area. Although all stations were not identical in capability, a typical station description follows.

Air monitoring was conducted on oxides of sulfur utilizing a Meloy Model 285 sulfur analyzer which was selected for its low noise characteristics. This was particularly significant since the bulk of the ambient data was expected to be below 10 ppb ($23 \mu\text{g}/\text{m}^3$). Ozone levels were measured with a Bendix Model 8002 ambient air analyzer. Particulates were monitored with a Model Rich 100 Environment/One Condensation Nuclei Detector. Ambient air was supplied to the monitoring instrumentation from a common Teflon manifold. High velocity flow was maintained through this manifold. Information from the air monitoring equipment, as well as data from meteorological instrumentation located at the sites, were collected by a microprocessor/datalogger and interfaced to a paper punch tape for storage and computer processing. The

FIGURE 1

MONITORING STATION LOCATION

meteorological information included windspeed and direction, temperature, humidity and solar radiation. All the equipment was housed in small, highly insulated trailers. Electrical power for most stations was derived from 5.5 kW propane-fueled generators. The power was divided into two sections: rough power for the heating, air conditioning, and pumps as well as stable power for the instrumentation. An uninterruptible power system supplied highly regulated 115-volt 60-Hz electricity necessary for the stable operation of the air-monitoring instrumentation. This equipment also provided power continuity for station operation during periods of short-term generator outage. One thousand-gallon storage containers provided a 45-day fuel supply for the generators. This was necessitated by the inaccessibility of some of the stations during the winter months in Montana.

A two-stage cyclone separator was operated in conjunction with the monitoring instrumentation. This provided particulate information which could be correlated with the gas data. The air-monitoring data were collected in increments of 4 minutes and these values were averaged for different pertinent intervals. The data was edited for spurious information and instrumental fluctuations.

A quality assurance program for verifying the integrity of the collected air-monitoring data was in effect throughout the operation of this program. Rockwell International, under contract from the Environmental Protection Agency (EPA), performed quarterly audits on a routine basis. The extent of each audit included all operational air-monitoring instrumentation and other calibration equipment at the sites visited. A record of the audit reports is included in Appendix A. During the course of these audits, relatively minor problems were identified in both the auditors' procedures and the field calibration techniques. Field experiments relating to the interesting problem of carbon dioxide interference in sulfur dioxide measurements during audits is also reported in Appendix B. Although the audits were useful in identifying problems, unfortunately no effort was made by the auditors to correct published audits even after field personnel identified errors in prior auditing procedures. A complete record of the instrumental calibration program may be found as a final item in Appendix A.

3.0 MONITORING DATA

The monthly averages of the data are shown in Tables 1A, 1B, 1C, and 1D. The concentrations of sulfur dioxide are quite low, with respect to the urban environment. Except for individual short-term events discussed later, the impact of oxides of nitrogen from the power plant upon the ozone averages would be masked by the ubiquitous ambient levels of this species. This same argument is valid for the monthly averaged condensation nuclei levels whose concentrations may be better correlated with atmospheric stability or winds, rather than the power plant plume. Each of these latter factors serve to overwhelm the plume particulate in the lower tropospheric levels. In general, the levels of ozone and particulate are consistent with those observed in other relatively clean environments.⁽⁹⁾

The concentrations fluctuations of gaseous sulfur at the stations is sufficient in some instances to be of interest. For example, in March the averaged sulfur dioxide concentrations at Hay Coulee, 7.5 miles from the power plant was 5.6 ppb. This represents a contribution of almost 0.5 ppb on an annually averaged basis from this single month. The Northern Cheyenne Indian Reservation extends to within 14 miles of the power plant, in the same general direction as Hay Coulee. This land bears a Class 1 air quality designation. With reference to Table 2, the Air Quality Standards, we see that an elevation of no more than 0.7 ppb is acceptable before significant air quality deterioration is suggested. Since values of this magnitude were not expected from EPA models utilized in this area, the question of the sulfur dioxide source and downwind dilution between 7 and 14 miles becomes rather important.

No reliable ambient sulfur dioxide background measurements are available prior to power plant operation. These data suggest that averaged present day background levels decline to about 0.7 ppb and are typically about 1 ppb ($2.31 \mu\text{g}/\text{m}^3$). Values of this magnitude correspond to those observed in the cleanest areas of industrialized nations.⁽¹⁰⁾ Assuming this to be a reasonable conservative minimum, the magnitude of the effect from a pollution source can then be considered. Lower background estimates would, of course, infer more potent anthropogenic sulfur dioxide sources. A summation and averaging of this data on an annual basis indicate that both KE and KW stations observed an

TABLE 1A
HAY COULEE MONTHLY AVERAGES

<u>DATE</u>	<u>WIND SPEED mph</u>	<u>RELATIVE HUMIDITY %</u>	<u>TEMPERATURE °C</u>	<u>OZONE ppb</u>	<u>SO₂ ppb</u>	<u>100x LOG (CCN) CCN / cc</u>
2/78	4.2	70.9	-11.2	43	3.7	351
3/78	4.2	61.3	- 2.4	42	5.6	313
4/78	7.6	54.6	8.2	39	1.8	246
5/78	6.5	68.2	12.6	41	1.3	167
6/78	5.7	56.6	19.4	40	2.3	288
7/78	5.4	52.4	24.1	43	1.6	---
8/78	5.5	43.0	22.3	33	1.0	---
9/78	5.6	56.0	15.8	28	1.5	---
10/78	4.6	50.0	7.3	27	1.7	---
11/78	3.4	61.5	- 8.7	33	1.5	---
12/78	5.7	55.4	-13.0	34	1.7	---

TABLE 1B
KLUVER EAST MONTHLY AVERAGES

<u>DATE</u>	<u>TEMPERATURE °C</u>	<u>OZONE ppb</u>	<u>SO₂ ppb</u>	<u>100x LOG (CCN) CCN / cc</u>
3/78	8.9	40	1.8	337
4/78	9.1	39	1.8	302
5/78	12.3	45	2.2	272
6/78	16.5	39	3.4	254
7/78	27.4	46	---	---
8/78	22.3	36	1.4	---
9/78	18.9	30	0.9	---
10/78	12.3	32	0.7	---

TABLE 1C
KLUVER WEST MONTHLY AVERAGES

<u>DATE</u>	<u>TEMPERATURE °C</u>	<u>OZONE ppb</u>	<u>SO₂ ppb</u>	<u>100xLOG (CCN) CCN / cc</u>
3/78	7.0	40	1.9	306
4/78	8.5	39	1.6	266
5/78	12.8	44	1.5	215
6/78	18.8	41	2.6	214
7/78	21.3	43	1.4	270

TABLE 1D

BNW-1 MONTHLY AVERAGES

<u>DATE</u>	<u>WIND DIRECTION</u>	<u>TEMPERATURE °C</u>	<u>OZONE ppb</u>	<u>SO₂ ppb</u>
7/78	---	24.3	45	2.0
8/78	---	24.0	41	1.4
9/78	229	17.2	34	1.4
10/78	250	10.8	34	1.3
11/78	231	-3.5	36	2.0
12/78	257	-5.4	36	2.6

TABLE 2
SULFUR DIOXIDE AIR QUALITY STANDARDS

		AVERAGES		
		<u>ANNUAL</u>	<u>24 HOUR</u>	<u>3 HOUR</u>
FEDERAL ^(a)		30 ppb (80 $\mu\text{g} / \text{m}^3$)	140 ppb (365 $\mu\text{g} / \text{m}^3$)	500 ppb (1300 $\mu\text{g} / \text{m}^3$)
EPA ^(a) (CLASSIFIED AREAS) PREVENTION OF SIGNIFICANT DETERIORATION				
CLASS 3	INDUSTRIAL	30 ppb	140 ppb	500 ppb
CLASS 2	MOST OF USA	5.7	38	267
CLASS 1	PRISTINE (NATL. PARKS, WILDERNESS INDIAN LANDS)	0.7 (2 $\mu\text{g} / \text{m}^3$)	1.9 (5 $\mu\text{g} / \text{m}^3$)	9.5 (25 $\mu\text{g} / \text{m}^3$)
STATE OF MONTANA		20	100 ^(c)	250 ^(b)

(a) NOT TO BE EXCEEDED MORE THAN ONCE / YEAR

(b) 1 HR AVERAGE NTBEX - 1 HR/4 CONSECUTIVE MONTHS

(c) NTBEX - 1 DAY/3 MONTH PERIOD

increase of 0.8 ppb ($1.9 \mu\text{g}/\text{m}^3$) even though KE is several miles further downwind of the Colstrip area. A similar increase was observed at BNW-1, very close to Colstrip. A slightly larger increase of 1.15 ppb ($2.66 \mu\text{g}/\text{m}^3$) was observed at Hay Coulee, downwind of the BNW-1 site. Although variations in operational periods exist, it appears that an overall elevation of 1 ppb of sulfur dioxide throughout the area were measured during 1978.

Evidence as to the source of the pollution comes from several areas throughout this report. Figure 2 illustrates the generally correlating character of the monthly sulfur dioxide fluctuations of the individual stations. This is indicative of a common pollution source influencing the area.

Monthly sulfur concentration comparisons were also made between individual sites and power plant output levels in an attempt to observe correlations. A summary of pertinent source information was published by the Montana Power Company and transmitted routinely to the State of Montana for overview purposes. This data and relevant calculations are included in Appendix C. The power plant influence at a particular site was normalized to the percent of time the winds were from the power plant direction. A sector, $\pm 30^\circ$ of the centerline direction, was chosen to represent the power plant winds. Figures 3A and 3B illustrate these results at KW and Hay Coulee. Although excellent correlations were observed for KW, the direct influence of power plant sulfur dioxide was less obvious at Hay Coulee. Data presented later in this report indicate that both wind direction and stability play dominant roles in transporting the plume to the sites. It is thus apparent that an additional comparison of atmospheric stability would be necessary to properly assess the direct power plant/monitoring station correlations.

In addition to the longer, time-averaged values mentioned, many interesting features of the monitoring information are apparent in the real time data. Due to the remote rural location of the stations, most of the air being monitored contains little more than hemispheric concentrations of gaseous and particulate materials. When meteorological conditions prevail that are conducive to downward transport of the power plant plume to the stations, plume strikes are unmistakably prominent features upon this data base. Figure 4A is a classical plume strike situation in which elevated levels of sulfur

FIGURE 2
MONTHLY SO₂ CORRELATIONS BETWEEN AIR MONITORING STATIONS

FIGURE 3A
COMPARISON OF SOURCE TERM AND DOWNWIND MONITORING DATA

FIGURE 3B
COMPARISON OF SOURCE TERM AND DOWNWIND MONITORING DATA

FIGURE 4A

AIR MONITORING INFORMATION: TYPICAL PLUME STRIKE

APRIL 18, 1978 THROUGH APRIL 20, 1978

HAY COULEE

dioxide are correlated with particulates from the power plant stack when the wind vector orients from the plant direction. Excesses of nitric oxide in the plume from high-temperature coal burning processes are often apparent in the data as a result of their interaction with atmospheric ozone, as follows:

The anticorrelations between sulfur dioxide and ozone are further evidence of the presence of the power plant plume. Not all sulfur plume strikes bear such evidence, however. Sulfur dioxide excursions are occasionally accompanied by unchanged or increasing ozone concentrations. Masking of the ozone anticorrelation can take place in several ways. At first, while consuming ozone, NO is converted to NO₂ and adds to that already emitted. A second process, creating ozone, is known to become important during daytime hours as the concentration of NO₂ increases:⁽¹¹⁾

Thus, the age of the pollutant plume may influence the net effect of NO and NO₂ on the correlating ozone concentrations.

Elevated ozone concentrations have also been observed above stable underlying air masses.⁽¹²⁾ Convective turbulence, which appears important in transferring the pollutant plume to the monitoring station may also, on occasion, be responsible for elevated ozone levels and interference with anticorrelations that were initially created by the pollution source.

A 2-day period is illustrated in Figure 4B in which three plume strikes were evident each time the wind cycled through the plant direction. It is apparent from the frequency of appearance of these conditions that plume strikes are rather common. Daytime convective turbulence as suggested by fluctuations in the solar data, appears often to mix the plume downward to the stations in spite of the elevated plume injection height and interfering terrain. Situations of direct transport of lower-level pollutants appear also to enter the data, as indicated by the nighttime strike shown in Figure 4C.

FIGURE 4 B

AIR MONITORING INFORMATION: MULTIPLE PLUME STRIKES

AUGUST 11, 1978 THROUGH AUGUST 13, 1978

HAY COULEE

FIGURE 4C

AIR MONITORING INFORMATION: NIGHTTIME PLUME STRIKE

JULY 31, 1978 THROUGH AUGUST 2, 1978

HAY COULEE

Important, interesting information was collected concerning the downwind pollution and the horizontal stretching of the power plant plumes. These data were derived from cases in which sulfur strikes occurred at two or more stations from the same plume in a time sequence appropriate for the prevailing meteorological situation. A typical example of such an event is illustrated in Figure 4D. The angular spacing of these stations (see Figure 1) illustrates the horizontal dispersion of the plume as well as its downwind progress and dilution.

As field experience was gained concerning the probable location of plume intercepts, emphases were placed on relocating the monitoring stations for maximum effectiveness. The results of such reorientation are shown in Figure 5. Here, three co-linearly oriented stations (see Figure 1) exhibited the effects from the same power plant plume. It is also a representation of the topographical features southeastward from the Colstrip, Montana area. The low peaks to the east are slightly south of the exact station orientation. Although Class 1 land falls within the Greenleaf site distance, it does not approach this site in its actual geographic fluctuations. The maximum concentrations observed at each site are listed. This was one of two similar triple strike situations that took place in early November 1978. At that time, approximately 500 ppm (1150 mg/m³) of sulfur dioxide were measured in the output from each of two power plant stacks. Thus, the concentration dilution for the first sample location two miles downwind was approximately 2.5×10^4 .

Previous estimates of the frequency and intensity of plume fumigations at the more distant monitoring stations were negligible. This was not found to be the case. These estimates were derived from diffusion models which attempted modification of existing flat surface models to the mountainous terrain environment. A brief attempt was made, under the auspices of this program, to compare downwind exposure predictions from the diffusion models that are in present usage, with those actually observed at the sites. Experience with the EPA, PTMTP atmospheric model used for comparison purposes during high sulfur dioxide exposures in February and March indicated a considerable underestimation of the observed values. Use was made, therefore, of a computer modeling program at the University of Montana relied upon for downwind plume estimates (Williams, 1978) in this type terrain. Atmospheric stability data was incorporated into this model derived from tower instrumentation located beside the

FIGURE 4D

AIR MONITORING INFORMATION: MULTIPLE STATION PLUME STRIKE

MAY 31, 1978 THROUGH JUNE 2, 1978

KE SITE WITH SO₂ DATA FROM OTHER SITES

FIGURE 5
SOUTHEAST TERRAIN CROSS SECTION FROM
THE COLSTRIP POWER PLANTS

power plant stack. Comparisons between actual and predicted concentrations of sulfur dioxide at the sites in Figure 5 are shown on Table 3. The model predictions were based upon maximum exposures from full power operation of the coal-fired plants. This was not the situation at this time; however, even these overestimates fall short of reality at the greater distances. Also evident in this case history is the variation of exposure with distance. Although the peak concentrations observed at the sites varied by a factor of 5, the integrated exposures did not change significantly with downwind travel. This produced unexpectedly high exposures at longer distances. Meteorological situations that promote such occurrences are evidently more frequent than expected.

The 1978 data set was interrogated with respect to 3-hr and calendar day sulfur dioxide exposures. These limits were used to allow comparisons with the National Air Quality Standards (Table 2). No excesses were observed for the Class 2 category on which the sites were located. The total number of estimated excesses with respect to the nearby Class 1 land are shown in Table 4 along with other pertinent data. A specific compilation by date and time are included in Appendix D. A significant number of these days are illustrated in the monitoring information. Individual plume strikes generally show chemical and physical correlations which are useful for source identification. The results of even this short-term averaging, however, obscure these effects on the atmospheric components ozone and particulates. The wind direction data is pertinent, however, and reflects the source direction from the particular monitoring station. Because of the close proximity of two sites (Greenleaf and KE) to the Class 1 area, their importance is enhanced.

In order to identify the location of probable sources of sulfur dioxide to each major monitoring station, the direction of incoming sulfur dioxide was correlated with its concentration isopleth. The entire year of data was utilized for this purpose in order to reflect all possible sources of sulfur dioxide. Figures 6A, 6B, and 6C illustrate the results of these comparisons. Each display is a sulfur dioxide concentration isopleth on an annual basis for 10° directional increments around the particular stations shown. Several features are common to these illustrations. Each has a major concentration lobe in the direction of the coal-fired power plants. All illustrate a rather

TABLE 3
DIFFUSION MODEL PREDICTIONS VS MEASURED HOURLY
AVERAGED (SO₂)

	<u>TIME</u>	<u>BNW-1</u>	<u>HC</u>	<u>GREENLEAF</u>
MODEL †	9 - 1000	0 ppb	0 ppb	0 ppb
	10 - 1100	1.1	0.2	2.7
	11 - 1200	0.1	0	0.1
	12 - 1300	22	10	0.5
MEASURED *	9 - 1000	2.5	3.5	2.5
	10 - 1100	5.0	5.0	3.0
	11 - 1200	3.0	6.0	4.5
	12 - 1300	3.0	4.5	5.0

† SEE (WILLIAMS, 1978)

* ALL VALUES ± 0.5 ppb

TABLE 4
FREQUENCY OCCURANCE OF ELEVATED SO₂ EXPOSURES DURING 1978

<u>SITE</u>	<u>DISTANCE FROM SOURCE (km)</u>	<u>3 hr AVE $\geq$ 10 ppb</u>	<u>24 hr AVE $\geq$ 2 ppb</u>	<u>AVE SO₂ (ppb)</u>	<u>OBSERVATION PERIOD (mo)</u>
BNW-1	4.1	9	72	3.1	5.5
KLUVER WEST	11.2	5	54	2.8	4.5
HAY COULEE	11.6	18	161	3.2	10.8
KLUVER NORTH	14.1	0	19	2.8	1.8
KLUVER EAST	18.2	0	47	2.7	6.3
<u>CLASS 1 LAND</u>	22.2	-	<u>12^{a)}</u>	-	<u>12^{a)}</u>
GREENLEAF	22.5	0	1	1.9	1.0

a) NUMBER OF EXCESSES OF AIR QUALITY STANDARDS AS INTERPOLATED FROM GRAPHIC ANALYSIS OF SULFUR CONCENTRATION VS DISTANCE FROM THE POWER PLANT

FIGURE 6A
TIME AVERAGED SO₂ CONCENTRATION ISOPLETH FOR 10° INCREMENTS
AROUND HAY COULEE FOR 1978

FIGURE 6B
TIME AVERAGED SO₂ CONCENTRATION ISOPLETH FOR 10° INCREMENTS
AROUND KE FOR 1978

FIGURE 6C
TIME AVERAGED SO₂ CONCENTRATION ISOPLETH FOR 10° INCREMENTS
AROUND KW FOR 1978

low sulfur dioxide input from southeasterly winds opposed to the power plant's direction. A lesser source term seems apparent to the northeast between 15° and 30° true north with respect to each station. A comparison of the topographical features of the area with this secondary source was helpful. It appears that the apparent direction of this secondary source correlates with the contours of Rosebud Creek. Evidently the common westerly winds fumigate the area to the north of our sites. Then sulfur dioxide becomes trapped in the lower terrain and northerly winds create flow through the valley bringing elevated concentrations of sulfur dioxide to the stations.

As the plant plume moves eastward over the station network, it will from time to time, as shown earlier, mix downward to ground level. The frequency of this occurrence as well as the magnitude of such events relate to the instantaneous and integrated exposures observed from the emitted pollutants. Table 5 illustrates the integrated hourly sulfur dioxide exposure frequency observed at the sites. This data is presented in a manner comparable with other field studies.^(13,14) These studies suggest that the product of the sulfur dioxide concentration and exposure time is correlated with the damage expected from such fumigations. A summary of the 1978 data is shown in Table 6 including the number of hours of valid data. The period of operation varied considerably from site to site as instrumentation was utilized in what appeared to be the most expeditious manner at the time. Data omission also occurred because of power failures, instrument breakdowns and data editing.

As expected, the frequency of elevated exposures to sulfur dioxide decreases with distance from the power plants; however, the particular site location could serve to obscure this effect. For example, although BNW-1 is close to the source, the plume may be injected into the atmosphere at an altitude above the site. This does not preclude downwind mixing processes that do, on occasion, bring the plume down to more distant stations.

During the term of this project some emphasis was placed on reporting plume strike activity at the stations as quickly as possible. This allowed immediate comparisons of power plant activity, and meteorological situations. For this purpose, backup capability was provided by strip chart recorders. The recorder charts can be utilized to improve the continuity of data collection; however, the computer-compatible datalogging system proved to have a

TABLE 5
FREQUENCY DISTRIBUTION OF SO₂ EXPOSURES
IN THE AIR MONITORING NETWORK

HOURLY AVERAGED SO ₂ (ppb)	NUMBER OF TIMES AIR CONCENTRATION EXCEEDED OR EQUALED					
	HAY COULEE	KE	KW	KN	BNW-1	GREENLEAF
*0	4638	1987	1926	821	3041	334
1	3035	1319	1339	386	1732	80
2	2408	1006	1040	297	1291	46
3	1625	660	676	196	846	22
4	944	368	274	123	537	8
5	577	180	103	59	297	1
6	320	57	39	21	168	0
7	194	23	22	7	94	0
8	125	11	15	1	66	0
9	90	4	11	0	49	0
10	43	3	5	0	37	0
11	28	1	5	0	27	0
12	19	1	4	0	23	0
13	15	1	2	0	15	0
14	12	1	1	0	11	0
15	9	1	1	0	8	0
16	7	1	1	0	8	0
17	6	1	1	0	6	0
18	1	1	1	0	6	0
19	0	1	0	0	6	0
20	0	1	0	0	5	0
21	0	1	0	0	4	0
22	0	1	0	0	3	0
23	0	1	0	0	3	0
24	0	1	0	0	3	0
25	0	0	0	0	3	0
26	0	0	0	0	3	0
27	0	0	0	0	2	0
28	0	0	0	0	1	0
·	·	·	·	·	·	·
·	·	·	·	·	·	·
·	·	·	·	·	·	·
·	·	·	·	·	·	·
50	0	0	0	0	1	0

* VALID DATA COLLECTION TIMES

TABLE 6
AIR MONITORING DATA AVERAGES FOR 1978 ^{a)}

	<u>HAY COULEE</u>	<u>KE</u>	<u>KW</u>	<u>KN</u>	<u>BNW-1</u>	<u>GREENLEAF</u>
SO ₂ (ppb)	2.04	1.83	1.84	1.3	1.73	0.47
O ₃ (ppb)	36.8	39.1	40.7	34.4	36.6	32.1
LOG NUCLEI (#)	2.92	2.92	2.49	---	2.99	---
WIND (°)	307	201	279	224	281	---
WIND (km/hr)	9.1	---	---	---	31	---
TEMPERATURE (°C)	6.9	14.8	13.3	-7.9	9.9	---
HUMIDITY (% RH)	57	---	---	---	---	---
RAD (LANGLEY/min)	0.23	0.25	0.25	0.19	---	---
TOTAL RECORDED HOURS SO ₂	4638	1987	1926	821	3041	334

a) MANY AVERAGES REFLECT ONLY SEASONAL VALUES BECAUSE OF VARIATIONS IN STATION OPERATION. SEE APPENDICIES FOR ACTUAL OPERATIONAL PERIODS.

high service reliability. Some of the sulfur dioxide plume strike correlations between sites that were observed in the overall data set are evident in the chart data. Appendix E is a compilation of these sulfur dioxide fumigation periods and includes other available data from the sites at that time. Data flags are included during time periods in which more than one station recorded elevated sulfur dioxide by the same pollutant plume.

4.0 AEROSOL SAMPLING DATA

An aerosol sampling program was conducted at three of the sites in conjunction with the air monitoring. Samples were collected at intervals of a day or longer depending upon weather and personnel availability. The sampling system consisted of a cyclone separator with special orifice and pump. Figure 7 illustrates the separator, flowmeter and connections to a 4 CFM pumping system. The systems were matched to provide an aerosol separation at slightly less than one micron. Figure 8 illustrates the calibration curves obtained using standardized aerosols. Two fractions were collected from each sample with the fine portion accumulating on Whatman 41 filter paper. The larger fraction was centrifugally maintained in a stainless cup of the separator. A procedure was developed for slurring this fraction and transferring it onto a polypropylene film. Then both fractions underwent x-ray fluorescence analysis for a series of trace elements. Thin film standards were routinely utilized in each batch analyzed by this technique.

Results from analysis of January 1978 samples during the rather clean aerosol period [snow on the ground and sulfur dioxide levels below 2 ppb ($4.6 \mu\text{g}/\text{m}^3$)] are shown in Table 7. The trace element concentrations of individual samples are below the detection limit of the analytical procedure for certain elements during such clean air periods. Consequently, the ratio between large and fine fractions have high uncertainties.

The entire 1978 data set was interrogated with respect to the appearance of high level sulfur dioxide concentrations. These are called plume "strike days" and are defined as those in which the hourly averaged sulfur dioxide concentrations exceeded 10 ppb ($23 \mu\text{g}/\text{m}^3$). It was also noted that this

FIGURE 7
AEROSOL PARTICLE SEPARATOR

FIGURE 8
CYCLONE SEPARATOR DISTRIBUTION

TABLE 7
JAN. 1978 COLSTRIP AEROSOL CONCENTRATIONS ng/m³*

Cl		K		Ca		Ti		V		Mn		Fe	
L	F	L	F	L	F	L	F	L	F	L	F	L	F
0.3	30	2.2	15	1.2	2	0.3	0	0	0	0.06	0	2.8	5
0	0	2.9	17	2.7	9	0	0	0	0	0.1	1.5	3.2	17
0	45	1.6	5	0.5	6	3.5	0	0.2	0	0.05	1.6	1.4	13
0.4	0	1.4	21	0.5	0	0	0	0	3.3	0.05	1.7	2.5	9
0	117	1.5	6.8	2.3	0	0.4	0	0	0	0.1	0.2	3.3	11
0.3	0	3.7	6	2.0	4	0.7	0	0	0	0	0.2	3.0	8
0	0	0.2	6	0.2	0	1.3	0	0	0	0.04	1.4	1.0	7
[AVE] 0.14	27	1.93	12	1.34	4.4	0.9	0	0.03	0.84	0.05	1.2	2.5	10

Cr		Co		Ni		Cu		Zn		Pb		Br	
L	F	L	F	L	F	L	F	L	F	L	F	L	F
0.1	1.5	0	0	1.3	2.2	1.4	4	0.05	0.2	0.04	3.3	0.03	0.3
0.1	2.7	0	0	4.8	25	0.5	4	0.3	2	0.2	1.7	0.01	1.0
0.04	3.6	0	0	0.5	34	0.4	3.4	0.2	1.4	0.1	1.7	0	1.6
0.03	1.7	0	0	0.2	6	0.4	4.4	0.2	2.7	0.1	2.1	0.01	1.5
0.05	1.6	0	2.4	5.8	4.8	0.2	3.4	0.2	2	0.2	5.6	0.02	1.6
0.03	0.2	0	0	3.8	23	0.7	3.3	1.8	3.5	0.2	2	0.03	1.2
0.05	0.2	0	0	0.5	23	0.1	2.8	0.01	0.3	0.03	4.3	0.01	0.3
[AVE] 0.06	1.9	0	0.34	2.4	20	0.53	3.8	0.39	1.9	0.12	3.4	0.02	1.2

*L = GREATER THAN 1 μ F = LESS THAN 1 μ

situation occurred only when the wind direction was from the power plants. A second set of background days or "non-strike days" were also derived from the data. These were days in which the winds blew from the power plant quadrant but the sulfur dioxide levels were less than 2 ppb ($4.6 \mu\text{g}/\text{m}^3$). The situation was prevalent when the plume failed to mix downward.

By comparing the elemental distributions of samples collected during these two periods, one can look for changes in the Colstrip natural aerosol levels with the addition of the power plant plume. Table 8 illustrates results of this comparison and includes background and source term information taken from earlier measurements in the Colstrip area. These data are shown in Appendix D and include results of studies prior to power plant operation.⁽¹⁵⁾

The ratios on the table were derived by first normalizing each element to the amount of iron found in the sample in question and then dividing that number by the elemental ratio observed in normal crustal material. The stack column illustrates the relative potency of the power plant emissions to change the natural aerosol distribution. The Colstrip aerosol column illustrates the aerosol differences that already exist between eastern Montana and average crustal distributions of elements. It appears that the selenium ratios had been modified in the aerosol by the stack; however, definitive explanations of other elemental changes are not as evident. The elevated lead and bromine values reflect the influence of Colstrip traffic upon the aerosols since the stack is incapable of modifying the ratios to the extent shown. The effects of mining operations in the plant direction versus those in other directions would also leave their imprint upon the particulate data although no such directional correlation was observed. In most situations, contributions to the aerosol come from several sources including the natural crustal materials and exact definition is complex. Significant elemental enrichment of the aerosol versus local soil were found for arsenic (26x) and Zn (3.5x) in background measurements of the Colstrip area prior to power plant startup.⁽¹⁵⁾

Utilizing the definition of strike and non-strike days given previously, Table 9 illustrates the ratios found between the fine and coarse particulate for each element in the aerosols. Those elements usually associated with crustal materials appear equally distributed between fractions. Elements

TABLE 8
ELEMENTAL DISTRIBUTIONS IN COLSTRIP AREA AEROSOLS
 RATIO IN SAMPLE / RATIO IN CRUSTAL*

<u>ELEMENT</u>	<u>NON STRIKE DAYS</u>	<u>STACK</u>	<u>STRIKE DAYS</u>	<u>HI-VOL COLSTRIP</u>	<u>COLSTRIP SOIL</u>
Ca	1.3	26	1.8	1.0	1.4
Ti	1.0	8	1.3	0.66	1.4
Mn	0.80	4.8	1.1	1.2	1.0
Fe	1	1	1	1	1
Cu	119	11	896	-	-
Zn	19	7	97	3.3	3.4
Se	983	26, 000	10, 000	1.1	600
Pb	68	68	450	-	-
As	90	350	825	26	9.3
K	1.1	0.1	1.6	-	1.7
Br	128	244	990	-	3

* ALL VALUES WERE NORMALIZED TO Fe

TABLE 9

**AEROSOL SIZE DISTRIBUTIONS IN
SO₂ POLLUTED AIR ON STRIKE DAYS**

RATIO OF FINE/ COARSE ($<1\mu / >1\mu$)

Ni	8 ± 6	Tl	0.13 ± 0.10
Cr	9 ± 5	Ca	0.86 ± 0.66
As	17 ± 6	Mn	0.69 ± 0.31
Zn	20 ± 4	K	0.68 ± 0.21
Pb	23 ± 14	Fe	1.3 ± 1.1
Se	28 ± 31		
Br	136 ± 81		

whose volatility or ability to fractionate to smaller particulate are found on the smaller fraction. It is informative to realize that strike days are associated with persistent rather than light and variable winds from the power plant direction. This would contribute to the increased coarse burden of crustal type material in the aerosol and, therefore, reduced particulate ratios.

5.0 SUMMARY

The pristine environment of Montana State lent itself to identifying, in part, the downwind impact from operation of the first major coal-fired power plants in that region. The complexity of contributing sources in the industrialized areas make specific plant impact relationships difficult to assess. For example, results from a monitoring program of similar orientation around two much larger power plants (3000 MW) indicate that their combined effect represents only a 10% sulfur dioxide increase in the seasonal background levels,⁽⁴⁾ whereas, our study showed that winds from the power plant bring greater than twice the SO₂ concentration to the monitoring network as from other directions. Although the Colstrip power plant plumes have been clearly identified, the quantitative levels of sulfur dioxide are very low. With respect to both exposures and maximum observable concentrations, we certainly are dealing in the parts per billion range.

Prior estimates of the extent of downwind sulfur dioxide fumigation were negligible with respect to the data presented here. In all specific cases studied beyond three miles the actual exposures were at least twice that predicted by field models in use, and generally more. Monthly averaged data as well as individual case situations indicate that although peak exposures may change dramatically with distance, the integrated exposures do not. The atmospheric models do not suggest this and, therefore, diverge from the measured values with distance. The high monthly values measured 7 miles from the power plant at Hay Coulee may well represent approximate exposures further downwind. These data strongly suggest longer-range monitoring information is necessary to improve power plant siting criteria.

The biological impact of the power plants has been under study for some time. Results from such work are reported on a continuing basis from the

Corvallis, EPA. (16) Three of the monitoring stations were co-located within rangeland plots that were set aside specifically for assessing biological changes in the power plant environment. Subtle effects on the biota, with time, have been noted in the experimental data prior to and during our monitoring program. These may now be compared with our data to determine if correlations with long-term low-level chronic sulfur dioxide exposures exist.

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APPENDIX A

A QUALITY ASSURANCE PROGRAM FOR DATA
VALIDATION AT COLSTRIP, MONTANA

A QUALITY ASSURANCE PROGRAM FOR DATA VALIDATION AT COLSTRIP, MONTANA

This appendix focuses on the evolution of procedures undertaken by Pacific Northwest Laboratory to insure the quality of ozone and sulfur gas data produced at the Colstrip air monitoring stations since August 1977. As shortcomings in the initial quality assurance (QA) plan became apparent, more elaborate and redundant self-checking techniques were developed to guarantee the integrity of the generated numbers. It is believed that the final quality assurance plan, to the extent possible, covered all error sources in the framework of field applications. Our primary concern was the quality assurance of ozone and sulfur. These instruments were known to be subject to a large amount of long-term drift. Other measured parameters such as flow readings, etc., have proven stability. Nonetheless, all other systems and parameters utilized were referenced on a semiannual basis against reliable standards. At no point did these other parameters fall outside the $\pm 10\%$ error margin limits.

The general procedure for checking the ozone and sulfur gas analyzers was to correlate the instrumental response with the known value of the concentration of an injected gas generated by a dynamic calibration unit. Sulfur dioxide gas was generated from a Teflon[®] NBS permeation tube in a temperature-controlled oven. Ozone was created by flowing zero air past a stable ultraviolet lamp. If the response was within 10% of the known value of the injected gas, the instrument was not adjusted. If the response exceeded this error limit, then, after correctly adjusting the zero and span potentiometers, a 4 or 5 point calibration was performed on the analyzer. Then, the instrumental calibration was checked for linearity and if found lacking ($r > .999$) the instrument was removed from service and repaired.

Initially, we maintained one Monitor Labs Model 8500 calibrator onsite to perform weekly zero/span checks of our sulfur and ozone monitors. A second 8500 calibrator was kept in Corvallis, Oregon and referenced to NBS

standards or Federal Code of Regulations Title 40 techniques. The calibrators were rotated every 4 months to provide a continuously updated reference source. This procedure worked effectively for one site only. As the number of stations rose to four, both calibrators were kept onsite (after June 1978). This was necessary in order to have at least a weekly check on each station, since 2 days are involved per site per calibration. One day is used to allow the calibrator to reach equilibrium. These calibrators were cross-referenced against each other on a weekly basis. At the same time we obtained a Bendix Dynacalibrator from the Forest Service which was used as a fixed base for checking our mobile calibrators. We now check weekly the sulfur channels of the mobile ML8500 calibrators against an NBS tube in the stationary Bendix instrument. This is the same technique performed in Corvallis. Also, the ozone channels are referenced to an ultraviolet ozone source in the Bendix calibrator. Our present observations have shown that the principal cause of change in calibrations is the act of moving the calibrator from one site to the next. Considering the locations of our sites and the type of country traversed, this is not surprising. We have observed a calibrator to change 30% in 3 weeks. This is the rationale for changing the initial quality assurance plan. Calibrators standardized at Corvallis and returned to the field would have a functional period of about 1 week. The initial quality assurance plan worked well under the initial monitoring conditions of only one or two sites. Under current conditions, continuous referencing is necessary. Our current use of UV generated ozone as a standard is considered by us to be inadequate. The long term stability of UV lamps is known to be questionable. The neutral buffered KI method used at Corvallis is also questionable.^(a) Therefore, we are now using a gas phase titration.^(b) This is the technique currently being utilized by the Rockwell auditing team. At the October 1978 audit we standardized our certified cylinder against the Rockwell NBS cylinder. We then used this standard to check weekly the ozone

(a) Interagency comparison of Iodometric Methods for Ozone Determination, W. B. Moore et al., Calibration in Air Monitoring, ASTM Publication #598, 1976.

(b) Application of Gas Phase Titration in the Calibration of Nitric Oxide, Nitrogen Dioxide and Ozone Analyzers, K. A. Rheme, Calibration in Air Monitoring, ASTM Publication #598, 1976.

channels of our mobile calibrators. The UV lamp is referenced to a certified nitric oxide cylinder by a gas phase titration using a nitrogen oxide analyzer as an intermediary. Alternately, a reverse gas phase titration was utilized with an ozone analyzer as an intermediary.

The zero/span records in this appendix span the time period since installation of the computerized data acquisition system. Records are also available from August 1977 through February 1978 at the Hay Coulee site. However, the data transcription during this early period was into stripcharts, relayed directly to the Corvallis, EPA Laboratory; neither these records nor the monitoring data are included in this document. Large breaks in time during the records may be due to an inoperative analyzer or an inoperative site. The time periods expressed in the data should be checked against the appropriate time periods of the quality assurance records. All values are documented as parts per billion at local pressure. The local pressure is approximately 670 mmHg.

The state of the quality assurance program at the monitoring stations was audited quarterly by an independent contractor of the EPA (Rockwell International, Atomics International Division, Air Monitoring Center). The audits reflect an evolution of procedures and understanding by the auditors themselves. The audit reports are included at the end of the appendix. The first two audits demonstrated the reliability of the ozone analyzer, but abnormally low results were obtained for sulfur dioxide. This prompted an investigation into probable causes. It was found that CO₂ levels created in the monitoring trailers by personnel respiration quenched the SO₂ response during audit days only as a result of improper auditor procedures. (See "Field Experience with Ambient Level Flame Photometric Sulfur Detectors" in Appendix B.) The January audit had more CO₂ interference than the September audit because the trailer was closed up tight for the winter and CO₂ reached higher levels inside the monitoring trailer. All of our calibrations used external air tapped at the manifold as a base for generating span gases, while the auditing team used air from inside the trailer. Subsequent audits utilizing outside zero air after January 1978 demonstrate the validity of the

SO₂ data throughout the project. The July 1978 audit demonstrated the drift problem in two mobile calibrators and led to the establishment of a base calibrator. The final audits reflect the improved reliability of our quality assurance plan. All audits experienced a minor but important anomaly. The audit teams' zero air was usually 3-5 ppb higher in SO₂ than ambient Colstrip air. This was probably caused by residual pollution in the audit equipment left from its storage and use in heavily polluted areas. It is interesting to note that the air in the Colstrip area, except during periods of power plant fumigation, contributes less SO₂ instrumental response than the auditor zero air. Zero air problems such as this are commonly encountered throughout the literature in ultra-trace gas analysis.

Anyone attempting an ambient air monitoring project of this nature should be aware of the complications experienced with different quality assurance procedures.

A summary of pertinent QA facts follows:

- 1) A single reference source is insufficient.
- 2) The user should be aware of interference present in the ambient gases and calibrate appropriately in their presence.
- 3) Complete onsite calibration facilities are preferred to remote calibration of calibrators, or to transport of calibration equipment.
- 4) Simplicity of techniques should be stressed. (Permeation tubes and GPT versus wet chemical methods.)
- 5) Every discrepancy is to be questioned thoroughly. Auditors are not perfect.

ZERO/SPAN RECORDS

HAY COULEE OZONE

<u>Date</u>	<u>Zero</u>	<u>Calculated Span</u>	<u>Observed Span</u>
2/2/78	0 ppb	190 ppb	183 ppb
2/6/78	0	190	175
2/16/78	0	190	178
2/21/78	0	185	175
3/3/78	0	207	203
3/11/78	0	171	169
3/17/78	0	208	197
4/14/78	0	171	179
5/6/78	0	186	198
5/16/78	0	186	196
5/23/78	0	186	182
5/29/78	0	186	188
6/2/78	0	117	110
6/19/78	0	94	96
6/26/78	0	80	76
7/12/78	0	52	52
7/19/78	0	52	47
7/21/78	Recalibrated analyzer		
7/23/78	0	60	66
7/24/78	0	60	71
7/24/78	Recalibrated analyzer		
7/27/78	0	60	60
7/28/78	0	53	51
7/31/78	0	63	60
8/3/78	0	63	60
8/3/78	Recalibrated analyzer		
8/8/78	0	164	159
8/9/78	0	156	152
8/26/78	0	161	176
9/4/78	0	65	60
9/7/78	0	113	102
9/12/78	0	104	103
9/20/78	0	146	141
9/27/78	0	66	60
10/3/78	0	60	56
10/17/78	0	66	61
10/18/78	0	156	155

ZERO/SPAN RECORDS
HAY COULEE OZONE (CONTINUED)

<u>Date</u>	<u>Zero</u>	<u>Calculated Span</u>	<u>Observed Span</u>
11/7/78	0	98	96
11/14/78	0	62	69
11/19/78	0	119	131
11/28/78	+1	45	48
12/28/78	+1	139	135
1/27/78	+1	45	48
2/1/78	+1	146	150
2/5/79	Recalibrated analyzer		
2/11/79	0	168	162

Instrumentation

Monitor Labs Model 8410 EPA S/N 067838

ZERO/SPAN RECORDS

HAY COULEE SULFUR GAS

<u>Date</u>	<u>Zero</u>	<u>Calculated Span</u>	<u>Observed Span</u>
2/2/78	0 ppb	27 ppb	36 ppb
2/2/78	Recalibrated analyzer		
2/6/78	3	32	30
2/7/78	-2	62	57
3/17/78	0	69	69
3/28/78	-5	28	26
4/14/78	0	75	74
5/23/78	0	75	75
5/23/78	Calibrated new analyzer		
5/24/78	1	28	25
5/25/78	0	28	28
5/27/78	1	28	25
5/29/78	-3	28	28
5/31/78	0	28	25
6/2/78	0	62	65
6/10/78	0	28	27
6/16/78	0	29	29
6/20/78	+3	27	26
6/26/78	+6	29	29
7/13/78	Recalibrated analyzer		
7/18/78	2	29	23
7/19/78	Recalibrated analyzer		
7/21/78	2	29	29
7/23/78	3	29	29
7/27/78	2	29	27
7/28/78	1	29	29
7/31/78	0	43	43
8/13/78	-1	66	64
8/15/78	0	48	47
8/31/78	0	77	79
9/6/78	-2	70	70
9/7/78	-2	38	37
9/12/78	0	45	42
9/20/78	+2	68	63
9/27/78	-4	71	69
10/3/78	+2	70	67
10/6/78	+1	47	44
10/12/78	+2	46	44

ZERO/SPAN RECORDS

HAY COULEE SULFUR GAS (CONTINUED)

<u>Date</u>	<u>Zero</u>	<u>Calculated Span</u>	<u>Observed Span</u>
10/17/78	+3	72 ppb	66 ppb
10/18/78	Recalibrated analyzer		
10/23/78	+1	83	72
10/23/78	Recalibrated Analyzer		
10/26/78	+2	81	80
10/28/78	0	77	76
11/2/78	-1	83	82
11/7/78	0	80	80
11/14/78	+3	64	63
11/19/78	+4	82	78
11/28/78	-5	80	80
12/6/78	+4	51	51
12/12/78	+3	81	81
1/3/79	Calibrated new analyzer		
1/11/79	-2	81	74
1/18/79	-2	81	69
1/18/79	Recalibrated analyzer		
1/24/79	-3	79	80
1/30/79	-1	105	100
1/30/79	Recalibrated analyzer		
2/1/79	-1	82	82
2/7/79	Calibrated new analyzer		

Instrumentation

2/2/78-2/7/78	Meloy SA 160	EPA S/N 111602
2/7/78-5/23/78	Meloy SA 285	S/N FL156
5/23/78-5/27/78	Meloy SA 160	EPA S/N 019981
5/27/78-12/18/78	Meloy SA 285	S/N FL156
1/3/79-2/7/79	Meloy SA 285	S/N 5J0F3

ZERO/SPAN RECORDS

BNWI OZONE

<u>Date</u>	<u>Zero</u>	<u>Calculated Span</u>	<u>Observed Span</u>
7/21/78	Calibrated Analyzer		
7/23/78	Recalibrated Analyzer		
7/27/78	0 ppb	96 ppb	98 ppb
7/29/78	0	46	41
7/29/78	Recalibrated Analyzer		
8/8/78	0	93	96
8/10/78	0	93	94
8/12/78	Recalibrated Analyzer		
8/14/78	0	83	83
8/15/78	0	83	84
8/18/78	0	83	85
8/24/78	0	83	85
8/30/78	0	83	88
9/4/78	0	83	87
9/8/78	0	83	84
9/13/78	0	83	81
9/20/78	0	83	85
9/26/78	0	83	86
10/2/78	0	83	85
10/9/78	0	83	86
10/16/78	0	83	89
10/20/78	0	74	68
10/20/78	Recalibrated Analyzer		
10/25/78	0	94	92
11/1/78	0	94	95
11/7/78	0	94	95
11/9/78	0	94	91
11/13/78	0	94	91
11/24/78	0	94	96
11/27/78	+1	94	97
12/4/78	+1	94	94
12/11/78	+1	94	93
1/5/79	+1	94	100
1/11/79	0	94	96
1/17/79	0	94	97
1/29/79	0	94	94

ZERO/SPAN RECORDS

BNWI OZONE (CONTINUED)

<u>Date</u>	<u>Zero</u>	<u>Calculated Span</u>	<u>Observed Span</u>
2/13/79	0	94	96
2/15/79	0	94	94
2/17/79	+1	94	100

Instrumentation

Bendix Model 8002 Ozone Analyzer

ZERO/SPAN RECORDS

BNWI SULFUR GAS

<u>Date</u>	<u>Zero</u>	<u>Calculated Span</u>	<u>Observed Span</u>
7/19/78	Calibrated Analyzer		
7/21/78	0 ppb	32 ppb	30 ppb
7/23/78	-1	32	34
7/27/78	+1	32	34
7/29/78	0	39	41
8/11/78	+1	29	32
8/12/78	Recalibrated Analyzer		
8/18/78	+2	37	34
8/24/78	0	46	43
8/30/78	0	43	45
9/8/78	0	43	39
9/11/78	0	51	50
9/22/78	0	46	48
9/26/78	0	46	48
10/2/78	+1	38	31
10/2/78	Recalibrated Analyzer		
10/9/78	-1	36	34
10/16/78	-1	52	51
10/25/78	+1	42	38
11/1/78	-1	53	49
11/7/78	-1	48	38
11/9/78	Recalibrated Analyzer		
11/24/78	+4	87	90
11/27/78	0	92	90
12/4/78	-1	60	57
12/11/78	0	60	56
1/5/79	-1	54	50
1/11/79	-2	63	58
1/17/79	+3	63	59
2/13/79	-1	50	48
2/15/79	+3	58	55
2/17/79	-1	50	47

Instrumentation

Meloy	SA 285	Sulfur Analyzer	S/N FL155
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ZERO/SPAN RECORDS

KLUVER EAST OZONE

<u>Date</u>	<u>Zero</u>	<u>Calculated Span</u>	<u>Observed Span</u>
2/28/78	Calibrated analyzer		
3/21/78	0 ppb	300 ppb	312 ppb
4/1/78	0	300	321
4/3/78	0	300	330
4/7/78	0	300	335
4/11/78	Recalibrated analyzer		
4/13/78	0	300	332
4/14/78	0	300	340
4/18/78	0	300	330
4/21/78	0	300	338
4/24/78	0	300	323
4/26/78	0	300	333
5/5/78	0	300	294
5/8/78	0	300	305
5/17/78	0	300	300
5/26/78	0	70	62
5/29/78	0	332	311
6/2/78	0	332	305
6/5/78	0	332	305
6/7/78	+1	332	310
6/15/78	-1	320	291
6/21/78	0	320	294
7/24/78	0	320	302
8/10/78	Recalibrated analyzer		
8/11/78	0	280	282
8/14/78	0	280	290
8/17/78	0	280	278
8/22/78	+1	280	286
8/24/78	0	280	290
8/26/78	0	280	283
8/28/78	0	280	279
8/30/78	0	280	284
9/1/78	0	280	280
9/21/78	+1	280	271
9/25/78	+1	280	285
9/29/78	0	75	75
10/6/78	0	280	290

Instrumentation

Bendix Model 8002 Ozone Analyzer

ZERO/SPAN RECORDS

KLUVER EAST SULFUR GAS

<u>Date</u>	<u>Zero</u>	<u>Calculated Span</u>	<u>Observed Span</u>
2/27/78	Calibrated analyzer		
3/20/78	Recalibrated analyzer		
4/11/78	Recalibrated analyzer		
5/26/78	0 ppb	70 ppb	62 ppb
5/26/78	Recalibrated analyzer		
6/21/78	0	33	35
7/25/78	Recalibrated analyzer		
8/11/78	Recalibrated analyzer		
8/17/78	+3	28	23
8/17/78	Recalibrated analyzer		
8/22/78	0	51	48
8/30/78	+1	37	35
9/21/78	+3	54	57
9/29/78	0	63	55
9/29/78	Recalibrated analyzer		
10/16/78	+2	52	49

Instrumentation

Bendix Model 8002 Ozone Analyzer

ZERO/SPAN RECORDS

KLUVER WEST OZONE

<u>Date</u>	<u>Zero</u>	<u>Calculated Span</u>	<u>Observed Span</u>
3/15/78	Calibrated Analyzer		
3/16/78	0 ppb	117 ppb	122 ppb
3/21/78	0	117	114
3/22/78	0	117	118
3/24/78	0	117	116
3/27/78	0	117	111
3/28/78	0	117	114
4/4/78	0	117	114
4/5/78	0	149	149
4/7/78	0	117	114
4/10/78	0	117	116
4/11/78	0	117	114
4/14/78	0	117	116
4/18/78	0	117	112
4/21/78	0	117	110
4/24/78	0	117	116
4/26/78	0	117	112
5/8/78	0	117	115
5/10/78	0	117	113
5/24/78	0	117	111
5/26/78	0	117	116
5/29/78	0	117	116
5/31/78	0	117	116
6/2/78	0	117	114
6/5/78	0	117	118
6/9/78	0	117	113
6/15/78	0	117	114
6/21/78	0	117	116
6/27/78	0	117	114
6/29/78	0	117	113
7/6/78	0	117	114
	Site down		
12/10/78	0	198	186
1/19/79	Calibrated Analyzer		
1/25/79	0	51	54

Instrumentation

Bendix Model 8002 Ozone Analyzer

ZERO/SPAN RECORDS

KLUVER WEST SULFUR GAS

<u>Date</u>	<u>Zero</u>	<u>Calculated Span</u>	<u>Observed Span</u>
3/16/78	Calibrated Analyzer		
3/22/78	Recalibrated Analyzer		
4/5/78	Recalibrated Analyzer		
5/24/78	0 ppb	70 ppb	70 ppb
6/5/78	0	29	29
6/9/78	-1	31	30
6/16/78	+3	28	26
6/21/78	0	27	25
6/29/78	0	33	33
7/6/78	0	34	39
7/6/78	Recalibrated Analyzer		
	Site down		
12/7/78	Calibrated Analyzer		
1/19/70	0	77	69
1/25/79	-1	77	71

Instrumentation

Meloy SA 285 Sulfur Analyzer

ZERO/SPAN RECORDS

KLUVER NORTH SULFUR GAS

<u>Date</u>	<u>Zero</u>	<u>Calculated Span</u>	<u>Observed Span</u>
8/10/78	Calibrated Analyzer		
9/4/78	Recalibrated Analyzer		
10/30/78	Recalibrated Analyzer		
11/6/78	-1 ppb	48 ppb	44 ppb
11/14/78	+2	84	78
11/20/78	+6	84	77
12/1/78	+1	58	53
12/8/78	+2	57	52
1/6/78	-3	62	54
1/6/78	Recalibrated Analyzer		
1/12/78	+1	62	59
1/19/78	-2	73	69
1/27/79	0	62	58
2/6/79	0	62	60

Instrumentation

Meloy SA 285 Sulfur Analyzer

ZERO/SPAN RECORDS

KLUVER NORTH OZONE

<u>Date</u>	<u>Zero</u>	<u>Calculated Span</u>	<u>Observed Span</u>
7/17/78	Calibrated Analyzer		
7/18/78	0 ppb	170 ppb	171 ppb
7/19/78	0	170	176
7/23/78	0	170	172
7/24/78	0	170	171
7/26/78	0	170	173
7/28/78	0	170	173
8/2/78	0	170	173
8/4/78	0	170	178
8/10/78	Recalibrated Analyzer		
8/15/78	0	159	159
8/31/78	0	159	150
10/30/78	Recalibrated Analyzer		
11/6/78	+1	280	275
11/14/78	0	280	265
11/29/78	0	280	274
12/1/78	0	280	269
12/8/78	0	280	260
12/8/78	Recalibrated Analyzer		
1/2/79	0	300	306
1/6/79	+1	300	302
1/6/79	Recalibrated Analyzer		
1/12/79	+1	230	233
1/19/79	0	230	238
1/27/79	0	230	236
2/6/79	0	230	235

Instrumentation

Bendix Model 8002 Ozone Analyzer

ZERO/SPAN RECORDS

GREENLEAF OZONE

<u>Date</u>	<u>Zero</u>	<u>Calculated Span</u>	<u>Observed Span</u>
9/20/78	Calibrated Analyzer		
9/26/78	0 ppb	188 ppb	184 ppb
10/7/78	0	188	185
10/11/78	+1	188	177
10/16/78	0	188	178

Instrumentation

Bendix Model 8002 Ozone Analyzer

ZERO/SPAN RECORDS

GREENLEAF SULFUR GAS

<u>Date</u>	<u>Zero</u>	<u>Calculated Span</u>	<u>Observed Span</u>
9/20/78	Calibrated Analyzer		
9/28/78	+2 ppb	31 ppb	30 ppb
10/7/78	0	32	33
10/9/78	Calibrated New Analyzer		
10/11/78	0	45	44

Instrumentation

9/20/78-10/9/78	Meloy SA 160	EPA S/N 111601
10/9/78-end of measuring	Meloy SA 285	S/N FL154

November 13, 1978

EMSC8303.173QAR

QUALITY ASSURANCE AUDIT REPORT

EPA COLSTRIP

October 20-21, 1978

Special Report to:

Environmental Protection Agency
Environmental Monitoring and Support Laboratory
Research Triangle Park, North Carolina 27711

Contract No. 68-02-2412

Project Officer: Steven M. Bromberg

Prepared By:

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Rockwell International

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QUALITY ASSURANCE AUDIT REPORT - COLSTRIP EPA STATION
COLSTRIP, MONTANA

SUMMARY

This report describes the results obtained during the October 1978 audit of the analyzers in the Hae Koolie^(b) and B&W 1 sites operated by Battelle Corporation for the EPA and located in Colstrip, Montana. Results are presented by comparing concentration C_1 , delivered by the audit device, with concentration C_2 predicted from the latest station calibration. The relationship is given by the equation $C_2 = \beta C_1 + \alpha$, where β and α are the linear constants. Values of β and α for the current audit are shown in the body of this report. Values for β for the audits to date are listed below.

Site B&W 1 in this audit report is the same station as the one described in the last audit report as the State of Montana trailer with EPA equipment.

Colstrip EPA Site (Hae Koolie)

Channel	9-21-77	1-26-78	4-17-78	7-31-78	10-20-78	2-1-79 ^(d)
SO ₂	0.867 ^(c)	0.493 ^(c)	0.889	1.216	0.914	0.922
O ₃	1.000	0.950	0.947	1.111	1.018	0.906
NO/NO _x	no analyzer currently in use	analyzer inoperable	analyzer inoperable	analyzer removed prior to audit	analyzer not in use	
Hi Vol	+21.7	(a)	(a)	(a)	(a)	

B&W 1 Site

SO ₂	---	---	---	1.172	1.065
O ₃	---	---	---	1.107	1.033

(a) Operation discontinued

(b) Correct spelling is Hay Coulee

(c) CO₂ interference present during audit; see Appendix B.

(d) Information from later audit not included in the October 20, 1978 report.

INTRODUCTION

This report describes the results of the field audits of the two Colstrip sites operated by Battelle Northwest for the EPA. The audit was performed by A. E. Jackson with Dave Weber and Khris Olsen, both Battelle personnel, present for the audits.

METHODS

Rockwell - A detailed description of the apparatus, standard procedures, definitions and evaluation criteria is given in Appendices A, B, and C.

Standard pollutant sources used during this audit were as follows:

for SO_2 - an NBS-SRM Permeation tube #39-36
certified by NBS to give 0.749 $\mu\text{g}/\text{min}$
at 30.00°C.

for NO - an Airco cylinder #FF2787 certified by
Rockwell to contain 104.1 ppm NO in N_2 .

Colstrip EPA - The station calibrations for both sites are accomplished by using a Monitor Labs 8500 Portable Calibrator, equipped with an ozone source. This is used in conjunction with a zero air supply and, for SO_2 calibrations, an NBS-SRM 2cm SO_2 permeation tube. Until this audit both the ozone source and the SO_2 tube were previously crosschecked at Corvallis, Oregon against wet chemical methods. This was done at regular intervals but has been recently discontinued in favor of in situ calibration of the ozone source by the gas phase titration technique and the substitution of an NBS-SRM SO_2 tube for the Monitor Labs device. The latest checks were made as listed in the body of this report by Khris Olsen and Dave Weber.

RESULTS

Results of the audit are presented by plotting concentration C_2 predicted by the latest state calibration against concentration C_1 delivered by the audit device. The relationship is described by the equation $C_2 = \beta C_1 + \alpha$, where β

is the slope and α is the intercept. Figures 1-4 show graphs for each of the channels audited and Table I shows the values of β and α . Also shown in Table I are the percent differences at full scale. These are calculated using the equation:

$$\% \text{ Diff} = 100 \left[(\beta - 1) + \frac{\alpha}{x} \right]$$

where x is the maximum of the instrument operating range in ppm.

Table II presents the results in another manner. For each audit concentration C_1 the percent difference (d_i) between it and the indicated station ppm output C_2 is calculated. These d_i 's are then averaged over all audit data points for a given channel, and the resultant value ($\bar{d}_j$) is used as a measure of station accuracy. The standard deviation S_j is also presented to allow calculation of the 95% upper and lower confidence levels of the data. Table III lists the average of averages and pooled standard deviation for this agency system. Appendices A, B, and C describe the data treatment in more detail.

The stations each contained the following instrumentation at the time of the audit:

<u>Channel</u>	<u>Analyzer</u>	<u>Operating Range (ppm)</u>	<u>Last Calibration</u>	<u>Method</u>
O ₃	Monitor Labs Model 8410	0.0-0.2		Known source. Gas Phase Titration
SO ₂	Meloy Model 285	0.0-0.1	10/20-21/73	NBS-SRM 2 cm perm tube

SO₂ Audits

Both audits resulted in β 's which lie within the established 10% working criteria. For the Hae Koolie Site the β was 0.914, while that for the B&W 1 Site was 1.065. At Hae Koolie Site, when the upscale audit point was introduced a large difference was found between the Rockwell and Station values. Since the station equipment was available, a one-point span check was run and gave a result which accounted for a good portion of the problem. The

β 's listed above reflect the fact that all data were corrected for this suspected analyzer drift.

Ozone Audits

The audit of the ozone instrument at the Hae Koolie site was run by gas phase titration making use of a TECO NO-NO_x analyzer present at that site. The audit of the B&W 1 site was performed by using reverse gas phase titration. Both yielded β values implying close agreement between the Rockwell and station ppm values. No problems were encountered at either site with analyzer linearity.

Special Discussion

Station personnel requested an on-the-spot crosscheck of the vendor's ppm value supplied with the NO cylinder currently used for gas phase titrations. This was accomplished by first calibrating the NO channel of the NO-NO_x analyzer at the Hae Koolie site using Rockwell's NBS-traceable standard cylinder and obtaining a ppm versus output voltage curve. The station cylinder was then plumbed through the portable audit device flow controller in exactly the same manner and concentration determinations made at four flow points. Rockwell found a value of 12.78 with a standard deviation of ± 0.05 , while the Linde certified value given as 10.00 ppm. The Rockwell determined value will be used by station personnel for subsequent calibrations.

TABLE I
AUDIT CONSTANTS FOR ANALYZERS

<u>Station/Site</u>	<u>Analyzer Channel</u>	<u>Operating Range (ppm)</u>	<u>Slope[*]</u> β	<u>Intercept[*]</u> α	<u>% Difference^{**} at full scale</u>
Hae Koolie	O ₃	0-0.2	1.018	0.005	4.3
	SO ₂	0-0.1	0.914	0.003	-5.6
B&W 1	O ₃	0-0.2	1.033	0.000	3.3
	SO ₂	0-0.1	1.065	0.001	7.5

* $C_2 = C_1 \beta + \alpha$, where C_2 = station ppm, C_1 = audit ppm, β is the slope and α is the intercept.

** % Diff = $100 \left[(\beta - 1) + \frac{\alpha}{x} \right]$ where x is the maximum value of the operating range of the instrument.

TABLE II
AUDIT AVERAGE % DIFFERENCES OF DATA POINTS
FOR EACH CHANNEL IN EACH STATION

<u>Station</u>	<u>Channel</u>	<u>Operating Range (ppm)</u>	<u>$\bar{d}_j^*$</u>	<u>S_j^*</u>	<u>UL[*]</u>	<u>LL[*]</u>
Hae Koolie	O ₃	0-0.2	11.1	9.2	29.1	-6.9
	SO ₂	0-0.1	-2.2	4.1	5.8	-10.2
B&W 1	O ₃	0-0.2	3.9	2.0	7.8	0.0
	SO ₂	0-0.1	7.3	1.2	9.7	4.9

* $\bar{d}_j$, S_j , UL and LL are fully explained in Appendix C.

TABLE III

AVERAGE OF AVERAGES - POOLED STANDARD DEVIATION

<u>Channel/Species</u>	<u>$\bar{D}^*$</u>	<u>S_a^*</u>
O_3	7.5	6.6
SO_2	4.8	3.0

* Calculation of $\bar{D}$ and S_a are explained fully in the Appendix.

Figures 1 and 2 - Graphs for Hae Koolie Site

Figures 3 and 4 - Graphs for B&W 1 Site

APPENDIX A

A description of the apparatus, calibration standards, audit procedures and evaluation criteria is presented in this appendix.

APPARATUS AND CALIBRATION STANDARDS

The Rockwell portable audit device is used in the audits of all continuous monitors. The audit device was designed and built at the Rockwell Air Monitoring Center. The audit device is capable of generating and delivering mixtures of various gaseous pollutants in air at precisely known concentrations. Mixtures are produced in one of four ways:

1. By dilution of gases contained in cylinders at high concentrations (e.g., NO, CO, CH₄).
2. By gas phase titration (e.g. NO₂).
3. By dilution of ozone produced by an ozone generator.
4. By dilution of gases diffusing from permeation devices (e.g., SO₂).

The audit device contains two Tylan mass flow controllers to control and measure the flow of dilution air and span gas from the high concentration cylinder. The span gas flow controller has a range of 0-50 cc/min. The dilution air flow controller has a range of 0-15000 cc/min. Each of these flow controllers is calibrated before and after each trip. Flows are reproducible and accurate to $\pm 1\%$. Thus, dilutions by factors of $15000/5 = 3000$ to $1500/50 = 30$ with an accuracy of $\pm 2\%$ can be readily made by dialing the desired flow. Since flow controllers measure mass flow, the flow calibration is given in standard cc/min and it is independent of ambient temperature and pressure.

The audit device has an air oven to maintain the temperature at $30.0 \pm 0.1^{\circ}\text{C}$. A mercury-in-glass thermometer, graduated in 0.01°C divisions and calibrated against an NBS certified thermometer, is used to read the temperature. The oven contains an ozone generating system and two separate Teflon permeation tube holders. The ozone is generated by means of a variable, current-controlled mercury lamp inserted in a Teflon block. Air flows through copper coils immersed in the air oven and reaches temperature equilibrium before entering the ozonizer block and the permeation tube holders. The air flow through these devices is approximately 50 cc/min, very much smaller than the dilution air flow, and hence it is controlled and measured with sufficient accuracy using needle valves and rotometers. All materials exposed to ozone or SO_2 are either Teflon or glass. Span gases passing through the flow controller are in contact with stainless steel, Teflon and glass. Diluted gases are in contact with only Teflon or glass.

A. Zero Air

Zero air is generated from ambient air by means of a Rockwell-built, portable, zero air source. Ambient air from a compressor is dried, ozonized, and passed through activated charcoal and a particulate filter. The air can also be passed through a catalytic oxidizer. Thus the zero air source delivers air which is essentially free of NO , NO_2 , O_3 , SO_2 , CO and hydrocarbons at a flow and pressure which meet the specifications of the dilution air flow controller used in the portable audit device. The quality of the zero air has been tested at the Rockwell QA laboratory, and has been found to meet the standards required of field audits.

B. Nitric Oxide (NO)

The NO standards are cylinders containing approximately 100 ppm NO in nitrogen. The cylinders are analyzed at the AMC by direct one-to-one comparison with a Standard Reference Material (SRM) cylinder obtained from the National Bureau of Standards (NBS) and containing approximately the same

concentration of NO. The analysis is done using a dilution system and a NO-NO_x analyzer. Identical dilution flows are used to eliminate flow measurement errors. The NO cylinders are also analyzed for NO₂ by the Saltzman method to insure that the NO₂ content is less than 0.5% of the NO content.

C. Nitrogen Dioxide (NO₂) and Ozone (O₃)

NO₂ is generated in the gas phase titration of NO with ozone. The concentration of NO₂ is determined with a previously calibrated NO analyzer (using the NO standard) by measuring the decrease in NO concentration as ozone is added to the NO flow. This procedure, in effect, calibrates the ozone lamp in the audit device at the ambient conditions in the site. The NO flow is then turned off, and the calibrated ozone lamp is used to audit the O₃ analyzer calibration. Except for special circumstances described separately, the ozone lamp is calibrated each time an audit is performed.

The conversion efficiency of the NO₂ converter in the NO-NO_x analyzer is audited during the gas phase titration procedure. The conversion efficiency (CE) is calculated by means of the equation:

$$CE = 100 \times \left[1 - \left(\frac{\Delta C_{NO_x}}{\Delta C_{NO}} \right) \right]$$

where ΔC_{NO} and ΔC_{NO_x} are the changes (decreases) in concentrations of NO and NO_x which are observed during the titration. In calculating ΔC_{NO} and ΔC_{NO_x} due allowance is made for the dilution effect of the added ozone stream. If there is no change in the NO_x concentration, then the CE is 100%. If the CE is below 90%, the converter is probably in need of repair.

D. Carbon Monoxide (CO)

The CO standards are cylinders containing 1000-2500 ppm CO in nitrogen. Cylinders are analyzed at the AMC by direct one-to-one comparison with an SRM cylinder obtained from NBS and containing approximately the same concentration of CO. The analysis is similar to that described for NO, except that a CO analyzer (Bendix NDIR) is used for the comparison.

E. Hydrocarbons

The hydrocarbon standards are cylinders containing approximately 1000 ppm CH₄ in air. Cylinders are analyzed at the AMC by direct comparison with a cylinder containing approximately the same concentration of CH₄. The latter cylinder was analyzed for CH₄ by NBS. The analysis is done using an FID gas chromatograph and measuring peak areas. Gas samples are injected undiluted by means of a gas sampling valve.

F. Sulfur Dioxide (SO₂)

The SO₂ standards are permeation tube devices. Normally SO₂ permeation tubes are 2 or 5 cm SRM tubes obtained from NBS. During the audit tubes are maintained at $30.0 \pm 0.1^\circ\text{C}$ in the calibrator oven. The permeation rate is given by NBS. Occasionally when auditing an analyzer which is operated in a high SO₂ range (greater than 1 ppm), longer permeation tubes obtained from Metronics Corporation are used. These latter tubes are calibrated at the AMC by comparison with an SRM tube using an SO₂ analyzer.

Laboratory Check of the Portable Audit Device

The portable audit device is checked at the AMC prior to and at the conclusion of each trip. The test includes a multipoint flow calibration check of the two flow controllers to assure that the calibration charts (standard flow vs. voltage) have not changed by more than 1%. A full performance test is then performed as follows. An analyzer is first calibrated at a single point to determine its sensitivity (in ppm/volt). For this purpose a fixed laboratory calibrator is used. The analyzer is

then calibrated again in an independent fashion using the portable audit device. The analyzer sensitivity obtained with the portable audit device is compared to that obtained with the fixed calibrator. Ideally, the ratio should be 1.00. Sensitivity checks are made for NO, NO₂, O₃ and SO₂. In this way all functional components of the audit device are checked. Since the object of the check is to evaluate the performance of the audit device, the same NO gas cylinder and SO₂ permeation tubes are used with the fixed calibrator and with the portable audit device.

The fixed laboratory calibrator is intended to be the primary calibration source. It is functionally similar to the portable audit device, except that it is permanently attached to a laboratory bench and its major use is for checking the portable device. Since the laboratory calibrator is not designed for field use, several changes were made to optimize reliability and accuracy. Thus the mixing chambers and connecting tubing are constructed of Pyrex glass using a minimum of demountable joints, and Pyrex and Teflon manual stopcocks are used in place of electrical solenoid valves. To attain more precise temperature control, permeation tube holders are immersed in a constant temperature water bath rather than in an air oven.

Since two independently calibrated flow controllers are involved in each device, the maximum expected discrepancy between the two sensitivity determinations is 4%. The portable audit device is judged to be in good order if the ratio of sensitivities determined by using the two devices (i.e., the portable audit device and the fixed calibrator) is between 0.96 and 1.04. Usually the observed ratio of sensitivities is between 0.98 and 1.02. A faulty solenoid valve, a leak in the system, contamination in the lines, a bad flowmeter calibration, or any other conceivable failure mode would be expected to cause the experimentally determined sensitivity ratio to deviate significantly from 1.00, and corrective action would then be necessary.

Table 1A shows the latest available audit device operational checks performed immediately before and after this audit. Sensitivities are given in ppm/volt. Because the laboratory analyzers are used for laboratory testing and not for monitoring purposes, they are not maintained in calibration. Occasionally different analyzers are used in the before and after test. Thus one should compare the constancy in the ratio of sensitivities before and after the audit rather than the constancy in the sensitivities themselves.

AUDIT PROCEDURE

The audit procedure consists of delivering to each analyzer five different concentrations, including zero, using the portable audit device. The output of the analyzer is read out with the measuring instrument which is normally in use at the station. The read-out device is either a strip chart recorder, a data logger, a mini-computer, or a digital voltmeter, and the output parameter is either the number of strip chart divisions, percent deflection, digital voltage, or ppm concentration. The result of the audit is in effect a 5-point calibration which is compared with the latest station calibration by one or more methods, as described below. When differences are unusually large, an attempt is made to locate the source of the problem.

Data Analysis

There are at least two ways in which audit results and station calibration data can be treated to obtain a useful measure of agreement between the two. Most agencies record their calibration data as a table or a graph which relates the input concentration to some arbitrary output parameter (mv, volts, % chart, chart divisions, etc.). The relationship is described by an equation of the form $C = A + BX$, where C is the concentration in ppm, X is the analyzer output parameter, and A and B are constants obtained by linear regression analysis. The equation is subsequently used to calculate ambient concentrations from measured outputs.

TABLE 1A

CALIBRATOR OPERATIONAL CHECK*

(Sensitivity in ppm/volt)

Channel	Fixed F	10-2-78 (before audit)		Fixed F	(after audit)	
		Portable P	Ratio P/F		Portable P	Ratio P/F
NO	0.566	0.581	1.027	0.515	0.503	0.977
NO ₂	0.385	0.382	0.992	0.526	0.515	0.979
O ₃	0.472	0.492	1.042	0.548	0.544	0.993
SO ₂	0.932	0.907	0.973			

* Audit device No. 1, colloquially known as Bessie.

The audit data is described by an equation similar to that developed for the station calibration. The most direct comparison between the two sets of data is to show graphically the two straight lines on the same C vs X graph. Differences between the station calibration and audit results are evaluated by comparing linear regression constants directly or, more conveniently, by calculating percent difference in C at full scale, as shown in equation A-1.

$$\% \text{ Difference} = 100 \times \frac{(\text{Station ppm at full scale}) - (\text{Audit ppm at full scale})}{(\text{Audit ppm at full scale})} \quad (\text{A-1})$$

The comparison procedures outlined above have in fact been used for most of the audits conducted since the beginning of the program until June, 1978. These procedures have the advantage that both calibration and audit data are fully displayed, and any deficiencies regarding calibration range, number of calibration points, instrumental sensitivity, precision, or non-linear response become readily apparent. The major disadvantage of the method is that comparison of calibration constants among different instruments and agencies is difficult because the magnitude of B depends on the units of the output parameter.

In order to achieve uniformity in the way audit results are reported, a second method has been adopted for audits conducted after June, 1978. The method is to compare the concentrations delivered to the analyzer from the audit device to those predicted by the station calibration equation. In a few agencies a station computer displays concentration directly rather than the analyzer output voltage, and for these agencies the second method of data analysis has been used previously. The audit report shows a graph of station concentration (y-axis) versus audit concentration (x-axis) as well as a table of the slope and intercept of the graph for each channel tested. Mathematically the results are expressed by equation A-2

$$C_2 = \alpha + \beta C_1, \quad (\text{A-2})$$

where C_2 is the station concentration, C_1 is the audit concentration, β is the slope, and α is the intercept. Perfect agreement between station and audit is represented in each graph by the dotted "unity line" $\beta = 1$, $\alpha = 0$.

The advantage of the second method is that β is non-dimensional, and its value is independent of the analyzer range and the units used to express analyzer output. The magnitude of β is a useful measure of relative agreement between the station calibration and the audit results, as discussed below. Also the results of different audits can be readily compared. Of course, details of the station calibration are not shown.

The percent difference between station and audit concentrations can be readily expressed in terms of the magnitude of α and β , as shown in equation A-3

$$\% \text{ Difference} = 100 \times \frac{C_2 - C_1}{C_1} = 100 \left[(\beta - 1) + \frac{\alpha}{C_1} \right] \quad (\text{A-3})$$

Since normally the magnitude of $\frac{\alpha}{C_1}$ is small compared to $\beta - 1$, the percent difference is a constant represented by the quantity $100 (\beta - 1)$. It is this latter relationship that makes β a useful comparison parameter.

There are two cases where the percent difference is not determined primarily by the value of β , and these are, of course, cases where the intercept α is large, or the audit concentration C_1 is very small. For these two cases the percent difference is not a constant, and its value depends on C_1 . In order to give a complete picture of the agency performance, audit reports show values of α and β for the latest audit. A summary page is also included listing the current and all previous values of β .

The two methods described in this appendix appear to give different measures of comparison between station calibrations and audit results. Appendix B demonstrates that the two methods are in fact equivalent.

Field Audit of High Volume Samplers

The high volume sampler flow rate is measured using a calibrated orifice plate (Sierra Instruments) and a water manometer. The ambient temperature and pressure at the time of the audit are also measured by Rockwell using a calibrated thermometer and pressure transducer. Unlike the hi-vol interlaboratory performance survey audits, a field audit is a single point check of

the flow rate in use at the site. At the same time that Rockwell measures the pressure drop across the orifice, the agency determines the flow according to its normal operating procedures. Since there is no uniformity among agencies in the way high volume flow is reported, the comparison between the audit measurement and the station calibration is made at the flow conditions specified by the agency or at EPA standard conditions. Typically flow rates are reported at one of the following conditions: a) EPA standard conditions (298°K, 760 mm Hg), (b) ambient temperature and pressure at the time of the measurement, (c) ambient laboratory conditions at the time of the original sensor calibration, or (d) unspecified (this occurs, for example, if the agency uses a fixed chart to convert from sensor reading to flow rate without any corrections for temperature or pressure).

The mathematics used to calculate Rockwell's audit flow at the desired flow conditions is outlined below.

The flow rate through the orifice plate is initially calibrated in the Rockwell laboratory using a 5M 125 CTR HI-VOL calibration meter (Roots-Meter). The flow rate is given by the equation $Q_1 = A + B \sqrt{\Delta P}$, where Q_1 is the ambient flow in cubic meters per minute (CMM) calculated at the Rockwell laboratory conditions during calibration, ΔP is the pressure drop at the orifice plate in inches of water, and A and B are empirically determined linear regression coefficients. The conversion of laboratory conditions to actual field conditions during the audit is obtained by means of the equation

$$Q_2 = Q_1 \left(\frac{P_1}{P_2} \times \frac{T_2}{T_1} \right)^{1/2}, \text{ where}$$

Q_2 = ambient flow rate calculated at field conditions

P_2 = ambient pressure in the field during audit (mm of Hg)

T_2 = ambient temperature in the field during audit (°K)

P_1 = pressure in the Rockwell laboratory during calibration of orifice (mm Hg)

T_1 = temperature in the Rockwell laboratory during calibration of orifice (°K)

To convert Q_2 to standard conditions, the following equation is used

$$Q_{STD} = Q_2 \times \frac{P_2}{760} \times \frac{298}{T_2}$$

To convert Q_2 to any other specified temperature T_c and pressure P_c , the following equation is used

$$Q_c = Q_2 \times \frac{P_2}{P_c} \times \frac{T_c}{T_2}$$

EVALUATION CRITERIA

Each instrument audit results in a comparison between the station calibration and the audit results. Normally the analyzer response is linear. In some cases, where single point checks are made (e.g., high volume sampler), the response is assumed to be linear. Usually, but not always, the difference in the zero concentration output measured during station calibration and during the audit is negligibly small, and differences between the station calibration and audit results cause the graph of C_2 vs C_1 to have a slope different from one. In these cases, the value of $100(\beta-1)$ gives the percent difference between the station and audit concentrations for all values of C . If deviations from linearity or zero differences are observed, they are specifically mentioned in the text.

Criteria for evaluating differences between station and audit concentrations are not rigidly defined and obviously have not been established. The definition for what constitutes satisfactory or unsatisfactory agreement is necessarily arbitrary and depends on the intended use of the data.

For the purposes of these audits, we offer the following working guideline, subject to revision or refinement:

Differences of 10% or less require no specific corrective action, and may be considered satisfactory.

Differences in excess of 10% are of immediate concern. In such cases, Rockwell will make a specific attempt to locate the source of the problem, and if this is not practical, likely sources of error will be identified and recommendations will be made to the agencies for further study. (A typical recommendation of this type is to request the agency to recalibrate (or calibrate for the first time) the station calibrator.)

APPENDIX B

Appendix A describes two methods for reporting audit results. This appendix shows how the A and B parameters in the first method are related to the α and β parameters of the second method.

In the first method concentration and analyzer output are described by equations B-1 and B-2

$$C_1 = A_1 + B_1 X, \quad (B-1)$$

and
$$C_2 = A_2 + B_2 X. \quad (B-2)$$

In these equations the subscript 1 refers to the audit results, and the subscript 2 refers to the station calibration. For a given analyzer output X the relationship between C_1 and C_2 is obtained by eliminating X from the two equations. The result is given by equation B-3

$$C_2 = \frac{B_2}{B_1} C_1 + \left(A_2 - \frac{B_2}{B_1} A_1 \right) \quad (B-3)$$

Comparing equation B-3 with equation A-2 it can be clearly seen that

$$\beta = \frac{B_2}{B_1} \quad (B-4)$$

$$\alpha = A_2 - \frac{B_2}{B_1} A_1 \quad (B-5)$$

Equations B-4 and B-5 show that α and β are readily derived from values of A and B.

It is interesting to compare percent difference at full scale (equation A-1) with the percent difference as expressed by equation A-3. Re-writing equation A-1 in terms of the A and B constants results in equation B-6

$$\% \text{ Diff} = 100X \frac{(B_2 - B_1) X + (A_2 - A_1)}{B_1 X + A_1} \quad (\text{B-6})$$

Equation B-6 shows that percent difference is a function of X and hence X is normally specified at full scale. Since usually the A term is small compared to BX, for sufficiently large X the percent difference becomes independent of X and reduces to the constant expression

$$\% \text{ Diff} \cong 100 X \frac{B_2 - B_1}{B_1} = 100 (B-1)$$

Thus within the approximation that intercepts are small, the percent difference at full scale and the quantity $100 (B-1)$ give similar results.

APPENDIX C

This appendix describes a third way in which audit results may be used to assess the accuracy of the monitoring data. The method involves the calculation of the average percent difference between C_1 and C_2 . The procedure is fully described in the EPA quality assurance requirements guideline for PSD air monitoring (Federal Register August 7, 1978 Part II) and is as follows:

Let X_i represent the known concentration C_1 in the audit gas for i^{th} audit point, and Y_i represent the concentration C_2 measured by the station. Assume n audit points (usually 4 span points plus zero). Calculate the percentage difference (d_i) for each audit point using equation 1:

$$d_i = \frac{Y_i - X_i}{X_i} \times 100 \quad (1)$$

For each instrument or instrument channel, calculate the average percentage deviation ($\bar{d}_j$) using equation 2 and the standard deviation (S_j) by means of equation 3:

$$\bar{d}_j = \frac{\sum_{i=1}^n d_i}{n} \quad (2)$$

$$S_j = \left[\frac{\sum_{i=1}^n d_i^2 - \left(\sum_{i=1}^n d_i \right)^2 / n}{n-1} \right]^{1/2} \quad (3)$$

The 95 percent probability limits for data accuracy are then calculated from Equations 4 and 5:

$$\text{Upper 95 Percent Probability Limit: } \bar{d}_j + 1.96 S_j \quad (4)$$

$$\text{Lower 95 Percent Probability Limit: } \bar{d}_j - 1.96 S_j \quad (5)$$

The above set of calculations is used for a single analyzer or analyzer channel in any one given station. In order to arrive at a measure of overall agency accuracy for a given species, the average of averages is calculated by means of equation 6, using results of instruments within the agency for a single pollutant:

$$\bar{D} = \sum_{j=1}^k \bar{d}_j / k \quad (6)$$

where

$\bar{D}$ is the average of averages, k is the number of instruments audited for any given pollutant species.

The agency standard deviation is calculated by means of equation 3, except that n is the total number of audit points for all instruments for any given pollutant.

The 95 percent probability limits for agency accuracy are calculated using equations similar to 4 and 5, except that $\bar{D}$ and S_a are used in place of $\bar{d}_j$ and S_j .

APPENDIX B

FIELD EXPERIENCE WITH AMBIENT LEVEL
FLAME PHOTOMETRIC SULFUR DETECTORS

FIELD EXPERIENCE WITH
AMBIENT LEVEL FLAME PHOTOMETRIC SULFUR DETECTORS

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ABSTRACT

Personnel respiration produces increased levels of carbon dioxide within field monitoring trailers. These levels were found sufficient to produce serious calibration errors in the flame photometric detector when measuring ambient concentrations of gaseous sulfur products. Quantitative measurement of the carbon dioxide interference in the sulfur emission is reported as well as a method of estimating the extent of quenching agent pollution.

FIELD EXPERIENCE WITH
AMBIENT LEVEL FLAME PHOTOMETRIC SULFUR DETECTORS

D. Weber, K. B. Olsen and J. D. Ludwick

A field program is in progress in Montana conducted by the Environmental Protection Agency (EPA) to identify and quantitate the environmental impact of coal-fired power plants. To this end, a portion of the effort is devoted to air quality monitoring and sampling several miles downwind from the Colstrip power plants #1 and #2 in a rather remote area of the state. Four such stations with varying degrees of sophistication have been established in the most prevalent downwind direction of air mass flow. These are located in semi-arid rangeland with access limited, by and large, to 4-wheel drive vehicles. Each site basically consists of a small trailer which serves to provide shelter and a controlled environment for the housed instruments. Three of the sites are completely self-contained, generating and regulating their own power systems. Among other instrumentation, each site is equipped with a sulfur analyzer for continuous monitoring of the atmosphere. At the present time, they are all flame photometric devices (FRD). The present report covers experiments conducted at our major monitoring location (Hay Coulee). Here we have had experience with several manufacturers' instruments as well as various analytical monitoring techniques for atmospheric sulfur analysis.

In a major effort to upgrade the accuracy of the data being collected under sponsorship of the EPA, an independent contractor (Rockwell International) has been assigned the task of quality assurance. On a routine schedule this agent of EPA inspects and tests all equipment utilized for data collection on programs operated by or for this Federal agency. The results from these routine audits are used to suggest methods of improving accuracy and defining the limits of error for a historical batch of data. In general, this program has been very useful in upgrading the quality of the air sampling and monitoring data throughout the agency. Responsibility for operation of the Colstrip, Montana stations was assigned to the Authors during the past year. Unexplained differences in the calibration of the sulfur instrumentation have been documented between the Rockwell audits and those conducted routinely at the sites by the authors. Each group, presumably, utilized standard NBS or NBS traceable permeation tube calibration sources and other accepted dilution techniques. This paper is a report of the cause of these errors, their magnitude, conditions conducive to their occurrence as well as their elimination.

Extensive use has been made of the flame spectrometric method for the analysis of sulfur containing compounds.^(1,2) This technique gives rise to the light from the excited S_2 band in a hydrogen-rich flame. The emission is dependent to

a great degree on the nature and temperature of the flame. Precise gas metering and mixing makes high accuracy and reproducibility attainable. The effect of other gaseous substances on the molecular emission of the S_2 species has been reported^(3,4) It was found that the presence of other gaseous organic compounds in the carrier gas used to transfer sulfur compounds into the flame detector led to a decrease in response when compared with that observed in their absence. The intensity of the sulfur emission was diminished by the presence of hydrocarbons, alcohols and carbon dioxide. Selected cases were examined and it was found that the interference with the molecular emission caused by organic compounds depends on the concentration of these organic materials. The decrease in the emission for two concentrations of sulfur containing material with increasing organic concentrations in the carrier gas was found to be similar in several cases.⁽⁵⁾

At our primary monitoring site, it was noted from time to time, that unexplained differences in the position of zero would occur when utilizing the internal trailer air as the carrier gas in spite of the gas cleanup system. These differences were not constant from day to day. Small zero shift effects which may not have been observed or considered important by other workers were critical to the integrity of our monitoring data since all values measured in the clean

environment were below 50 ppb. For this reason we made it a practice to always use outside ambient air as the primary source of zero air after passing it through appropriate cleanup beds. At the time of the last audit we noted that inside air was used as the carrier gas before presenting the unknown sulfur dioxide concentrations to our instrumentation for verification. It seemed reasonable to assume that concentrations of interfering materials which were not scrubbed from the carrier gas might be causing these discrepancies. Although environmental control of temperature is maintained within the trailers for the instrumentation, no provision was made for outside air ventilation. In fact, some effort was made, in the past, to reduce such interchange due to the harsh climate. The most obvious possibility for flame interference was increased concentrations of CO_2 gas from personnel respiration. If this was found to be significant in the instrumental range of concern, one could readily envision the probable effects from extra personnel during audit days (3-4 adults).

EXPERIMENTAL

To examine and quantitate the effects of CO_2 concentration changes in the carrier gas on sulfur response, an experimental arrangement for gas mixture control was built. This consisted of a supply of pure CO_2 gas fed into a double dilution air system. The dilution air was cleansed with ascarite to remove CO_2 .

Standardized air concentrations of CO_2 could then be prepared including the range typical of normal air. This mixture was purified over silica gel and charcoal before entering an SO_2 permeation system with traceability to NBS calibration. The response to changing mixtures of SO_2 and CO_2 were measured in a standard FPD sulfur analyzer.^(a) This instrument was initially calibrated using normal outside air and a SO_2 permeation tube. In this manner, deviations in SO_2 response due to changing CO_2 concentrations could be observed and related to auditing difficulties. Four concentrations of SO_2 gas were used in the range between 20-100 ppb. At each of these concentrations, the sulfur emission intensity was observed in the presence of 4 standard carbon dioxide carrier gas mixtures and normal outside air. The ranges of these mixtures were chosen to encompass CO_2 concentrations to be anticipated by workers under similar confined situations. Another series of similar experiments were conducted with a second ambient air monitor.^(b) Both of these monitors were utilized on this project for sulfur analysis.

DISCUSSION

A composite of the results from carbon dioxide interference in the sulfur emission is shown in Figure 1. Also included for comparison is carrier air whose CO_2 concentration was that produced during a typical day with two adult workers inside the trailer. It is apparent that the slopes of these curves are essentially constant. That is, the interference with the emission is independent of the

(a) Meloy Laboratories Model SA 160 Ambient Sulfur Analyzer

(b) Meloy Laboratories Model 285E Ambient Sulfur Analyzer.

concentration of the sulfur dioxide. This is in agreement with Sugiyama et al. for other quenching agents. ⁽⁵⁾

A plot of the instrumental response to low concentrations of SO₂ in the presence of varying CO₂ levels is shown in Figure 2. Extrapolation of the instrumental output to higher concentrations of carbon dioxide illustrate the complete remission of sulfur response at about 3000 ppm. The slopes of the curves are a function of the SO₂ concentrations while the intercept is essentially independent of these low SO₂ levels. Figure 3 is a curve generated by log-log regression analysis, illustrating the empirical relationship between changing instrumental response and changing interference levels. The slope of the carbon dioxide to response curve may be expressed as a function of the SO₂ levels,

$$\frac{\Delta \ln [\text{CO}_2]}{\Delta \text{response}} = f [\text{SO}_2] \quad (1)$$

where the [CO₂] and [SO₂] are expressed in ppm and ppb respectively.

The curve suggests the variance in SO₂ may be represented as:

$$f (\text{SO}_2) = K[\text{SO}_2]^x \quad (2)$$

and, therefore, the change in instrumental output is,

$$\Delta \text{response} = \frac{\Delta \ln [\text{CO}_2]}{K[\text{SO}_2]^x} \quad (3)$$

K and x were evaluated from this curve and found to be -140.62 and -1.9643 respectively. Then,

$$\Delta \text{ response} = \frac{\ln [\text{CO}_2]_{\text{final}} - \ln [\text{CO}_2]_{\text{initial}} [\text{SO}_2]^{1.9643}}{-140.62} \quad (4)$$

The instrumental response can then be predicted from anticipated carbon dioxide level changes and observations of standard condition situations with formula (4). Using the response changes from Figure 1 for any concentration of sulfur dioxide and substituting into equation (4) we can also calculate the level of CO_2 present when the trailer contained two occupants. This was found to be 750 ppm.

Other estimates can be made of the anticipated carbon dioxide concentration within the instrumented trailer from personnel occupancy. The respiratory rate for a man in light activity is about 1200 liters/hr, with an oxygen to carbon dioxide conversion of about 4%.⁶ The net carbon dioxide input is, therefore, 48 liters CO_2 /man-hr and thus 96 liters CO_2 /2 man-hr. Our trailer volume is approximately 40,000 liters of which 13.2 liters is CO_2 under standard conditions. Assuming that sufficient time had elapsed

for CO_2 equilibrium to exist, then the value of 750 ppm measured represents the resultant input from two men occupants. This net carbon dioxide gain of 17 liters/hr is the result of the production rate (96 liters/hr), less the trailer loss rate. The rate of carbon dioxide loss is, therefore, 79 liters/hr. If we assume that complete mixing occurs between incoming air containing 330 ppm and outgoing polluted air, then some 2.7 air changes occur per hour within the trailer. Less complete mixing would allow the observed carbon dioxide concentrations with less air turnover. From this, estimates of the carbon dioxide concentrations expected from additional personnel occupancy can be made. From the rate of personnel respiration, it is apparent that without some ventilation the 8-hr exposure limit of 5000 ppm (American Institute of Industrial Hygiene) could be exceeded within the trailer during an 8-hour day.

Experimental results from testing of the second instrumental type were sufficiently different from the first to be of interest. In this case, lower interference levels were observed in the presence of CO_2 ; however, certain peculiarities were manifest. Figure 4 illustrates the change in sulfur response with varying CO_2 concentrations. Both positive and negative effects were observed in the presence of elevated CO_2 levels when compared with instruments calibrated to operate in air containing ambient CO_2 concentrations. The synergistic effect of positive sulfur response coupled with both positive and/or negative CO_2 effects served to produce an anomalous correct response in the region of about 30 ppb. Above that point, increasing concentrations of CO_2 serve to provide more quenching of the sulfur

emission. This is in agreement with the observations in our first case study. Below this point, unexpected positive instrumental responses correlating with increasing CO₂ concentrations were noted.

Obviously, analysts must be on guard concerning the possibility for carbon dioxide or other organic material buildup in their carrier air. This can result not only from personnel respiration, but from many other sources including natural abberations (swamps, biota), anthropogenic (downwind stack measurements), fire and others. It is important either to be aware of the changing interfering components present or to make measurements after calibrating in their immediate presence.

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FIGURE 1

LOW-LEVEL SULFUR EMISSION QUENCHING BY CO_2

FIGURE 2

EFFECT OF CO_2 ON FPD RESPONSE TO VARYING $[\text{SO}_2]$

FIGURE 3

RELATIONSHIP BETWEEN CHANGING CONCENTRATIONS
OF CO_2 FOR LOW-LEVEL SULFUR EMISSION

FIGURE 4

INTERFERING EFFECTS OF CO_2 ON THE SO_2 RESPONSE
OF A MELOY 285E AMBIENT SULFUR ANALYZER

CREDIT

This work was performed for the U. S.
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FIGURE 1. Low-Level Sulfur Emission Quenching by CO₂

FIGURE 2. Effect of CO_2 on FPD Response to Varying $[\text{SO}_2]$

FIGURE 3. Relationship Between Changing Concentrations of CO_2 for Low-Level Sulfur Emission

FIGURE 4. Interfering Effects of CO_2 on the SO_2 Response of a Meloy 285E Ambient Sulfur Analyzer

APPENDIX C
POWER PLANT DATA

TABLE C.1. The Relative Influence of SO₂ Powerplant Emissions at Downwind Monitoring Stations

	TONS SO ₂ INPUT*		TONS SO ₂ OUTPUT**		TOTAL OUTPUT	FRACTION OF WIND: STATION ORIENTED RELATIVE SO ₂ INFLUENCE (tons)			
	UNIT I	UNIT II	UNIT I	UNIT II		HAY COULEE	KW	KE	BNW-1
JANUARY	1700	971	287	225	512	---	---	---	---
FEBRUARY	1620	1384	170	284	454	0.146 (66)	---	---	---
MARCH	1997	1120	281	161	442	0.243 (102)	0.447 (198)	0.160 (71)	---
APRIL	1330	138	310	32	342	0.294 (101)	0.370 (127)	0.269 (92)	---
MAY	33	1872	1	223	224	0.331 (74)	0.368 (82)	0.204 (46)	---
JUNE	1073	1594	211	349	560	0.241 (135)	0.442 (248)	0.246 (138)	---
JULY	1156	1283	214	217	431	0.303 (131)	0.178 (77)	0.186 (80)	---
AUGUST	1592	1528	255	319	574	0.243 (139)	---	0.204 (117)	---
SEPTEMBER	1390	1269	205	240	445	0.198 (88)	---	0.184 (82)	0.329 (146)
OCTOBER	1584	1569	261	311	572	0.291 (166)	---	0.295 (169)	0.388 (222)
NOVEMBER	1493	1633	280	334	614	0.170 (104)	---	---	0.304 (185)
DECEMBER	1756	1947	260	281	541	0.166 (90)	---	---	0.348 (188)

*ASSUMING 95% CONVERSION OF S TO SO₂

**APPROXIMATELY 10⁴ Btu/kWh INCLUDING PLANT EFFICIENCY

TABLE C.2.A. Colstrip Unit #1 Emission Data (January 1978)

Date	SO ₂ Avg.	Inlet Peak	SO ₂ Avg.	Outlet Peak	NO _x Avg.	Outlet Peak	Opacity Avg.	CO ₂ Avg.	Gross Generations KWH	Time on Line Hr.-Min.
	ppm		#/MMBtu		#/MMBtu		%	%		
1	428	480	0.10	0.16	0.32	0.37	14	12.2	281958	24
2	447	473	0.13	0.22	0.36	0.43	13	12.5	324625	24
3	449	455	0.23	0.34	0.31	0.34	12	12.4	280292	24
4	500(a)	518(a)	0.40	0.45	0.36	0.38	12	12.2	317617	24
5	509	578	0.44	0.70	0.34	0.40	12	12.2	283542	24
6	473	503	0.40	0.51	0.32	0.38	15	12.2	270667	24
7	246(a)	285(a)	0.50	0.50	0.29	0.29	14	12.1	211310	1-41
8	255(a)	278(a)	0.36	0.47	0.31	0.33	13	11.8	214522	8-28
9	413	428	0.49	0.51	0.37	0.45	13	12.0	264375	24
10	510(a)	720(a)	0.52	0.71	0.32	0.38	12	12.0	279042	24
11	480	559	0.49	0.58	0.33	0.35	12	12.0	295875	24
12	576	589	0.46	0.55	0.31	0.35	12	12.0	284292	24
13	616	675	0.39	0.49	0.32	0.37	12	12.2	290750	24
14	527	570	0.27	0.44	0.33	0.39	12	12.2	296292	24
15	621	672	0.26	0.48	0.29	0.35	11	12.0	248750	24
16	554	675	0.31	0.43	0.32	0.38	10	12.0	285083	24
17	489	660	0.31	0.43	0.30	0.34	10	12.0	268125	24
18	470(a)	495(a)	0.22(b)	0.32(b)	0.32	0.38	14	12.0	283708	24
19	-	-	0.17	0.17	0.20	0.20	9	10.8	74797	1-4
20	349	488	0.21	0.37	0.31	0.36	11	11.5	228064	14-56
21	185(a)	210(a)	0.32	0.47	0.33	0.36	12	12.3	303958	24
22	177(a)	255(a)	0.24	0.31	0.29	0.31	12	12.4	293375	24
23	265	330	0.26	0.33	0.31	0.35	12	12.5	300500	24
24	309	469	0.25	0.42	0.32	0.39	13	12.3	279458	24
25	233	345	0.25	0.28	0.38	0.45	13	12.0	306375	24
26	290(a)	390(a)	0.11	0.21	0.35	0.41	12	11.7	263240	22-28
27	320	360	0.15	0.24	0.40	0.44	13	12.2	306750	24
28	376	488	0.18	0.30	0.37	0.43	13	12.1	284167	24
29	298	375	0.13	0.20	0.31	0.40	11	12.1	262333	24
30	365(a)	435(a)	0.16	0.30	0.38	0.45	13	12.2	272958	24
31	284(a)	390(a)	0.16	0.30	0.34	0.38	13	12.0	301083	24

(a) Data from one inlet monitor only.

(b) Data from outlet monitors.

Dashed indicate no data due to monitor malfunctions.

Coal Consumption: 126,836.4 tons

Coal Analysis: 0.70% S

Scrubber Availability: 95.7%

Total Time on Line: 672 hr., 47 min.

TABLE C.2.B. Colstrip Unit #2 Emission Data (January 1978)

Date	SO ₂ Avg. ppm	Inlet Peak	SO ₂ Avg. #/MMBtu	Outlet Peak	NO _x Avg. #/MMBtu	Outlet Peak	Opacity Avg. %	CO ₂ Avg. %	Gross Generations KWH	Time on Line Hr.-Min.
1	406	428	0.36	0.43	0.48	0.51	13	11.2	337500	24
2	387	405	0.35	0.43	0.39	0.46	14	11.8	314417	24
3	404	439	0.38	0.44	0.45	0.48	13	11.5	328250	24
4	200(a)	360(a)	0.19	0.19	0.18	0.18	10	12.5(b)	161085	3-04
5	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0
10	0	0	Unit Off Line		0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0
14	0	0	0.13	0.24	0.29	0.35	12	12.5	123929	3-58
15	207	225	0.40	0.65	0.38	0.44	11	12.5	228333	24
16	361	450	0.44	0.49	0.37	0.44	11	12.5	237293	22-59
17	414	473	0.37	0.43	0.39	0.41	12	12.5	272625	24
18	418	484	0.33	0.43	0.51	0.52	12	12.5	287667	24
19	387	503	0.35	0.52	0.40	0.44	12	12.5	277292	24
20	409	465	0.36	0.54	0.43	0.49	13	12.5	276250	24
21	412	488	0.38	0.46	0.42	0.50	14	12.5	274372	23-53
22	0	0	Unit Off Line		0	0	0	0	0	0
23	445	585	0.34	0.44	0.37	0.43	11	12.5	245291	11-41
24	415	439	0.40	0.44	0.44	0.47	13	12.5	324917	24
25	361	488	0.32	0.42	0.44	0.46	12	12.5	305708	24
26	288	353	0.30	0.36	0.45	0.48	14	12.5	314417	24
27	275	345	0.29	0.39	0.39	0.44	13	12.5	253815	24
28	290	330	0.34	0.47	0.51	0.55	16	12.5	326583	24
29	309	394	0.30	0.50	0.41	0.48	14	12.5	279708	24
30	339	390	0.34	0.45	0.42	0.48	14	12.5	318500	24
31	285(a)	300(a)	0.28	0.42	0.47	0.52	15	12.5	280792	24

(a) Data from one inlet monitor only.

(b) #/MMBtu values calculated using the design CO₂ average of 12.5% for the duration of the month.

Coal Consumption: 72,300.9 tons

Coal Analysis: 0.70% sulfur

Scrubber Availability: 97.3%

Total Time on Line: 449 hr., 35 min.

TABLE C.3.A Colstrip Unit #1 Emission Data (February 1978)

Date	SO ₂ Avg.	Inlet Peak	SO ₂ Avg.	Outlet Peak	NO _x Avg.	Outlet Peak	Opacity Avg.	CO ₂ Avg.	Gross Generations KWH	Time on Line Hr.-Min.
	ppm		#/MMBtu		#/MMBtu		%	%		
1	296	360	0.20	0.33	0.33	0.36	14	12.0	278958	24
2	286	440	0.16	0.30	0.32	0.40	14	12.0	274625	24
3	247	300	0.24	0.29	0.31	0.35	14	12.3	295875	24
4	263	270	0.17	0.27	0.32	0.42	13	12.2	290958	24
5	113	240	0.19	0.26	0.33	0.41	13	12.3	288292	24
6	418	630	0.16	0.23	0.29	0.32	13	12.3	272917	24
7	536	695	0.19	0.31	0.28	0.32	15	12.1	277042	24
8	516	690	0.19	0.21	0.30	0.32	14	12.4	303250	24
9	386	425	0.13	0.18	0.29	0.37	15	12.5	260042	24
10	392	450	0.12	0.16	0.31	0.34	14	12.2	279250	24
11	456	490	0.15	0.18	0.31	0.32	15	12.1	301417	24
12	375	510	0.13	0.18	0.31	0.35	14	12.0	277708	24
13	495	488	0.19	0.21	0.33	0.39	14	12.5	304250	24
14	495	558(a)	0.12	0.16	0.31	0.38	14	12.4	270917	24
15	347	438	0.13	0.18	0.31	0.33	15	12.5	280875	24
16	325	379	0.13	0.17	0.31	0.35	16	12.5	305417	24
17	337	382	0.12	0.15	0.26	0.28	15	12.4	277042	24
18	357	377	0.19	0.22	0.28	0.33	16	12.8	308083	24
19	365	413	0.15	0.20	0.27	0.32	15	12.4	281625	24
20	411	427	0.17	0.28	0.29	0.33	14	12.6	307958	24
21	413	456	0.22	0.36	0.29	0.31	15	12.5	275875	24
22	398	420	0.21	0.36	0.27	0.36	14	12.5	289792	24
23	434	460	0.32	0.39	0.30	0.34	15	12.4	297041	24
24	332	365	0.18	0.22	0.27	0.31	12	12.1	268125	24
25	310	351	0.14	0.18	0.29	0.31	13	12.1	282750	24
26	371	395	0.21	0.24	0.32	0.35	13	12.2	306750	24
27	283	330	0.13	0.23	0.29	0.31	11	12.0	271500	24
28	323	365	0.29	0.40	0.36	0.39	12	12.4	307792	24

(a) Data from one inlet monitor only.

Coal Consumption: 124,045.0 tons

Coal Analysis: 0.68% sulfur

Scrubber Availability: 99.5%

Total Time on Line: 672 hr.

TABLE C.3.B Colstrip Unit #2 Emission Data (February 1978)

Date	SO ₂ Avg. ppm	Inlet Peak	SO ₂ Avg. #/MMBtu	Outlet Peak	NO _x Avg. #/MMBtu	Outlet Peak	Opacity Avg. %	CO ₂ Avg. %	Gross Generations KWH	Time on Line Hr.-Min.
1	209(a)	750(a)	0.35	0.46	0.48	0.53	15	12.5(b)	304167	24
2	830	965	0.33	0.53	0.42	0.52	14	12.5	275000	24
3	906	915	0.41	0.51	0.45	0.48	14	12.5	287500	24
4	764	965	0.27	0.31	0.35	0.43	12	12.5	235125	24
5	848	1010	0.40	0.52	0.44	0.51	13	12.5	308417	24
6	752	805	0.40	0.51	0.44	0.52	14	12.5	298917	24
7	751	795	0.35	0.45	0.34	0.36	13	12.5	22917	24
8	664	705	0.31	0.49	0.37	0.45	12	12.5	218499	23-49
9	0	0	0	0	0	0	0	0	0	0
10	484	665	0.32	0.43	0.41	0.47	15	12.5	288557	20-06
11	681	825	0.34	0.46	0.46	0.51	14	12.5	295708	24
12	598	610	0.37	0.42	0.49	0.51	16	12.5	339042	24
13	613	650	0.30	0.39	0.48	0.53	17	12.5	306833	24
14	526	645	0.32	0.38	0.54	0.56	17	12.5	338417	24
15	635	657	0.25	0.33	0.49	0.53	18	12.5	297250	24
16	464	631	0.14(c)	0.24(c)	0.33	0.43	12	12.5	115561	3-55
17	566	648	0.09	0.18	0.34	0.47	17	12.5	232134	11-57
18	613	634	0.20	0.26	0.50	0.54	17	12.5	329333	24
19	610	720(a)	0.22	0.29	0.46	0.50	18	12.5	33212-	24
20	624	720(a)	0.13	0.24	0.45	0.51	17	12.5	293708	24
21	701(a)	720(a)	0.19	0.26	0.44	0.47	14	12.5	342458	24
22	697(a)	720(a)	0.28	0.31	0.48	0.53	15	12.5	348167	24
23	605	622	0.34	0.42	0.49	0.51	14	12.5	351500	24
24	571	585	0.37	0.47	0.52	0.59	15	12.5	352208	24
25	586	605	0.29	0.45	0.39	0.45	15	12.5	313958	24
26	585	595	0.47	0.53	0.52	0.59	16	12.5	353292	24
27	560	570	0.39	0.44	0.53	0.59	15	12.5	335875	24
28	645	665	0.33	0.48	0.38	0.43	16	12.5	237625	24

(a) Data from one inlet monitor only.

(b) #/MMBtu values calculated using the design CO₂ average of 12.5% for the entire month.

(c) Data from outlet monitors only.

Coal Consumption: 106,089.0 tons

Coal Analysis: 0.68% sulfur

Scrubber Availability: 94.5%

Total Time on Line: 611 hr., 47 min.

TABLE C.4.A Colstrip Unit #1 Emission Data (March 1978)

Date	SO ₂ Avg. ppm	Inlet Peak	SO ₂ Avg. #/MMBtu	Outlet Peak	NO _x Avg. #/MMBtu	Outlet Peak	Opacity Avg. %	CO ₂ Avg. %	Gross Generations KWH	Time on Line Hr.-Min.
1	306	495	0.32	0.53	0.34	0.37	13	12.3	274500	24
2	316	690	0.44	0.55	0.31	0.35	12	12.5	249000	24
3	516	555	0.52	0.66	0.34	0.37	11	12.1	253250	24
4	433	600	0.37	0.69	0.40	0.43	13	12.1	288458	24
5	361	393	0.19	0.32	0.33	0.40	12	12.1	263292	24
6	315	343	0.17	0.25	0.32	0.35	15	12.2	282792	24
7	302	379	0.20	0.36	0.30	0.32	12	12.2	253667	24
8	347	385	0.27	0.34	0.31	0.39	14	12.5	312417	24
9	370	408	0.21	0.43	0.26	0.28	13	12.4	256833	24
10	287	370	0.26	0.41	0.28	0.32	11	12.5	243917	24
11	230	326	0.34	0.40	0.30	0.32	12	12.3	238583	24
12	218	234	0.14	0.22	0.26	0.28	13	12.3	229708	24
13	198	232	0.13	0.18	0.28	0.29	14	12.3	254208	24
14	259	495	0.36	0.53	0.33	0.36	11	12.3	258292	24
15	194	425	0.25	0.37	0.34	0.41	13	12.1	240958	24
16	424	475	0.34	0.59	0.36	0.47	14	12.2	287583	24
17	341	420	0.52	0.69	0.31	0.36	13	12.2	262583	24
18	429	635	0.54	0.62	0.32	0.38	11	11.1	257466	22-58
19	402	425	0.52	0.69	0.36	0.39	12	12.1	306542	24
20	349	390	0.25	0.31	0.41	0.45	12	11.2	300542	24
21	484	667	0.29	0.59	0.37	0.48	12	11.1	266167	24
22	642	720	0.44	0.65	0.40	0.52	13	12.2	298375	24
23	372(a)	610(a)	0.19	0.51	0.35	0.41	11	12.1	279292	24
24	325(a)	570(a)	0.13	0.29	0.35	0.37	12	12.2	281042	24
25	380	443	0.19	0.24	0.36	0.38	13	12.2	308417	24
26	345	370	0.10	0.25	0.34	0.39	13	11.4	282375	24
27	297	340	0.18	0.17	0.35	0.38	13	11.1	307792	24
28	368	375	0.24	0.30	0.30	0.39	14	11.0	245792	24
29	385	468	0.26	0.50	0.34	0.41	14	11.2	277208	24
30	376	555	0.18	0.38	0.32	0.37	14	11.1	273513	23-22
31	0	0	0	0	0	0	0	0	72917	00-29

(a) Data from one inlet monitor only.

Coal Consumption: 125,310.3 tons
 Scrubber Availability: 92.0%
 Coal Analysis: 0.83% sulfur
 Total Time on Line: 718 hr. 49 min.

On March 17, 18 and 19 the SO₂ outlet data was taken from the outlet monitors.

TABLE C.4.B Colstrip Unit #2 Emission Data (March 1978)

Date	SO ₂ Avg. ppm	Inlet Peak	SO ₂ Avg. #/MMBtu	Outlet Peak	NO _x Avg. #/MMBtu	Outlet Peak	Opacity Avg. %	CO ₂ Avg. %	Gross Generations KWH	Time on Line Hr.-Min.
1	551	625	0.41	0.48	0.48	0.53	15	12.5(a)	334417	24
2	496	575	0.43	0.52	0.52	0.56	15	12.5(a)	339083	24
3	579	620	0.58	0.64	0.52	0.55	17	12.5(a)	341292	24
4	565	605	0.21	0.35	0.48	0.56	14	12.5(a)	307833	24
5	480	530	0.09	0.13	0.52	0.54	16	12.5(a)	337333	24
6	432	446	0.24	0.25	0.42	0.53	15	12.2	336375	24
7	430	468	0.22	0.26	0.37	0.45	15	10.8	334792	24
8	395	463	0.23	0.50	0.27	0.33	14	10.6	307042	24
9	494	565	0.42	0.54	0.30	0.35	15	11.3	324167	24
10	402(b)	540(b)	0.34	0.45	0.16	0.23	13	10.6	216625	24
11	386	413	0.29	0.42	0.21	0.26	12	11.3	216208	24
12	386	398	0.23	0.27	0.17	0.22	12	11.3	214750	24
13	371	400	0.19	0.23	0.12	0.12	13	11.8	218417	24
14	495(c)	560(c)	0.36	0.52	0.13	0.15	12	11.7	227917	24
15	552(c)	690(c)	0.36	0.52	0.14	0.14	12	11.5	232167	24
16	372(c)	580(c)	0.33	0.43	0.16	0.21	14	11.8	206844	18-51
17	547(c)	590(c)	0.14	0.30	0.21	0.27	11	9.5	176089	11-15
18	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0

(a) #/MMBtu values calculated using the design CO₂ average of 12.5%.

(b) Data from scrubber log sheets.

(c) Data from one inlet monitor only.

Coal Consumption: 70,210.6 tons

Scrubber Availability: 89.1%

Coal Analysis: 0.83% sulfur

Total time on line: 390 hr. 06 min.

TABLE C.5.A Colstrip Unit #1 Emission Data (April 1978)

Date	SO ₂ Avg. ppm	Inlet Peak	SO ₂ Avg. #/MMBtu	Outlet Peak	NO _x Avg. #/MMBtu	Outlet Peak	Opacity Avg. %	CO ₂ Avg. %	Gross Generations KWH	Time on Line Hr.-Min.
1	539	820	0.47	0.58	0.40	0.46	11	10.7	215659	10-55
2	730	930	0.80	0.92	0.36	0.44	13	11.5	243958	24
3	611	668	0.54	0.75	0.32	0.39	11	11.4	203083	24
4	488	590	0.53	0.68	0.35	0.38	13	11.2	235375	24
5	481	543	0.53	0.60	0.36	0.40	13	12.2	283000	24
6	536	725	0.51	0.61	0.34	0.38	13	10.8	231500	24
7	430	488	0.55	0.67	0.39	0.43	13	10.7	272500	24
8	454	710	0.34	0.51	0.35	0.43	12	10.9	247589	22-42
9	362	405	0.33	0.49	0.35	0.43	13	10.8	266771	19-05
10	358	398	0.31	0.40	0.37	0.47	14	10.7	273574	23-30
11	351	370	0.42	0.57	0.43	0.47	15	11.3	291125	24
12	555	600	0.55	0.63	0.33	0.36	9	11.6	230250	24
13	538	540	0.54	0.61	0.33	0.36	9	11.5	230458	24
14	464	590	0.45	0.62	0.28	0.32	10	11.8	233500	24
15	465	500	0.36	0.57	0.31	0.35	11	11.3	229542	24
16	469	495	0.37	0.46	0.29	0.35	10	11.4	226417	24
17	448	473	0.38	0.48	0.27	0.32	10	11.4	242167	24
18	469	490	0.35	0.46	0.29	0.32	10	11.8	240917	24
19	486	510	0.25	0.37	0.24	0.27	10	12.3	233958	24
20	479	500	0.27	0.38	0.24	0.25	10	12.5	235725	24
21	452	460	0.20	0.26	0.25	0.28	10	12.8	236875	24
22	453	475	0.20	0.24	0.25	0.28	11	13.5	239750	24
23	484	515	0.23	0.35	0.24	0.25	11	13.3	233875	24
24	478	570	0.23	0.33	0.26	0.34	11	12.8	230756	22-30
25	600	690	0.30	0.36	0.27	0.30	12	13.7	235250	24
26	628	740	0.42	0.49	0.28	0.32	13	13.0	227917	24
27	660	780	0.56	0.69	0.32	0.38	12	10.9	208375	24
28	539	570	0.42	0.53	0.39	0.40	13	8.8	173197	11-14
29	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0

Coal Consumption: 93,595.1 tons

Coal Analysis: 0.74T Sulfur

Scrubber Availability: 99.8%

Total Time on Line: 637 hr., 56 min.

TABLE C.5.B Colstrip Unit #2 Emission Data (April 1978)

Date	SO ₂ Avg.	Inlet Peak	SO ₂ Avg.	Outlet Peak	NO _x Avg.	Outlet Peak	Opacity Avg.	CO ₂ Avg.	Gross Generations KWH	Time on Line Hr.-Min.
	ppm		#/MMBtu		#/MMBtu		%	%		
1	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0
26	0	67	0.03	0.20	0.31	0.40	10	4.7	82923	14-14
27	0	0	0	0	0	0	0	0	0	0
28	151	197	0.41	0.56	0.36	0.43	11	10.2	185003	17-52
29	218	323	0.60	0.85	0.32	0.39	13	10.5	244125	24
30	183	253	0.48	0.71	0.33	0.38	12	10.8	245913	23

Coal Consumption: 9,796.7 tons
 Coal Analysis: 0.74% Sulfur
 Scrubber Availability: 86.9%
 Total Time on Line: 79 hr., 0.6 min.

TABLE C.6.A Colstrip Unit #1 Emission Data (May 1978)

Date	SO ₂ Avg. ppm	Inlet Peak	SO ₂ Avg. #/MMBtu	Outlet Peak	NO _x Avg. #/MMBtu	Outlet Peak	Opacity Avg. %	CO ₂ Avg. %	Gross Generations KWH	Time on Line Hr.-Min.
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
14										
15	Unit Off Line		Unit Off Line		Unit Off Line		Unit Off Line		Unit Off Line	
16										
17										
18										
19										
20										
21										
22										
23										
24										
25										
26										
27										
28										
29										
30										
30	-(a)	-(a)	0.30	0.30	0.34	0.40	11	7.7	72077	9-55

(a) Unit being brought on-line after completion of annual overhaul.

Coal Consumption: 2,383.9 tons

Coal Analysis: 0.71% Sulfur

Scrubber Availability: 66.0%

Total Time on Line: 9 hr., 55 min.

TABLE C.6.B Colstrip Unit #2 Emission Data (May 1978)

Date	SO ₂ Avg. ppm	Inlet Peak	SO ₂ Avg. #/MMBtu	Outlet Peak	NO _x Avg. #/MMBtu	Outlet Peak	Opacity Avg. %	CO ₂ Avg. %	Gross Generations KWH	Time on Line Hr.-Min.
1	505	565	0.50	0.60	0.40	0.46	10	10.7	250917	24
2	532	660	0.34	0.51	0.40	0.48	11	11.3	279542	24
3	495	560	0.28	0.37	0.48	0.57	14	11.2	291292	24
4	340	555	0.32	0.35	0.57	0.64	15	11.2	351458	24
5	-(a)	-(a)	0.33	0.37	0.66	0.72	16	11.4	352500	24
6	-(a)	-(a)	0.35	0.42	0.51	0.57	17	11.8	340250	24
7	-(a)	-(a)	0.17	0.31	0.48	0.60	15	10.3	214750	24
8	-(a)	-(a)	0.26	0.35	0.55	0.65	18	11.0	279000	24
9	-(a)	-(a)	0.06	0.06	0.24	0.40	13	4.8	80515	2-43
10	451	585	0.31	0.41	0.37	0.41	17	11.7	302125	24
11	411	440	0.36	0.46	0.49	0.53	16	11.6	348042	24
12	362	420	0.27	0.35	0.45	0.51	15	11.0	277080	17-40
13	394	450	0.24	0.29	0.35	0.42	16	12.1	333250	24
14	302	440	0.16	0.23	0.32	0.34	16	11.7	272083	24
15	424	460	0.15	0.30	0.32	0.50	16	11.9	264917	24
16	416	460	0.14	0.18	0.32	0.34	16	12.8	337833	24
17	422	435	0.15	0.25	0.48	0.52	16	12.1	292083	24
18	300	410	0.14	0.23	0.44	0.59	18	10.5	258889	18-54
19	242	212	0.19	0.25	0.51	0.67	17	10.7	225125	24
20	344	400	0.20	0.25	0.47	0.59	17	11.2	251333	24
21	330	380	0.12	0.22	0.45	0.59	15	10.6	203417	24
22	406	463	0.19	0.29	0.32	0.43	18	11.9	266611	21-50
23	363	413	0.15	0.30	0.38	0.45	17	12.3	294208	24
24	401	457	0.26	0.34	0.33	0.37	17	12.5	322632	23-41
25	0	0	0	0	0	0	0	0	0	0
26	261	380	0.16	0.23	0.42	0.55	16	11.3	245949	18-01
27	233	420	0.14	0.23	0.42	0.45	15	11.2	207875	24
28	160	180	0.10	0.15	0.36	0.40	16	11.5	157402	22-38
29	184	270	0.09	0.12	0.48	0.54	15	11.3	166208	24
30	476	591	0.30	0.45	0.38	0.54	15	13.5	278208	24
31	481	563	0.27	0.39	0.46	0.55	16	12.8	319958	24

(a) No data due to water damage to inlet monitors.

Coal Consumption: 237,320 tons

Coal Analysis: 0.71% Sulfur

Scrubber Availability: 99.1%

Total Time on Line: 677 hr., 27 min.

TABLE C.7.A Colstrip Unit #1 Emission Data (June 1978)

Date	SO ₂ Avg.	Inlet Peak	SO ₂ Avg.	Outlet Peak	NO _x Avg.	Outlet Peak	Opacity Avg.	CO ₂ Avg.	Gross Generations KWH	Time on Line Hr.-Min.
	ppm		#/MMBtu		#/MMBtu		%	%		
1	(a)	(a)	0.06	0.12	0.26	0.31	12	11.2	152450	17-21
2	(a)	(a)	0.15	0.31	0.33	0.36	15	10.0	165861	13-39
3	340	373	0.28	0.35	0.28	0.32	15	12.8	216395	19-02
4	345	373	0.22	0.27	0.26	0.28	16	13.8	230875	24
5	343	407	0.21	0.29	0.28	0.33	15	13.5	232875	24
6	433	447	0.24	0.43	0.30	0.34	15	14.0	256917	24
7	311	360	0.34	0.46	0.28	0.29	13	13.8	230833	24
8	528	592	0.28	0.37	0.27	0.29	13	14.4	228125	24
9	606	705	0.29	0.45	0.27	0.29	15	13.3	207197	22-22
10	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0
12	597	717	0.26	0.35	0.29	0.32	14	11.7	163454	15-29
13	684	745	0.39	0.45	0.26	0.29	15	14.2	220749	23-14
14	634	747	0.38	0.48	0.24	0.27	16	14.4	223875	24
15	460	482	0.29	0.36	0.24	0.28	13	13.2	197250	24
16	411	432	0.33	0.39	0.26	0.27	11	13.8	228417	24
17	335	425	0.30	0.40	0.26	0.27	13	12.8	205695	13-31
18	509	594	0.34	0.39	0.22	0.23	10	14.2	222292	24
19	409	515	0.34	0.37	0.23	0.29	10	14.4	228625	24
20	374	420	0.30	0.40	0.29	0.33	11	13.8	254458	24
21	331	437	0.20	0.27	0.17	0.25	11	13.9	273833	24
22	410	452	0.32	0.39	0.29	0.34	11	14.5	237792	24
23	337	372	0.17	0.22	0.34	0.34	10	14.2	275208	24
24	0	0	0	0	0	0	0	0	87500	0-05
25	314	408	0.18	0.21	0.32	0.24	7	9.8	175446	5-03
26	382	490	0.38	0.54	0.43	0.47	12	11.8	305958	24
27	329	355	0.37	0.53	0.50	0.51	12	12.4	338292	24
28	420	465	0.47	0.67(a)	0.49	0.54	13	12.9	341750	24
29	390	410	0.42	0.45	0.50	0.52	13	13.1	336708	24
30	377	405	0.37	0.46	0.46	0.52	14	12.9	333500	24

(a) No data due to recorder malfunctions.

Coal Consumption: 76,594.6 tons

Coal Analysis: 0.73% sulfur

Scrubber Availability: 76.0%.

Total Time on Line: 586 hr., 16 min.

TABLE C.7.B Colstrip Unit #2 Emission Data (June 1978)

Date	SO ₂ Avg.	Inlet Peak	SO ₂ Avg.	Outlet Peak	NO _x Avg.	Outlet Peak	Opacity Avg.	CO ₂ Avg.	Gross Generations KWH	Time on Line Hr.-Min.
	ppm		#/MMBtu		#/MMBtu		%	%		
1	438	460	0.26	0.55	0.48	0.60	15	11.5	290958	24
2	408	453	0.26	0.38	0.47	0.52	15	11.2	318542	24
3	410	437	0.23	0.33	0.51	0.60	16	11.3	290125	24
4	422	473	0.24	0.35	0.52	0.53	16	12.2	340000	24
5	407	477	0.27	0.37	0.55	0.61	16	11.3	306417	24
6	422	463	0.36	0.49	0.57	0.61	17	11.3	334208	24
7	0	0	0	0	0	0	0	0	105556	0-43
8	345	393	0.26	0.33	0.62	0.71	17	9.5	264823	18-05
9	490	553	0.46	0.61	0.59	0.67	16	10.6	314792	24
10	382	583	0.38	0.59	0.56	0.63	17	10.0	271643	20-38
11	264	447	0.39	0.62	0.59	0.64	15	9.5	208693	17-50
12	438	653	0.39	0.54	0.62	0.65	16	9.9	277004	21-50
13	404	462	0.38	0.56	0.59	0.66	14	9.7	265829	23-28
14	384	412	0.42	0.58	0.59	0.67	17	10.1	304752	23-47
15	390	570	0.41	0.52	0.52	0.62	17	10.5	286378	18-30
16	355	383	0.26	0.39	0.56	0.58	15	10.3	320375	24
17	427	462	0.52	0.60	0.60	0.62	17	10.5	334208	24
18	432	492	0.41	0.59	0.49	0.63	15	10.0	257167	24
19	452	472	0.43	0.56	0.58	0.67	17	10.4	327917	24
20	532	653	0.36	0.48	0.56	0.64	17	10.3	282083	24
21	448	535	0.28	0.40	0.54	0.63	15	10.6	295625	24
22	443	630	0.32	0.49	0.57	0.63	16	11.0	340458	24
23	413	470	0.33	0.40	0.62	0.68	16	11.0	347917	24
24	527	595	0.34	0.41	0.62	0.66	17	10.8	347833	24
25	555	598	0.40	0.51	0.65	0.67	16	10.4	345500	24
26	370	510	0.29	0.36	0.57	0.63	15	10.7	328125	24
27	337	440	0.33	0.45	0.45	0.62	15	11.1	276833	24
28	477	617	0.43	0.58	0.60	0.66	15	11.1	327390	23-13
29	249	510	0.22	0.41	0.46	0.55	17	10.5	286326	21-43
30	379	477	0.32	0.43	0.57	0.62	17	11.5	332000	24

Coal Consumption: 113,799.5 tons

Coal Analysis: 0.73% sulfur

Scrubber Availability: 97.4%

Total Time on Line: 669 hr., 47 min.

TABLE C.8.A Colstrip Unit #1 Emission Data (July 1978)

Date	SO ₂ Avg. ppm	Inlet Peak	SO ₂ Avg. #/MMBtu	Outlet Peak #/MMBtu	NO _x Avg. #/MMBtu	Outlet Peak #/MMBtu	Opacity Avg. %	CO ₂ Avg. %	Gross Generations KWH	Time on Line Hr.-Min.
1	317	370	0.25	0.30	0.43	0.46	15	12.6	321,200	22-50
2	329	410	0.31	0.47	0.44	0.49	15	12.5	306,667	23-33
3	0	0	0	0	0	0	0	0	0	0
4	290	353	0.06	0.06	0.36	0.36	15	5.2	43,077	0-39
5	305	377	0.26	0.36	0.46	0.52	16	11.3	268458	24
6	314	388	0.28	0.47	0.46	0.53	16	10.8	253018	19-03
7	274	310	0.34	0.41	0.47	0.55	15	11.9	309375	24
8	319	338	0.33	0.39	0.41	0.42	16	12.8	321333	24
9	303	337	0.31	0.34	0.51	0.55	17	12.5	343208	24
10	432	560	0.20	0.34	0.33	0.49	15	11.8	227250	24
11	389	458	0.20	0.25	0.31	0.39	15	12.3	231792	24
12	315	370	0.21	0.26	0.33	0.35	16	11.8	256583	24
13	342	377	0.18	0.24	0.37	0.44	16	11.6	265417	24
14	347	377	0.19	0.27	0.41	0.44	-	13.1	304125	24
15	375	463	0.23	0.36	0.43	0.50	18	12.5(a)	298833	24
16	519	643	0.23	0.32	0.33	0.45	18	12.5(a)	245833	24
17	418	457	0.20	0.22	0.30	0.32	14	12.5(a)	228458	24
18	568	737	0.18	0.22	0.31	0.34	14	12.5(a)	231750	24
19	466	505	0.23	0.28	0.34	0.42	14	12.5(a)	242292	24
20	416	487	0.26	0.26	0.28	0.28	13	12.5(a)	83721	0-26
21	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0
23	143	437	0.14	0.15	0.26	0.26	9	12.5(a)	155520	9-20
24	342	453	0.25	0.31	0.39	0.48	11	12.5(a)	251630	22-42
25	533	600	0.27	0.34	-	-	9	12.5(a)	291391	23
26	531	603	0.30	0.38	-	-	17	12.5(a)	278125	24
27	266	593	0.31	0.38	-	-	16	12.5(a)	283075	13-32
28	348	390	0.28	0.37	0.46	0.48	15	12.1	339875	24
29	268	335	0.39	0.44	0.47	0.50	14	11.8	344500	24
30	380	455	0.30	0.40	0.48	0.51	11	11.9	346375	24
31	235	373	0.32	0.47	0.46	0.49	12	11.9	324708	24

(a) #/MMBtu values calculated using the design CO₂ average of 12.5%.

Coal Consumption: 100,294.4 tons

Coal Analysis: 0.60% sulfur

Scrubber Availability: 95.7%

Total Time on Line: 591 hr., 05 min.

TABLE C.8.B Colstrip Unit #2 Emission Data (July 1978)

Date	SO ₂ Avg. ppm	Inlet Peak	SO ₂ Avg. %/MMBtu	Outlet Peak	NO _x Avg. #/MMBtu	Outlet Peak	Opacity Avg. %	CO ₂ Avg. %	Gross Generations KWH	Time on Line Hr.-Min.
1	0(a)	0(a)	0.15	0.21	0.43	0.55	17	11.5	252625	24
2	350	550	0.21	0.32	0.51	0.70	17	10.3	296465	22-38
3	114	273	0.31	0.45	0.34	0.37	12	10.5	214439	16-50
4	470	517	0.32	0.39	0.59	0.66	14	10.8	325625	24-00
5	515	620	0.32	0.52	0.60	0.67	15	10.7	318167	24-00
6	308	447	0.26	0.44	0.45	0.58	15	10.2	235711	23-08
7	-(a)	-(a)	0	0	0	0	0	0	0	0
8	-	-	0	0	0	0	0	0	0	0
9	-	-	0	0	0	0	0	0	22388	00-40
10	-	-	0.17	0.24	0.37	0.42	15	10.7	184833	24
11	-	-	0.18	0.20	0.42	0.52	14	10.6	222708	24
12	-	-	0.17	0.31	0.47	0.58	15	10.4	209375	24
13	-	-	0.12	0.21	0.47	0.54	15	11.0	197875	24
14	-	-	0.10	0.21	0.52	0.57	17	10.8	237750	24
15	-	-	0.06	0.09	0.53	0.57	16	10.9	252667	24
16	-	-	0.09	0.13	0.57	0.64	15	10.8	277667	24
17	-	-	0.14	0.24	0.56	0.63	15	10.4	287212	22-08
18	-	-	0.20	0.29	0.63	0.66	14	10.6	323917	24
19	-	-	0.16	0.19	0.55	0.65	15	10.4	296083	24
20	-	-	0.32	0.52	0.58	0.71	16	10.7	336417	24
21	-	-	0.20	0.30	0.52	0.61	15	10.7	290708	24
22	-	-	0.24	0.28	0.54	0.56	15	10.6	331958	24
23	-	-	0.23	0.27	0.51	0.53	15	10.7	331583	24
24	-	-	0.25	0.29	0.51	0.59	16	10.9	321292	24
25	-	-	0.23	0.27	0.55	0.59	16	10.7	309000	24
26	-	-	0.23	0.35	0.57	0.63	16	10.8	289542	24
27	-	-	0.34	0.47	0.63	0.67	17	10.9	333583	24
28	-	-	0.24	0.36	0.61	0.64	17	10.9	321833	24
29	-	-	0.53	0.57	0.61	0.65	16	10.8	330333	24
30	-	-	0.41	0.53	0.61	0.67	15	10.6	327833	24
31	-	-	0.28	0.45	0.61	0.70	14	9.7	280942	22-18

(a) No data due to monitor equipment malfunction.

Coal Consumption: 111,395.7 tons

Coal Analysis: 0.60% sulfur

Scrubber Availability: 96.4%

Total Time on Line: 659 hr., 42 min.

TABLE C.9.A Colstrip Unit #1 Emission Data (August 1978)

	SO ₂ Avg.	Inlet Peak	SO ₂ Avg.	Outlet Peak	NO _x Avg.	Outlet Peak	Opacity Avg.	CO ₂ Avg.	Gross Generations KWH	Time on Line Hr.-Min.
Date	ppm		#/MMBtu		\$/MMBtu		%	%		
1	115	115	0.26	0.33	0.45	0.52	12	11.2	298292	24
2	150	215	0.22	0.26	0.47	0.55	13	10.7	292375	24
3	281	400	0.28	0.35	0.53	0.57	13	10.8	328875	24
4	394	447	0.32	0.35	0.50	0.58	11	11.5	323000	24
5	441	527	0.31	0.37	0.55	0.57	16	12.3	337042	24
6	200	200	0.03	0.03	0.32	0.32	10	5.4	210000	00-48
7	380	435	0.27	0.35	0.41	0.49	15	12.0	295242	22-42
8	446	505	0.38	0.44	0.44	0.51	18	13.0	341375	24
9	400	458	0.30	0.38	0.44	0.49	16	12.2	305625	24
10	342	520	0.28	0.34	0.29	0.30	14	13.0	263667	24
11	468	547	0.25	0.35	0.28	0.32	14	12.7	314055	22-16
12	606	773	0.24	0.32	0.21	0.31	14	12.6	295250	24
13	528	600	0.16	0.20	0.22	0.31	13	11.6	234417	24
14	264	340	0.24	0.29	0.32	0.62	13	11.3	296542	24
15	347	460	0.27	0.29	0.66	0.66	14	11.7	347333	24
16	-	-	0.33	0.49	-	- (b)	15	11.4	311042	24
17	-	-	0.45	0.57	-	-	16	11.2	309958	24
18	-	-	0.56	0.73	-	-	17	11.7	340208	24
19	-	-	0.36	0.61	-	-	16	11.1	295250	24
20	356	417	0.14	0.28	-	-	16	10.4	232167	24
21	329	483	0.19	0.32	-	-	15	11.2	270958	24
22	369	396	0.36	0.52	-	-	16	12.4	334000	24
23	354	425	0.38	0.52	-	-	16	12.5	334917	24
24	292	317	0.12	0.24	-	-	15	11.8	285125	24
25	212	235	0.05	0.09	-	-	16	11.6	278167	24
26	170	170	0.28	0.35(c)	-	-	15	9.8	187000	24
27	148	180	0.21	0.27	-	-	15	10.5	223250	24
28	-	-	0.10	0.15	0.29	0.29	15	10.2	174172	10-16
29	-	-	0.11	0.13	0.38	0.43	15	12.5(a)	171333	24
30	398	410	0.09	0.11	0.37	0.40	13	12.5(a)	177583	24
31	346	393	0.22	0.35(c)	0.36	0.37	12	12.5(a)	173458	24

(a) #/MMBtu values calculated using the design CO₂ average of 12.5%.

(b) Across stack alignment of monitor out of calibration.

(c) SO₂ values calculate using data from Outlet SO₂ monitors.

Coal Consumption: 115,132.7 tons

Coal Analysis: 0.72% sulfur

Scrubber Availability: 96.8%

Total Time on Line: 704 hr., 02 min.

TABLE C.9.B Colstrip Unit #2 Emission Data (August 1978)

Date	SO ₂ Avg. ppm	Inlet Peak	SO ₂ Avg. #/MMBtu	Outlet Peak	NO _x Avg. #/MMBtu	Outlet Peak	Opacity Avg. %	CO ₂ Avg. %	Gross Generations KWH	Time on Line Hr.-Min.
1	-	-(b)	0.31	0.36	0.62	0.70	14	9.9	301833	24
2	503	527	0.33	0.41	0.56	0.61	15	10.6	297458	24
3	465	520	0.35	0.49	0.55	0.67	14	10.5	292625	24
4	422	490	0.34	0.38	0.61	0.62	15	10.3	297542	24
5	383	417	0.37	0.46	0.61	0.65	16	10.8	325417	24
6	332	355	0.31	0.37	0.58	0.61	17	10.8	324667	24
7	415	580	0.27	0.40	0.51	0.62	17	10.6	285583	24
8	367	428	0.30	0.38	0.58	0.67	14	10.1	302708	24
9	450	533	0.43	0.48	0.54	0.56	15	10.8	328250	24
10	512	520	0.43	0.49	0.54	0.63	15	11.1	321667	24
11	-	-(b)	0.29	0.35	0.51	0.59	15	10.5	277708	24
12	-	-	0.38	0.33	0.62	0.63	15	11.0	324458	24
13	-	-	0.34	0.38	0.61	0.66	17	10.8	321708	24
14	-	-	0.28	0.36	0.60	0.65	15	10.2	269167	24
15	459	470	0.29	0.36	0.63	0.68	15	10.9	323625	24
16	468	483	0.37	0.42	0.64	0.67	15	10.7	325259	22-10
17	-	-	0.19	0.25	0.50	0.56	10	8.3	198422	06-58
18	-	-	0	0	0	0	0	0	0	0
19	-	-(b)	0.29	0.35(c)	0.48	0.51	9	12.5(a)	184957	10-34
20	513	527	0.43	0.60	0.59	0.63	12	10.9	289507	22-18
21	-	-(b)	0.39	0.47	0.50	0.61	14	11.0	289549	23-44
22	-	-	0	0	0	0	0	0	0	0
23	-	-(b)	0.31	0.39(c)	-	-(d)	-(d)	12.5(a)	189829	14-39
24	-	-	0.29	0.37(c)	-	-(d)	-(d)	12.5	286268	17-33
25	-	-	0.21	0.30(c)	0.58	0.62	12	12.5	316583	24
26	434	443	0.40	0.46(c)	0.54	0.59	14	12.5	319542	24
27	467	517	0.33	0.41(c)	0.56	0.60	12	12.5	281667	24
28	430	447	0.41	0.49(c)	0.59	0.63	12	12.5	329333	24
29	446	463	0.30	0.39(c)	0.45	0.50	8	12.5	284333	24
30	402	410	0.28	0.35(c)	0	0	0	12.5	301625	24
31	510	553	0.27	0.33(c)	0.47	0.52	12	12.5	264167	24

(a) #/MMBtu values calculated using the design CO₂ average of 12.5%.

(b) No data due to monitor equipment malfunction.

(c) SO₂ values calculated using data from Outlet SO₂ monitors.

(d) Rewiring of monitors.

Coal Consumption: 110,542.6 tons

Coal Analysis: 0.72% sulfur

Scrubber Availability: 99.2%

Total Time on Line: 645 hr., 56 min.

TABLE C.10.A Colstrip Unit #1 Emission Data (September 1978)

Date	SO ₂ Avg. ppm	Inlet Peak	SO ₂ Avg. #/MMBtu	Outlet Peak	NO _x Avg. #/MMBtu	Outlet Peak	Opacity Avg. %	CO ₂ Avg. %	Gross Generations KWH	Time on Line Hr.-Min.
1	710	710	0.22	0.52(c)	0.43	0.56	16	12.5(b)	193708	24
2	405	457	0.35	0.46(a)	0.55	0.65	16	12.5(a)	291542	24
3	570	570	0.35	0.47(a)	0.44	0.48	16	12.5(a)	258500	24
4	552	690	0.39	0.49(a)	0.45	0.54	17	12.5(a)	291708	24
5	577	597	0.28	0.32	0.48	0.54	16	12.5(a)	320292	24
6	556	663	0.27	0.35	0.47	0.53	15	12.5(a)	291500	24
7	485	485	0.17	0.17	0.42	0.42	15	12.5(a)	232836	02-41
8	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0
10	510	510	0.03	0.03	0.33	0.33	9	6.6	36628	01-43
11	572	640	0.13	0.27	0.31	0.40	13	13.6	246750	24
12	629	773	0.32	0.44	0.40	0.46	15	13.2	343333	24
13	549	667	0.26	0.32	0.55	0.63	17	13.2	352208	24
14	470	483	0.16	0.19	0.48	0.58	14	12.1	309333	24
15	400	420	0.18	0.20	0.52	0.57	15	13.0	356458	24
16	414	423	0.14	0.18	0.49	0.56	15	13.5	338042	24
17	-	-	0.15	0.20	0.50	0.53	15	12.7	344250	24
18	467	487	0.15	0.22	0.53	0.63	15	12.6	338125	24
19	473	480	0.20	0.21	0.61	0.69	15	12.0	336667	24
20	350	380	0.22	0.24	0.55	0.57	15	11.7	337625	24
21	450	460	0.19	0.24	0.54	0.59	16	12.0	327750	24
22	403	440	0.21	0.26	0.37	0.45	16	13.7	339042	24
23	440	533	0.28	0.31	0.38	0.49	15	13.5	326542	24
24	385	517	0.16	0.20	0.42	0.45	15	12.7	294375	24
25	538	617	0.23	0.36	0.36	0.43	15	13.1	247708	24
26	433	567	0.26	0.38	0.39	0.46	15	13.7	294125	24
27	389	497	0.11	0.26	0.35	0.40	14	14.0	369668	24
28	363	477	0.17	0.24	0.37	0.39	15	14.5	339042	24
29	-	-	0.18	0.20	0.43	0.53	15	13.8	344500	24
30	-	-	0.17	0.19	0.43	0.45	15	13.3	344792	24

(a) Data from one inlet monitor only.

(b) #/MMBtu values calculated using the design CO₂ average of 12.5%.(c) SO₂ values calculated using data from Outlet SO₂ monitors.

Coal Consumption: 111,349.1 tons

Coal Analysis: 0.65% Sulfur

Scrubber Availability: 96.3%

Total Time on Line: 628 hrs. 24 min.

TABLE C.10.B Colstrip Unit #2 Emission Data (September 1978)

Date	SO ₂ Avg. ppm	Inlet Peak	SO ₂ Avg. #/MMBtu	Outlet Peak	NO _x Avg. #/MMBtu	Outlet Peak	Opacity Avg. %	CO ₂ Avg. %	Gross Generations KWH	Time on Line Hr.-Min.
1	470	530	0.27	0.35(c)	0.51	0.54	12	12.5(b)	302167	24
2	535	600	0.28	0.43(a)	0.49	0.57	13	12.5(a)	261667	24
3	442	453	0.26	0.33(a)	0.44	0.48	12	12.5(a)	277125	24
4	427	453	0.24	0.31(a)	0.52	0.55	12	12.5(a)	312958	24
5	507	577	0.27	0.32(a)	0.43	0.51	13	12.5(a)	269958	24
6	391	400	0.22	0.26(a)	0.53	0.55	17	12.5(a)	320833	24
7	390	420	0.13	0.22(a)	0.54	0.55	15	12.5(a)	321208	24
8	400	430	0.28	0.48(a)	0.53	0.54	16	12.5(a)	316458	24
9	500	510	0.32	0.59(a)	-	-	12	12.5(a)	229333	24
10	390	450	0.25	0.25	0.40	0.45	10	12.5	319917	24
11	370	380	0.28	0.34	0.44	0.55	10	12.0	330667	24
12	-	-	0.32	0.36	0.52	0.55	15	12.3	315717	24
13	520	540	0.27	0.29	0.56	0.57	15	13.1	333792	24
14	490	680	0.21	0.22	0.49	0.55	15	11.7	278375	24
15	600	750	0.25	0.30	0.40	0.53	14	13.2	249625	24
16	560	750	0.18	0.25	0.42	0.46	15	12.1	208958	24
17	650	750	0.27	0.31	0.52	0.63	14	12.9	297917	24
18	550	590	0.30	0.33	0.59	0.65	14	10.9	314375	24
19	600	630	0.20	0.21	0.30	0.35	14	11.0	221245	22-58
20	620	650	0.21	0.26	0.31	0.35	14	10.6	210714	14-17
21	550	650	0.22	0.27	0.39	0.56	14	10.9	242876	15-18
22	0	0	0	0	0	0	0	0	0	0
23	-	-	0.27	0.35	0.43	0.53	14	11.7	259395	19-51
24	580	580	0.29	0.30	-	-	15	12.5	299858	14-05
25	571	587	0.45	0.60	0.53	0.64	15	12.2	301542	24
26	655	690	0.26	0.35	0.42	0.47	15	12.0	247625	24
27	652	660	0.18	0.29	0.43	0.53	15	12.2	228625	24
28	533	627	0.23	0.29	0.58	0.63	15	12.3	307250	24
29	601	617	0.27	0.30	0.55	0.61	15	12.9	327000	24
30	-	-	0.22	0.25	0.47	0.53	15	12.6	290500	24

(a) Data from one inlet monitor only.

(b) #/MMBtu values calculated using the design CO₂ average of 12.5%.(c) SO₂ values calculated using data from Outlet SO₂ monitors.

Coal Consumption: 104,778.7 tons

Coal Analysis: 0.65% Sulfur

Scrubber Availability: 94.4%

Total Time on Line: 662 hrs. 29 min.

TABLE C.11.A Colstrip Unit #1 Emission Data (October 1978)

Date	SO ₂ Avg. ppm	Inlet Peak	SO ₂ Avg. #/MMBtu	Outlet Peak	NO _x Avg. #/MMBtu	Outlet Peak	Opacity Avg. %	CO ₂ Avg. %	Gross Generations KWH	Time on Line Hr.-Min.
1	509	583	0.15	0.20	0.53	0.57	13	12.9	304083	24
2	503	530	0.17	0.24	0.54	0.57	14	13.4	344625	24
3	-	-	0.17	0.20	0.56	0.59	16	13.1	338583	24
4	460	480	0.18	0.26	0.52	0.58	15	12.6	327458	24
5	480	490	0.16	0.24	0.54	0.58	16	11.1	282542	24
6	538	550	0.28	0.38	0.56	0.65	15	11.1	294583	24
7	618	667	0.19	0.21	0.39	0.42	14	10.5	191973	23-40
8	390	390	0.09	0.15	0.41	0.45	14	12.0	228458	24
9	696	750	0.08	0.17	0.42	0.49	15	11.3	232083	24
10	-(a)	-(a)	0.11	0.16	0.49	0.57	17	12.3	301667	24
11	-	-	0.10	0.26	0.46	0.64	17	11.6	304208	24
12	-	-	0.26	0.28	0.62	0.65	16	11.4	269801	07-01
13	-	-	0.32	0.43	0.30	0.42	14	8.4	210497	12-40
14	-	-	0.31	0.44	0.40	0.44	15	10.3	299458	24
15	-	-	0.33	0.45	0.34	0.41	16	10.0	232000	24
16	718	735	0.28	0.43	0.42	0.46	16	11.3	331750	24
17	723	753	0.30	0.34	0.34	0.40	15	11.1	267167	24
18	734	873	0.27	0.33	0.38	0.46	17	10.4	250167	24
19	604	660	0.33	0.38	0.42	0.45	17	10.8	313792	24
20	584	617	0.37	0.42	0.45	0.46	16	11.5	326792	24
21	726	797	0.30	0.39	0.36	0.55	16	11.3	294667	24
22	723	813	0.25	0.31	0.60	0.68	16	11.0	296458	24
23	712	737	0.29	0.30	0.56	0.62	15	12.3	337125	24
24	680	787	0.28	0.33	0.54	0.61	15	11.4	317750	24
25	605	837	0.30	0.36	0.58	0.66	15	12.0	311458	24
26	630	660	0.23	0.27	0.50	0.53	15	11.5	319625	24
27	642	680	0.20	0.27	0.51	0.57	15	10.7	267331	23-36
28	595	623	0.25	0.30	0.52	0.61	14	11.0	301000	24
29	581	637	0.27	0.30	0.56	0.60	14	10.8	328560	24
30	645	767	0.27	0.37	0.57	0.65	14	10.3	301458	24
31	717	750	0.33	0.46	0.55	0.64	15	10.4	297750	24

(a) Monitor equipment failure

Coal Consumption: 119,643.3 tons

Coal Analysis: 0.69% Sulfur

Scrubber Availability: 94.5%

Total Time on Line: 714 hrs., 57 min.

TABLE C.11.B Colstrip Unit #2 Emission Data (October 1978)

Date	SO ₂ Avg. ppm	Inlet Peak	SO ₂ Avg. #/MMBtu	Outlet Peak	NO _x Avg. #/MMBtu	Outlet Peak	Opacity Avg. %	CO ₂ Avg. %	Gross Generations KWH	Time on Line Hr.-Min.
1	513	547	0.27	0.31	0.52	0.55	15	12.9	326083	24
2	542	623	0.23	0.29	0.50	0.55	14	13.8	291625	24
3	703	837	0.26	0.29	0.44	0.52	14	13.2	316458	24
4	776	820	0.22	0.28	0.45	0.49	13	12.3	299292	24
5	766	820	0.24	0.31	0.42	0.44	15	14.0	317125	24
6	827	860	0.28	0.34	0.42	0.49	14	13.9	289583	24
7	805	810	0.29	0.32	0.48	0.54	15	13.8	305833	24
8	848	853	0.27	0.34	0.44	0.50	13	12.7	288292	24
9	757	800	0.29	0.33	0.48	0.52	13	12.4	322958	24
10	736	830	0.28	0.34	0.37	0.45	13	12.1	293583	24
11	691	707	0.21	0.29	0.32	0.47	14	11.6	225708	24
12	722	823	0.30	0.36	0.43	0.47	14	12.1	300208	24
13	637	717	0.33	0.38	0.45	0.48	15	11.5	322917	24
14	767	843	0.21	0.27	0.32	0.49	14	11.6	205292	24
15	698	777	0.24	0.35	0.35	0.45	14	11.0	235333	24
16	248	797	0.24	0.33	0.35	0.45	12	11.7	247000	24
17	-	-	0.26	0.30	0.31	0.45	13	12.5	211208	24
18	774	783	0.22	0.27	0.36	0.49	14	12.4	201750	24
19	836	930	0.27	0.37	0.29	0.31	13	13.6	175250	24
20	714	900	0.32	0.38	0.32	0.38	15	13.8	292292	24
21	651	817	0.31	0.35	0.34	0.45	14	13.3	305500	24
22	601	633	0.31	0.34	0.47	0.52	16	14.3	324458	24
23	606	667	0.31	0.41	0.43	0.49	13	13.5	291042	24
24	684	810	0.35	0.38	0.41	0.45	11	12.3	298250	24
25	641	665	0.35	0.39	0.41	0.46	11	11.5	301667	24
26	669	817	0.30	0.39	0.46	0.60	11	13.4	296542	24
27	707	790	0.33	0.43	0.54	0.63	12	13.3	307417	24
28	740	800	0.41	0.47	0.56	0.67	11	8.9	316667	24
29	810	830	0.34	0.37	0.32	0.41	10	9.4	186280	24
30	700	760	0.43	0.49	0.55	0.67	12	10.2	306542	24
31	748	817	0.48	0.54	0.54	0.59	13	11.8	320792	24

Coal Consumption: 118,465.6 tons

Coal Analysis: 0.69% Sulfur

Scrubber Availability: 99.6%

Total Time on Line: 744 hrs.

TABLE C.12.A Colstrip Unit #1 Emission Data (November 1978)

Date	SO ₂ Avg. ppm	Inlet Peak	SO ₂ Avg. #/MMBtu	Outlet Peak	NO _x Avg. #/MMBtu	Outlet Peak	Opacity Avg. %	CO ₂ Avg. %	Gross Generations KWH	Time on Line Hr.-Min.
1	791	820	0.38	0.44	0.49	0.56	14	10.9	305,792	24
2	794	815	0.43	0.55	0.41	0.49	14	10.1	298,417	24
3	884	903	0.27	0.43	0.38	0.48	12	8.6	182,958	24
4	--	--(a)	0.42	0.53	0.41	0.47	13	9.6	219,667	24
5	786	815	0.42	0.49	0.41	0.55	14	9.9	234,833	24
6	--	--(a)	0.45	0.55	0.37	0.40	14	10.5	233,417	24
7	711	753	0.33	0.41	0.39	0.45	14	11.4	307,625	24
8	820	863	0.33	0.51	0.43	0.52	16	11.5	298,208	24
9	717	857	0.34	0.44	0.38	0.45	15	10.0	241,500	24
10	550	550	0.35	0.47	0.45	0.52	16	10.6	326,833	24
11	--	--(a)	0.34	0.51	0.51	0.69	16	9.3	333,708	24
12	--	--(a)	0.33	0.49	0.49	0.64	16	9.4	336,917	24
13	--	--(a)	0.36	0.44	0.44	0.58	16	12.5(b)	282,481	17-59
14	--	--(a)	0.31	0.44	0.57	0.66	16	12.0	323,333	24
15	715	765	0.42	0.47	0.59	0.65	16	13.5	327,833	24
16	623	703	0.49	0.54	0.45	0.52	16	13.3	337,833	24
17	575	620	0.49	0.60	0.44	0.51	15	12.8	277,625	24
18	--	--(a)	0.35	0.48	0.32	0.46	14	12.2	210,875	24
19	--	--(a)	0.32	0.53	0.50	0.59	16	12.0	291,125	24
20	--	--(a)	0.26	0.35	0.51	0.57	18	11.6	300,000	24
21	--	--(a)	0.21	0.25	0.55	0.58	19	11.9	335,542	24
22	--	--(a)	0.18	0.31	0.46	0.54	18	12.0	323,542	24
23	--	--(a)	0.32	0.37	0.46	0.51	15	11.3	307,004	15-25
24	0	0	0	0	0	0	0	0	0	0
25	--	--(a)	0.16	0.18	0.38	0.46	14	12.5(b)	183,925	9-35
26	--	--(a)	0.14	0.15	0.45	0.52	16	12.5(b)	245,732	11-28
27	--	--(a)	0.10	0.12	0.45	0.59	10	12.5(b)	193,908	6-44
28	--	--(a)	0.23	0.41	0.56	0.60	15	11.5	328,417	24
29	--	--(a)	0.22	0.24	0.55	0.56	15	12.5	330,333	24
30	524	530	0.16	0.21	0.55	0.63	--	13.0	332,167	24

(a) Monitoring Equipment Malfunction.

(b) #/MMBTU values calculated using the design CO₂ average of 12.5%.

Coal Consumption: 106,234.1 tons

Coal Analysis: 0.74% Sulfur

Scrubber Availability: 91.1%

Total Time on Line: 637 hrs., 11 minutes

TABLE C.12.B Colstrip Unit #2 Emission Data (November 1978)

Date	SO ₂ Avg.	Inlet Peak	SO ₂ Avg.	Outlet Peak	NO _x Avg.	Outlet Peak	Opacity Avg.	CO ₂ Avg.	Gross Generations KWH	Time on Line Hr.-Min.
	ppm		#/MMBtu		#/MM B tu		%	%		
1	709	797	0.48	0.54	0.39	0.51	12	11.9	256,625	24
2	861	933	0.50	0.61	0.47	0.57	12	11.2	270,625	24
3	741	777	0.49	0.60	0.46	0.53	12	12.7	291,292	24
4	863	883	0.46	0.61	0.41	0.54	12	11.4	238,458	24
5	--	--(a)	0.49	0.57	0.47	0.61	12	11.5	222,142	20-49
6				Off Line					0	0
7	--	--(a)	0.20	0.35	0.52	0.63	11	8.2	173,716	11-41
8	527	527	0.38	0.53	0.49	0.63	12	11.1	264,333	24
9	543	560	0.32	0.43	0.50	0.58	14	12.4	283,042	24
10	502	585	0.34	0.49	0.56	0.69	15	9.9	259,042	24
11	432	455	0.38	0.42	0.60	0.68	15	13.8	303,917	24
12	400	400	0.34	0.45	0.50	0.58	13	13.8	274,000	24
13	443	460	0.34	0.41	0.60	0.68	15	13.8	324,125	24
14	487	525	0.27	0.44	0.53	0.65	15	11.6	283,458	24
15	583	585	0.47	0.53	0.49	0.62	17	11.7	325,000	24
16	582	600	0.33	0.44	0.51	0.62	15	10.2	262,861	20-46
17	600	643	0.43	0.48	0.52	0.58	13	9.7	277,881	17-06
18	559	593	0.48	0.52	0.58	0.60	17	12.1	328,750	24
19	549	573	0.47	0.54	0.53	0.64	18	11.6	288,167	24
20	534	577	0.39	0.47	0.54	0.58	16	11.7	288,792	24
21	510	533	0.25	0.35	0.44	0.50	13	1.2	255,500	24
22	467	497	0.25	0.34	0.54	0.63	15	11.1	306,500	24
23	491	507	0.29	0.32	0.59	0.62	16	10.5	324,583	24
24	519	547	0.23	0.30	0.58	0.62	15	10.0	301,583	24
25	475	497	0.29	0.39	0.56	0.62	15	11.4	314,500	24
26	495	533	0.23	0.29	0.53	0.64	15	10.6	304,708	24
27	470	530	0.25	0.31	0.60	0.63	15	10.2	313,083	24
28	490	527	0.27	0.34	0.44	0.46	15	10.9	325,667	24
29	469	480	0.20	0.26	0.41	0.46	16	11.1	298,583	24
30	463	477	0.21	0.25	0.44	0.45	16	11.0	321,208	24

(a) Monitoring Equipment Malfunction

Coal Consumption: 116,195.2 tons

Coal Analysis: 0.74% Sulfur

Scrubber Availability: 99.5%

Total Time on Line: 668 hrs., 22 mins.

TABLE C.13.A Colstrip Unit #1 Emission Data (December 1978)

Date	SO ₂ Avg. ppm	Inlet Peak	SO ₂ Avg. #/MMBtu	Outlet Peak	NO _x Avg. #/MMBtu	Outlet Peak	Opacity Avg. %	CO ₂ Avg. %	Gross Generations KWH	Time on Line Hr.-Min.
1	593	660	0.22	0.26	0.58	0.67	18	10.6	331625	24
2	679	727	0.30	0.40	0.38	0.46	17	10.7	307542	24
3	605	620	0.24	0.28	0.45	0.51	15	9.8	313625	24
4	698	743	0.29	0.34	0.41	0.48	15	11.9	330167	24
5	887	1137	0.21	0.34	0.47	0.53	14	10.2	196901	21-18
6	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0
8	1055	1120	0.32	0.45	0.35	0.39	14	9.0	183032	18-48
9	808	947	0.23	0.30	0.39	0.45	12	11.1	296667	24
10	739	857	0.28	0.40	0.35	0.49	11	12.0	298167	24
11	695	710	0.27	0.31	0.44	0.50	13	14.5	323542	24
12	-	-	0.26	0.34	0.45	0.50	14	14.1	323458	24
13	-	-	0.31	0.37	0.58	0.64	15	12.1	298792	24
14	-	-	0.26	0.27	0.55	0.61	14	10.9	322208	24
15	717	753	0.28	0.31	0.57	0.59	16	10.7	322333	24
16	753	817	0.24	0.29	0.57	0.63	15	9.3	297625	24
17	755	800	0.22	0.25	0.62	0.68	14	11.4	314333	24
18	694	727	0.21	0.25	0.54	0.63	15	11.6	293917	24
19	742	830	0.24	0.30	0.51	0.62	13	11.0	321550	23-29
20	825	850	0.27	0.37	0.42	0.45	12	10.6	282095	23-41
21	730	813	0.26	0.34	0.43	0.49	12	11.1	316542	24
22	710	777	0.32	0.35	0.48	0.55	13	11.1	315208	24
23	698	793	0.25	0.38	0.47	0.54	12	10.8	284875	24
24	-	-	0.33	0.37	0.47	0.50	13	11.1	307875	24
25	-	-	0.21	0.27	0.51	0.56	13	10.1	289208	24
26	-	-	0.22	0.24	0.51	0.53	13	11.3	311833	24
27	-	-	0.20	0.25	0.47	0.52	14	10.8	314667	24
28	-	-	0.15	0.22	0.54	0.58	14	9.9	293125	24
29	-	-	0.21	0.26	0.58	0.64	16	10.2	314250	24
30	-	-	0.24	0.34	0.50	0.60	15	9.9	289587	22-17
31	-	-	0.25	0.31	0.55	0.60	15	12.8	317333	24

Note: November 30 opacity average for unit 1 equals 16%.

Coal Consumption: 121,574.6 tons

Scrubber Availability: 96.7%

Total Time on Line: 685 hrs., 33 min.

TABLE C.13.B Colstrip Unit #2 Emission Data (December 1978)

Date	SO ₂ Avg. ppm	Inlet Peak	SO ₂ Avg. #/MMBtu	Outlet Peak	NO _x Avg. #/MMBtu	Outlet Peak	Opacity Avg. %	CO ₂ Avg. %	Gross Generations KWH	Time on Line Hr.-Min.
1	473	503	0.22	0.28	0.48	0.53	16	11.8	289375	24
2	524	603	0.29	0.34	0.52	0.60	14	10.4	309000	24
3	529	563	0.23	0.31	0.51	0.63	14	11.4	296208	24
4	547	593	0.31	0.39	0.50	0.55	17	11.8	319917	24
5	570	607	0.37	0.47	0.41	0.49	17	11.2	295708	24
6	529	500	0.36	0.42	0.48	0.53	18	10.9	321875	24
7	598	693	0.26	0.35	0.44	0.47	15	9.7	294125	24
8	628	640	0.35	0.43	0.48	0.55	16	10.0	313667	24
9	612	643	0.24	0.39	0.32	0.37	16	10.6	254708	24
10	568	587	0.28	0.31	0.38	0.41	17	11.1	318417	24
11	588	687	0.24	0.29	0.43	0.45	14	10.2	318042	24
12	832	877	0.34	0.44	0.35	0.39	14	10.4	235583	24
13	-	-	0.36	0.52	0.36	0.40	15	10.6	206000	24
14	-	-	0.23	0.30	0.33	0.42	12	10.9	243375	24
15	728	769	0.21	0.26	0.23	0.25	13	11.5	224166	24
16	749	817	0.25	0.42	0.26	0.28	14	11.8	234250	24
17	657	680	0.18	0.25	0.30	0.34	16	11.6	284167	24
18	-	-	0.21	0.34	0.33	0.35	18	11.6	313000	24
19	628	713	0.19	0.27	0.25	0.38	17	11.7	265583	24
20	-	-	0.31	0.49	0.46	0.47	15	12.7	233917	24
21	-	-	0.21	0.32	0.40	0.48	14	11.2	224583	24
22	597	617	0.27	0.37	0.51	0.61	15	11.4	276917	24
23	563	620	0.38	0.38	0.58	0.63	16	11.6	321458	24
24	708	890	0.30	0.36	0.44	0.50	13	11.4	283750	24
25	600	630	0.29	0.32	0.52	0.54	16	11.8	320167	24
26	583	613	0.26	0.28	0.55	0.58	16	11.6	320500	24
27	579	739	0.20	0.27	0.50	0.56	16	11.1	280292	24
28	470	503	0.19	0.21	0.53	0.57	15	11.4	308042	24
29	-	-	0.21	0.27	0.48	0.62	17	11.4	319542	24
30	-	-	0.29	0.40	0.61	0.63	17	11.4	313625	24
31	-	-	0.22	0.38	0.51	0.56	17	11.0	265792	24

Coal Consumption: 134,834.4 tons

Scrubber Availability: 91.2%

Total Time on Line: 774 hrs., 00 mins.

APPENDIX D

EXCESSES OF CLASS 1 AIR QUALITY STANDARD
REGARDLESS OF STATION LOCATION DURING 1978

TABLE D.1. Excesses of Class 1 Air Quality Standard
Regardless of Station Location During 1978

DATE	HAY COULEE		KLUVER EAST		KLUVER WEST		KLUVER NORTH		BNW-1		GREENLEAF	
	3 hr	24 hr	3 hr	24 hr	3 hr	24 hr	3 hr	24 hr	3 hr	24 hr	3 hr	24 hr
2/6		1										
2/7		1										
2/8		1										
2/9		1										
2/10		1										
2/11		1										
2/12		1										
2/13		1										
2/14		1										
2/15		1										
2/16		1										
2/17		1										
2/18		1										
2/20	1	1										
2/21		1										
2/22	2	1										
2/23	2	1										
2/24	2	1										
2/25	1	1										
2/26	2	1										
2/27		1										
2/28		1										
3/1		1										
3/2		1										
3/3		1										
3/4		1										
3/5												
3/6		1										
3/7		1										
3/9	1	1										
3/10		1										

TABLE D.1. (continued)

[illegible]

TABLE D.1. (continued)

[illegible]

TABLE D.1. (continued)

DATE	HAY COULEE		KLUVER EAST		KLUVER WEST		KLUVER NORTH		BNW-1		GREENLEAF	
	3 hr	24 hr	3 hr	24 hr	3 hr	24 hr	3 hr	24 hr	3 hr	24 hr	3 hr	24 hr
5/22						1						
5/23		1										
5/24		1				1						
5/25		1				1						
5/26		1				1						
5/27		1		1		1						
5/28		1		1								
5/29		1				1						
5/30		1		1		1						
5/31		1		1		1						
6/1		1		1		1						
6/2		1		1		1						
6/3				1		1						
6/5		1				1						
6/6		1		1		1						
6/7		1		1		1						
6/8		1				1						
6/9		1				1						
6/10		1		1		1						
6/11		1		1		1						
6/12		1				1						
6/13						1						
6/15						1						
6/16		1		1		1						
6/17		1		1		1						
6/18		1										
6/19		1		1		1						
6/20		1		1		1						
6/21		1				1						
6/22		1				1						
6/23		1				1						

TABLE D.1. (continued)

DATE	HAY COULEE		KLUVER EAST		KLUVER WEST		KLUVER NORTH		BNW-1		GREENLEAF	
	3 hr	24 hr	3 hr	24 hr	3 hr	24 hr	3 hr	24 hr	3 hr	24 hr	3 hr	24 hr
6/24						1						
6/25		1										
6/26		1										
6/27		1				1						
6/28		1				1						
6/29		1				1						
6/30						1						
7/1		1				1						
7/2					1	1						
7/3					1	1						
7/4												
7/5		1										
7/6		1			1	1						
7/7		1										
7/8		1				1						
7/10		1										
7/12		1										
7/13		1										
7/14		1										
7/15		1										
7/23										1		
7/24		1		1								
7/25				1					1	1		
7/26		1										
7/27		1								1		
7/28										1		
7/29		1								1		
7/30		1								1		
7/31		1								1		
8/1		1										
8/2										1		

TABLE D.1. (continued)

[illegible]

TABLE D.1. (continued)

DATE	HAY COULEE		KLUVER EAST		KLUVER WEST		KLUVER NORTH		BNW-1		GREENLEAF	
	3 hr	24 hr	3 hr	24 hr	3 hr	24 hr	3 hr	24 hr	3 hr	24 hr	3 hr	24 hr
9/12		1								1		
9/13										1		
9/14				1						1		
9/15												
9/16		1								1		
9/17										1		
9/18		1										
9/19		1								1		
9/20				1						1		
9/21				1								
9/22										1		
9/24		1										
9/25				1								
9/28		1										
9/29		1										
10/2		1								1		
10/3		1								1		
10/4										1		
10/5		1		1						1		
10/6		1		1								
10/12		1								1		1
10/13		1								1		
10/14		1										
10/16										1		
10/17		1								1		
10/18		1								1		1
10/19												
10/20										1		
10/21		1								1		
10/22		1								1		
10/23		1								1		

TABLE D.1. (continued)

DATE	HAY COULEE		KLUVER EAST		KLUVER WEST		KLUVER NORTH		BNW-1		GREENLEAF	
	3 hr	24 hr	3 hr	24 hr	3 hr	24 hr	3 hr	24 hr	3 hr	24 hr	3 hr	24 hr
10/24		1								1		
10/25		1										
10/27		1										
10/28		1										
10/30		1										
11/3		1										
11/6		1										
11/9		1					1			1		
11/10		1								1		
11/11		1					1					
11/13		1										
11/14		1					1					
11/15		1					1					
11/17									1	1		
11/18							1		1	1		
11/19							1			1		
11/20							1			1		
11/22		1								1		
11/23	1	1					1		1	1		
11/24		1					1		1	1		
11/25									3	1		
11/26										1		
11/27		1								1		
11/28										1		
11/29		1										
11/30		1					1			1		
12/1		1					1			1		
12/2		1					1			1		
12/3										1		
12/4										1		
12/5		1					1			1		

TABLE D.1. (continued)

DATE	HAY COULEE		KLUVER EAST		KLUVER WEST		KLUVER NORTH		BNW-1		GREENLEAF	
	3 hr	24 hr	3 hr	24 hr	3 hr	24 hr	3 hr	24 hr	3 hr	24 hr	3 hr	24 hr
12/6		1						1		1		
12/7		1								1		
12/8		1						1		1		
12/9										1		
12/10		1				1		1		1		
12/11								1		1		
12/12										1		
12/13								1		1		
12/14										1		
12/16								1		1		
12/17										1		
12/18										1		
12/19										1		
12/20								1		1		
12/21										1		
12/22										1		
12/23										1		
12/24						1						
12/26												
12/28								1				
12/29						1		1		1		
12/30						1		1		1		
12/31								1		1		

APPENDIX E

POWER PLANT PLUME FUMIGATIONS

TABLE E.1. Power Plant Plume Intercepts at Hay Coulee

Date	Start	End	SO_2 Max.	ΔO_3 Max.	Temp.	Humidity	Wind Spd.	Wind Dir.
			ppb		°C	%	mph	°N
8/24/77	2300	2335	7 (a)	30	23-24	42-43	6-26	270
8/25/77	0600	0700	9 (a)	13	18-21	42-45	2-26	230-270
8/25/77	0850	0922	9 (a)	0	22	41-42	0-17	270-008
8/29/77	1435	1545	19 (a)	30	20-28	39-41	5-23	248-340
9/3/77	1322	1530	5 (a)	20	30	25-32	4-26	242-346
9/7/77	1015	1130	5 (a)	18	29-32	38-41	0-14	162-018
9/8/77	0830	0900	2 (a)	34	8	67-91	4-34	248-330
9/15/77	1745	1810	4 (b)	22	16	47-48	2-16	248-313
9/15/77	1845	1945	6 (b)	27	13-15	48-57	2-20	248-356
9/15/77	2000	2030	4 (b)	23	12-14	58-62	1-13	248-334
9/17/77	1220	1240	3 (b)	10	14	76-79	0-10	260-346
9/21/77	1130	1230	5 (a)	16	12-13	60-70	0-20	248-324
9/26/77	0845	1100	9 (b)	0	14-18	44-48	0-6	variable
9/27/77	1500	1600	5 (b)	10	22-23	33-38	0-13	248-045
9/29/77	1250	1345	7 (b)	4	15	66-76	0-11	162-216
9/29/77	1455	1610	6 (b)	11	13-16	69-78	0-14	265-330
10/7/77	0630	1000	5 (a)	10	6	22-85	0-14	238-313
10/7/77	1030	1340	8 (a)	17	6-8	75-78	4-20	238-340
10/7/77	1945	2020	3 (a)	22	4	85-91	4-28	227-302
10/30/77	0755	0840	10 (a)	18	5-6	83-86	0-13	227-324

The letters following the sulfur values denote which of three analyzers was utilized to collect the data. At times more than one analyzer were run side by side for comparison.

- (a) Meloy 285
- (b) Monitor Labs 8450
- (c) Meloy 160

To convert ppb SO_2 to micrograms SO_2/m^3 at the Hay Coulee altitude multiply ppb values by the constant 2.31.

Table E.1. (continued)

Date	Start	End	SO ₂ Max. ppb	ΔO ₃ Max.	Temp. °C	Humidity %	Wind Spd. mph	Wind Dir. °N
11/2/77	1130	1140	8 (a)	7	17-18	22-31	9-28	270-335
11/2/77	2030	2050	2 (a)	6	2	34-36	2-8	265-281
11/2/77	2155	2220	3 (a)	10	-5--0	40-43	0-3	281-308
11/6/77	0700	1520	12 (a)	21	2-9	47-74	0	227-340
11/7/77	1845	2400	7 (a)	34	2-3	47-59	0	0
11/8/77	0230	0450	17 (a)	36	-6--5	65-72	0	0
11/8/77	0815	0900	9 (a)	28	-7--5	74-81	0	0
11/8/77	1000	1120	15 (a)	29	-5--1	47-69	0	0
11/15/77	1205	1230	3 (a)	8	3	37-40	3-7	260-340
11/16/77	1445	1510	7 (a)	0	3	35	5-20	254-335
11/24/77	1130	1400	20 (a)	26	-3--12	52-70	0-35	222-340
11/26/77	1245	1310	19 (a)	22	-1	63-64	0	281
11/26/77	1750	1835	17 (a)	36	-8	67	0	281
11/29/77	2050	2200	3 (a)	40	1-4	78-90	6-28	0
12/1/77	0235	0250	3 (a)	27	-8	76-77	5-20	254-319
12/1/77	0820	0825	5 (a)	6	-7	60-63	1-15	258-307
12/3-4/77	2340	0200	10 (a)	28	-2--3	45-75	7-33	216-346
12/4/77	0320	0500	12 (a)	30	-9--5	75-78	0-17	232-340
12/5/77	0810	1020	9 (a)	16	-23	55	0-20	248-340
12/5/77	1205	1250	7 (a)	10	-23	52	4-19	243-313
12/5/77	1415	1500	8 (a)	12	-24	53	4-14	281-346
12/7/77	1240	1400	4 (a)	6	-17	70	3-15	281-346
12/7/77	1520	1620	4 (a)	16	-20	63-65	6-18	265-335
12/7/77	2030	2135	11 (a)	26	-25	59	8-23	254-319
12/8/77	0010	0100	12 (a)	26	-26	55	2-19	248-319
12/8/77	0430	1340	19 (a)	21	-30	50	3-23	238-351
12/17/77	1000	1600	23 (a)	18	0	52-56	3-27	243-356
12/17-18/77	2310	0700	18 (a)	30	-7	75-78	0-6	0
12/19/77	1740	2000	14 (a)	26	-10	52-65	5-25	0
12/19/77	0900	1200	7 (a)	6	-5	75-80	0	0
12/25/77	2030	2130	29 (a)	0	-7	52-54	2-14	243-335
12/26/77	0115	0215	14 (a)	0	-7	54-64	10-33	248-346
12/26/77	0415	0615	10 (a)	0	-7	66	0-10	254-329
12/26/77	1055	1530	15 (a)	0	-7	55-65	4-34	254-329

Table E.1. (continued)

Date	Start	End	SO ₂ Max	ΔO ₃ Max.	Temp.	Humidity	Wind Spd.	Wind Dir.
			ppb		°C	%	mph	°N
1/12/78	1515	2100	3 (a)	30	-8-5	47-73	3-31	248-351
1/13/78	0115	0415	10 (a)	12	-13	80	0-13	259-335
1/17/78	1035	1045	6 (a)	10	-14	66	4-12	308-329
1/18/78	0050	0300	6 (a)	11	-20	65-70	3-20	248-324
1/24/78	1900	2020	10 (a)	20	-6	79-82	6-29	259-324
1/31/78	0615	0745	16 (a)	24	-24	68-71	0-21	0
2/10/78	1740	Inst.	12 (a)	31	-23	70	0	0
2/18/78	1345	Inst.	8 (c)	7	1	75-78	3-13	259-335
2/18/78	1850	1915	4 (c)	10	-1	69	4-20	270-313
2/19/78	0830	1700	11 (c)	16	-17--7	49-86	0-39	200-340
2/21/78	1830	1915	10 (c)	12	11	48	0	265-329
2/22/78	0740	1820	26 (c)	18	6-11	48-60	0	259-335
2/26/78	1140	1620	43 (c)	34	-2	55-59	0	281-023
3/1/78	1100	2130	23 (c)	18	-18--17	63-68	0	270-346
3/10/78	1020	1130	18 (c)	10	2	50-55	0	265-351
3/14/78	0945	1650	23 (c)	10	-5--0	47-75	2-24	254-018
3/15/78	1510	1815	28 (c)	9	-5--0	48-57	2-30	259-002
3/16/78	1515	1800	24 (c)	10	4	31-40	0-13	292-329
3/18/78	0705	0730	16 (c)	15	8	45	3-18	270-356
3/21/78	0700	1820	22 (c)	15	3-17	32-46	0-16	216-023
3/24/78	1245	1515	15 (c)	12	5-10	46-74	3-17	265-013
3/27/78	0900	2100	22 (c)	15	17-21	27-69	0-18	238-083
3/28/78	1100	2000	17 (c)	15	5-21	24-45	0-18	254-356
4/5/78	1200	1300	15 (c)	12	12-16	0	6-27	254-356
4/8/78	2220	1200	9 (c)	19	2-7	28-67	2-37	238-018
4/10/78	0815	1830	6 (c)	9	3-12	20-39	0-32	248-018
4/11/78	1545	1750	9 (c)	12	8-12	13-30	12-47	265-007
4/11/78	1915	2005	10 (c)	18	2-3	44-47	7-35	286-340
4/11/78	2340	2400	11 (c)	9	1	43-48	6-34	270-346

Table E.1. (continued)

Date	Start	End	SO ₂ Max. ppb	ΔO ₃ Max.	Temp. °C	Humidity %	Wind Spd. mph	Wind Dir. °N
4/17/78	1610	1810	10 (c) 12 (b)	15	5-6	48-52	7-42	281-007
4/18/78	1235	1405	8 (c) 11 (b)	12	2-3	82-87	8-30	281-351
4/19/78	0830	0930	30 (c) 31 (b)	26	3-5	48-64	0-16	281-007
4/21/78	1530	1830	5 (c)	12	5-7	52-75	4-23	259-018
5/3/78	0900	1615	11 (c)	14	10-17	38-70	0-17	275-061
5/3/78	2245	2300	5 (c)	13	5	83-84	8-20	318-340
5/4/78	0100	1300	12 (c)	34	2-5	75-87	5-28	302-356
5/4/78	1655	1735	3 (c)	10	3	85-87	3-9	286-307
5/4/78	1900	1930	4 (c)	20	3	89-91	6-14	286-329
5/8/78	0845	1800	9 (c)	20	3-15	40-87	5-42	259-360
5/11/78	1035	1300	10 (c)	14	7-15	50-90	0-32	259-180
5/16/78	1700	2010	10 (c)	30	10-18	42-44	3-23	275-351
5/17/78	0650	0945	14 (c)	20	8-9	91-94	4-25	270-351
5/24/78	1445	1600	10 (c)	18	21-22	43-47	5-23	281-356
5/27/78	1030	1215	3 (a) 5 (c)	15	19-20	45-50	0-17	243-110
5/30/78	1010	1320	10 (c)	17	7-8	81-91	3-31	259-356
6/1/78	0630	0915	11 (a) 12 (c)	28	7-9	63-82	2-14	254-351
6/1/78	1530	1650	8 (a)	12	13-16	47-59	0-13	232-018
6/4/78	0920	1345	15 (a) 17 (b)	17	23-27	39-43	0-22	281-056
6/6/78	1745	2400	15 (a) 17 (b)	28	24-29	46-87	0-39	0
6/7/78	1500	2000	9 (a) 9 (b)	16	18-21	43-46	0-20	265-061
6/8/78	0900	1000	7 (a) 9 (b)	8	21-24	42-45	0-10	205-297
6/11/78	1720	1900	10 (a) 12 (b)	12	17-18	43-44	6-25	297-013
6/13/78	0915	0935	17 (a) 13 (b)	21	26-27	42-45	0-8	0
6/13/78	1135	1155	9 (a)	4	28	39-40	6-25	0
6/14/78	1840	1910	8 (a)	12	24-26	47-54	6-38	0
6/14/78	2040	2045	11 (a)	35	17	57	5-8	0

Table E.1. (continued)

Date	Start	End	SO ₂ Max	ΔO ₃ Max.	Temp.	Humidity	Wind Spd.	Wind Dir.
			ppb		°C	%	mph	°N
6/15/78	0600	1300	28 (a)	21	18-25	44-70	0-28	0
6/15/78	1435	1500	9 (a)	16	17-19	0	4-22	0
6/19/78	1205	2220	20 (a)	34	11-18	42-58	0	0
6/22/78	1430	1930	20 (a)	19	25-30	38-44	0-15	265-356
6/24/78	1030	2000	10 (a)	8	12-20	24-42	0-40	0-360
6/26/78	1600	1930	8 (a)	10	16-25	40-53	0-15	227-356
6/27-7/13/78	Recorder Down							
7/13/78	1800	1840	9 (a) 6 (b)	20	32	16-19	5-15	254-356
7/14/78	0800	2000	7 (a) 5 (b)	16	20-32	11-45	0-26	184-028
7/15/78	1000	1030	8 (a) 6 (b)	16	31-35	30-42	0-10	0-360
7/17/78	0615	1700	14 (a) 12 (b)	32	20-27	27-57	3-33	237-034
7/18/78	0045	0130	3 (a)	20	13	86	3-9	291-335
7/21/78	1600	1800	5 (a)	N/A	13	45-85	6-30	226-180
7/23/78	1700	1915	6 (a)	10	21-34	15-40	0-21	275-292
7/25/78	1100	1600	14 (a)	22	32	14-18	3-23	254-039
7/26/78	1030	1800	10 (a)	12	31-33	12-25	0-21	0-360
7/27/78	1200	2300	13 (a)	10	20-37	27-40	0-50	0-360
7/28/78	1000	1530	12 (a)	20	27	35	0-20	270-039
7/29/78	1430	1900	19 (a)	28	26-31	22-40	3-33	270-039
7/30/78	0800	1800	10 (a)	22	24-30	20-43	0-16	0-360
8/1/78	0800	1800	8 (a)	34	20-27	35-55	0-36	216-061
8/1/78	0200	0500	8 (a)	56	15-18	50-70	0-28	216-104
8/4/78	1700	1900	14 (a)	34	27-31	15-25	2-15	302-356
8/7/78	1400	1900	8 (a)	20	15-24	15-24	6-24	200-007
8/10/78	1015	2100	16 (a)	N/A	30-36	10-43	0-36	168-029
8/11/78	0930	1900	8 (a)	16	30-36	10-30	0-18	0-360
8/12/78	0900	2200	22 (a)	30	30-38	10-30	0-40	0-360
8/13/78	0800	1615	13 (a)	40	24-30	20-30	8-30	254-029
8/16/78	1030	2015	14 (a)	22	15-30	15-80	0-36	
8/21/78	0215	0300	9	34	17-21	221-17	2-19	27-42
8/22/78	1700	1715	6	14	28	308-2	7-31	35-40

Table E.1. (continued)

Date	Start	End	SO ₂ Max.	ΔO ₃ Max.	Temp.	Humidity	Wind Spd.	Wind Dir.
				ppb	°C	%	mph	°N
8/22/78	1030	1130	18	20	28	324-83	3-20	41
8/27/78	0900	1830	8	20	17-21	167-18	0-23	36-8
8/31/78	1350	1620	81	14	32	205-23	0-22	18-15
9/8/78	0130	0615	10	24	17-21	211-335	0-20	47-70
9/10/78	1030	1415	13	26	28-32	259-34	2-20	10-20
9/13/78	1530	1800	7	14	12	275-7	2-16	50-55
9/27/78	0800	1200	12	30	17-20	259-2	2-22	39-25
10/1/78	0945	1600	5	20	21	354-34	2-24	35-25
10/2/78	1370	1500	12	30	12	270-7	4-35	30-33
10/3/78	2300	0300	7	30	8-17	270-2	4-39	20-42
10/4/78	1520	2135	5	26	8-12		254-2	2-29
10/5/78	850	1540	14	28	8-13		265-29	1-24
10/8/78	1250	1515	9	24	20-13		254-2	0-12
10/11/78	2440	600	5	30	12-17		254-2	0-20
10/11/78	1200	1400	5	16	12-13		275-28	3-20
10/13/78	1310	1620	6	22	10-12	14-21	259-7	6-32
10/24/78	1000	1100	7	20	11-19	23-41	265-2	0-38
10/24/78	1240	1435	12	26	11-15	20-30	259-356	8-44
10/24-25/78	1740	400	7	32	1-7	44-85	265-7	0-34
10/25/78	1730	1830	7	32	4-5	22-32	259-340	1-22
10/29/78	1540	1030	5	22	9-10	43-45	270-335	5-22
11/3/78	9110	1400	13	20	18-16	20	216-67	
11/5/78	1610	1930	9	20	2-9	1272	227-302	0-4
11/5/78	600	820	7	18	-4 (1)	42-48	275-340	1-11
11/17/78	2020	2140	16	30	-13- 11	62-70	275-356	
11/17/78	2230	600	18	34	-19- 13	61-75	265-2	
11/22-23/78	Slow Rise	SO ₂			272200-700			
11/26/78	Slow Rise	SO ₂			700-1900			
11/ /78	2200	2330	5	16	-5	286-340		
11/28/78	1210	1430	6	20	0	62-58	243-340	6-31
11/30/78	Slow Rise	SO ₂	1800					0-16

Table E.1. (continued)

<u>Date</u>	<u>Start</u>	<u>End</u>	<u>SO₂ Max</u>	<u>ΔO₃ Max.</u>	<u>Temp.</u>	<u>Humidity</u>	<u>Wind Spd.</u>	<u>Wind Dir.</u>
			<u>ppb</u>		<u>°C</u>	<u>%</u>	<u>mph</u>	<u>°N</u>
12/4/78	230	240	6	24	-1.4	81-84	292-335	5-16
12/4/78	2215	2240	5	16	-9	75-78	254-302	3-12
12/5/78	1500	1600	6	10	-14-11	60-50	275-340	7-20
12/6/78	1130	1200	9	12	-16	57-55	281-335	7-20
12/8/78	Slow Rise SO ₂		500-1700				216-302	5-27
12/12	1220	1330	10	12	-4	50-55	275-346	5-20
12/12	1620	1730	9	10	-7-6	56-63	281-329	4-19
12/16	Slow rise SO ₂			100-1400	7			0-20
12/17	Slow rise SO ₂			730-12				

TABLE E.2. Power Plant Plume Intercepts BNW #1

<u>Date</u>	<u>Start</u>	<u>End</u>	<u>SO_x max. ppb</u>	<u>ΔO₃ max. ppb</u>	<u>Temp. °F</u>	<u>Humidity</u>	<u>Wind Spd.</u>	<u>Wind Dir.</u>
7/21/78	0830	1500	8 (a)	12	63-73			
7/21/78	1600	1700	8 (a)	20	69			
7/23/78	0630	0800	11 (a)	32	70-82			
7/23/78	1220	1345	14 (a)	30	93-100			
7/23/78	1720	1830	20 (a)	30	84-89			
7/24/78	0045	0200	13 (a)	28	72			
7/25/78	0915	1430	47 (a)	42	80-90			
7/25/78	1630	1720	14 (a)	24	86			
7/26/78	0630	0720	15 (a)	26	80			
7/26/78	0945	1300	17 (a)	36	89-93			
7/27/78	1415	1715	19 (a)	20	90-99			
7/28/78	0945	1800	37 (a)	40	74-80			
7/28-7/29/78	2030	0300	62 (a)	62	69-83			
7/29/78	0300	0.615	10 (a)	20	69			
7/29/78	1610	1840	44 (a)	40	78-84			
7/29-7/30/78	2310	0030	13 (a)	16	61-66			
7/30/78	0650	1645	29 (a)	40	67-86			

(a) Monitor Labs 8450

Table E.2. (continued)

Date	Start MST	End MST	Sulfur max. ppb	O ₃ max. ppb	Aitken Nuclei max.	Temp. °F
8/1/78	0200	0455	29	50	-	57-61
8/1/78	0900	1000	15	-	16.8K nuclei/ml	66-73
8/3/78	0730	1325	15	18	17.1K	66-79
8/4/78	1405	1810	58	54	11.1K	81-87
8/6/78	1030	1905	45	32	9.6K	86-94
8/7/78	0825	0910	11	14	4.5K	79-81
8/7/78	1135	1800	41	30	8.7K	83-90
8/10/78	1550	1720	88	49	8.1K	86-89
8/11/78	0620	1300	64	39	6.3K	71-97
8/11/78	1530	1710	26	35	3.3K	90-93
8/12/78	0810	1520	100+ (overscale)	42	9.0K	79-100
8/13/78	0810	1205	42	30	8.1K	74-81
8/13/78	1250	1540	49	36	17.1K	71-81
8/13/78	1720	1740	11	14	3.3K	64
8/13/78	1940	1955	10	21	4.8K	57
8/14/78	0950	1125	14	23	5.4K	61-64
8/14/78	1410	1420	12	25	3.9K	61-64
8/16/78	0920	1650	62	30	12.6K	71-85
8/16/78	1835	2000	100+ (overscale)	30	30.0K+ (overscale)	56-64
8/17/78	1750	1920	17	13	8.1K	53-60
8/17/78	2105	2140	11	4	8.1K	50
8/20/78	1035	1240	11	16	6.0K	81-90
8/22/78	1655	1705	10	14	6.6K	73-77
8/25/78	1240	1305	12	38	10.5K	91-94
8/25/78	1510	1540	5	15	5.4K	91-94
8/26/78	0220	0510	11	27	12.6K	61-64
8/27/78	1650	1750	10	23	3.0K	90-91
8/28/78	1145	1605	22	32	7.2K	69-83
8/28/78	1710	1720	6	12	3.0K	73-74
8/29/78	0715	0830	6	32	22.8K	63-66
8/30/78	1045	1115	8	20	12.0K	79-86
8/31/78	0845	1715	45	40	22.5K	61-90

Table E.2. (continued)

Date	Start MST	End MST	Sulfur max.	O ₃ max. ppb	Aiken Nuclei max.	Temp. °F
9/1/78	1750	2255	9	28	11.7K	71-84
9/2/78	1800	1915	7	20	4.2K	83-87
9/2/78	2105	2120	6	38	15.6K	80
9/3/78	1615	1725	16	32	8.1K	90-93
9/3/78	2205	2220	7	24	10.5K	81-83
9/4/78	0220	0515	6	22	18.0K	73-74
9/4/78	2100	2135	7	26	3.0K	79-84
9/5/78	1220	1325	13	22	4.5K	93-91
9/5/78	1430	1955	21	42	30.0K+ (overscale)	83-97
9/5/78	2315	2345	7	26	30.0K+ (overscale)	76-77
9/6/78	1055	1325	25	34	4.8K	80-89
9/8/78	0105	0155	16	22	2.3K	66-69
9/8/78	1235	1245	7	20	0.9K	74-77
9/8/78	1345	1350	5	18	0.9K	73-74
9/8/78	1535	1550	7	22	0.9K	74-76
9/8/78	1630	1705	16	38	0.9K	74-77
9/10/78	0905	0945	13	26	0.9K	74-77
9/10/78	1040	1300	21	31	1.2K	79-86

The suffix (K) on the Aitken nuclei values denotes multiplication by 1000.

To convert sulfur values to micrograms/cubic meter, multiply the ppb values by the constant 2.31.

Table E.2. (continued)

<u>Date</u>	<u>Start</u>	<u>End</u>	<u>SO₂ max. ppb</u>	<u>ΔO₃ max. ppb</u>	<u>Temp. °F</u>	<u>Wind Dir.</u>	<u>Max. CN</u>	<u>Type</u>
9/13/78	1515	1730	23	20	50	N.A.	6K	Inter.
9/14/78	1300	1450	18	20	64	N.A.	6K	Inter.
9/18/78	1430	1030	5	20	50-52	N.A.	3K	Inter.
9/19/78	1645	1745	5	20	43	N.A.	9K	Inter.
9/23/78	0130	0500	6	22	53-57	N.A.	2.4K	Inter.
9/23/78	1600	1615	8	16	73	N.A.	.7K	Inter.
9/28/78	0800	1230	19	34	57-67	295-007	.9K	Inter.
9/29/78	1200	1500	25	34	60-65	295-004	.9K	Inter.
10/1/78	0215	0315	12	32	60	306-360	8.1K	Inter.
10/1/78	0815	1500	23	34	50-67	0-360	10.5K	Inter.

Table E.2. (continued)

Date	Start	End	SO ₂ max. ppb	ΔO ₃ max. ppb	CCN	Temp. °F	Wind Dir.	Neph.
10/2/78	1230	1645	43	26	10K	51-53	320-11	
10/4/78	2240	130	25	34	30K	51.5-60.3	320-360	
10/4/78	215	250	7	32	16K	45.6-48.5	328-360	
10/4/78	1200	1210	9	22	10K	53	328-360	
10/4/78	1350	1410	21	28	11K	46-54	306-360	
10/4/78	1510	1535	11	18	30K	52.9-54	338-360	
10/4/78	1545	1845	43	32	30K	50-52.4	328-360	
10/5/78	120	135	2	20	8K	29.7	338-360	
10/5/78	825	840	2	14	6K	41	328-360	
10/5/78	905	935	4	14	30K	41-42.6	320-360	
10/5/78	940	1100	17	20	30K	44-42.6	306-360	
10/5/78	1210	1220	4	14	30K	45.5-47	320-360	
10/5/78	1220	1240	2	8	30K	41	320-25	
10/5/78	1240	1250	9	12	>30K	48.5	328-25	
10/5/78	1250	1310	14	18	>30K	48.5	331-360	
10/5/78	1355	1435	10	20	>30K	48.5-50	335-18	
10/5/78	1625	1785	2	18	>30K	44-50	324-29	
10/8/78	620	640	9	14	3K	57.4	310-342	
10/8/78	900	920	5	10	4.5K	55.8-60.3	313-349	
10/8/78	1235	1305	6	16	6.6K	61.8-63.2	310-356	
10/8/78	1310	1340	5	20	>30K	64.7	317-360	
10/8/78	1525	1535	4	16	>30K	44.7	342-360	
10/8/78	1615	1650	3	12	>30K	63.2	140-47	
10/8/78	1710	1725	3	18	16K	58.8-60.3	346-43	
10/9/78	155	205	3	10	1K	51.5	317-335	
10/10/78	1725	1740	2	16	24K	67.6	313-331	
10/10/78	1750	1755	2	18	10K	66.0	295-328	
10/10/78	2120	2130	2	16	13K	66.2	306-331	
10/10/78	2140	2150	2	14	16K	66.2	2990320	
10/10/78	2215	2230	2	16	18K	66.2	310-328	
10/11/78	130	150	6	26	0.3K	51.5	338-360	
10/11/78	150	210	4	18	3K	57-59	338-360	
10/11/78	330	460	7	28	3K	55.4	324-360	

Table E.2. (continued)

Date	Start	End	SO ₂ max. ppb	ΔO ₃ max. ppb	CCN	Temp. °F	Wind Dir.	Neph.
10/11/78	1120	1140	7	26	1K	51-54	162-18	
10/11/78	1215	1245	7	14	1K	51-54	299-18	
10/11/78	1330	1440	5	16	3K	53-57	251-18	
10/11/78	1410	1430	8	20	2K	53-54	169-18	
10/11/78	1450	1505	5	10	0.3K	53-54	331-47	
10/11/78	1510	1535	9	26	2K	54-57.4	320-18	
10/11/78	1605	1635	5	20	1K	47	313-360	
10/11/78	2010	1045	5	16	30K	45.6-47	198-40	
10/11/78	2340	2355	4	20	6K	41.2-42.6	245-360	
10/12/78	2440	140	16	32	15K	38-39.7	249-360	
10/12/78	730	815	16	24	24K	34-39.7	320-360	
10/12/78	820	845	4	16	0.3K	39.7	320-356	
10/12/78	830	900	23	22	7.8K	34-39.7	281-360	
10/12/78	910	1000	6	10	1.2K	38.7-42.1	306-356	
10/12/78	1030	1120	3	14	2.4K	42.6-45.6	295-356	
10/12/78	1130	1140	3	16	3.6K	45.6	184-360	
10/12/78	1210	1219	3	14	7K	44.8-47.8	306-360	
10/12/78	1220	1245	6	26	8.7K	46.3	324-360	
10/12/78	1250	1318	11	28	14K	45.6-47	295-360	
10/12/78	1320	1350	4	16	6.6K	45.6-48.5	306-360	
10/12/78	1550	1600	3	20	26K	45.6-46.3	310-29	
10/13/78	Zero	Span 1315-1615						
10/14/78	1910	1918	10	26	4.5K	57.4-58.8	310-335	
10/14/78	1814	1900	5	16	17K	58.1-58.8	317-346	
10/14/78	1640	1735	6	26	26K	58.8-63.2	295-14	
10/16/78	1314	1318	7	30	4.8K	64.7-66.2	65-360	
10/16/78	1935	1950	6	12	6K	60.3	310-344	
10/21/78	0620	0640	7	10	6K	53	331-360	
10/24/78	1720	1820	20	28	24K	42-43	N.D.	
10/24/78	1540	1645	7	24	12K	44-46	N.D.	
10/24/78	1235	1350	26	30	20K	53-54	N.D.	
10/24/78	1010	1030	26	26	10K	59-63	313-360	
10/24/78	1846	1925	12	26	8K	42		

Table E.2. (continued)

Date	Start	End	SO ₂ max. ppb	ΔO ₃ max. ppb	CCN	Temp. °F	Wind Dir.	Neph.
10/24/78	2046	2145	22	24	10K	36		
10/24/78	2345	140	9	14	17K	32	N.D.	
10/25/78	1945	2050	6	12	7K	40-41	N.D.	
10/26/78	1305	1510	26	34	10K	61-66	N.D.	
10/28/78	150	240	8	32	>30K	41-38	N.D.	
10/28/78	850	1005	6	14	24K	51-49	N.D.	
10/28/78	1145	1350	8	22	23K	66-59	N.D.	
10/29/78	1510	1655	14	36	28K	43-51	N.D.	
10/29/78	2015	2045	5	26	7K	33-35	N.D.	
11/3/78	940	1135	29	32	17K	59-63	N.D.	
11/3/78	1215	1325	15	24	16K	59-62	N.D.	
11/4/78	1335	1515	26	42	9K	54-60	N.D.	
11/5/78	1100	1240	6	16	1K	39-45	N.D.	
11/17/78	1820	1835	24	32	3K	32-35	335-360	
11/17/78	1950	2150	23	24	7K	13-18	310-344	
11/18/78	2220	320	34	26	5K	4.4-13	306-356	
11/18/78	440	515	13	14	1K	3	330-352	
11/22/78	225	235	10	16	4K	1.5	356-360	
11/22/78	310	320	5	20	7K	1.5	313-324	
11/26/78	2145	2415	9	10	3K	25	302-356	
11/27/78	2440	145	9	12	3K	22-23	310-360	
11/27/78	220	250	17	20	3K	22	304-349	
11/28/78	1250	1305	28	30	10K	35	292-349	
11/28/78	1470	1445	15	24	17K	34	313-346	
12/4/78	225	230	14	22	4K	31	306-338	
12/4/78	320	340	9	24	5K	22	313-346	
12/4/78	720	740	10	26	5K	20.6	292-342	
12/4/78	2035	2245	29	22	22K	19	306-360	
12/12/78	425	640	64	32	5K	29-34	292-349	N.D.
12/12/78	935	1140	43	16	25K	28-31	306-349	N.D.
12/12/78	1210	1345	28	24	30K	26	324-356	N.D.
12/12/78	1600	1625	6	10	9K	24	320-356	N.D.
12/12/78	1710	1840	25	22	8K	22-24	302-349	N.D.

Table E.2. (continued)

Date	Start	End	SO ₂ max. ppb	ΔO ₃ max. ppb	CCN	Temp. °F	Wind Dir.	Neph.
12/18/78	1850	1905	8	12	2K	18	292-310	27
12/18/78	1955	2010	6	28	6K	18	320-346	34
12/18-12/19/78	2355	2440	8	20	2K	14	299-342	23
12/19/78	200	420	19	22	5K	13-15	299-346	34
12/19/78	515	845	15	22	5K	11-13	277-349	38
12/19/78	1710	1805	18	22	3K	20	288-331	23
12/19/78	1900	2000	5	14	6K	19-19	302-331	27
12/21/78	1125	1156	51	22	9K	25-37	306-349	61
12/21/78	1230	1340	30	28	9K	24	306-349	46
12/21/78	1355	1510	24	24	8K	24-26	320-360	38
12/21/78	1640	1740	27	30	9K	21-25	306-349	23
12/22/78	2120	2131	11	18	8K	29	313-346	23
12/22/78	2150	2220	12	24	6K	29	306-349	19
12/22/78	2235	2320	16	20	8K	28	295-360	23
12/22-12/23/78	2330	2430	16	24	9K	26	313-349	23
12/24/78	955	1020	8	10	3K	32-37	306-310	15
12/24/78	1330	1350	7	14	7K	31-32	306-313	15
12/24/78	1510	1515	8	20	3K	29	310-356	19
12/24/78	2015	2130	32	28	4K	22-28	295-356	23
12/24/78	2145	2315	40	30	3K	22	302-349	27
12/27/78	1355	1420	61	40	N.D.	15-16	130-3.6	19
12/28/78	2450	140	16	22	N.D.	7	317-353	42
12/28/78	150	305	15	18	N.D.	6	299-356	42
12/28/78	405	430	9	18	N.D.	3	302-346	49
12/28/78	540	625	13	22	N.D.	1.5	310-335	42
12/28/78	835	845	10	10	N.D.	<0	310-328	65
12/28/78	930	945	10	14	N.D.	<0	310-349	42
12/29/78	915	935	11	10	N.D.	<0	306-353	19
12/29/78	1520	1540	12	16	N.D.	<0	155-349	19

TABLE E.3.A. Power Plant Plume Intercepts Kluver West

Date	Start MST	End	SO ₂ max. ppb	ΔO ₃ max. ppb	Temp. °F	Wind Dir. °N
3/28/78	1430	1556	5			
3/29/78	1028	2000	13			
3/30/78	1204	1228	8			
3/30/78	1512	1600	5			
4/5/78	0512	0612	2			
4/5/78	0720	0808	8			
4/8/78	0816	1124	26			
4/17/78	0304	1008	5			
5/3/78	1350	1430	5			223-317
5/10/78	1210	1235	9	18	67	259-306
5/10/78	1350	1355	4	16	56	288-310
5/10/78	1635	1645	4	8	56-57	248-299
5/10/78	1705	1725	4	14	56-57	259-324
5/10/78	1755	1845	9	18	58-59	230-306
5/11/78	1610	1700	6	28	48-56	256-324
5/12/78	0340	0405	3	22	43	263-310
5/12/78	0505	0600	5	28	41-44	256-313
5/22/78	0930	1100	19	30	70-74	234-338
5/24/78	0800	1330	19	16	61-65	266-334
5/30/78	1715	1730	6	16	46	237-266
6/1/78	1645	1700	8	20	54	252-324
6/4/78	1130	1330	11	18	71-74	220-342
6/5/78	1000	1800	6	10	71-78	250-334
6/6/78	0700	0830	14	16	70-74	262-324
6/6/78	1000	1245	15	18	74-79	262-316
6/6/78	1405	1430	7	10	71-74	194-270
6/6/78	1610	1715	5	10	59-63	187-338

TABLE E.3.B. Power Plant Plume Intercepts Kluver East

<u>Date</u>	<u>Start MST</u>	<u>End</u>	<u>SO₂ max. ppb</u>	<u>ΔO₃ max. ppb</u>	<u>Aitken nuclei</u>	<u>Temp. °F</u>	<u>Wind Dir.</u>
5/8/78	1900	1910	7	-	-	46	202-238
6/1/78	1705	1735	8	16	0.3K	57	238-324
6/12/78	0935	1000	11	4	8.4K	79-83	277-331
6/16/78	0720	1135	13	16	6.3K	64-71	162-331

The (K) suffix on the Aitken nuclei values denotes multiplication by 1000.

TABLE E.3.C. Power Plant Plume Intercepts Kluver North

<u>Date</u>	<u>Start</u>	<u>End</u>	<u>SO₂ max. ppb</u>	<u>ΔO₃ max. ppb</u>	<u>Aitken nuclei</u>	<u>Wind Spd. mph</u>	<u>Wind Dir.</u>
7/27/78	1410	2000	11	8	2.3K	0-7	234-072
8/4/78	1120	1200	5	20	7.5K	-	198-360
8/4/78	1221	1620	9	12	4.4K	-	-

TABLE E.4. Power Plant Plume Intercepts at Greenleaf

<u>Date</u>	<u>Start</u>	<u>End</u>	<u>SO₂ Max.</u>	<u>ΔO₃ Max.</u>
			ppb	
09/23/78	1539	1600	3	7
09/25/78	1140	1154	4	7
09/28/78	0815	0954	7	21
09/29/78	0754	1545	6	13
10/01/78	0636	--	10	22
10/02/78	0135	--	4	18
10/04/78	0927	0945	3	8
10/29/78	1622	1630	1	15
11/03/78	1124	1303	7	9
11/04/78	2124	2151	2.5	6

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