12.0 DISCUSSION OF THE PLUME TRANSPORT AND DISPERSION

This discussion of the transport and dispersion of the plumes begins with an analysis of the ground level sulfur hexafluoride tracer data, because it is these results which most unambiguously define the plume geometry. The reader can gain an excellent impression of the main features of the observations in the South Coast Air Basin by looking at the highway traverse data in Figures E-1 through E-7 in Appendix E. Those results show that (1) about half-way between the plants and the Puente Hills the plume was well defined at ground level and had an approximately Gaussian profile, (2) the plume was found in almost exactly the same location each afternoon, and (3) the dispersion of the plume was greatly increased on passing over the Puente Hills. The reproducibility of the plume trajectory on each of the six test days is also apparent in Figure 12-1 in Section 12.1.4, which shows the stations in the sampling network at which the SF_6 plume tracer was detected.

The following discussion contains the results of an examination of all of the data collected by the cooperating contractors, and constructs a reasonably complete picture of the transport and dispersion of the plumes for the participating power plants during the time period of this study. This Section carries the analysis as far as determining the plume trajectories and the ground level concentrations due to the plume. The discussion of the plume impact in comparison with the impact of other sources, and in comparison with air quality standards, is contained in Section 14.0.

12.1 GROUND LEVEL SULFUR HEXAFLUORIDE DATA

The primary reason that the sulfur hexafluoride tracer measurements are so useful for determining the plume geometry is that enough SF_6 was injected at the stack that the concentrations observed in the field were typically well above those due to other sources. In addition, a gas chromatograph with an electron capture detector is so sensitive that the concentration of the released SF_6 can be measured several tens of kilometers downwind. However, SF_6 from

other sources was not entirely negligible in this study, so an analysis of the background readings is an important part of this discussion. It is found that some SF_6 readings are due to other sources, and therefore can be eliminated from further consideration. The discussion on which this conclusion is based is rather extensive, because care should always be taken when selecting data. The result of this examination of the SF_6 data is a consistent and highly useful description of the transport and dispersion of the plume; no other segment of the data from this study can equally well identify the stations where the plume impact was small or zero.

12.1.1 Estimation of SF_6 Levels due to Other Sources

The design of the SF_6 ground level measurements included taking data in the field for one or two hours before the start of the release of SF_6 from the stack. During this time, the observed SF_6 must be from other sources, and the readings obtained at this time provide a measure of their importance. In the South Coast Air Basin data, it is safe to assume that no SF_6 remained from the previous test day because the test days were always separated by several days, and it was typically observed that the SF_6 on each test day was swept out of the basin on a time scale of hours after the end of the SF_6 release each afternoon. However, the following analysis does not give any information on how the concentration of SF_6 due to other sources varies during the day.

In the South Coast Air Basin, the SF_6 release was begun at 9:00 a.m. PST on the first test day, October 1, and at 10:00 a.m. PST on all subsequent test days. Since the levels of SF_6 due to other sources varied significantly from station to station, the results were analyzed separately for each station. Table 12-1 gives the number of readings, and the maximum and mean values for all data for each station before the start of the SF_6 release, and the standard deviation of readings about the mean. In addition, the number of non-zero readings as well as the mean and standard deviation of these readings is tabulated to give more information on the distribution of values obtained.

It can be seen that no site was free of detectable levels of SF_6 from other sources. However, for the stations between the power plants and the Puente Hills,

TABLE 12-1

SF_6 Readings Before Start of the SF_6 Releases

in the South Coast Air Basin

Caltech Number	Name	All Readings				Non-Zero Readings		
		Number	Maximum	Mean	Std. Dev.	Number	Mean	Std. Dev.
1	Long Beach APCD	5	10.1	4.1	4.9	3	6.8	4.4
2	Anaheim F.S.#2	8	5.4	2.9	1.4	8	2.9	1.4
3	Palm Harbor Medical Center	8	7.8	2.3	3.2	4	4.7	3.1
4	Fullerton F.S.#2	9	19.1	5.1	5.8	7	6.6	5.85
5	Whittier APCD	9	21.1	5.1	6.3	8	5.8	6.4
6	Lynwood APCD	8	19.9	7.8	6.1	8	7.8	6.1
7	Orange F.S.#3	8	6.1	3.1	1.7	7	3.6	1.2
8	Fullerton F.S.#5	8	6.7	2.7	2.7	5	4.3	2.0
9	Anaheim F.S.#8	9	2.6	0.5	1.0	2	2.4	0.4
10	Lennox APCD	9	21.6	6.2	7.6	6	9.3	7.6
11	L.A. Downtown APCD	9	7.3	2.7	2.9	5	4.9	1.7
12	Baldwin Park	2	3.9	2.0	2.8	1	3.9	-
13	Diamond Bar F.S.	2	4.7	3.1	2.3	2	3.1	2.3
14	Featherly Park	3	5.6	1.9	3.2	1	5.6	-
15	Walnut F.S.	2	4.2	2.1	3.0	1	4.2	-
16	Azusa APCD	9	8.8	2.8	2.9	6	4.2	2.5
17	Pomona APCD	9	28.4	10.8	10.1	6	16.2	7.7
18	Chino APCD	4	9.9	6.0	3.1	4	6.0	3.1
19	Corona F.S.	7	11.6	4.5	4.6	5	6.3	4.1
20	Riverside F.S.#8	3	7.0	3.3	3.5	2	4.9	3.0
21	Riverside Central	9	6.2	3.8	2.4	7	4.8	1.4
22	San Bernardino APCD	9	7.7	2.3	2.6	6	3.5	2.4
	Mean		10.3	3.9				
	Standard Deviation		7.0	2.3				

the concentrations of SF_6 due to the plume were enough greater than those due to other sources that the data are easily interpreted. Perhaps the greatest problems with other sources of SF_6 arise at Pomona. This is an interesting station, because it appears that the plume passed over this station each test day. However, the dispersion of the plume is greatly increased by the Puente Hills, so that peak concentrations are much lower than they are on the ocean side of the hills. Because the largest impact of SF_6 from other sources is observed at Pomona, these data are somewhat masked by SF_6 from other sources.

12.1.2 Comparison with an Earlier Ground Level SF_6 Release in Anaheim

Before examining the SF_6 data further, it is helpful to look at the results of an earlier SF_6 release in the South Coast Air Basin. On 19 July 1973, Drivas and Shair (10) released 33.5 kg of SF_6 in Anaheim and observed its arrival in Pomona, Riverside, San Bernardino, Cajon Pass, and Palm Springs. In that experiment, a larger release rate was used for a shorter period of time, so that pulses of SF_6 were observed in the field. In addition, the syringes were filled quickly rather than over a integrating time of one-hour. As a result, it was much simpler to distinguish SF_6 due to the tracer release from SF_6 due to other sources. The results of this earlier release are considered here to obtain an estimate of the SF_6 levels which might be expected in the present study at the sites east of the Puente Hills.

The release rate in Anaheim was 33.5 kg in 45 min, or 12.4 g sec^{-1}. The highest concentration observed inland was 28 ppt at Riverside, 55 km away. Lesser concentrations were observed at Pomona, which was not in the path of maximum concentration, and at more distant sites. The release rates used in the present study ranged between 5.14 and 8.97 g sec^{-1}. Had one of these limiting release rates been used in the Anaheim study, the Riverside maximum would have been either 11.6 or 20.2 ppt.

The power plants are about 15 km farther from Riverside than the ground level release point used in the earlier study, but the release was continuous rather than being a 45 min pulse. Therefore, it is expected that similar dispersion conditions to those observed in the earlier study would lead to SF_6 concentrations in the range of 10 to 20 ppt in Riverside on those occasions in which the plume

trajectory goes over that location. Tracer concentrations in this range were observed in Riverside or San Bernardino in five of the six South Coast Air Basin test days.

12.1.3 Discussion of the SF_6 Data for 7 November 1974

The data for 7 November are unusual in that SF_6 was observed in widely scattered stations which had not seen SF_6 in the earlier test days. Because these observations do not fit the general pattern of a plume which is well defined and which follows the same path each day, it is worthwhile to examine them in some detail.

There are 19 SF_6 concentrations above 50 ppt reported for this day. In addition, there were two much higher readings which were questionable, and therefore were not included in the final report (3). The following comparison of the remaining 19 readings with other data available at the same site or nearby locations shows that nine of them are probably due to SF_6 sources other than the tracer release at the Alamitos Generating Station.

Table 12-2 lists seven times when high concentrations of SF_6 were observed while the SO_2 concentration recorded at the same station remained low and constant. The SO_2 concentrations predicted from the SF_6 readings are calculated both for the case in which the plumes from Haynes and Alamitos remain separate, and the case in which they are well mixed.

The Lynwood readings are the ones most clearly due to other sources. For the two late afternoon readings, this conclusion is also supported by the wind patterns both at the surface and aloft, which were such that the plume could not have been carried to Lynwood. At Pomona, only the 10 to 11 hour reading can be ruled out on the basis of wind data. The tracer release began at 10, and the winds were not strong enough to carry the SF_6 47 km to Pomona in less than one hour. Sulfur hexafluoride readings between 10 and 40 ppt are observed at Pomona most of the afternoon, and these are quite likely due to the tracer release at Alamitos. The high reading for the afternoon of 36.8 ppt SF_6 at 16-17 hours is accompanied by an increase in the sulfur dioxide concentration from 1 pphm to 2 pphm (20 ppb), which is the high SO_2 reading for the day. The SO_2

TABLE 12-2

SF_6 Readings on 7 November 1974 not Accompanied by SO_2

Station			Reported	Predicted SO_2 ppb		Observed
Caltech No.	Name	Hour PST	SF_6 ppt	Both Plants	Alamitos Only	SO_2 ppb
6	Lynwood APCD	12-13	162	64	38	10
		17-18	117	46	28	10
		18-19	73.3	29	17	10
16	Azusa APCD	15-16	63.5	25	25	10 (AMC)
						10 (APCD)
17	Pomona APCD	10-11	80.0	32	19	10
		19-20	95.7	38	23	10
		20-21	56.0	22	13	10

concentration predicted from the SF_6 reading on the assumption that the plumes from Haynes and Alamitos are well mixed is 14.5, which agrees well. Therefore, this SF_6 reading is certainly due to the tracer release.

The dispersion of the plume shown in the highway traverse data in Figures E-3 and E-4, and in Figure 12-5, support the assumption that the plumes from Haynes and Alamitos are well mixed in Pomona. Therefore, the predicted SO_2 values in Table 12-2 for both plants should be used, leading to predicted SO_2 concentrations enough higher than observed that the SF_6 readings are easily classified as being due to other sources.

The SF_6 reading at the Azusa APCD station was not accompanied by SO_2. Both the AMC and the APCD instruments gave constant readings during this time, whereas a 20 ppb increase in the one-hour average would have been expected if the SF_6 were due to the tracer release. The second highest SF_6 reading at Azusa is 9.4 ppt. For these reasons, the highest reading of 63.5 ppt is probably due to other sources.

It is also believed that the readings between 14 and 15 hours of 139 ppt at Orange Fire Station No. 3 (site 7) and 71.9 ppt at Anaheim Fire Station No. 8 (site 9) are due to other sources. Figures E-5 and E-6 in Appendix E show automobile traverse data taken at the same time on a nearby highway in which the plume is well defined and well removed from these stations. The airplane data for this day also shows a well defined plume, not one which is broken up in a way that would be needed to explain the above data. Therefore, it is believed that all of the nine SF_6 readings discussed above are due to other sources, and can be omitted from the tracer data considered in this study. The remaining SF_6 data fit the general pattern observed on other test days very well, and there is no reason to question them. As summarized in Table 12-3, five of the remaining readings are corroborated by SO_2 readings at the same site at the same time, and five of the SF_6 readings are not accompanied by nearby data which can be used to demonstrate their validity.

12.1.4 Comments on the SF_6 Data by Station Location

In this section, the results from each ground station location are considered

TABLE 12-3

Classification of the SF_6 Readings Above 50 ppt on

7 November 1974

Station Caltech No.	Station Name	Corroborated by SO_2 Data	No Comparison Data	Due to Other Sources	Basis for Assignment to Other Sources
2	Anaheim F.S. No. 2	3			
4	Fullerton F.S. No. 2	2			
6	Lynwood APCD			3	No SO_2
7	Orange F.S. No. 3		1	1	Does not match traverse
9	Anaheim F.S. No. 8			1	Does not match traverse
13	Diamond Bar F.S.		2		
15	Walnut F.S.		2		
16	Azusa APCD			1	No SO_2
17	Pomona APCD			3	No SO_2
	TOTALS	5	5	9	

and the frequency of observation of the SF_6 tracer is determined. The results of this analysis are summarized in Figure 12-1, which is a modified version of the map of the station locations in Figure 7-2. The result of this discussion is clear evidence that the trajectory of the plume is quite reproducible from day-to-day.

1. Long Beach APCD. No SF_6 due to the tracer release was observed here. The highest and third highest readings (10.1 and 8.6 ppt) were observed before the start of the tracer release, and the second highest reading (8.7 ppt) was observed one to two hours after the end of the release at a time when the winds at plume height carried the plume directly away from this ground station.

2. Anaheim Fire Station No. 2. The impact of the plumes carrying the tracer were about equal here and at Fullerton Fire Station No 2, and significantly above that at any other station. As shown in Table 12-1 and by the frequent low readings during the time of the tracer release, very little SF_6 from other sources is seen at this site.

3. Palm Harbor Medical Center. Only four readings above 5 ppt SF_6 were obtained after the start of the tracer release. They are: 8.1 ppt at 14-15 hr on 11 October, 13.0 ppt at 12-13 hr on 24 October, and 9.8 ppt at 10-11 hr and 17.6 ppt at 11-12 hr on 7 November. The highest reading before the start of the tracer release was 7.8 ppt. Therefore, there may have been one or perhaps two small observations of SF_6 tracer at this location, but the station is classified in Figure 12-1 as one at which tracer was never seen.

4. Fullerton Fire Station No. 2. The amount of SF_6 due to other sources is somewhat higher at this site than at Anaheim Fire Station No. 2, but otherwise the comments on data taken there apply equally well to the results from this site.

5. Whittier APCD. This site also has more than the usual amount of SF_6 from unwanted sources. During the tracer release, SF_6 concentrations in the 10-20 ppt range are quite common, but only five are higher. The readings of 38.5 ppt and 25.3 ppt early on 7 November may be due to

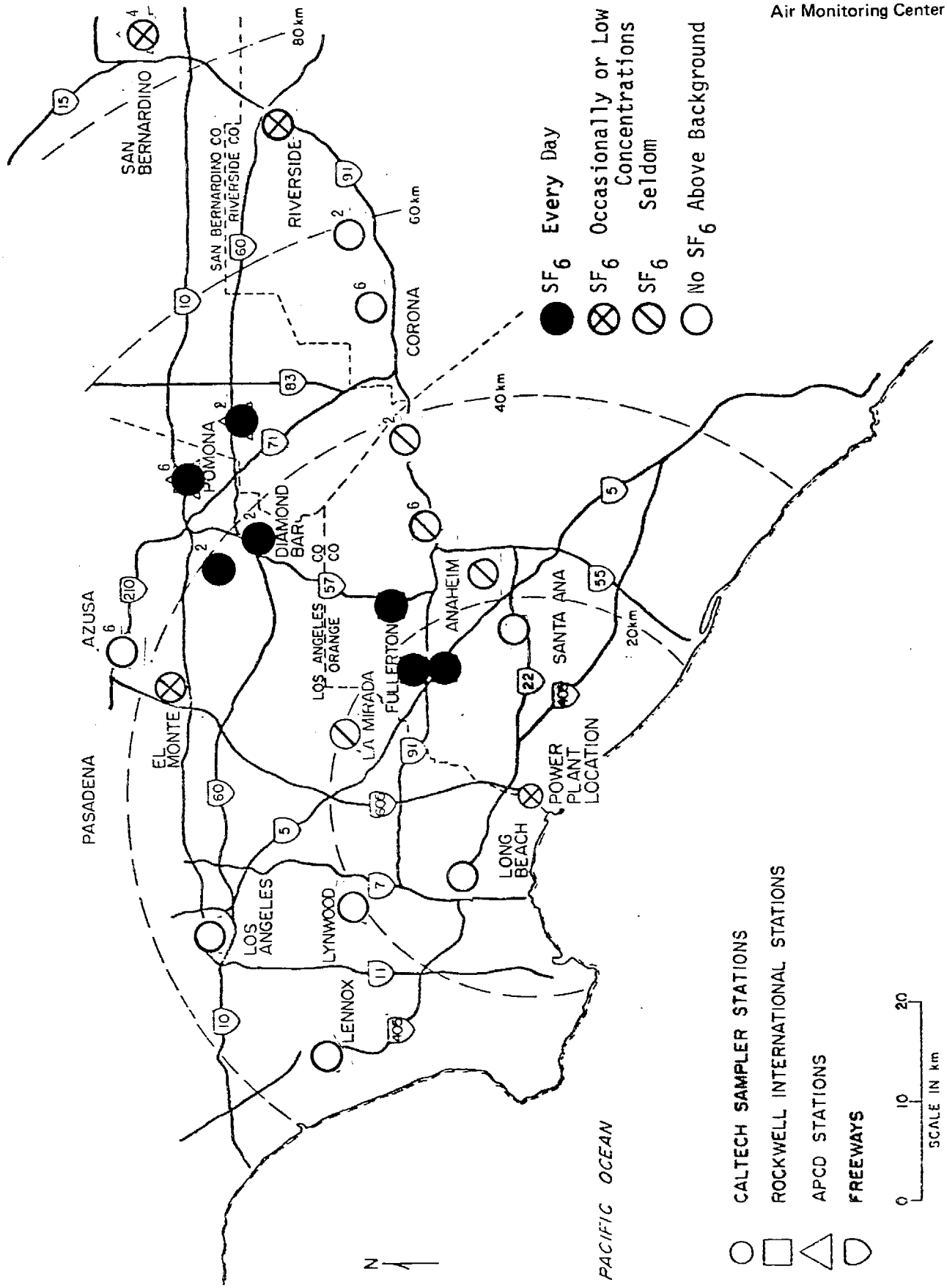

Figure 12-1. Summary of Fixed-Station SF_6 Observations

other sources. (They follow a reading of 21.1 before the start of the tracer release.) This station is classed as one at which the tracer is seldom seen.

6. Lywood APCD. No SF_6 due to the tracer release was observed at this station. The concentrations of SF_6 due to other sources observed before the start of the tracer release are only second to Pomona. Also, it was shown in the previous section that the three highest readings on 7 November are due to other sources. Therefore, the remaining data on 7 November and the reading of 22.1 ppt at 16-17 hr on 17 October are assigned to other sources.

7. Orange Fire Station No. 3. The SF_6 tracer is seldom seen at this location. The best reading is 24.5 ppt at 12-13 hr on 25 October. The highest reading on 7 November has been assigned to other sources, and it is quite possible that some of the other readings on this day are also due to other sources.

8. Fullerton Fire Station No. 5. This station ranks third in observed concentrations of the SF_6 tracer. Tracer due to the plume was seen on each of the five test days this station was operated.

9. Anaheim Fire Station No. 8. This station had the lowest values of any for the SF_6 concentrations before the start of the tracer release. SF_6 due to the plume was observed only twice: 25.0 ppt at 13-14 hr on 17 October, and 28.0 ppt at 13-14 hr on 25 October. The highest reading on 7 November has been assigned to other sources, and it is likely that the other readings on this day are not due to the plume tracer. The highest SF_6 reading not listed here is 7.7 ppt.

10. Lennox APCD. No SF_6 concentrations significantly above those due to other sources was observed at this location.

11. Los Angeles Downtown APCD. No SF_6 concentrations significantly above those due to other sources were observed at this location.

12. Baldwin Park. This station was operated only on the last two test days, and SF_6 was observed twice: 20.2 ppt at 14-15 hr on 30 October, and 39.4 ppt at 16-17 hr on 7 November.

13. Diamond Bar Fire Station. This station was operated only on the last two test days, but SF_6 readings beginning at 14 hr and continuing for the rest of the day were observed both days.

14. Featherly Park. This station was used only for the first two days of the study, and the highest reading was 13.9 ppt at 11-12 hr on 11 October. Thus, a small amount of the plume may have briefly reached this site on one day.

15. Walnut Fire Station. This site was used only on the last two days of the study. The readings were not as consistent as those at Diamond Bar, and usually not as large. Therefore, this site could be equally well classed as one in which SF_6 was seen every day or one at which SF_6 was seen occasionally.

16. Azusa APCD. No SF_6 concentrations significantly above those due to other sources were observed at this location. When the reading due to another source on 7 November is omitted, the next highest reading during the tracer release is 9.4 ppt, which is to be compared with a reading of 8.8 before the start of the tracer release.

17. Pomona APCD. The SF_6 tracer was seen at this station on all six test days. However, the plume was appreciably dispersed by the Puente Hills before reaching this station, and the SF_6 concentrations before the start of the tracer release are higher there than at any other station. Therefore, the contribution of the plume to the readings is often comparable to that of other sources, and the data are usually difficult to interpret except on a statistical basis. The impact of the plume in Pomona compared to that of other sources is estimated in Section 14.1.

18. Chino APCD. This station was used only on the second and third test days, and significant amounts of SF_6 tracer were seen on both days. The impact of the plume is greater here than at the Walnut Fire Station.

19. Corona Forest Fire Station. This station was operated on all test days, and saw no SF_6 at concentrations above those due to other sources.

The reading of 21 ppt at 10-11 hr on 7 November was too soon after the start of the tracer release to have been due to that release.

20. Riverside Fire Station No. 8. This station was operated only on the first two days of the study, and the SF_6 concentrations observed after the start of the tracer release were essentially the same as those observed before the start of the release.

21. Riverside Central Fire Station. This station was operated on all days, and the SF_6 levels in the 10 to 20 ppt range were observed on all days except 30 October. The comparison in Section 12.1.2 with an earlier tracer release shows that this is the concentration range to be expected. Therefore, it appears that the plume had a small impact on this location on nearly all test days.

22. San Bernardino APCD. Data are available from this station for the first four test days. Concentrations in the expected range were seen on the first three test days, but none on 25 October. The reading of 75 ppt at 16-17 hr on 11 October is higher than expected, and does not fit the pattern of the remaining results.

The fact that a few SF_6 readings due to other sources are included among the hundreds of SF_6 readings taken in this program should not be allowed to obscure the importance of the tracer data. For any other parameter measured in the field, it is common for pollutants from other sources to totally obscure the concentrations due to the plume, rather than to influence only a few results. The extensive discussion of the impact of other sources of the SF_6 data is included in this report because care should always be taken when discarding it from an analysis. Once the readings from other sources are removed from consideration, a very clear picture of a well defined plume which follows the same trajectory on each test day emerges from the SF_6 data. To some extent, this picture is presented in Figure 12-1.

12.1.5 Frequency of Occurrence of Elevated SF_6 Concentrations

Table 12-4 lists the frequency of occurrence of elevated SF_6 concentrations

TABLE 12-4

Frequency of Occurrence of Elevated SF_6 Concentrations as a Function of the Time of Day

Station Caltech No.	Station Name	SF_6 Concentration Range ppt	Time of Day Pacific Standard Time AM 8-9	9-10	10-11	11-12	PM 12-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	Total
2	Anaheim F.S. #2	Below 30	3	5	5	3	4	3	2	2	3	5	4	5	2	46
		30-49				1		1	1				1			4
		50-69					1									1
		70-89						1	1	1						3
		90-109							1							1
		110-159								1	1					2
		160-Up								1	1					2
		TOTAL	3	5	5	4	5	5	5	5	5	5	4	4	2	59
4	Fullerton F.S. #2	Below 30	4	6	6	5	3	6	2	1	1	4	6	6	1	51
		30-49				1	1		1	1	3	1				8
		50-69					1			3						4
		70-89							1							1
		90-109							1							1
		110-159					1		1	1		1				4
		160-Up									2					2
		TOTAL	4	6	6	6	6	6	6	6	6	6	6	6	1	71
8	Fullerton F.S. #8	Below 30	4	5	5	5	4	3	5	3	3	3	5	5	1	51
		30-49					1	1			1	1				4
		50-69								1	1					2
		70-89						1		1						2
		90-109										1				1
		110-159														0
		160-Up														0
		TOTAL	4	5	5	5	5	5	5	5	5	5	5	5	1	60
17	Pomona APCD	Below 30	4	6	4	5	5	5	5	3	3	3	2	2		47
		30-49			1	1	1	1		2	2	1	2	2	1	13
		50-69								1	1	2		1	1	6
		70-89							1				2			3
		90-109														0
		110-159														0
		160-Up														0
		TOTAL	4	6	5	6	6	6	6	6	6	6	6	5	1	69

as a function of the ground station location and the time of day for the four sites where the greatest impact was observed. The format of this table is similar to the one used for the SO_2 data in Section 7.6. The purpose of this table is to give an overview of the times and locations where the plume impact is the greatest as the plume is transported downwind and dispersed.

This table does not include the SF_6 readings due to other sources identified in Section 12.1.3. It does include one reading at Pomona which may be influenced by other sources. The 88 ppt reading at 14-15 hr on 11 October gives a predicted SO_2 concentration of 46 ppb, but the observed SO_2 concentration was 20 ppb.

When examining these data, it should be remembered that the SF_6 release ended at 5:00 p.m. on most test days, so the SF_6 readings at Stations 2, 4, and 8 would be expected to fall to zero shortly after 6:00 p.m. even if the plume impact continued at these sites. On the other hand, significant amounts of SF_6 were observed in the 7:00-8:00 p.m. samples at Pomona on three of the six test days, and the one 8:00-9:00 p.m. sample also contained 58 ppt SF_6. Therefore, the impact of the plume continued past the end of the day in Pomona. As expected, the peak SF_6 readings in Pomona are lower than those recorded closer to the source.

The data in Table 12-4 show a very similar impact of the plume at Stations 2 and 4, in contrast to the SO_2 data. Both the SO_2 and SF_6 data from these stations are discussed in Section 12.2.2.

12.1.6 Highway Traverse SF_6 Data

The sulfur hexafluoride tracer data taken in automobile traverses along the Santa Ana Freeway (Interstate 5) and the Pomona Freeway (U.S. 60), shown in Figures E-1 through E-7 in Appendix E, provide an excellent summary of the information obtained in this program on the dispersion of the plumes from the studied power plants. The following quantitative information can be drawn from these traverses.

These traverses show that the ground level concentration on the Santa Ana

Freeway has an approximately Gaussian profile. The crosswind standard deviations σ_y of the observed profiles were determined and reported by Caltech (3), and were found to vary between 534 m and 2460 m, and to have a mean of 1046 m. This mean plume width at a distance of 15 km corresponds to Pasquill-Gifford stability class D.

The two traverses on the Pomona Freeway show that the dispersion of the plume is greatly increased by the Puente Hills. This is not unexpected, because the ridge of the hills fluctuates around 300 m (1000 ft.), and the airborne data show that much of the plume is below this elevation. The width perpendicular to the wind direction required to contain 90% of the SF_6 was determined for both of these traverses, and found to be 10 400 m on 25 October and 8 700 m on 30 October. Had the dispersion conditions experienced between the plant and the traverse on the Santa Ana Freeway continued to this distance, the width required to contain 90% of the plume would have been only 6000 m. Thus, the increased dispersion of the plume observed on the Pomona Freeway 30 km downwind is caused by the Puente Hills and may not be observed for similar plumes in other locations.

One property of these traverses that should be noted is that they were all taken between 14 and 16 hr. Thus, they serve to document the transport and dispersion of the plume only at that time in the afternoon. Even given this restriction in sampling times, it is remarkable how exactly the plume location is the same in each of the reported traverses.

There were three traverses which are not included in Appendix E because the plume was not seen. These runs were made on 7 November at 10:54 to 11:14, 11:51 to 12:10, and 12:50 to 13:08 hr. The MRI data show that the plume was headed in the general direction of the traverses at this time of day, so it is possible that atmospheric stability was such that the plume did not mix to the ground at these times, but the plume trajectory information is not good enough to prove this.

The Caltech report also contains estimates of the SF_6 flux at the Santa Ana Freeway based on the assumption that the plume is well mixed between the ground and the mixing height. The general agreement between the calculated fluxes and the release rates shows that this assumption is at least approximately valid. Further comments on this point are contained in Section 12.3,

where flux calculations based on airborne data are discussed.

12.1.7 Maximum Ground Concentrations Estimated from SF_6 Observations

One important role of the SF_6 tracer in this study is to separate the impact of the studied plumes from the impact of other sources on the data observed in the field. This separation is particularly important at times of high pollution levels, when the effects of pollution are the greatest and when the pollutant concentrations specified in air quality standards might be approached or exceeded. The data in Table 12-5 show the concentrations of SO_2, sulfate, and NO_x calculated from the higher SF_6 concentrations observed on the ground in this study. The tabulations include instantaneous values observed on the traverses, one-hour averages observed at the ground stations, and the two highest 24-hour averages determined from the ground station data on the reasonably reliable assumption that additional SF_6 would not have been observed in Fullerton or Anaheim had the release and sampling extended for the full day. The use of this assumption in the South Coast Air Basin is strongly supported by the data in Tables 7-26 through 7-32.

The calculations are based on the emission rate data in Table 9-12. In the South Coast Air Basin, the calculations are done twice; once considering only emissions from the plant at which SF_6 was released, and then again on the assumption that the emissions from both of the participating power plants are well mixed. These data are used in Section 14 in the discussion of the impact of the plumes in relation to other sources and to air quality standards.

12.1.8 Moss Landing Sulfur Hexafluoride Data

The levels of SF_6 from other sources are much lower near Moss Landing than in the South Coast Air Basin. The mean of all readings taken before the start of the tracer release is 1.7 ppt SF_6, the high reading is 8.1 ppt, and approximately half of the readings are zero.

The bar graphs and isopleths in the Caltech final report (3) clearly show the areas of plume impact on the three test days. On 10 September, there was

TABLE 12-5

Maximum Ground Concentrations Estimated from SF_6 Observations

Date 1974	Location Code[a]	Sampling Duration	SF_6 Concentration ppt	Equivalent Concentrations SO_2 ppm One Plant[b]	SO_2 ppm Both Plants	$SO_4^{=}$ $\mu g/m^3$ One Plant[b]	$SO_4^{=}$ $\mu g/m^3$ Both Plants	NO_x ppm One Plant[b]	NO_x ppm Both Plants
Moss Landing									
11 Sept.	#9	24 Hour	49	0.007		0.8		0.0005	
11 Sept.	#4	Hour	420	0.062		7.3		0.042	
11 Sept.	E.Blanco Rd	Inst.	640	0.094		11.1		0.064	
12 Sept.	#5	Hour	257	0.0		0.0		0.019	
South Coast Air Basin									
1 Oct.	#4	24 Hour	19	0.004	0.009		0.7	0.004	0.009
1 Oct.	#4	Hour	245	0.046	0.120	3.6	9.5	0.056	0.112
11 Oct.	#17	Hour	88	0.022	0.046	1.8	3.7	0.028	0.047
11 Oct.	I 5	Inst.	257	0.064	0.134	5.2	10.8	0.088	0.136
17 Oct.	#4	Hour	121	0.025	0.062	2.0	4.9	0.031	0.058
17 Oct.	I 5	Inst.	215	0.044	0.110	3.5	8.8	0.055	0.103
25 Oct.	#4	Hour	164	0.029	0.047	2.3	3.8	0.021	0.046
25 Oct.	I 5	Inst.	309	0.055	0.089	4.4	7.1	0.040	0.087
25 Oct.	Cal 60	Inst.	143	0.026	0.041	2.1	3.3	0.018	0.040
30 Oct.	#2	24 Hour	23	0.005	0.010		0.8	0.004	0.008
30 Oct.	#2	Hour	314	0.074	0.132	5.9	10.5	0.058	0.112
30 Oct.	I 5	Inst.	174	0.041	0.073	3.3	5.8	0.032	0.062
30 Oct.	Cal 71	Inst.	71	0.015	0.028	1.3	2.4	0.013	0.025
7 Nov.	#4	Hour	132	0.031	0.052	2.5	4.2	0.023	0.042
7 Nov.	I 5	Inst.	233	0.055	0.092	4.4	7.4	0.041	0.075

(a) Caltech station number or route number.
(b) Only emissions from plant at which SF_6 was injected are included.

a strong inversion which kept the plume from mixing to the ground. On 11 September, strong, steady winds carried the plume down the Salinas Valley, where high concentrations were detected by several ground stations. On 12 September, the plume traveled more nearly toward the east, and was not as narrow as on the previous day. Therefore, much more day-to-day variation was observed in the three Moss Landing test days than in the six days in the South Coast Air Basin. Further reviews of the meteorology and plume trajectories observed near Moss Landing are contained in the Caltech (3) and MRI (6) reports. Those discussions do not require further amplification here.

12.2 GROUND LEVEL SULFUR DIOXIDE DATA FROM THE FIXED STATIONS

The general pattern of the plume transport and dispersion which emerge from the examination of the SF_6 tracer data is entirely consistent with the ground level SO_2 data. In part, this results from using some SO_2 data to eliminate SF_6 readings due to other sources, and hence to influence the conclusions already drawn from the SF_6 data.

This section continues the development of information about the transport and dispersion of the plume. Because SO_2 is emitted from so many sources in the South Coast Air Basin, the SO_2 results are primarily used to estimate the plume impact where that impact is high. In these cases, the SO_2 data have the advantage that they are more easily obtained than the SF_6 data, and hence are available for much longer periods of time.

12.2.1 Sulfur Dioxide to Sulfur Hexafluoride Ratios

The primary reason for computing the ratio of the concentrations of sulfur dioxide to sulfur hexafluoride in the field and comparing these ratios with those determined at the sources is to see if conversion of SO_2 into other chemical forms in the atmosphere can be detected. In addition, these ratios serve to compare the SO_2 and SF_6 results to aid in obtaining information about the transport and dispersion of the plume.

The ratios calculated from the data taken in the Moss Landing phase of the

study are reported in Tables 7-3 and 7-4. It is only on these two occasions that the Moss Landing plume was observed at a station where both SO_2 and SF_6 were measured when the plant was burning oil. Similar ratios were calculated for the data taken in the South Coast Air Basin of the study, except that the concentration of SO_2 due to other sources was estimated and subtracted from the field data before taking the ratio. These results are not contained in this report because they varied at random from half to twice the expected value, and therefore are of limited use.

The reason for this variation is quite understandable and easily explained. The SF_6 was injected in only one stack, but the SO_2 was emitted from a number of stacks separated by as much as 900 m. The plume dispersion was not great enough to mix these gases before they reached the field locations where the data of interest were taken. An example demonstrating this is shown in Figure 12-2. Here, the solid line represents the concentration of SF_6 determined in the highway traverse shown in Figure E-5 in Appendix E. The SF_6 was injected at Unit 6 of the Alamitos Generating Station on this test day. The dotted line shows this same profile displaced by an amount equal to the component of the separation of the Haynes and Alamitos power plants which is perpendicular to the plume axis. The dotted curve has also been reduced by a factor of 4140/6380 = 0.66, which is the ratio of the SO_2 emission rates at the two plants. Therefore, the dotted line shows the data that might have been obtained had 0.66 as much SF_6 been injected at Haynes.

The sum of the two curves would represent the SO_2 concentration profile to be expected at the time the traverse was made. It can be seen that the SO_2/SF_6 ratios predicted by these profiles are far from constant. On the left side of the figure, the ratio is that for the emissions from Alamitos only. The ratio increases with increasing distance along the highway, and has much larger values at distances of 7 to 8 km. Therefore, a fixed ground station sampling the plume would not be expected to observe a SO_2/SF_6 concentration ratio which is related to the source strengths in a useful way. In most other traverses, the plume width was significantly smaller than in this example, so the mixing of the plumes is usually even less complete than shown here.

The above discussion of the comparison of SF_6 and SO_2 data applies primarily

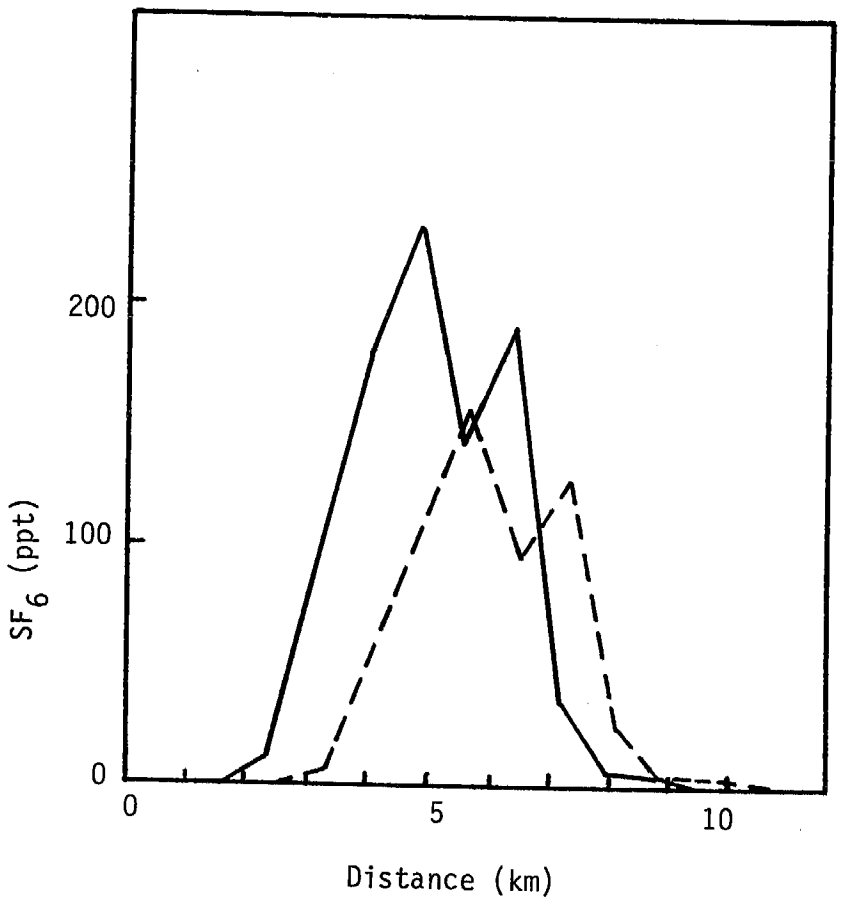

Figure 12-2. A comparison of the plume width on the Santa Ana Freeway (I-5) with the power plant separation when the mixing of the plumes is greater than usually observed.

to instantaneous readings, or to relatively short averaging times such as one-hour. It is expected that these effects would average out over longer periods of time, so that plume impacts measured by either SF_6 or SO_2 would be comparable. However, the discussion in the following section of the data taken at Fullerton Fire Station No. 2 and Anaheim Fire Station No. 2 shows that this is not always the case.

12.2.2 Sulfur Dioxide Impact in Fullerton and Anaheim

The greatest sulfur dioxide impact at any of the ground stations used for this program was observed at Fullerton Fire Station No. 2 (Caltech No.4, AIHL No. 0), which is 17.4 km (10.8 mi) northeast of the power plants. The next greatest impact was observed at Anaheim Fire Station No. 2 (Caltech No. 2, AIHL No. 1), which is 15.4 km (9.6 mi) northeast of the power plants. These two ground stations are 2.8 km (1.8 mi) apart on Brookhurst Street, and the component of their separation perpendicular to the plume axis is 2.2 km. It is interesting that even though these stations are quite close together, the SO_2 impact at them is appreciably different.

Continuous data are available for 41 days at Fullerton Fire Station No. 2, where the greatest impact was observed. The plumes were not detected at this station on only two of these days, and on six more days the impact was small enough that the SO_2 concentration in the plume was only 10 ppb or so above the surrounding levels. Significant increases in SO_2 concentrations due to the plume were observed on the remaining 33 days.

In general, the plume was present at these ground stations for only brief times on each day. To measure this duration, the width at half height at Fullerton Fire Station No. 2 was calculated for each day. This is the length of time the SO_2 concentration due to the plume was above half of the daily maximum value. October 13 and 14 were eliminated from this calculation because the SO_2 concentration due to other sources was quite high on these days. The mean width at half height was found to be 54 min, and the standard deviation about this mean was 30 min. The two longest times were 94 and 127 min. On many days, the plume was observed at the station more than once, but

the above calculation was done for only the highest reading on each day. It is believed that the coming and going of the plume during the afternoon was due more to slight changes in wind direction than to changes in the atmospheric stability.

Another measure of the plume impact is the distribution of values observed for the ratio χ/Q, where χ is the ground level SO_2 concentration and Q is the rate of SO_2 emission by the power plants. This distribution was constructed for the daily maximum one-hour average SO_2 concentrations, and is shown in Figure 12-3. However, these data contain a number of approximations, so they should be used with some caution. The only source strength data available for all 41 days were those tabulated by the APCD (13), so 24-hour average emission rates have been used rather than those appropriate for the time of day when the concentration maximum was observed. Also, no effort was made to estimate the fraction of the SO_2 due to other sources, and to subtract this from the observed maximum. Including this correction would substantially change the results at the lower SO_2 concentrations. However, it is the upper end of the concentration distribution which is of primary interest, and this correction would have a relatively minor effect on these results.

Figure 12-4 contains a χ/Q distribution for Anaheim Fire Station No. 2 which was calculated in the same manner as was Figure 12-3. For comparison, each figure contains a broken line representing the data on the other figure. It can be seen that the impact of the plume is appreciably less at this site than in Fullerton. This result is also apparent from a different presentation of the same data in Tables 7-26 and 7-28, where the frequency of SO_2 concentrations in specified ranges is tabulated. When the data in Table 7-26 are multiplied by a factor of 41/26 to put them on the same basis as those in Table 7-28, it is found that the Fullerton station observed SO_2 concentrations above 30 ppb three times as often as does the Anaheim station. The Fullerton station also observed concentrations above 40 ppb or 50 ppb three times as often. There are six observations equal to or greater than 70 ppb at Fullerton, but none at Anaheim.

Ideally, the distribution of $\chi U/Q$, where U is the wind speed at plume height, should be used in Figures 12-3 and 12-4. This was not done because of

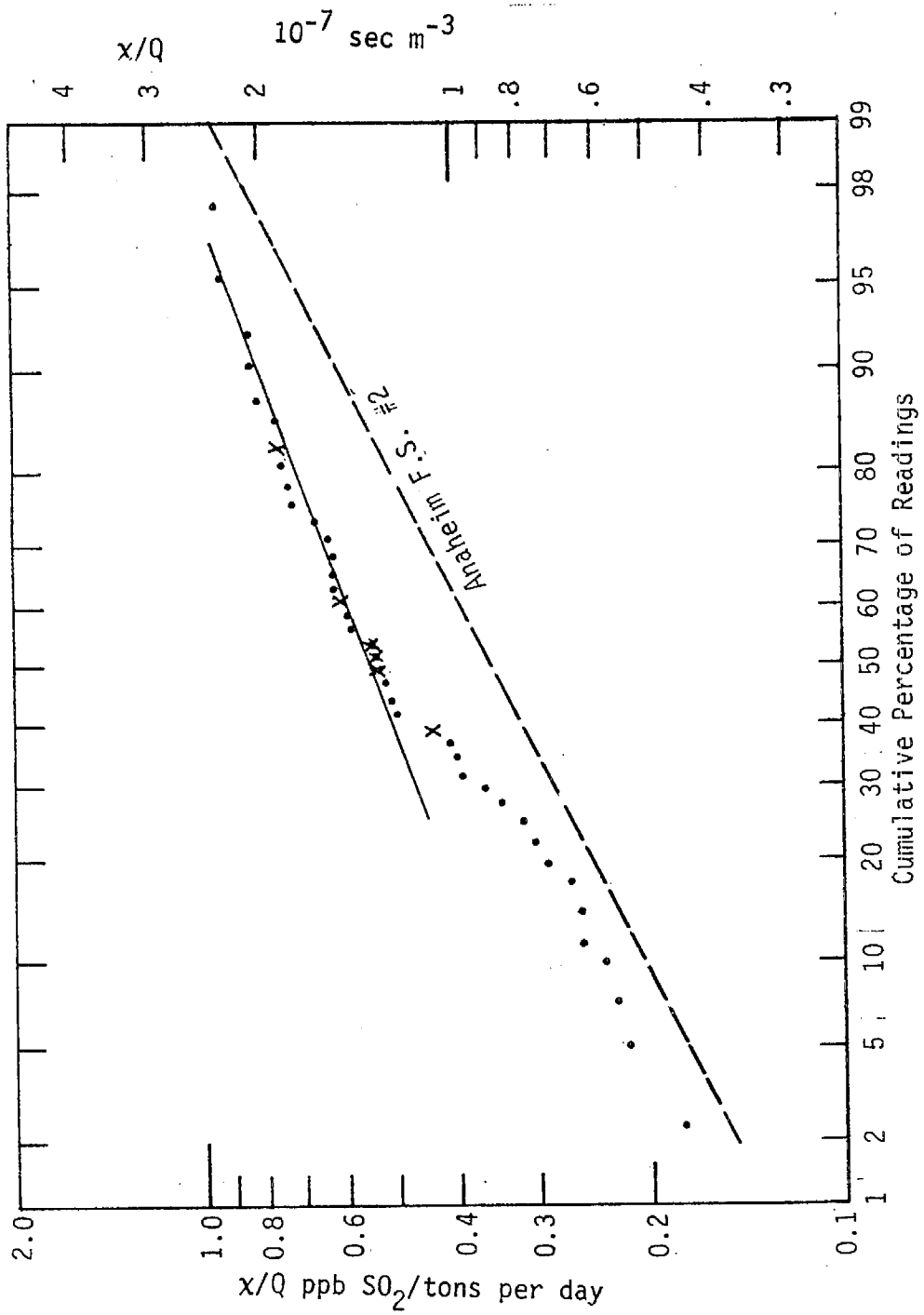

Figure 12-3. Cumulative Frequency Distribution of x/Q Values for Daily Maximum One-Hour Average SO_2 Concentrations for 41 Days at Fullerton Fire Station No. 2. Points for test days are indicated by X.

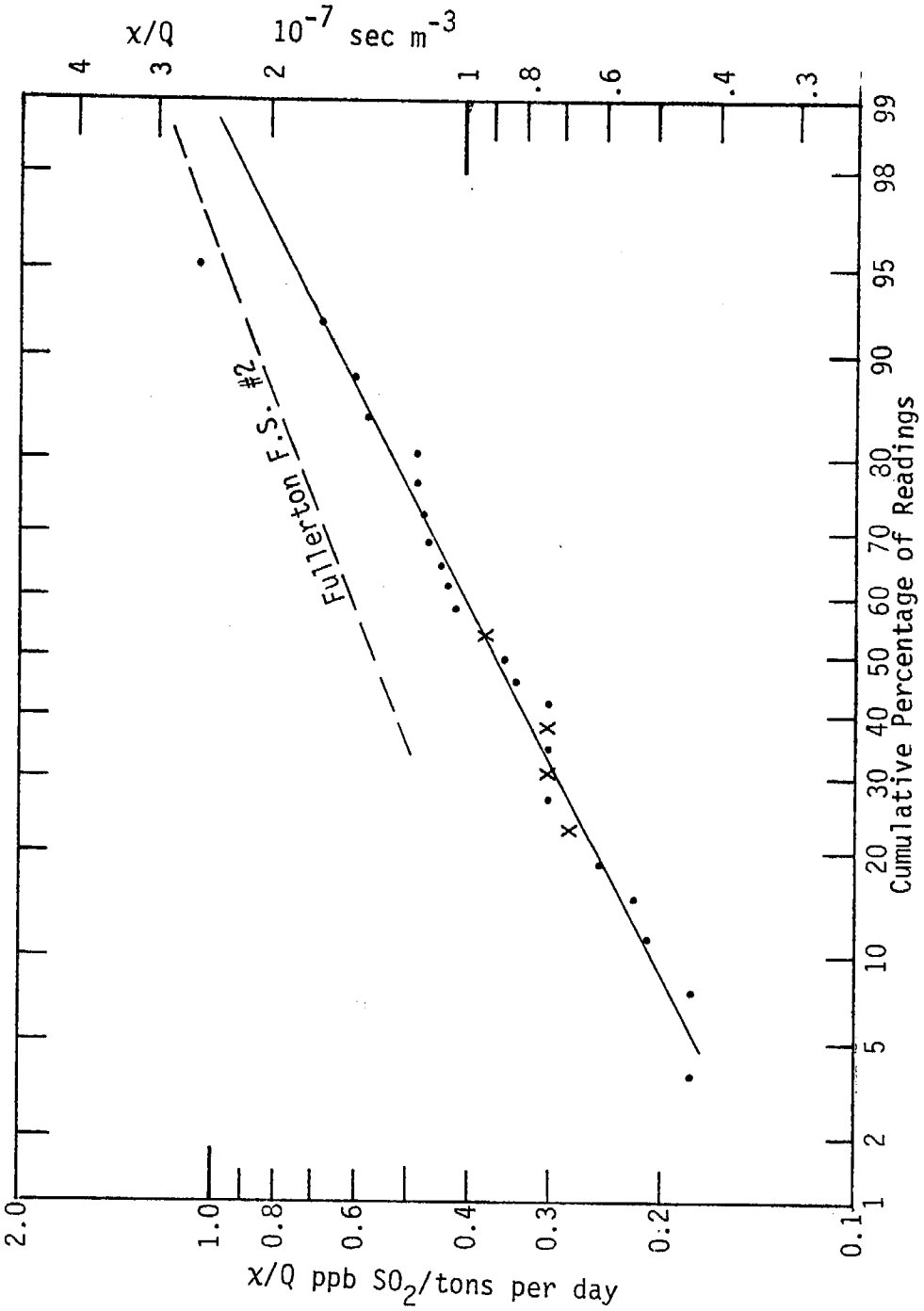

Figure 12-4. Cumulative Frequency Distribution of x/Q Values for Daily Maximum One-Hour Average SO_2 Concentrations for 26 Days at Anaheim Fire Station No. 2. Points for test days are indicated by X.

lack of ready access to the appropriate wind speed data. The advantage of using the ratio $\chi U/Q$ is that the results depend less on the meteorological conditions under which the data were collected, and hence become more general. The data in Figures 12-3 and 12-4 apply only to a distribution of meteorological conditions like those which occurred between 1 October and 10 November 1974.

The value of $\chi U/Q$ at these two stations can be calculated for the test days, when wind speed at plume height and hourly emission rate data are available. These results are given in Table 12-6. The total emissions from both plants have been used in these calculations. Because the plumes are incompletely mixed at these stations, a more correct calculation would use a somewhat smaller vaue for Q. The values of $\chi U/Q$ obtained here are appropriate for the C to D stability classes.

All the above data show that there is a significantly greater impact of the plume at the Fullerton station than the one in Anaheim. This result was double checked by placing the original strip chart records side-by-side, and comparing them. The differences were due to the plume impact, which can be easily evaluated because of the relatively short time the plume is present, and not due to differences in the background levels at the two stations. The difference between the impacts at the two stations is interesting, and somewhat unexpected, in view of the fact that the stations are separated by only 2.2 km in a direction perpendicular to the plume axis. This difference is a measure of the narrowness of the plume and the repeatability of its trajectory during the time period of the study.

As already noted, the SF_6 ground station data in Appendix E do not show this difference. This can be seen most clearly by comparing the frequency of occurrence data for the two stations in Table 12-4. On the other hand, the highway traverse SF_6 data in Figures E-1 through E-7 in Appendix E rather clearly show that a greater impact of the plume as measured by SF_6 is to be expected at the Fullerton station. An explanation for this difference between the SO_2 and SF_6 results has not been formulated. The difference is larger than the estimated uncertainties in the experimental results. Although it is not likely to be the case, it is possible that the plume trajectories were such that the different results were caused by the incomplete mixing of the plumes described

TABLE 12-6

Values of $\chi U/Q$ in Fullerton and Anaheim

Date 1974	Hour of Maximum PST	SO_2 Concentration χ (a) ppb	Wind Speed U m/sec	Emission Rate Q lb/hr	$\chi U/Q$ m^{-2}
Fullerton Fire Station No. 2					
1 October	16	75	4.0	9200	6.73×10^{-7}
11 October	15	54	3.0	8800	3.80×10^{-7}
17 October	12	53	2.8	8800	3.48×10^{-7}
25 October	15	52	3.4	9300	3.92×10^{-7}
30 October	18	46	4.0	9500	4.0×10^{-7}
7 November	17	67	5.0	10400	6.65×10^{-7}
Anaheim Fire Station No. 2					
11 October	14	26	2.0	8800	1.22×10^{-7}
17 October	15	28	2.8	9200	1.76×10^{-7}
25 October	12	28	2.0	8800	1.31×10^{-7}
7 November	15	53	5.0	10400	5.26×10^{-7}

(a) χ = Maximum one-hour SO_2 concentration on each test day.

in Section 12.2.1.

Because two ground stations so close together observe such different impacts from the plume, it is logical to ask if another nearby location might observe an even greater impact. The highway traverse data show that the Fullerton station was at least close to being on the plume axis, but it is entirely possible that a significantly higher plume impact might have been observed at a nearby location. These data show that either a very dense, or a very carefully placed network of ground stations is required if fixed stations are to be used to characterize the impact of power plant plumes in the South Coast Air Basin.

It appears that no APCD station is well situated to observe the impact of the plumes from the Haynes and Alamitos power plants under the meteorological conditions encountered in this study. The one which comes closest is the Los Alamitos-Orangewood station, which is discussed next.

12.2.3 Sulfur Dioxide Impact at the Los Alamitos-Orangewood APCD Station

A description of the location of this station and a summary of the data observed there have been presented in Section 10.2. The station is 7 km from the plant, and the results developed earlier in this section makes it seem likely that the plume usually travelled slightly to the north of this APCD station during the period of this study.

The highest peak SO_2 concentrations observed at any ground station were recorded here. However, the plume was observed at this station much less frequently than it was at the Fullerton Fire Station No. 2. It is quite likely that there is a sampling location near or slightly north of a line between these two stations at which the plume would be seen nearly every day at concentrations appreciably higher than those observed in Fullerton.

Neither a χ/Q nor a $\chi U/Q$ distribution has been prepared for this station because of the difficulty of identifying with certainty the impact of the plume. The highest SO_2 concentrations observed at a time when wind speed and emission rate data were available occurred on 1 October 1974. In this case, the peak concentration was 0.16 ppm at 15 hr, when the wind speed at the 300 m

plume height was 4.5 m/sec and the SO_2 emission rate from both plants was 9350 lb/hr. The calculated value for $\chi U/Q$ is 1.6×10^{-6} m^{-2}. Standard Gaussian plume calculations for C stability and a plume height of 300 m gives a maximum value of $\chi U/Q$ of 1.6×10^{-6} m^{-2} at a distance of 4 km, and a value of about 1.0×10^{-6} m^{-2} at the 7 km distance appropriate for the station (16). Therefore, the observed concentrations are slightly higher than those calculated for C stability.

The search of the data taken at this station between March and December 1974 for SO_2 concentrations above 0.1 ppm showed that such concentrations occurred only in the hours between 8 and 18, and that most such concentrations occurred between 11 and 16 hr. These results are given in Tables 10-6 and 10-7. The fact that the frequency of elevated SO_2 concentrations follows the same pattern as the intensity of the solar heating of the ground implies that fumigation is a dominant mechanism leading to plume impact at this station. In a coastal location such as the one studied here, it is possible for fumigation conditions to continue for extended periods of time, rather than to occur only during the breakup of a radiation inversion in the morning (17).

12.2.4 Sulfur Dioxide Impact at Other Ground Stations

It is not possible to learn more about the plume transport and dispersion from a discussion of the SO_2 data at the other South Coast Air Basin ground stations than has already been learned from the SF_6 data. The reason is that stations out of the direct path of the plume receive the majority of the observed SO_2 from other sources, so the SO_2 concentration due to the plume cannot be accurately estimated.

In contrast to the South Coast Air Basin data, the SO_2 and SF_6 data from the Moss Landing test days agree with each other very well. In addition, the test days were consecutive, so SO_2 and SF_6 data were taken on the same number of days. Therefore, the SO_2 data do not add to the information on the plume transport and dispersion which can be obtained from an examination of the SF_6 results.

12.3 COMPARISONS BETWEEN GROUND LEVEL AND AIRBORNE DATA

In those cases where there is an opportunity to compare ground level and airborne data, the agreement is satisfactory. The general results from this comparison are as follows:

a. The crosswind plume width determined from the airborne data (Table 5-1 of reference 6) is generally smaller than determined from the ground level SF_6 traverses (Table 8 of reference 3).

b. Airborne and ground level maximum concentration data at 16 km are similar. For example, on 25 October the maximum SO_2 concentration at 1000 ft (305 m) elevation at the Santa Ana Freeway (Interstate 5) was 0.08 ppm, while a one-hour average concentration of 0.052 ppm was observed at the same time slightly further downwind at Fullerton Fire Station No. 2.

The observation of similar concentrations at 300 m elevation and on the ground indicates that the plume is well mixed to the ground at a distance of 16 km. This observation is supported by the success of the SF_6 flux calculations in Table 7 of the Caltech report (3), where it is assumed that the SF_6 concentrations between the ground and the mixing height are the same as those measured on a highway traverse. Furthermore, the data in Tables 6-20 and 6-21 of the MRI report (6) show that the flux of SO_2 and SF_6 at elevations above 300 meters is a small fraction (usually less than 10%) of that emitted from the plant. On the basis of these observations, it is recommended that models of the plume in the South Coast Air Basin be adjusted so that the plume is well mixed in the vertical direction between the ground and the mixing height at a distance of 16 km. The figure of 16 km in this recommendation arises from the fact that the Santa Ana Freeway, Anaheim Fire Station No.2, and Fullerton Fire Station No. 2 are all about this distance from the source, so this is the distance at which ground level data are available.

While discussing the data taken aloft, it is interesting to note that the plume trajectories calculated for each South Coast Air Basin test day from the pibal data show much more variability than do the observed trajectories. When

the predicted and observed trajectories differ, the one derived from the pibal data is usually further south. The discrepancy is perhaps the greatest on 11 October. These differences between the observed and calculated trajectories give a measure of the problems which are to be expected when modeling the plume.

The first test day near Moss Landing stands out as being different from all of the others. On this day, there was a strong inversion which prevented the mixing of the plume to the ground. As a result, neither SO_2 nor SF_6 were observed in significant concentrations anywhere on the ground on that test day. Also, as reported in Table 6-19 of the MRI report, the flux of SF_6 and SO_2 emitted from the stacks could be accounted for by flux calculations based on the airplane traverse data.

Inversions are common along the California coast. On those occasions when it is possible to inject the plumes above the inversion, very low ground concentrations can be achieved. When the plume is injected below the inversion, ground level concentrations are enhanced by the inversion.

12.4 MOBILE GROUND LEVEL AND OVERHEAD BURDEN DATA FOR SO_2 AND NO_2

Environmental Measurements, Inc. operated a mobile laboratory on 10 and 11 September near Moss Landing and 11, 16, 17 and 30 October in the South Coast Air Basin (4). It was equipped with two Barringer COSPEC III correlation spectrometers which viewed the sky to determine the overhead burden of SO_2 and NO_2, a flame photometric sulfur gas analyzer, and a chemiluminescent NO-NO_x monitor. The overhead burden data were multiplied by the component of the wind velocity perpendicular to the road to determine the flux of the pollutant across the road.

In the following figures, the direction and speed of the wind used in the calculations are indicated in the lower left. The calculated flux in metric tons per day (MT/D) along each traverse is indicated by the length of the line extending in the wind direction from the roadway. The flux maps are reproduced from the EMI final report (4), except that a road map has been added as an inset and the route taken darkened so that it is possible to see where the data were taken. The start and end time of each traverse is indicated.

Figure 12-5 shows the SO_2 flux recorded on 11 October 1974. The plume trajectory evident in this figure is in excellent agreement with the SF_6 traverse data in Figure E-1 in Appendix E. In addition, this figure shows very clearly that the plume is difficult to distinguish once it has passed over the Puente Hills.

Figure 12-6 shows a similar record of the SO_2 flux obtained on 30 October, and again the plume location agrees well with the location found in the SF_6 traverse in Figure E-4. The plume is also easily distinguished further downstream between LaHabra and Brea, just before it goes over the Puente Hills.

Figure 12-7 shows SO_2 flux data obtained on 16 October, which was not a test day. It is reproduced here because it shows a plume trajectory which is different from the one observed on all six of the test days. Had SF_6 data been collected on this day, it is likely that a plume trajectory through the Santa Ana Canyon would have been observed. This is the trajectory that was expected to be the most common one when the fixed station sites were selected for the South Coast Air Basin phase of this study.

The highest ground concentration of SO_2 observed at any time during this study was recorded on a traverse along Interstate 605 north of the plants on 17 October. From a visual observation of the plume, it appeared that it was parallel to and almost directly over the highway (4). The highest concentrations were observed at 16:20 PST 8 to 9 km from the source, and were 290 ppb SO_2 and 320 ppb NO_x. For sulfur dioxide, the value of $\chi U/Q$ in this case is 1.8×10^{-6} m^{-2}. Table 10-5 shows that a SO_2 concentration almost this high was also recorded at the Los Alamitos-Orangewood APCD station.

EMI began its operations between 8 and 10 hr each day data were recorded, and observed well defined plumes on most mornings. These data stand out as the only morning plume trajectory data taken as part of this study. However, they are not included in the EMI final report, and so are not discussed here.

12.5 DRY DEPOSITION RATE CALCULATIONS

It is known that sulfur dioxide reacts with vegetation and with other

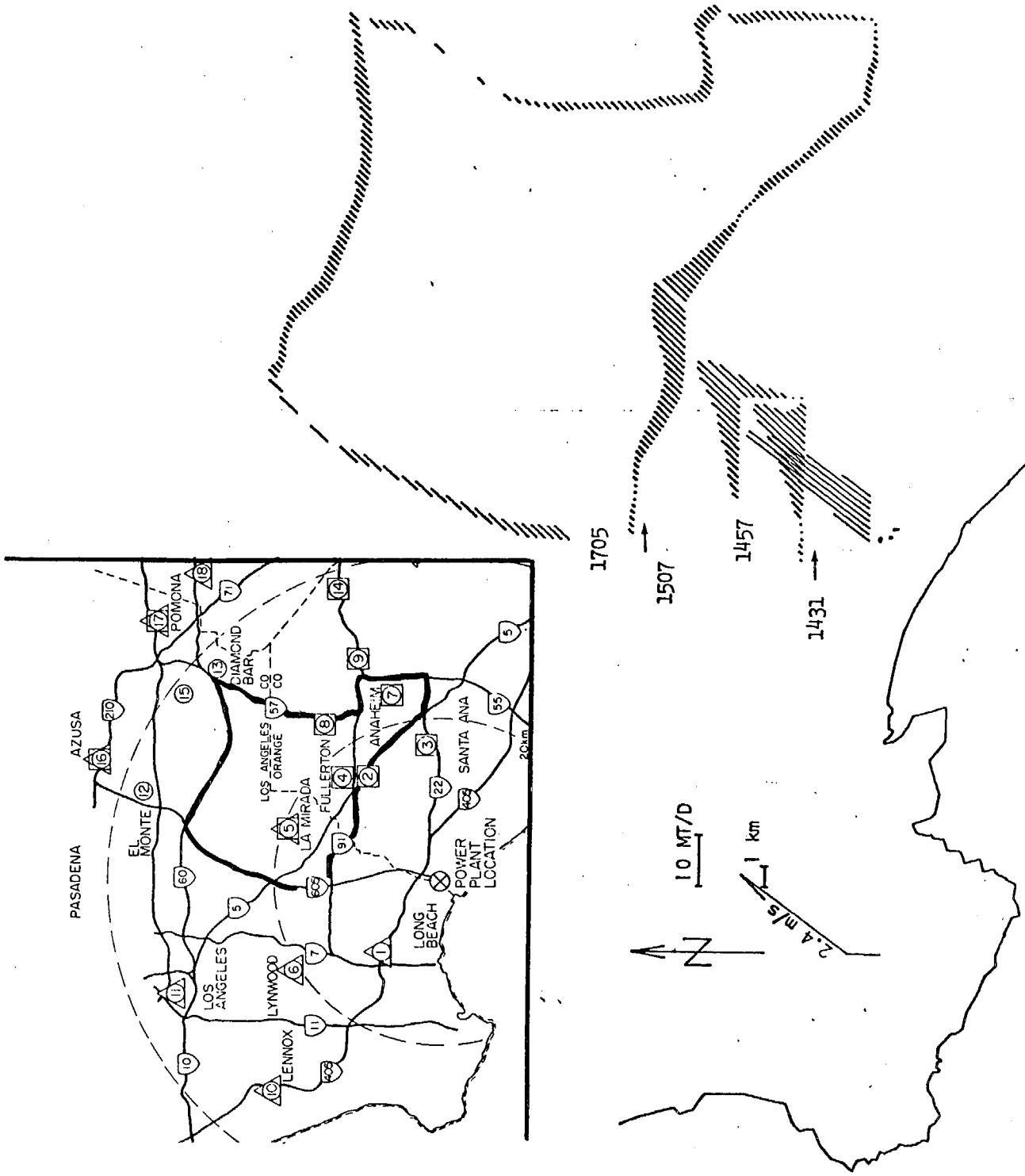

Figure 12-5. Sulfur Dioxide Flux Map for 11 October 1974

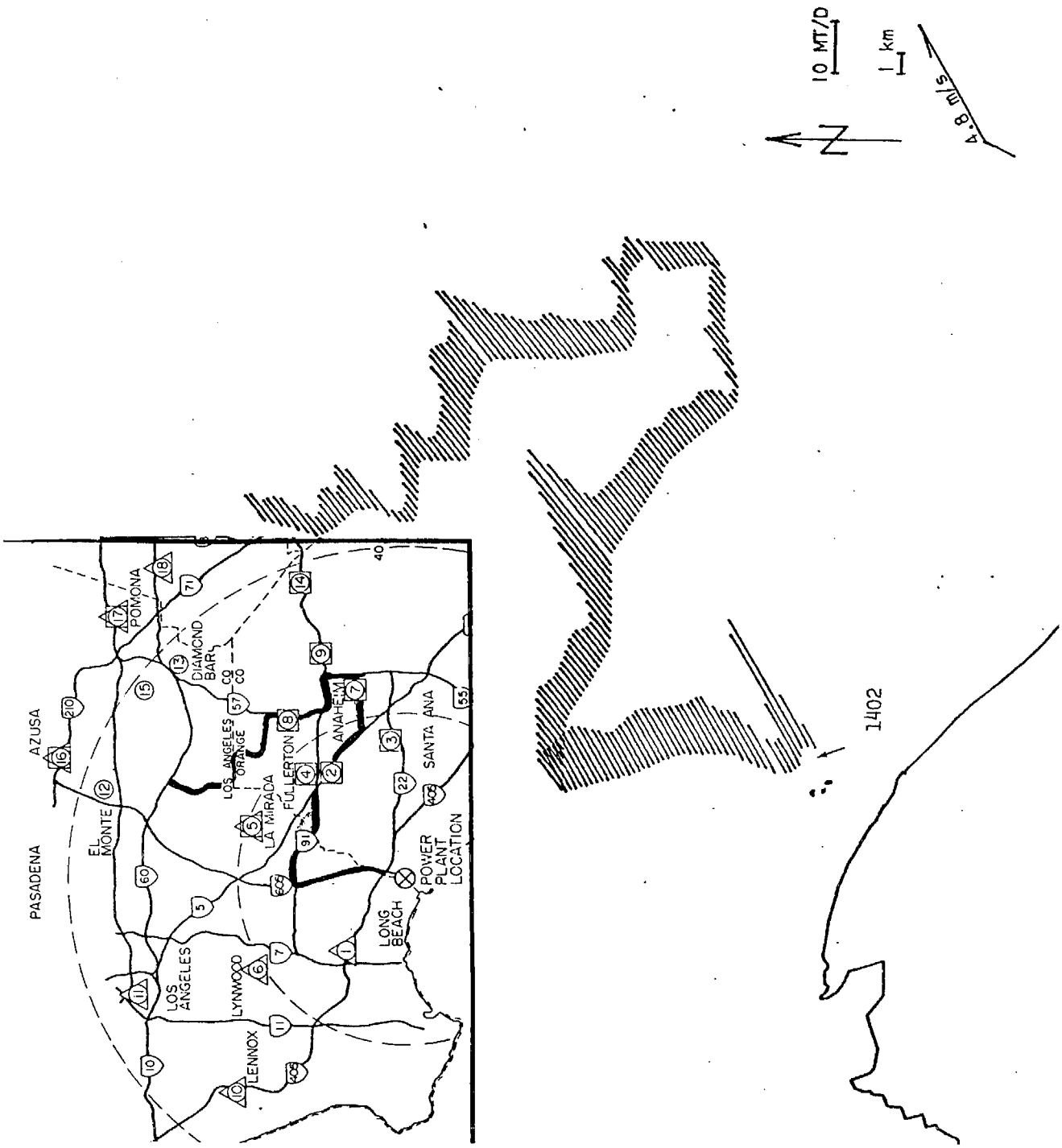

Figure 12-6. Sulfur Dioxide Flux Map for 30 October 1974

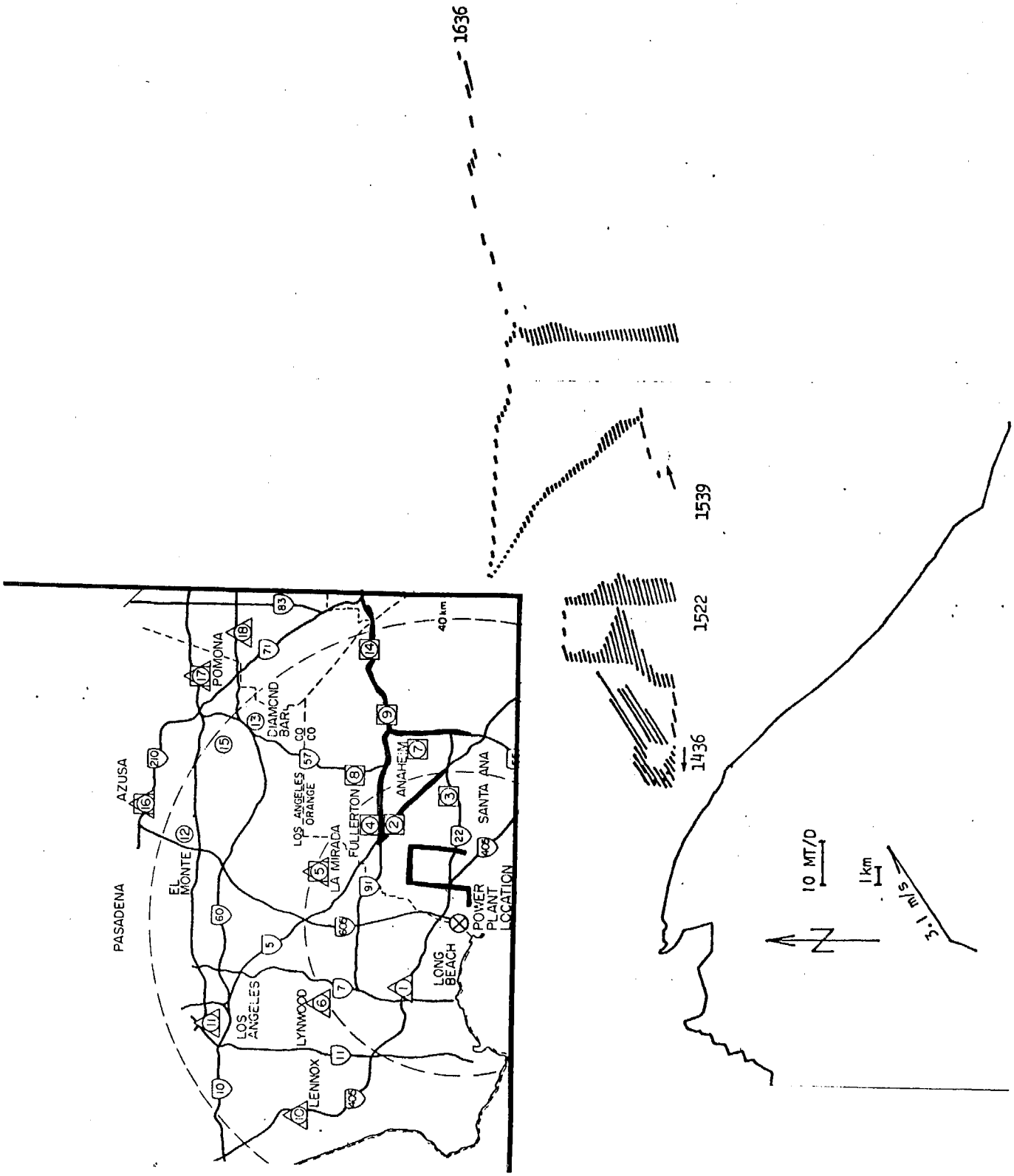

Figure 12-7. Sulfur Dioxide Flux Map for 16 October 1974

surface materials at appreciable rates, and that this process can remove important amounts of sulfur dioxide from the atmosphere (18). Therefore, expressions for the rate of this dry deposition process under conditions appropriate for the present study were developed and evaluated to see if this process is important in modifying the SO_2 concentrations observed near Moss Landing and in the South Coast Air Basin. It was found that dry deposition is expected to reduce the SO_2 concentrations in the plumes by only a few percent at the downwind distances at which data were taken, so these processes do not enter into the interpretation of the present data in an important way. Therefore, the details of the calculations are not given here.

The rate of reaction of SO_2 with the ground and other surfaces is usually proportional to the SO_2 concentration at the ground, and hence it can be expressed as a deposition velocity

$$V = (\text{deposition/surface area/time})/(\text{atmospheric concentration}) \quad .$$

The deposition velocity for various types of surfaces is not well established. Data obtained at a height of 1 m over grassland range between 0.3 and 2 cm/sec (see work summarized in (18)). Recent measurements over summertime vegetation near St. Louis, MO, gave values between 6 and 26 cm/sec (19). Because of the strong ability of vegetation in the above studies to absorb SO_2, it is expected that the deposition velocity in the part of the South Coast Air Basin traversed by the studied plumes will be in the low end of the range of rates observed for grassland, or perhaps even smaller. For purposes of example, the rate of 0.3 cm/sec is used in the following estimates.

Near the source, the SO_2 concentration profiles at the ground were derived from the Gaussian plume model. The crosswind dispersion of the plume does not influence the total deposition as a function of downwind distance. Therefore, only the vertical dispersion of the plume need be known. Calculations were done to determine the fraction of the SO_2 deposited to the ground in the first 16 km for an effective source height of 300 m, a wind velocity of 4 m/sec, and a deposition velocity of 0.3 m/sec. For B to C stability conditions, 1% of the SO_2 was deposited, and for E stability conditions, much less than 1% was deposited.

It is shown in Section 12.3 that the plume is usually well mixed to the ground by the time it has traveled 16 km. When the plume is well mixed between the ground and the mixing height L, the rate of ground deposition is given by the expression

$$Q \frac{v}{U} \frac{\Delta x}{L} = Q \frac{v}{L} \Delta t \qquad (12\text{-}1)$$

where Q is the source emission rate, U is the wind speed, Δx is the downwind distance over which deposition is considered, and Δt is the time required for the plume to be transported a distance Δx. For a mixing height of 300 m (which is smaller than that usually observed in this study) and a deposition velocity of 0.3 cm/sec, it is found that the SO_2 concentration in the plume decreases by 3.6% per hour. For a wind velocity of 4 m/sec, which is typical for many test days, the dry deposition decreases the SO_2 concentration by less than 0.3% per kilometer. Therefore, at the distances considered in this study, the decrease in SO_2 concentration due to dry deposition is not large enough to require its inclusion in the data analysis.

The 0.3% removal rate per kilometer multiplied by the SO_2 emission rate for the combined plants of approximately 9000 lb/hr gives a sulfur dioxide deposition rate of 27 lb/hr per kilometer of plume, or 43 lb/hr per mile of plume.

Rockwell International
Atomics International Division
Air Monitoring Center

13.0 DISCUSSION OF THE PLUME CHEMISTRY

It is a major objective of this study to determine the most important chemical processes taking place in power plant plumes in California, both in clean environments and in the presence of photochemical smog. In this section, the chemical data gathered in the study are examined, and it is shown that the only chemical process which clearly stands out in the data is the reaction of the emitted NO with ambient ozone to form NO_2. Therefore, this and other reactions of the nitrogen oxides are discussed first. Because of the indications from health effects studies that sulfates may be harmful to human health, there is great interest in the nature and rate of the processes which convert SO_2 into sulfates. Portions of this study were designed to measure the rate of this process, but it was found to be below the limit of detection. In fact, there are indications that sulfate is initially lost from the plumes under some circumstances rather than being formed in them.

After the discussion of the sulfur chemistry, the data from the chemical analysis of the filters is examined. The most interesting observations are that nitrate in the ambient aerosol can be volatilized by the acidity of the plume, and that vanadium levels in the plume may be just above the limit of detection. The section ends with some comments on the information obtained in this study on the nature and origins of the aerosol in the South Coast Air Basin.

13.1 THE OXIDES OF NITROGEN CHEMISTRY

The most easily observed chemical process taking place in the plume is the conversion of nitric oxide, NO, into nitrogen dioxide, NO_2. The rate of this process is of great interest because the nitrogen oxides are emitted primarily as NO, but ambient air quality standards exist only for NO_2. It is shown in the analysis below that this conversion is primarily due to the mixing of the plume with the ambient air, which contains ozone, and the reaction

$$NO + O_3 = NO_2 + O_2 \quad . \qquad (13\text{-}1)$$

Another process of lesser importance is the direct reaction of NO with molecular oxygen, which is discussed first. In addition, NO can be converted into NO_2 by photochemical reactions involving hydrocarbons, but this process is shown to be relatively unimportant during the time that the plume is distinguishable from the background concentrations. In part, this result can be attributed to the fact that power plant plumes do not contain hydrocarbons in the way that automobile exhaust does.

13.1.1 The Reaction of NO with O_2

A relatively unimportant chemical process which takes place in the early stages of the dilution of the plume is the reaction of NO with oxygen according to the equation

$$2\ NO + O_2 = 2\ NO_2 \quad . \qquad (13\text{-}2)$$

This reaction has been studied under conditions appropriate for plumes by England and Corcoran (20). Their findings were in agreement with most earlier work, and showed that for up to 10% conversion to NO_2, the rate of consumption of NO is given by the expression

$$d[NO]/dt = -k_2[O_2][NO]^2 \qquad (13\text{-}3)$$

and that the value of k_2 decreases with temperature.

The highest stack concentration observed in this study for oxygen was 8% and for NO was about 200 ppm. Extrapolating the 25°C to 50°C data of England and Corcoran to a typical stack temperature of 127°C (260°F) gives a rate constant of

$$k_2 = 0.90\text{x}10^4\ l^2\ mole^{-2}sec^{-1} = 0.50\text{x}10^{-9}\ ppm^{-2}min^{-1} \quad . \qquad (13\text{-}4)$$

Under these conditions, the NO is converted to NO_2 at an initial rate of 0.8% min^{-1}. Since the gases remain in the stack for only a few seconds after they pass the point where the stack sampling is done, the additional conversion of NO into NO_2 in the stack is negligible. Typically, about 5% of the NO_x is NO_2 at the location where sampling is done.

To describe the rate of the reaction 13-2 in the atmosphere as the plume is diluted by ambient air, it is convenient to introduce the quantity f, which is the fraction of a given gas sample in the plume that came from the stack. Then the NO concentration is f times the stack concentration, or about 200f ppm at Haynes and Alamitos plants. The oxygen concentration is 8f + 21(1-f)% as the stack gases are diluted by air containing 21% oxygen. If these expressions are substituted in Equation 13-3, it is found that the rate of the reaction is very nearly proportional to f.

In the approximation that the stack gases are diluted exponentially

$$f = \exp\,(t/t_0) \quad , \qquad (13\text{-}5)$$

where t_0 is a characteristic dilution time. The SF_6 data show that the value of t_0 is approximately 10 minutes (see Appendix A-6 of reference 3). The approximation that the rate of the reaction is proportional to f gives the result that the extent of the reaction on complete dilution of the plume is given by t_0 times the initial rate. Therefore, the upper limit of the conversion of NO into NO_2 by this reaction in the Haynes and Alamitos plumes is about 8% conversion.

At Moss Landing, the stack concentrations were about 3% oxygen and 120 ppm NO. At the stack temperature of 148°C (300°F), the rate constant for the reaction is

$$k_2 = 0.84\text{x}10^4 \;\; l^2 mole^{-2} sec^{-1} = 0.42\text{x}10^{-9} \; ppm^{-2} min^{-1} \qquad (13\text{-}6)$$

and NO is converted to NO_2 at a rate of 0.15% min^{-1}. As the stack gases are diluted in the atmosphere, the rate of the reaction initially accelerates because the increase in oxygen concentration dominates the dilution of the NO.

Even so, under these conditions, the total conversion of NO to NO_2 due to the reaction with molecular oxygen is of the order of 3%.

England and Corcoran also studied the kinetics of systems containing NO, oxygen, and water vapor, and found that water vapor had no effect on the observed rate of conversion of NO into NO_2 at the upper end of their temperature range (20). As a result, it is expected that their rate data are applicable under the conditions found in the studied plumes.

13.1.2 The Reaction of NO with Ambient Ozone

The reaction between NO and ozone in Equation 13-1 has a rate constant of 23 ppm^{-1} min^{-1}, and therefore goes to "completion" on a time scale of minutes even at ambient concentrations (21). As a result, the rate of this reaction is controlled by the rate at which eddy diffusion in the atmosphere mixes the NO in the plume with the ambient ozone. Once NO_2 is formed, it is rapidly photolyzed (during the daytime), and this leads to a series of fast reactions which place constraints on the concentrations of NO, NO_2 and O_3. The need for a mathematical description of the combined atmospheric dispersion and chemical processes taking place in the plumes observed in this study became apparent during the analysis of these data, and has been worked out in an article by Peters and Richards which is included as Appendix F. Example 4 in the paper applies the general mathematical results to the particular problem at hand. It is shown that as long as the smog reactions which cause a net conversion of NO into NO_2 are unimportant,

$$\frac{[O_3] - [O_3]_o + [NO_2] - [NO_2]_o}{[NO_x] - [NO_x]_o} = \frac{Q_{O_3} + Q_{NO_2}}{Q_{NO_x}} , \qquad (13\text{-}7)$$

where the brackets represent concentrations, and the subscript zero indicates ambient concentrations surrounding the plume. The Q's represent the rate of emission of the indicated chemical species. In this case, the Q's should be corrected for the effect of reaction 13-2 described in Section 13.1.1. Therefore, the right hand side of Equation 13-7 has the value 0.13 in the South Coast

Air Basin and 0.08 near Moss Landing, once the plume has been in the atmosphere for about 20 minutes. If the photochemical reactions converting NO into NO_2 begin to become important, then the value of this ratio begins to increase.

Appendix F derives Equation 13-7 for a case of uniform atmospheric dispersion, which leads to a Gaussian plume profile. In fact, Equation 13-7 is more general than this, and even applies when a puff of the stack gases are carried off from the main plume. Therefore, it can be applied to ground station data even though it is not known where the station is in relation to the plume, or even whether the plume is well defined or a series of loops and puffs. However, the equation strictly applies only to instantaneous concentrations, such as obtained by the airplane. It may or may not apply to time averaged values, such as reported in the basic tabs. The reason for this is that time averaged values may or may not satisfy the equilibrium expression in Equation 2 of Appendix F.

It is believed that the greatest practical problem in the use of Equation 13-7 is determining the appropriate values of the background or ambient concentrations of NO, NO_2, and O_3. This is especially difficult when only data from a fixed station are available. In the following discussion of airborne data, the background concentrations were determined from the beginning and end of the traverse from which the peak readings were taken.

The Moss Landing results do not contain enough data so that this model can be put to a real test in a clean environment. The data that are available were taken 1.6 km from the plant, which is close enough to the stacks that reactions other than those included in the model are certainly likely to be unimportant. Therefore, the fact that the data taken there fit the model to within experimental error is to be expected.

In the South Coast Air Basin, nitrogen oxides data in the plume are available up to 19 km from the stacks, so a useful test of the model can be made there. The greatest source of discrepancy between the model and the data is the approximation that the background concentrations of ozone, NO and NO_2 remain constant. Aside from this problem, the model accounts for the major trends observed in the data in this study, and there is no evidence that photochemical reactions

are important in converting NO into NO_2 in the first 19 km of travel of the plume.

The data are presented in Tables 13-1 and 13-2. Table 13-1 contains the experimental readings as well as the calculated value of the ratio in equation 13-7, which makes it possible to see how the concentrations change with distance. The value of -0.33 for the ratio at a distance of 19.2 km is physically unreasonable, and arises from small errors in the experimental data. Changing two concentration readings by only 0.01 ppm each could change the value of the ratio to zero. All of the data which extend to distances of 16 and 19 km are summarized in Table 13-2. The ozone concentrations on 30 October were less than half those on 11 October, so a range of ambient conditions are represented in these data. These data show that the conversion of NO to NO_2 can be accounted for by the mixing with the ambient ozone, so that the photochemical conversion of NO into NO_2 in the plume is unimportant.

The above analysis examines the data taken in the center of the plume at various downwind distances. A complimentary analysis of the NO, NO_2 and O_3 concentrations along a crosswind traverse at a single downwind distance is reported in Table 7-1 and Figure 7-1 of the MRI final report (6). It is also found there that an analysis similar to the one presented here can account for the experimental observations.

It is possible that other sources along the plume trajectory can interfere with this analysis. It is shown in Section 12.3 that the plume is well mixed to the ground at a distance of 16 km, so nitrogen oxides from automotive sources, for example, could be mixed into the plume. However, these problems are minimized by taking differences between the concentrations in the plume and the concentrations just beyond the edges of the plume in the same crosswind traverse.

No ground level measurements of NO-NO_x were made as part of this study, so there is no opportunity to test the model on this ground. Comparison of the model in Equation 13-7 with the Los Alamitos-Orangewood data in Tables 10-1 through 10-4 produces only qualitative agreement, mostly because the background pollutant concentrations must be estimated. For example, on 1 October, the oxidant level was 9 pphm at 12 and 13 hr, before the plume arrived, and dropped below 1 pphm at 15 hr when the plume was present. The NO_2 concentration at 15 hr is only 6 pphm, which is not enough to account for the apparent ozone deficit.

TABLE 13-1

Computation of the Ratio in Equation 13-7 for

11 October 1974

Distance From Source Time Elevation	Gas Concentrations ppm (a) At NO_x Maximum (b) Outside Plume (c) Difference Δ				$\frac{\Delta O_3 + \Delta NO_2}{\Delta NO_x}$
	O_3	NO_x	NO	NO_2	
0.8 km	0.02	0.51	0.33	0.18	
13:50	0.08	0.055	0.01	0.04	0.17
427 m	-0.06	0.46	0.32	0.14	
4.8 km	0.035	0.215	0.075	0.14	
14:29	0.09	0.10	0.02	0.08	0.04
442 m	-0.055	0.115	0.055	0.06	
9.6 km	0.03	0.20	0.05	0.15	
15:16	0.095	0.08	0.015	0.065	0.17
366 m	-0.065	0.12	0.035	0.085	
19.2 km	0.06	0.145	0.045	0.10	
15:54	0.105	0.085	0.010	0.075	-0.33
518 m	-0.045	0.06	0.035	0.025	

TABLE 13-2

Summary of the NO to NO_2 Conversion Data

at the NO_x Maximum

Date	Distance km	Elevation m	ΔNO_x	$\frac{\Delta O_3 + \Delta NO_2}{\Delta NO_x}$
11 October	0.8	427	0.46	0.17
	4.8	442	0.115	0.04
	9.6	366	0.12	0.17
	19.2	518	0.06	-0.33
25 October	0.8	305	0.46	-0.02
	4.8	305	0.12	-0.04
	16.0	579	0.11	0.05
30 October	0.8	427	0.62	0.04
	4.8	305	0.173	0.10
	4.8	457	0.20	-0.05
	16.0	427	0.11	0.09

All that can be said from the Los Alamitos-Orangewood data is that a greater conversion of NO to NO_2 is observed when the ambient ozone levels are high.

It is interesting to apply this model to the data taken in Pomona to estimate the extent to which the plume chemistry could contribute to the depressed oxidant levels observed there. The data in Table 12-4 show that the afternoon SF_6 concentrations are usually below 30 ppt, and rarely exceed 70 ppt. The NO_x/SF_6 ratios in Table 9-12 show that the plumes would usually contribute less than about 10 ppb to the NO_x concentrations in Pomona. Therefore, the plume chemistry could not produce more than a 10 ppb or 0.01 ppm reduction in the oxidant concentration. This difference is appreciably smaller than the 0.05 ppm oxidant difference between the average Upland and Pomona readings in October 1974.

13.2 THE CHEMICAL REACTIONS OF SULFUR DIOXIDE

The ground level sulfur dioxide data were most useful for establishing the ground level impact of the plume where the impact was relatively great, but were not useful for providing information about the plume chemistry. There are two reasons for this:

1. In the South Coast Air Basin phase of the study, the sulfur dioxide and sulfur hexafluoride tracer were not uniformly mixed at the sources, as described in Section 12.2.1. Therefore, it was not possible to detect small decreases in the SO_2 concentration from fixed station data.
2. Small losses of sulfur dioxide are much more difficult to detect in the presence of other sources than are the corresponding increases in sulfate. The oxidation of only 1 ppb of SO_2 to sulfate would produce about 4 $\mu g/m^3$ of $SO_4^=$.

As a result, the most interesting data on the chemistry of sulfur compounds in the plume comes from the analysis of filter samples, and these data are discussed in the following section.

The effect of non-uniform mixing of the SO_2 and SF_6 can be eliminated by integrating the concentrations of both species on traverses which are perpendicular to the plume axis. Data of this kind were collected by the airplane and

analyzed by MRI, and it was concluded that the rate of consumption of SO_2 in the plume was slow enough that it was below the limit of detection.

13.3 THE FILTER CHEMISTRY DATA

All of the filter chemistry data obtained in this program are tabulated in Appendix C. Information on how they were obtained is given in Sections 5.3.1 and 8.0. To aid in the interpretation of these data, the concentrations of some species were divided by the total aerosol mass, and the ratios are tabulated as a percent of total mass in Appendix D. Also, the one-hour average SF_6 data have been combined into two-hour averages which match the two-hour filter collection times and tabulated in the same format as the filter data. These results are at the end of Appendix E.

13.3.1 Sulfate

The filter chemistry data of greatest potential interest are those for sulfate. However, when the background sulfate levels were low enough that the sulfate concentrations due to the plume could be discerned, it was found that the sulfate concentrations were the same, or perhaps less than, those to be expected from the source tests. There was no evidence for sulfate formation in the studied plumes.

At Moss Landing, the filter chemistry data show that if anything, sulfate is lost from the plume rather than formed in it. Because of the stability of the atmosphere which kept the plume from touching down on 10 September, and the use of natural gas on 12 September, the only sulfate data were obtained on 11 September when the stack emissions contained 0.0173 $\mu g/m^3$ sulfate per ppt SF_6. The highest SF_6 readings were obtained between 14 and 16 hr PDT, and lead to predicted sulfate concentrations due to the plume of 6.1 $\mu g/m^3$ at Salinas Fire Station No. 5 (where a total of 7.94 $\mu g/m^3$ sulfate was observed) and 4.5 $\mu g/m^3$ sulfate at Yoder Brothers (where a total of 6.88 $\mu g/m^3$ was observed). The sulfate concentrations where no SF_6 was recorded were generally in the range between 2 and 5 $\mu g/m^3$, but some observations were as high as 9 $\mu g/m^3$. All of

the observed sulfate concentrations were used as the basis for making an estimate of the amount of the observed sulfate due to the plume and the amount due to other sources. The estimated concentrations due to the plume are compared in Table 13-3 with those calculated from the sulfate/SF_6 ratios in Table 9-12 and the observed SF_6 concentrations. It is safe to say that less sulfate due to the plume was observed at the SF_6 peaks on 11 September than would be expected if the emitted sulfate were conserved in the plume.

The interpretation of the Moss Landing data at lower SF_6 readings is more subjective, because the fluctuations in the amount of sulfate from other sources make it difficult to estimate the sulfate due to the plume. Even so, these data were examined, and the opinion formed that the remaining data are more consistent with loss of sulfate from the plume than with sulfate formation. The data obtained in Gonzales, 43 km from the source, are potentially the most interesting, but there are no nearby data from which to estimate the concentration of sulfate due to other sources. No evidence of sulfate formation in the Moss Landing plume can be found in these data.

The interpretation of the data from the South Coast Air Basin is quite subjective because of the large and variable sulfate background readings. In an effort to eliminate some of this subjectivity, two people estimated the amount of sulfate due to the plume, and then these estimates were combined. Rough estimates were made before consulting the SF_6 data, and then the final estimates were made with the SF_6 data at hand, but with no information on the ratio of sulfate to SF_6 at the source. The only times when the presence or absence of the plume could be determined with some reliability from the South Coast Air Basin sulfate data alone was on 30 October and 7 November.

The data for 11 October are not included in Table 13-3 because the interpretation of these results is highly subjective. High sulfate readings were obtained at Fullerton Fire Station No. 5 whether or not the plume was present. On 25 October, the estimates are higher than the values calculated from the SF_6 data, and may well be too high. It should be noticed that the estimated sulfate values do not correlate well with those calculated from SF_6 on this day. The overall assessment of the data from the South Coast Air Basin is that there is no evidence that sulfate is either formed in or lost from the plume.

TABLE 13-3

Comparison of Predicted and Observed Sulfate Concentrations due to the Plume

Date 1974	Sampling Site Caltech No.	Name	Time	Sulfate Concentrations Above Background $\mu g/m^3$ Predicted from SF_6	Estimated from Observations
11 September	4	Salinas F.S. #5	12-14 PDT	1.4	< 1
			14-16	6.1	4
			16-18	1.5	2.5
	15	Yoder Brothers	14-16 PDT	4.5[a]	3
1 October	4	Fullerton F.S.#2	15-17 PST	5.7	3
17 October	4	Fullerton F.S.#2	11-13 PST	3.0	< 2
			13-15	0.2	2
			15-17	1.8	3
	2	Anaheim F.S. #2	15-17 PST	1.9	3
	8	Fullerton F.S.#5	13-15	2.0	1
			15-17	0.4	2
			17-19	2.3	2
25 October	2	Anaheim F.S. #2	11-13 PST	1.3	3
			13-15	1.6	2
			15-17	1.8	2
	4	Fullerton F.S.#2	11-13 PST	0.8	4
			13-15	1.2	4
			15-17	3.2	5
	8	Fullerton F.S.#5	11-13 PST	0.6	4
			13-15	0.7	4
			15-17	0.9	1
30 October	2	Anaheim F.S. #2	14-16 PST	3.4	2
			16-18	5.7	5
	4	Fullerton F.S.#2	14-16 PST	1.9	1
			16-18	2.4	3
			18-20	0.2	1
	8	Fullerton F.S.#5	14-16 PST	1.2	1
			16-18	0.7	1
7 November	2	Anaheim F.S. #2	12-14 PST	1.3	0
			14-16	3.3	5
	4	Fullerton F.S.#2	14-16	3.2	6
	8	Fullerton F.S.#5	14-16	2.8[b]	4

(a) The SF_6 Concentration observed during one hour in this time interval is assumed to apply to both hours.
(b) Predicted from the SO_2 concentration on the assumption that all SO_2 is due to the plume.

The upper limit placed on the oxidation rate of SO_2 in the plume can be estimated as follows. The plume trajectory calculations reported in Figures 5-10 through 5-15 of the MRI final report (6) show that between 1.0 and 1.7 hr were required for the plume to be carried to ground stations in Anaheim and Fullerton and that the mean transit time was about 1.5 hr. At the source, about 2% of the sulfur is in the form of sulfates. Thus, an oxidation rate of 2% per hour would more than double the amount of sulfate in the plume over Fullerton and Anaheim, and it is believed that such an increase would have been detectable.

Roberts and Friedlander (22,23) observed changes in the SO_2 and sulfate concentrations along air trajectories in the South Coast Air Basin, and estimated pseudo first order oxidation rates between 2% and 11% per hour from their data. Those results are not inconsistent with the findings reported here, because the SO_2 in the plume is in the presence of relatively high concentrations of NO and depressed concentrations of ozone. Nitric oxide is known to be an excellent scavenger for free radicals which might ozidize NO. Therefore, the oxidation rate observed in this study during the first stages of the dilution of the plume may not be typical of the oxidation rate once the NO in the plume has largely been oxidized.

13.3.2 Nitrate

The examination of the nitrate data taken in the South Coast Air Basin showed that the nitrate concentrations were often lower when the plume was present than otherwise. In addition, this effect is much more noticeable on 30 October and 7 November, when the sulfate concentrations were unusually low, than on 1 and 11 October, when the sulfate concentrations were relatively high. A small sample of data is given in Table 13-4, where the interaction of the plume and nitrate concentrations stands out clearly. The estimated range of the background nitrate concentration is indicated, but these numbers are somewhat subjective.

As with the sulfate data, the variability of the background concentrations is large enough that it is difficult to quantitatively determine the magnitude of the effect of the plume on the nitrate concentrations. Also, the effect is

TABLE 13-4

An Example of a Large Decrease of Nitrate in the Plume on 7 November 1974 at Fullerton Fire Station No. 2

Time PST	12-14	14-16	16-18
SF_6 ppt	11.6	101.0	18.9
Sulfate $\mu g/m^3$	2.92	9.16	1.22
Nitrate $\mu g/m^3$	7.26	4.68	13.4
Background Nitrate $\mu g/m^3$	5-6	8-9	11-13

not present in the Moss Landing data, and is difficult to discern in the data taken during the first few test days in the South Coast Air Basin. Therefore, the reality of the effect could be questioned.

As a result of these observations, experiments were carried out under controlled laboratory conditions to see if sulfur and nitrogen aerosol chemistry interact with each other (24). This laboratory work was not carried out as a part of this contract, but results obtained are outlined here because of their relevance to the chemistry of aerosols in California.

In these experiments, aerosols were photochemically produced in a Teflon bag exposed to natural sunlight. The concentrations of the important trace gases were monitored continuously, and the aerosol growth was observed with an electrostatic aerosol analyzer (25). Aerosol samples were collected on filters, and analyzed for sulfate and nitrate by x-ray photoelectron spectroscopy (XPS).

In one experiment, the bag was filled with particle free ambient air, and propylene, ammonia, and NO_2 were added to give concentrations of 3 ppm, 30 ppb, and 0.1 ppm respectively. After an hour, an aerosol sample was removed for analysis. Then the experiment was repeated with 80 ppb of SO_2 added to the reaction chamber. The results of the two experiments are shown in Figure 13-1. It should be noted that even though the nitrate formation is essentially completely suppressed by 80 ppb of sulfur dioxide, the amount of ammonium is the aerosol is unchanged. In another experiment in which the nitrate was deter-

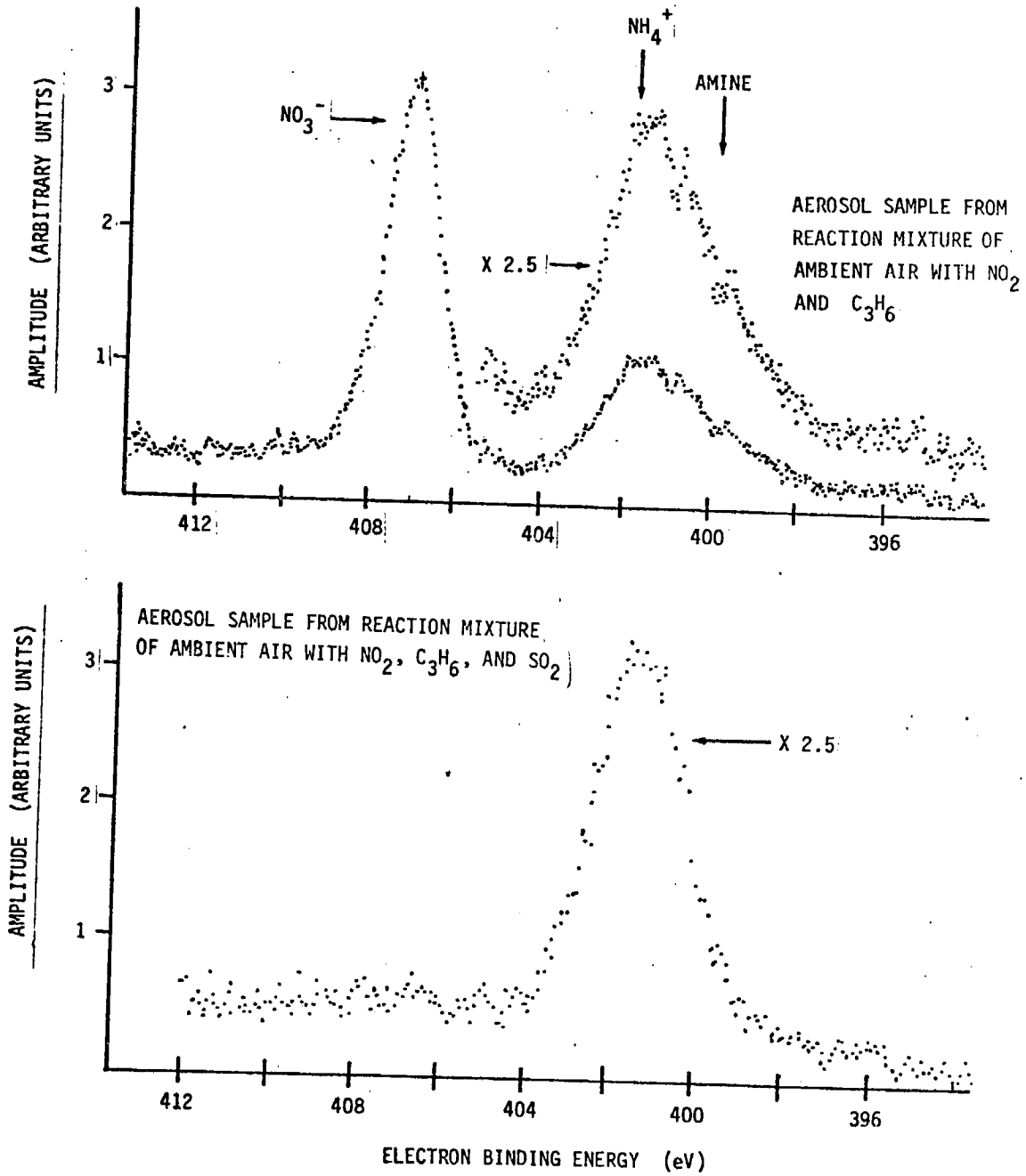

Figure 13-1. X-Ray Photoelectron Spectrum of Nitrogen 1s Electron Region of a Photochemically Formed Aerosol Produced in a Laboratory Reaction Chamber, Showing the Effect of Adding SO_2 to the Mixture.

mined by wet chemical means, increasing the SO_2 concentration from 18 ppb to 54 ppb suppressed the nitrate formation by a factor of two.

Experiments were also done in which an aerosol was formed in particle-free ambient air to which propylene and NO_2 had been added, and then SO_2 was added after the experiment had been underway for about an hour. The added SO_2 caused a marked increase in the aerosol formation rate, but it also caused the amount of nitrate in the aerosol to decrease. Therefore, laboratory experiments do confirm the field results of this study which show that the aerosol nitrate concentration in the plume is smaller than the aerosol nitrate concentration in the air surrounding the plume.

There are almost certainly a number of chemical processes which contribute to the removal of nitrate from the aerosol observed in the plumes and in the laboratory. However, it is quite likely that one important reaction is the combination of sulfuric acid with ammonium nitrate to produce ammonium sulfate and the volatile nitric acid. This reaction does not destroy nitrate, but only converts it to a volatile form. Thus, dilution of the plume by ambient air containing trace amounts of ammonia should lead to a rapid return of the nitrate to the aerosol.

Once these effects have been observed in the plumes and in the laboratory, it is possible to see them in earlier data. For example, Figure 13-2 reproduces data from Figure 4-16 in Volume IV of the final report on the ACHEX study in which nitrate concentrations are high in the morning, but decrease as the day progresses (26). At the same time, the sulfate concentrations are increasing. These results could be due to the transport of different air masses past the mobile laboratory, but is also possible that the above chemical processes played an important role on these days.

These results observed in the laboratory, in the plumes in the South Coast Air Basin, and perhaps in the ACHEX data, are interesting because they show why nitrate levels in California are often higher than those observed in the urban areas in the eastern United States. Sulfur dioxide concentrations are typically much lower in California than in the east, where SO_2 concentrations are often high enough to strongly suppress nitrate formation.

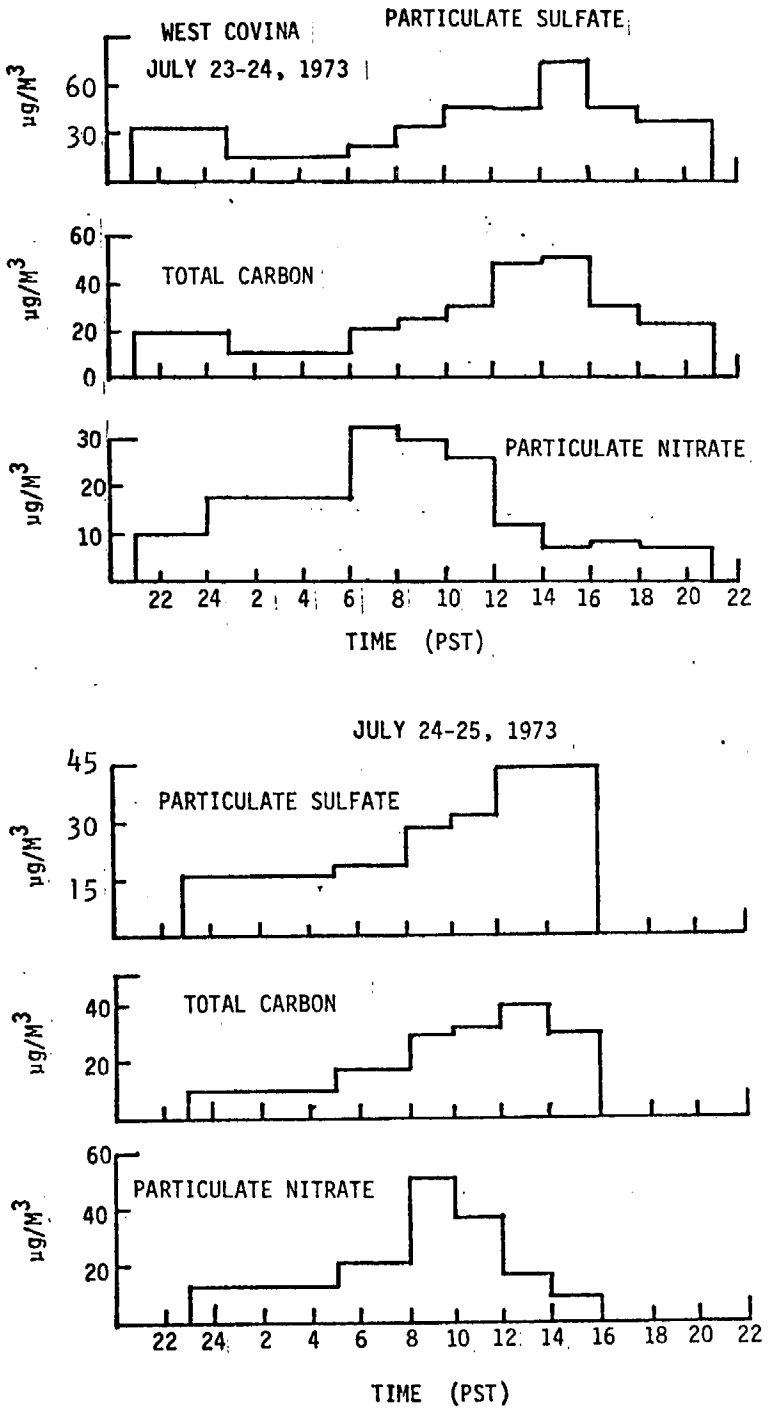

Figure 13-2. Diurnal Variation of the Concentrations of Sulfate, Nitrate, and Total Carbon.

The formation of nitrate in the South Coast Air Basin is of interest because there is good evidence that it significantly contributes to visibility reduction (27), and it is reasonable to believe that it could produce adverse health effects.

13.3.3 Vanadium

The vanadium data are consistent with the hypothesis that most of the vanadium in the fuel is emitted in the plume, but so few data points are available that it is not possible to make a stronger statement. Vanadium is not one of the elements best determined with x-ray fluroescence. Therefore, most of the data fall below the limit of detection of this technique. The few cases in which both SF_6 and vanadium data are available and the SF_6 levels are high enough that vanadium might be detected are listed in Table 13-5. The SF_6 concentrations reported in the table are the two-hour averages corresponding to the filter collection times reported in Tables E-11 through E-13 in Appendix E. The calculation of the vanadium concentrations in the plume from the SF_6 data uses the tentative assumption that the vanadium in the fuel is all emitted in the plume. The data for this calculation are given in Table 9-11. The background vanadium concentration is not subtracted from the observations because its value is not known.

It is believed that the high vanadium concentrations reported for 15-17 hr on 1 and 11 October are spurious. On these two days the data contain other high vanadium readings which do not correlate with any known source. The remaining data are consistent with the hypothesis that the vanadium in the fuel is emitted, but are not good enough to prove that this is the case.

13.3.4 Other Elements

An examination of the remaining x-ray fluorescence data for the elemental composition of the aerosol did not result in additional useful information. Most of the data for the following elements showed that they were below the limit of detection: Mg, Cl in the South Coast Air Basin, Cr, Cu, and Br near Moss

TABLE 13-5

Comparison of Observed Vanadium Concentrations with those Emitted from Fuel and SF_6 Data

Date 1974	Time PST	Caltech Station No.(a)	SF_6 ppt	Vanadium Concentration From SF_6 $\mu g/m^3$	Vanadium Concentration Observed $\mu g/m^3$
1 October	15-17	4	146	0.31	0.96
	11-13	4	40.8	0.09	0.14
11 October	15-17	8	50.7	0.11	0.79
	15-17	4	46.3	0.10	0.22
	15-17	2	23.2	0.05	0.09
	13-15	2	20.6	0.05	0.11
17 October	11-13	4	72.9	0.15	0.09
	17-19	8	55.8	0.12	< 0.13
	15-17	2	47.5	0.10	< 0.14
	15-17	4	43.2	0.09	0.13
25 October	15-17	4	139	0.15	0.10
	15-17	2	78	0.09	< 0.13
	13-15	2	71	0.08	< 0.12
	11-13	2	58	0.06	< 0.13
	13-15	4	52.6	0.06	< 0.14
30 October	16-18	2	171	0.26	0.24
	14-16	2	100	0.15	< 0.13
	16-18	4	72.2	0.11	< 0.14
	14-16	4	57.1	0.09	< 0.14
	14-16	8	36.1	0.05	< 0.14
7 November	14-16	4	101	0.19	< 0.14
	14-16	2	97.6	0.19	0.15
	12-14	2	39.1	0.07	< 0.15

(a) Caltech Station No.

Caltech Station No.	Name
2	Anaheim Fire Station No. 2
4	Fullerton Fire Station No. 2
8	Fullerton Fire Station No. 5

Landing, Mn, Ni, Zn, and Pb near Moss Landing, The elements whose concentrations could be measured on nearly all filter samples, but showed no correlation with the plume were: Na, Si, K, Ca, Fe, Br in the South Coast Air Basin, and Pb in the South Coast Air Basin.

The concentrations of sulfur did correlate with the presence of the plume and with the wet chemical sulfate data, but they are not discussed here because they are analyzed in the AIHL final report (1).

13.4 GENERAL COMMENTS ON THE OBSERVED AEROSOL CHEMISTRY

The chemistry data obtained in the ground station network provide information of general interest in addition to the specific information about the plume. For example, it is observed in the first two South Coast Air Basin test days, 1 and 11 October, that the sulfate concentration is uniformly high in the morning, and falls steadily during the day. Also, the lower sulfate concentrations are observed first at the stations near the coast, and then these lower concentrations move inland with the sea breeze. On 1 October, the sulfate concentrations decreased from 30 to 40 $\mu g/m^3$ at 9-11 hr to 5 to 10 $\mu g/m^3$ at 21-23 hr PST.

On 17 October, the 21-23 hr sulfate concentrations increased at the three sampling sites closest to the coast in comparison to the concentrations observed earlier in the evening or at the other sampling sites. So few data are available that this observation could be statistical fluctuation, but it could also be a clue that sulfate formation along the coast at night where the humidity is often high may be important.

The difference in the aerosol chemistry between the Salinas River Valley and the South Coast Air Basin is apparent. The automobiles in the South Coast Air Basin cause higher Pb and Br concentrations in the aerosol there. On the other hand, the Na and Cl readings show a greater sea salt content in the Salinas aerosol samples. Also, the ratio of Cl to Na in the South Coast Air Basin is much smaller than in Salinas, indicating that the Cl tends to be removed from the aerosol near Los Angeles. These general characteristics of the aerosol have been observed in earlier studies.

14.0 DISCUSSION OF THE PLUME IMPACT

14.1 THE RELATIVE IMPACT OF THE PLUMES

The use of a sulfur hexafluoride tracer in this study makes it possible to separate the concentrations of SO_2 and NO_x due to the plume from those due to other sources, and hence to evaluate the impact of the plume in relation to the impact of other sources. This calculation has been carried out for the ground stations where the greatest plume impact was observed, and the results are given in Table 14-1.

The SF_6 data are available when the plume impact is at a maximum at the ground stations. Therefore, the relative plume impacts in Table 14-1 are appreciably larger than they would be on a 24 hr basis. The time intervals selected in the calculation are designed to fit the SF_6 release times. Except where data are missing, the time interval begins two hours after the start of the SF_6 release and ends one hour after the end of the SF_6 release for ground stations Nos. 2, 4, 5, and 8. For the stations farther inland, the time interval starts and ends three hours after the start and end of the SF_6 release. It is possible that this delay is not long enough for the Riverside and San Bernardino stations.

The calculation of the concentrations of SO_2 and NO_x due to the plume from the observed SF_6 concentrations includes a correction for the SF_6 due to other sources. The mean SF_6 concentration before the start of the tracer release given in Table 12-1 is subtracted from each observed SF_6 concentration. Then the SO_2/SF_6 and NO_x/SF_6 ratios in Table 9-12 are used to determine the concentration of each gas due to the plume. The relative plume impact at the station is determined by dividing the sum of the SO_2 or NO_x concentrations calculated from the SF_6 data by the sum of the observed concentrations.

The results show that during the afternoon, the sulfur dioxide at the Anaheim and Fullerton stations is largely due to the plumes. However, the examination of the SO_2 data shows that the impact of the plumes at other times

TABLE 14-1

Afternoon Impact of the Plumes in Relation to Other Sources

Ground Station Caltech No.	Name	Date 1974	Hours PST	Average SF_6 ppt	Sulfur Dioxide ppb From SF_6	Sulfur Dioxide ppb Average Observed	Plume Relative Impact
2	Anaheim F.S. #2	11 Oct.	12-18	15.4	6.5	16	68%
		17 Oct.	12-18	18.0	8.	17	
		25 Oct.	12-18	61.3	17.	16	
		7 Nov.	12-18	50.4	19.	15	
4	Fullerton F.S.#2	1 Oct.	12-17	73.5	33.	46	53%
		11 Oct.	12-18	23.3	10.	36	
		17 Oct.	12-18	36.5	16.	30	
		25 Oct.	12-18	72.7	20.	38	
		30 Oct.	12-18	44.2	16.	24	
		7 Nov.	12-18	43.7	15.	34	
5	Whittier APCD	1 Oct.	12-17	3.1	0	34	8%
		11 Oct.	12-18	7.1	1.	26	
		17 Oct.	12-18	21.2	8.	32	
		25 Oct.	12-18	1.1	0	20	
		30 Oct.	12-18	4.2	0	22	
		7 Nov.	12-18	15.7	4.	20	
8	Fullerton F.S.#5	1 Oct.	12-17	15.0	6.	17	69%
		11 Oct.	12-18	19.5	9.	17	
		17 Oct.	12-18	38.1	18.	15	
		25 Nov.	12-18	37.1	10.	13	
17	Pomona APCD	1 Oct.	12-19	25.9	7.	30	42%
		11 Oct.	13-20	38.7	15.	21	
		17 Oct.	13-20	50.6	20.	40	
		25 Oct.	13-20	17.1	2.	14	
		30 Oct.	13-20	27.2	7.	11	
		7 Nov.	13-18	17.8	3.	12	
21	Riverside Central F.S. (a)	1 Oct.	12-19	4.3	0	25	7%
		11 Oct.	13-20	6.7	2.	19	
		17 Oct.	13-20	11.0	4.	13	
		25 Oct.	13-20	4.4	0	18	
		30 Nov.	13-20	1.4	0	16	
22	San Bernardino APCD (a)	1 Oct.	12-19	11.9	5.	36	19%
		11 Oct.	13-20	19.0	9.	36	
		17 Oct.	13-18	8.1	3.	< 10	
		24 Nov.	13-20	0.2	0	11	

(a) SO_2 removal processes will cause the actual SO_2 impact in Riverside and San Bernardino to be less than calculated here.

TABLE 14-1 (Continued)

Afternoon Impact of the Plumes in Relation to Other Sources

Ground Station Caltech No.	Name	Date 1974	Hours PST	Average SF_6 ppt	Nitrogen Oxides ppb From SF_6	Nitrogen Oxides ppb Average Observed	Plume Relative Impact
17	Pomona APCD Nitrogen Oxides	1 Oct.	13-19	28.1	8.	107	7%
		11 Oct.	13-20	38.7	15.	144	
		17 Oct.	13-20	50.6	19.	177	
		25 Oct.	13-20	17.1	2.	91	
		30 Oct.	13-20	27.2	6.	132	
		7 Nov.	13-18	17.8	2.	122	

of the day is very much less. It is also apparent that the plumes make a major contribution to the SO_2 levels in Pomona, but a much smaller proportionate contribution to the NO_x concentrations there. The plume impact at San Bernardino as measured by SO_2 is still significant, and this is the most distant station at which data were taken.

The interpretation of the data in Table 14-1 should also take into account an observation made in Section 10.4. There it was noted that the impact of the plumes in LaHabra on the test days was significantly greater than during the month of October as a whole. Therefore, it is possible that the plume relative impacts tabulated for the test days are larger than they would have been if data were taken throughout October.

It is clear that relative impact of the plume as measured by NO_x is much less than that measured by SO_2. As a further example of this, the average maximum NO_x concentration measured by the airplane 4.8 km (3 mi) from the source is 0.20 ppm. These measurements were made appreciably closer to the source than the location of the maximum ground level concentration, so it is expected that the maximum ground level concentration will on the average be lower than 0.20 ppm.

By way of comparison, the average NO_x concentration from 6:00 to 7:00 a.m. at the Lennox APCD station during the month of October was 0.38 ppm. This station is near the San Diego Freeway, and provides a measure of the ground level

NO_x concentrations near a major freeway.

Because the pollution levels near Moss Landing are so low, the relative impact of the plume there is much larger. In general, it is not necessary to use a tracer to separate the concentrations due to the plume from those due to other sources. This is especially true when the plant is burning oil so that the plume contains sulfur dioxide.

14.2 THE PLUME IMPACT IN RELATION TO STANDARDS

Most concentrations observed in this study were well below those specified by air quality standards. However, the data in the basic tabs show that NO_2 standards were exceeded in October and November 1974 in Pomona and LaHabra on days other than the six test days. It is likely that the plumes contributed to these exceedances, but the data on the second page of Table 14-1 show that this contribution was probably small.

The closest approaches to the SO_2 standards in the data are the 24 hr SO_2 concentration of 0.032 ppm on 11 April at the Los Alamitos-Orangewood APCD station (see Table 10-5), and the 24 hr SO_2 concentration of 0.039 ppm at Fullerton Fire Station No. 2 on 14 October 1974 (see Table 7-16). It was noted in Section 10.1 that the SO_2 concentrations were high in a wide area on 14 October, so the readings in Fullerton on this day contain appreciable contributions by other sources.

It was noted in the previous section that the average of the maximum NO_x concentrations observed each day by the airplane in the South Coast Air Basin at 4.8 km from the sources was 0.20 ppm. This is to be compared with the one-hour average NO_2 standard of 0.25 ppm. Similarly the average maximum SO_2 concentration at 4.8 km was 0.15 ppm, which is to be compared with the one-hour average SO_2 standard of 0.50 ppm. Therefore, violations of the SO_2 and NO_2 standards in which the plants studied in the South Coast Air Basin play a major role are not expected under conditions similar to those encountered in this study.

The χ/Q cumulative frequency distributions in Figures 12-3 and 12-4 are useful in estimating the probability of elevated SO_2 concentrations during

during meteorological conditions similar to those encountered in this study. It is believed that extrapolating these data to a full year would be unwise, because the meteorological conditions typical of other seasons were not observed. Also, it should be remembered that the SO_2 due to other sources are included in these data. Even so, they can be used to estimate the frequency of high SO_2 concentrations. Figure 12-3 shows a χ/Q of 0.97 ppb SO_2/ton per day with a frequency of once per month. During the time period of this study, emission rates from the two plants were sometimes in excess of 100 tons per day. At this emission rate, one-hour SO_2 concentrations of 100 ppb would be expected approximately once per month in Fullerton. This concentration is well below the one-hour standard of 500 ppb.

The close approaches to, or the exceedances of, the standards mentioned above occur under circumstances in which other sources make major contributions to the ambient concentrations. The SF_6 data permit the separate estimation of the concentrations due only to the power plants participating in this study. Table 12-5 summarizes the highest instantaneous, one-hour average, and 24-hour average SF_6 concentrations observed in this study, as well as the concentrations of SO_2, sulfate, and NO_x contributed by the power plants at these times. No concentrations are larger than half the corresponding standard.

The data obtained in this study do not provide new information on the important question of how rapidly the emitted SO_2 is oxidized to sulfate once the plume has been well mixed into the other ambient pollutants. Therefore, the best that can be done at present is to assume that the contribution of the power plants to sulfate in the South Coast Air Basin is approximately proportional to their contribution of sulfur oxides. This assumption is supported by the observation in this study that sulfate formation in the plumes is not important before the plumes are dispersed.

14.3 GENERAL COMMENT ON THE PLUME IMPACT

It is the general conclusion of the South Coast Air Basin portion of this study that the plumes are well defined and follow the same trajectory between the sources and the Puente Hills each of the six test days. In this region, the

only important chemistry in the plumes results from the mixing of NO with the ambient ozone. Even though the plumes are a dominant source of SO_2 in Fullerton, the SO_2 and NO_x impacts are well below standards. In this region, the sulfate concentrations in the plume are due to the direct emission of sulfate at the source.

However, some of the worst pollution problems in the South Coast Air Basin occur east of the Puente Hills. Here the plume is well enough mixed with emissions from other sources that it can no longer be distinguished, except by a tracer such as SF_6. Therefore, it is no longer possible to study the plume as a distinct entity in this region. The relative impact of the plume here is best determined by comparing the emission rates of the power plants with the emission rates of other sources that contribute to ambient concentrations in this portion of the Basin.

The fact that little chemical conversion was observed in the plume before the Puente Hills in no way implies that the plume has little impact on the atmospheric chemistry in the Basin as a whole. Before the Puente Hills, the NO concentrations in the plume are relatively high, hence the oxidant and free radical concentrations are depressed. At greater downwind distances, the NO is largely oxidized, and other oxidation processes will become important. At present, the processes of greatest interest are those which convert SO_2 into sulfate. However, the investigation of these processes requires gathering more data farther from the sources than were obtained in this study.

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APPENDIX A

EMISSIONS FROM THE MOSS LANDING POWER PLANT OF PACIFIC GAS AND ELECTRIC COMPANY

STATE OF CALIFORNIA

AIR RESOURCES BOARD

SOURCE TEST REPORT

EMISSIONS FROM THE MOSS LANDING POWER

PLANT OF PACIFIC GAS AND ELECTRIC COMPANY

MOSS LANDING

MONTEREY COUNTY

SEPTEMBER 10, 11, and 12, 1974

DIVISION OF

IMPLEMENTATION AND ENFORCEMENT

ENGINEERING EVALUATION UNIT

REPORT NO. C4-028

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State of California

AIR RESOURCES BOARD

Division of Implementation and Enforcement

Report on Emissions From the Moss Landing

Power Plant of Pacific Gas and Electric Company

Index

State of California

AIR RESOURCES BOARD

Division of Implementation and Enforcement

Report on Emissions from the Moss Landing Power Plant of Pacific Gas and Electric Company

1. INTRODUCTION

As requested by the Research Section of the Air Resources Board, source tests were conducted on emissions from Units 6 and 7 at the Moss Landing Power Plant of Pacific Gas and Electric Company (PG&E) on September 10, 11 and 12, 1974. These tests were part of a research project entitled "The Chemistry, Dispersion, and Transport of Air Pollutants Emitted from Fossil Fuel Power Plants". The objectives of the study are a) to determine the impact on air quality of emissions of sulfur oxides (SOx) and nitrogen oxides (NOx) associated with power plant combustion of fuel oils, b) to define the effect of SOx and NOx emissions on the formation of sulfate and nitrate aerosols, and c) to assess the plume dispersion characteristics and transport of emissions under different meteorological conditions.

Concurrently with the source tests by the Air Resources Board, Meteorological Research Incorporated measured pollutant concentrations in the plume from an instrumented aircraft and recorded meteorological data, Rockwell International Science Center measured ground-level concentrations of pollutants, and the California Institute of Technology injected a tracer gas, sulfur hexafluoride, into the stack of Unit 7 and measured the concentration of the tracer gas downwind.

PG&E furnished operating data and NOx concentrations for the other units at Moss Landing for the times during which the source tests were conducted.

2. PLANT DESCRIPTION

The Moss Landing power plant is located on the coastline of the Pacific Ocean at Monterey Bay, about a mile north of the village of Moss Landing. Figure 1 is a photograph of the plant, viewed from the ocean. The plant has seven generating units for commercial production and three house units. These have capacities as follows:

Unit 1	114,000 KW
Unit 2	113,000 KW
Unit 3	115,000 KW
Unit 4	122,000 KW
Unit 5	122,000 KW
Unit 6	750,000 KW
Unit 7	750,000 KW
House Unit 1	9,000 KW
House Unit 2	9,000 KW
House Unit 3	9,000 KW

Units 1, 2 and 3 are supplied with steam from Boilers 1 through 6; Units 4 and 5 are supplied with steam from Boilers 7 and 8; Units 6 and 7 respectively are supplied with steam from Boilers 6-1, and 7-1. The label on each stack in Figure 1 indicates the boiler with which the stack is associated. The stacks for Boilers 1 thru 6 are 224 feet, 6 inches high, above grade, and are 11 feet, 4 inches in inside diameter.

The stacks for Boilers 7 and 8 are 224 feet, 6 inches high, above grade, and are 13 feet in inside diameter. Stacks 6-1 and 7-1 are 500 feet high, above grade, and are 17 feet, 8 inches in inside diameter. Grade is 30 feet above mean sea level.

All of the boilers at this power plant can be fired with either natural gas or fuel oil. The switch from natural gas to fuel oil, or vice versa, takes about 3 hours. The load on the boilers is reduced for the switch.

3. TESTS CONDUCTED

Tests were conducted on Units 6 and 7 on September 10, 11 and 12, 1974, for the determination of the concentrations in the stack-gas of: water vapor; carbon dioxide; oxygen; carbon monoxide; oxides of nitrogen; sulfur dioxide; sulfuric-acid mist. One test was conducted on Unit 6 on September 10 to determine the concentration of hydrogen sulfide. Samples of fuel oil were taken from Units 6 and 7 on September 10 and 11 for the determination of the content of sulfur, carbon, hydrogen, water and ash; density at the meter temperature and the gross heating value were also determined.

Operating data were recorded for Units 6 and 7 during the tests so that stack gas flow rates and unit loads could be determined. In addition, PG&E furnished data on fuel flow rates, oxygen content, concentrations of oxides of nitrogen, and stack-gas temperatures for Boilers 1 through 8.

The Monterey Bay Unified Air Pollution Control District operated a continuous NOx analyzer and PG&E operated continuous NOx analyzers

and a carbon-monoxide analyzer during the tests. Data were obtained from these instruments.

During the tests, Units 6 and 7 operated at full load. On September 10 and 11, they burned fuel oil, and, on September 12, natural gas.

3.1 Water Vapor

The concentration of water vapor in stack-gas was determined once each day on each of Units 6 and 7 on September 10, 11 and 12 using EPA Test Method 4. Additionally, the concentration of water vapor was determined once each day on each of Units 6 and 7 from the water collected in the impingers during the tests for sulfur dioxide.

3.2 Carbon Dioxide, Oxygen, and Carbon Monoxide

The concentrations of carbon dioxide, oxygen, and carbon monoxide in stack-gas were determined by gas chromatography from samples taken from each of Units 6 and 7 on September 10, 11, and 12.

PG&E monitored carbon monoxide with an MSA "Lira" nondispersive infrared analyzer that drew its sample from either Unit 6 or Unit 7. Data were recorded from this instrument from 1045 to 1610 hours on September 10, and from 1000 to 1600 hours on September 11 and 12.

3.3 Oxides of Nitrogen

The concentrations of oxides of nitrogen were determined by EPA Test Method 7 from samples taken from each of Units 6 and 7. The central portion of the duct was traversed for these samples, and the traverse points recorded. The number of samples each day for each units was:

Date	Unit 6	Unit 7
9/10/74	12	13
9/11/74	16	16
9/12/74	16	16

A Thermoelectron Model 12A chemiluminescent analyzer was used to monitor oxides of nitrogen in stack-gas on Unit 6 continuously from 0900 to 1700 hours each day. The sample gas was aspirated from the stack-gas duct just prior to the air preheater and was cooled and filtered in a conditioner before entering the instrument.

The Monterey Bay Unified Air Pollution Control District had previously installed a Thermoelectron Model 12A chemiluminescent analyzer to monitor oxides of nitrogen continuously from either Unit 6 or Unit 7. The sample gas for both this instrument and the PG&E instruments was aspirated from several points in the stack-gas ducts near the economizers and was cooled and filtered prior to entering the instruments. Data from this instrument were recorded at half-hour intervals from 1046 to 1610 hours on September 10, and from 0900 to 1700 hours on September 11 and 12.

PG&E had previously installed a Beckman NOx analyzer on each of Units 6 and 7 and also a Dynasciences NOx analyzer that could monitor either Unit 6 or 7. Data from Beckman NOx analyzers were recorded every half hour from 0900 to 1700 hours on September 10 and 11. Data from the Dynasciences NOx analyzer was recorded about every half hour from 1045 hours to 1610 hours on September 10, and from 1000 to 1600 hours on September 11 and 12.

3.4 Sulfur Dioxide and Sulfuric Acid Mist

The concentrations of sulfur dioxide and sulfuric acid mist were determined using EPA Test Method 8 once each afternoon on September 10, 11, and 12, on each of Units 6 and 7.

3.5 Hydrogen Sulfide

The concentration of hydrogen sulfide was determined once on Unit 6 on September 10 using EPA Method 11.

3.6 Fuel Oil Analysis

Three samples of fuel oil were taken each day from each of Units 6 and 7 on September 10 and 11. The sulfur content and heating value of the samples were determined by ASTM Method D240. The carbon and hydrogen contents of the samples were determined by the PREGL micro-analytic combustion technique. The water content and density of the samples were determined by ASTM Methods D95 and D891 Method C, respectively.

3.7 Operating Data

Every half hour from 0900 to 1700 hours inclusive, on September 10, 11, and 12, the following variables were recorded:

Temperature of inlet oil;

Temperature of stack-gas at air preheater;

Concentration of oxygen in stack-gas;

Gross Unit Load;

Steam Rate;

Steam Temperature;

Steam Pressure;

Fuel Oil or Natural Gas Flow.

In addition, PG&E furnished the following data for each hour of operation from 1900 to 1700 hours inclusive on September 10, 11, and 12 for Boilers 1 through 8:

Concentration of oxides of nitrogen in stack-gas;

Flow of natural gas to boiler;

Concentration of oxygen in stack-gas;

Temperature of stack-gas.

4. OBSERVATIONS

From 0800 to 1115 hours on September 10, flue-gas recirculation was not used on Unit 6, and as a result the concentration of oxides of nitrogen was higher during that time.

5. TEST RESULTS

A summary of the test results is shown in Table 1. The stack-gas flow rates shown in this table are calculated from combustion calculations using the fuel-flow rates, the fuel analyses and the concentrations of oxygen and water vapor. These flow rates are shown in standard cubic feet per minute on a wet basis.

The actual stack-gas flow rates must be determined using the stack gas temperature. The concentrations of water vapor, carbon dioxide, oxygen, carbon monoxide, and nitrogen are all shown on a wet basis. The concentrations of nitrogen are calculated by difference; the other concentrations are from analyses of the grab samples.

The concentrations of oxides of nitrogen shown in Table 1 are averaged from the concentrations determined by EPA Method 7, Phenoldisulfonic Acid (PDS). The concentrations shown on this table are on a wet basis. In determining these concentrations, obviously erroneous data ("invalid" data) were not included. Tables 2 through 7 show all of the data for oxides of nitrogen from all of the grab samples and the continuous instruments.

All of the invalid data excluded from the calculations of the average values shown in Table 1 are marked with an asterisk in Tables 2 through 7. Since the PDS samples were taken from 1310 hours onward on September 10, and since higher concentrations of oxides of nitrogen were present up until 1115 hours on September 10 on Unit 6 because flue gas recirculation was not used, it is recommended that Table 2 be used for data from 0900 to 1115 hours on September 10.

The concentrations of sulfur dioxide shown in Table 1 are on a wet basis. The concentration of sulfur dioxide determined from the sulfur content of the fuel assumes that all of the sulfur is converted to sulfur dioxide.

The concentrations of sulfuric acid mist shown in Table 1 are also on a wet basis. These values were from the tests by EPA Method 8.

Tables 2 thru 7 show the concentrations of oxides of nitrogen on a dry basis measured by the ARB Model 12A Thermoelectron analyzer, the Monterey Bay Unified APCD's Model 12A Thermoelectron analyzer, PG&E's Dynascience analyzer, the Beckman analyzers, and the PDS samples. The ARB analyzer was carefully calibrated at the Air and Industrial Hygiene Laboratory (AIHL) at Berkeley prior to the tests. However, the readings of this instrument are consistently higher, by a factor of 1.32, than the valid PDS data (or a factor of 0.76 applied to the ARB analyzer data). The district's instrument and the PG&E instruments were calibrated by span gases. The concentrations of these span gases were later determined by AIHL using both the Saltzman and PDS methods. These determinations showed the certified concentrations to be correct within experimental error.

The concentrations of carbon monoxide measured by the PG&E MSA nondispersive infrared analyzer and the analyses of the grab bag samples by gas chromatography are shown on Table 8.

Tables 9 and 10 show the concentrations of oxides of nitrogen in the stack gases on a wet basis, the stack gas flow rates at standard conditions on a wet basis, and the stack gas temperatures for each hour from 0900 to 1700 hours on September 10, 11, and 12 for Boilers 1 through 8. The given stack-gas flow rates must be corrected for temperature to obtain actual stack-gas flow rates.

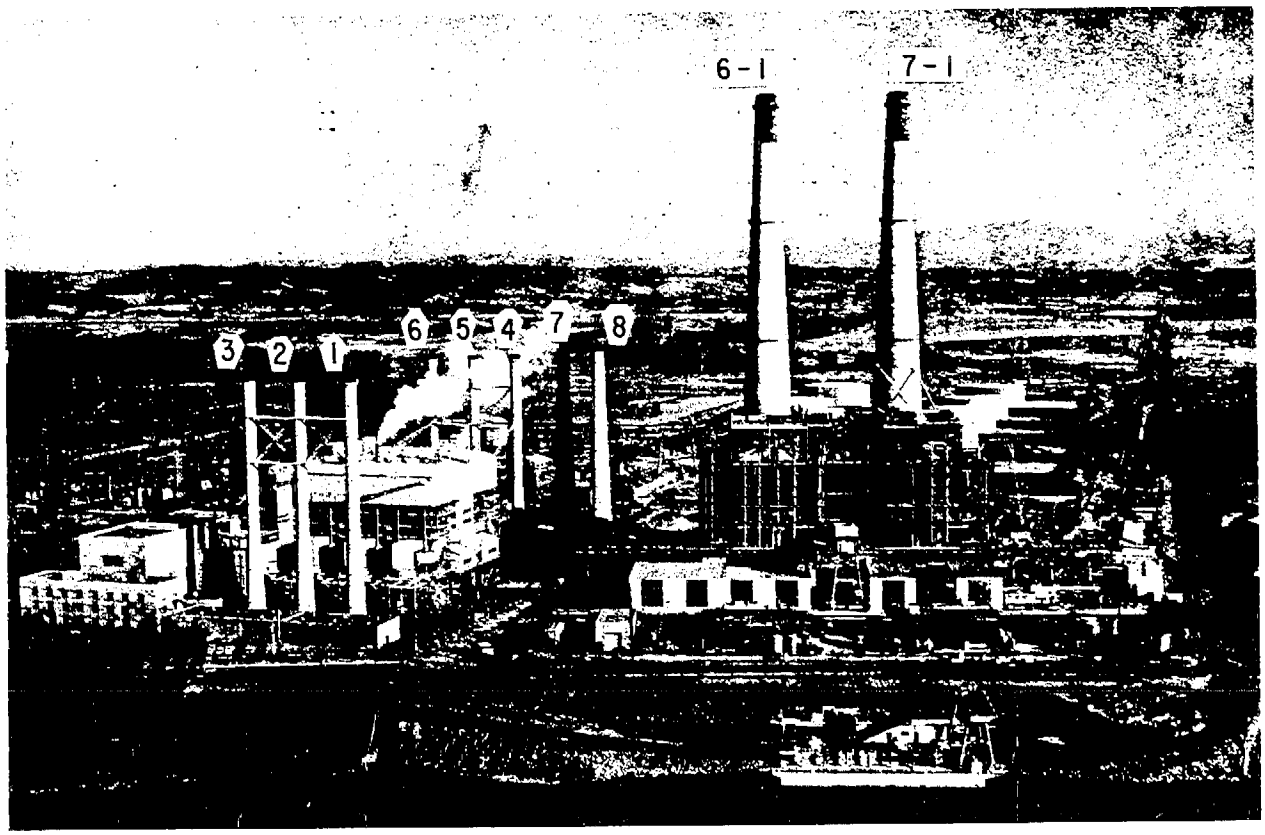

FIGURE 1: Moss Landing Power Plant of P.G.&E. as Viewed from the Pacific Ocean

Photograph by Courtesy of P.G.&E. Company

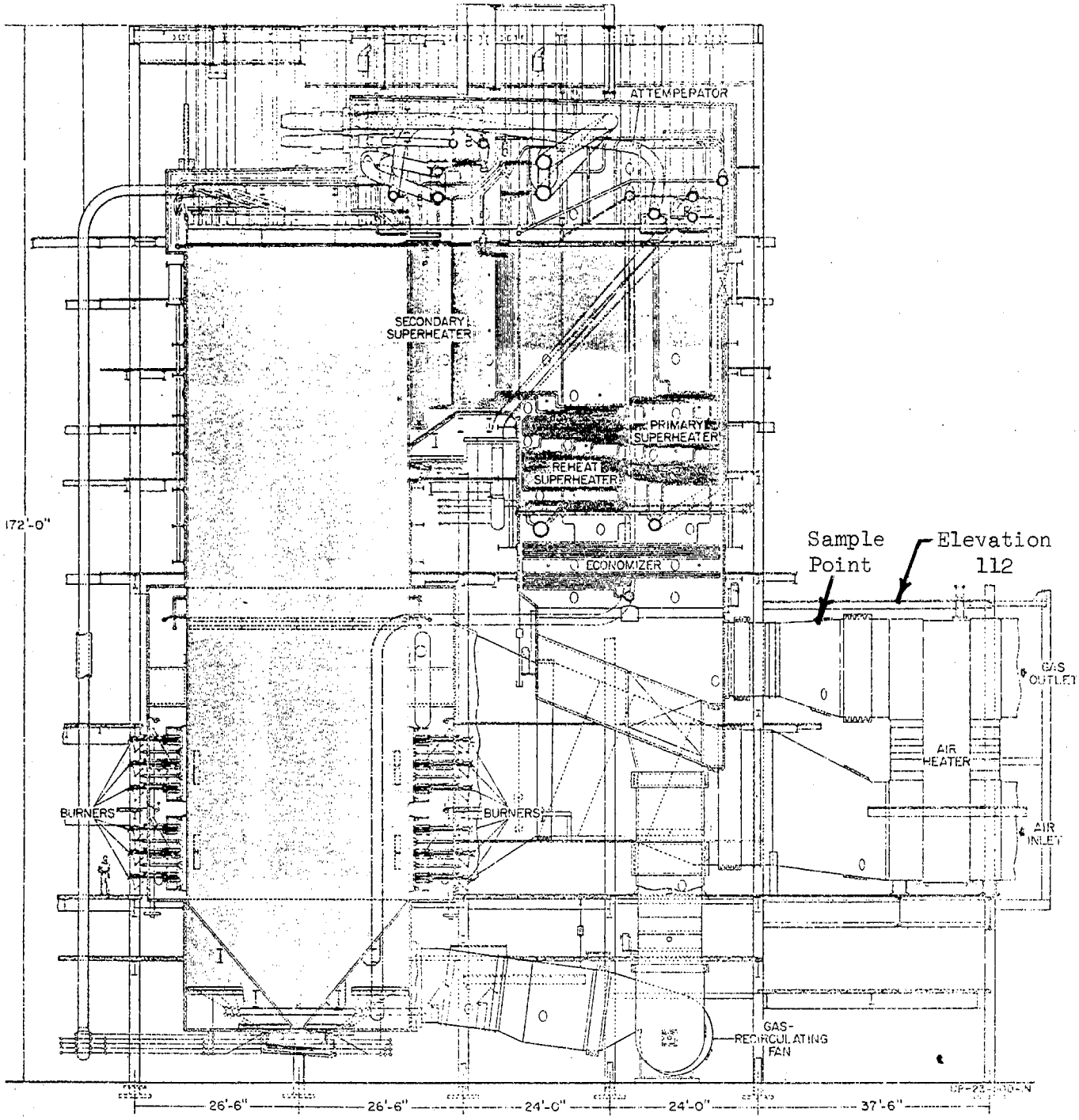

Figure 2: Boilers 6-1 and 7-1

Courtesy of Pacific Gas and Electric Company

Table 1 File No. C4-028

State of California

AIR RESOURCES BOARD

Division of Implementation and Enforcement

SUMMARY OF RESULTS OF TESTS CONDUCTED AT THE MOSS LANDING POWER PLANT OF PG&E

Average Values

Date of Test	9/10/74		9/11/74		9/12/74	
Unit No.	6	7	6	7	6	7
Average Gross Load, MW	733	718	732	716	738	712
Stack Gas Flow Rate, Thousands of SCFM*	1,311.3	1,408.4	1,288.7	1,302.3	1,266.8	1,227.4
Stack Gas Temperature, °F	306	301	264	304	313	307
Concentration of H_2O, % by Vol.*	10.83	10.01	10.86	10.37	17.07	16.99
Concentration of CO_2, % by Vol.*	12.75	12.20	12.26	13.11	9.95	10.35
Concentration of O_2, % by Vol.*	2.92	4.02	3.03	3.54	2.39	2.32
Concentration of CO, % by Vol.*	0.005	0.002	0.001	0.008	0.008	0.002
Concentration of N_2, % by Vol.*	73.50	73.68	73.85	72.97	70.58	70.34
Concentration of NOx by PDS, ppm*	118**	133	113	115	110	66
Concentration of SO_2 by Source Test, ppm*	171	158	201	192	1.32	0.99
Concentration of SO_2 by Sulfur in Fuel, ppm*	176	163	199	194	0	0
Concentration of Sulfuric Acid Mist, gr/scf*	0.011	0.008	0.008	0.009	0.002	0.001

* Expressed on a wet basis

** From 1130 to 1700 hours only; see Table 2 for concentration before 1130 hours

Table 2

State of California

AIR RESOURCES BOARD

Division of Implementation and Enforcement

Concentrations of Oxides of Nitrogen

Unit 6, September 10, 1974

Time of Day	Concentration of NOx as NO_2, ppm (dry basis)				
	EPA Method 7 ARB	TECO** ARB	TECO*** MBUAPCD	Dynascience PG&E	Beckman PG&E
900	—	255	—	—	—
930	—	260	—	—	—
1000	—	265	—	—	—
1030	—	265	—	—	—
1045	—	—	—	208	—
1100	—	270	—	—	—
1115	—	—	—	203	—
1130	—	208	—	—	—
1148	—	—	—	115	—
1200	—	190	—	—	—
1230	—	180	—	—	—
1300	—	170	—	—	—
1310	79*	—	—	—	—
1312	—	—	—	130	—
1330	58*	180	—	—	—
1350	121	—	—	—	—
1400	—	190	—	—	—
1410	140	—	—	—	—
1418	—	—	—	115	—
1430	25*	180	—	—	—
1447	—	—	130	—	—
1450	43*	—	—	—	—
1500	—	165	—	—	—
1510	3*	—	—	—	—
1518	—	—	127	—	—
1530	136	165	—	—	—
1550	125	—	—	—	—
1600	—	170	135	—	
1610	137	—	—	—	—
1630	142	170	—	—	—
1650	126	—	—	—	—

* Invalid data

** A factor of 0.76 applied to the ARB TECO data gives average ARB TECO concentrations the same value as the average of the valid PDS data

*** Monterey Bay Unified Air Pollution Control District

Table 3

State of California

AIR RESOURCES BOARD

Division of Implementation and Enforcement

Concentrations of Oxides of Nitrogen

Unit 7, September 10, 1974

Time of Day	Concentration of NOx as NO_2, ppm (dry basis)				
	EPA Method 7 ARB	TECO** ARB	TECO *** MBUAPCD	Dynascience PG&E	Beckman PG&E
1045	—	—	120	—	—
1115	—	—	120	—	—
1148	—	—	123	—	—
1300	83*	—	—	—	—
1312	—	—	117	—	—
1320	156	—	—	—	—
1340	139	—	—	—	—
1347	—	—	125	118	—
1400	135	—	—	—	—
1418			125	115	
1420	151	—	—	—	—
1440	156	—	—	—	—
1447	—	—	—	118	—
1500	144	—	—	—	—
1520	140	—	—	—	—
1540	130	—	—	—	—
1600	155	—	—	—	—
1610	—	—	—	115	—
1620	148	—	—	—	—
1640	1*	—	—	—	—
1700	171	—	—	—	—

* Invalid data

** A factor of 0.76 applied to the ARB TECO data gives the average ARB TECO concentration the same value as the average of the valid PDS data.

*** Monterey Bay Unified Air Pollution Control District

File No. C4-068

Table 4

State of California

AIR RESOURCES BOARD

Division of Implementation and Enforcement

Concentrations of Oxides of Nitrogen

Unit 6, September 11, 1974

Time of Day	Concentration of NOx as NO_2, ppm (dry basis)				
	EPA Method 7 ARB	TECO** ARB	TECO *** MBUAPCD	Dynascience PG&E	Beckman PG&E
900	—	125	135	—	136
930	—	160	—	—	—
935	—	—	124	—	121
1000	—	165	—	—	—
1005	—	—	134	125	141
1030	—	170	—	—	—
1035	—	—	134	118	146
1100	—	170	—	—	—
1105	—	—	—	125	134
1130	—	165	—	—	—
1137	—	—	127	125	131
1140	40*	—	—	—	—
1200	3*	175	—	—	—
1205	—	—	132	125	124
1220	10*	—	—	—	—
1230	—	175	—	—	—
1235	—	—	125	115	116
1240	35*	—	—	—	—
1300	94	175	—	—	—
1303	—	—	135	125	131
1320	32*	—	—	—	—
1330	—	175	—	—	—
1336	—	—	135	—	126
1340	128	—	—	—	—
1400	—	175	—	—	—
1406	—	—	135	—	131
1420	136	—	—	—	—
1430	—	175	—	—	—
1436	—	—	118*	—	131
1440	138	—	—	—	—
1500	—	160	—	—	—
1507	—	—	135	—	121
1520	25*	—	—	—	—
1530	—	175	—	—	—
1536	—	—	—	—	126
1540	134	—	—	—	—
1600	120	175	135	—	121
1620	125	—	—	—	—
1630	—	170	134	—	116
1640	137	—	—	—	—
1700	—	—	132	—	114

* Invalid data

** A factor of 0.76 applied to the ARB TECO data gives the average ARB TECO concentration the same value as the average of the valid PDS data.

*** Monterey Bay Unified Air Pollution Control District

Table 5

State of California

AIR RESOURCES BOARD

Division of Implementation and Enforcement

Concentrations of Oxides of Nitrogen

Unit 7, September 11, 1974

Time of Day	Concentration of NOx as NO_2, ppm (dry basis)				
	EPA Method 7 ARB	TECO** ARB	TECO*** MBUAPCD	Dynascience PG&E	Beckman PG&E
900	—	—	—	—	126
935	—	—	—	—	107
1005	—	—	—	—	123
1035	—	—	—	—	126
1105	—	—	—	—	134
1130	113	—	—	—	—
1137	—	—	—	—	136
1150	143	—	—	—	—
1205	—	—	—	—	139
1210	140	—	—	—	—
1230	141	—	—	—	—
1235	—	—	—	—	131
1250	141	—	—	—	—
1303	—	—	—	—	111
1310	8*	—	—	—	—
1330	124	—	—	—	—
1336	—	—	—	115	136
1350	119	—	—	—	—
1406	—	—	—	120	131
1410	117	—	—	—	—
1430	127	—	—	—	—
1436	—	—	—	120	107
1450	125	—	—	—	—
1507	—	—	—	120	136
1510	128	—	—	—	—
1530	124	—	—	—	—
1536	—	—	—	120	131
1550	127	—	—	—	—
1600	—	—	—	120	126
1610	134	—	—	—	—
1630	128	—	—	—	126
1700	—	—	—	—	111

* Invalid data

** A factor of 0.76 applied to the ARB TECO data gives the average ARB TECO concentration the same value as the average valid PDS data.

*** Monterey Bay Unified Air Pollution Control District

Table 6

State of California

AIR RESOURCES BOARD

Division of Implementation and Enforcement

Concentrations of Oxides of Nitrogen

Unit 6, September 12, 1974

Time of Day	Concentration of NOx as NO_2, ppm (dry basis)				
	EPA Method 7 ARB	TECO** ARB	TECO *** MBUAPCD	Dynascience PG&E	Beckman PG&E
900	—	—	143	—	—
930	—	—	—	—	121
1000	—	170	138	—	146
1030	—	185	140	128	131
1100	—	195	150	135	141
1130	151	195	146	138	141
1150	142	—	—	—	—
1200	—	175	152	140	146
1210	153	—	—	—	—
1230	125	175	154	140	146
1250	131	—	—	—	—
1300	—	160	140	130	131
1310	118	—	—	—	—
1330	73*	165	136	—	119
1350	133	—	—	—	—
1400	—	180	140	—	124
1410	139	—	—	—	—
1430	129	180	142	—	124
1450	125	—	—	—	—
1500	—	180	142	—	126
1510	129	—	—	—	—
1530	135	175	135	—	121
1550	142	—	—	—	—
1600	—	170	137	—	123.5
1610	125	—	—	—	—
1630	134	165	134	—	119
1700	—	—	133	—	114

* Invalid data

** A factor of 0.76 applied to the ARB TECO data gives the average ARB TECO concentration the same value as the average of the valid PDS data.

*** Monterey Bay Unified Air Pollution Control District

Table 7

State of California

AIR RESOURCES BOARD

Division of Implementation and Enforcement

Concentrations of Oxides of Nitrogen

Unit 7 , September 12, 1974

Time of Day	Concentration of NOx as NO_2, ppm (dry basis)				
	EPA Method 7 ARB	TECO** ARB	TECO *** MBUAPCD	Dynascience PG&E	Beckman PG&E
900	—	—	—	—	84
930	—	—	—	—	94
1000	—	—	—	—	94
1030	—	—	—	—	89
1100	—	—	—	—	98
1130	—	—	—	—	98
1140	85	—	—	—	—
1200	83	—	—	—	94
1220	85	—	—	—	—
1230	—	—	—	—	89
1240	87	—	—	—	—
1300	66	—	—	—	136
1320	82	—	—	—	—
1330	—	—	—	105	89
1340	77	—	—	—	—
1400	75	—	—	93	131
1420	73	—	—	—	—
1430	—	—	—	93	77
1440	76	—	—	—	—
1500	73	—	—	—	74
1520	76	—	—	—	—
1530	—	—	—	85	84
1540	86	—	—	—	—
1600	87	—	—	85	77
1620	87	—	—	85	—
1630	—	—	—	—	73
1640	78	—	—	—	—
1700	—	—	—	—	74

* Invalid data

** A factor of 0.76 applied to the ARB TECO data gives the average ARB TECO concentration the same value as the average of the valid PDS data.

*** Monterey Bay Unified Air Pollution Control District

TABLE 8a

AIR RESOURCES BOARD

Division of Implementation and Enforcement

Concentrations of Carbon Monoxide

Units 6 and 7, P.G.&E. Moss Landing

September 10, 1974

Time	Unit 6, Concentrations ppm		Time	Unit 7, Concentrations ppm	
	GC 1/	MSA 2/		GC 1/	MSA 2/
0906	169	--	1030	24*	--
1015	41	--	1115	7	--
1045	--	40	1310	20	--
1106	31*	--	1347	--	48
1115	--	33	1350	50	--
1148	--	42	1418	--	36
1205	25	--	1435	7	--
1325	24	--	1447	--	31
1405	28	--	1518	--	26
			1610	--	36

* Invalid data.

1/ Determination by analysis of grab sample by gas chromatograph.

2/ Determination by MSA nondispersive infrared analyzer.

TABLE 8-b

AIR RESOURCES BOARD

Division of Implementation and Enforcement

Concentrations of Carbon Monoxide

Units 6 and 7, P.G.&E. Moss Landing

September 11, 1974

Time	Unit 6, Concentrations ppm		Time	Unit 7, Concentrations ppm	
	GC 1/	MSA 2/		GC 1/	MSA 2/
0905	6	--	0945	18	--
0935	4	--	1015	11	--
1005	12	47	1110	11	--
1035	--	48	1250	18	--
1105	21	55	1336	--	56
1137	--	54	1405	293	--
1205	--	54	1406	--	66
1235	--	48	1436	--	62
1245	16	--	1507	--	50
1303	--	47	1536	--	54
1335	19	56	1600	--	57
1406	--	66			
1436	--	62			
1507	--	59			

1/ Determination by analysis of grab samples by gas chromatograph.

2/ Determination by MSA nondispersive infrared analyzer.

TABLE 8-c

AIR RESOURCES BOARD

Division of Implementation and Enforcement

Concentrations of Carbon Monoxide

Units 6 and 7, P.G.&E. Moss Landing

September 12, 1974

Time	Unit 6, Concentrations ppm		Time	Unit 7, Concentrations ppm	
	GC 1/	MSA 2/		GC 1/	MSA 2/
0900	298	--	0940	10	--
1010	29	--	1018	57	--
1030	--	450	1035	16	--
1040	5	--	1125	4*	--
1100	--	440	--	--	--
1115	254	--	1330	--	1100
1130	--	400	1340	17	--
1200	--	520	1400	--	100
1230	--	480	1425	30	--
1250	54	--	1430	--	100
1300	--	340	1430	--	100
1335	50	--	1530	--	130
1406	14	--	1620	--	130

* Invalid data

1/ Determination by analysis of grab samples by gas chromatograph.

2/ Determination by MSA nondispersive infrared analyzer.

TABLE 9

State of California

AIR RESOURCES BOARD

Division Of Implementation And Enforcement

OXIDES OF NITROGEN FROM BOILERS 1, 2 & 3

(Concentrations and flows on a wet basis)

Date	Time	Boiler No. 1			Boiler No. 2			Boiler No. 3		
		Stack I.D...11'-4"			Stack I.D...11'-4"			Stack I.D...11'-4"		
		NO_x ppm	Stack Gas Flow 1000's SCFM	Stack Gas Temp. °F	NO_x ppm	Stack Gas Flow 1000's SCFM	Stack Gas Temp. °F	NO_x ppm	Stack Gas Flow 1000's SCFM	Stack Gas Temp. °F
9/10/74	9									
	10				38.1	40.0	270			
	11				44.1	39.9	270			
	12				44.1	39.9	270			
	1	45.0	39.6	270	48.8	41.4	275			
	2	45.0	39.6	270	121.0	118.1	315			
	3				127.6	134.2	325			
	4				127.6	134.2	325			
	5				126.6	134.2	325			
9/11/74	9				96.3	78.9	300			
	10				109.6	95.9	305			
	11				98.4	80.6	300	40.7	40.0	270
	12				88.0	69.5	290	40.7	40.0	270
	1	44.1	41.5	275	67.6	54.3	280	40.7	40.0	270
	2	41.0	39.6	270	75.9	58.7	285	34.6	36.9	270
	3	41.0	39.6	270	75.9	58.7	285	34.6	36.9	270
	4	41.0	39.6	270	75.9	58.7	285	34.6	36.9	270
	5	80.7	63.1	290	98.4	80.6	300	94.2	77.1	295

File No. C4-028

TABLE 10

State of California

AIR RESOURCES BOARD

Division Of Implementation And Enforcement

OXIDES OF NITROGEN FROM BOILERS

(Concentrations and flows on a wet basis)

Date	Time	Boiler No. 4			Boiler No. 7			Boiler No. 8		
		Stack I.D...11'-4"			Stack I.D...13'-0"			Stack I.D...13'-0"		
		NO_x ppm.	Stack Gas Flow 1000's SCFM	Stack Gas Temp. °F	NO_x ppm	Stack Gas Flow 1000's SCFM	Stack Gas Temp. °F	NO_x ppm	Stack Gas Flow 1000's SCFM	Stack Gas Temp. °F
9/10/74	9	67.6	54.3	280	94	157.9	310	90	150	300
	10	67.6	54.3	280	94	157.9	310	94	158	300
	11	53.1	44.3	280	86	142.0	305	90	150	300
	12	56.5	47.1	280	95	160.0	315	94	158	300
	1	56.5	47.1	280	93	159.0	310	94	158	300
	2	122.7	120.1	315	96	160.3	315	98	165	315
	3	129.3	139.5	325	103	175.2	320	105	178	320
	4	128.4	136.3	325	105	178.4	325	107	178	325
	5	128.4	136.3	325	102	173.1	320	104	179	320
9/11/74	9	101	83.4	300	75	117	290	80	126	295
	10	111	98.1	305	86	142	295	87	143	305
	11	101	83.4	300	95	160	315	97	163	315
	12	92	74.3	295	88	145	315	92	153	310
	1	81	63.1	290	75	117	290	80	126	295
	2	86	67.6	290	87	144	305	88	147	305
	3	86	67.6	290	93	155	310	92	153	310
	4	86	67.6	290	91	151	310	95	160	315
	5	101	83.4	300	97	163	315	98	167	320
9/12/74	9	74	57.1	285	81	128	300	81	128	300
	10	74	57.1	285	81	128	300	81	128	300
	11	74	57.1	285	80	126	295	80	126	295
	12	74	57.1	285	81	129	300	79	125	295
	1	74	57.1	285	90	148	310	87	147	305
	2	74	57.1	285	81	130	300			
	3	74	57.1	285	91	151	310			
	4	74	57.1	285	80	126	295			
	5	74	57.1	285	82	132	300			

Rockwell International
Atomics International Division
Air Monitoring Center

APPENDIX B

MEASUREMENTS OF EMISSIONS FROM STEAM GENERATORS AT TWO POWER PLANTS IN LOS ANGELES COUNTY

AIR POLLUTION CONTROL DISTRICT

434 SOUTH SAN PEDRO STREET, LOS ANGELES, CALIF. 90013 - MADISON 9-4711 / COUNTY OF LOS ANGELES

TECHNICAL REPORT

FOR

CALIFORNIA STATE AIR RESOURCES BOARD
(CONTRACT 4-286)

MEASUREMENTS OF EMISSIONS FROM STEAM GENERATORS AT TWO POWER PLANTS IN LOS ANGELES COUNTY

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Robert J. MacKnight
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Date:

FOREWORD

The statements and conclusions in this report are those of the Los Angeles County Air Pollution Control District, as a contractor to the ARB, and not necessarily those of the State Air Resources Board. The mention of commercial products, their source or their use in connection with material reported herein is not to be construed as either an actual or implied endorsement of such products.

ABSTRACT

This report describes tests conducted by the Source Testing Section, Engineering Division, Los Angeles County Air Pollution Control District, for the State Air Resources Board under the research project on "The Chemistry, Dispersion and Transport of Air Pollutants Emitted from Fossil Fuel Power Plants." The effort was funded by California State Contract No. ARB 4-286.

Tests were conducted at the Haynes Plant on October 1, 4, 11, and 17; at the Alamitos Plant October 25, 30, and November 7, 1974.

INTRODUCTION

A total of seven stack sampling tests of emissions from selected power plants in Los Angeles County were conducted by the Air Pollution Control District. Each test included the measurements of emissions from two independent steam generators. Tests were conducted at the Haynes Steam Plant, City of Los Angeles Department of Water and Power, and the Alamitos Steam Plant, Southern California Edison Company. Both facilities are in the southeast coastal corner of Los Angeles County.

Collected samples were analyzed to determine the emission rates and concentrations of SO_2, SO_3 as H_2SO_4, non-acid or neutral sulfates, total nitrogen oxides (combined NO and NO_2), carbon dioxide, carbon monoxide, and oxygen for each steam generator tested. Operational data was recorded by source-testing personnel and included with the experimental data for each test.

TEST RESULTS

The results of each test, i.e., on two steam generators for a given date, are reported on separate sheets. Results for the entire program are presented on pages 4 to 10.

The chemical analyses of the fuel oil samples were furnished by the Berkeley laboratory of the California Department of Health.

DESCRIPTION

Haynes (DWP) samples were taken in the breechings (or in the stack immediately following), except for the tests on Unit No. 4, which were taken in the stack.

Alamitos (Edison) samples were taken in the stack sufficiently downstream of the breechings to achieve adequate mixing of the two flows.

The power plant steam generators were operating at essentially full load while firing low-sulfur fuel oil. For the Haynes tests, it should be noted that the air preheater bypass modifications to these units were still under construction when these tests were conducted and thus were not in use for this program.

SAMPLING PROCEDURE AND ANALYSIS

Gas Sample Collection

Gas samples (for constituents other than sulfur compounds) were collected directly from the purged sampling line from each steam generator. The integrated samples were collected in plastic bags.

Nitrogen Oxides

Primary determination of nitrogen oxides (NO and NO_2) concentration was made by collecting gas samples in evacuated two-liter flasks containing twenty-five ml of a hydrogen peroxide-sulfuric acid mixture, and analyzed by the phenol-disulfonic acid method. Total nitrogen oxides are reported as nitrogen dioxide (NO_2).

Field determination of NO_x concentration was made with the use of an Enviro-Metrics Model 200 analyzer.

Carbon Dioxide, Oxygen, and Carbon Monoxide

The carbon dioxide concentration was determined by use of an Orsat analyzer. The oxygen concentration was measured with a Teledyne oxygen analyzer.

The carbon monoxide concentration was estimated using MSA detector tubes. Reported zero results indicate concentrations below the limit of detection (less than 10 ppm).

Sulfur Oxides

Primary determination of SO_2 concentration, as well as the measurement of SO_3, was accomplished with a sampling train shown schematically on page 11. Results are reported for SO_3 (as H_2SO_4), neutral sulfates (sometimes called solid particulate sulfates) as sulfate (SO_4), and SO_2.

Field determination of SO_2 concentration was made with the use of an Enviro-Metrics Model 200 analyzer, using the SO_2 channel of the instrument.

Flue Gas Flow Rate

The flow rate for each stack was determined by means of a carbon balance utilizing the fuel oil flow rate, the carbon content of the fuel, and the carbon dioxide concentration in the flue gas.

OPERATIONAL DATA

Data for load (megawatts), combustion air flow, fuel flow, carbon monoxide, and excess oxygen were obtained from instrumentation in the control rooms. The combustion air flow, as explained in the summary sheets, is only an arbitrary scale. Excess oxygen is measured at a location prior to the preheater, while the APCD oxygen samples were taken after the preheater (along with NO_x, SO_x, etc.) and consequently show the effect of air dilution (on concentration values only).

Test No. C-2204-A

Page 4

Date Oct. 1, 1974

SUMMARY OF RESULTS

Company City of Los Angeles Department of Water and Power

Address Haynes Steam Plant, Long Beach

Unit Number		5	6
Time of Test		1:00 - 4:00	9:00 - 12:00
A. DATA OBTAINED BY APCD			
SO_2	(#/hr)	786	1270
	(ppm)	128	196
SO_3 (as H_2SO_4)	(#/hr)	19	28
	(ppm)	2	3
Non-acid Sulfates	(#/hr)	7	6
NO_x (avg)	(#/hr)	662	677
	(ppm)	150	145
CO_2 (avg)	(%)	10.6	10.2
O_2 (avg)	(%)	7.4	7.0
CO (avg)	(ppm)	0	0
B. OPERATIONAL DATA			
Load (avg)	(MW)	300	330
Combustion Air Flow (avg)	(%)*	95	91
Fuel Flow (avg)	(#/hr)	142,000	145,000
CO (avg)	(ppm)	60	50
Excess O_2 (avg)	(%)	5.5	5.3
C. ADDITIONAL CALCULATED RESULTS			
Stack Gas Flow Rate (avg)	(SCFM)	608,000	642,000
NO_x @ 3% O_2	(ppm)	196	187

NOTES: All concentrations and SCFM on dry basis.

*The combustion air flow is an arbitrary scale that indicates the change in conditions. The scale implies that the value displayed is a percentage of a maximum or design value; however, the original design has been changed since the construction was completed. Hence, no specific figure can be assigned to the scale display.

Test No. C-2204-B

Date Oct. 4, 1974

SUMMARY OF RESULTS

Company City of Los Angeles Department of Water and Power

Address Haynes Steam Plant, Long Beach

Unit Number (Breeching)		5(A)	5(B)
Time of Test		9:45 - 12:45	9:45 - 12:45
A. DATA OBTAINED BY APCD			
SO_2	(#/hr)	1415	1300
	(ppm)	226	216
SO_3 (as H_2SO_4)	(#/hr)	23	54
	(ppm)	2	6
Non-acid Sulfates	(#/hr)	0	7
NO_x (avg)	(#/hr)	526	512
	(ppm)	117	118
CO_2 (avg)	(%)	10.4	10.9
O_2 (avg)	(%)	6.6	6.0
CO (avg)	(ppm)	0	0
B. OPERATIONAL DATA			
Load (avg)	(MW)	300	300
Combustion Air Flow (avg)	(%)*	93	93
Fuel Flow (avg)	(#/hr)	142,000	142,000
CO (avg)	(ppm)	60	60
Excess O_2 (avg)	(%)	3.9	3.7
C. ADDITIONAL CALCULATED RESULTS			
Stack Gas Flow Rate (avg)	(SCFM)	620,000	597,000
NO_x @ 3% O_2	(ppm)	146	141

NOTES: All concentrations and SCFM on dry basis.

*The combustion air flow is an arbitrary scale that indicates the change in conditions. The scale implies that the value displayed is a percentage of a maximum or design value; however, the original design has been changed since the construction was completed. Hence, no specific figure can be assigned to the scale display.

Test No. C-2204-C

Date Oct. 11, 1974

SUMMARY OF RESULTS

Company City of Los Angeles Department of Water and Power

Address Haynes Steam Plant, Long Beach

Unit Number		4	6
Time of Test		10:00 - 1:00	9:45 - 12:45
A. DATA OBTAINED BY APCD			
SO_2	(#/hr)	1093	1192
	(ppm)	222	172
SO_3 (as H_2SO_4)	(#/hr)	10	26
	(ppm)	1	2
Non-acid Sulfates	(#/hr)	3	6
NO_x (avg)	(#/hr)	643	716
	(ppm)	181	144
CO_2 (avg)	(%)	10.6	9.4
O_2 (avg)	(%)	6.3	8.0
CO (avg)	(ppm)	0	0
B. OPERATIONAL DATA			
Load (avg)	(MW)	236	327
Combustion Air Flow (avg)	(%)*	92	97
Fuel Flow (avg)	(#/hr)	114,000	143,000
CO (avg)	(ppm)	33	20
Excess O_2 (avg)	(%)	4.1	4.7
C. ADDITIONAL CALCULATED RESULTS			
Stack Gas Flow Rate (avg)	(SCFM)	487,000	685,000
NO_x @ 3% O_2	(ppm)	222	200

NOTES: All concentrations and SCFM on dry basis.

*The combustion air flow is an arbitrary scale that indicates the change in conditions. The scale implies that the value displayed is a percentage of a maximum or design value; however, the original design has been changed since the construction was completed. Hence, no specific figure can be assigned to the scale display.

Test No. C-2204-D

Date Oct. 17, 1974

SUMMARY OF RESULTS

Company City of Los Angeles Department of Water and Power

Address Haynes Steam Plant, Long Beach

Unit Number		4	6
Time of Test		11:03 - 2:03	10:23 - 1:23
A. DATA OBTAINED BY APCD			
SO_2	(#/hr)	1176	1346
	(ppm)	235	196
SO_3 (as H_2SO_4)	(#/hr)	10	41
	(ppm)	1	4
Non-acid Sulfates	(#/hr)	4	4
NO_x (avg)	(#/hr)	745	789
	(ppm)	207	160
CO_2 (avg)	(%)	10.5	9.8
O_2 (avg)	(%)	6.9	8.0
CO (avg)	(ppm)	0	0
B. OPERATIONAL DATA			
Load (avg)	(MW)	236	350
Combustion Air Flow (avg)	(%)*	91	96
Fuel Flow (avg)	(#/hr)	114,000	146,000
CO (avg)	(ppm)	0	0
Excess O_2 (avg)	(%)	41.	3.7
C. ADDITIONAL CALCULATED RESULTS			
Stack Gas Flow Rate (avg)	(SCFM)	494,000	677,000
NO_x @ 3% O_2	(ppm)	265	222

NOTES: All concentrations and SCFM on dry basis.

*The combustion air flow is an arbitrary scale that indicates the change in conditions. The scale implies that the value displayed is a percentage of a maximum or design value; however, the original design has been changed since the construction was completed. Hence, no specific figure can be assigned to the scale display.

Test No. C-2217-A / C-2218

Page 8

Date Oct. 25, 1974

SUMMARY OF RESULTS

Company Southern California Edison Company

Address Alamitos Steam Plant, Long Beach

Unit Number		5	6
Time of Test		10:05 - 1:05	10:04 - 1:04
A. DATA OBTAINED BY APCD			
SO_2	(#/hr)	2107	2210
	(ppm)	218	210
SO_3 (as H_2SO_4)	(#/hr)	19	91
	(ppm)	1	6
Non-acid Sulfates	(#/hr)	7	7
NO_x (avg)	(#/hr)	1307	831
	(ppm)	189	110
CO_2 (avg)	(%)	11.2	10.9
O_2 (avg)	(%)	5.6	6.3
CO (avg)	(ppm)	0	0
B. OPERATIONAL DATA			
Load (avg)	(MW)	480	463
Combustion Air Flow (avg)	(%)*	80	82
Fuel Flow (avg)	(#/hr)	235,000	249,000
CO (avg)	(ppm)	(Inop.)	(Inop.)
Excess O_2 (avg)	(%)	2.0	2.4
C. ADDITIONAL CALCULATED RESULTS			
Stack Gas Flow Rate (avg)	(SCFM)	953,000	1,038,000
NO_x @ 3% O_2	(ppm)	221	135

NOTES: All concentrations and SCFM on dry basis.

*The combustion air flow is an arbitrary scale that indicates the change in conditions. The scale implies that the value displayed is a percentage of a maximum or design value; however, the original design has been changed since the construction was completed. Hence, no specific figure can be assigned to the scale display.

Test No. C-2217 / C-2218 B

Date Oct. 30, 1974

SUMMARY OF RESULTS

Company Southern California Edison Company

Address Alamitos Steam Plant, Long Beach

Unit Number		5	6
Time of Test		9:45 - 12:45	9:45 - 12:45
A. DATA OBTAINED BY APCD			
SO_2	(#/hr)	2130	2180
	(ppm)	219	218
SO_3 (as H_2SO_4)	(#/hr)	26	92
	(ppm)	2	6
Non-acid Sulfates	(#/hr)	8	10
NO_x (avg)	(#/hr)	1140	1400
	(ppm)	164	195
CO_2 (avg)	(%)	11.0	11.1
O_2 (avg)	(%)	6.0	6.1
CO (avg)	(ppm)	0	0
B. OPERATIONAL DATA			
Load (avg)	(MW)	470	459
Combustion Air Flow (avg)	(%)*	82	79
Fuel Flow (avg)	(#/hr)	231,000	240,000
CO (avg)	(ppm)	(Inop.)	(Inop.)
Excess O_2 (avg)	(%)	2.3	2.0
C. ADDITIONAL CALCULATED RESULTS			
Stack Gas Flow Rate (avg)	(SCFM)	959,000	984,000
NO_x @ 3% O_2	(ppm)	197	235

NOTES: All concentrations and SCFM on dry basis.

*The combustion air flow is an arbitrary scale that indicates the change in conditions. The scale implies that the value displayed is a percentage of a maximum or design value; however, the original design has been changed since the construction was completed. Hence, no specific figure can be assigned to the scale display.

Test No. C-2217 / C-2218 C

Date Nov. 7, 1974

SUMMARY OF RESULTS

Company Southern California Edison Company

Address Alamitos Steam Plant, Long Beach

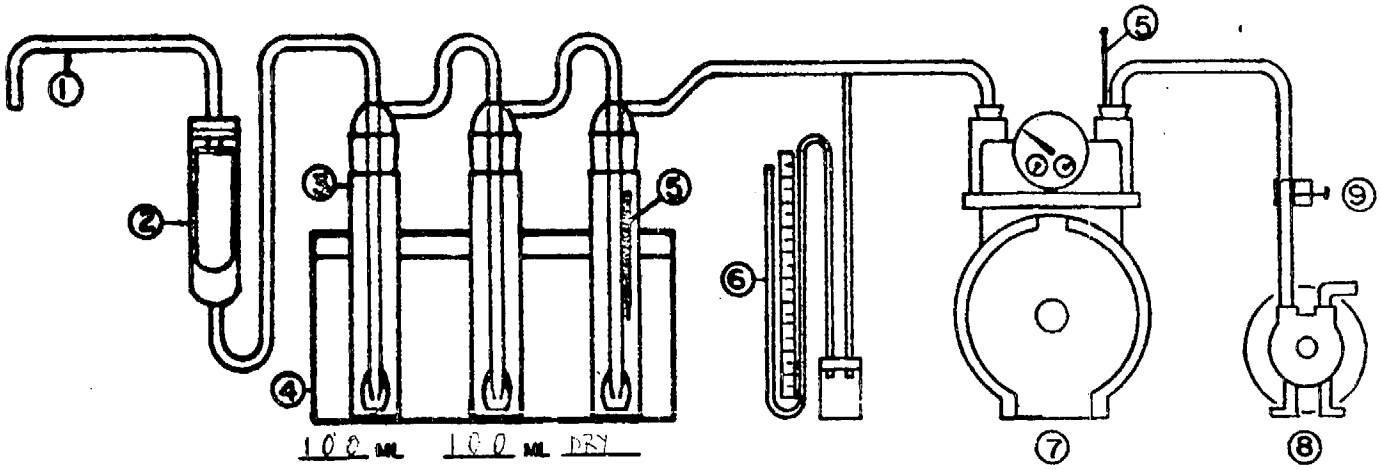
Unit Number		5	6
Time of Test		9:47 - 12:47	9:50 - 12:50
A. DATA OBTAINED BY APCD			
SO_2	(#/hr)	2182	2137
	(ppm)	217	200
SO_3 (as H_2SO_4)	(#/hr)	36	162
	(ppm)	2	10
Non-acid Sulfates	(#/hr)	15	18
NO_x (avg)	(#/hr)	1070	1380
	(ppm)	148	180
CO_2 (avg)	(%)	11.0	10.4
O_2 (avg)	(%)	5.8	6.9
CO (avg)	(ppm)	0	0
B. OPERATIONAL DATA			
Load (avg)	(MW)	473	452
Combustion Air Flow (avg)	(%)*	84	83
Fuel Flow (avg)	(#/hr)	241,000	240,000
CO (avg)	(ppm)	(Inop.)	(Inop.)
Excess O_2 (avg)	(%)	2.7	3.0
C. ADDITIONAL CALCULATED RESULTS			
Stack Gas Flow Rate (avg)	(SCFM)	993,000	1,053,000
NO_x @ 3% O_2	(ppm)	175	230

NOTES: All concentrations and SCFM on dry basis.

*The combustion air flow is an arbitrary scale that indicates the change in conditions. The scale implies that the value displayed is a percentage of a maximum or design value; however, the original design has been changed since the construction was completed. Hence, no specific figure can be assigned to the scale display.

TEST NO. C-2204
C-2217
C-2218

SAMPLING APPARATUS
FOR
SULFUR OXIDES



1. SAMPLING PROBE
2. DRY FILTER (heated)
3. IMPINGER
4. ICE BATH CONTAINER
5. THERMOMETER
6. MERCURY MANOMETER
7. SPRAGUE DRY GAS METER (ZEPHYR NO. 1A)
8. VACUUM PUMP
9. HOSE CLAMP TO CONTROL GAS FLOW RATE

IMPINGER SOLUTION

5% NaOH