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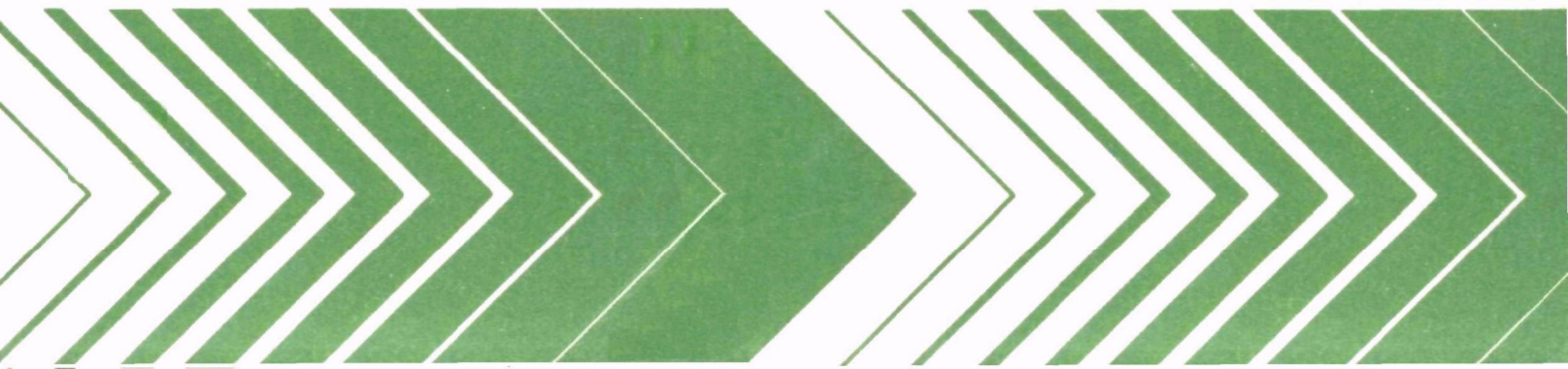
Trace Elements in Soil Around the Four Corners Power Plant



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TRACE ELEMENTS IN SOIL AROUND THE FOUR CORNERS POWER PLANT

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FOREWORD

Protection of the environment requires effective regulatory actions which are based on sound technical and scientific information. This information must include the quantitative description and linking of pollutant sources, transport mechanisms, interactions, and resulting effects on man and his environment. Because of the complexities involved, assessment of specific pollutants in the environment requires a total systems approach which transcends the media of air, water, and land. The Environmental Monitoring and Support Laboratory-Las Vegas contributes to the formation and enhancement of a sound monitoring data base for exposure assessment through programs designed to:

- develop and optimize systems and strategies for monitoring pollutants and their impact on the environment
- demonstrate new monitoring systems and technologies by applying them to fulfill special monitoring needs of the Agency's operating programs

The report presents data on trace element distribution in soil around the Four Corners Power Plant. The data are part of a larger effort to determine the feasibility of using biological monitors to detect accumulation of certain trace elements around point source pollution. These data will be considered by EPA and others in making decisions concerning control of trace element emissions from coal-fired utilities. For additional information, please contact the Pollutant Pathways Branch, Environmental Monitoring and Support Laboratory-LV, P.O. Box 15027, Las Vegas, Nevada 89114.

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INTRODUCTION

There are indications that state and local air pollution control agencies are becoming increasingly concerned about the possible environmental threat from trace elements emitted from coal-fired electric power generating plants (Lee and Von Lehmden, 1973). The total amount of coal burned in recent years has been steadily increasing over the 500 million tons (454 million metric tons) consumed in 1970 and is likely to increase even more as the policy of substituting coal for oil is stringently enforced. Because of this increased potential for trace element emissions, it is logical to study the distribution of these trace elements from coal-fired power plants.

This study was undertaken primarily to find biological monitors for trace elements around the Four Corners Power Plant, but the data reported in this paper for zinc, lead, copper, and cadmium are for the soil analyses only. Vegetation data are still being analyzed and will be presented in a subsequent paper. The results of mercury residues in soil around the Four Corners Power Plant were reported previously by Crockett and Kinnison (1977).

Trace element distribution around coal-fired plants in the United States has been studied at several locations. Klein and Russell (1973) studied the levels of trace elements around a 650 megawatt (MW) coal-fired power plant on the eastern shore of Lake Michigan. They claimed to detect enrichment for a variety of trace elements, including zinc and copper, two elements reported on in this paper, and mercury, an element also studied in this project but reported earlier by Crockett and Kinnison (1977).

Anderson and Smith (1977) studied mercury distribution around the Kinkaid Power Plant in Central Illinois. They reported relatively high mercury levels downwind from the plant.

Extensive studies have been carried out at the coal-fired Allen Steam Plant (Bolton et al., 1973; Bolton et al., 1974 and Klein et al., 1975). The major emphasis at the Allen Steam Plant was the development of a mass balance for trace elements. Those portions of the project dealing with soils showed little relationship of elemental concentration in soil with distance from the Allen Steam Plant.

In an attempt to put trace element emission in perspective, Bertine and Goldberg (1971) compared estimated elemental emissions with natural weathering processes such as erosion. Their data must be viewed with considerable caution since the emission estimates are based on only rough estimates of elemental concentrations in coal and on the total estimated amounts burned

(Boulding, 1976). To compare any man-induced activity to wide-scale weathering processes will automatically insure a favorable analysis for man's activities, because weathering processes take place on such an immense scale. Their estimated elemental emissions are interesting, however, in a relative sense, for the four trace elements that will be reported in this paper, zinc, lead, copper, and cadmium. The data in Table 1 indicate the possible order of mobilization for the four elements reported on in our study.

TABLE 1. RELATIVE MOBILIZATION OF ZINC, LEAD, COPPER AND CADMIUM FROM FOSSIL FUEL COMBUSTION (BERTINE AND GOLDBERG, 1971)

Element	Fossil Fuel Mobilization Coal (x 10^9 g/year)
Zinc	7.0
Lead	3.5
Copper	2.1
Cadmium	---

We chose the Four Corners Power Plant in Fruitland, New Mexico, because of its large size (>2150 MW), its coal consumption [6.3 x 10^9 kilograms per year (kg/y)], its length of operation (since 1963), and its relatively short stacks (two are 76 meters (m) and two are 91 m). In addition, the surrounding arid terrain (15 to 20 centimeters per year (cm/y) precipitation) is undisturbed by cultivation.

There also exists considerable background information concerning the Four Corners Power Plant. Billings et al. (1973), Billings and Matson (1971) and Green and Robinson (1971) studied mercury emissions from this power plant. Several studies have been conducted on the distribution of trace elements in soil and vegetation around the Four Corners Power Plant (Cannon and Anderson, 1972 and Stark and Harris, 1972). Wangen and Wienke (1976) published a review of all trace element studies related to coal combustion in the Four Corners area of New Mexico.

CONCLUSIONS

The study reported here is the most intensive soil sampling program to date around the Four Corners Power Plant. Average concentrations of zinc, lead, and copper do not appear elevated with respect to those found near other power plants. Cadmium values reported in this paper are higher than those reported elsewhere.

Residue levels for zinc, lead, copper, and cadmium are all higher to the west of the power plant. The difference between east and west is statistically significant for zinc, lead, and copper. Wind rose data and location of ash ponds provide a partial explanation for this phenomenon.

RECOMMENDATIONS

1. Analyze soil for arsenic and selenium levels by a reliable analytical method and report on results.

2. Analyze vegetation samples collected at time of soil samples and report on the levels of trace elements of environmental interest.

3. Evaluate the usefulness of the plant species collected as biological monitors for various trace elements.

SAMPLING AND ANALYSIS

The sampling design selected was a radial grid employing 16 evenly spaced radii and five approximately logarithmically spaced concentric circles around the power plant (Figure 1). The radii of the circles (A-E) were 1.0, 2.9, 6.8, 14.6, and 30 km. From the 80 sites on the grid, only 70 composite soil samples were collected since some sites fell in the mine area or in Morgan Lake. Each sample was a composite of 10 subsamples collected 15 m apart. The upper 1 to 2 cm of soil was collected by trowel and stored in pint glass jars.

In addition, a second soil sampling was made in April 1976. Soil samples were collected at all sites on circles A and E. The purpose was to serve as verification for the previously collected soil samples.

It should be pointed out that the San Juan Power Plant is located about 10 km due north of the Four Corners Power Plant. Its influence on trace element distribution in the area is unknown. The road net within a 30-km radius of the Four Corners Power Plant is not well developed. The majority of samples were collected well away from any major road.

Ninety-six soil samples were acid extracted and analyzed by atomic absorption spectrometry. Twenty-five milliliters (ml) of concentrated nitric acid was added to 10 grams of oven-dried (60° C) soil in a 125-ml Erlenmeyer flask. The samples were boiled under reflux for 17 hours. The soil was separated from the supernatant by centrifugation or filtration and washed three times with distilled deionized water. The supernatant and washes were combined in a volumetric flask and diluted to 100 ml. Sample extracts, distilled water blanks, acid blanks, standards and spike standards were

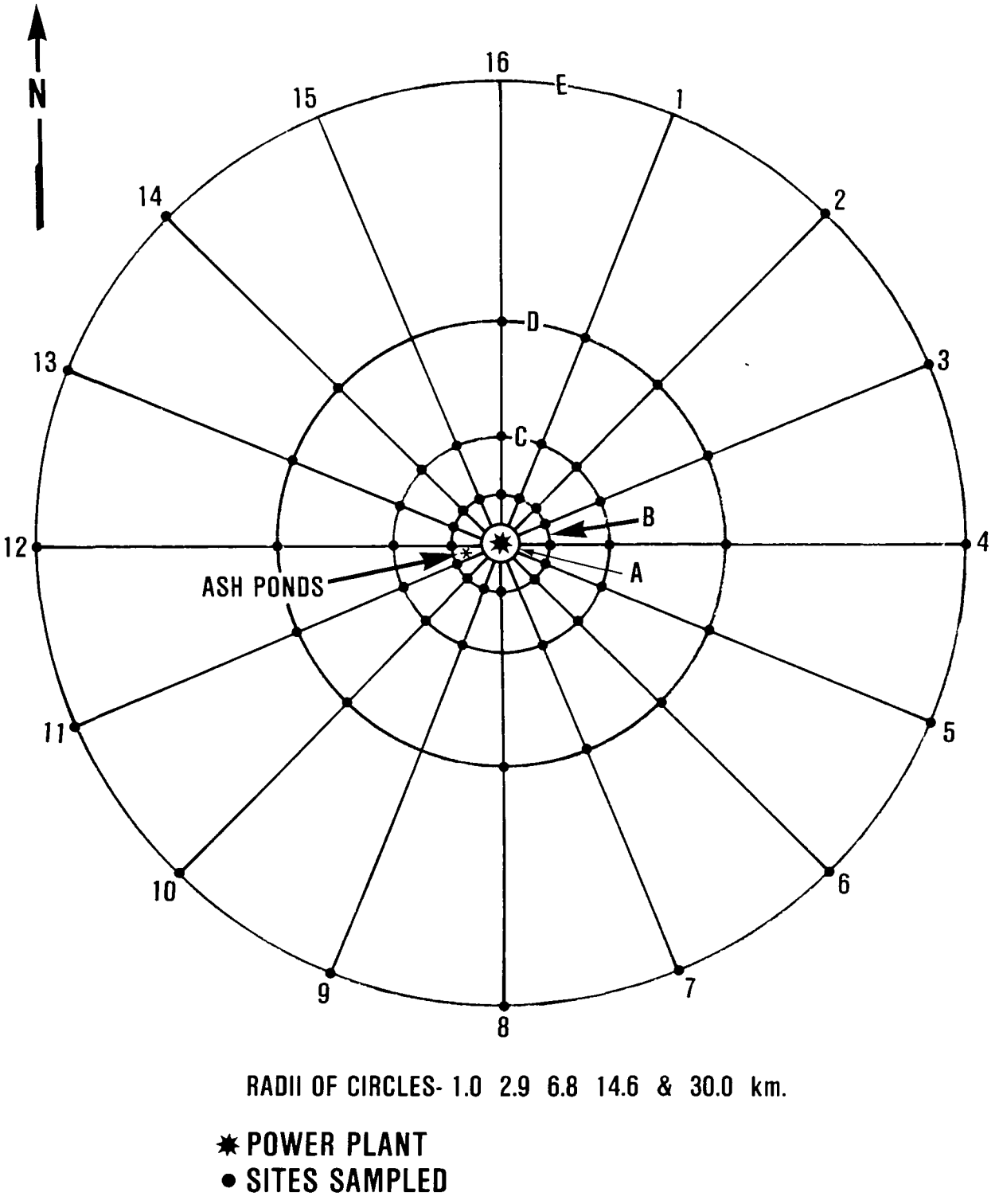

Figure 1. Soil sampling sites around the Four Corners Power Plant.

analyzed in duplicate for zinc, lead, and copper. Single analyses were made for cadmium using the same quality control procedures. Analyses were done using a Perkin-Elmer 603 Atomic Absorption Spectrophotometer.

Table 2 summarizes the results of acid blanks, standards, and spikes for zinc, copper, cadmium, and lead. Acid blanks are the acid used for extraction run with the samples. Standards, of course, are known values run as samples and spikes are samples with a known amount of the element analyzed added. The data were not corrected for spike recoveries.

TABLE 2. SUMMARY OF CONTROL SAMPLE FOR ANALYTICAL RESULTS

	Cu		Pb		Zn		Cd
	Run I $\bar{X}$[1] ± S.D.[2]	Run II $\bar{X}$ ± S.D.	Run I $\bar{X}$ ± S.D.	Run II $\bar{X}$ ± S.D.	Run I $\bar{X}$ ± S.D.	Run II $\bar{X}$ ± S.D.	Run I $\bar{X}$ ± S.D.
Acid Blanks (5 reps)	0.02± 0.01	0.02± 0.01	0.03± 0.03	0.00± 0.01	0.01± 0.05	0.02± 0.02	0.00± 0.01
0.5 g/ml Standard (4 reps)	0.50± 0.00	0.50± 0.02	0.50± 0.01	0.50± 0.01	---	---	---
1.0 g/ml Standard (4 reps)	1.01± 0.00	1.02± 0.02	1.01± 0.01	1.01± 0.02*	1.01± 0.02	1.01± 0.02	1.00
2.0 g/ml Standard (4 reps)	---	---	---	---	2.00± 0.01	2.00± 0.00	2.00
0.1 g/ml Spike and 0.2 g/ml Spike (% recovery)	94.7	93.3	106.7	99.6	97.0	97.0	96.6

* Three replicates
[1] Mean
[2] Standard Deviation

RESULTS

Table 3 shows the results for lead by site. Included is the resampling done at circles A and E and labeled A_2 and E_2. A two-way analysis of variance (ANOVA) was performed for all circles and radii 2 through 6 and radii

TABLE 3. LEAD RESIDUES IN SOIL BY SITE (ppm)

Radius Number	Direction	Concentric Circle $A\frac{1}{2}$ [1]	A	B	C	D	E	$E\frac{1}{2}$ [1]	Mean [7]	Standard Deviation [7]
1	NNE	---	---	5.8	33.0	9.0	---	19.0	15.9	14.9
2	NE	---	16.0	5.0	13.0	11.0	9.5	18.0	10.9	4.1
3	ENE	15.0	9.0	7.5	7.2	18.0	7.8	18.0	9.9	4.6
4	E	10.0	10.0	6.0	7.8	7.8	5.2	8.0	7.4	1.9
5	ESE	9.2	11.0	5.8	5.8	4.5	7.0	7.5	6.8	2.5
6	SE	12.0	8.5	11.0	7.0	9.0	4.5	9.0	8.0	2.4
Mean [2]			10.9	7.1	8.2	10.1	6.8			
Standard Deviation [2]			3.0	2.4	2.8	5.0	2.0			
Overall Mean [3]									8.6	---
7	SSE	7.0	11.0	---	7.0	6.0	6.5	34.0	7.6	2.3
8	S	9.0	7.0	14.0	---	11.0	11.0	8.0	10.8	2.9
9	SSW	10.0	11.0	18.0	10.0	---	6.5	7.0	11.4	4.8
10	SW	12.0	10.0	23.0	14.0	22.0	9.8	9.5	15.8	6.4
11	WSW	6.0	17.0	22.0	15.0	17.0	8.0	---	15.8	5.1
12	W	6.0	12.0	23.0	14.0	16.0	15.0	19.0	16.0	4.2
13	WNW	20.0	18.0	19.0	18.0	17.0	21.0	18.0	18.6	1.5
14	NW	19.0	11.0	14.0	18.0	18.0	6.2	19.0	13.4	5.0
Mean [4]			13.6	20.2	15.8	18.0	12.0			
Standard Deviation [4]			3.6	3.8	2.0	2.4	6.0			
Overall Mean [5]									15.9	---
15	NNW	---	---	19.0	12.0	---	---	19.0	16.0	5.0
16	N	---	---	6.0	22.0	16.0	---	---	15.0	8.1
Mean [6]		11.3	11.6	13.3	13.6	13.0	9.1	15.2	12.0	
Standard Deviation [6]		4.6	3.3	7.0	7.2	5.3	4.5	7.5		5.8

1/ Circle sampled in April 1976.

2/ Mean and standard deviation for radii 2-6.

3/ Overall mean for radii 2-6 and circles A to E.

4/ Mean and standard deviation for radii 10-14.

5/ Overall mean for radii 10-14 and circles A to E.

6/ Overall mean and standard deviation for each circle calculated using all radii.

7/ Mean and standard deviation for circles A to E only.

10 through 14. The F ratio for the circles was 2.27 (4/36 degrees of freedom, df) which indicates there is no significant difference in residue levels among the circles. However, the F value for radii comparison was 6.06 (9/36 df) which is significant at the 99.5 percent level. This indicates that there is a 99.5 percent probability that the average lead levels of at least two radii are different. Further, an orthogonal comparison (F ratio = 46) between radii 2 to 6 (to the east of the power plant) versus radii 10 to 14 (to the west of the power plant) indicated a highly significant difference in the mean lead residue levels for those radii to the east of the plant compared to those west of the plant. This result is shown graphically in Figure 2. The points are averages of 5 radii that intersect the respective circles (see Table 3).

Table 4 shows the results for zinc by site. A two-way ANOVA indicated no significant difference among circles (F - 1.18 with 4/36 df) but a highly significant difference among radii (F = 6.14 with 9/36 df). An orthogonal comparison of radii 2 through 6 and 10 through 14 shows a highly significant difference (F = 43.2). These results are shown graphically in Figure 2. The plotted points are averages of 5 radii that intersect the respective circles (see Table 4).

Table 5 and 6 show similar results for copper and cadmium, respectively. A two-way ANOVA for copper data shows no significant difference among circles but a significant difference is shown for radii (F = 3.52 with 9/36 df) and an orthogonal comparison of radii 2 through 6 with radii 10 through 14 shows a highly significant difference (F = 16.6). However, the cadmium data show no significant difference for a similar statistical analysis.

Linear regression could detect no significant relationship between distance from the plant and residue levels for any of the elements studied. This was true when all the original data were used and also when only radii 2 through 6 and 10 through 14 were used.

DISCUSSION

The overall mean lead results reported in our paper of 12.0 ppm are below lead levels reported in the literature for other power plant and point source emitters. Direct comparisons should be made with caution since different sampling procedures and analytical techniques might have been used; however, the studies cited below do provide a rough comparison for the lead data reported in our study.

Lindberg et al. (1975) report on residue levels in soils around the Allen Steam Plant. Their lead results varied from 5 to 100 ppm with an average of 26 ppm. They report a world concentration of lead in soil of 12 ppm. Linzon et al. (1976) report on lead residues in soils in urban areas around a secondary lead smelter and an urban battery manufacturer. Lead concentration in soil around the smelter varied from approximately 250 ppm to a high of 21,200 ppm. Most of these samples were collected within 600 m of the source. Similar data for lead in soil around the battery manufacturer show values ranging from 95 to 17,000 ppm. Further, their overall average lead concentration for urban soils for the upper 2.5 cm of

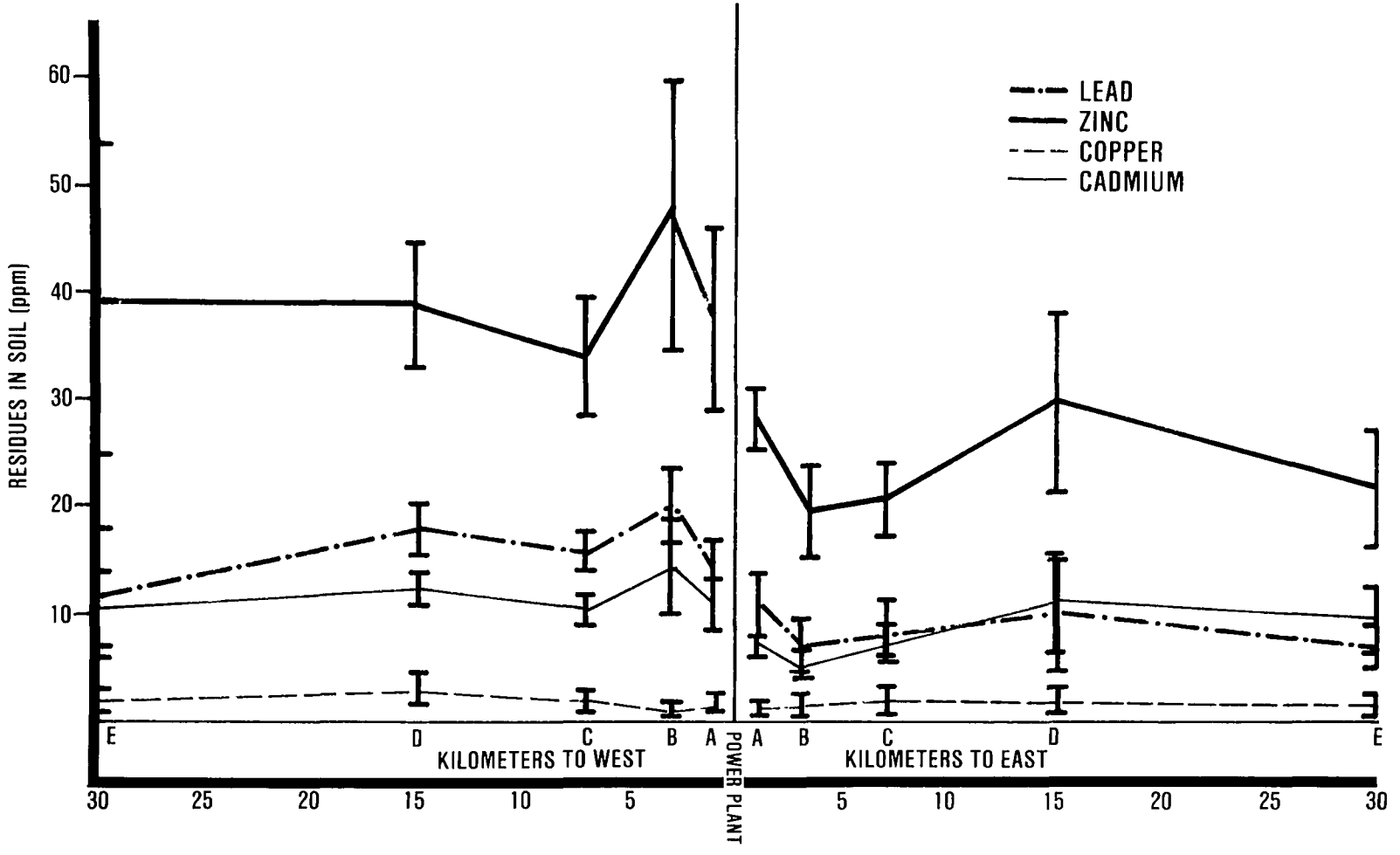

Figure 2. Mean residue levels for lead, zinc, copper and cadmium to the east and west of the power plant.

TABLE 4. ZINC RESIDUES IN SOIL BY SITE (ppm)

Radius Number	Direction	A 1/2 [1]	A	B	C	D	E	E 1/2 [1]	Mean [7]	Standard Deviation [7]
1	NNE	---	---	22.0	57.0	29.0	---	34.0	36.0	18.5
2	NE	---	30.0	20.0	26.0	41.0	30.0	42.0	29.4	7.7
3	ENE	32.0	24.0	19.0	19.0	31.0	20.0	40.0	22.6	5.1
4	E	30.0	28.0	16.0	22.0	27.0	22.0	20.0	23.0	4.8
5	ESE	32.0	28.0	16.0	17.0	18.0	15.0	20.0	18.8	5.3
6	SE	46.0	32.0	26.0	19.0	32.0	21.0	16.0	26.0	6.0
Mean [2]			28.4	19.4	20.6	29.8	21.6			
Standard Deviation [2]			3.0	4.1	3.5	8.4	5.4			
Overall Mean [3]									24.0	
7	SSE	29.0	33.0	---	21.0	18.0	34.0	33.0	26.5	8.2
8	S	33.0	23.0	33.0	---	28.0	33.0	18.0	29.2	4.8
9	SSW	37.0	32.0	43.0	27.0	---	26.0	23.0	32.0	7.8
10	SW	34.0	33.0	60.0	26.0	40.0	34.0	32.0	38.6	13.0
11	WSW	33.0	44.0	50.0	38.0	40.0	28.0	---	40.0	8.1
12	W	20.0	30.0	54.0	32.0	32.0	38.0	39.0	37.2	9.9
13	WNW	55.0	48.0	48.0	40.0	36.0	67.0	39.0	47.8	11.9
14	NW	48.0	30.0	27.0	34.0	48.0	31.0	42.0	34.0	8.2
Mean [4]			37.0	47.8	34.0	39.2	39.6			
Standard Deviation [4]			8.4	12.5	5.5	5.9	15.8			
Overall Mean [5]									39.5	
15	NNW	---	---	34.0	34.0	---	---	44.0	34.0	0
16	N	---	---	14.0	66.0	41.0	---	---	40.3	26.0
Mean [6]		35.7	32.0	32.1	31.8	32.9	30.7	31.6	32.0	
Standard Deviation [6]		9.5	7.0	15.3	14.0	8.7	12.8	10.1		12.0

1/ Circle sampled in April 1976.

2/ Mean and standard deviation for radii 2-6.

3/ Overall mean for radii 2-6 and circles A to E.

4/ Mean and standard deviation for radii 10-14.

5/ Overall mean for radii 10-14 and circles A to E.

6/ Overall mean and standard deviation for each circle calculated using all radii.

7/ Mean and standard deviation for circles A to E only.

TABLE 5. COPPER RESIDUES IN SOIL BY SITE (ppm)

Radius Number	Direction	A 1/2 [1]	Concentric Circles A	B	C	D	E	E 1/2 [1]	Mean [7]	Standard Deviation [7]
1	NNE	---	---	6.0	15.0	10.0	---	12.0	10.3	4.5
2	NE	---	8.0	6.0	8.2	18.0	13.0	18.0	10.6	4.8
3	ENE	8.0	7.0	5.8	7.2	12.0	11.1	14.0	8.6	2.7
4	E	7.8	7.2	4.5	8.5	9.5	9.0	7.0	7.7	2.0
5	ESE	7.5	8.0	5.5	5.8	5.2	5.0	8.5	5.9	1.2
6	SE	10.0	6.0	8.8	8.0	11.0	8.8	8.2	8.5	1.8
Mean [2]			7.2	6.1	7.5	11.1	9.4			
Standard Deviation [2]			0.8	1.6	1.1	4.6	3.0			
Overall Mean [3]									8.3	
7	SSE	9.2	14.0	---	8.5	5.8	12.0	12.0	10.0	3.6
8	S	11.0	7.0	10.0	---	12.0	14.0	7.2	10.7	3.0
9	SSW	12.0	9.0	12.0	8.0	---	6.8	8.0	9.0	2.2
10	SW	12.0	9.0	18.0	9.5	14.0	8.2	9.2	11.7	4.2
11	WSW	7.2	13.0	16.0	12.0	14.0	8.2	---	12.6	2.9
12	W	7.5	10.0	18.0	9.2	10.0	11.0	14.0	11.6	3.6
13	WNW	16.0	14.0	14.0	12.0	12.0	16.0	12.0	13.6	1.7
14	NW	14.0	9.2	7.2	11.0	14.0	9.8	12.0	10.2	2.5
Mean [4]			11.0	14.6	10.7	12.8	10.6			
Standard Deviation [4]			2.3	4.5	1.3	1.8	3.2			
Overall Mean [5]										
15	NNW	---	---	14.0	11.0	---	---	13.0	12.5	2.1
16	N	---	---	5.0	17.0	14.0	---	---	12.0	6.2
Mean [6]		10.2	9.3	10.3	10.1	11.5	10.2	11.1	10.0	
Standard Deviation [6]		2.9	2.7	4.9	3.0	3.4	3.0	3.2		3.5

1/ Circle sampled in April 1976.

2/ Mean and standard deviation for radii 2-6.

3/ Overall mean for radii 2-6 and circles A to E.

4/ Mean and standard deviation for radii 10-14.

5/ Overall mean for radii 10-14 and circles A to E.

6/ Overall mean and standard deviation for each circle calculated using all radii.

7/ Mean and standard deviation for circles A to E only.

TABLE 6. CADMIUM RESIDUES IN SOIL BY SITE (ppm)

Radius Number	Direction	Concentric Circles A 1/2 [1]	A	B	C	D	E	E 1/2 [1]	Mean [7]	Standard Deviation [7]
1	NNE	---	---	1.0	1.0	1.0	---	2.0	1.0	0.0
2	NE	---	1.5	2.5	3.5	3.5	1.0	1.5	2.4	1.1
3	ENE	2.0	1.0	0.5	3.0	2.0	1.0	2.0	1.5	1.0
4	E	1.0	1.0	0.5	1.0	1.0	4.5	0.5	1.6	1.6
5	ESE	1.0	1.0	2.0	1.5	2.5	0.5	1.5	1.5	0.8
6	SE	1.5	1.0	1.0	1.5	1.0	1.0	1.0	1.1	0.2
Mean [2]			1.1	1.3	2.1	2.0	1.6			
Standard Deviation [2]			0.2	0.9	1.1	1.1	1.6			
Overall Mean [3]									1.6	
7	SSE	1.0	1.5	---	1.5	1.0	1.0	2.5	1.2	0.3
8	S	3.0	1.5	2.5	---	1.5	2.0	2.5	1.9	0.5
9	SSW	1.5	3.5	1.5	2.0	---	1.0	1.0	2.0	1.1
10	SW	1.5	1.5	2.0	---	2.5	1.0	8.0	1.8	0.6
11	WSW	1.0	2.0	1.0	1.0	5.5	1.5	---	2.2	1.9
12	W	1.0	2.5	1.5	2.0	2.0	2.0	5.5	2.0	0.3
13	WNW	1.5	1.5	1.0	3.0	2.0	3.5	2.0	2.2	1.0
14	NW	2.0	1.5	1.0	3.0	3.0	1.5	2.5	2.0	0.9
Mean [4]			1.8	1.1	2.2	3.1	2.1			
Standard Deviation [4]			0.5	0.3	1.0	1.6	0.9			
Overall Mean [5]									2.1	
15	NNW	---	---	1.0	1.0	---	---	2.0	1.0	0
16	N	---	---	6.0	1.5	2.0	---	---	3.2	2.5
Mean [6]		1.5	1.6	1.7	1.9	2.2	1.6	2.5	1.8	
Standard Deviation [6]		0.6	0.7	1.4	0.9	1.2	1.1	2.0		1.1

1/ Circle sampled in April 1976.

2/ Mean and standard deviation for radii 2-6.

3/ Overall mean for radii 2-6 and circles A to E.

4/ Mean and standard deviation for radii 11-14.

5/ Overall mean for radii 11-14 and circles A to E.

6/ Overall mean and standard deviation for each circle calculated using all radii.

7/ Mean and standard deviation for circles A to E only.

soil is 292 ppm. Similar levels were found in Yugoslavia (Djuric et al., 1971). Hemphill et al. (1974) found lead residue alongside ore truck routes in lead mining areas to range from 36.0 to 809.0 ppm.

Wangen and Wienke (1976) present composite data from a variety of investigators at the Four Corners Power Plant (exclusive of our report). They report lead data in the upper 5 cm of soil to range from 5 to 21 ppm. This compares favorably with overall average lead levels shown in Table 3 of 12.0 ppm.

Zinc residues in soil (Table 4) have an overall average of 32.0 ppm. Results from Lindberg et al. (1975) around the Allen Steam Plant show zinc residues in soil ranging from 256 to 711 ppm with an average concentration of 458 ppm. They report a world background level of 50 ppm. Linzon et al. (1976) report zinc levels in urban soils of 154 ppm. Wangen and Wienke (1976) report from their review of literature at the Four Corners Power Plant a composite picture of zinc concentration in soil ranging from 9 to 57 ppm. The results for zinc reported by Wangen and Wienke (1976) compare favorably with our overall average of 32.0 ppm of zinc in soil, but this figure is considerably below residue levels reported for other areas.

The overall average copper values in our study were 10.0 ppm. This is slightly lower than previously reported copper residues in soil around the Four Corners Power Plant which ranged from 12 to 37 ppm (Wangen and Wienke, 1976) and considerably lower than copper levels around the Allen Steam Plant which ranged from 16 ppm to 64 ppm with an average concentration of 28 ppm (Lindberg et al., 1975). Copper levels in urban soils of 33.2 ppm (Linzon et al., 1976) are three times the copper levels found in our study.

The overall average cadmium residue from our study was 1.8 ppm (Table 6). This value is higher than residue levels reported for cadmium in soil given by Wangen and Wienke (1976). They indicate some uncertainty in the reported cadmium residue levels with approximate values ranging from 0.2 to 0.75 ppm. Our cadmium residues are higher than at the Allen Steam Plant. Lindberg et al., (1975) report 0.3 to 4.0 ppm of cadmium in soil with an average concentration of 1.4 ppm. They report a world concentration of cadmium in similar soil of 0.5 ppm. Linzon et al. (1976) report urban cadmium levels of 2.3 ppm.

The difference in mean residue levels detected between radii to the east of the power plant versus radii to the west for lead, zinc, and copper cannot be ignored. A review of Tables 3, 4, 5, and 6 will indicate the average residue level to the west of the plant is always greater than to the east (cadmium results are not statistically significant for all elements). One possible explanation deals with prevailing wind patterns around the Four Corners Power Plant. Figure 3 shows wind rose data for all observations from 200 feet [61 meters (m)] elevation for the period May 20 to December 11, 1973. These data show the wind to have had a very strong easterly component. This easterly component had a much higher percent occurrence of high winds than the west to northwest components show (Westinghouse Environmental Systems Department, 1975). Figure 4 shows

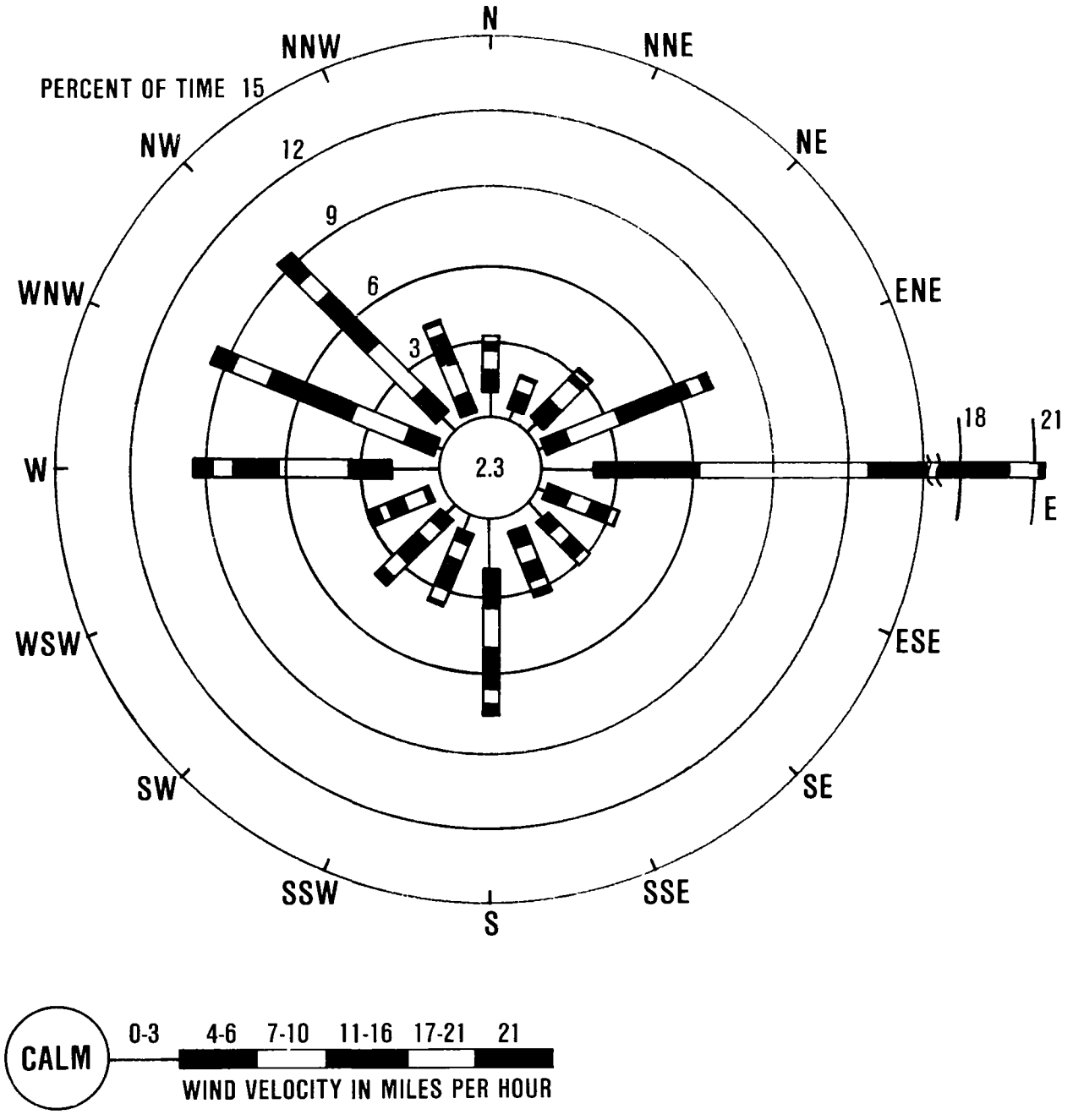

Figure 3. Wind rose at 200-foot-level of tower at the Four Corners Power Plant site — all observations for May 20 to December 11, 1973. Source: WESD from Intercomp data (Westinghouse Environmental Systems Department, 1975).

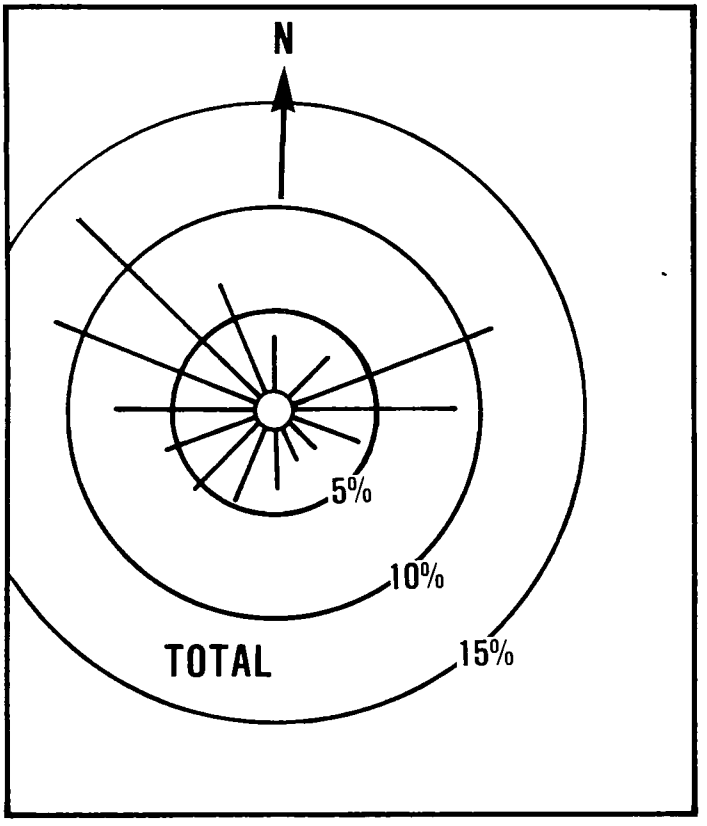

Figure 4. Wind roses at 100-foot-level of meteorological – all observations for September 1973 to June 1976 (Williams, 1976).

another wind rose for the period September 1973 to June 1976 (Williams, 1976). Once again a strong easterly component is depicted with a stronger west to northwest component shown. Nothing can be said about the relative intensity of the winds. These wind rose data are for 100 feet (30.5 m) above ground level.

Another possible explanation for the differences in residue levels between east and west is the location of the fly ash ponds to the west of the power plant (see Figure 1). These ash ponds are connected to the three venturi scrubbers on units 1, 2, and 3. Wangen and Wienke (1976) speculate that the higher values found on transect A-A (Cannon and Anderson, 1972), which runs due west from the power plant for approximately 2 miles (approximately 3.4 km), results from creep, saltation, and deposition of suspended material from the dried ash disposal ponds rather than from stack emissions.

A look at Figure 2 shows higher residue levels for zinc, copper, and lead approximately 2.9 km (Circle B) to the west. This is the approximate location of the ash ponds. Cannon and Anderson (1972) analyzed the gray wind-blown material they found deposited on soil and vegetation 1.6 to 3.2 km west of the power plant. They are not clear as to whether this material was actually from the settling ponds. The results of these analyses indicate average residues of zinc, 40 ppm; lead, 20 ppm; copper, 30 ppm; and cadmium, 0.3 ppm. These residue levels are all higher than the overall average levels reported in our study of 32.0 ppm zinc, 12 ppm lead, and 10 ppm copper. Only the cadmium residue level is below our overall average cadmium level of 1.8 ppm, and cadmium is the one element in our study that showed no peak at circle B to the west of the power plant (Figure 2), the approximate location of the ash ponds. For the closer rings, therefore, the Wangen and Wienke explanation may suffice. Whether this is a valid explanation at distances approaching 30 km is questionable. Considerably more information needs to be gathered than is currently available before a satisfactory explanation can be made about the higher residues to the west of the plant versus to the east of the plant. Another possible explanation is as simple as abrupt changes in soil type.

The regression analysis was carried out to see if there was a relationship between distance from the power plant and residue levels in soils. The lack of significant regression of residue levels versus distance from the power plant is not surprising. The plotted standard deviations in Figure 2 reveal wide variations about each of the averaged points. Further, as Wangen and Wienke (1976) state, it can be expected that the impact on soils of trace elements from the Four Corners Power Plant can be quite small in relation to the natural trace element content of the soils.

Several of the trace elements reported in our study are likely to be transported over great distances. Ragaini and Ondov (1976) have studied particle size distribution emitted from four boilers at an unnamed western power plant. Two of the boilers had electrostatic precipitators with a 97 percent efficiency and two had a scrubber system that removed 99.2 percent of the incident particles. The power plant had a total of five generating units with a generating capacity of 2100 MW, a configuration remarkably

similar in many respects to the Four Corners Power Plant. The data reported are particularly applicable to this study. Particles were classified into small and large with the small particles having number median diameters of 0.06 μm to 0.1 μm and the larger particles having number median diameters of 0.5 to 0.7 μm. They found that the more volatile elements tended to concentrate on the smaller particle. Whereas the nonvolatile elements tended to concentrate on the larger particles.

Ragaini and Ondov (1976) reported that zinc had a significant small particle association. Enrichment factors in emission from both scrubbers and ESP units for zinc ranged from 2 to 10 times the concentrations in source coal. In a later report, Ondov et al. (1977a) determined enrichment factors for trace elements in the power plant plumes, and reported that the enrichment factor for zinc in the plume increases up to a measured distance of 20 to 40 miles (32.3 to 64.5 kilometers).

Ondov et al. (1977b) also found that several trace elements (among which were zinc, lead, copper and cadmium) exhibited significant enrichment in the fly ash as particle size decreased. These data supported the supposition that the elements reported on in our study are likely to be transported considerable distances downwind in the power plant plume, although Ondov et al. (1977a) reported no plume measurements in the plume for lead, copper, and cadmium. This larger downwind transport dispenses elements over a considerably larger area, making detection of a relationship between buildup in soils and distance from the power plant very difficult.

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15. SUPPLEMENTARY NOTES

16. ABSTRACT

Ninety-six soil samples were collected on a radial grid employing 16 evenly spaced radii and 5 logarithmically spaced circles, concentric around the Four Corners Power Plant. The soil samples were analyzed for zinc, lead, copper, and cadmium by atomic absorption spectrophotometry. No statistical relationship could be detected between residue levels for the four elements and increasing distance from the power plant. A two-way analysis of variance indicated no significant difference among circles but there was a significant difference among radii for zinc, lead, and copper, with higher residues of these elements consistently indicated to the west of the power plant. Elevated levels of zinc, lead, and copper to the west of the power plant could be partially explained by wind rose patterns and the location of the fly ash settling ponds. Average residue levels for zinc, lead, and copper are below average residue levels reported for other power plants. Average cadmium levels are slightly higher than cadmium levels reported in the literature for other power plants.

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