

## Radionuclides and Inorganics in Ambient Aerosols

### Introduction

CEMRC collects and analyzes samples of particulate matter from the atmosphere ("aerosols") as part of its WIPP Environmental Monitoring (EM) project. These atmospheric studies are an important part of the WIPP EM because if a situation arose in which radioactive or chemical contaminants were released from the WIPP, those materials could be rapidly dispersed through the atmosphere and spread throughout the environment. In addition, in such a scenario, the inhalation of aerosol contaminants from the WIPP would represent a potential route of exposure to radionuclides and other chemicals for the local citizenry.

The WIPP EM aerosol studies began prior to March 26, 1999, which is when the first radioactive waste shipment was received at the facility. Baseline samples collected before the receipt of the waste have been used for the first objective of the study, that is, to characterize the background concentrations of selected radionuclides and inorganic substances in the atmosphere of the area surrounding the WIPP. These data also are being used in statistical comparisons to determine whether the concentrations of any of these substances have changed since the WIPP became operational, that is, after shipments of nuclear waste began arriving at the facility. A final objective for the aerosol studies was to investigate the relationships between the concentrations of radioactive and non-radioactive substances in aerosol particles.

This report is one of a series, beginning with the 1998 report, that presents information on actinide concentrations in aerosols resulting from the CEMRC WIPP EM project. The accompanying elemental and aerosol ion analyses complement the radionuclide studies because the inorganic data provide information about the types of aerosols in the atmosphere and how their concentrations have varied over time. In addition, a recent study of soils for the WIPP EM (Kirchner et al., J.

*Environ. Rad.*, in press) has demonstrated the complementary nature of the radionuclide and inorganic data by showing that radionuclide activities in soils are correlated with certain elements indicative of crustal materials and environmental pollutants. Furthermore, some of the trace elements being studied (As, Be, Ba, Cd, Cr, Pb, Hg, Se and Ag) are listed as components of the Permitted TRU Mixed Wastes in the WIPP hazardous waste permit (*Waste Acceptance Criteria for the Waste Isolation Pilot Plant*, DOE/WIPP-069, November 8, 1999). Several of these elements are of concern due to possible toxicological effects for humans and ecosystems, but from a practical standpoint, they are also useful as potential chemical tracers of material releases from the WIPP.

### Methods

Detailed information regarding the sampling design for the WIPP EM ambient aerosol studies was presented in the CEMRC 1998 and 1999 reports. Briefly, for the radionuclide studies, ambient aerosol samples were collected from three sampling stations (Fig. 2). These high-volume samples were collected on 20 x 25 cm Gelman A/E® glass fiber filters, which were changed when the flow rate dropped to 90% of its original value. As a result, the time intervals for the radionuclide sample collections were variable but typically several weeks in length. At Cactus Flats and Near Field, high-volume samples for the radiochemistry studies were collected for both total suspended particles (TSP) and PM<sub>10</sub> (particles less than 10 µm, aerodynamic equivalent diameter). At On Site, only TSP samples were collected.

Gravimetric determinations were made for the aerosol masses collected on the high-volume filters. Prior to sampling, new filters were weighed without being desiccated. At the end of the sample collection period, the sample filter holder and filter were returned to the lab where the filter was removed from the holder, folded, and placed in a desiccator for 24 hours. The filters were then reweighed,

heat-sealed in plastic, and delivered to the radiochemistry laboratory for analyses. The total mass accumulated on the filter during a sampling period was divided by the total air volume drawn through the filter to calculate the aerosol mass concentration. Activity density was calculated as the activity for each nuclide per unit mass of aerosol material collected. The gravimetric determinations were only made on the high-volume filters because static charge and other technical problems caused the weights of the low-volume filters used for other analytes to vary erratically.

The high-volume samples were analyzed for selected radionuclides, including  $^{238}\text{Pu}$  and  $^{239,240}\text{Pu}$ . For the radiochemical analyses, entire filters were muffled for 4 hr at  $500^\circ\text{C}$  and then spiked with Pu tracers. The samples were dissolved using HF, HCl and  $\text{HClO}_4$ , and the resulting solutions processed by multiple precipitation, co-precipitation, and ion-exchange and/or extraction chromatography steps to separate and purify Pu. The nuclides of interest were then precipitated with  $\text{LaF}_3$ , deposited onto filters, mounted, and counted using an alpha spectroscopy system.

For the trace element (TE) and ion chromatography (IC) studies, aerosol samples were collected from the same three stations used for radionuclide sampling. Aerosol samples for these studies were collected using low-volume ( $\sim 10\text{ L min}^{-1}$ ) systems for collecting TSP,  $\text{PM}_{10}$  and  $\text{PM}_{2.5}$  (particulate matter less than  $2.5\ \mu\text{m}$  in diameter). Samples for IC analyses were collected on  $2\text{-}\mu\text{m}$  pore-size, 47-mm diameter Gelman Teflo® PTFE Teflon® filters while the TE samples were collected on  $0.8\text{-}\mu\text{m}$  pore-size, 47-mm diameter cellulose-ester Gelman Metricel® filters. Since February 1998, TE/IC sampling periods of two, two, and three days per week have been used (the filters are replaced on Monday, Wednesday, Friday). The analyses of the filters alternated between TE and IC, with every second sample archived (TE, archive, IC, archive, TE, archive, IC, archive etc.). The results presented here cover the periods from 4 November 1997 to 30 June 2000, and 3 February 1998 to 30 June 2000 for the IC and TE analyses, respectively.

Aerosol filters were prepared for elemental analyses using a microwave digestion system and  $\text{HNO}_3$ , HCl, and HF. The concentrations of major and trace elements were determined in the aerosol samples by atomic absorption (AA) spectrometry and inductively-coupled plasma mass spectrometry. An inductively-coupled plasma emission spectrometer was used instead of the ICP-MS for analyses prior to January 1999. For the IC analyses, aqueous extracts of the Teflo® filters were determined using an ion chromatography (IC) system equipped with anion or cation columns, using chemical suppression, conductivity detection, and multiple levels of calibration.

## Results and Discussion

$^{238}\text{Pu}$  was quantified in only two of the 138 samples analyzed. The activity concentrations calculated on a volume basis for these two samples, which were both TSP, were  $5.8$  and  $7.6\ \text{nBq m}^{-3}$ . These were collected at the On Site station from 19 November to 20 December, 1999 and at the Cactus Flats station from 10 April to 1 May, 2000, respectively. The corresponding mass concentrations for the samples were  $0.11\ \text{mBq g}^{-1}$  of aerosol mass (On Site sample) and  $0.16\ \text{mBq g}^{-1}$  (Cactus Flats sample). As all aerosol samples collected prior to the receipt of waste at the WIPP had  $^{238}\text{Pu}$  activities less than the minimum detectable concentrations, no baseline data for  $^{238}\text{Pu}$  are available from CEMRC studies. However, pre-operational data from the Environmental Evaluation Group (EEG), reported in Kenny et al. (1998, *Preoperational Radiation Surveillance of the WIPP Project by EEG during 1993 through 1995*, EEG-67) show  $^{238}\text{Pu}$  concentrations ranging from below detection up to  $160\ \text{nBq m}^{-3}$ , which is roughly 50 times higher than in the two CEMRC samples having quantifiable  $^{238}\text{Pu}$ .

$^{239,240}\text{Pu}$  was quantified in all 138 samples analyzed. The arithmetic mean volume-based activity concentrations for the  $\text{PM}_{10}$  samples were  $8.9\ \text{nBq m}^{-3}$  at Near Field and  $12\ \text{nBq m}^{-3}$  at Cactus Flats, while the means for the TSP samples over the same time periods were 17, 22, and  $18\ \text{nBq m}^{-3}$  at Near Field, Cactus Flats, and On Site respectively. Comparisons of the

means for the PM<sub>10</sub> and TSP samples show that the volume-based activity concentrations in the PM<sub>10</sub> fractions relative to TSP were similar (52% at Near Field and 55% at Cactus Flats).

The mean PM<sub>10</sub> <sup>239,240</sup>Pu activity densities were 0.42 and 0.49 mBq g<sup>-1</sup> at Near Field and Cactus Flats, respectively. The corresponding mean TSP activity densities were 0.50 (Near Field), 0.59 (Cactus Flats), and 0.34 (On Site) mBq g<sup>-1</sup>. The percentages of the activity densities for <sup>239,240</sup>Pu in the PM<sub>10</sub> fractions relative to TSP were therefore 84% at Near Field vs. 83% at Cactus Flats.

It is noteworthy that when calculated on a per unit volume basis, the <sup>239,240</sup>Pu activity concentration was lower in the PM<sub>10</sub>-sized fraction than was aerosol mass. That is, the ratio of the mean <sup>239,240</sup>Pu activity concentrations in the PM<sub>10</sub> size fraction vs. TSP (<sup>239,240</sup>Pu activity concentration in PM<sub>10</sub> / <sup>239,240</sup>Pu activity concentration in TSP) was less than the corresponding ratio of aerosol masses (mass in PM<sub>10</sub> fraction/mass in TSP). This relationship held at both Near Field and Cactus Flats. Generally one would expect Pu to be enriched in small particles as has been observed for soils from the study area (Kirchner et al., *op cit.*). While there is no direct evidence for small particle <sup>239,240</sup>Pu enrichments in the aerosol data, the results could be explained by the existence of PM<sub>10</sub> aerosols that contribute to the aerosol mass but contain little or no <sup>239,240</sup>Pu. Two likely candidates for the small particle aerosols are major ions, such as nitrate and sulfate, and organic compounds, both of which are often produced through gas-to-particle conversion processes. These results demonstrate the advantages for the WIPP EM of collecting data for non-radioactive substances that provide a context for the distributions of <sup>239,240</sup>Pu, and presumably other radionuclides, in the environment. Follow-up studies of the contributions of major ions to mass loadings are planned.

Comparisons between the baseline and operational data were made by testing the differences in the mean values of <sup>239,240</sup>Pu for statistical significance through 2-way analysis of variance (2-way ANOVA). For these analyses, the <sup>239,240</sup>Pu data were grouped by

category (i.e., Baseline vs. Operational) and by sampling site. Separate analyses were conducted for the PM<sub>10</sub> (Near Field vs. Cactus Flats) and TSP (On Site vs. Near Field vs. Cactus Flats) samples. Parallel statistical analyses were conducted for selected TE and IC constituents as a means of investigating concurrent changes in other types of aerosol particles.

For the PM<sub>10</sub> samples, neither of the 2-way ANOVAs testing for differences in the mean <sup>239,240</sup>Pu activity concentrations or densities (i.e., activities calculated on a volumetric or mass basis) showed any statistically significant differences at a probability for chance occurrence of less than 5% ( $p < 0.05$ ). Therefore, neither the differences in the means for the baseline vs. operational PM<sub>10</sub> samples nor those in the mean PM<sub>10</sub> activities for the three different sites were statistically significant.

Two-way ANOVAs for the TSP samples showed that the differences in the mean <sup>239,240</sup>Pu activity concentrations among sites were not significant, but the difference between the <sup>239,240</sup>Pu activity concentrations for baseline vs. operational samples was marginally significant at  $p = 0.021$ . It is noteworthy that although not statistically significant, the highest mean activities, both for the baseline and operational samples, were observed at Cactus Flats, the site farthest from the WIPP. Furthermore, related studies show that the soils at Cactus Flats have higher concentrations of many radionuclides, including <sup>239,240</sup>Pu than those from Near Field.

For the TSP activity densities, the differences among sites were highly significant ( $p < 0.0001$ ), and as with the activity concentrations, the highest activity densities were observed at Cactus Flats. In contrast to the activity concentrations, the differences in the mean <sup>239,240</sup>Pu activity densities for baseline vs. operational samples were clearly not significant ( $p = 0.18$ ).

One explanation for the difference in the mean activity concentrations between the sets of baseline vs. operational samples is a problem related to aliasing in time-series analysis. Strong seasonal cycles are evident in the <sup>239,240</sup>Pu data for both TSP and PM<sub>10</sub>, with higher activity concentrations occurring in

spring of each of the three years of available data (Figs. 12 and 13). As a result of these seasonal cycles, and to avoid aliasing, one must ensure that time intervals are properly matched when making comparisons. The baseline data for the radionuclide activities cover almost exactly one year, from 2 February 1998 to 12 February 1999, while the operational data include two of the high-activity spring events. Recalculating the 2-way ANOVA using only the first full year of operational data substantially increases the probability of a chance occurrence for a difference as large as that observed, from  $p = 0.021$  to  $p = 0.036$ .

The EEG has reported data for  $^{239}\text{Pu}$  in aerosols on their web site (<http://www.rt66.com/~eeg/>) that are in good agreement with the CEMRC  $^{239,240}\text{Pu}$  data reported here. The EEG results were based on quarterly composites of low-volume samples collected at Artesia, Carlsbad, Hobbs, Loving and three sites at the WIPP. Quarterly data were reported by EEG for 1993, 1994, 1995 and 1998, but data were not posted for all quarters at all sites, and many samples were reported below detection limits (including negative activities). The EEG results represent the average activities for the composite samples grouped by calendar quarter. As might be expected for longer sampling periods, seasonal patterns were less evident in the EEG  $^{239}\text{Pu}$  aerosol data than in the CEMRC results, but high relative  $^{239}\text{Pu}$  activities were evident for the spring periods at Artesia and Carlsbad. More important and relevant to the CEMRC results, the EEG quarterly data for the pre-operational period, which were also reported in Kenny et al., (*op. cit.*), encompass all of the CEMRC values, including the high values observed at Cactus Flats in 1999.

One explanation for the temporal trends in the  $^{239,240}\text{Pu}$  data is that the concentrations of this nuclide vary from year-to-year and that the loadings of various kinds of aerosols were simply higher during the first year of the WIPP operations than during the baseline period. This can be illustrated by examining the temporal trends of other types of aerosols, focusing on data from the low-volume aerosol samples collected coincident with the high-

volume samples. For example, the mean aerosol aluminum concentrations, which are an indicator of the loadings of mineral dust in the atmosphere (Duce et al., 1980. *Science* 209, 1522), changed in a manner similar to  $^{239,240}\text{Pu}$  (Fig. 14), that is, with strong peaks observed from late winter into spring. A 2-way ANOVA comparing the mean Al concentrations in the TSP samples for one year of baseline vs. one year of operational data (as defined by the receipt of radioactive waste) produced a probability for chance occurrence of 0.014. Such interannual variability in mineral dust concentrations is well documented in the atmospheric sciences literature and differences of this type are influenced both by conditions in the dust source regions (Prospero, J and R. T. Nees, 1986, *Nature* 320, 735) and variations in transport pathways.

The analysis of variance also showed that the mean Al concentrations were not significantly different among sites. More importantly, trends resembling those observed for  $^{239,240}\text{Pu}$  (higher concentrations of dust in the operational vs. baseline samples) were observed at all sites. At Cactus Flats, the mean aerosol/Al concentration for the first year of the operational phase ( $620 \text{ ng m}^{-3}$ ) was  $\sim 70\%$  higher than the mean for the baseline samples ( $360 \text{ ng m}^{-3}$ ).

Pronounced seasonal cycles also were observed for U, nitrate, and sulfate concentrations in aerosols from all three CEMRC sampling sites (Figs. 14 and 15). These cycles were not exactly coincident, however. In particular, the peak in sulfate concentrations occurred after July whereas the maximum concentrations in the other types of aerosols, including  $^{239,240}\text{Pu}$ , were several months earlier. Interannual variability is especially evident in the nitrate data, with much higher concentrations observed in 2000 than in the preceding two years.

A summary of maximum and minimum concentrations for the elemental data is provided as a reference for baseline conditions (Table 4). The first shipment of mixed waste was delivered to WIPP on 9 September 2000, and thus all of the elemental data included in this report can be considered part of the "mixed waste" baseline. Particular attention

in future analyses will be given to samples that exceed the maxima observed during this baseline phase.

It is highly improbable that any activities at the WIPP could affect the concentrations of Al, U, nitrate and sulfate over such a vast area, especially since (a) the concentrations of these substances and  $^{239,240}\text{Pu}$  were often highest at Cactus Flats, which is ~ 19 km to the southeast and upwind of the WIPP and (b) the seasonal patterns in the four analytes were offset, indicating multiple sources were likely important. A much more compelling explanation for the observed differences between baseline and operational concentrations of  $^{239,240}\text{Pu}$  and other inorganic substances is that the aerosol loadings and composition were responding to the ensemble of processes responsible for the production,

removal and composition of the aerosols. That is, the concentrations of these substances were affected by trends in the prevailing winds, rainfall, and other factors that favor the generation of dust as well as by those physical forces that lead to the transport and removal of particles from the atmosphere (Tegen, I. and R. Miller, 1998, *J. Geophys. Res.* 103, 25, 975). Finally, perturbation of a magnitude sufficient to affect all of these analytes almost certainly would have been evident in the FAS data, but as discussed elsewhere in this report, no such indications of enhancements of the magnitude needed to affect such changes were found.

Tables presenting the aerosol data summarized herein are available on the CEMRC web site at <http://www.cemrc.org>.

**Table 4. Ranges of Elemental Concentrations (ng m<sup>-3</sup>) in Aerosols Collected during February 1998 - July 2000**

Location:	Cactus Flats	Cactus Flats	Cactus Flats	Near Field	Near Field	Near Field	On Site	
<sup>a</sup> Sample Type:	LPM <sub>10</sub>	LPM <sub>2.5</sub>	LTSP	LPM <sub>10</sub>	LPM <sub>2.5</sub>	LTSP	LTSP	
	<sup>b</sup> Total N	64	64	82	63	64	73	68
Ag	N	21	15	19	21	20	19	12
	Minimum	1.84E-02	1.74E-02	4.74E-03	1.68E-02	1.47E-02	1.73E-03	1.66E-02
	Maximum	1.62E-01	5.02E-01	4.14E-01	6.43E-01	1.99E+00	1.56E-01	6.23E-02
Al	N	63	51	82	61	52	70	66
	Minimum	5.16E+01	2.33E+01	7.35E+01	6.80E+01	1.45E+01	3.66E+01	5.16E+01
	Maximum	1.43E+03	5.39E+02	1.86E+03	2.31E+03	7.06E+02	2.86E+03	1.44E+03
As	N	3	1	4	4	4	1	1
	Minimum	2.57E+00	3.60E+00	2.52E+00	2.10E+00	1.76E+00	3.77E+00	7.21E-01
	Maximum	3.79E+00	3.60E+00	5.47E+00	4.30E+00	4.44E+00	3.77E+00	7.21E-01
Ba	N	62	48	81	60	52	69	65
	Minimum	9.36E-01	2.15E-01	8.90E-01	6.47E-01	2.59E-01	8.46E-01	1.05E+00
	Maximum	1.39E+01	5.30E+00	3.33E+01	1.84E+01	2.08E+01	2.30E+01	2.71E+01
Be	N	1	1	0	0	0	0	1
	Minimum	9.02E-02	6.39E-02	<sup>c</sup> NA	NA	NA	NA	9.32E-02
	Maximum	9.02E-02	6.39E-02	NA	NA	NA	NA	9.32E-02
Ca	N	62	36	75	55	37	68	65
	Minimum	8.37E+01	7.93E+01	1.54E+02	1.53E+02	6.10E+01	1.24E+02	1.38E+02
	Maximum	1.17E+03	1.01E+03	2.23E+03	1.91E+03	8.33E+02	4.55E+03	5.30E+03
Cd	N	16	14	19	19	28	19	11
	Minimum	4.63E-02	5.92E-02	7.21E-02	6.31E-02	3.43E-02	3.82E-02	9.20E-02
	Maximum	2.92E+00	8.79E+00	1.39E+00	1.92E+00	1.11E+00	2.21E+00	1.56E+00
Ce	N	63	63	82	61	60	70	67
	Minimum	6.00E-02	1.99E-02	4.76E-02	5.04E-02	1.65E-02	1.47E-02	4.07E-02
	Maximum	1.72E+00	3.68E-01	1.90E+00	3.43E+00	9.48E-01	3.99E+00	1.61E+00
Co	N	46	23	56	36	23	48	51
	Minimum	1.32E-01	7.17E-02	2.08E-01	1.27E-01	1.45E-01	1.07E-01	2.08E-01
	Maximum	2.92E+00	8.62E+00	1.29E+01	3.71E+00	2.24E+00	3.10E+00	8.03E+01
Cr	N	5	3	10	8	5	11	10
	Minimum	1.68E+01	8.03E+00	4.45E+00	3.13E+00	9.25E+00	3.22E+00	5.21E+00
	Maximum	6.14E+01	2.38E+02	5.37E+01	5.51E+01	3.59E+01	6.01E+01	4.09E+01
Cu	N	53	39	65	51	39	57	56
	Minimum	4.06E-01	5.16E-01	4.50E-01	4.32E-01	4.02E-01	5.93E-01	4.69E-01
	Maximum	7.80E+00	1.70E+01	1.30E+01	4.81E+01	6.65E+01	4.89E+01	1.34E+01
Dy	N	56	23	79	57	21	61	56
	Minimum	5.86E-03	4.00E-03	4.12E-03	3.84E-03	2.88E-03	5.10E-03	3.84E-03
	Maximum	1.11E-01	2.03E-02	1.41E-01	2.61E-01	8.58E-02	2.94E-01	1.15E-01
Er	N	40	9	66	36	14	47	46
	Minimum	3.97E-03	3.50E-03	6.09E-03	1.16E-03	1.41E-03	5.46E-03	4.10E-03
	Maximum	6.27E-02	1.23E-02	8.81E-02	1.36E-01	6.21E-02	1.66E-01	7.40E-02

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**Table 4. Ranges of Elemental Concentrations (ng m<sup>-3</sup>) in Aerosols Collected during February 1998 - July 2000 (Cont.)**

Location:		Cactus Flats	Cactus Flats	Cactus Flats	Near Field	Near Field	Near Field	On Site
<sup>a</sup> Sample Type:		LPM <sub>10</sub>	LPM <sub>2.5</sub>	LTSP	LPM <sub>10</sub>	LPM <sub>2.5</sub>	LTSP	LTSP
Eu	N	26	4	54	24	6	38	39
	Minimum	4.52E-03	3.55E-04	3.02E-03	4.22E-03	2.35E-04	1.97E-03	3.88E-03
	Maximum	2.99E-02	1.05E+01	4.39E-02	5.40E-02	1.42E-02	7.06E-02	4.19E-02
Fe	N	55	36	66	50	30	58	53
	Minimum	3.48E+01	0.00E+00	2.70E+01	1.85E+01	1.22E+01	2.54E+01	2.60E+01
	Maximum	7.61E+02	2.33E+02	8.73E+02	1.19E+03	3.92E+02	1.52E+03	6.88E+02
Gd	N	58	31	79	58	28	64	60
	Minimum	5.91E-03	3.02E-03	5.28E-03	6.06E-03	4.31E-03	5.05E-03	4.82E-03
	Maximum	1.51E-01	3.64E-02	2.60E-01	3.30E-01	9.29E-02	3.54E-01	2.34E-01
Hg	N	7	7	18	6	3	15	14
	Minimum	1.69E-02	4.38E-03	2.21E-03	1.90E-02	4.22E-02	1.07E-02	1.29E-02
	Maximum	2.37E-01	2.47E-01	2.25E-01	1.46E-01	1.43E-01	2.10E-01	1.39E-01
K	N	59	39	77	57	47	68	63
	Minimum	4.85E+01	5.93E+00	3.78E+01	6.08E+01	4.39E+01	4.01E+01	4.16E+01
	Maximum	5.42E+02	2.60E+02	6.30E+02	1.04E+03	4.76E+02	1.23E+03	1.14E+03
La	N	50	46	68	48	45	56	54
	Minimum	5.69E-02	1.68E-02	3.49E-02	3.82E-02	7.04E-03	6.74E-02	2.03E-02
	Maximum	1.67E+00	3.07E+00	1.97E+00	1.59E+00	8.63E-01	7.61E+00	1.46E+00
Li	N	9	6	28	8	1	19	20
	Minimum	1.52E-01	8.59E-01	1.64E-01	1.72E-01	1.65E-01	2.54E-01	2.09E-01
	Maximum	2.18E+00	1.93E+00	2.72E+00	1.86E+00	1.65E-01	1.16E+00	1.08E+00
Mg	N	61	42	79	58	45	69	67
	Minimum	2.12E+01	1.26E+01	9.69E+00	3.04E+01	1.29E+01	1.59E+01	2.52E+01
	Maximum	2.40E+02	1.96E+02	3.64E+02	5.66E+02	1.64E+02	6.69E+02	6.10E+02
Mn	N	62	47	80	63	47	68	65
	Minimum	9.96E-01	4.91E-01	7.87E-01	4.54E-01	4.51E-01	7.12E-01	6.69E-01
	Maximum	1.48E+01	4.55E+00	1.89E+01	3.16E+01	2.75E+01	3.70E+01	1.65E+01
Mo	N	1	3	10	8	1	6	9
	Minimum	4.57E-02	1.22E-01	5.33E-02	6.44E-02	2.13E-02	4.01E-02	4.09E-02
	Maximum	4.57E-02	4.86E+00	8.79E-01	1.26E+01	2.13E-02	3.57E-01	4.75E-01
Na	N	39	15	50	39	17	53	50
	Minimum	5.66E+01	7.46E+01	1.03E+02	6.95E+01	6.75E+01	6.39E+01	8.86E+01
	Maximum	5.35E+02	1.15E+03	3.23E+03	6.91E+02	3.35E+02	2.40E+03	7.34E+02
Nd	N	64	61	82	61	61	70	67
	Minimum	1.18E-02	1.04E-02	1.29E-02	1.61E-02	9.17E-03	9.18E-03	1.19E-02
	Maximum	7.31E-01	1.56E-01	8.40E-01	1.60E+00	3.92E-01	1.75E+00	6.64E-01
Ni	N	18	17	34	18	17	29	34
	Minimum	8.75E-01	1.36E+00	1.16E+00	7.40E-01	6.33E-01	1.02E+00	9.53E-01
	Maximum	3.20E+01	2.32E+01	4.07E+01	8.84E+01	4.92E+01	2.08E+01	5.93E+01
Pb	N	60	52	74	56	57	62	58
	Minimum	2.38E-01	1.44E-01	6.55E-02	2.07E-01	1.17E-01	2.70E-01	1.99E-01
	Maximum	3.38E+00	2.73E+01	2.95E+00	4.18E+00	4.70E+00	4.91E+00	2.05E+00

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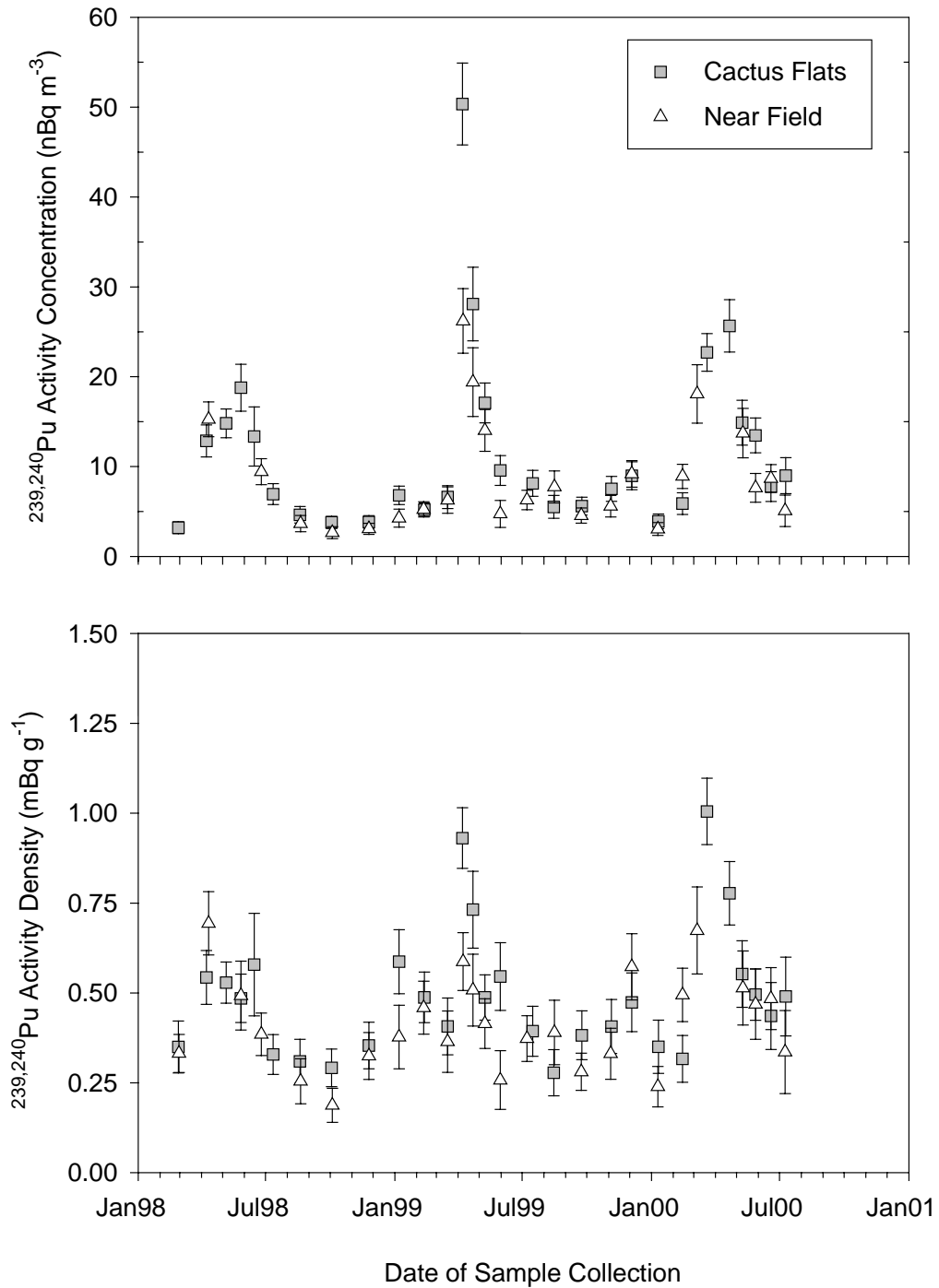
**Table 4. Ranges of Elemental Concentrations (ng m<sup>-3</sup>) in Aerosols Collected during February 1998 - July 2000 (Cont.)**

Location:		Cactus Flats	Cactus Flats	Cactus Flats	Near Field	Near Field	Near Field	On Site
<sup>a</sup> Sample Type:		LPM <sub>10</sub>	LPM <sub>2.5</sub>	LTSP	LPM <sub>10</sub>	LPM <sub>2.5</sub>	LTSP	LTSP
Pr	N	64	46	81	62	50	69	65
	Minimum	1.05E-02	5.39E-03	1.02E-02	7.34E-03	4.40E-03	1.03E-02	8.03E-03
	Maximum	1.96E-01	4.60E-02	2.29E-01	4.07E-01	1.05E-01	7.57E-01	1.89E-01
Sb	N	14	15	28	16	17	26	25
	Minimum	9.47E-02	4.89E-02	7.96E-02	4.54E-02	4.11E-02	4.37E-02	4.10E-02
	Maximum	5.10E-01	3.13E-01	1.38E+01	3.86E-01	3.12E-01	5.85E-01	7.65E-01
Sc	N	2	0	14	2	0	12	12
	Minimum	1.46E-01	NA	1.56E-01	1.86E-01	NA	2.06E-01	1.66E-01
	Maximum	3.32E-01	NA	1.59E+00	3.50E-01	NA	1.19E+00	1.32E+00
Se	N	0	1	2	1	0	0	1
	Minimum	NA	1.57E+00	4.75E-01	5.73E-01	NA	NA	2.51E+00
	Maximum	NA	1.57E+00	7.94E-01	5.73E-01	NA	NA	2.51E+00
Sm	N	55	20	76	56	23	63	56
	Minimum	6.69E-03	4.40E-03	6.58E-03	5.21E-03	2.58E-03	7.65E-03	5.63E-03
	Maximum	1.38E-01	2.87E-02	1.90E-01	3.08E-01	7.73E-02	3.42E-01	1.44E-01
Sn	N	2	2	3	5	3	3	7
	Minimum	1.98E+01	1.87E+01	1.84E+01	1.24E+01	2.53E+01	1.70E+01	8.05E+00
	Maximum	3.68E+01	6.54E+01	3.15E-01	6.20E+01	9.21E+01	1.01E+02	6.32E+01
Sr	N	59	37	73	52	38	60	61
	Minimum	1.69E-01	1.46E-01	3.15E-01	3.22E-02	1.38E-01	3.19E-01	6.08E-01
	Maximum	5.91E+00	2.92E+00	8.72E+00	1.46E+01	3.58E+00	2.07E+01	9.82E+00
Th	N	61	38	81	58	38	68	60
	Minimum	9.69E-03	4.19E-03	4.65E-03	6.96E-03	5.28E-03	6.41E-03	4.12E-03
	Maximum	2.45E-01	5.71E-02	3.45E-01	5.44E-01	1.43E-01	6.28E-01	2.70E-01
Ti	N	60	28	78	57	30	64	58
	Minimum	6.27E-01	3.81E+00	6.48E+00	5.84E+00	3.25E+00	3.58E+00	7.39E+00
	Maximum	8.43E+01	2.82E+01	9.49E+01	1.43E+02	3.67E+01	1.71E+02	8.11E+01
Tl	N	5	8	10	3	3	8	11
	Minimum	2.48E-02	7.12E-03	1.08E-02	2.12E-02	2.98E-02	1.09E-02	4.07E-03
	Maximum	3.05E-01	1.01E+00	9.04E-02	6.16E-02	7.51E-02	2.53E-01	6.20E-01
U	N	51	11	73	50	13	56	52
	Minimum	5.02E-03	2.35E-03	8.24E-03	4.91E-03	1.71E-03	3.70E-03	2.44E-03
	Maximum	6.76E-02	7.47E-02	1.00E-01	1.07E-01	1.21E-01	1.28E-01	7.40E-02
V	N	22	17	26	19	19	21	24
	Minimum	1.09E+00	1.01E+00	9.93E-01	1.07E+00	1.12E+00	1.16E+00	1.04E+00
	Maximum	2.25E+01	2.01E+01	3.08E+01	3.00E+01	3.15E+01	1.03E+01	2.14E+01
Zn	N	21	19	20	26	21	20	23
	Minimum	4.13E+00	3.72E+00	3.22E+00	5.14E+00	4.46E+00	3.89E+00	2.93E+00
	Maximum	1.88E+02	9.44E+01	1.84E+02	1.10E+02	6.73E+02	7.19E+01	1.62E+02

<sup>a</sup>Sample type: LPM<sub>10</sub>, LPM<sub>2.5</sub> and LTSP stand for low-volume PM<sub>10</sub>, PM<sub>2.5</sub> and total suspended particle samplers, respectively

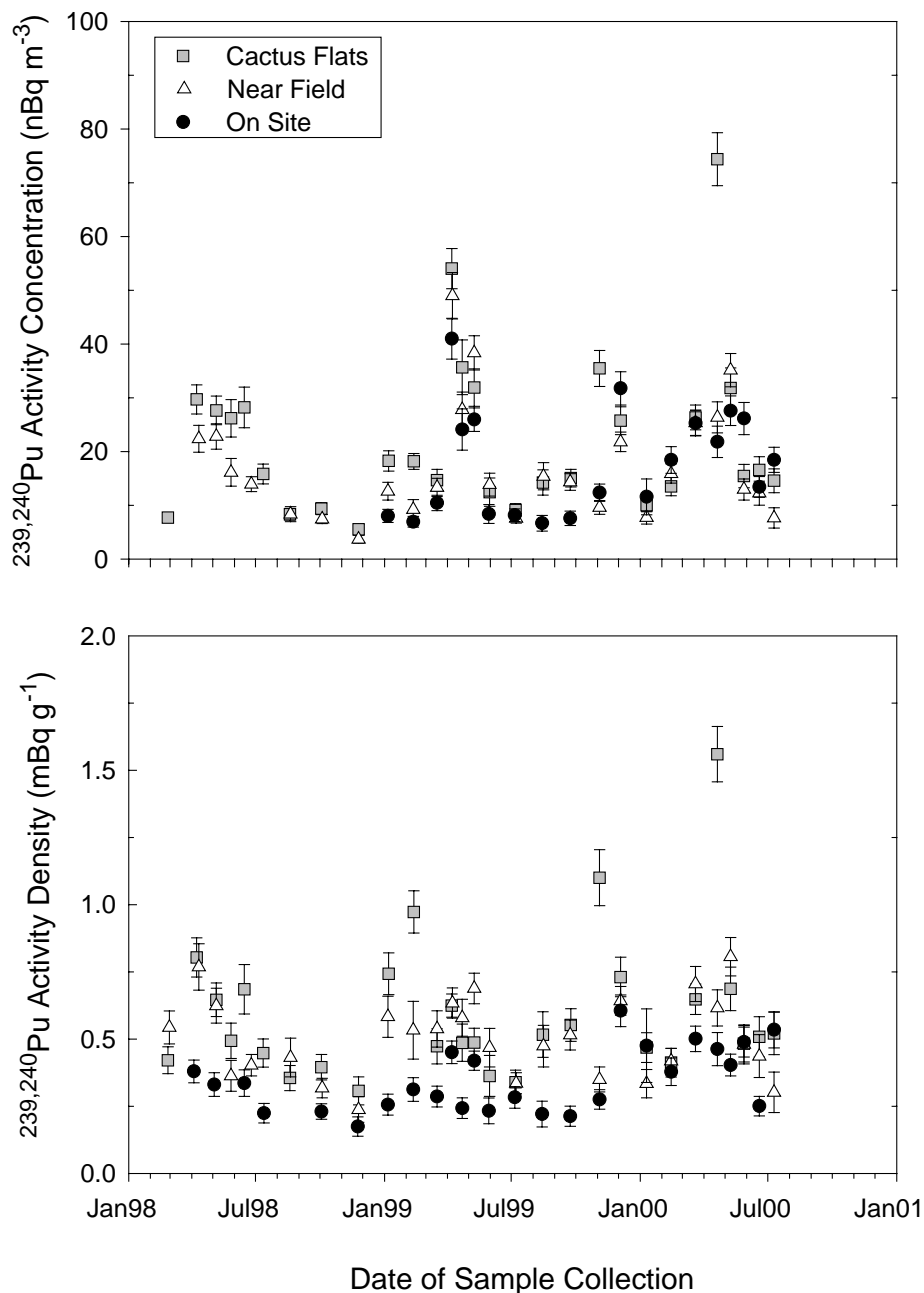
<sup>b</sup>N = number of samples, subsequent rows show number of samples above method detection limit

<sup>c</sup>NA = not applicable



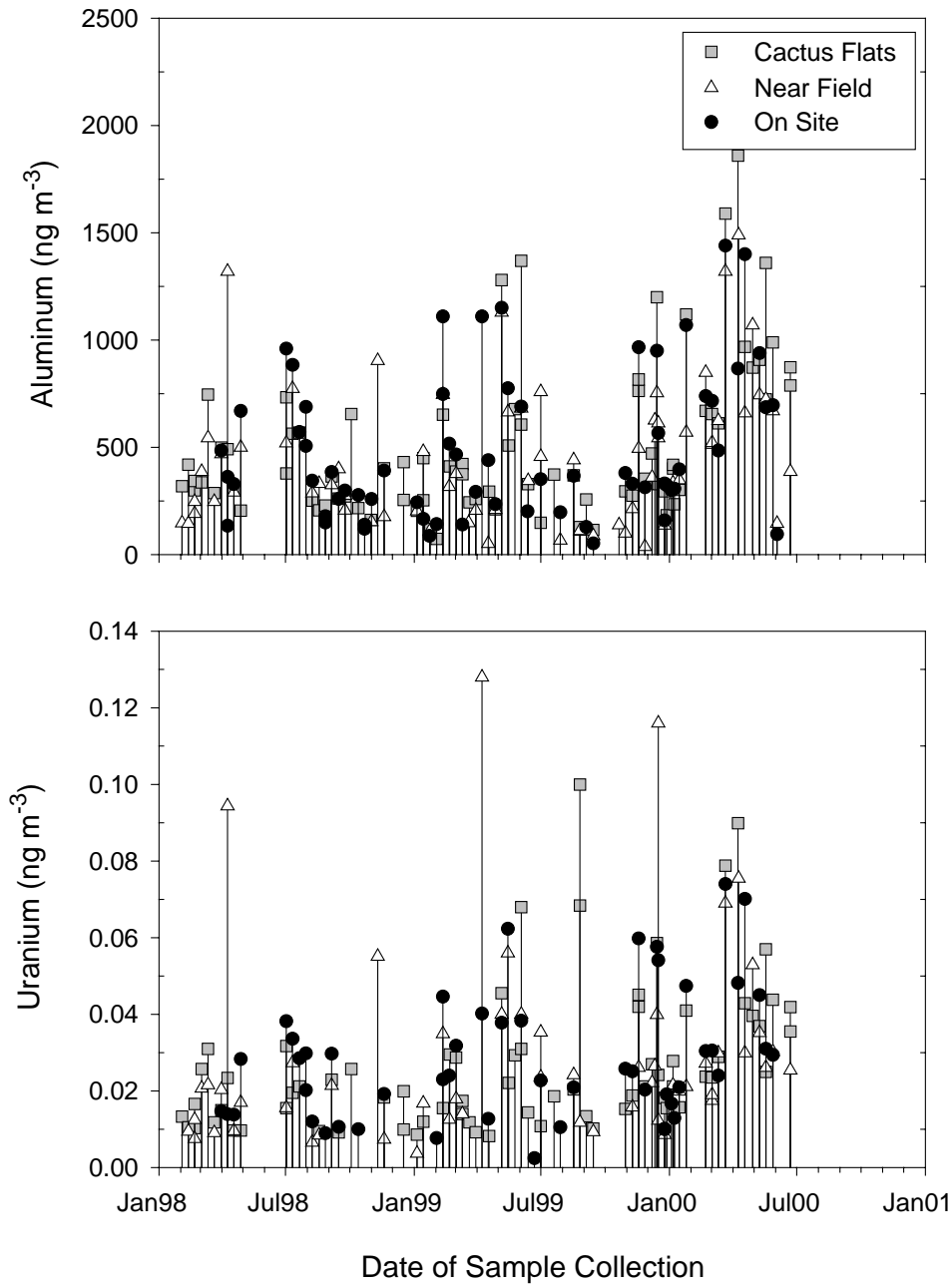
**Figure 12.  $^{239,240}\text{Pu}$  Activities for  $\text{PM}_{10}$  High Volume Aerosol Samples Collected during February 1998 - July 2000**

Error bars show  $\pm$  one standard deviation based on total radioanalytical uncertainty inventory.

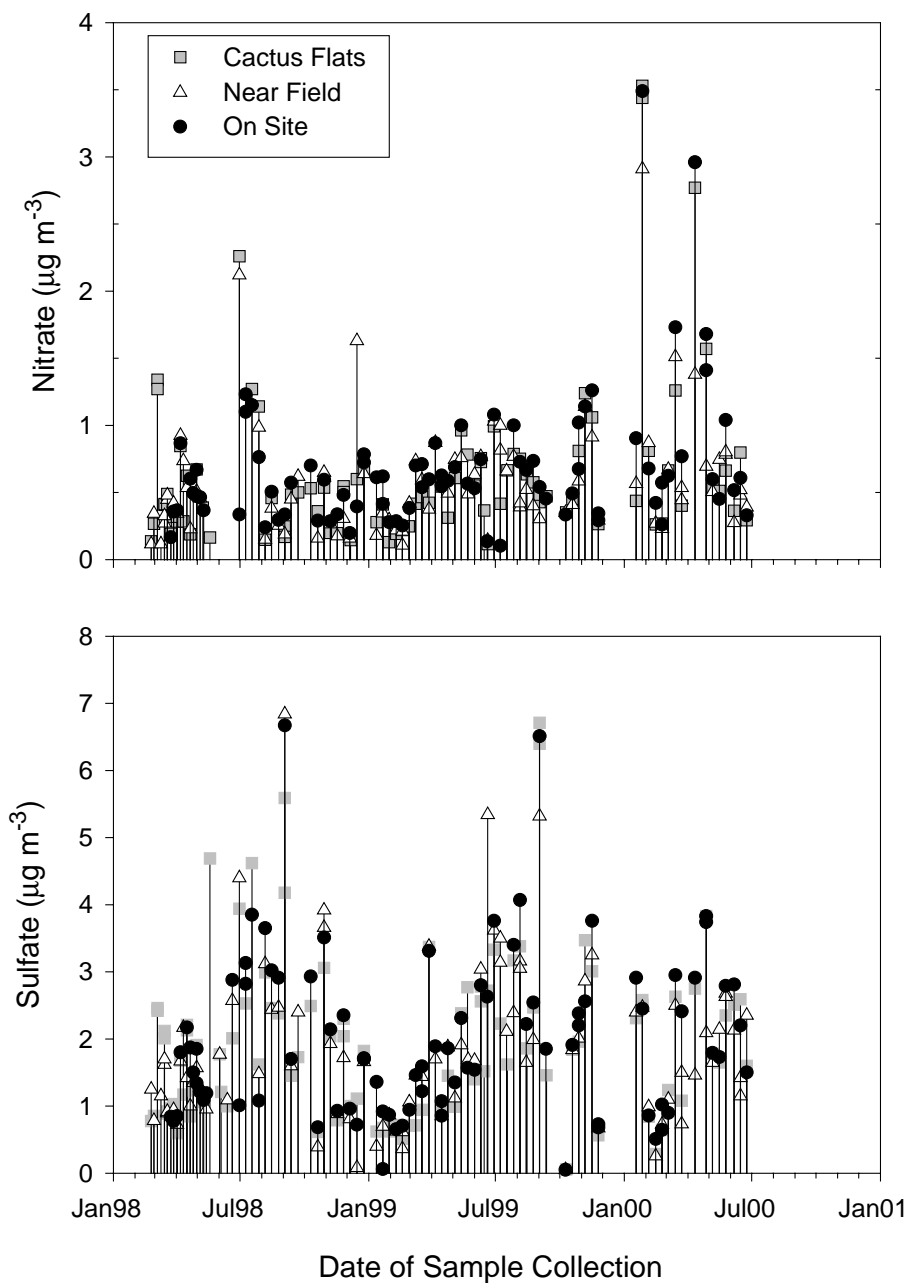


**Figure 13.  $^{239,240}\text{Pu}$  Activities for TSP High Volume Aerosol Samples Collected during February 1998 - July 2000**

Error bars show  $\pm$  one standard deviation based on total radioanalytical uncertainty inventory.



**Figure 14. Aluminum and Uranium Concentrations in TSP Aerosol Samples Collected during February 1998 - July 2000**



**Figure 15. Nitrate and Sulfate Concentrations in TSP Aerosol Samples Collected during February 1998 - July 2000**