

Radionuclides and Inorganics in WIPP Exhaust Air

Introduction

The CEMRC aerosol sampling program for the WIPP EM is designed to study the pathway that is the most likely route by which contaminants from the WIPP site could become rapidly dispersed in the environment. One facet of this comprehensive program is the monitoring of aerosols in the WIPP exhaust shaft. These samples are collected at a location (Station A) that represents the release point of aerosol effluents from the underground to the environment. CEMRC is interested in obtaining information on air quality from Station A because it provides a means for characterizing a source-term that will be needed for the interpretation of future monitoring results from the WIPP EM. For example, if radioactive or hazardous material was released from the WIPP, we would expect to detect it at Station A before it is observed in the local population or environment. In addition, source-term data collected at Station A would be of critical importance for the determination of public or worker dose in the event of an accident at the WIPP.

Another objective of the sampling program at Station A is to provide a gross check of emissions on a short resolution time-scale (e.g. weeks). For example, many of the WIPP EM analyses require many months to complete once the samples are collected. Such time is needed because of the specificity and sensitivity of the analyses. At Station A, gross monitoring results (less specific and sensitive) are provided within three weeks of sample collection and are used to trigger more detailed investigations if necessary.

Methods

A detailed description of the sampling protocol, aerosol sampler, analytical methods and detection limits are provided in the CEMRC 1999 Report. This report and continually updated results can be found at the CEMRC website (<http://www.cemrc.org>). In summary, the monitoring program consists of daily aerosol sampling, gravimetric and gross

alpha/beta analyses of individual filters, elemental and gamma-ray analysis of weekly filter composites and actinide analysis of quarterly filter composites.

Some changes to effluent sampling and analytical methods were made during this reporting period. Specifically, changes were made to the sampling location within Station A, frequency of sampling and the efficiency calibration used for gross alpha/beta analyses. These changes are described below.

At Station A, there are three shrouded-probe aerosol samplers, located on three separate sampling skids (skids 1-3). On each skid, aerosols are split into three sampling legs such that three concurrent samples can be collected from a single skid. On 15 January 2000, the CEMRC effluent sampling location was moved from skid 2, leg 1 to skid 3, leg 2. This change was made to facilitate more direct data comparisons among all organizations sampling at Station A (CEMRC, Environmental Evaluation Group (EEG) and Westinghouse/MK Ferguson). In addition, all organizations sampling at Station A were having difficulties with low flow rates at the end of sampling periods. It was hypothesized that the problem was the result of increased mass loading due to mining activities. To help resolve this issue, CEMRC (and the other organizations) began changing filters twice daily Monday through Friday, rather than once daily. In most situations, a single filter was still collected over the weekend.

In December 1999, calibration methods for the gross alpha/beta measurements were revised to encompass a larger range of mass deposition. The revised methodology provides a calibration factor for mass loadings ranging from 0.5 to 122 mg (previously 3 to 31 mg). The revised calibration range encompasses all values of mass loading observed to date at Station A.

In addition to routine monitoring, two minor experiments were conducted at Station A in an effort to improve sampling methodologies. The first experiment was conducted to evaluate an alternative filter

medium (glass fiber). As previously mentioned, filters were being changed twice daily to accommodate increases in mass loading. This solution is rather labor intensive, and it was hypothesized that a more robust filter medium, with respect to mass loading characteristics, could be identified that would allow the sampling frequency to be reduced (ideally once daily). Incorporating input from EEG and Westinghouse/MK Ferguson, glass fiber was selected as the test medium. The experiment was conducted by collection of concurrent aerosol samples on all three legs of skid 2 during Spring 2000. Aerosols were collected until the flow rate on one leg of the skid dropped to $1.8 \text{ ft}^3 \text{ min}^{-1}$ (set point for each leg is $2.0 \text{ ft}^3 \text{ min}^{-1}$). When this occurred, the filters on all three legs were changed and the mass loading on each leg was determined. At CEMRC, side by side measurements, comparing the glass fiber to the current Versapore filter, were also performed to evaluate any differences in mass loading. These measurements were performed using PM_{10} low volume aerosol samplers.

A second experiment was conducted in Spring 2000 to evaluate elemental and organic carbon loading on aerosol filters collected at Station A. For these measurements, four 24-hour aerosol samples were collected from skid 2 using quartz fiber filters. These filters were analyzed for organic carbon, high temperature organic carbon and elemental carbon at DRI.

Results and Discussion

Routine Monitoring

Aerosol sampling has been conducted continuously at Station A by CEMRC since 12 December 1998. Monitoring results from 1 July 1999 through 1 July 2000 are discussed herein. Tables presenting aerosol data summarized herein are available on the CEMRC web site at <http://www.cemrc.org>. For measurements of radioactivity, data reported during the current period are considered operational monitoring, since radioactive waste was received in March 1998. The determination of baseline concentrations of elemental constituents is considered ongoing for the purposes of this report, since WIPP had not received any mixed waste

(containing both hazardous and radioactive constituents) as of 1 July 2000.

Values of gross alpha activity concentration and density ranged from $< \text{MDC}$ (≈ 0.03) to 0.4 mBq m^{-3} and $< \text{MDC}$ (≈ 0.4) to 9.2 Bq g^{-1} , respectively. Values of gross beta activity concentration and density ranged from $< \text{MDC}$ (≈ 0.07) to 3.3 mBq m^{-3} and $< \text{MDC}$ (≈ 1) to 80.1 Bq g^{-1} , respectively. In general, quarterly mean values of gross alpha and beta concentration and density have decreased since the WIPP began receiving waste in March 1998. (Table 5). For gross alpha, such decreases were observed in all operational quarters and the levels of decrease were as much as 74% and 82% per quarter for activity concentration and density, respectively. A similar trend was observed for gross beta. However, mean values of gross beta activity concentration and density did not decrease relative to pre-operational values in the fourth and third quarters of 1999, respectively (although they decreased in all other operational quarters). It is important to note that no single gross alpha or beta result observed during operational monitoring has exceeded the highest value observed during the pre-operational baseline (Table 5).

Similar trends were also observed for daily gross alpha and beta measurements (Figs. 16 and 17). This trend was most notable for measurements of activity density, suggesting the level of radioactivity contained in WIPP aerosol effluents has decreased per unit of airborne particulate mass. This observation was supported by weekly elemental analyses of U and Th (Fig. 18), where the mass concentration of these elements decreased over time, coinciding with decreases in gross alpha and beta radioactivity.

The observed trends may be the result of environmental phenomena, changes in WIPP operational practices or a combination of these factors. The most notable decrease in these measurements appeared to coincide with increased mining activity at the WIPP during the fall of 1999. At that time, the WIPP began excavation of a second panel for mixed waste disposal. Mining activities for the panel were then ongoing for the remainder of this reporting period (through 1 July 2000) and

may have resulted in increased salt per unit of aerosol particulate mass, relative to pre-operational conditions. Recent studies (The Next Generation Underground Observatory of the Universe, U.S. DOE Workshop, Carlsbad, NM, June 12-14, 2000) suggest that WIPP salts contain lower amounts of naturally occurring radioactive elements (e.g. U and Th) than crustally derived materials. Within this context, it would be expected that as the proportion of salt per unit of aerosol mass increases, radioactivity per unit mass in WIPP effluents would decrease.

Another factor that may be contributing to the decrease in radioactive emissions could be an increase in the concentration of carbon aerosols from the burning of fossil fuels (e.g. vehicle exhaust). One would expect vehicle exhaust to be greatest during periods of extensive mining. Aerosol samples collected during May 2000 showed total carbon loading to be greater than $30 \mu\text{g m}^{-3}$, which would account for nearly 50% of aerosol mass during this time period. Of the total carbon, greater than 70% was organic, and of this fraction, approximately 80% was high temperature carbon (consistent with vehicle exhaust). Applying similar logic as with salt, an increased proportion of organic carbon may decrease effluent radioactivity per unit mass. It is important to note that these carbon analyses were quite limited and no other data (e.g. non-mining) are available for comparison.

Numerous elemental constituents were observed in weekly composites (Table 6). Greater than 80% of all of the 39 elements were observed in 75-100% of the weekly composites. Tl was the only element not detected in any weekly composite and this element may serve as a useful tracer for future WIPP aerosol studies. Many of the hazardous elements (e.g. Pb, Be, Cd, etc.) expected to be contained in WIPP mixed waste are already present in WIPP aerosol effluents. A high degree of variability in weekly concentrations was observed for most elements, where the ratio between maximum and minimum values frequently exceeded 200 (Table 6). Capturing this level of variability is an essential aspect of baseline characterization and will be important

when interpreting monitoring results after mixed waste is received.

For many elements, volumetric concentrations were similar to those reported herein (Radionuclides and Trace Elements in Ambient Aerosols) for the TSP fraction at the On Site sampling location. When making such comparisons, it is important to note that the sampling methodologies (e.g. sampler type, filter type, and sampling frequency) are quite different between the two locations. Therefore, slight differences in concentrations should be interpreted with caution. The volumetric concentrations of several elements were slightly enriched in FAS samples over ambient aerosol samples (factors 3 to 20), which would be expected since mass loading is much greater in WIPP exhaust than surface air. In contrast, the ratios between U concentrations in exhaust air samples and ambient aerosols were near unity. The same was true for Th concentrations. This observation suggests that naturally occurring radioactive material in WIPP effluents are depleted relative to surface air.

Volume concentrations for Sb and Na appeared to be highly enriched (factors of 140 and 200, respectively) relative to surface aerosols as measured at the On Site location. It is doubtful that such large enrichment factors were due to differences in sampling methodology. The enrichment of Na is likely due to an increased concentration of salt in WIPP aerosols when compared to surface aerosols. This finding is consistent with that reported in the CERMC 1999 report. Sb enrichment may be associated with vehicle exhaust emissions, but further investigation is necessary.

With the exception of ^7Be , no detectable gamma-emitting radionuclides were observed during this monitoring period. ^7Be was detected in approximately 33% of samples, ranging in activity concentration and density from 4 to 13 mBq m^{-3} and 16 to 223 Bq g^{-1} , respectively. For detectable results, mean values (\pm SE) of activity concentration and density were 7.1 (\pm 0.4) mBq m^{-3} and 49 (\pm 8) Bq g^{-1} , respectively. ^7Be values during this monitoring period were consistent with those reported in the CERMC 1999 Report. These results indicate that the

aerosols entering through the WIPP air intake eventually reach the exhaust system and are released as exhaust effluents. The presence of ^7Be in the exhaust is an indicator of this mechanism because ^7Be is a short-lived radionuclide ($T_{1/2} = 53$ days) that is produced in the stratosphere through spallation of atmospheric gases (not occurring naturally in the WIPP underground). This finding may be of importance because other aerosols containing radionuclides of concern (e.g. Pu, ^{137}Cs) may follow a similar process and be detected in the exhaust in the absence of a WIPP-related contamination event. Therefore, ^7Be may be a useful tracer for understanding aerosol residence times in the WIPP.

Naturally occurring U and Th isotopes were detected in quarterly composites during all monitoring quarters with the exception of the fourth quarter of 1999 (Table 7). During this quarter, the U analysis failed due to low recovery, and concentration values were not reported. Elemental analyses of weekly composites showed no unusual changes in U concentrations during this time period. In general, U and Th concentrations have decreased relative to pre-operational values. This decrease was most notable in the first and second quarters of 2000 and is consistent with gross alpha/beta and elemental results reported herein.

For ^{238}Pu , no detectable concentrations were observed in any operational quarter (Table 7). No detectable $^{239,240}\text{Pu}$ or ^{241}Am were observed in the first and second quarters of 2000. Values for $^{239,240}\text{Pu}$ and ^{241}Am were not reported in the second, third and fourth quarters of 1999 due to sample contamination at CEMRC (described in detail in the CEMRC 1999 Report). However, Station A monitoring results reported by the EEG (Gray et al., 2000, *Operational Radiation Surveillance of the WIPP Project by EEG during 1999*, EEG-79), for this time period, showed no activity (at two standard deviations) above zero for $^{239,240}\text{Pu}$, ^{238}Pu and ^{241}Am . Direct comparison of CEMRC results to those of EEG is difficult, since EEG does not distinguish when analytical results are less than detection limit (e.g. no detectable radioactivity in the sample).

^{234}U results were indistinguishable (at two standard deviations) from those of ^{238}U for

activity concentration and density, suggesting secular equilibrium between the two isotopes (Table 7). Such results are expected for many natural sources of U. ^{228}Th activity concentration and density appeared to be enriched by a factor of $\cong 2$ in comparison to ^{232}Th , but this effect is not statistically significant at two standard deviations (reported as such in the CEMRC 1999 Report). Investigation into this observation suggests an analytical bias resulting from ^{228}Th introduced into the sample from the decay of ^{232}U added as chemical yield tracer.

Filter Medium Experiment

For the filter medium experiment, 19 side-by-side sampling events using the glass fiber filter were evaluated (57 individual samples). The geometric mean (\pm SD) of mass loading on the glass fiber filters was $28.8(\pm 1.7)$ mg. The geometric mean (\pm SD) of samples collected on the same skid (previous fall) with the same final flow criteria ($1.8 \text{ ft}^3 \text{ min}^{-1}$) using the Versapore filter were $8.1 (\pm 2.1)$ mg. Although the data are not directly comparable due to differences in sampling time, they suggest that more mass can be sampled using the glass fiber filter. These results were promising and suggested that if the glass fiber filters were utilized, sampling frequency could be decreased.

However, side by side comparisons between the glass fiber and Versapore filters conducted at CEMRC showed that the glass fiber filters collected $42 \pm 19\%$ (mean \pm SE) less mass in the PM_{10} fraction than did the Versapore filter when sampling the same air. Although not statistically robust, these data suggest that if the glass fiber filters were used at Station A, particles less than $10 \mu\text{m}$ may be under-sampled relative to the current methodology. In addition, the glass fiber filter has the disadvantage that the filter matrix contains significant levels of U (which is not the case with the Versapore filter), which could make weekly and quarterly U composite analyses extremely difficult, if not impossible. As a result, no effort has been made to switch to glass fiber filters for effluent monitoring at Station A.

The filter medium experiment also provided useful information regarding intra-

skid comparability of mass loading and final flow. Concurrent samples were collected on each of the skid's three legs during 19 sampling events. Ideally, the mass loaded on the filters and the final flow at the time of collection should be identical (within some small deviation) for each leg. Mass loading values between legs of the same skid were more strongly correlated than final flow rate between legs. Correlation coefficients for mass loading between the three legs were 0.92 to 0.97, while correlation coefficients for final flows were 0.28 to 0.64. These values for final flows indicate little to no correlation between legs (for this sample size, anything less than 0.5 is considered no better than random). The lack of correlation may

introduce significant uncertainty for metrics involving air volume for this skid.

As previously mentioned, mass loading exhibited better correlation between skid legs. However, from these data the confidence in comparability between legs for a single sampling event would be no greater than 8%. If intra-skid comparability is limited to 8%, it is likely that comparability between skids would be much worse, adding uncertainty to the efficacy of representative sampling at Station A. It is important to note that this discussion is based on limited data, and further investigation is necessary to bound the comparability of effluent sampling at Station A as currently configured.

Table 5. Summary Statistics for Gross Alpha/Beta Analyses of Daily FAS Filters

Gross Emission	^a N	% \geq ^b MDC	Activity Concentration (Bq m ⁻³)				Activity Density (Bq g ⁻¹)			
			^c Mean	^d SE	^e Max	^f RPC (%)	Mean	SE	Max	RPC (%)
Pre-Operational Baseline										
Alpha	71	100	3.1E-04	3.1E-05	1.5E-03	NA	3.6E+00	5.8E-01	3.7E+01	NA
Beta	71	100	1.1E-03	9.1E-05	4.9E-03	NA	1.4E+01	1.9E+00	1.2E+02	NA
Operational Monitoring Second Quarter, 1999										
Alpha	65	100	1.1E-04	6.5E-06	2.7E-04	-65	1.7E+00	1.6E-01	7.6E+00	-53
Beta	65	100	8.2E-04	2.3E-05	1.4E-03	-25	1.6E+01	1.6E+00	5.4E+01	14
Operational Monitoring Third Quarter, 1999										
Alpha	70	100	8.5E-05	5.4E-06	3.2E-04	-73	2.6E+00	8.6E-01	9.2E+00	-27
Beta	70	100	9.7E-04	5.3E-05	3.0E-03	-12	2.9E+01	5.1E+00	8.0E+01	107
Operational Monitoring Fourth Quarter, 1999										
Alpha	39	98	1.4E-04	1.3E-05	3.7E-04	-56	8.1E-01	1.4E-01	4.2E+00	-78
Beta	40	100	1.3E-03	9.1E-05	3.3E-03	23	1.1E+01	2.5E+00	7.0E+01	-24
Operational Monitoring First Quarter, 2000										
Alpha	58	44	1.7E-04	1.1E-05	3.9E-04	-44	8.7E-01	2.1E-01	9.2E+00	-76
Beta	121	92	1.1E-03	4.4E-05	2.3E-03	0	3.9E+00	6.6E-01	4.8E+01	-72
Operational Monitoring Second Quarter, 2000										
Alpha	25	19	8.2E-05	6.1E-06	1.4E-04	-74	6.5E-01	1.2E-01	2.5E+00	-82
Beta	118	90	8.1E-04	2.6E-05	1.6E-03	-26	3.9E+00	4.3E-01	3.6E+01	-72

^aN = number of samples

^bMDC = minimum detectable concentration

^cMean = arithmetic mean

^dSE = standard error

^eMax = maximum

^fRPC = relative percent change calculated as ((observed mean - baseline mean)/baseline mean) * 100

Table 6. Summary Statistics for Elemental Constituents in Weekly FAS Composites Collected during 12 December 1998 – 30 June 2000

Analyte	^a Frequency of Detection (%)	Volume Concentration (ng m ⁻³)				Mass Concentration (ng mg ⁻¹)			
		^b Mean	^c SE	^d Min	^e Max	Mean	SE	Min	Max
Ag	83	1.1E-01	2.2E-02	1.8E-02	1.2E+00	8.3E-01	1.1E-01	7.2E-02	4.7E+00
Al	99	7.3E+02	1.0E+02	1.3E+02	7.8E+03	6.2E+03	1.2E+03	3.9E+02	8.9E+04
As	70	1.3E+00	1.3E-01	3.5E-01	4.7E+00	1.2E+01	1.5E+00	1.3E+00	4.1E+01
Ba	100	7.8E+00	4.4E-01	1.5E+00	2.0E+01	6.9E+01	6.5E+00	1.1E+01	3.0E+02
Be	8	2.9E-01	1.4E-01	8.8E-02	9.8E-01	2.9E+00	1.7E+00	3.8E-01	1.1E+01
Ca	100	4.1E+03	9.4E+02	2.4E+02	7.0E+04	2.0E+04	1.4E+03	7.4E+03	6.9E+04
Cd	84	8.9E-01	2.4E-01	8.2E-02	1.5E+01	7.5E+00	1.4E+00	5.4E-01	6.0E+01
Ce	99	7.6E-01	5.0E-02	1.5E-01	2.1E+00	6.7E+00	6.1E-01	4.5E-01	2.5E+01
Co	94	2.8E+00	4.6E-01	3.5E-01	2.4E+01	1.4E+01	1.4E+00	2.4E+00	6.5E+01
Cr	57	6.0E+01	1.5E+01	8.7E+00	6.2E+02	2.6E+02	7.6E+01	3.2E+01	3.3E+03
Cu	100	3.6E+01	2.1E+00	1.2E+01	1.1E+02	3.2E+02	3.0E+01	4.2E+01	1.7E+03
Dy	100	4.7E-02	3.6E-03	1.0E-02	1.6E-01	4.2E-01	4.4E-02	4.0E-02	1.8E+00
Er	96	2.9E-02	2.5E-03	5.1E-03	1.5E-01	2.7E-01	3.1E-02	2.7E-02	1.7E+00
Eu	92	1.5E-02	1.0E-03	3.8E-03	3.7E-02	1.3E-01	1.2E-02	1.8E-02	5.3E-01
Fe	100	8.1E+02	8.4E+01	3.6E+01	5.8E+03	7.3E+03	7.9E+02	1.5E+02	3.1E+04
Gd	99	7.1E-02	5.7E-03	1.4E-02	2.8E-01	6.4E-01	7.2E-02	1.6E-02	3.2E+00
Hg	25	1.3E-01	3.0E-02	3.1E-02	5.7E-01	7.5E-01	1.2E-01	9.8E-02	1.8E+00
K	99	1.3E+03	1.2E+02	8.2E+01	5.4E+03	7.8E+03	4.3E+02	1.5E+03	2.7E+04
La	100	4.6E-01	3.1E-02	8.9E-02	1.3E+00	4.0E+00	3.6E-01	3.4E-01	1.5E+01
Li	78	2.5E+00	2.7E-01	5.8E-01	1.4E+01	1.2E+01	7.0E-01	4.5E+00	3.8E+01
Ma	100	3.4E+01	3.7E+00	1.4E+00	1.4E+02	3.5E+02	5.6E+01	2.9E+00	3.0E+03
Mg	100	2.8E+03	6.8E+02	1.3E+02	5.1E+04	1.2E+04	7.9E+02	3.9E+03	5.0E+04
Mo	66	4.5E+00	1.4E+00	8.2E-01	7.5E+01	2.3E+01	7.8E+00	2.9E+00	4.1E+02
Na	100	6.7E+04	7.6E+03	1.4E+03	2.9E+05	3.5E+05	3.5E+04	4.8E+04	1.6E+06
Nd	100	3.2E-01	2.1E-02	5.9E-02	9.2E-01	2.9E+00	2.7E-01	1.4E-01	1.2E+01
Ni	91	1.8E+01	6.1E+00	1.8E+00	4.2E+02	1.0E+02	3.2E+01	9.1E+00	2.3E+03
Pb	100	6.8E+00	7.7E-01	1.1E+00	4.6E+01	5.8E+01	6.9E+00	4.5E+00	3.3E+02
Pr	100	9.1E-02	5.9E-03	1.8E-02	2.7E-01	8.1E-01	7.5E-02	6.4E-02	3.4E+00
Sa	100	4.6E-01	2.1E-02	1.6E-01	1.2E+00	4.4E+00	4.6E-01	4.9E-01	2.7E+01
Sb	100	3.2E+01	3.3E+00	3.1E+00	2.2E+02	4.5E+02	1.1E+02	1.4E+01	7.7E+03
Se	27	5.3E-01	4.8E-02	3.0E-01	1.1E+00	6.3E+00	9.8E-01	1.0E+00	1.5E+01
Sn	0	^f NA	NA	NA	NA	NA	NA	NA	NA
Sr	100	7.0E+01	1.9E+01	3.3E+00	1.4E+03	3.1E+02	2.5E+01	1.3E+02	1.4E+03
Th	96	1.2E-01	9.9E-03	2.0E-02	4.8E-01	1.1E+00	1.1E-01	1.0E-01	4.6E+00

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Table 6. Summary Statistics for Elemental Constituents in Weekly FAS Composites Collected during 12 December 1998 – 30 June 2000 (Cont.)

Analyte	^a Frequency of Detection (%)	Volume Concentration (ng m ⁻³)				Mass Concentration (ng mg ⁻¹)			
		^b Mean	^c SE	^d Min	^e Max	Mean	SE	Min	Max
Ti	99	4.5E+01	3.4E+00	9.9E+00	2.1E+02	3.5E+02	3.0E+01	8.3E+01	1.3E+03
Tl	0	NA	NA	NA	NA	NA	NA	NA	NA
U	91	4.9E-02	4.8E-03	8.8E-03	2.4E-01	4.0E-01	5.6E-02	6.6E-02	2.8E+00
V	62	4.2E+00	5.3E-01	1.0E+00	1.7E+01	2.6E+01	2.0E+00	6.9E+00	6.9E+01
Zn	97	2.8E+02	8.5E+01	2.4E+01	4.7E+03	2.7E+03	8.5E+02	1.5E+02	4.9E+04

^aA total of 77 weekly composites were analyzed during this interval

^bMean = arithmetic mean

^cSE = standard error

^dMin = minimum

^eMax = maximum

^fNA = not applicable

Table 7. Results of Actinide Analyses for Quarterly FAS Composite Samples

Radionuclide	Activity Concentration (Bq m ⁻³)				Activity Density (Bq g ⁻¹)			
	^a C	^b SD	^c MDC	^d RPC (%)	C	SD	MDC	RPC (%)
Pre-operational Baseline								
²³⁸ Pu	< MDC	^e NA	2.4E-08	NA	< MDC	NA	3.0E-04	NA
^{239, 240} Pu	< MDC	NA	2.4E-08	NA	< MDC	NA	2.9E-04	NA
²⁴¹ Am	< MDC	NA	5.5E-08	NA	< MDC	NA	6.9E-04	NA
²²⁸ Th	7.6E-07	5.2E-08	9.7E-08	NA	8.1E-03	5.6E-04	1.2E-03	NA
²³⁰ Th	7.0E-07	4.9E-08	6.8E-08	NA	7.5E-03	5.3E-04	8.3E-04	NA
²³² Th	4.9E-07	3.7E-08	3.6E-08	NA	5.2E-03	4.0E-04	4.3E-04	NA
²³⁴ U	8.9E-07	4.9E-08	3.0E-08	NA	9.5E-03	5.3E-04	3.8E-04	NA
²³⁵ U	4.1E-08	1.5E-08	2.7E-08	NA	4.4E-04	1.6E-04	3.2E-04	NA
²³⁸ U	8.5E-07	4.9E-08	2.4E-08	NA	9.1E-03	5.2E-04	3.0E-04	NA
Operational Monitoring Second Quarter, 1999								
²³⁸ Pu	< MDC	NA	2.4E-08	NA	< MDC	NA	3.0E-04	NA
^{239, 240} Pu	^f NR	NR	NR	NA	NR	NR	NR	NA
²⁴¹ Am	NR	NR	NR	NA	NR	NR	NR	NA
²²⁸ Th	1.1E-06	7.0E-08	9.7E-08	4.5E+01	1.5E-02	9.6E-04	1.2E-03	85
²³⁰ Th	5.6E-07	4.6E-08	6.8E-08	-2.0E+01	7.6E-03	6.3E-04	8.3E-04	1.3
²³² Th	5.8E-07	4.0E-08	3.6E-08	1.8E+01	7.9E-03	5.5E-04	4.3E-04	52
²³⁴ U	7.3E-07	4.6E-08	3.0E-08	-1.8E+01	9.9E-03	6.2E-04	3.8E-04	4.2
²³⁵ U	3.3E-08	1.2E-08	2.7E-08	-2.0E+01	4.5E-04	1.6E-04	3.2E-04	2.3
²³⁸ U	6.1E-07	4.1E-08	2.4E-08	-2.8E+01	8.4E-03	5.6E-04	3.0E-04	-7.7
Operational Monitoring Third Quarter, 1999								
²³⁸ Pu	< MDC	NA	9.3E-08	NA	< MDC	NA	1.6E-06	NA
^{239, 240} Pu	NR	NR	NR	NA	NR	NR	NR	NA
²⁴¹ Am	NR	NR	NR	NA	NR	NR	NR	NA
²²⁸ Th	6.9E-07	5.4E-08	7.8E-08	-8.9E+00	1.2E-02	9.5E-04	1.4E-03	51
²³⁰ Th	2.5E-07	4.2E-08	7.8E-08	-6.4E+01	4.5E-03	7.5E-04	1.4E-03	-40
²³² Th	1.9E-07	2.9E-08	5.4E-08	-6.2E+01	3.3E-03	5.2E-04	9.6E-04	-37
²³⁴ U	5.1E-07	6.4E-08	7.8E-08	-4.2E+01	9.1E-03	1.1E-03	1.4E-03	-4.3
²³⁵ U	< MDC	NA	8.5E-08	NA	< MDC	NA	1.5E-03	NA
²³⁸ U	3.7E-07	5.7E-08	1.1E-07	-5.6E+01	6.6E-03	1.0E-03	1.9E-03	-28
Operational Monitoring Fourth Quarter, 1999								
²³⁸ Pu	< MDC	NA	2.3E-07	NA	< MDC	NA	8.3E-04	NA
^{239, 240} Pu	NR	NR	NA	NA	NR	NR	NA	NA
²⁴¹ Am	NR	NR	NA	NA	NR	NR	NA	NA
²²⁸ Th	1.2E-06	1.5E-07	3.8E-07	6.0E+01	4.4E-03	5.6E-04	1.4E-03	-45
²³⁰ Th	1.0E-06	1.6E-07	3.1E-07	4.3E+01	3.6E-03	5.9E-04	1.1E-03	-51
²³² Th	6.0E-07	9.6E-08	1.8E-07	2.3E+01	2.2E-03	3.5E-04	6.4E-04	-58
²³⁴ U	NR	NA	NR	NA	NR	NR	NA	NA
²³⁵ U	NR	NA	NR	NA	NR	NR	NA	NA
²³⁸ U	NR	NA	NR	NA	NR	NR	NA	NA

Table continued on next page

Table 7. Results of Actinide Analyses for Quarterly FAS Composite Samples (Cont.)

Radionuclide	Activity Concentration (Bq m ⁻³)				Activity Density (Bq g ⁻¹)			
	^a C	^b SD	^c MDC	^d RPC (%)	C	SD	MDC	RPC (%)
Operational Monitoring First Quarter, 2000								
²³⁸ Pu	< MDC	NA	7.1E-08	NA	< MDC	NA	1.7E-04	NA
^{239, 240} Pu	< MDC	NA	5.6E-08	NA	< MDC	NA	1.3E-04	NA
²⁴¹ Am	< MDC	NA	4.9E-08	NA	< MDC	NA	1.2E-04	NA
²²⁸ Th	1.2E-06	6.8E-08	9.4E-08	5.8E+01	2.8E-03	1.6E-04	2.2E-04	-65
²³⁰ Th	5.8E-07	5.0E-08	6.5E-08	-1.7E+01	1.4E-03	1.2E-04	1.5E-04	-82
²³² Th	4.1E-07	3.7E-08	3.2E-08	-1.5E+01	9.8E-04	8.8E-05	7.6E-05	-81
²³⁴ U	1.0E-06	7.5E-08	8.0E-08	1.2E+01	2.4E-03	1.8E-04	1.9E-04	-75
²³⁵ U	1.3E-07	3.9E-08	1.1E-07	2.2E+02	3.1E-04	9.2E-05	2.6E-04	-29
²³⁸ U	8.6E-07	7.0E-08	7.5E-08	1.5E+00	2.0E-03	1.7E-04	1.8E-04	-7.8E+01
Operational Monitoring Second Quarter, 2000								
²³⁸ Pu	< MDC	NA	9.3E-08	NA	< MDC	NA	4.1E-04	NA
^{239, 240} Pu	< MDC	NA	7.5E-08	NA	< MDC	NA	3.3E-04	NA
²⁴¹ Am	< MDC	NA	6.0E-08	NA	< MDC	NA	2.6E-04	NA
²²⁸ Th	4.9E-07	7.1E-08	1.5E-07	-3.5E+01	2.2E-03	3.1E-04	6.7E-04	-7.3E+01
²³⁰ Th	4.0E-07	6.4E-08	1.1E-07	-4.3E+01	1.8E-03	2.8E-04	4.7E-04	-7.7E+01
²³² Th	2.3E-07	4.3E-08	8.8E-08	-5.3E+01	1.0E-03	1.9E-04	3.8E-04	-8.0E+01
²³⁴ U	6.3E-07	6.9E-08	8.1E-08	-2.9E+01	2.8E-03	3.0E-04	3.6E-04	-7.1E+01
²³⁵ U	< MDC	NA	8.1E-08	NA	< MDC	NA	3.5E-04	NA
²³⁸ U	5.0E-07	6.3E-08	1.0E-07	-4.2E+01	2.2E-03	2.8E-04	4.5E-04	-7.6E+01

^aC = concentration^bSD = standard deviation^cMDC = minimum detectable concentration^dRPC = relative percent change, calculated as ((observed value - baseline value)/baseline value) * 100^eNA = not applicable^fNR = data not reported

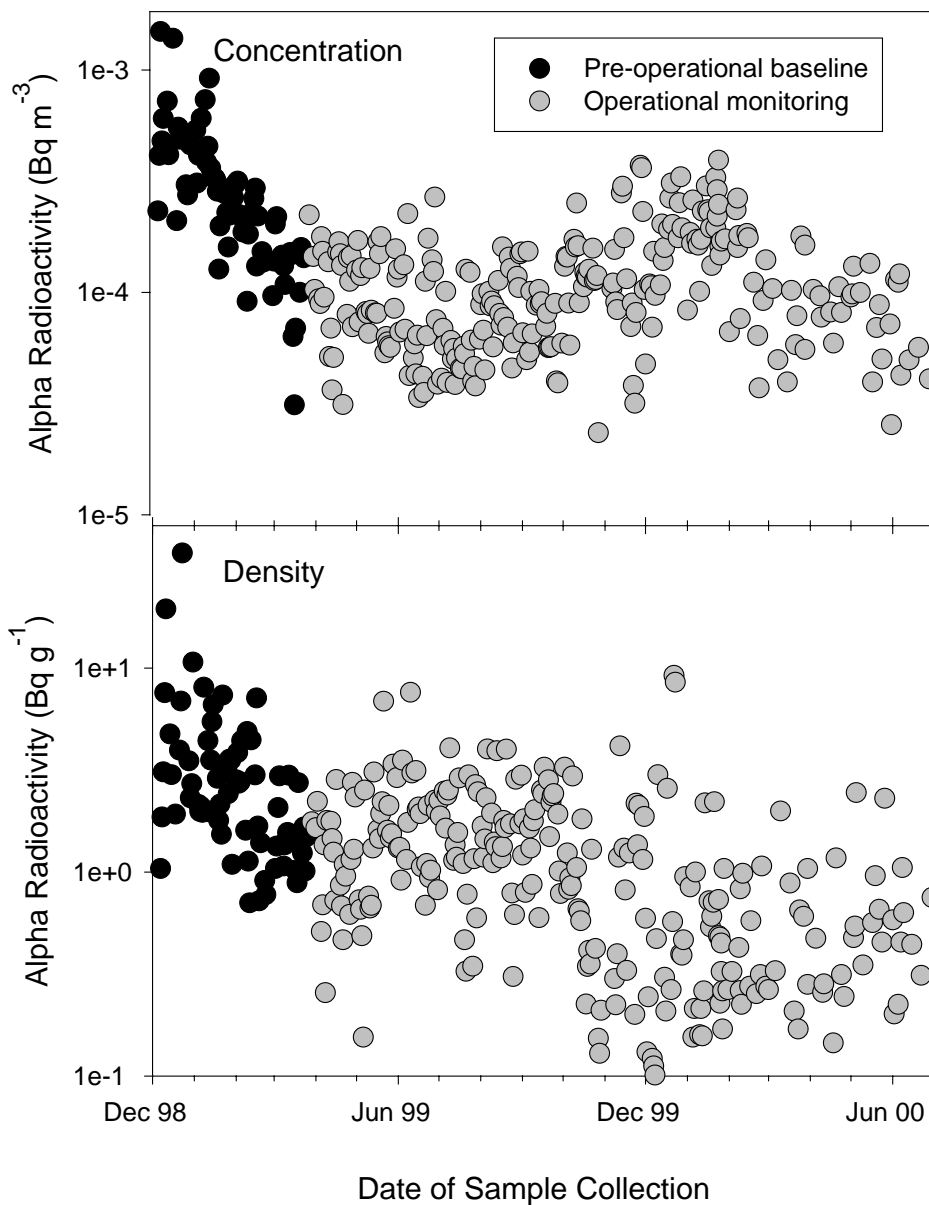


Figure 16. Alpha Emitting Radioactivity in FAS Samples Collected during December 1998 - July 2000

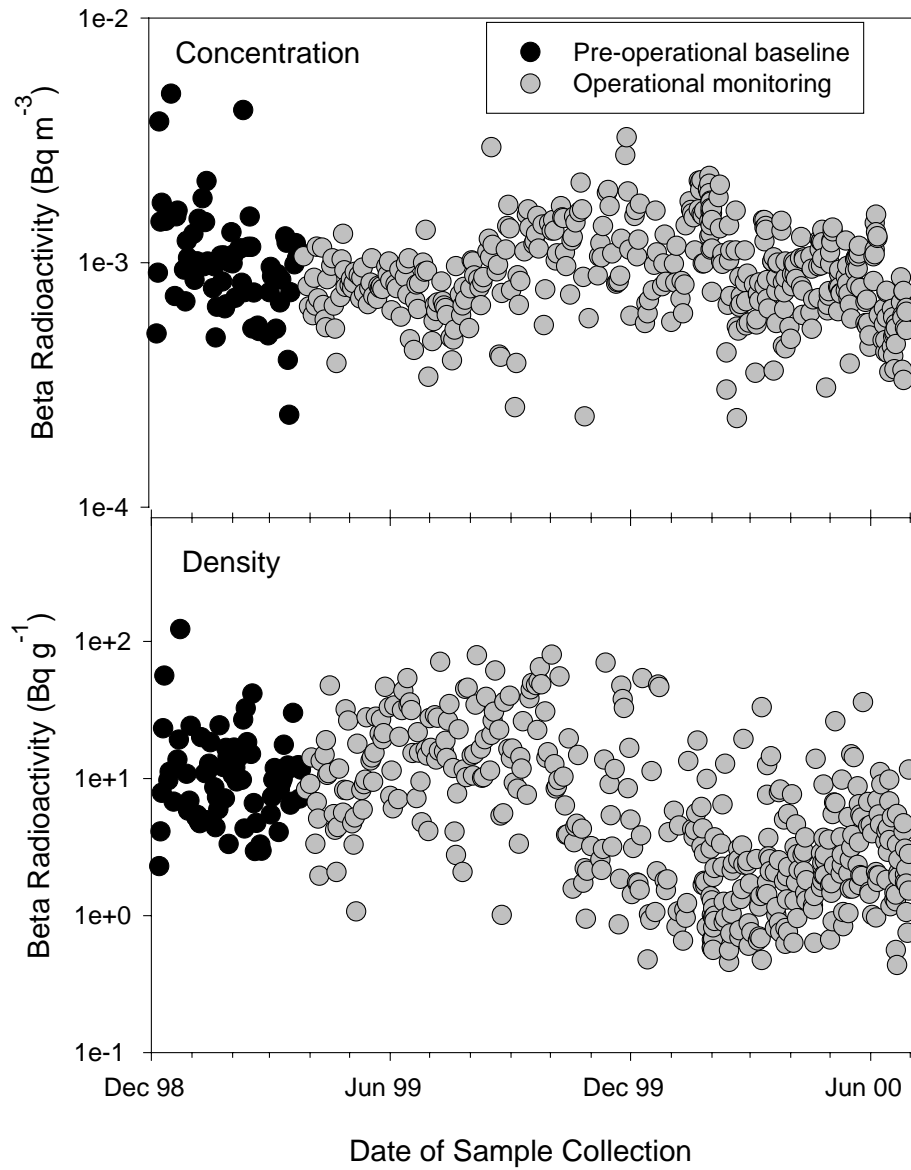


Figure 17. Beta Emitting Radioactivity in FAS Samples Collected during December 1998 - July 2000

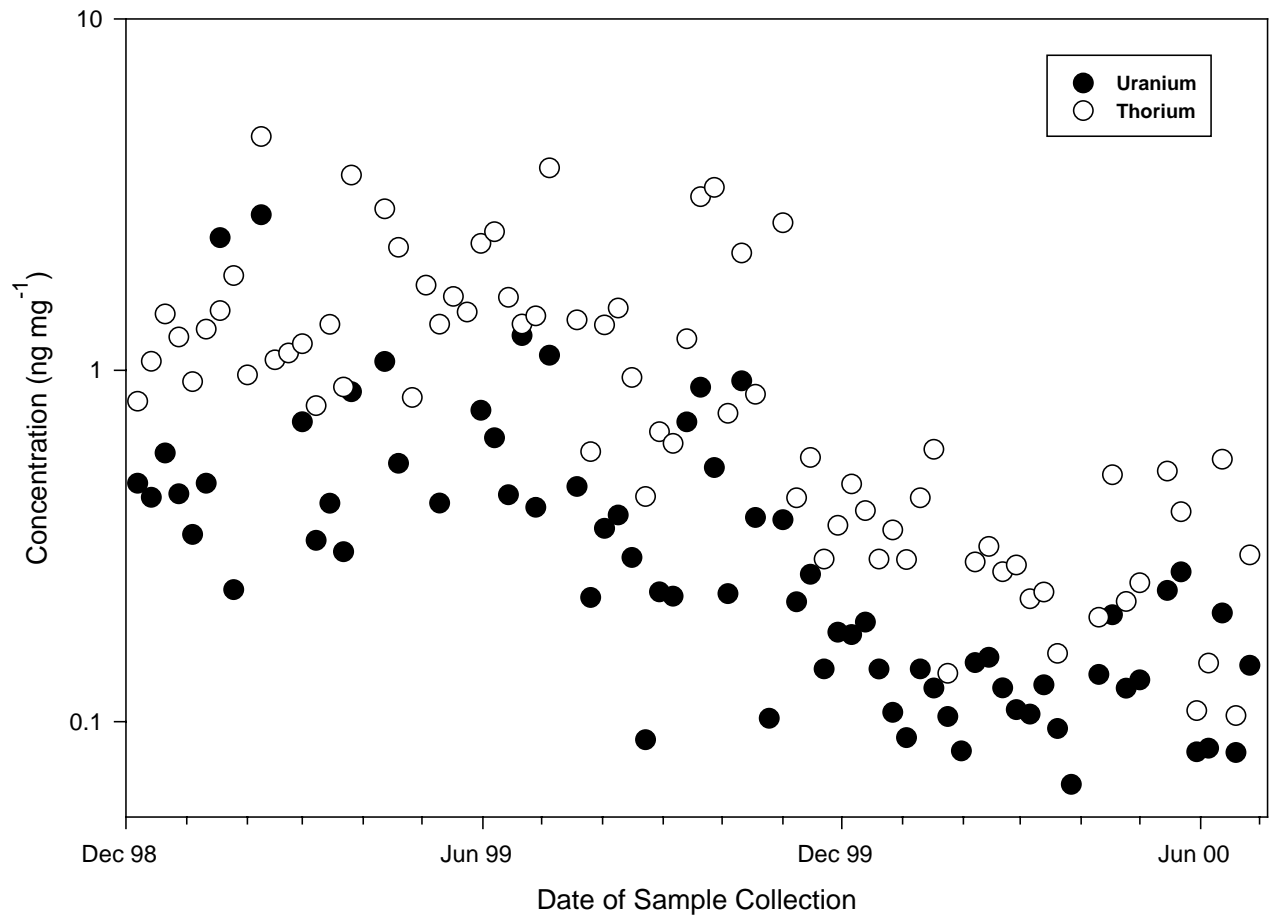


Figure 18. Radioactive Elemental Constituents Released as Aerosols in the Exhaust from the WIPP