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Characterization of MWC Ashes and Leachates from MSW Landfills, Monofills, and Co-Disposal Sites

Summary—Volume I of VII

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FINAL

CHARACTERIZATION OF MUNICIPAL WASTE COMBUSTOR ASHES AND LEACHATES FROM MUNICIPAL SOLID WASTE LANDFILLS, MONOFILLS, AND CODISPOSAL SITES

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CHARACTERIZATION OF MUNICIPAL WASTE COMBUSTOR ASHES AND LEACHATES FROM MUNICIPAL SOLID WASTE LANDFILLS, MONOFILLS, AND CODISPOSAL SITES

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ACRONYMS AND DEFINITIONS

BNA	Base-neutral and Acid Extractables
BOD	Biological Oxygen Demand
CAS	Chemical Abstract Service
CB	Chlorobiphenyl
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
COD	Chemical Oxygen Demand
Codisposal	Disposal together of municipal solid wastes and municipal solid waste combustion ashes
CP	Chlorinated Phenols
DWE	Deionized Water Extraction Test Method
EP	Extraction Procedure
EPA	U.S. Environmental Protection Agency
ESP	Electrostatic Precipitator
HSWA	Hazardous and Solid Waste Amendments
HWC	Hazardous Waste Combustion
LF	Landfill
MCL	Maximum Contaminant Level
Monofill	A landfill that contains only solid waste combustion ashes and residues
MSW	Municipal Solid Waste
MW	Monitoring Well
MWC	Municipal Waste Combustion
MWEP	Monofilled Waste Extraction Procedure, also known as SW-924
ND	Not Detected
NPDES	National Pollutant Discharge Elimination System
PAHs	Polynuclear Aromatic Hydrocarbons
PCBs	Polychlorinated Biphenyls

ACRONYMS AND DEFINITIONS
PAGE TWO

PCDDs	Polychlorinated dibenzo-p-dioxins
PCDFs	Polychlorinated dibenzofurans
POTW	Publically Owned Treatment Works
RCRA	Resource Conservation and Recovery Act
RDF	Refuse Derived Fuel
RPD	Relative Percent Difference
SS	Suspended Solids
SW-924	Deionized Water Extraction Test Method
TCLP	Toxic Characteristics Leaching Procedure Test Method
TDS	Total Dissolved Solids
TEF	Toxic Equivalency Factors
TNK	Total Nitrogen Kjeldahl
TOC	Total Organic Carbon
TSCA	Toxic Substances Control Act

EXECUTIVE SUMMARY

The Hazardous and Solid Waste Amendments (HSWA) to RCRA, which were signed into law on November 8, 1984, require that the EPA address the issue of Subtitle D. The EPA is to determine whether the existing Subtitle D, nonhazardous, Criteria (40 CFR Part 257) are adequate to protect human health and the environment from groundwater contamination and to recommend whether additional authorities are needed to enforce the Criteria. The agency is to present its conclusions in a report to Congress by November 8, 1987. Additionally, the EPA must revise the Criteria by March 31, 1988, for facilities that may receive hazardous household waste or waste from small-quantity generators.

Recently, there has been a move toward reduction of waste volume because of a steady decrease in space available for municipal solid waste disposal. Both government and the public have been concerned about identifying and implementing alternatives for reducing waste volume. Incineration of solid waste is one of the primary alternatives pursued for waste reduction. However, questions have been raised about the potential environmental effects of this alternative.

Incineration produces ashes, which must be managed. Effective management includes consideration of produced leachates. Ashes are generally contained within the disposal site area. Municipal Waste Combustor (MWC) ash, by the nature of its origin, consists predominantly of silicon oxide (SiO_2), i.e., glass. Additional components within the ash matrix are aluminum oxide; iron oxide; calcium oxide; magnesium oxide; sodium oxide; potassium oxide; titanium oxide; and sulfate, chloride and phosphate ions. When disposed in municipal waste landfills (codisposal landfills) some of these constituents may leach. Certain inorganics (metals) and organics, including dioxins, are of particular concern.

Because of the metal and organic content of MWC ashes, questions have been raised about whether tighter control over ash disposal is necessary. Data that chemically characterize MWC residues can be used to determine whether an alternative management strategy is needed and, if a strategy is needed, what structure it should have.

To assist the EPA in data collection in support of regulatory decisions, NUS Corporation and Versar, Incorporated, have conducted several studies that are herein combined into one report entitled "Characterization of Municipal Waste Combustor Ashes and Leachates from Municipal Solid Waste Landfills, Monofills, and Codisposal Sites." The main objective of these projects was to assist EPA in developing data to evaluate the potential health and environmental effects of leachate from municipal landfills, codisposal landfills, and monofills.

As part of these projects, NUS conducted a study of the available literature from the United States, Canada, Japan, and Europe to collect baseline data on municipal waste landfills, codisposal landfills, and monofills. The baseline data included ranges of concentrations of organics and inorganics in fly ash, bottom ash, and combined ash. Next, four municipal waste disposal sites, two codisposal sites, and four incinerator sites were chosen for field studies.

NUS collected 3 samples of leachate from each of four selected municipal waste disposal sites (for a total of 12 samples) plus 1 duplicate sample. NUS also collected 3 samples of leachate from each of two selected codisposal sites for a total of 6 samples. In addition, NUS collected 2 samples of fresh ashes that were being delivered to the codisposal site for disposal. Versar sampled leachate, waste combustion ashes, and quench water from four incinerators and their companion monofills. In total, Versar collected 12 composite samples of combined bottom/fly ash, 5 composite samples of bottom ash (limited to one facility), 20 composite samples of fly ash, 10 samples of quench water, 9 samples of leachate, and 2 composite samples of disposed ash.

Leachate and quench water samples were analyzed for metals; for organics, including PCBs, polychlorinated dibenzo-p-dioxins (PCDDs), and polychlorinated dibenzo-furans (PCDFs); and for selected conventional parameters, including pH, specific conductance, chemical oxygen demand, and ammonia-nitrogen, etc.

Ash samples were analyzed for metals and organics, including PCBs, base-neutral acid extractables (BNAs), PCDDs, and PCDFs. The ashes were subjected to simulated leachability tests in the laboratory, which included the three most commonly applied leaching tests -- the Extraction Procedure (EP) toxicity test, the Toxicity Characteristics Leaching Procedure (TCLP) toxicity test, and the Monofilled Waste

Extraction Procedure (SW-924) test. The laboratory-produced leachates or extracts were then analyzed for inorganic constituents (metals), semi-volatile compounds, and the homologs of PCDDs and PCDFs.

Because of the nature of the sites sampled, the limited number of sites sampled, the relatively small number of samples collected at each site, and the types of samples collected, the data obtained from these studies and presented here are not necessarily representative of all municipal waste combustion facilities or ash fills. In particular, the monofills evaluated were designed and became operational in the 1970s and early 1980s and are not likely to accurately represent the performance of the current generation of monofills. Monofills currently being put into operation generally include more extensive controls and more precise management than those included in this study.

The four MSW and the two codisposal sites selected for sampling by NUS were sites that do not accept industrial waste and which became operational only after RCRA regulations come into effect. Therefore, they represent "best case scenarios" of the waste industry. A limited number of incinerator sites (i.e., four) were sampled and a limited number of samples were taken at each of these sites. (See Table 1-2 for complete sampling information.)

In addition, MWC ashes are extremely heterogeneous in nature and collecting representative "laboratory scale" ash samples is extremely difficult. For this reason, ashes collected from the combustors (the Versar study) were grab sampled at predesignated intervals and then composited to a single sample. This compositing was intended to "smooth out" the great heterogeneity of the ashes. However, in reality, the variability of obtained results between days, shifts, and units within the same facility is extremely great. The differences between facilities are even greater. This indicates that the variability in operating characteristics, facility design, and feed material composition have a significant effect on the resultant MWC residue quality. The great variability was observed for metals, organics, PCDDs, and PCDFs.

Of the residue fractions, i.e., fly ash, bottom ash and combined bottom and fly ash, the fly ash, because of its finer particles, contains higher concentrations of toxic metals, PCBs, PCDDs, and PCDFs. The bottom ash contains the lowest concentrations of these constituents and the combined ash levels fall in between the bottom ash

and the fly ash. Combining the ash fractions effectively dilutes the total metals concentrations of the fly ash. Unlike the metals, the semivolatile compounds, i.e., naphthalene, phthalates, phenanthrene, seem to concentrate in the bottom ash.

Concentrations of 2,3,7,8-TCDD in fly ash solids ranged from 0.07 to 3.9 ppb, as indicated in Table ES-1. Concentrations in bottom ash samples ranged from below detectable limits to 0.01 ppb.

Metal content in leachates was lower than metal content in ashes (see Tables ES-2 and ES-3). The metal content in actual leachate collected from the codisposal sites and from the monofills was always lower than in test leachates (EP, TCLP, or SW-924) (see Table ES-3). (Note: The table references values for lead and cadmium only since these metals were the ones that occasionally exceeded the maximum allowable limits.) The actual leachates were always below the EP Toxicity Maximum Allowable Limit. However, one ash sample collected from one of the two codisposal sites exceeded the EP Toxicity Maximum Allowable Limit of 5 mg/l (parts per million [ppm]) for lead when subjected to all three test methods, and the second ash sample exceeded this limit when subjected to the TCLP test method.

None of the leaching procedures extracted base neutral compounds or PCBs. The EP and SW-924 extracted the higher homologs of PCDDs and PCDFs in very small quantities. (A homolog refers to the number of chlorine atoms on the organic structure, but not the position of those atoms; there are eight homologs of PCDD and eight homologs of PCDF. The higher the homolog the more chlorine atoms on the structure). The TCLP failed to extract any of the PCDDs or the PCDFs. The concentrations of PCBs, PCDDs, PCDFs, and semivolatile compounds were negligible in the actual leachate samples and in the laboratory-prepared leachate samples (see Table ES-4). Therefore, these compounds appear to be relatively immobile in the natural environment. Since the leachate samples were not filtered prior to analysis, the extremely low (parts per trillion) levels of these compounds detected in these leachates reflect total values, i.e., values in the water and in the suspended solids. All leachate samples, those collected by Versar and those collected by NUS, were

TABLE ES-1

SUMMARY FOR PCDD AND PCDF VALUES IN ASHES
(All units of ashes in ng/g or parts per billion)

	Total CDD	Total CDF	2,3,7,8-TCDD	2,3,7,8-TCDF
Fly Ash, Versar	0–12,018 (22)*	5.52–3,187 (22)	0.07–3.9 (22)	0.66–26 (2)
Combined Fly Ash and Bottom Ash, Versar	6.2–350 (12)	12.34–480.4 (12)	0.02–0.78 (12)	0.41–12 (12)
Bottom Ash, Versar	0.27–40.25 (5)	0.16–15.9 (5)	<0.04–0.01 (5)	0.02–0.3 (5)
Landfill Composite, Versar	20.7–28.8 (2)	14.41–27.31 (2)	0.07–0.15 (2)	0.51–1.3 (2)
Combined Ash, NUS	0.55–14.67 (2)	1.24–6.21 (2)	0 (2)	0.07–0.11 (2)

* = Number in ( ) indicates number of samples

TABLE ES-2

SUMMARY OF METAL CONTENT IN ASHES
(All Units in ppm)

Parameter	Versar Fly Ash	Versar Bottom Ash	Versar Combined Ash	Versar Landfill Composite	NUS Landfill Composite
Cadmium	107–475	1.1–43	7.8–45	8.7–30	8.6-14.8
Chromium	48–105	24–105	12–332	52–85	28.2-55.2
Copper	484–2,380	581–10,700	193–5,900	402–1,190	226-5,100
Iron	5,960–22,300	12,000–115,000	2,100–95,100	19,600–60,600	11,900-18,900
Lead	2,830–14,400	1,380–3,930	259–13,200	709–1,210	630-3,240
Manganese	320–1,410	430–1,520	110–3,130	445–572	352-508
Nickel	52–245	17–90	13–556	51–120	144-498
Zinc	8,460–38,800	914–12,400	545–46,000	2,050–4,740	1,510-3,750
Arsenic	16–149	2.2–24.6	2.9–22.8	6.0–14.8	11.4-19.6
Selenium	2.5–15.6	2.5	0.25–2.5	<2.5–<5	<5
Mercury	0.94–35	0.12–0.36	0.11–8.7	0.25–0.57	0.1-3.8
No. of Samples	20	5	15	2	2

TABLE ES-3

CADMIUM AND LEAD IN EXTRACTS AND LEACHATES
(Units in ppm)

VERSAR

	Cd	Pb	No. of Samples
Fly Ash			
EP Toxicity	6.02-18	4.72-25.2	6
TCLP	0.015-17.2	0.0025-15.2	6
SW-924 Fluid #1	0.005-0.122	0.025-0.128	3
SW-924 Fluid #2	0.005-0.033	0.025-0.148	3
Combined Fly Ash and Bottom Ash			
EP Toxicity	0.06-0.827	2.09-34	3
TCLP	0.025-3.32	0.655-30.1	3
SW-924 Fluid #1	0.005	0.025-0.063	3
SW-924 Fluid #2	0.005	0.025	3
Bottom Ash			
EP Toxicity	0.388	34	1
TCLP	0.418	30.1	1
SW-924 Fluid #1	<0.01	<0.05	1
SW-924 Fluid #2	<0.01	<0.05	1
Actual Leachates Monofills	0.0025-0.044	0.025-2.92	9

NUS

Combined Ash			
EP Toxicity	0.195-0.275	48.8-3.17	2
TCLP	0.155-0.275	9.58-240	2
SW-924 Fluid #1	<0.02	75.4	1
Actual Leachates Codisposal Sites	0.006-0.011	0.010-0.027	6

TABLE ES-4

SUMMARY OF PCDD AND PCDF VALUES IN LEACHATES AND EXTRACTS
(All units in ng/l or parts per trillion)
VERSAR STUDY

	Total CDD	Total CDF	2,3,7,8-TCDD	2,3,7,8-TCDF
Quench Water, Versar	0.06–2,550 (9)	0.06–4,338 (9)	0.035–17 (9)	0.03–110 (9)
Field Leachates, Versar	0.06–543 (8)	0.1–823 (8)	0.025–1.6 (8)	0.025–11 (8)
Groundwater, Versar	0 (4)	0 (4)	0 (4)	0 (4)
TCLP, extract of Fly Ash, Versar	0–0.188 (4)	0–0.049 (4)	0 (4)	0 (4)
TCLP, extract of Bottom Ash, Versar	0.91 (1)	0.054 (1)	0 (1)	0 (1)
TCLP, extract of Bottom /Fly Ash, Versar	0 (3)	0 (3)	0 (3)	0 (3)
Field Leachates, NUS	0.38–15.9 (2)	0.14–0.21 (2)	0 (2)	0 (2)
TCLP Combined Ashes, NUS	0 (2)	0 (2)	0 (2)	0 (2)
EP-Toxicity, NUS	0.033–0.052 (2)	0–0.012 (2)	0 (2)	0 (2)
SW-924, NUS	0.035 (1)	0 (1)	0 (1)	0 (1)

* = Number in ( ) indicates number of samples

turbid and thus contained suspended solids. The suspended solids are probably the main contributor of these contaminants to the total reported values.

Of the three extraction tests, ashes subjected to the SW-924 were found to have values that correspond most closely to those of actual leachates collected from monofills. The TCLP procedure using extracting fluid number one produces extracts that follow the SW-924 in meeting actual leachate values. The EP toxicity is the most aggressive in extracting chemical constituents of ashes and produces extracts most unlike field leachates. The TCLP procedure using extracting fluid number two seems to counteract such treatment processes as in-stack lime-treatment, which is used to collect the fine particles and thus prevent them from exiting the stacks. It requires the acidification with a pH of 2.88 of wastes that exhibit very basic characteristics. This acidification releases "fixed" metals from the treated ash.

In general, there are no discernible differences between the quality of leachates from the codisposal sites sampled in this study (which came into operation following adoption of RCRA requirements and which do not accept industrial waste) and those leachates from the municipal disposal sites. This indicates that the neutral (pH 6.98 to 7.82) generated leachates do not promote leaching of metals from the MWC ashes. On the contrary, they can provide dilution.

The pH in leachates from monofills, as reported in the literature, ranged between 8.04 and 8.3, and in leachates from the monofills sampled by Versar, ranged between 7.44 and 8.58. The pH in leachates from the two codisposal sites collected, by NUS ranged from 7.2 to 7.3. The neutral to basic pH conditions in the municipal solid waste (MSW) facilities, the codisposal sites, and the monofills indicate an environment in which the solubilities of metals are limited.

Bacterial activities appear to be under way at all the sampled sites. The pH of the monofill leachates ranged between 7.44 and 8.58. These slightly to moderately basic waters can sustain bacteria, especially since they contained TOC levels that indicate sufficient sources of nutrition. Such bacteria can play a vital role in shaping the water quality of the monofill leachate. The presence of ammonia (although at very low levels) is evidence of anaerobic bacterial activity.

Additional data are needed in several areas. The data base for the general characterization and toxic characteristics of codisposal sites and monofills is very limited. While the data base for metal levels in extracts from ashes is large, data on the relationship between ashes and leachates in codisposal sites and monofills is almost absent. In addition, levels of PCDDs and PCDFs in leachates from municipal waste disposal sites should be determined. A recent Canadian Government publication claims that PCDDs and PCDFs have been found in raw municipal solid waste. Further studies in this area are recommended.

Levels of PCDDs and PCDFs in leachates from codisposal sites and levels of semi-volatile compounds in leachates from monofills should be established and evaluated. It also appears that several systematic studies are necessary to characterize discharges from the MSW incineration cycle and to expand the existing data base, in particular, in the area of comparison between simulated and actual leachate tests.

In summary, in general the data from the EPA-sponsored studies (NUS and Versar) were consistent with the data in the literature. Key findings of the project are as follows:

- Ash data showed dioxins/furans and metals content.

- Compared to monofills, leachate from MSW and codisposal facilities contained somewhat lower concentrations of metals but considerably higher concentrations of organic compounds, especially Volatile Organic Compounds (VOCs).

- Leaching tests did not simulate the environment, and results differed among tests. Differences in EP, TCLP, and distilled water clearly indicated that acid environments enhance leachability. Contrary to earlier studies, combined ash failed the EP test for lead nearly as often as did fly ash alone. (A limited number of ash samples from each facility were collected; additional analyses may be necessary.)

- pH from monofills, codisposal facilities, and new MSW landfills did not differ significantly.

It is important to remember that these data are based on samples collected from a small number of sites. Additional studies may be necessary in the future.

1.0 INTRODUCTION

This report, "Characterization of Municipal Waste Combustor Ashes and Leachates from Municipal Solid Waste Disposal Sites, Monofills, and Codisposal Sites," has been prepared for the United States Environmental Protection Agency (EPA) in response to Work Assignment No. 4 under Contract No. 68-01-7310.

1.1 BACKGROUND

1.1.1 Federal Regulation of Wastes

In 1979, under authority of Sections 1008(a)(3) and 4004(a) of Subtitle D of the Resource Conservation and Recovery Act (RCRA), EPA promulgated "Criteria" for determining whether specific Subtitle D (nonhazardous waste) disposal facilities and practices pose a reasonable probability of adverse effects to human health or to the environment (40 CFR Part 257). Major provisions of the Criteria include prohibitions concerning adverse effects to endangered species, discharges to surface water, and discharges to groundwater. Those facilities that violate the Criteria are considered "open dumps" and are prohibited under RCRA.

EPA also promulgated guidelines for the development of State Solid Waste Management Plans (40 CFR Part 256) in 1979. These guidelines required that states seeking EPA Subtitle D grant funds be given the authority to prohibit, close, and upgrade open dumps. These grant funds were available from 1977 to 1981; state participation in this program was voluntary. Except for approval of the state plans and disbursement of grant funds, EPA had no direct implementation authority. Thus, Subtitle D has basically been a state-administered program.

Federal funding of State Subtitle D activities was terminated after 1981. Since then, the focus of EPA's efforts under RCRA has been on the Subtitle C (hazardous waste) provisions. As a result, EPA has little current information regarding the status of state nonhazardous waste programs and the Subtitle D facilities themselves.

The Hazardous and Solid Waste Amendments (HSWA) to RCRA, signed into law on November 8, 1984, require EPA to submit a report to Congress by November 8, 1987, addressing whether the Subtitle D Criteria (40 CFR Part 257) are adequate to protect human health and the environment from groundwater contamination and recommending whether additional authorities are needed to enforce the Criteria. Further, EPA must revise the Criteria by March 31, 1988, for facilities that may receive hazardous household waste or small quantity generator waste. These revisions are to include groundwater monitoring, location restrictions, and corrective action, as appropriate.

Within 18 months of the promulgation of the revised Criteria, each state must develop a permit program or other system of prior approval to ensure that each facility eligible to receive hazardous household waste or small quantity generator waste is in compliance with the Criteria. The HSWA envision Subtitle D to continue to be state implemented. However, if the states fail to enforce the Criteria, EPA may intervene.

1.1.2 Concern Regarding Leachates

Data available in the literature regarding the chemical composition of leachates generated by municipal disposal facilities have raised concerns about the chemical composition of leachate generated from municipal waste landfills. These concerns center on the detection of certain toxic inorganics (mainly metals) and organic constituents in the leachates generated from municipal Subtitle D facilities, and on the lack of available data for a comprehensive and defensible evaluation of the effects of these leachates on human health and the environment.

At the same time, there has been a steady decrease in space available for municipal solid waste (MSW) disposal. Therefore, there is an increased concern by local, state, and Federal governments, as well as by the public, for identifying and implementing alternatives for reducing the volume of MSW by means that are compatible with environmental, economic, and social factors.

1.1.3 Municipal Waste Incineration

Incineration of municipal solid waste to reduce waste volume and to produce energy is currently being considered as an important alternative. However, there is concern about the effects of leachates from ash disposal landfills on human health and the environment. Certain organics and heavy metals are of particular concern.

The potential for increasing MWC emissions to the air and increasing the volume of produced leachates to water resources, has alerted regulators and the public to the need to assess the actual public health and environmental effects of MWC ashes. For this purpose, EPA has retained the services of NUS and Versar to assist EPA in developing data to assess the effects of MWC ashes. Table 1-1 provides a summary of municipal solid waste incinerator statistics.

1.2 OBJECTIVES

The principal objective of NUS' part of the project was to assist EPA in developing data to evaluate the potential health and environmental effects of leachate from municipal landfills and codisposal sites. To meet this objective, a number of tasks with more precise objectives were developed. These objectives were

- To conduct a study of the available literature to present baseline data on the chemical characteristics of leachates generated from municipal waste landfills, codisposal landfills, and monofills.

- To conduct a literature study regarding the chemical composition of MWC ashes.

- To provide information from that review on the range of concentrations of organics and inorganics in MWC fly ash, bottom ash, and combined ash.

- To select four municipal waste disposal sites and sample their leachates (minimum of three samples per site).

TABLE 1-1

SUMMARY OF MSW INCINERATOR STATISTICS*

	Total	Modular	Conventional	RDF
Total facilities operating number	102	51	48	3
With heat recovery	55	31	24	NA
Total MSW Managed (Ton/Day)	33,541	5,296	26,018	2,227
Total Ash Generated (Ton/Day)				
a. Ash Disposed	7,547	1,943	5,374	231
b. Dry-weight Basis	5,191	965	4,027	199
c. Bottom Ash as Disposed	2,930	1,630	1,175	125
d. Fly Ash as Disposed	361	143	114	105
e. Combined Ash as Disposed	4,255	169	4,085	0
Number of Facilities				
a. Disposal Method				
1. Onsite Landfill	23	12	9	2
2. Offsite Landfill	73	36	36	1
3. Other/Unknown	6	3	3	0
b. Type of Landfill				
1. Monofill	36	16	18	2
2. Codisposal	41	19	21	1
3. Other/Unknown/Not LF	25	16	9	0
Ash Disposed of:				
a. Disposal Method				
1. Onsite Landfill	22.78%	3.37%	28.61%	50.39%
2. Offsite Landfill	77.22%	96.63%	71.39%	49.61%
3. Other/Unknown	0.00%	0.00%	0.00%	0.00%
b. Type of Landfill				
1. Monofill	35.50%	25.97%	38.30%	50.39%
2. Codisposal	17.45%	46.14%	5.70%	49.61%
3. Other/Unknown/Not LF	46.57%	27.89%	55.32%	0.00%

Source: Engineering Science
RDF = Refuse Derived Fuel
LF = Landfill

* Note: These statistics were developed independently of those in EPA's recent MWC study; however, trends in the two studies are generally consistent.

- To select two codisposal sites (MSW disposal sites in which municipal incinerator ashes are also disposed) and sample their leachates (minimum of three samples per site).

- To sample MWC ashes as they are arriving at the two selected codisposal sites.

- To analyze all collected leachate samples for conventional parameters (i.e., ammonia, BOD, COD, etc.) and the compounds on the RCRA Appendix IX list by qualified, experienced, and competent laboratories.

- To subject the collected MWC ashes to the three most commonly applied leaching tests: the EP toxicity test, the TCLP toxicity test, and the SW-924 test.

- To analyze the laboratory-produced leachates (extracts) for inorganic constituents (metals), semi-volatile compounds, and homologs of polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs).

- To analyze the ashes and the leachates collected from the codisposal facilities for homologs of polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs).

- To sample the four incinerators sampled by Versar and to analyze the samples for conventional parameters including pH, specific conductance, COD, and ammonia-nitrogen.

- To compare analytical chemical results obtained for the collected leachate samples from the codisposal sites to those obtained for the extracts.

- To compare the analytical chemical results obtained from the collected leachate samples and the extracts to results obtained for leachate collected from hazardous waste sites.

The main objectives of the Versar study were

- To collect MWC ashes, both separately and combined: fly ash from air emission control equipment and bottom ash, and combined fly ash and bottom ash from four different monofilled landfills.

- To collect process quench water, leachates, and groundwater from monofilled landfills containing solid residues.

- To analyze ashes, leachates, and quench water for inorganics (metals), organics, and dioxins.

- To subject collected ashes to the EP, TCLP, and the SW-924 extraction procedures and analyze extracts for metals, organics,and dioxins.

The overall objective of this entire project was to provide data to assess the potential health and environmental effects which result from MWC ash disposal in municipal landfills or in monofilled landfills and to assess the availability of management tools to reduce or minimize such potential effects.

1.3 SCOPE OF WORK/APPROACH

Several tasks were conducted to effectively meet the objectives of this project.

- First, a literature review of the environmental effects of municipal waste disposal sites was conducted. The data from this review were presented in two NUS reports:

  - Characterization of Municipal Landfill Leachates - A Literature Review, September 1987 (Volume II of this report).

  - Addendum to Characterization of Municipal Landfill Leachates - A Literature Review, September 1987 (Volume III of this report).

- Next, a literature review was conducted of the environmental effects of municipal waste combustion residues and their leachates. This effort resulted in the following NUS report:

  - Characterization of Municipal Waste Combustion Residues and their Leachates – A Literature Review, September 1987 (Volume IV of this report).

- Versar then conducted a characterization study of municipal combustor residues. As part of the study, four incinerators and associated monofills were sampled for their ashes, quench waters, and leachates. This study is presented in the following report:

  - Characterization of Municipal Waste Combustor Residues, April 1987 (Volume V of this report).

- Next, NUS conducted a characterization of leachates from four municipal waste disposal sites and two codisposal sites This study resulted in the following NUS report:

  - Characterization of Leachates from Municipal Waste Disposal Sites and Codisposal Sites, September 1987 (Volume VI of this report).

- Finally, NUS revisited the incinerators sampled by Versar to sample for pH, specific conductance, COD, and ammonia-nitrogen, and to obtain additional facility information. This study resulted in the following NUS report:

  - Addendum to Monofill Report, September 1987 (Volume VII of this report).

1.4 SUMMARY REPORT

This report is a summary report and is not intended to repeat data presented in the other volumes, but rather to discuss findings based on the data presented in detail in Volumes II through VII.

This report focuses primarily on issues related to ash characteristics. A large body of literature has been developed concerning the potential effects of combustion properties and flue-gas-cleaning devices on both air emissions and residues. Although some of the findings of this report may relate to such issues, the report is not intended to address those subjects in depth.

Section 2.0 of this report summarizes the available information regarding the chemical characteristics of all ashes: fly ash, bottom ash, and combined ashes. The characterization includes available data regarding inorganic constituents (including metals), organics, polychlorinated biphenyls (PCBs), polychlorinated dibenzo-p-dioxins (PCDDs), and polychlorinated dibenzofurans (PCDFs).

Section 3.0 reports the available information regarding major chemical constituents (i.e., Total Dissolved Solids (TDS), Total Suspended Solids (TSS), pH, sulfate, chloride, nitrate, nitrite, phosphate) in municipal landfills, codisposal landfills, and monofills. Section 4.0 reports the inorganic content (including metals) in leachates from monofills, codisposal landfills, and municipal landfills and in extracts from the different ashes. Similarly, Section 5.0 summarizes findings of the organic content and PCBs in leachates from the three different types of landfills and in extracts. In Section 6.0, levels of polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans in extracts and in monofill leachates are detailed. Section 7.0 provides a discussion of the results reported in Sections 2.0 through 6.0, and Section 8.0 lists the cited references.

1.5 DATA LIMITATIONS

Data obtained from the literature (Volumes II through IV) have inherent limitations that must be considered. These limitations include many unknowns such as sampling procedures, analytical methodologies, quality assurance and quality control (QA/QC) procedures employed in the field and in the laboratory, information regarding the type of wastes disposed of at the facility, etc.

In contrast to these limitations of the data obtained from the literature, the data obtained from the EPA-sponsored studies (Volume V and Volume VI) are reliable because these studies adhered to stringent QA/QC protocols, employed the most

acceptable analytical methodologies, and provided descriptions of the sampled facilities. Data obtained through these two EPA-sponsored studies are of acceptable accuracy and precision. For this reason, information obtained from the literature is reported here, but the main emphasis and the majority of the conclusions drawn originate from data obtained from these two EPA-sponsored studies.

The NUS sampling data used in this study originated from only four municipal facilities and only two codisposal facilities, none of which accepted industrial waste. All four facilities went into operation after RCRA was promulgated. Three grab leachate samples were collected from each disposal facility. In addition, from each codisposal facility, two grab samples of fresh incinerator ash brought in for disposal were collected. For these reasons, this data are by no means representative of the solid waste industry in general.

The Versar sampling data used in this report originated from only four incinerators and associated monofilled landfills. No well purging occurred prior to groundwater sampling by Versar, except for Facility C. At Facility C, the well was purged with five standing volumes prior to sample collection. According to EPA protocols, well purging prior to sampling is required so that samples represent the water quality of the aquifer, not the quality of water standing in the wells. All groundwater samples were "grab" samples.

Table 1-2 provides a listing of the make-up of the composite samples and the number of composite samples analyzed at the four facility studied by Versar. MSW ashes are extremely heterogeneous in nature and collecting representative "laboratory scale" ash samples is extremely difficult, almost impossible, For this reason, compositing of samples collected at known time intervals may somewhat overcome this difficulty.

Combustion facilities sampled are not state-of-the-art facilities. Poor combustion at these facilities may lead to higher levels of organics in ashes than at new facilities. In addition, air pollution control devices at these facilities sampled may not capture as high a level of metals and organics as are captured by air pollution control devices at newer facilities. The monofills sampled are also not state-of-the-art facilities.

This doesn't affect data; however, controls at new monofills are likely to be substantially greater.

None of the liquid samples collected by either NUS or Versar were filtered in the field or in the laboratory prior to analysis. All leachate samples collected by NUS and Versar were all turbid indicating the presence of fine particles. In addition, samples designated for metal analyses were acidified in the field without filtration. Thus, all chemical analyses reported by NUS and Versar represent total values levels in the liquid phase and in the fine particles suspended in the liquid.

1.6 ACRONYMS AND DEFINITIONS

To assist readers of this report, a list of commonly used acronyms and definitions of some specialized terms is included in each volume, except Volume V. This list can be found following the Table of Contents of each volume.

TABLE 1-2

MAKEUP OF COMPOSITE SAMPLES TAKEN BY VERSAR AND NUMBER OF COMPOSITE SAMPLES ANALYZED AT THE FOUR FACILITIES

	Bottom/Fly Ash	Bottom Ash	Fly Ash	Quench Water	Leachate	Landfill Disposed Ash
Facility A	• 8 grab samples - one per hour • Total of 3 composite samples	None	• 8 grab samples - one per hour • Total of 5 composite samples	• 1 grab sample from each unit • Total of 2 samples	None	None
Facility B	None	• 4 grab samples • Total of 5 composite samples	• 4 grab samples • Total of 5 composite samples	• 1 grab sample from each unit • Total of 3 samples	• 1 grab sample from each location • Total of 3 samples	None
Facility C	• 8 grab samples - one per hour • Total of 5 composite samples	None	• 8 grab samples each of three fractions (fine, medium, coarse) • Total of 5 composite samples	• 1 grab sample from each unit • Total of 2 samples	• 1 grab sample from each location • Total of 3 samples	• 50, 2-foot core sections from landfill perimeter • Total of 1 composite sample
Facility D	• 8 grab samples - one every 40 minutes for 6 hours • Total of 4 composite samples	None	• 8 grab samples one every 40 minutes for 6 hours • Total of 5 composite samples	• 1 grab sample • Total of 3 samples	• 1 grab sample from each location • Total of 3 samples	• 50, 2-foot core sections from landfill perimeter • Total of 1 composite sample

2.0 CHEMICAL CHARACTERIZATION OF MWC ASHES

The incineration of municipal solid waste (MSW) results in municipal waste combustor (MWC) ashes: fly ash and bottom ash. In assessing the chemical characteristics, these ashes are characterized individually, or combined. Disposal is usually in a combined form. Table 2-1 contains a summary of MSW stream data statistics, as of 1986 (Engineering Science, 1986). These materials constitute the "feed" into incinerators and once incinerated, yield MWC ashes.

Data on the chemical characteristics of ashes have been generated by industry because of two main regulatory requirements: (1) assessment of potential effects on air quality and (2) assessment of the quality of extracts generated via regulatory procedures (i.e., EP-toxicity and TCLP) and experimental extraction procedures, (i.e., deionized water, column leaching, etc.) and the assessment of the effects these extracts may have on surface and groundwater resources.

The chemical characteristics of MWC ashes have been determined in terms of inorganic constituents (including metals) and organics, including polychlorinated biphenyls (PCBs), polychlorinated dibenzo-p-dioxins (PCDDs), and polychlorinated dibenzofurans (PCDFs).

2.1 INORGANIC CONSTITUENT CONTENT IN MWC ASHES

Table 2-2 lists the ranges of inorganic constituents detected by the different studies, including the EPA-sponsored Versar study (Volume V of this report), of fly ashes, bottom ashes, and combined ashes. The data in this table clearly demonstrate that inorganic constituents are generally more concentrated in the smaller particles of fly ash than in the larger particles, which generally constitute the bottom ash. The combined ash content generally falls in between. Exceptions to this trend were exhibited by copper and iron, which were detected at higher concentrations in bottom ash than in fly ash. Canadian and German studies also verify this trend.

The "volatilization-condensation" reaction mechanism, may have a significant effect on the leachability of inorganics from ashes. According to this mechanism

TABLE 2-1

MATERIALS DISPOSED INTO THE MUNICIPAL WASTE STREAM
(In Millions of Tons and Percent)

Materials	1970		1984		2000	
	Tons	%	Tons	%	Tons	%
Paper and Paperboard	36.5	33.1	49.4	37.1	65.1	41.0
Glass	12.5	11.3	12.9	9.7	12.1	7.6
Metals	13.5	12.2	12.8	9.6	14.3	9.0
Plastics	3.0	2.7	9.6	7.2	15.5	9.8
Rubber and Leather	3.0	2.7	3.3	2.5	3.8	2.4
Textiles	2.2	2.0	2.8	2.1	3.5	2.2
Wood	4.0	3.6	5.1	3.8	6.1	3.8
Other	-	0.1	0.1	0.1	0.1	0.1
Food Wastes	12.7	11.5	10.8	8.1	10.8	6.8
Yard Wastes	21.0	19.0	23.8	17.9	24.4	15.3
Miscellaneous Inorganic Wastes	1.8	1.6	2.4	1.8	3.1	2.0
TOTAL	110.3	100.0	133.0	100.0	158.8	100.0

Source: PCR Engineering, 1986

TABLE 2-2

RANGES OF CONCENTRATIONS OF INORGANIC CONSTITUENTS IN FLY ASH, COMBINED ASH, AND BOTTOM ASH FROM MUNICIPAL WASTE INCINERATORS IN µg/g (ppm)

Parameter	Fly Ash	Combined Bottom and Fly Ash	Bottom Ash
Arsenic	15-750	2.9-50	1.3-24.6
Barium	88-9,000	79-2,700	47-2,000
Cadmium	<5-2,210	0.18-100	1.1-46
Chromium	21-1,900	12-1,500	13-520
Lead	200-26,600	31-36,600	110-5,000
Mercury	0.9-35	0.05-17.5	ND-1.9
Selenium	0.48-15.6	0.10-50	ND-2.5
Silver	ND-700	0.05-93.4	ND-38
Aluminum	5,300-176,000	5,000-60,000	5,400-53,400
Antimony	139-760	<120-<260	
Beryllium	ND-<4	ND.1-2.4	ND-<0.44
Bismuth	36-<100		ND
Boron	35-5,654	24-174	85
Bromine	21-250		
Calcium	13,960-270,000	4,100-85,000	5,900-69,500
Cesium	2,100-12,000		
Cobalt	2.3-1,670	1.7-91	3-62
Copper	187-2,380	40-5,900	80-10,700
Iron	900-87,000	690-133,500	1,000-133,500
Lithium	7.9-34	6.9-37	7-19
Magnesium	2,150-21,000	700-16,000	880-10,100
Manganese	171-8,500	14-3,130	50-3,100
Molybdenum	9.2-700	2.4-290	29
Nickel	9.9-1,966	13-12,910	9-226

TABLE 2-2
RANGES OF CONCENTRATIONS OF INORGANIC CONSTITUENTS
IN FLY ASH, COMBINED ASH, AND BOTTOM ASH
FROM MUNICIPAL WASTE INCINERATORS IN µg/g (ppm)

PAGE TWO

Parameter	Fly Ash	Combined Bottom and Fly Ash	Bottom Ash
Phosphorus	2,900-9,300	290-5,000	3,400-17,800
Potassium	11,000-65,800	290-12,000	920-13,133
Silicon	1,783-266,000		1,333-188,300
Sodium	9, 780-49,500	1,100-33,300	1,800-33,300
Strontium	98-1,100	12-640	81-240
Tin	300-12,500	13-380	40-800
Titanium	<50-42,000	1,000-28,000	3,067-11,400
Vanadium	22-166	13-150	53
Yttrium	2-380	0.55-8.3	
Zinc	2,800-152,000	92-46,000	200-12,400
Gold	0.16-100		
Chloride	1,160-11,200		
Country	USA, Canada	USA	USA, Canada

ND - Not detected at the detection limit
Blank - Not reported, not analyzed for
Source: Literature (Volume IV) and Versar Study (Volume V)

theory, it is suggested that during combustion, metals became deposited on fly ash particles as metal oxides, hydroxides and/or salts by means of the volatilization-condensation reaction mechanism. According to this mechanism, which is highly dependent on combustion conditions, the majority of metals do not occur as cations on the ash particles but rather as coatings of metal oxides, hydroxides, and chlorides.

The primary factor that determines whether a metal will occur in the particle matrix or will be surface deposited is its boiling point. The "volatilization condensation" mechanism occurs when inorganic constituents such as cadmium and lead volatilize in the high-temperature combustion zone and then condensate at lower temperatures onto the surfaces of the less volatile metals that stay in the matrix, such as manganese, silicon, and aluminum (Cahill and Newland, 1982). The condensation occurs in the form of the metal oxides, hydroxides, and chlorides, which later dissolve in the presence of water. Although these metals may be present in a relatively nonsoluble form in the original waste, in the incinerator they are oxidized, and in the oxidized form they adhere to the surfaces of the small fly-ash particles. They are relatively more soluble in aqueous and acid solutions in this ionic form, particularly if they have oxidized on small particles.

In support of this mechanism, Klein et al. (1975) have classified the elements found in coal ash into four classes. Despite the major differences between coal ashes and MWC ashes, general trends can be observed. The four classes discussed by Klein et al. (1975) are as follows.

Class I	Al, Ba, Be, Ca, Co, Fe, K, Mg, Mn, Si, Sr, Ti, - non-volatizing elements which stay in matrix.
Class II	As, Cd, Cu, Ga, Pb, Sb, Zn, Se, - volatizing elements which become oxides on particle surfaces.
Class III	Hg, Cl, and Br, - volatile elements that remain essentially in the gas phase; and do not condense on ash.
Class IV	Cr, Cs, Ni, U, V, - unclassified elements exhibiting properties of either Class I or Class II.

The Class III elements Cl, Hg, F and Br are highly volatile, and are present as gases at all times during the combustion process. For this reason, mercury levels are very low in MWC ashes. However, some newer MWC incinerators include pollution-control equipment designed to condense these elements onto the fly ash.

Class I elements, having boiling points above the oven temperatures, are not volatilized in the combustion zone. Instead, they form a melt of uniform composition that becomes the matrix. Class I elements remain in the condensed state and exhibit minimal surface deposition.

Class II elements are volatilized during combustion and have little opportunity to become incorporated in the bottom ash. These elements, including cadmium, and lead, condense or become absorbed onto the fly ash particle surface as the flue gas cools.

Following are boiling points of some possible inorganic species during combustion, according to Cahill and Newland (1982).

Species Boiling or Subliming <1,550° C	Species Boiling or Subliming >1,550° C
Cd, CdO, CdS	Cr, Cr_2O_3
$Cr(CO)_6$, $CrCl_3$, Cr_2S_3	Cu, CuO
$PbCl_2$, PbO, PbS	Mn, MnO, MnO_2
	Pb

This topic is further discussed in Section 4.0.

Several studies (for particulars, see Volume IV) describe the fly ash characteristics by particle size. The data generated by these studies further demonstrate that the respirable (less than 5 microns in size), smaller particles contain higher levels of inorganic constituents (including metals).

The data given in Table 2-2 indicate that concentrations of several inorganic constituents regulated under RCRA were as follows: Arsenic values ranged

between 15 and 750 µg/g (ppm) in fly ash, 2.9 and 50 µg/g (ppm) in combined ash, and 1.3 and 24.6 µg/g (ppm) in bottom ash; lead values ranged between 200 and 26,600 µg/g (ppm) in fly ash, between 31 and 36,600 µg/g (ppm) in combined ash, and between 110 and 5,000 µg/g (ppm) in bottom ash; cadmium values ranged between <5 and 2,210 µg/g (ppm) in fly ash; 0.18 and 100 µg/g (ppm) in combined ash, and 1.1 and 46 µg/g (ppm) in bottom ash; values of chromium ranged between 21 and 1,900 µg/g (ppm) in fly ash, 12 and 1,500 µg/g (ppm) in combined ash, and 13 and 520 µg/g (ppm) in bottom ash. For purposes of evaluating impacts on groundwater, the concentrations in leachate are most useful and, hence, various leaching and leachate studies were performed.

The wide range in concentrations may result from differences in the sampling, analytical, and QA/QC procedures employed. It also reflects differences in the incinerated wastes, in the operating conditions of the incinerator, and in the pollution control equipment employed at the incinerator. Different pollution equipment types remove different sizes of particles, and as a result, different levels of inorganics, including metals in the removed ashes. The fabric filter dust collectors (baghouses), which have a higher efficiency of removing smaller particles, would thus contain higher levels of inorganics. Similarly, pollution control technologies employed to remove the respirable (less than 5 microns in size), finer particles, with the use of additives such as lime, would also result in ashes containing higher levels of inorganics.

To better define the levels of inorganic constituents (including metals) in ashes, the individual analyses conducted in the course of the properly designed, EPA-sponsored, Versar study are worth reviewing here. The entire Versar Report is presented in Volume V of this report.

Samples of fly ash, bottom ash, and combined bottom and fly ash collected from four incinerator facilities, as described in detail in Volume V, were analyzed for Cadmium (Cd), Chromium (Cr), Copper (Cu), Iron (Fe), Lead (Pb), Manganese (Mn), Nickel (Ni), Zinc (Zn), Arsenic (As), Selenium (Se), and Mercury (Hg). To better understand the data obtained by the Versar study, Table 2-3 describes the ash characteristics of their associated monofills and Table 2-4 describes the municipal waste combustor design. For confidentiality the facilities are designated as A through D, as are the monofills. Facility A sends the MWC ashes to Monofill A,

TABLE 2-3

ASH MONOFILL CHARACTERISTICS

Facility	Years of Operation	Combustor Residue Disposed	Other Types of Waste Disposed	Leachate Collection System	Cover	Runoff Control	No. of Usable Groundwater Monitoring Wells
A	1982-1987	60 TPD	Tires, construction debris, and noncombustibles	None	Daily soil cover; 3 foot clay final cover	Impermeable cap; graded contour; diversion ditch around landfill perimeter	1
B	1981-1987	130	Large items and construction debris	None	Soil 6-12 inches	Relatively thin cap; hay bales around one corner of landfill to inhibit runoff	2
C	1970-1987	155	Noncombustible items	None	NA	Adjacent mounds of waste tend to trap surface water, erosion of slope evident	3
D	Post-1980 1987	90	Tires and noncombustibles	Gravel (not functioning)	NA	Flat area adjacent to waste pile tends to collect surface water	0

TPD = Tons Per Day
NA = Not Applicable

TABLE 2-4

MUNICIPAL WASTE COMBUSTOR DESIGN AND OPERATING CHARACTERISTICS

Facility	Facility Type	No. of Combustors	Year of Construction	Capacity tons/day (design)	Design Combustion Temperature (°F)	Air Pollution Control	Waste Composition* %Residential %Com./Indust	Waste Processing or Pre Handling
A	Resource/energy recovery continuous feed, water-wall, rotary kiln	2 #1/#2	1981/1982	100/100	1,200	Cyclone, ESP	50 50	Remove large objects, separate glass, iron and aluminum for recycle
B	Energy recovery continuous feed water wall, traveling grate	3 #2/#3/#4	1974 1986	360/360/ 400	1,800	Cyclone, ESP	80 20	Remove large appliances and shred tires
C	Continuous feed, reciprocating grate, rotary kiln	2 #1/#2	1970	300/300	1,800	ESP	50 50	Remove large items
D	Energy recovery continuous feed water wall reciprocating grate	2 #1/#2	1972	360/360	1,800	ESP	50 50	Remove tires and large noncombustible materials recycle ferrous metals as scrap periodically shred and burn tires

ESP = Electrostatic precipitation

*Based on operator estimate

Facility B sends the ashes to Monofill B, and so forth. The results obtained by Versar for these metal levels in the ash samples are listed in Table 2-5. The composite samples collected from the landfill had been subjected to weathering, whereas the bottom and fly ash samples collected at the incinerators were fresh samples. Thus, the landfill samples reflect the effects of mixing the different ashes as well as weathering effects.

Figures 2-1 through 2-3 depict graphically the levels of selected metals found in fly ash, bottom ash, and combined ash respectively in each of the facilities sampled by Versar. Each bar in these three graphs represents the concentration of the specific metal in each individual sample. Each sample consists of a composite of several grab samples collected at an individual unit at an individual shift as listed in Table 1-2 and in the notes on the individual figures.

Figure 2-4 depicts graphically the levels of selected metals detected in the landfill composite samples collected from the two monofills sampled by Versar.

Review of the fly-ash data in Table 2-5 and Figures 2-1 through 2-3 indicated that the variability between shifts and/or units at any given facility was relatively small without any dominant trends, except that at Facility B, Unit 4 generally had higher metal concentrations than Unit 3. The variability between facilities was relatively large compared to that between shifts and units. In general, Facility B had the highest metal concentration (for 5 out of the 11 metals), whereas Facility C had the lowest metal concentration (for 6 out of the 11 metals). The predominant metals were iron and zinc, which were followed closely by lead, while the least prevalent metal was selenium.

A review of the metals data for the combined bottom/fly ash and bottom ash showed that the variability between shifts and units was relatively high, although no significant trends were observed. The variability between the facilities was very high, with the standard deviation generally exceeding the average metal concentrations. Facility B had the highest concentration of metals (the highest or second highest concentrations for 10 out of 11 metals), whereas Facility A had the lowest concentration of metals (the lowest or second lowest concentrations for 9 out of the 11 metals). The predominant metals were iron, zinc, lead, and copper.

TABLE 2-5
TOTAL METALS DATA FOR SOLID SAMPLES, VERSAR STUDY

FLY ASH

Facility	Sample Description	Cd mg/kg	Cr mg/kg	Cu mg/kg	Fe mg/kg	Pb mg/kg	Mn mg/kg	Ni mg/kg	Zn mg/kg	As mg/kg	Se mg/kg	Hg mg/kg
A	Unit 1, 9/26, AM	193	79	2380	17400	5550	1010	106	15700	41.9	<5	27
A	Unit 1, 9/26, AM, Dup	186	66	2040	15000	5400	1020	91	14500	38.0	<5	23
A	Unit 1, 9/26, PM	215	67	1870	9730	5660	1060	98	15100	48.8	<5	35
A	Unit 2, 9/26, AM	222	66	1250	20200	5480	807	97	17400	36.8	<5	25
A	Unit 2, 9/26, PM	138	76	1040	15900	6090	1090	160	9480	16.0	<5	24
	FACILITY A AVERAGE	190.8	70.8	1716	15646	5636	997	110	14436	36.3	2.5	26.8
	STANDARD DEVIATION	29.6	5.6	499	3444	243	99	25	2660	11.0	0	4.3
B	Unit 3, 9/28, AM	322	105	745	9900	7350	895	80	32700	106	<10	9.3
B	Unit 3, 9/28, AM, Dup	316	98	724	9350	7270	889	76	31800	89.9	<10	8.0
B	Unit 3, 9/29, PM	251	74	588	5960	5280	824	52	23600	79.0	10.0	12
B	Unit 4, 9/28, AM	381	97	912	16200	9230	1310	67	34000	131	11.7	19
B	Unit 4, 9/29, PM	475	100	854	22300	14400	1070	68	38800	149	15.6	21
	FACILITY B AVERAGE	349.0	94.8	765	12742	8706	998	69	32180	111.0	9.5	13.9
	STANDARD DEVIATION	75.3	10.8	112	5812	3109	176	10	4923	25.8	4.1	5.2
C	Unit 2, 9/28, PM	107	76	1050	9030	3260	320	130	10200	29.0	4.9	1.3
C	Unit 2, 9/29, PM	191	54	531	8200	3490	388	102	10300	16.2	7.6	5
C	Unit 2, 9/29, PM, Dup	157	52	556	8450	3130	382	95	8460	17.7	6.2	4.0
C	Unit 2, 9/30, AM	223	48	484	16700	3420	341	245	10600	26.8	7.6	3.5
C	Unit 2, 9/30, PM	188	49	485	14400	2830	353	212	9940	32.2	8.8	1.4
	FACILITY C AVERAGE	173.2	55.8	621	11356	3226	357	157	9900	24.4	7.0	3.0
	STANDARD DEVIATION	39.1	10.3	216	3511	234	25	61	750	6.3	1.3	1.5
D	Unit 1-2, 10/3, AM	259	77	516	8320	5450	857	63	22100	50.7	9.6	1.8
D	Unit 1-2, 10/3, AM, Dup	172	67	518	7190	4600	751	55	18600	54.5	9.1	2.0
D	Unit 1-2, 10/3, PM	286	93	597	8790	5770	1250	86	23900	60.4	15.5	1.4
D	Unit 1-2, 10/4, AM	210	89	486	8960	4740	1410	89	17600	47.2	10.7	0.94
D	Unit 1-2, 10/4, PM	206	90	510	9170	4430	1190	86	17300	43.2	9.6	1.0
	FACILITY D AVERAGE	226.6	83.2	525	8486	4998	1092	76	19900	51.2	10.9	1.4
	STANDARD DEVIATION	40.6	9.8	38	706	519	248	14	2630	5.9	2.4	0.4
	TOTAL NUMBER	20	20	20	20	20	20	20	20	20	20	20
	MINIMUM	107	48	484	5960	2830	320	52	8460	16	2.5	0.94
	MAXIMUM	475	105	2380	22300	14400	1410	245	38800	149	15.6	35
	OVERALL AVERAGE	235	76.2	907	12058	5642	861	103	19104	55.7	7.5	11.3
	STANDARD DEVIATION	85	17.2	550	4611	2534	335	49	8901	36.4	4.0	10.7

TABLE 2-5
TOTAL METALS DATA FOR SOLID SAMPLES, VERSAR STUDY
PAGE TWO

COMBINED BOTTOM AND FLY ASH

Facility	Sample Description	Cd mg/kg	Cr mg/kg	Cu mg/kg	Fe mg/kg	Pb mg/kg	Mn mg/kg	Ni mg/kg	Zn mg/kg	As mg/kg	Se mg/kg	Hg mg/kg
A	Unit 1, 9/28, AM	17	25	452	5130	633	281	21	1810	6.1	<0.5	6.8
A	Unit 1, 9/26, PM	13	19	387	6500	585	331	30	1480	2.9	<2.5	3.9
A	Unit 2, 9/26, AM	17	12	369	6650	2200	184	22	1730	7.9	<5	6.9
A	Unit 2, 9/26, AM, Dup	15	16	377	9140	1140	251	24	3050	12.2	<5	5.0
A	Unit 2, 9/26, PM	37	12	193	2100	1670	188	13	1980	4.7	<0.5	8.7
	FACILITY A AVERAGE	19.8	16.8	356	5904	1246	247	22.0	2010	6.8	1.4	6.3
	STANDARD DEVIATION	8.7	4.9	86	2300	619	56	5.5	544	3.2	1.0	1.7
C	Unit 2, 9/28, PM	7.8	22	329	5220	259	110	44	545	4	1.4	0.51
C	Unit 2, 9/29, PM	10	332	5900	22300	6950	339	556	1520	4.7	<5.	0.21
C	Unit 2, 9/30, AM	24	19	3420	5040	1700	155	42	1570	5.7	<5.	0.62
C	Unit 2, 9/30, AM, Dup	27	26	608	9720	1060	1810	38	3250	7	<0.5	0.18
C	Unit 2, 9/30, PM	20	37	5900	16000	13200	254	93	2980	22.8	<5.	0.59
	FACILITY C AVERAGE	17.8	87.2	3231	11656	4634	534	154.6	1973	8.8	1.8	0.4
	STANDARD DEVIATION	7.6	122.6	2432	6650	4884	643	201.7	1005	7.1	0.9	0.2
D	Unit 1-2, 10/3, AM	45	38	424	24500	3410	462	37	2950	16.4	<2.5	0.12
D	Unit 1-2, 10/3, PM	18	28	1060	8000	819	797	25	1920	4.3	<1	0.16
D	Unit 1-2, 10/4, AM	17	31	289	8590	571	3130	26	2400	5.4	<1	0.21
D	Unit 1-2, 10/4, AM, Dup	18	36	728	95100	612	640	119	46000	6.1	<1	0.13
D	Unit 1-2, 10/4, PM	23	43	524	19000	688	544	82	2390	6.4	<2.5	0.11
	FACILITY D AVERAGE	24.2	35.2	606	31038	1220	1115	57.8	11132	7.7	0.8	0.1
	STANDARD DEVIATION	10.6	5.3	269	32638	1098	1014	37.0	17437	4.4	0.4	0.0
	TOTAL NUMBER	15	15	15	15	15	15	15	15	15	15	15
	MINIMUM	7.8	12	193	2100	259	110	13	545	2.9	0.25	0.11
	MAXIMUM	45	332	5900	95100	13200	3130	556	46000	22.8	2.5	8.7
	OVERALL AVERAGE	20.6	46.4	1397	16199	2366	632	78.1	5038	7.77	1.327	2.276
	STANDARD DEVIATION	9.5	76.9	1921	22073	3324	782	131.0	10971	5.21	0.910	2.980

TABLE 2-5
TOTAL METALS DATA FOR SOLID SAMPLES, VERSAR STUDY
PAGE THREE

BOTTOM ASH

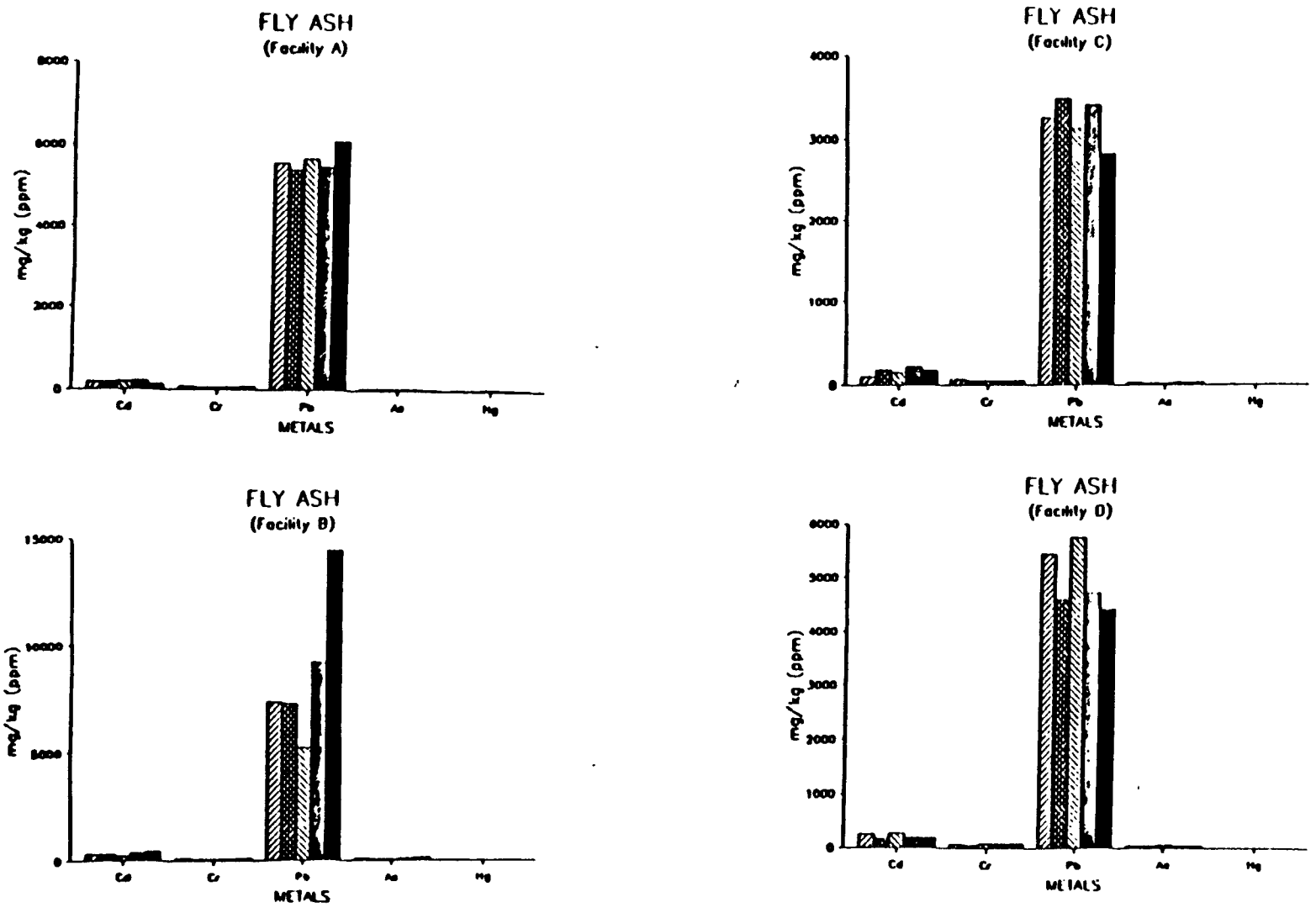
Facility	Sample Description	Cd mg/kg	Cr mg/kg	Cu mg/kg	Fe mg/kg	Pb mg/kg	Mn mg/kg	Ni mg/kg	Zn mg/kg	As mg/kg	Se mg/kg	Hg mg/kg
B	Unit 3, 9/28, AM	2.3	105	10700	12000	2920	1520	35	1930	3.4	<5.	0.36
B	Unit 3, 9/29, PM	1.1	24	7250	27100	1380	430	17	914	2.2	<5.	0.13
B	Unit 4, 9/28, AM	3.8	66	792	115000	2140	1010	36	2350	8.9	<5.	0.12
B	Unit 4, 9/28, AM, Dup	3.5	78	581	24100	3930	938	90	5760	6.9	<5.	0.12
B	Unit 4, 9/29, PM	43	33	1720	17500	3630	538	29	12400	24.6	<5.	0.13
	No.	5	5	5	5	5	5	5	5	5	5	5
	Min.	1.1	24	581	12000	1380	430	17	914	2.2	2.5	0.12
	Max.	43	105	10700	115000	3930	1520	90	12400	24.6	2.5	0.36
	Avg.	10.74	61.20	4209	39140	2800	887	41.4	4671	9.20	2.50	0.17
	Std. Dev.	16.16	29.67	4060	38290	942	387	25.2	4194	8.06	0.00	0.09

LANDFILL COMPOSITE

Facility	Sample Description	Cd mg/kg	Cr mg/kg	Cu mg/kg	Fe mg/kg	Pb mg/kg	Mn mg/kg	Ni mg/kg	Zn mg/kg	As mg/kg	Se mg/kg	Hg mg/kg
C	Perimeter Composite	8.7	85	1190	60600	709	572	120	4740	6.0	<5	0.57
D	Perimeter Composite	30	52	402	19600	1210	455	51	2050	14.8	<2.5	0.25

FIGURE 2-1

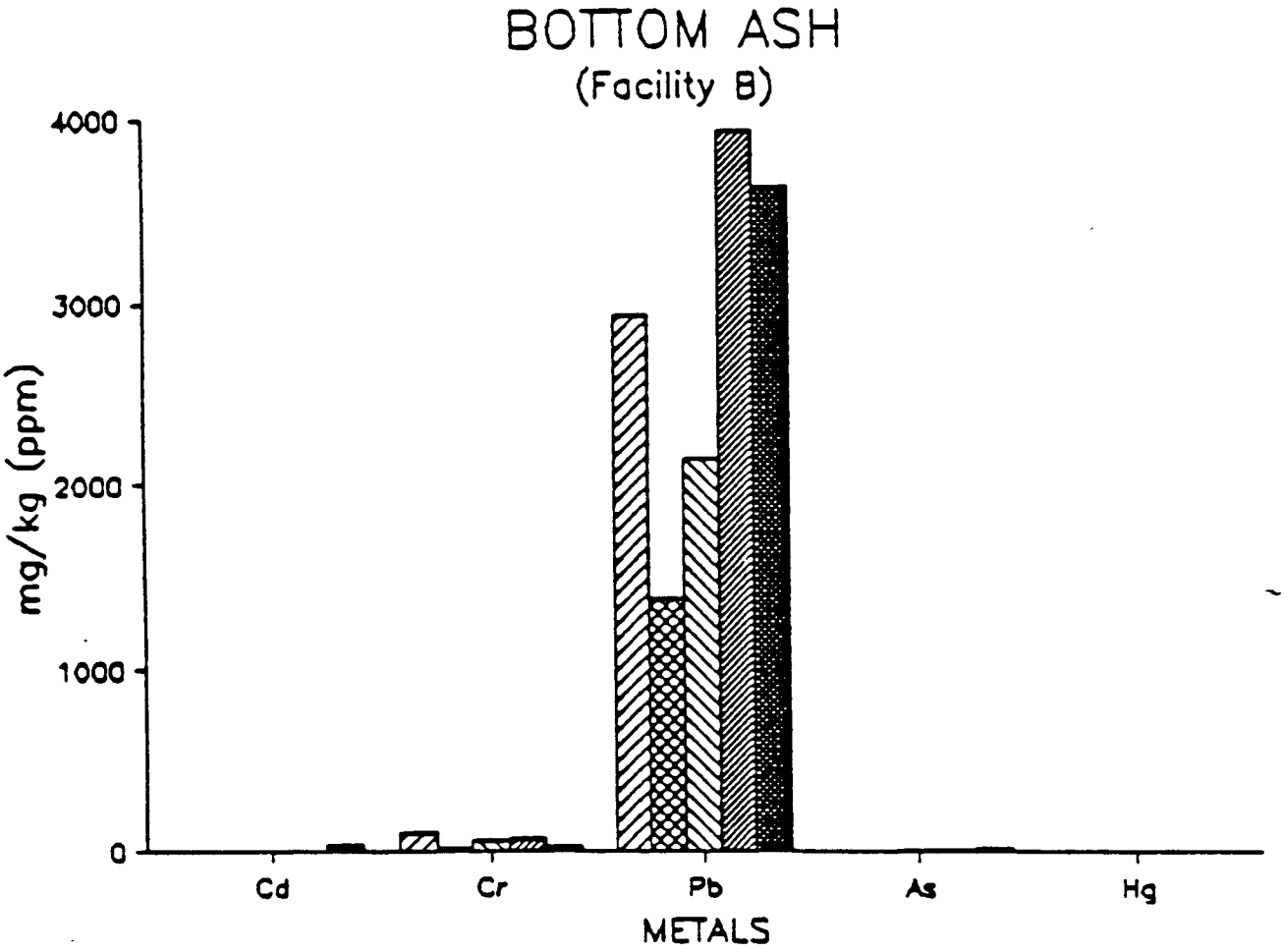
Concentrations of Metals in Fly Ash Sampled by Versar at Facilities A, B, C, and D in mg/kg (ppm)



Note: Each bar represents an individual sample collected from an individual unit during an individual shift. Each sample consists of a composite of 8 grab samples taken during that shift, except for facility B which had only 4 samples (Table 1-2).

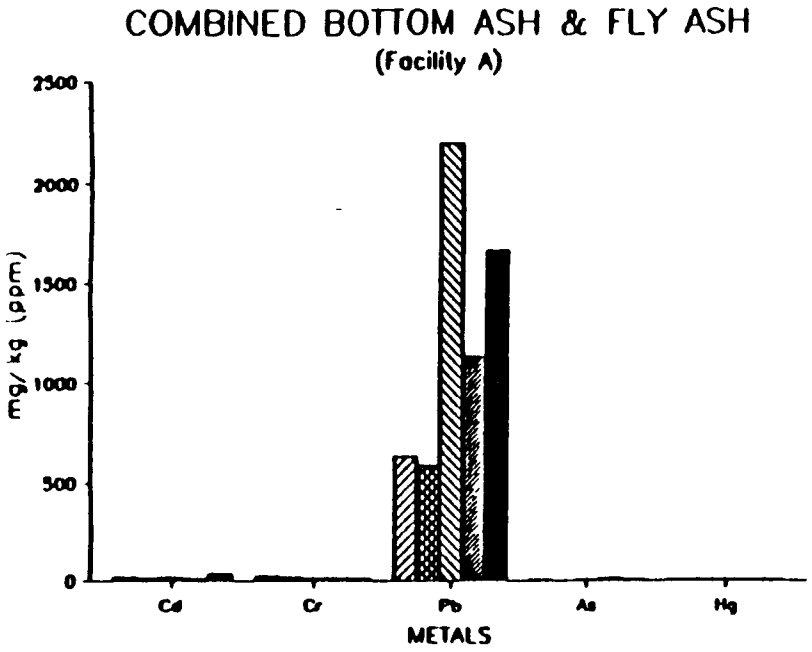
FIGURE 2-2

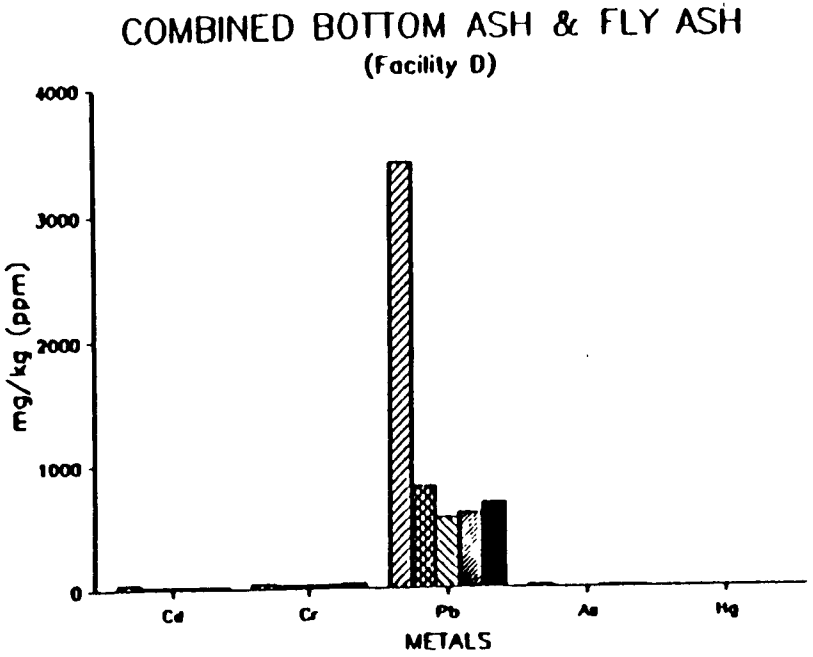
Concentrations of Metals in Bottom Ash from Facility B in mg/kg (ppm)

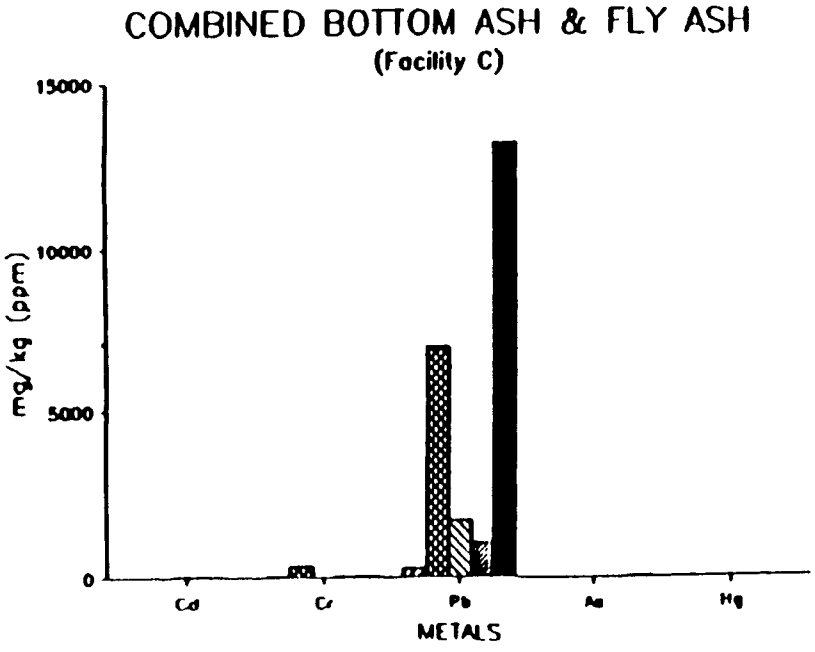


Note: Each bar represents an individual sample collected from an individual unit during an individual shift. Each sample consists of a composite of four grab samples taken during that shift (Table 1-2).

Concentrations of Metals in Combined Bottom Ash and Fly Ash
Sampled at Versar at Facilities A, C, and D in mg/kg (ppm)



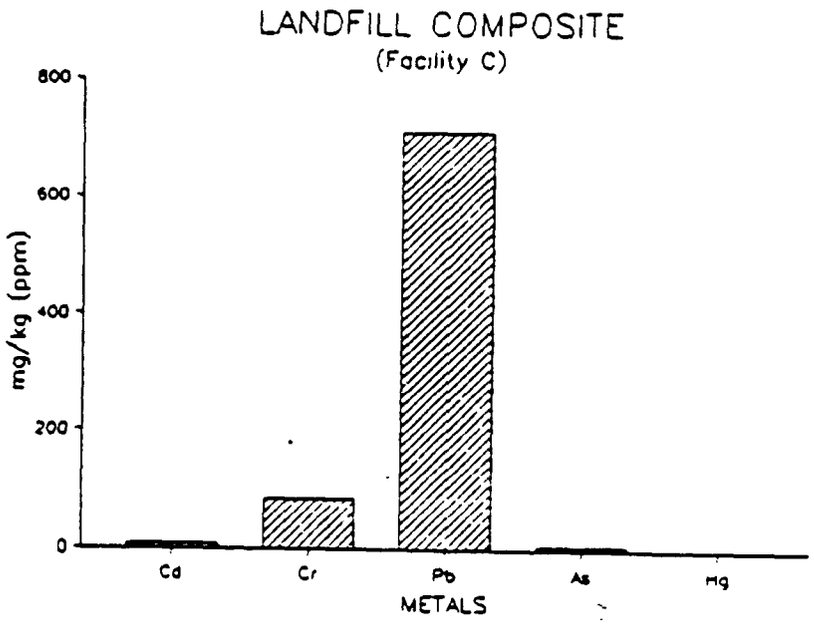


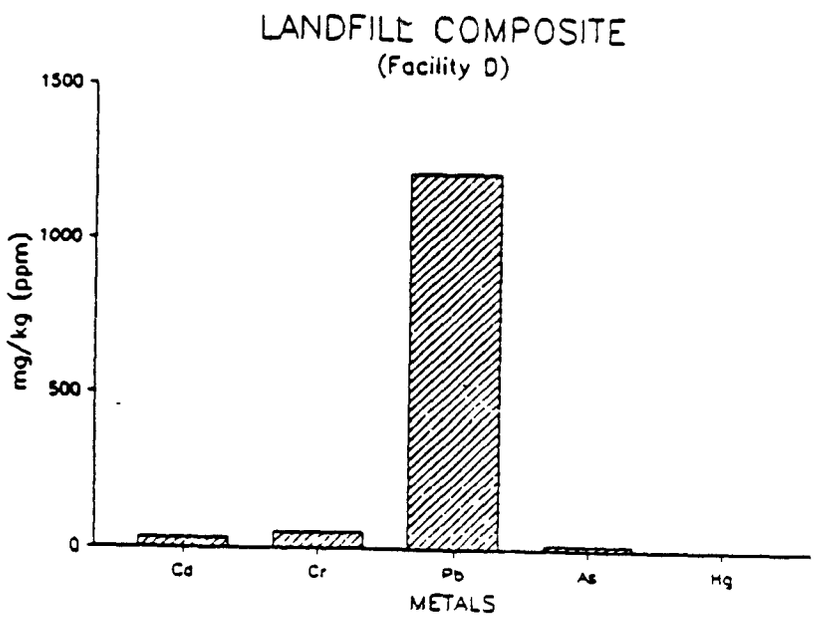


Note: Each bar represents an individual sample collected from an individual unit during an individual shift. Each sample consists of a composite of 8 grab samples taken during the shift. (Table 1-2)

FIGURE 2-4

Concentrations of Metals in One Landfill Composite Sample Collected by Versar at Facility C and Facility D in mg/kg (parts per million)





Selenium was again the least prevalent. Selenium, a relatively volatile element, may exhibit behavior which fits the Klein et al. (1975) Class III classification.

The landfill perimeter composite metals data, Figure 2-4, was similar to combined bottom ash/fly ash data from the same facilities. Although there were some exceptions, the landfill composite samples generally contained lower concentrations of each metal than did their corresponding bottom/fly ash samples. Again, this was expected because the landfill composite samples had been subjected to weathering, which would leach some of the component metals. It is interesting to note that although the metal concentrations were typically lower in the weathered ash than in freshly generated ash, except for the lead concentration in Facility C, considerable concentrations of metals remain in the weathered ash. This fact suggests that a major portion of the metals in the ash may not be readily mobile in the environment.

A comparison of the concentrations of metals in the fly ash to those in the combined bottom/fly and bottom ash, indicates the following:

- The variability between shifts, units, and facilities was substantially higher for the combined and bottom ash than it was for the fly ash. In fact, the variability between shifts and units for the bottom/fly and bottom ash was greater than the variability between facilities for the fly ash. This observation was expected because of the heterogeneous nature of the bottom/fly and bottom ash based on the diverse range of particle sizes compared to the more homogeneous nature of the fly ash. This heterogeneity made it extremely difficult to collect representative, comparable samples, as evidenced by the standard deviations.

- The concentrations of cadmium, mercury, chromium, lead, nickel, zinc, selenium, and arsenic were between 1.5 and 10 times higher in the fly ash than in the bottom/fly or bottom ash.

- The concentrations of copper and iron were approximately two times higher in the bottom/fly and bottom ash than they were in the fly ash.

- The concentration of manganese was approximately equivalent for both ash fractions.

- The metal distribution in bottom ash or fly ash generally fit the Klein (1975) metal classification, as described in Section 2.1.

2.2 ORGANIC COMPOUNDS FOUND IN MWC ASHES

Table 2-6 lists the ranges of organic compounds detected in MWC ashes as reported by the different studies reported in the literature, including the EPA-sponsored Versar study. (see Volume IV) The data presented in this table clearly demonstrate the absence of one fraction of organic chemical compounds that are extremely prevalent in hazardous wastes sites, namely, volatile compounds. Volatiles are not expected to be present in materials that were combusted in incinerators at temperatures much higher than the boiling points of these compounds. This point is being raised because several recent studies (Plumb and Fitzsimmons, 1984; Plumb, June 1985; Plumb, November 1985; and Plumb and Parolini, 1986) conducted on hazardous waste sites recommend using volatile compounds as indicator parameters for assessing leachate "problems" at hazardous waste sites. Such indicators would not be appropriate for ash disposal sites.

Examination of the data provided in Table 2-6 indicates that polyaromatic hydrocarbons (PAHs), phthalates, chlorobenzenes, and chlorophenols are the most prevalent types of compounds found in MWC ashes. Like the inorganics in ashes, the ranges of organics vary widely, covering several orders of magnitude. Variations in combustion quality are likely to contribute to this variability, along with several of the factors described in Section 2.1.

The organic compounds, except for PCBs, PCDDs, and PCDFs, were detected more frequently in the larger particles of the bottom ash. A proper example is the behavior of the phthalates. Based on the limited data reported in Table 2-6, the phthalates seem to be concentrating in the bottom ash rather than the fly ash. For example, butylbenzyl-phthalate was not detected (ND) in fly ash while present at 180 ng/g (ppb) in bottom ash; similarly di-n-butyl phthalate was not detected in fly ash, while present at 360 ng/g (ppb) in bottom ash; bis(2-ethylhexyl) phthalate was present in fly ash at 85 ng/g (ppb) while in bottom ash it was detected at

TABLE 2-6

RANGES OF CONCENTRATIONS OF ORGANICS IN FLY AND BOTTOM ASH FROM MUNICIPAL WASTE INCINERATORS in ng/g (ppb)

Constituent	Range, Fly Ash	Range, Bottom Ash
Naphthalene	270-9,300	570-580
Biphenyl	2-1,300	
Acenaphthylene	ND-3,500	37-390
Anthracene	1-500	53
Fluorene	0-100	ND-150
Phenanthrene	21-7,600	500-540
Di-n-butyl phthalate	ND	360
Fluoranthene	0-6,500	110-230
Pyrene	0-5,400	150-220
Butyl benzyl phthalate	ND	180
Chrysene	0-690	ND-37
Bis(2-ethylhexyl)phthalate	85	2,100
Benzanthrene	0-300	
Benzo(k)fluoranthene	ND-470	ND-51
Benzo(a)pyrene	ND-400	ND-5
Benzo(g,h,i)perylene	0-190	ND
Diethyl phthalate	6,300	
Acenaphthene		28
Normal alkanes	50,000	
Chlorobenzenes	80-4,220	17
Chlorophenols	50.1-9,630	0
Country	USA, Canada, Japan and The Netherlands	USA and Canada

ND = Below detection limit
Blank = Not reported
Source: Literature (Volume IV) and Versar Study (Volume V)

2,100 ng/g (ppb). However, diethyl phthalate was not detected in bottom ash but was detected at 6,300 ng/g (ppb) in fly ash. It is possible that organics are left in the bottom ash rather than in the fly ash. The fly ash is exposed to higher temperatures in the incinerator, where these compounds are being pyrolized.

2.3 RANGES OF PCDDs, PCDFs, AND PCBs IN MWC ASHES

Ranges of PCDDs, PCDFs and PCBs in fly ash, bottom ash, and combined ash are listed in Table 2-7. The data presented in this table clearly indicate that many homologs of PCDDs and PCDFs as well as PCBs are found in MWC ashes. The levels are higher in the smaller fly-ash particles than in the larger bottom-ash particles. The levels in combined ashes fall in between. The higher concentrations in fly ash may result because the smaller particles have larger surface area relative to the total weight. These data may also imply that these compounds have a higher affinity for smaller particles than for larger particles. Smaller particles offer greater surface area for sorption, and the lower mass increases the concentration.

Table 2-8 lists levels of PCDDs and PCDFs in the different ash samples collected by Versar (Volume V). Figures 2-5 through 2-9 depict graphically the levels of the total PCDD and PCDF homologs in fly ash, bottom ash, and combined ash in each sampled facility. Each bar represents the concentration of each homolog in each sample. Each sample consists of a composite of several grab samples collected at an individual unit at an individual shift. The number of samples in each composite sample is given in Table 1-2 and in the notes given on each figure.

A review of the PCDD homolog concentrations in the fly ash (Figure 2-5) showed that the variability of the homolog concentrations between units and shift was relatively small, and the variability of these concentrations between the facilities was extremely large. Facility C had the highest concentration of total PCDDs, as well as the highest concentration of each PCDD homolog. Facility B had the second highest concentration of each PCDD homolog, followed by Facility D and Facility A which had the lowest concentration of each PCDD homolog. The hexa-CDD homolog was the most prevalent at three of the four facilities (it was the third most prevalent at Facility B), and the tetra-CDD homolog was the least prevalent at all four facilities. Approximately 5 percent of the total tetra-CDDs was made up of the 2,3,7,8-TCDD isomer.

TABLE 2-7

RANGES OF CONCENTRATIONS OF PCDDs, PCDFs, AND PCBs
IN FLY ASH FROM MUNICIPAL WASTE INCINERATORS in ng/g (ppb)

Constituent	Range Fly Ash	Range Combined Ash	Range Bottom Ash
MCDD	2.0		ND
DCDD	0.4-200		ND
T_3CDD	1.1-82		ND
T_4CDD	ND-250	0.14-14	<0.04-0.65
PCDD	ND-722	1.9-50	ND-3
HCDD	ND-5,565	1 4-78	ND-2.3
H_7CDD	ND-3,030	1 4-120	ND-6.3
OCDD	ND-3,152	0.84-89	ND-29
2,3,7,8-TCDD	0.1-42	0.02-0.78	<0.04-0.7
Total PCDD	5.23-10,883	6.2-350	ND-110
MCDF	41		1.1
DCDF	ND-90		0.63
T_3CDF	0.7-550		ND
T_4CDF	ND-410	2.3-91	0.15-1.4
PCDF	ND-1,800	1.6-37	0.07-6.2
HCDF	Tr-2,353	1.2-35	ND-2.5
H_7CDF	Tr-666	0.62-36	ND-6.9
OCDF	ND-362	0.18-8.4	ND-3.7
2,3,7,8-TCDF	0.1-5.4	0.41-12	ND.10
Total PCDF	3.73-3,187	6.14-153.9	ND-65
Mono CB	0.29-9.5	ND	ND-1.3
Di CB	0.13-9.9	0.126-1.35	ND-5.5
Tri CB	ND-25	0.35-14.3	ND-80
Tetra CB	0.5-42	16.5-16.5	ND-47
Penta CB	0.87-225	ND	ND-48
Hexa CB	0.45-65		ND-39
Hepta CB	ND-0.1		ND
Octa CB	ND-1.2		ND
Nona CB	ND		ND
Deca CB	ND		ND
Total PCB	ND-250	ND-32.15	ND-180
Country	USA, Canada, West Germany The Netherlands, Japan	USA	USA, Canada, Japan

ND = Below Detection Limit
Tr = 0.01<Tr<0.1 ng/g
Blank = Not reported
Source: Literature (Vol IV) and Versar Study (Vol. V)

TABLE 2-8

PCDD AND PCDF IN SOLID SAMPLES - VERSAR STUDY

FLY ASH (DIOXIN HOMOLOGS)

Plant	Sample Description	2,3,7,8 TCDD (ng/g)	TETRA -CDD (ng/g)	PENTA -CDD (ng/g)	HEXA -CDD (ng/g)	HEPTA -CDD (ng/g)	OCTA -CDD (ng/g)	TOTAL -CDD (ng/g)
A	Unit 1, 9/26, AM	0.093	2.3	11	20	14	17	64.3
A	Unit 1, 9/26, AM, Dup	0.11	2.8	14	20	14	18	68.8
A	Unit 1, 9/26, PM	0.13	4.7	20	35	26	31	116.7
A	Unit 2, 9/26, AM	0.24	5.2	16	18	14	13	66.2
A	Unit 2, 9/26, PM	0.22	6.6	32	24	14	11	87.6
	FACILITY A AVERAGE	0.16	4.32	18.60	23.40	16.40	18.00	80.7
	STANDARD DEVIATION	0.06	1.58	7.31	6.12	4.80	6.99	19.8
B	Unit 3, 9/28, AM	0.38	12	139	126	100	96	473
B	Unit 3, 9/28, AM, Dup	0.38	11	114	123	93	89	430
B	Unit 3, 9/29, PM	0.63	18	137	322	203	210	890
B	Unit 4, 9/28, AM	0.24	6.5	84	207	352	586	1235.5
B	Unit 4, 9/29, PM	0.13	7.0	99	209	435	1363	2113
	FACILITY B AVERAGE	0.35	10.90	114.60	197	237	469	1028
	STANDARD DEVIATION	0.17	4.15	21.34	73	136	482	617
C	Unit 2, 9/28, PM	2.2	27	238	697	331	393	1686
C	Unit 2, 9/29, PM	1.5	31	710	5565	1759	2460	10525
C	Unit 2, 9/29, PM, Dup	2.1	33	722	3946	3030	3152	10883
C	Unit 2, 9/30, AM	2.4	43	513	1430	1751	2338	6075
C	Unit 2, 9/30, PM	1.5	18	335	1052	1089	1433	3927
C	Unit 2, Coarse	<0.14	<0.14	<0.02	<0.03	<0.06	<0.16	0
C	Unit 2, Fine (ESP)	3.9	38	980	3400	4900	2700	12018
	FACILTIY C AVERAGE	1.95	27.2	500	2299	1837	1782	6445
	STANDARD DEVIATION	1.07	13.3	309	1880	1559	1116	4441
D	Unit 1-2, 10/3, AM	0.38	5.2	54	105	45	44	253.2
D	Unit 1-2, 10/3, AM, Dup	0.45	5.1	46	103	48	48	250.1
D	Unit 1-2, 10/3, PM	0.83	19	91	106	81	113	410
D	Unit 1-2, 10/4, AM	0.66	11	61	89	39	35	235
D	Unit 1-2, 10/4, PM	0.37	7.9	45	49	37	37	175.9
	FACILITY D AVERAGE	0.54	9.64	59.4	90.4	50.0	55.4	265
	STANDARD DEVIATION	0.18	5.15	16.8	21.6	16.0	29.2	77.7
	TOTAL NUMBER	22	22	22	22	22	22	22
	MINIMUM	0.07	0.07	0.01	0.015	0.03	0.08	0
	MAXIMUM	3.9	43	980	5565	4900	3152	12018
	OVERALL AVERAGE	0.86	14.3	203	802	653	690	2363
	STANDARD DEVIATION	0.98	12.2	270	1475	1199	1017	3775

TABLE 2-8
PCDD AND PCDF IN SOLID SAMPLES - VERSAR STUDY
PAGE TWO

FLY ASH (FURAN HOMOLOGS)

Plant	Sample Description	2,3,7,8 TCDF (ng/g)	TETRA -CDF (ng/g)	PENTA -CDF (ng/g)	HEXA -CDF (ng/g)	HEPTA -CDF (ng/g)	OCTA -CDF (ng/g)	TOTAL -CDF (ng/g)	TCDD + TCDF (ng/g)
A	Unit 1, 9/26, AM		20	7.1	17	14	2.1	60.2	124.5
A	Unit 1, 9/26, AM, Dup		23	10	14	12	2.3	61.3	130.1
A	Unit 1, 9/26, PM		34	15	23	22	4.0	98	214.7
A	Unit 2, 9/26, AM		52	16	96	44	1.4	209.4	275.6
A	Unit 2, 9/26, PM		89	32	18	9.9	2.0	150.9	238.5
	FACILITY A AVERAGE		43.6	16.0	33.6	20.4	2.4	116.0	196.7
	STANDARD DEVIATION		25.3	8.6	31.3	12.5	0.9	57.2	59.9
B	Unit 3, 9/28, AM		91	64	56	40	8.1	259.1	732.1
B	Unit 3, 9/28, AM, Dup		97	65	61	40	8.3	271.3	701.3
B	Unit 3, 9/29, PM		107	61	241	19	21	449	1339
B	Unit 4, 9/28, AM		48	37	41	49	11	186	1421.5
B	Unit 4, 9/29, PM		59	46	54	63	34	256	2369
	FACILITY B AVERAGE		80.4	54.6	90.6	42.2	16.5	284	1313
	STANDARD DEVIATION		22.8	11.1	75.5	14.3	9.9	87.6	606
C	Unit 2, 9/28, PM		61	56	54	10	24	205	1891
C	Unit 2, 9/29, PM		164	221	336	32	60	813	11338
C	Unit 2, 9/29, PM, Dup		169	226	2353	77	362	3187	14070
C	Unit 2, 9/30, AM		130	153	473	666	108	1530	7605
C	Unit 2, 9/30, PM		73	93	638	610	175	1589	5516
C	Unit 2, Coarse *	0.66	3.8	1.5	0.22	<0.03	<0.15	5.52	5.52
C	Unit 2, Fine (ESP) *	26	110	310	590	570	170	1750	13768
	FACILITY C AVERAGE	13	102	152	635	281	128	1297	7742
	STANDARD DEVIATION	13	55	100	738	292	114	1001	5187
D	Unit 1-2, 10/3, AM		36	32	115	80	4.9	267.9	521.1
D	Unit 1-2, 10/3, AM, Dup		36	27	21	3.8	5.6	93.4	343.5
D	Unit 1-2, 10/3, PM		93	47	87	75	9.8	311.8	721.8
D	Unit 1-2, 10/4, AM		70	32	87	50	3.1	242.1	477.1
D	Unit 1-2, 10/4, PM		53	27	37	29	3.7	149.7	325.6
	FACILITY D AVERAGE		57.6	33.0	69.4	47.6	5.4	213	478
	STANDARD DEVIATION		21.7	7.3	34.9	28.5	2.4	79.9	143
	TOTAL NUMBER	2	22	22	22	22	22	22	22
	MINIMUM	0.66	3.8	1.5	0.22	0.015	0.075	5.52	5.52
	MAXIMUM	26	169	310	2353	666	362	3187	14070
	OVERALL AVERAGE	13.33	73.6	71.8	246	114	46	552	2915
	STANDARD DEVIATION	12.67	43.2	80.0	496	201	86	765	4436

*See text

TABLE 2-8
PCDD AND PCDF IN SOLID SAMPLES - VERSAR STUDY
PAGE THREE

COMBINED BOTTOM ASH AND FLY ASH (DIOXIN HOMOLOGS)

Plant	Sample Description	2,3,7,8 TCDD (ng/g)	TETRA -CDD (ng/g)	PENTA -CDD (ng/g)	HEXA -CDD (ng/g)	HEPTA -CDD (ng/g)	OCTA -CDD (ng/g)	TOTAL -CDD (ng/g)
A	Unit 1, 9/26, AM	0.02	1.5	2.7	1.9	1.7	0.89	8.69
A	Unit 1, 9/26, PM							
A	Unit 2, 9/26, AM	0.07	2.2	3.2	2	1.5	0.84	9.74
A	Unit 2, 9/26, PM	0.33	13	19	11	8.2	3.7	54.9
	FACILITY A AVERAGE	0.14	5.57	8.30	4.97	3.80	1.81	24.44
	STANDARD DEVIATION	0.14	5.26	7.57	4.27	3.11	1.34	21.54
C	Unit 2, 9/28, PM	0.12	2.2	11	13	15	7.7	48.9
C	Unit 2, 9/29, PM	0.13	2	11	18	31	18	80
C	Unit 2, 9/30, AM	0.62	14	47	67	120	89	337
C	Unit 2, 9/30, AM, Dup	0.78	13	50	78	120	89	350
C	Unit 2, 9/30, PM	<0.31	1.3	10	11	22	18	62.3
	FACILITY C AVERAGE	0.36	6.50	25.8	37.4	61.6	44.3	176
	STANDARD DEVIATION	0.28	5.73	18.6	29.0	48.0	36.7	137
D	Unit 1-2, 10/3, AM	0.07	1.3	4	3.4	3.3	2.6	14.6
D	Unit 1-2, 10/3, PM	<0.08	0.46	2.3	1.4	1.4	1.4	6.96
D	Unit 1-2, 10/4, AM	<0.28	<0.28	1.9	1.5	1.5	1.3	6.2
D	Unit 1-2, 10/4, PM	0.04	1.1	2.6	1.8	1.6	1.2	8.3
	FACILITY D AVERAGE	0.07	0.75	2.70	2.03	1.95	1.63	9.02
	STANDARD DEVIATION	0.04	0.47	0.79	0.81	0.78	0.57	3.31
	TOTAL NUMBER	12	12	12	12	12	12	12
	MINIMUM	0.02	0.14	1.9	1.4	1.4	0.84	6.2
	MAXIMUM	0.78	14	50	78	120	89	350
	OVERALL AVERAGE	0.21	4.35	13.7	17.5	27.3	19.5	82.3
	STANDARD DEVIATION	0.24	5.23	16.3	25.3	42.5	31.7	119

TABLE 2-8
PCDD AND PCDF IN SOLID SAMPLES - VERSAR STUDY
PAGE FOUR

COMBINED BOTTOM ASH AND FLY ASH (FURAN HOMOLOGS)

Plant	Sample Description	2,3,7,8 TCDF (ng/g)	TETRA -CDF (ng/g)	PENTA -CDF (ng/g)	HEXA -CDF (ng/g)	HEPTA -CDF (ng/g)	OCTA -CDF (ng/g)	TOTAL -CDF (ng/g)	TCDD + TCDF (ng/g)
A	Unit 1, 9/26, AM	0.88	6.3	2.5	1.3	0.62	0.18	10.9	19.59
A	Unit 1, 9/26, PM								
A	Unit 2, 9/26, AM	2.4	20	6.7	3.2	1.2	0.28	31.38	41.12
A	Unit 2, 9/26, PM	12	91	37	18	6.6	1.3	153.9	208.8
	FACILITY A AVERAGE	5.09	39.10	15.40	7.50	2.81	0.59	65.4	89.8
	STANDARD DEVIATION	4.92	37.12	15.37	7.47	2.69	0.51	63.1	84.6
C	Unit 2, 9/28, PM	0.8	5	5.2	6.4	4.8	1.4	22.8	71.7
C	Unit 2, 9/29, PM	0.89	4.7	5.5	11	8	1.8	31	111
C	Unit 2, 9/30, AM	2.9	20	20	24	27	6.7	97.7	434.7
C	Unit 2, 9/30, AM, Dup	3.8	24	27	35	36	8.4	130.4	480.4
C	Unit 2, 9/30, PM	0.55	3.4	4.8	6.3	8.2	2.1	24.8	87.1
	FACILITY C AVERAGE	1.79	11.42	12.50	16.54	16.80	4.08	61.34	237
	STANDARD DEVIATION	1.31	8.75	9.25	11.27	12.39	2.89	44.34	181
D	Unit 1-2, 10/3, AM	0.76	5.1	4.7	4.1	2.6	0.59	17.09	31.69
D	Unit 1-2, 10/3, PM	0.44	3.1	2	1.3	0.81	0.27	7.48	14.44
D	Unit 1-2, 10/4, AM	0.41	2.3	1.6	1.2	0.83	0.21	6.14	12.34
D	Unit 1-2, 10/4, PM	0.62	3.4	2.2	1.8	1.1	0.23	8.73	17.03
	FACILITY D AVERAGE	0.56	3.48	2.63	2.10	1.34	0.33	9.86	18.88
	STANDARD DEVIATION	0.14	1.02	1.22	1.18	0.74	0.15	4.27	7.58
	TOTAL NUMBER	12	12	12	12	12	12	12	12
	MINIMUM	0.41	2.3	1.6	1.2	0.62	0.18	6.14	12.34
	MAXIMUM	12	91	37	35	36	8.4	153.9	480.4
	OVERALL AVERAGE	2.20	15.69	9.93	9.47	8.15	1.96	45.2	127
	STANDARD DEVIATION	3.14	23.90	11.10	10.35	10.95	2.61	49.5	157

TABLE 2-8
PCDD AND PCDF IN SOLID SAMPLES - VERSAR STUDY
PAGE FIVE

BOTTOM ASH (DIOXIN HOMOLOGS)

Plant	Sample Description	2,3,7,8 TCDD (ng/g)	TETRA -CDD (ng/g)	PENTA -CDD (ng/g)	HEXA -CDD (ng/g)	HEPTA -CDD (ng/g)	OCTA -CDD (ng/g)	TOTAL -CDD (ng/g)
B	Unit 3, 9/28, AM	<0.04	<0.04	<0.01	0.02	0.09	0.16	0.27
B	Unit 3, 9/29, PM	<0.04	<0.04	<0.02	0.03	0.13	0.16	0.32
B	Unit 4, 9/28, AM	<0.08	<0.08	<0.05	0.07	0.13	0.35	0.55
B	Unit 4, 9/28, AM, Dup	0.01	0.11	0.21	0.16	0.24	0.61	1.33
B	Unit 4, 9/29, PM	<0.14	0.65	2	2.3	6.3	29	40.25
	FACILITY B AVERAGE	0.03	0.17	0.45	0.52	1.38	6.06	8.54
	STANDARD DEVIATION	0.02	0.24	0.78	0.89	2.46	11.47	15.86

BOTTOM ASH (FURAN HOMOLOGS)

Plant	Sample Description	2,3,7,8 TCDF (ng/g)	TETRA -CDF (ng/g)	PENTA -CDF (ng/g)	HEXA -CDF (ng/g)	HEPTA -CDF (ng/g)	OCTA -CDF (ng/g)	TOTAL -CDF (ng/g)	TCDD + TCDF (ng/g)
B	Unit 3, 9/28, AM	0.03	0.15	0.07	0.02	0.04	<0.04	0.28	0.55
B	Unit 3, 9/29, PM	0.02	0.06	0.02	0.05	0.03	<0.04	0.16	0.48
B	Unit 4, 9/28, AM	0.05	0.28	0.18	0.1	0.1	0.06	0.72	1.27
B	Unit 4, 9/28, AM, Dup	0.09	0.68	0.33	0.26	0.26	0.12	1.65	2.98
B	Unit 4, 9/29, PM	0.3	1.3	1.5	2.5	6.9	3.7	15.9	56.15
	FACILITY B AVERAGE	0.10	0.49	0.42	0.59	1.47	0.78	3.74	12.29
	STANDARD DEVIATION	0.10	0.46	0.55	0.96	2.72	1.46	6.10	21.95

TABLE 2-8
PCDD AND PCDF IN SOLID SAMPLES - VERSAR STUDY
PAGE SIX

LANDFILL COMPOSITE (DIOXIN HOMOLOGS)

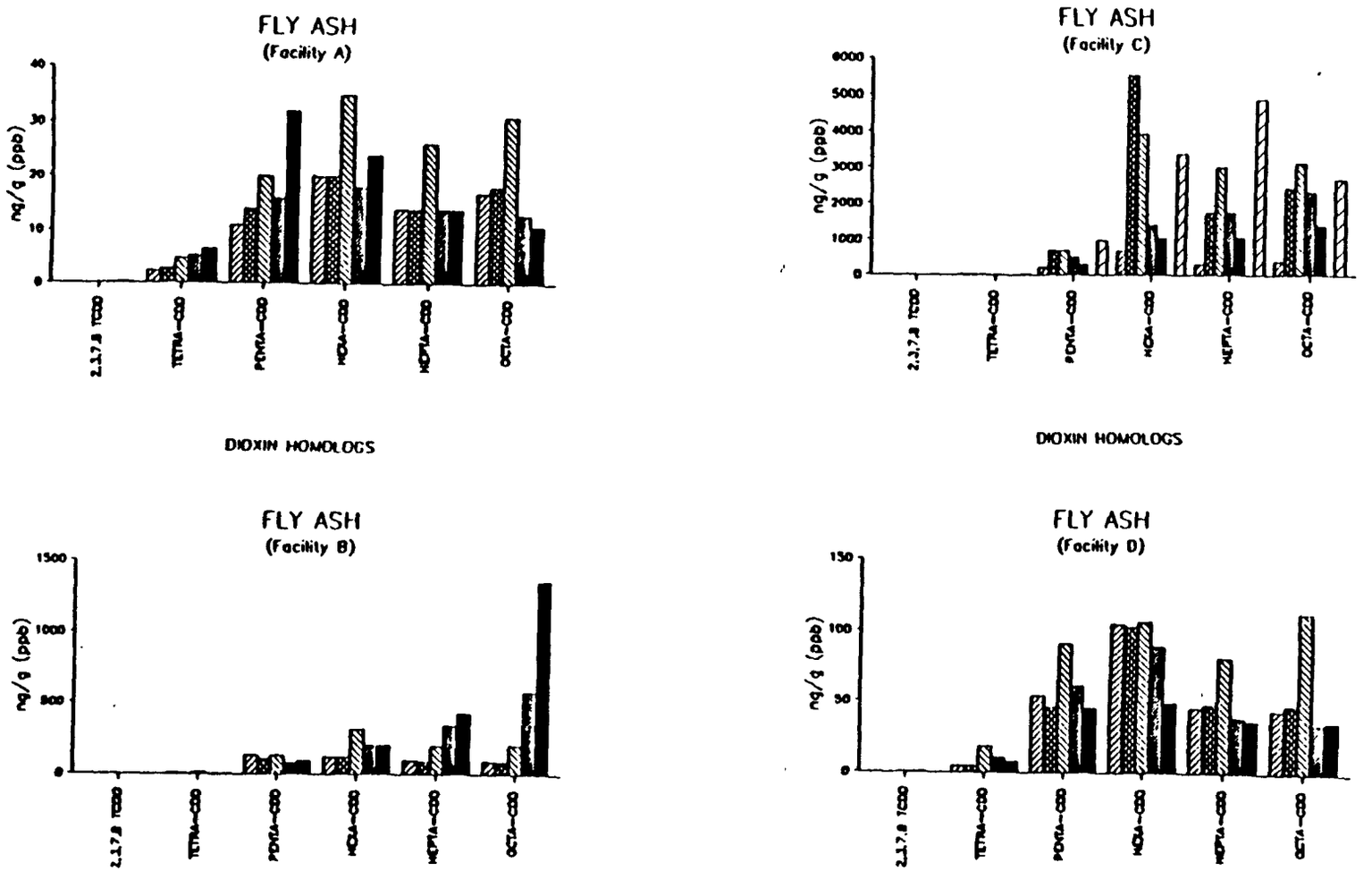
Plant	Sample Description	2,3,7,8 TCDD (ng/g)	TETRA -CDD (ng/g)	PENTA -CDD (ng/g)	HEXA -CDD (ng/g)	HEPTA -CDD (ng/g)	OCTA -CDD (ng/g)	TOTAL -CDD (ng/g)
C	Perimeter Composite	0.07	1.2	5.7	6.8	9	6.1	28.8
D	Perimeter Composite	0.15	2.5	6	4.1	4.2	3.9	20.7

LANDFILL COMPOSITE (FURAN HOMOLOGS)

Plant	Sample Description	2,3,7,8 TCDF (ng/g)	TETRA -CDF (ng/g)	PENTA -CDF (ng/g)	HEXA -CDF (ng/g)	HEPTA -CDF (ng/g)	OCTA -CDF (ng/g)	TOTAL -CDF (ng/g)	TCDD + TCDF (ng/g)
C	Perimeter Composite	0.51	2.4	3.9	4	3.3	0.81	14.41	43.21
D	Perimeter Composite	1.3	11	7.7	5.3	2.7	0.61	27.31	48.01

FIGURE 2-5

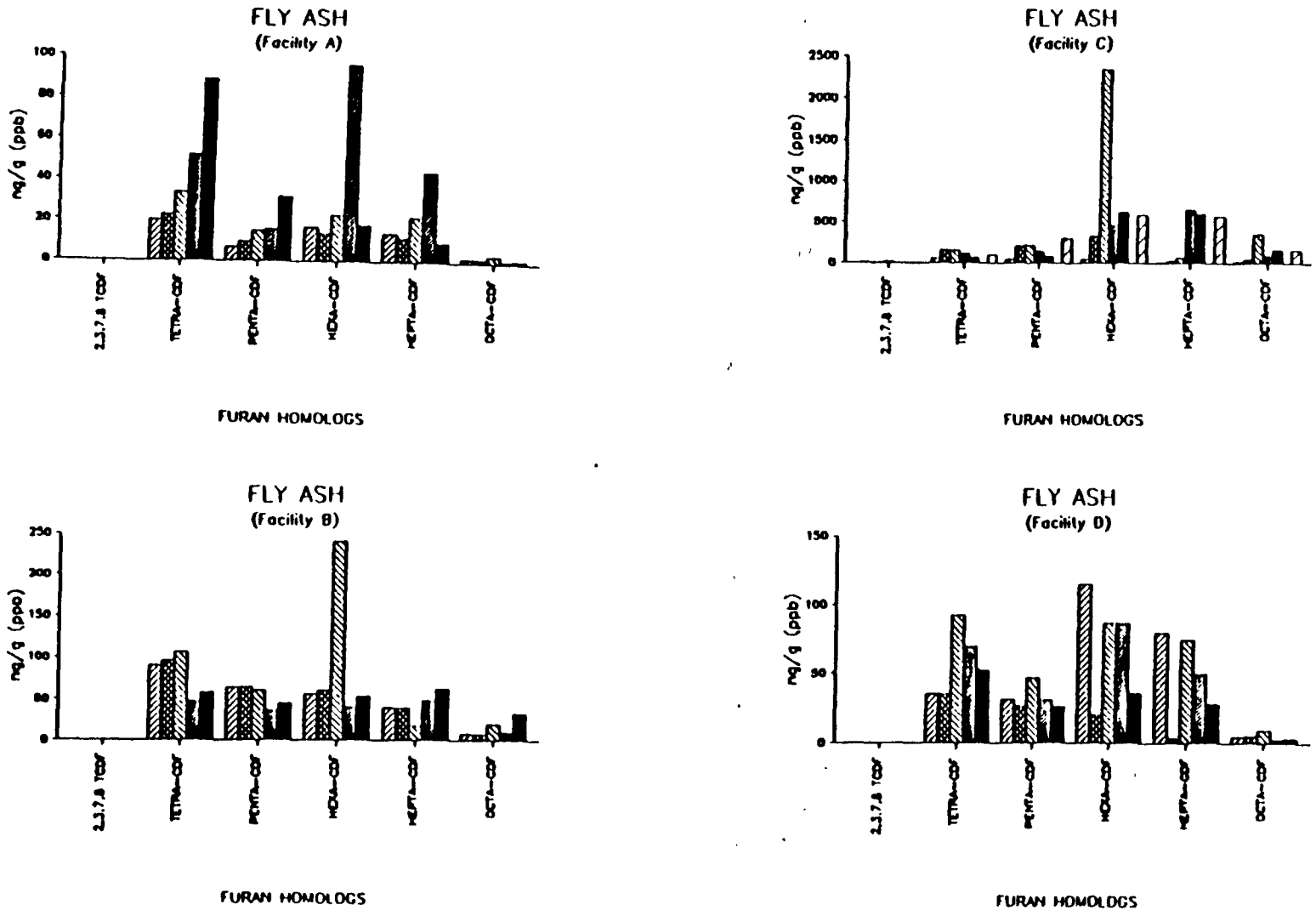
Concentrations of Dioxin Homologs in Fly Ash from the Four Facilities Sampled by Versar in ng/g (parts per billion)



Note: Each bar represents an individual sample collected from an individual unit during an individual shift. Each sample consists of a composite of 8 grab samples taken during that shift, except facility B which consists of four grab samples (Table 1-2).

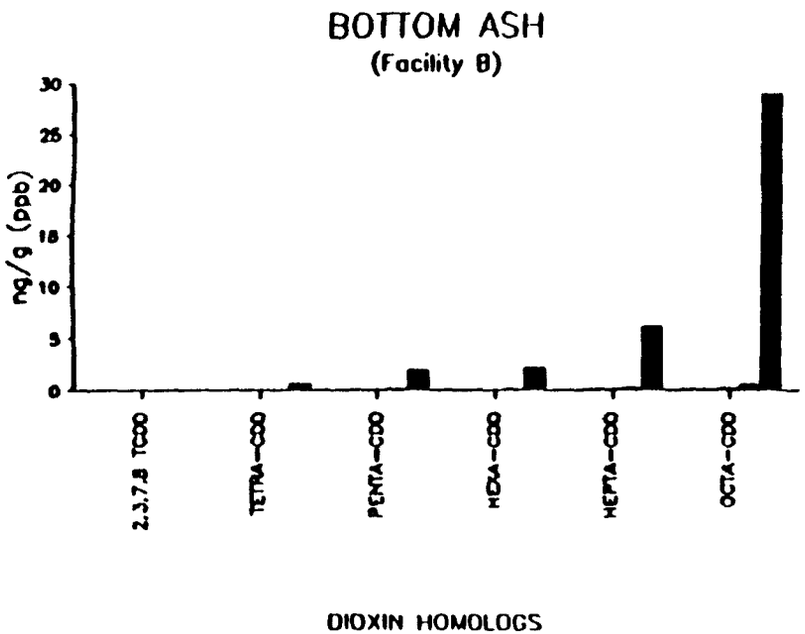
FIGURE 2-6

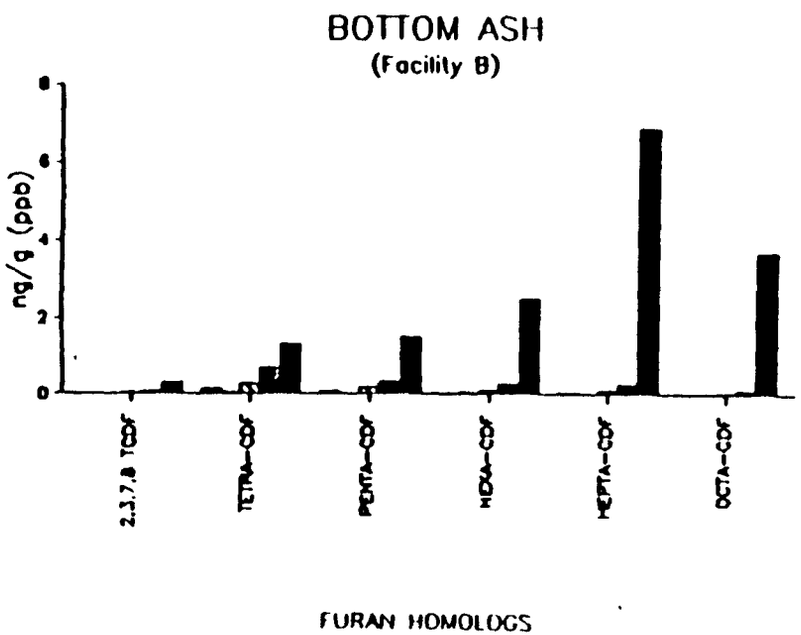
Concentrations of Furan Homologs in Fly Ash from the Four Facilities Sampled by Versar in ng/g (parts per billion)



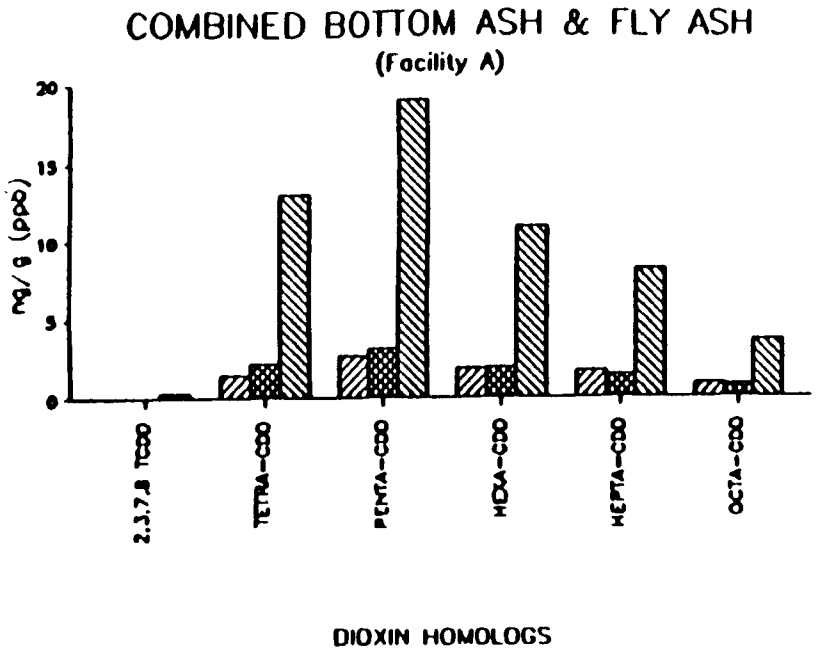
Note: Each bar represents an individual sample collected from an individual unit during an individual shift. Each sample consists of a composite of 8 grab samples taken during that shift, except for facility B which consisted of four grab samples (Table I-2).

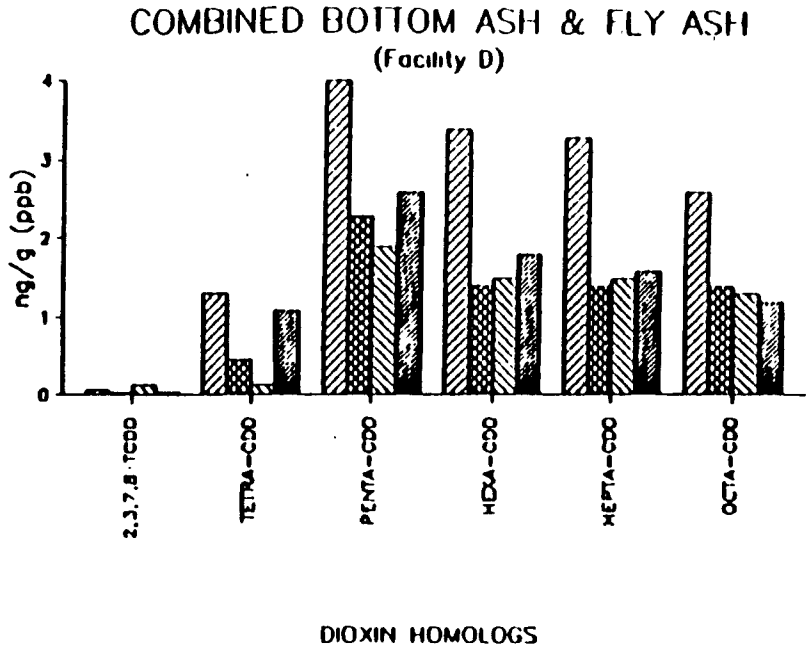
Concentrations of Dioxin and Furan Homologs in Bottom Ash from Facility B Sampled by Versar in ng/g (parts per billion)

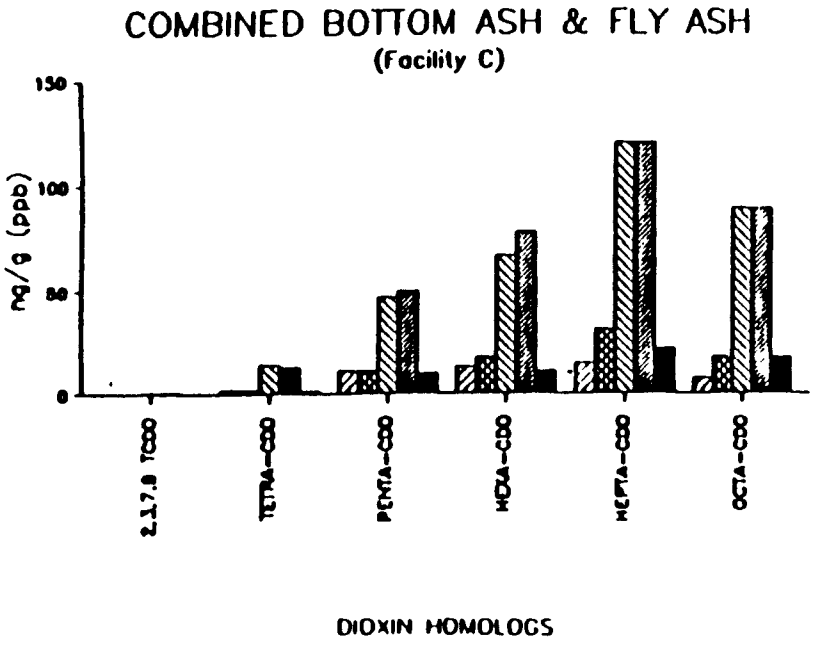




Note: Each bar represents an individual sample collected from an individual unit during an individual shift. Each sample consists of a composite of four grab samples taken during that shift.

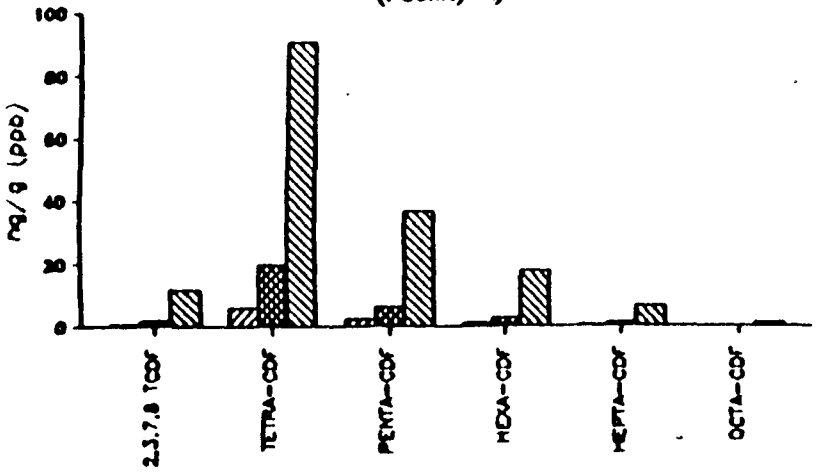






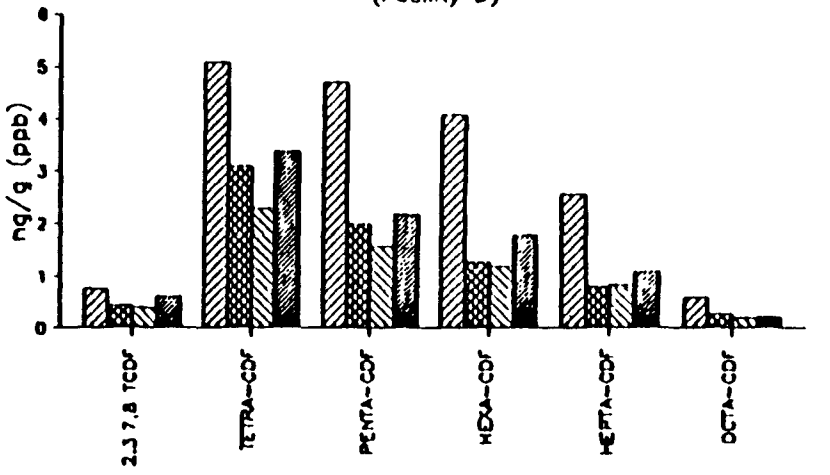
Note: Each bar represents an individual sample collected from an individual unit during an individual shift. Each sample consists of a composite of 8 grab sampled taken at approximately equal intervals during that shift.

COMBINED BOTTOM ASH & FLY ASH
(Facility A)



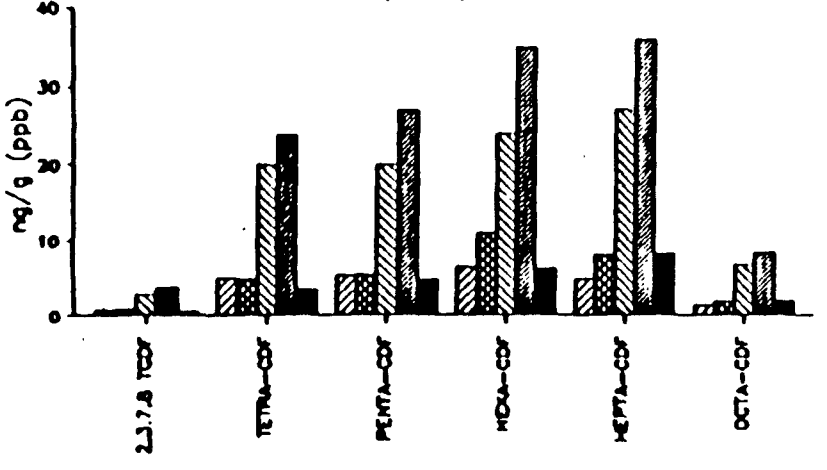
FURAN HOMOLOGS

COMBINED BOTTOM ASH & FLY ASH
(Facility D)



FURAN HOMOLOGS

COMBINED BOTTOM ASH & FLY ASH
(Facility C)



FURAN HOMOLOGS

Note: Each bar represents an individual sample collected from an individual unit during an individual shift. Each sample consits of a composite of 8 grab samples taken during that shift.

Finally, one significant trend was noted. As the total PCDDs increased, the abundance of the hexa- through octa-chlorinated classes increased disproportionately (i.e., when the total PCDD concentration was less than 500 ng/g (ppb), the hexa- through octa-chlorinated classes accounted for 70 percent of the total PCDD concentration; however, when the total PCDD concentrations exceeded 500 ng/g (ppb), the hexa- through octa-chlorinated classes accounted for 90 percent of the total PCDD concentration).

At Facility C, two discrete fly-ash fractions were analyzed for PCDDs (see Table 2-8). The first of these, the coarse fly ash (i.e., economizer ash), did not contain any detectable PCDDs. However, the second of these fractions, the fine fly ash (i.e., electrostatic precipitator ash), contained the highest PCDD concentrations of any fly ash sample that was analyzed in the coarse of the Versar Study. This was expected because the PCDD compounds adhere more strongly to finer particles.

A review of the PCDF homolog concentrations in the fly ash, Figure 2-6, again showed that the variability between the shift and units was relatively small, whereas the concentration variability between facilities was extremely large (i.e., the concentrations standard deviations for the homologs exceeded the average homolog concentrations). Facility C had the highest concentrations of total PCDFs, as well as the highest concentrations of each PCDF homolog, followed by Facility B, Facility D, and Facility A, which had the lowest concentration of each PCDF homolog. The hexa-CDF homolog was the most prevalent at three facilities, and the second most prevalent at the fourth facility. Similarly, the octa-CDF homolog was the least prevalent at three facilities, and the second least prevalent at the fourth facility. The tetra-CDF homolog was generally the second most prevalent, with the exception of Facility C, where it was the least prevalent. As was the case for the PCDDs, the hexa- through octa-chlorinated classes of PCDFs increased disproportionately as the total PCDFs increased.

As was the case for the PCDDs, two discrete fly ash fractions from Facility C were analyzed for PCDFs (see Table 2-8). Again, the coarse fly-ash fraction contained a minimal quantity of PCDFs, but the fine fly-ash fraction exhibited the highest concentrations of PCDF homologs found in any fly-ash sample. This was again anticipated because the PCDF compounds, acting similarly to the PCDD compounds, adhere more strongly to the finer fly-ash particles.

Comparison of PCDD with PCDF levels in the fly ash indicated that the total concentrations of PCDDs and PCDFs followed the same sequence of abundance among the facilities (i.e., the total concentrations of both PCDDs and PCDFs increased in the order: Facility A – Facility D – Facility B – Facility C; the production of the hexa-chlorinated classes of PCDDs and PCDFs was favored at each of four facilities; the penta- and/or hepta-chlorinated classes of both PCDD and PCDF were never the most or least abundant. Also, there was no correlation between the relative abundances (i.e., percentage) of PCDD or PCDF homologs in the total PCDD/PCDF concentrations.

A review of the PCDD homolog concentrations in the combined bottom/fly ash (Figure 2-8) and bottom ash (Figure 2-7) showed that the variability between shifts and units was relatively small compared to the variability between facilities. Facility C combined-ash samples had the highest concentrations of individual PCDD homologs as well as total PCDDs. The samples from Facility A had the second highest PCDD concentrations, followed by the samples from Facilities D and B, sequentially. There were no notable trends for the relative abundances of the individual PCDD homologs. For example, the penta-CDD homolog was the most abundant for Facilities A and D, while the octa-CDD and hepta-CDD homologs predominated at Facilities B and C, respectively. Similarly, the least abundant homolog was tetra-CDD for Facilities B, C, and D; however, the octa-CDD homolog, which was the most abundant at Facility B, was the least abundant at Facility A. The 2,3,7,8-TCDD isomer concentrations were very low for all four facilities, usually being only slightly above the detection limit.

A review of the PCDF homolog concentrations in the combined bottom/fly ash (Figure 2-9) and bottom ash (Figure 2-7) samples indicated that the variability between shifts and units was relatively large, and that the variability between facilities was extremely large.

The combined-ash samples from Facilities A and C had the highest concentrations of PCDFs. The octa-CDF homolog was the least prevalent for three of the facilities; however, it was the second most abundant homolog for Facility B. This difference may be attributed to the Facility B sample, which consisted exclusively of bottom ash, whereas the samples from the other three facilities consisted of combined

bottom/fly ash. The tetra- and hepta-CDF homologs predominated, each being the most abundant homolog at two facilities. The concentrations of the penta- and hexa-CDF homologs were approximately equal; these homologs were never the most or least abundant at any facility. The 2,3,7,8-TCDF isomer accounted for 15 to 20 percent of the total tetra-CDF homologs.

Comparison of the PCDD and PCDF concentrations in the combined and bottom ash indicates the following observation. The facilities that had the higher concentrations of PCDDs had the highest concentrations of PCDFs, and this was also true for the facilities with the lowest concentrations. There was no apparent correlation or trend between the relative abundances of PCDDs or PCDFs in the total PCDD/PCDF concentrations.

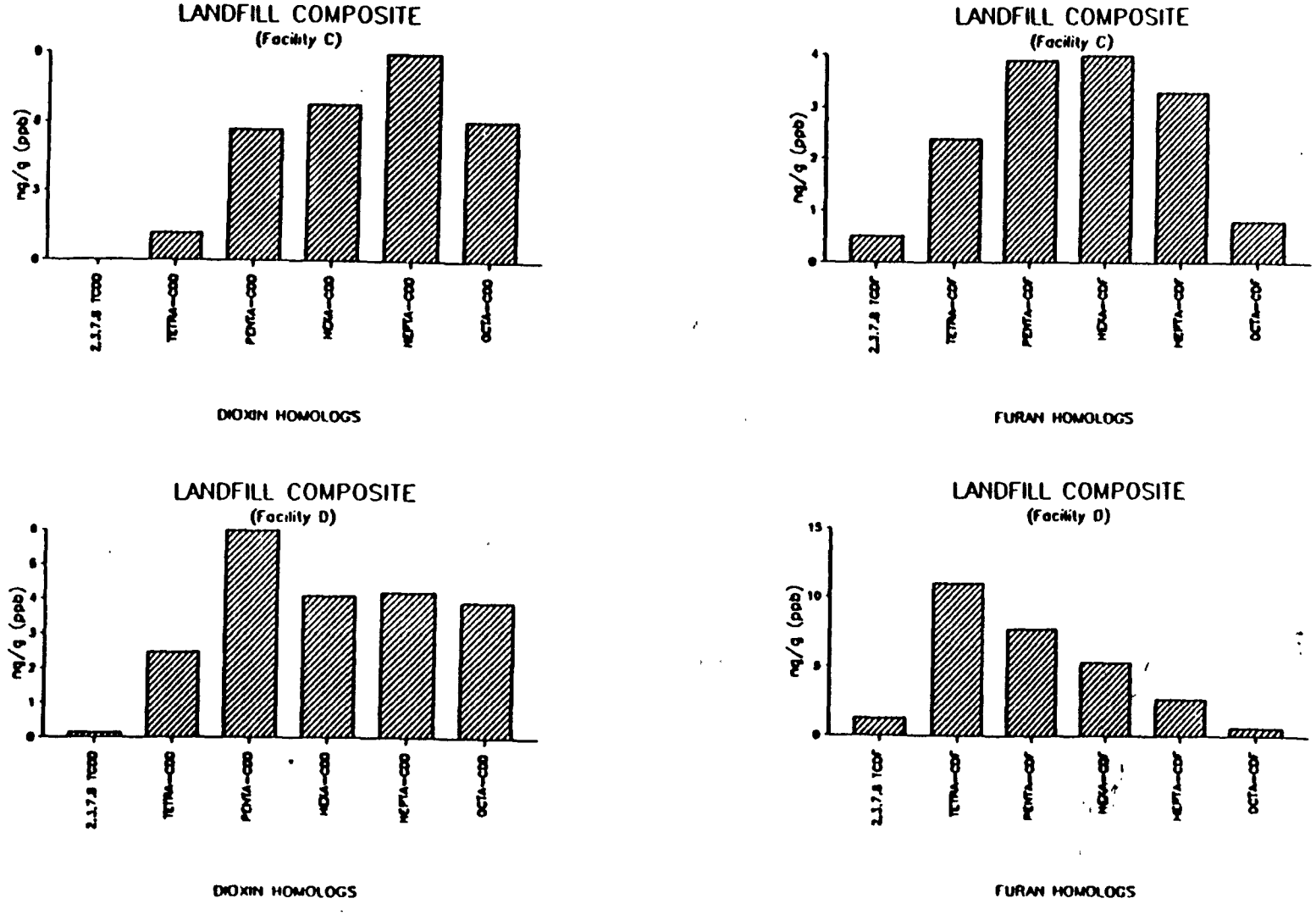
A review of the landfill composite sample results for PCDDs (Figure 2-10) showed that Facilities C and D were approximately equal. The tetra-CDD homolog was the least abundant at both facilities, and the hepta-CDD and penta-CDD homologs were the most abundant. The tetra-CDDs at each facility were approximately 6 percent 2,3,7,8-TCDD.

The PCDF results of the landfill composite samples (Figure 2-10) showed that Facility D contained higher concentrations than Facility C. The octa-CDF homolog was the least prevalent at each facility, and the hexa-CDF and tetra-CDF homologs were the most prevalent at both facilities. There did not appear to be any trend concerning the concentrations of 2,3,7,8-TCDF, or the relative abundances of PCDD or PCDF in the total PCDD/PCDF concentrations.

Comparison of the PCDD and PCDF results of the combined bottom/fly ash (Figures 2-8 and 2-9; Table 2-8) with the landfill perimeter composite samples from Facilities C and D (Figure 2-10 and Table 2-8) indicate that the combined ash from Facility C contained six times more PCDDs and four times more PCDFs than the landfill composite. Conversely, at Facility D, the landfill composite sample contained two times more PCDDs and five times more PCDFs than the combined ash samples. The reason for this occurrence may be that the landfill composite samples at Facility C may have been biased by bottom ash, whereas the landfill composite sample at Facility D may have been biased by fly ash, which contained significantly more PCDDs and PCDFs than the bottom or combined ash.

FIGURE 2-10

Concentrations of Dioxin and Furan Homologs in Landfill Composites from the Two Facilities Sampled by Versar in ng/g (parts per billion)



Note: Each composite sample consisted of 50 2-foot core sections taken from the landfill perimeters (Table 1-2)

Upon comparing the PCDD and PCDF results of the fly ash with the combined bottom/fly ash or bottom ash, the following observations were noted. First, the variability between facilities for both fly ash and combined/bottom ash PCDD and PCDF concentrations is extremely high. This may be a consequence of differences the feed material, incinerator conditions, and plant designs at the four facilities or it may be a consequence of sampling variability. Second, the variabilities between shifts and units for both PCDDs and PCDFs in the combined/bottom ash are greater than the corresponding variabilities for the fly ash. This discrepancy is probably caused by the relatively higher heterogeneity of the combined/bottom ash compared to the relatively higher homogeneity of the fly ash. Third, the fly ash from three facilities contained from 3 to 40 times more PCDDs than the combined ash, and the fly ash from Facility B contained 120 times more PCDDs than the facility's bottom ash. This indicates that the PCDDs are associated with the fine fly-ash particles and that PCDD concentrations in the bottom ash are minimal. Therefore, the difference between the PCDD concentrations in the fly ash and combined ash is probably caused by a bottom-ash dilution effect. Similarly, the fly ash from three facilities contained from 2 to 25 times more PCDFs than the combined ash, and the fly ash from Facility B contained 75 times more PCDFs than the facility's bottom ash. Therefore, the difference between PCDF concentration in the combined ash and fly ash is probably a result of the dilution effect from the bottom ash. Fourth, the tetra-CDD homologs are the least prevalent in both the fly ash and the combined/bottom ash, whereas the hexa- through octa-chlorinated classes of PCDDs are the most prevalent. This suggests that the typical incinerator conditions favor the production of the more highly chlorinated PCDD species. However, for both the fly ash and combined/bottom ash, the tetra- through hexa-PCDFs are more abundant than the hexa through octa. This may suggest that the same incinerator conditions that favor the formation of the higher PCDDs also favor the formation of the lower PCDFs.

The toxicity of the individual PCDD and PCDF homologs varies greatly. The tetra homologs are more toxic than the others, and of the tetra, the 2,3,7,8-TCDD is the most toxic. In a recent March 1987 publication of the Risk Assessment Forum of the U.S. EPA: Interim Procedures for Estimating Risks Associated with Exposures to Mixtures of Chlorinate Dibenzo-p-Dioxins and Dibenzofurans (CDDs and CDFs) (Bellin and Barnes, 1987), and distributed in a draft form by Lee M. Thomas in

January 7, 1987, a methodology of converting the concentrations of PCDD and PCDF homologs to 2,3,7,8-TCDD is given. This methodology, which determines the "Toxicity Equivalence Factors" (TEF), was used to determine the individual TEFs for ashes and their natural and simulated leachates. This is further discussed and reported in the applicable tables presented in Section 6.0 of this report.

According to recently obtained information from Canadian studies (Sawell, 1987) dioxin entering the incinerator is actually destroyed by the incinerator. However, during incineration, new dioxins are formed from chlorinated organic compounds that can produce dioxins. These Canadian studies report that incinerators are net destroyers of dioxins.

3.0 CONVENTIONAL PARAMETERS IN LEACHATES FROM MSW DISPOSAL SITES, CODISPOSAL SITES, AND MONOFILLS

Table 3-1 lists ranges of conventional parameters (i.e., pH, specific conductance, total dissolved solids, ammonia-nitrogen, sulfate, nitrate-nitrogen, COD, BOD, TOC, etc.) in leachates collected from MSW sites, as reported in the literature and as found by the NUS study. Results obtained from the EPA-sponsored study, conducted by NUS, are given in the last two columns: ranges of the six samples collected from the two codisposal sites are given in the last column, and of the thirteen samples collected from the four MSW sites, in the column next to the last. The study is described in detail in Volume VI of this report and the literature information is reported in Volumes II and III of this report.

The NUS-selected MSW and codisposal sites were carefully chosen (as described in Section 2.0 of Volume VI) to include only sites constructed after RCRA regulations came into effect and sites that do not accept industrial wastes. The selected codisposal sites accept in excess of 25 percent of their waste in the form of MWC ashes.

To better understand the data obtained by the NUS study, Table 3-2 lists the characteristics of the four selected municipal solid waste disposal sites and Table 3-3 lists the characteristics of the two selected codisposal sites.

The data presented in Table 3-1 indicate a great variation in levels of each of the analyzed parameters. The variability in the data reported in the literature ranges over several orders of magnitude. For example, pH ranges from acidic (3.7) to basic (8.5). The behavior of the other parameters is similar. Values of BOD, COD, and TOC are high, as expected, ranging from not detected (ND) to 720,000 mg/l (ppm) for BOD; ND to 750,000 mg/l (ppm) for COD; and from ND to 30,500 mg/l (ppm) for TOC. Nitrate-nitrogen values, for which there is a drinking water standard of 10 mg/l (ppm), ranged from ND to 1,300 mg/l (ppm).

TABLE 3-1

CONVENTIONAL CONTAMINANT CONCENTRATION RANGES IN LEACHATES FROM MUNICIPAL DISPOSAL AND CODISPOSAL SITES

	George (1972)	Chian/ DeWalle (1977)	Metry/Cross (1975)	Cameron (1978)	Wisconsin Report (20 sites)	Sobotka Report (44 sites)	NUS Municipal (4 Sites)	NUS Codisposal (2 Sites)
pH	3.7-8.5	3.7-8.5	3.7-8.5	3.7-8.5	5-8.9	5.4-8.0	6.98-7.8	7.2-7.3
Alkalinity	0-20,850	0-20,850	310-9,500	0-20,900	ND-15,050	0-7375	1,600-4,700	1,800-3,900
Total Solids		0-59,200				1,900-25,873		
TDS	0-42,276	584-44,900	100-51,000	0-42,300	584-50,430	1,400-16,120	2,710-31,800	1,930-7,970
Total Suspended Solids	6-2,685	10-700	13-26,500		2-140,900	28-2,835	32-928	45-2,220
Specific Conductance		2,810-16,800	100-1,200		480-72,500		300->10,000	8,400->10,000
BOD	9-54,610	81-33,360	2,200-720,000	9-55,000	ND-195,000	7-21,600		
COD	0-89,520	40-89,520	800-750,000	0-9,000	6.6-97,900	440-50,450	1,000-8,700	1,300-3,900
TOC		256-28,000			ND-30,500	5-6,884	138-2,680	438-1,310
Bicarbonate			3,260-5,730					
Hardness	0-22,800	0-22,800	35-8,700	0-22,800	52-225,000	0-8-9,380	670-3,000	900-2,200
Chlorides	34-2,800	4.7-2,467	47-2,350	34-2,800	2-11,375	120-5,475	570-1,600	1,200-2,100
Fluorides				0-2.13	0-0.74	0.12-0.790		
Sulfates	1-1,826	1-1,558	20-1,370	0-1,826	ND-1,850	8-500	<4-420	<20-57
Sulfide				0-0.13				
Total-K-Nitrogen	0-1,416				2-3,320	47.3-938	73-660	190-450
NH_3-Nitrogen	0-1,106	0-1,106	0.2-845	0-1,106		11.3-1,200	53-580	160-410
Organic Nitrogen			2.4-550			4.5-78.2	20-100	10-70
NO_3 Nitrogen	0-1,300	0.2-10.29	4.5-18			0-50.95	<0.1-0.2	<0.1-0.7
Total Phosphorus	1-154	0-130			ND-234		0.2-3.8	0.97-2.3
Ortho-Phosphorus		6.5-85	0.3-136	0-154				
No. of Samples							13	6

All concentrations in mg/l except pH (std units) and Sp. Cond. (μmhos/cm).
ND = Not detected

TABLE 3-2

CHARACTERISTICS OF MUNICIPAL SOLID WASTE DISPOSAL SITES SELECTED FOR NUS STUDY

Facility	Opened for Operation	Capacity (yards³/year)	Geographic Profile	Waste Characteristics	Method of Placement	Liner	Leachate Collection/ Treatment System	Cover
PC	1983 Closure ~1998	80,000	18 6 acres in rolling hills, areas range from rural agricultural to residential; soil is glacial and moraine, mostly highly permeable sandy till	Garbage Refuse Wood matter Demolition debris	Area-fill	5 foot-thick clay (permeability 7×10^{-3} to 4×10^{-2} cm/sec)	6 inch perforated PVC pipes in gravel trenches, hauled to POTW	Daily - 6 inches of soil Final 2 feet of compacted clay soil and 6 inches of topsoil
FL	May 1975 Closure ~1992	23,000	120-acre site in forested area; soils are medium- to fine-grained sands, underlain by silty to clay-like sand	Garbage Construction debris Yard trash Tomato waste Wood scrap	Sequential trench method	6-inch thick bentonite polymer and soil (permeability 1×10^{-7} cm/sec)	6 inch perforated PVC pipes in gravel trenches, pumped to sealed pool, evaporated and hauled to POTW	Daily - 6 inches of soil Final - 18 inches of bentonite soil mix
SM	1976	1.5×10^{6}	58 acres in floodplain and adjacent uplands; agricultural area soil consists of clay, mudstone, sandstone, and volcanic rocks	Municipal waste Municipal sewage sludge	Trench and area fill	None - naturally lined with clay and mudstone	Collected in trenches, pumped to lagoon, stored in winter, spray irrigated on adjacent land in summer	Daily 6 inches of soil. Final 2 feet of clay topsoil
VD	January 1980	480,000 (75 tons/day)	100 acres in a large drainage ravine; ground is shale covered with slope wash soils and residual soils (clay and shale)	Municipal Waste Construction Debris Dead Animals Sludge	Ramp Method	None	Collection reservoir on downgradient side of fill, leachate is sprayed back over landfill area	Daily 6 inches of weathered shale Final 2 feet of compacted topsoil

TABLE 3-3

CHARACTERISTICS OF SELECTED CODISPOSAL (MSW AND MWC ASH) SITES

Facility	Opened for Operation	Geographic Profile	Capacity (yards^3/year)	Waste Characteristics	Liner	Leachate Collection/ Treatment System	Cover
NY	April 1985	Not available	4×10^4 tons/year ash and refuse and 8,000 yards^3/year sludge and ash	Ash Hardfill (i.e., metal scrap) Sewage sludge Sewage sludge ash Humane society wastes	Two clay liners	Collection system between two liners, pumped to holding tanks and then to POTW	None
NC	November 1981	Not available	Not available	MWC ash Calcium nitrite Glass sludge Dimethylterphthalate MSW (MSW:ASH = 3:1)	3-foot, sand, high-density liner 2-foot, sand, 20-mil PCV liner	Collection system above liners, pumped to lined lagoon, then to POTW	MWC ash is used as a daily cover

Leachates collected from the NUS-selected sites, both the MSW and the codisposal sites, contained the same parameters, reported by other studies (Table 3-1) but at lower levels. For example, the pH in the NUS municipal leachate samples were neutral to slightly basic ranging between 6.98 and 7.8 and, in the codisposal leachate samples, the pH was slightly basic ranging between 7.2 and 7.3; COD levels ranged between 1,000 and 8,700 mg/l (ppm) in the MSW leachates and 1,300 and 3,900 mg/l (ppm) in the codisposal leachates; nitrate-nitrogen values were all well below the maximum contaminant level (MCL) of 10 mg/l (ppm). They ranged between <0.1 and 0.2 mg/l (ppm) in the MSW leachates and <0.1 and 0.7 mg/l (ppm) in the codisposal leachates.

Generally, there was no difference between the leachates collected from the four MSW sites and the two codisposal sites. The ranges overlapped, and as stated previously, fell well within the ranges of other MSW leachates.

There are two main reasons why leachates collected for this EPA-sponsored NUS study were relatively "cleaner:"

- The selected sites were all constructed in the post-RCRA era. Thus, these sites are not likely to contain hazardous wastes other than those from small-quantity generators.

- The selected sites do not accept industrial wastes.

During the week of June 2nd through June 6th 1987, the four monofills sampled by Versar in 1986, which had not originally been sampled for conventional parameters, were resampled by NUS for pH, specific conductance, COD, and ammonia-nitrogen. The facilities were resampled for leachates and quench waters at the same location points where the original samples had been collected. Results are summarized in Table 3-4. The original sampling effort is described in Volume V of this report and the results of the NUS effort are described in the form of a trip report in Volume VII of this report. Volume VII also contains pertinent information regarding the facility's operating practices, as obtained in June of 1987.

Comparison of the limited monofill data available and listed in Table 3-4 with the data given in Table 3-1 indicates that, as expected, ammonia-nitrogen and COD

TABLE 3-4

CONVENTIONAL PARAMETERS IN LEACHATES FROM MONOFILLS AND IN QUENCH WATERS

Parameter	Facility A		Facility B		Facility C		Facility D	
	Leachate	Quench Water	Leachate	Quench Water	Leachate	Quench Water	Leachate	Quench Water
pH, pH Units	-	11 91	7 44	12.09	8.58	5.68	8.12	11 73
Specific Conductance	-	4,900	4,200	5,100	>10,000	9,100	9,300	<10,000
COD, mg/l (ppm)	-	38	<5	810	1,200	470	840	820
NH_3-N, mg/l (ppm)	-	0.7	1.2	3 9	3 0	4.1	36	4 5
Temperature, °C	-	36.3	27 5	32.5	33.3	40 8	29 3	31 5

Specific conductance in µmhos/cm
No leachate collection system

levels in the monofill leachates were much lower than in the MSW disposal and codisposal leachates. However, levels of specific conductance, which provide a measure of total dissolved solids, were similar to the values obtained for the MSW and the codisposal sites. The pH of leachates from the monofill were, as expected, on the basic side (7.44-8.58) and the quench waters, except for Facility C (5.68), were even more basic (11.73-12.09).

The presence of ammonia-nitrogen in the monofill samples, although in very small concentrations, suggests the presence of anaerobic bacteria. Given adequate time and carbonaceous substrate, which serve as nutrients for the bacteria, significant microbial activity will take place.

TABLE 4-1
INORGANIC CONCENTRATION RANGES IN LEACHATES
FROM MUNICIPAL DISPOSAL AND CODISPOSAL SITES IN mg/l (ppm)

Trace Element	George (1972)	Chian/ DeWalle (1977)	Metry/Cross (1975)	Cameron (1978)	Wisconsin Report (20 sites)	Sobotka Report (44 sites)	NUS Municipal (4 Sites)	NUS Codisposal (2 Sites)	EP Toxicity Maximum Allowable Limit
Aluminum				ND-122	ND-85	0 010-5 07	1 6-5 8	ND	
Arsenic				ND-11.6	ND-70.2	ND-0 08	0.006-0 23	0 008-0 046	5 0
Barium				ND-5 4	ND-12.5	ND 01-10	0 34-1 7	0 27-0 89	
Beryllium				ND-0 3	ND-0.36	0.001-0 01	ND	ND	
Boron				ND 3-73	0.867-13				
Cadmium		0 03-17		ND-0 19	ND- 04	ND-0 1	0 002-0 007	ND 0 011	1 0
Calcium	5-4080	60-7200	240-2570	5-4000	200-2500	95 5-2100	146-794	174-803	
Total Chromium				ND-33 4	ND-5 6	0 001-1 0	0 002-0 039	ND-0 013	5 0
Copper	ND-9.9	ND-9 9		ND-10	ND-4 06	0 003-0 32	ND	ND	--
Cyanide				ND-0 11	ND-6	ND-4 0			
Iron	0 2-5500	0-2820	0.12-1700	0 2-5500	ND-1500	0.22-1400	6 4-268	21.1-104	--
Lead	ND-5 0	<0.10-2 0		ND-5 0	ND-14 2	0.001-1.11	ND-0 061	0 01-0 27	5.0
Magnesium	16.5-15600	17-15600	64-547	16.5-15600	ND-780	76-927	74-424	114-199	
Manganese	0.06-1400	0 09-125	13	0 06-1400	ND-31.1	0 03-43	0 27-8 87	1.29-11.3	--
Mercury				ND-0.064	ND-0 01	ND-0 02	ND	ND	0 2
Molybendum				ND-0 52	0 01-1 43				
Nickel				ND 01-0 8	ND-7 5	0 01-1.25	ND-0 16	ND-0 24	--
Potassium	2 8-3770	28-3770	28-3800	2 8-3770	ND-2,800	30-1375	145 2-871 1	508-780	
Sodium	ND-7700	ND-7700	85-3800	ND-7700	12-6010		118-1510 5	1076-2280	
Titanium				ND-5 0	<0 01				
Vanadium				ND-1 4	0 01		ND 02024	ND-0.029	
Zinc	ND-1000	ND-370	0 03-135	ND-1000	ND-731	0.01-67	0.01-67	0 09-1 21	--
No of Samples							13	6	

ND = Not detected at the detection limit
Blank = Not Reported
Source: Literature (Volumes II and III) and NUS Study (Volume VI)

TABLE 4-2

RANGES OF LEACHATE CONCENTRATIONS OF INORGANIC CONSTITUENTS FROM MONOFILLS in mg/l (ppm)

Constituent	Concentration	EP Toxicity Maximum Allowable Limit	Primary Drinking Water Standard
Arsenic	0.005-0.218	5.0	0.050
Barium	1.0	100.0	1.000
Cadmium	ND-0.044	1.0	0.010
Chromium	0.006-1.53	5.0	0.050
Lead	0.012-2.92	5.0	0.050
Mercury	0.001-0.008	0.2	0.002
Selenium	0.0025-0.037	1.0	0.010
Silver	0.07	5.0	0.050
Aluminum			
Beryllium			
Boron			
Calcium	21		
Cobalt			
Copper	0.022-24		
Iron	0.168-121		
Lithium			
Magnesium			
Manganese	0.103-4.57		
Molybdenum			
Nickel	ND-0.412		
Potassium	21.5		
Sodium	200-4,000		
Strontium			
Tin			

TABLE 4-2
RANGES OF LEACHATE CONCENTRATIONS OF INORGANIC CONSTITUENTS FROM MONOFILLS in mg/l (ppm)
PAGE TWO

Constituent	Concentration	EP Toxicity Maximum Allowable Limit	Primary Drinking Water Standard
Titanium			
Vanadium			
Yttrium			
Zinc	ND - 3.3		
Chloride	1,803-18,500		
Sulfate	94		
pH	8.04-8.3		
TDS	11,300-28,900		
Country			

ND = Below Detected Limit
Blank = Not Reported
Source: Literature (Volume IV) and Versar Study (Volume V)

level ranges of three studies exceeded the 5.0 mg/l (ppm) EP Toxicity Maximum Allowable Limit of lead.

The municipal and codisposal sites selected by NUS for sampling generated leachates (last two columns of Table 4-1) of similar inorganic content, but at much lower concentrations that those reported in the literature. The two main possible reasons for this occurrence, as discussed in Section 3.0, are the fact that the NUS sampled sites began operation after RCRA requirements came in effect, and that these sites do not accept industrial waste for disposal.

Data presented in Table 4-2 regarding the inorganic content in leachates collected from monofills indicate that all EP Toxicity Maximum Allowable Limits were met. The pH in the monofills was basic, as expected, ranging between 8.04 and 8.3.

Comparison between data listed in Tables 4-1 and 4-2 indicates that the high range of metals of concern in leachates from monofills is lower than the high ranges in MSW facilities as reported in the literature for the following elements: arsenic, barium, beryllium, cadmium, chromium, iron, lead, manganese, mercury, potassium, sodium, and zinc.

Tables 4-3 and 4-4 list the concentrations of the inorganic parameters (including metals) in the individual codisposal sites (Volume VI) and the individual monofill sites (Volume V), respectively. Samples collected by Versar and by NUS were grab samples. Samples were not filtered in the field prior to acidification for preservation purposes. Thus, the results reported in Tables 4-3 and 4-4 represent total values, i.e., the values found in the aqueous phase and the values found in the fine particles suspended in the leachate samples.

TABLE 4-3

INORGANIC CONSTITUENTS IN FIELD LEACHATES FROM CODISPOSAL SITES (NUS) IN mg/l (ppm)

Inorganic Constituent	NY-01	NY-02	NY-03	NC-01	NC-02	NC-03	Range	EP Toxicity Maximum Allowable Limit	Primary Drinking Water Standards
Arsenic	0.010	0 008	0.012	0 044	0 046	0.044	0 008- 0 046	5 0	0 050
Cadmium	0.011	0.009	0.006	ND	ND	ND	0.006-0.011	1 0	0 010
Chromium	0.009	0.011	0 013	ND	0 005	0 008	0 005-0 013	5 0	0 050
Copper	0.18	0 20	0.19	ND	ND	ND	ND 0 20	---	---
Iron	93.8	92.4	93 8	21.1	104	20 9	20 9-104	---	---
Lead	0.018	0 010	0.022	0 026	0 027	0.018	0 010-0.027	5 0	0.050
Manganese	11.3	11.2	11.3	1.31	1.48	1.29	1 29-11.3	---	---
Mercury	ND	ND	ND	ND	ND	ND	ND	0 2	0 002
Nickel	0 23	0.23	0.24	0.13	0.14	ND	0 13-0.24	---	---
Selenium	ND	ND	ND	ND	ND	ND	ND	1 0	0 010
Zinc	1.21	1 21	1.21	0.15	0 09	0 12	0 09-1.21	---	---
pH, pH Units	7.2	7.2	7.2	7.3	7.3	7.3	7.2-7 3	---	---

ND = Below detection limit
Source: NUS Study (Vomume VI)

TABLE 4-4

INORGANICS CONSTITUENTS FOR FIELD LEACHATES FROM MONOFILLS (VERSAR) IN mg/l (ppm)

Inorganic Constituent	Facility Location											
	B East	B North	B Northeast	C North	C Northeast	C Northwest	D Northeast	D Northeast (DUP)	D Southeast	Range	EP Toxicity Maximum Allowable Limit	Primary Drinking Water Standard
Arsenic	<0.010	<0.010	<0.010	0.017	0.218	0.013	0.027	0.025	0.011	<0.010 0.218	5.0	0.050
Cadmium	<0.010	<0.010	0.044	<0.010	<0.050	<0.010	0.031	0.023	<0.005	<0.005 0.044	1.0	0.010
Chromium	<0.005	<0.005	0.024	0.011	0.914	0.0053	0.13	0.099	0.069	<0.005 0.914	5.0	0.050
Copper	0.112	0.089	0.091	0.2	2.57	0.045	0.762	0.603	0.222	0.045 0.762		
Iron	0.758	3.92	34.5	12.9	121	0.832	51.4	45.2	8.03	0.758 51.4		
Lead	0.050	0.050	0.206	0.068	2.92	0.025	1.33	0.925	0.214	0.025 2.92	5.0	0.050
Manganese	0.105	0.456	4.57	0.244	2.13	0.103	0.431	0.369	0.214	0.013 4.57	--	-
Mercury	<0.0007	0.0002	0.0023	0.00021	0.0080	<0.0002	0.00079	0.00061	<0.0002	<0.0002 0.0080	0.2	0.002
Nickel	<0.015	0.015	0.039	0.027	0.412	<0.015	0.156	0.149	0.117	<0.015 0.412		
Selenium	<0.005	<0.025	<0.005	<0.025	0.037	<0.025	<0.025	<0.025	<0.025	<0.005 0.037	1.0	0.010
Zinc	0.048	0.099	0.098	0.346	1.32	0.412	3.3	2.69	0.624	0.048-3.3	-	-

Source: Versar Study (Volume V)

4.2 INORGANIC CONTENT IN EXTRACTS FROM MWC ASHES

Many extraction procedures have been suggested by industry, academia, technical organizations, and regulatory agencies. The main objective of such leaching tests is to simulate natural leaching conditions in the absence of actual field leachate composition data. The data obtained from these tests usually serve as input for designing landfills and leachate treatment facilities. For this purpose, the tests are intended to be conservative, because a facility that is overtreating wastes is always preferred to a facility that is undertreating wastes.

Two extraction procedures have regulatory significance; the leaching characteristics from these methods are used to classify a waste as "hazardous" or "nonhazardous" under the Resource Conservation and Recovery Act (RCRA). These two procedures are the present Extraction Procedure (EP) and the proposed Toxicity Characteristic Leaching Procedure (TCLP).

Since the EP toxicity and the TCLP procedures are required by regulatory agencies, a significant amount of data has been generated for these procedures. Data for any of the other procedures are not readily available in the published literature except for one procedure in which leaching is being done with distilled water. Thus, in addition to the two regulatory procedures, the Monofilled Waste Extraction Procedure (MWEP) (also known as SW-924), in which distilled water is used, has been used in the two EPA-sponsored studies (Versar, Volume V of this report, and NUS, Volume VI of this report). Data reported in the literature for distilled or deionized water extraction was referred to throughout this section as data obtained through method SW-924, although all such data may not have been obtained through this specific method. Following are summary conditions for these three extraction procedures:

SUMMARY CONDITIONS FOR EP, TCLP, and MWEP METHODS

Conditions	EP[a]	TCLP[b]	MWEP[c]
Liquid: Solid Ratio	20:1	20:1	10:1 per extraction
Extraction Medium	0.5N acetic acid	0.1N acetate buffer	Distilled/deionized water
pH Control	5	5 or 3	None
Extraction Time	24 hours	18 hours	18 hours per extraction
Agitation Method	Tumbler	Tumbler @ 30 ± 2 rpm	Tumbler
Temperature Control	20-40°C	22 ± 3°C	25 ± 1°C
Particle Size	< 9.5 mm	< 9.5 mm	< 9.5 mmg
Number of Extractions	1	1	4. sequentially[d]

a EP - Extraction Procedures (40 CFR 261, Appendix II), 1980.
b TCLP - Toxicity Characteristic Leaching Procedure (Revised 40 CFR 261, Appendix II), 1986.
c MWEP - Monofilled Waste Extraction Procedure (A Procedure for Estimating Monofilled Solid Waste Leachate Composition. Technical Resource Document SW-924. 2nd Edition).
d For the Versar and NUS projects, a modified MWEP method was used with only one or two sequential extractions.

The following three subsections describe the details of these procedures. This information is important in order to understand the differences in concentration levels of individual constituents leached by the different methods, and more importantly, the reasons the leaching procedures are extracting significantly higher levels of certain pollutants than occur in the natural leachate.

4.2.1 Extraction Procedure (EP)

The EP method was developed to classify a solid waste as hazardous or nonhazardous, based on predetermined hazard levels for 14 specific constituents. Therefore, the analytical results from the EP-prepared ash residues may be used to formulate regulatory strategies and to evaluate the adequacy of current disposal practices. For solid residue samples that contain no filterable liquid (i.e., contain only surface and interstitial moisture), the EP method is performed as follows:

1. Obtain a representative 100 gram sample of residue.

2. Crush material to < 9.5 mm, if necessary.

3. Place sized solid residue in extractor vessel.

4. Add amount of deionized water equal to 16 times the weight of the solid residue.

5. Begin agitation and measure pH.
   a. If pH is > 5.0, adjust to 5.0 ± 0.2 with 0.5N acetic acid.
   b. If pH is ≤ 5.0, no adjustment is necessary.

6. Continue monitoring pH at specified intervals, adjusting pH, as required in 5a, for 6 hours. The maximum amount of acid added should not exceed four times the mass of the extracted residue.

7. Agitate mixture for a total of 24 hours between 20-40°C.
   a. If at the end of 24 hours the pH is > 5.2, adjust to 5.0 ± 0.2 and continue agitation for an additional 4 hours.
   b. If pH is ≤ 5.2, no additional agitation is necessary.

8. Add required amount of deionized water to equal 20:1 ratio, accounting for volume of acid added, and filter mixture using a 0.45 µm membrane filter.

9. Analyze or preserve filtrate (i.e., laboratory leachate) as required.

If the residue sample contains filterable liquid, the sample is first separated into its component phases, and the above procedure is performed on the solid phase. Then, the initial filtrate and solid extract are combined for analysis.

4.2.2 Toxicity Characteristic Leaching Procedure (TCLP)

The TCLP method was developed by the EPA to replace the EP as the hazardous waste classification criteria under RCRA; however, the TCLP method has not yet legally replaced the EP method. The TCLP classification criteria are based on all Appendix IX constituents, including volatiles, whereas the EP classifications are based on predetermined hazard levels for only the 14 specific contaminants of the Primary Drinking Water Standards.

When the residue sample contains no filterable liquid, the TCLP method is performed as follows:

1. Obtain a representative 100 gram sample of residue.

2. Crush material to < 9.5 mm, if necessary, and place residue in extraction vessel.

3. Determine appropriate extraction medium:
   a. Weigh out 5 grams subsample of residue; reduce particle size to < 1mm, if required; place sample in a 500 ml beaker.
   b. Add 96.5 ml of distilled/deionized water (ASTM Type II).
   c. Stir sample vigorously for 5 minutes with magnetic stirrer.
   d. Measure pH, and, if pH is $\leq$ 5, use Extraction Fluid #1.
   e. If pH > 5, add 3.5 ml 1.) N HCl; slurry for 30 seconds; heat to 50°C for 10 minutes.
   f. Allow mixture to cool to room temperature and measure pH.
   g. If pH $\leq$ 5, use Extraction Fluid #1, and if pH > 5, use Extraction Fluid #2.

4. Add amount of extraction fluid selected in Step 3 equal to 20 times the weight of the solid residue.

5. Close extraction vessel, and agitate in rotary extractor device at 30 ± 2 rpm for 18 hours, maintaining the temperature at 22 ± 3°C.

6. Filter material through a 0.6 to 0.8 µm glass fiber filter.

7. Analyze or preserve filtrate as required.

If the residue sample contains filterable liquid, the sample is first separated into its component phases, and the above procedure is carried out on the solid phase. Then, if the initial filtrate and solid extract are compatible (i.e., will not form multiple phases or precipitates on combination), they are analyzed separately, and the results are mathematically combined to yield the total leachable composition.

Since the pH of the waste determines the nature of the extraction fluid used, either Extraction Fluid #1 or #2, it is important to define the TCLP definition of these Fluids:

- Extraction Fluid #1 is made by combining 64.3 ml of 1.0 N NaOH and 5.7 ml glacial acetic acid to the appropriate volume of water and diluting to a volume of one liter. The pH of this fluid should be 4.93 ± 0.02

- Extraction Fluid #2 is made by diluting 5.7 ml glacial acetic acid with ASTM Type 2 water to a volume of one liter. The pH of this fluid should be 2.88 ± 0.02.

4.2.3 Monofilled Waste Extraction Procedure (MWEP)

The MWEP method was developed to estimate the quantity of potentially leachable constituents in a given solid waste and to measure the concentration of these constituents in extracts. The procedure includes a sequential four-step batch extraction, which produces data that can be used to construct an aqueous extraction profile for each of the constituents. For the EPA-sponsored studies--the NUS and Versar studies (Volume V and Volume VI of this Report)--a modified MWEP method with only two sequential batch extraction was used. Unlike the EP and TCLP methods, the MWEP has no regulatory significance.

The modified MWEP method is performed as follows:

1. Obtain subsample and determine percent solids.

2. Obtain representative sample equal to 100 grams dry weight and place in extraction vessel.

3. Add appropriate amount of distilled/deionized water to give a 10:1 liquid-to-solid weight ratio, taking into account the moisture determined in step 1.

4. Extract (i.e., agitate using a tumbler) the mixture for 18 hours at a temperature of 25 ± 1°C.

5. Filter mixture through a 0.45 µm nitrocellulose membrane filter (for inorganic analyses) or a 0 .6 - 0.8 µm glass fiber filter (for organic analyses).

6. Retain filtrate for subsequent analysis. Place in properly cleaned sample container and preserve as required.

7. Place filter cake (i.e., solid residue) back into extraction vessel and add 1 liter of fresh distilled/deionized water.

8. Repeat steps 4 through 6.

9. Analyze the two sequential extracts separately.

Data obtained from the literature, which indicated extraction with deionized water, was considered to have been extracted in a manner similar to this procedure.

4.2.4 Inorganic Concentrations in Extracts from MWC Ashes

Table 4-5 lists ranges of inorganic parameters (including metals) detected in extracts produced by the deionized water extraction procedure (SW-924), EP and TCLP from MWC fly ash; Table 4-6 lists levels of inorganic parameters (including metals) observed in such leachates produced from combined (fly and bottom) ashes as reported in the literature and by the Versar Study. The reviewed literature (Volume IV of this report) did not contain similar leachate information for bottom ashes. This is probably because bottom ashes contain much lower levels of inorganics than fly ashes and than combined ashes, as discussed in Section 2.0 and as illustrated in Table 2-2. Thus, the assessment of the leachability of inorganics from bottom ashes is not as significant. For comparison purposes, the EP Toxicity Maximum Allowable Limit and the Primary Drinking Water Standards are included in the last two columns of each table.

Only one published reference included data from the TCLP extractions by Fluid #1 and Fluid #2. These values are listed in Tables 4-5 and 4-6. Examination of the data

TABLE 4-5

RANGES OF INORGANIC CONCENTRATIONS IN LEACHATES
PRODUCED BY SW-924, EP, AND TCLP LEACHING PROCEDURES FROM FLY ASH, IN mg/l (ppm)

Constituent	Ranges of Concentrations SW-924	Ranges of Concentrations EP Toxicity	Ranges of Concentrations TCLP	Ranges of Concentrations - TCLP		EP Toxicity Maximum Allowable Limit	Primary Drinking Water Standards
				Fluid #1	Fluid #2		
Arsenic	0.005-0.005	0 002-0 05	0 005-0 111			5 0	0 050
Barium	0 19-1 68	0 067-22.8		0 38-1.48	0 5-1 86	100 0	1 000
Cadmium	ND-33	0 025-18	0 015-17 2	0 03-18 8	0 03-20 3	1 0	0 010
Chromium	0.0025-176	0.0025-0 135	0 0025-0.544	0 02-0 12	0 02-0 03	5 0	0 050
Lead	0-150,000	0.019-53.35	0 025-15 2	6.10-26 8	5.3-36 6	5 0	0.050
Mercury	0 00002-0.02	ND-0.007	0 004-0 004			0 2	0 002
Selenium	0 0025-0 108	0 003-0 085	0 0025-0 025			1.0	0 010
Silver	0 02-0 05	0 001-0 051		0 02-0 07	0 02-0 08	5 0	0 050
Aluminum	0.09-0.25	0.159-18 8		0 21-16 0	0 09-0 09		
Beryllium	0.01-0 01	0 005-0.005		0 01-0 01	0 01-0 01		
Boron	ND-2100	1 53-6.53		1 36-7 3	1.79-5.94		
Calcium	896-4620	1,150-5,810		1,450-5,390	1,210-5,070		
Cobalt	ND-0.12	0 025-0 114		0 03-0.14	0.03-0 06		
Copper	0 0025-1,240	0 033-10.6	0.0025-0 201	0.02-14.70	0 02-1.08		
Iron	0 0025-0.167	0.0025-0.49	0.0025-190	0 03-0.17	0.03-0 03		
Lithium	0 27-0 38	0.261-0.455		0.25-0 55	0 28-0 53		
Magnesium	0 03-37.6	0.093-149		0 06-171	0.04-109.0		

TABLE 4-5
RANGES OF INORGANIC CONCENTRATIONS IN LEACHATES
PRODUCED BY SW-924, EP, AND TCLP LEACHING PROCEDURES FROM FLY ASH, IN mg/l (ppm)
PAGE TWO

Constituent	Ranges of Concentrations SW-924	Ranges of Concentrations EP Toxicity	Ranges of Concentrations TCLP	Ranges of Concentrations - TCLP		EP Toxicity Maximum Allowable Limit	Primary Drinking Water Standards
				Fluid #1	Fluid #2		
Manganese	0 0005-0 052	0 005-8 03	0 049-14 7	0 01-7 19	0.01-3.28		
Molybdenum	0 22-0 34	0.10-0.229		0 10-0 28	0 10-0 31		
Nickel	ND-420	0 09-2 9	0 0075-1 52	0 09-2 48	0 09-0 63		
Potassium	702-2530	616-2,170		574-2,390	708-2,780		
Sodium	587-971	506-821		474-922	1,950-2,500		
Strontium	2 6-17.7	3 5-16		3 97-14.6	3 4-17 30		
Tin	0 09-0 09	0 09-0 09		0 09-0.09	0.09-0 09		
Titanium	0.05-0.05	0 05-0.05		0.05-0 05	0 05-0 05		
Vanadium	0 02-0.02	0.015-0.015		0 02-0 02	0 02-0 02		
Yttrium	0.05-0.05	0.05-0.05		0 05-0 05	0.05-0 05		
Zinc	0.005-4.15	3.36-768	0 151-746	2.27-885	384-621		

ND - Below detection limit
Blank - Not reported
Source: Literature (Volume VI) and Versar Study (Volume V)

TABLE 4-6

RANGES OF INORGANIC CONCENTRATIONS IN EXTRACTS PRODUCED BY SW-924, EP, AND TCLP LEACHING PROCEDURES FROM COMBINED ASH, IN mg/l (ppm)

Constituent	Ranges of Concentrations SW-924	Ranges of Concentrations EP Toxicity	Ranges of Concentrations TCLP	Ranges of Concentrations - TCLP		EP Toxicity Maximum Allowable Limit	Primary Drinking Water Standard
				Fluid #1	Fluid #2		
Arsenic	0.005-0.05	0.005-0.1	0.005-0 037	0.01-0.03	0 01-0.10	5.0	0 050
Barium	0.15-0.39	0.027-6.3		0.10-3.2	0 05-0 63	100.0	1 00
Cadmium	0.005-0.03	0.01-3.94	0.025-3.32	0 03-1 9	0 01-0.47	1.0	0 010
Chromium	0.0025-0 02	0.0059-0 46	0.025-0 439	0 2-0.32	0 01-0 16	5.0	0 050
Lead	0.025-2.98	0.02-34	0.655-30 1	0 9-47	0.05-6 10	5.0	0 050
Mercury	0 01-0 1	ND-6.0	0 004-0.004	0.05-0 06	ND-0.10	0 2	0 002
Selenium	0.0025-0.05	0 002-0.10	0.0025-0 025	0.01-0 01	0 01-0 05	1 0	0 010
Silver	ND-0.05	0.001-0.10		0 02-0.04	0 01-0.05	5.0	0.050
Aluminum	0 17-29.4	31.9-43.8		30.8-32.8	0 09-0.09		
Beryllium	ND-0 01	0 005-0.005		0.01-0.01	0 01-0.01		
Boron	0.1-0.22	1.23-2.33		2.53-2.89	1.75-1.77		
Calcium	122-536	77-1,740		1,930-1,990	362-1,430		
Cobalt	0 01-0 03	0 050-0 057		0 05-0 05	0 03-0.03		
Copper	0.0025-0.19	0 039-1.19	0 0025-0 019	0.05-0.09	0 02-0 02		
Iron	0.0025-0.038	4.5-143	0.828-60.6	183-230	2.18-6.33		
Lithium	0.01-0.05	0.063-0.093		0 09-0.10	0 06-0.06		

TABLE 4-6
RANGES OF INORGANIC CONCENTRATIONS IN EXTRACTS
PRODUCED BY SW-924, EP, AND TCLP LEACHING PROCEDURES FROM COMBINED ASH, IN mg/l (ppm)
PAGE TWO

Constituent	Ranges of Concentrations SW-924	Ranges of Concentrations EP Toxicity	Ranges of Concentrations TCLP	Ranges of Concentrations - TCLP		EP Toxicity Maximum Allowable Limit	Primary Drinking Water Standards
				Fluid #1	Fluid #2		
Magnesium	ND-0.19	22.8-42.7		41 7-41.8	0 14-27 9		
Manganese	ND-0 01	3 6-6.24	4 2-11 9	7.04-7.47	3.22-3.34		
Molybdenum	0.07-0.1	0.10-0.10		0.10-0.10	0.10-0 10		
Nickel	0 0075-0 09	0.241-2.03	0 346-0.805	0.33-0 41	0.09-0.09		
Potassium	85.2-120	10-154		106-111	86.5-93.9		
Sodium	68.3-85.3	89.9-100		103-110	1,410-1,500		
Strontium	0.58-3.19	2.45-4.9		5.34-5.47	3.94-4.01		
Tin	0.02-0.09	0 09-0.09		0.09-0.09	0.09-0.09		
Titanium	0.01-0.05	0:05-0.05		0.05-0.08	0 05-0.05		
Vanadium	0 02-0 03	0 015-0 015		0 05-0.06	0 02-0 02		
Yttrium	0 01-0 05	0.05-0 05		0 05-0.05	0 05-0.05		
Zinc	0 0015-0.96	38 5-726	23.3-373	72.2-83.2	23.5-32		
Chloride	209-644	78-952			302-625		
Sulfate	156-571	85-1,150			260-1,450		

ND - Below detection limit
Blank - Not reported
Source: Literature (Volume IV) and Versar (Volume I)

listed in Tables 4-5 and 4-6 indicates that the EP Toxicity Maximum Allowable Limit is not met by the high range values of cadmium and lead extracted by the EP and the TCLP tests from fly ash and combined ash. Arsenic, barium, selenium, and silver values obtained by any of the tests from either fly ash or combined ash met the EP Toxicity Maximum Allowable Limit. Mercury extracted from fly ash by every one of the extraction procedures met the EP Toxicity Maximum Allowable Limit. Only one mercury value (6.0 mg/l) ppm obtained by the EP toxicity test from combined ash did not meet the EP Toxicity Maximum Allowable Limit. This suggests that the single high mercury value (6.0 mg/l) was probably an anomaly. Similarly, one chromium value, obtained when extracting fly ash with deionized water, did not meet the EP Toxicity Maximum Allowable Limit.

The study conducted by Cahill and Newland (1982) was designed to compare efficiencies of metal extraction from municipal incinerator ashes. In this study, also cited and discussed in Section 2.0 of this report, batch extractions were performed for two metals, cadmium and manganese, from refuse ash using deionized water, 0.1 N HCl, 1.0 N HCl, and 6.0 N HCl. The results of this part of the Cahill and Newland study indicated that increased amounts of cadmium and manganese were leached with increasing acidity. These two metals were chosen because of their different presumed mechanism of ash deposition during combustion (see Section 2.0 for discussion of the volatilization-condensation reaction mechanism). Cadmium exhibits surface predominance, whereas manganese exhibits matrix predominance.

The metals most likely to be leached are those that occur principally as surface deposited metals. Elements with lower boiling points typically exhibit higher extractability, whereas elements with higher boiling points show lower extractability. A "volatilization condensation" mechanism occurs when metals, such as cadmium and lead, volatilize in the high-temperature combustion zone of the incinerator and then condense at lower temperatures onto the surfaces of less volatile metals such as manganese, silicon, and aluminum. The data presented in Tables 4-5 and 4-6 confirm these conclusions. The condensation of these metals occurs in the oxide form which is relatively soluble in water and acids. Thus, although these metals may be present in the raw waste in relatively insoluble forms, after the oxidation in the incinerator to a combination of oxides and metal salts, their solubility in water and acids increases. Cadmium and lead are extracted by the

deionized water, and the acid solutions used by the EP and TCLP, to a much higher degree than any of the other metals.

A better understanding of these three different leaching procedures and their actual correlation with the reality of metal leaching from MWC ashes can be obtained by reviewing the following paragraphs, which summarize the data obtained from the two EPA-sponsored studies, the Versar and NUS studies (described in detail in Volume V and Volume VI of this report).

In the Versar study, leachates prepared by EP, TCLP, and SW-924 were analyzed for the following metals: cadmium, (Cd), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), manganese (Mn), nickel (Ni), zinc (Zn), arsenic (As), selenium (Se), and mercury (Hg). The results of these analyses are tabulated by sample matrix, facility, and leachate procedure in Table 4-7. The MWEP method yielded two extracts from each laboratory extract composite sample. These extracts are listed in Table 4-7 as EX1 (i.e., Extraction 1) and EX2 (i.e., Extraction 2).

Tables 2-3 and 2-4 respectively list the characteristics of the sampled incinerators and the sampled monofills. A review of Table 4-7 indicates the following:

- The variability between extraction procedures and sample matrices appears to be much greater than the variability between facilities.

- Zinc, iron, lead, and manganese were present in the highest concentrations in the extracts, whereas mercury was not present in any of the extracts.

A comparison between the different extraction procedures as provided by Table 4-7 indicates the following:

- The EP and TCLP extraction methods were much more aggressive than the MWEP for leaching every metal, except selenium. In fact, the MWEP method was the only extraction procedure that leached selenium. Data obtained from the literature (Volume IV), Tables 4-5 and 4-6, indicate that deionized water leached metals.

TABLE 4-7

EXTRACTABLE METALS DATA FOR THREE LABORATORY LEACHING PROCEDURES, VERSAR STUDY

Leachate Procedure	Facility	Sample Matrix	Cd mg/L	Cr mg/L	Cu mg/L	Fe mg/L	Pb mg/L	Mn mg/L	Ni mg/L	Zn mg/L	As mg/L	Hg mg/L	Se mg/L
EP Tox	A	Bottom/Fly	0.827	0.016	1.19	4.50	20.8	4.15	0.241	38.5	<0.01	<0.008	<0.0
TCLP	A	Bottom/Fly	0.682	0.096	0.019	60.6	16.3	7.18	0.346	55.8	0.020	<0.008	<0.0
SW924-EX1	A	Bottom/Fly	<0.01	<0.005	<0.005	<0.005	<0.05	<0.001	<0.015	<0.003	<0.01	<0.02	<0.00
SW924-EX2	A	Bottom/Fly	<0.01	<0.005	<0.005	<0.005	<0.05	<0.001	<0.015	0.0031	<0.01	<0.02	<0.00
EP Tox	C	Bottom/Fly	0.060	0.0059	0.039	143	2.09	4.11	0.337	726	<0.01	<0.008	<0.0
TCLP	C	Bottom/Fly	3.32	<0.005	0.0076	23.4	7.30	11.9	0.805	373	<0.01	<0.008	<0.0
SW924-EX1	C	Bottom/Fly	<0.01	<0.005	0.023	0.038	0.063	0.0021	<0.015	0.067	<0.01	<0.02	<0.0
SW924-EX2	C	Bottom/Fly	<0.01	<0.005	<0.005	0.015	<0.05	<0.001	<0.015	0.051	<0.01	<0.02	<0.00
EP Tox	D	Bottom/Fly	0.649	0.033	0.051	66.4	7.26	6.24	0.415	61.7	<0.01	<0.008	<0.0
TCLP	D	Bottom/Fly	0.025	<0.005	<0.005	0.828	0.655	4.20	0.573	23.3	<0.01	<0.008	<0.00
SW924-EX1	D	Bottom/Fly	<0.01	0.005	0.070	<0.005	<0.05	<0.001	<0.015	<0.003	<0.01	<0.02	<0.00
SW924-EX2	D	Bottom/Fly	<0.01	<0.005	0.009	0.01	<0.05	<0.001	<0.015	0.0034	<0.01	<0.02	<0.00
EP Tox	B	Bottom	0.388	0.150	0.127	21.0	34.0	3.60	0.250	58.4	<0.01	<0.008	<0.0
TCLP	B	Bottom	0.418	0.439	0.018	52.8	30.1	6.82	0.473	83.2	0.037	<0.008	<0.0
SW924-EX1	B	Bottom	<0.01	<0.005	0.0089	<0.005	<0.05	<0.001	<0.015	<0.003	<0.01	<0.02	<0.025
SW924-EX2	B	Bottom	<0.01	<0.005	<0.005	0.024	<0.05	0.0012	<0.015	0.018	<0.01	<0.02	<0.00
EP Tox	A	Fly	6.02	<0.005	0.045	<0.005	4.72	6.62	0.326	186	<0.01	<0.008	<0.05
EP Tox	A	Fly (Dup.)	7.72	<0.005	0.254	0.007	10.9	8.03	0.466	262	<0.01	<0.008	<0.05
TCLP	A	Fly	0.015	0.136	<0.005	190	0.962	4.62	0.372	77.6	0.024	<0.008	<0.025
TCLP	A	Fly (Dup.)	0.032	<0.005	0.116	<0.005	<0.05	0.049	<0.015	0.151	<0.01	<0.008	<0.05
SW924-EX1	A	Fly	<0.015	0.010	0.027	0.167	<0.075	0.0058	0.0225	0.026	<0.01	<0.04	<0.05
SW924-EX1	A	Fly (Dup.)	<0.01	<0.005	0.089	<0.005	<0.05	0.0017	<0.015	0.045	<0.01	<0.02	<0.005
SW924-EX2	A	Fly	<0.01	<0.005	0.009	0.057	0.072	0.003	<0.015	0.083	<0.01	<0.02	<0.005
SW924-EX2	A	Fly (Dup.)	<0.01	<0.005	<0.005	<0.005	<0.05	<0.001	<0.015	<0.003	<0.01	<0.02	<0.005
EP Tox	B	Fly	18.0	<0.005	0.171	0.060	19.3	4.65	0.137	726	<0.01	<0.008	<0.05
TCLP	B	Fly	17.2	<0.005	0.078	0.019	6.91	3.97	0.076	275	<0.01	<0.008	<0.05
SW924-EX1	B	Fly	<0.01	0.0086	<0.005	<0.005	<0.05	0.0024	<0.015	0.026	<0.01	<0.02	<0.05
SW924-EX2	B	Fly	0.033	0.01	0.012	0.118	0.148	0.0052	<0.015	1.2	<0.01	<0.02	<0.025
EP Tox	C	Fly	7.89	0.038	1.62	0.490	17.8	2.71	1.92	362	<0.01	<0.008	<0.05
TCLP	C	Fly	8.36	0.129	0.201	34.2	13.4	5.14	1.52	446	0.036	<0.008	<0.025
SW924-EX1	C	Fly	0.122	0.0060	0.045	0.067	0.128	0.014	<0.015	1.22	<0.01	<0.02	0.108
SW924-EX2	C	Fly	<0.01	<0.005	<0.005	<0.005	<0.05	<0.001	<0.015	<0.003	<0.01	<0.02	<0.025
EP Tox	D	Fly	8.60	<0.005	0.041	0.012	19.6	6.74	0.288	430	<0.01	<0.008	<0.05
EP Tox	D	Fly (Dup.)	9.18	<0.005	0.131	0.0074	25.2	7.6	0.284	458	<0.01	<0.008	<0.05
TCLP	D	Fly	10.3	0.487	0.018	12.8	15.2	14.7	0.582	746	0.086	<0.008	<0.05
TCLP	D	Fly (Dup.)	8.90	0.544	0.0059	15.0	12.8	13.6	0.567	624	0.111	<0.008	<0.005
SW924-EX1	D	Fly	0.015	0.071	0.0052	<0.005	<0.05	0.0061	<0.015	0.180	<0.01	<0.02	0.047
SW924-EX1	D	Fly (Dup.)	<0.01	0.114	0.0051	<0.005	<0.05	<0.001	0.022	0.036	<0.01	<0.02	<0.05
SW924-EX2	D	Fly	<0.01	0.116	<0.005	<0.005	<0.05	0.002	<0.015	0.018	<0.01	<0.02	<0.025
SW924-EX2	D	Fly (Dup.)	<0.01	0.15	<0.005	<0.005	<0.05	<0.001	<0.015	0.02	<0.01	<0.02	<0.025

TABLE 4-7
EXTRACTABLE METALS DATA FOR
THREE LABORATORY LEACHING PROCEDURES, VERSAR STUDY
PAGE TWO

Leachate Procedure	Sample Type	Summary Statistics	Cd mg/L	Cr mg/L	Cu mg/L	Fe mg/L	Pb mg/L	Mn mg/L	Ni mg/L	Zn mg/L	As mg/L	Hg mg/L	Se mg/L
EP Tox	Combined	Min.	0.06	0.0059	0.039	4.5	2.09	3.6	0.241	38.5	0.005	0.004	0.025
	Bottom/	Max.	0.827	0.15	1.19	143	34	6.24	0.415	726	0.005	0.004	0.025
	Fly Ash	Avg.	0.481	0.051	0.352	58.725	16.038	4.525	0.311	221.150	0.005	0.004	0.025
		Std Dev	0.289	0.058	0.485	53.677	12.419	1.014	0.071	291.610	0.000	0.000	0.000
TCLP	Combined	Min.	0.025	0.0025	0.0025	0.828	0.655	4.2	0.346	23.3	0.005	0.004	0.0025
	Bottom/	Max.	3.32	0.439	0.019	60.6	30.1	11.9	0.805	373	0.037	0.004	0.025
	Fly Ash	Avg.	1.111	0.135	0.012	34.407	13.589	7.525	0.549	133.825	0.017	0.004	0.019
		Std Dev	1.296	0.180	0.007	23.838	11.032	2.775	0.168	139.706	0.013	0.000	0.010
SW 924	Combined	Min.	0.005	0.0025	0.0025	0.0025	0.025	0.0005	0.0075	0.0015	0.005	0.01	0.0025
Extract 1	Bottom/	Max.	0.005	0.005	0.07	0.038	0.063	0.0021	0.0075	0.067	0.005	0.01	0.025
	Fly Ash	Avg.	0.005	0.003	0.026	0.011	0.035	0.001	0.008	0.018	0.005	0.010	0.011
		Std Dev	0.000	0.001	0.026	0.015	0.016	0.001	0.000	0.028	0.000	0.000	0.009
SW 924	Combined	Min.	0.005	0.0025	0.0025	0.0025	0.025	0.0005	0.0075	0.0031	0.005	0.01	0.0025
Extract 2	Bottom/	Max.	0.005	0.0025	0.009	0.024	0.025	0.0012	0.0075	0.051	0.005	0.01	0.0025
	Fly Ash	Avg.	0.005	0.003	0.004	0.013	0.025	0.001	0.008	0.019	0.005	0.010	0.003
		Std Dev	0.000	0.000	0.003	0.008	0.000	0.000	0.000	0.020	0.000	0.000	0.000
EP Tox	Fly Ash	Min.	6.02	0.0025	0.041	0.0025	4.72	2.71	0.137	186	0.005	0.004	0.025
		Max.	18	0.038	1.62	0.49	25.2	8.03	1.92	726	0.005	0.004	0.025
		Avg.	9.568	0.008	0.377	0.096	16.237	6.058	0.570	404.000	0.005	0.004	0.025
		Std Dev	3.895	0.013	0.561	0.177	6.654	1.837	0.611	171.624	0.000	0.000	0.000
TCLP	Fly Ash	Min.	0.015	0.0025	0.0025	0.0025	0.025	0.049	0.0075	0.151	0.005	0.004	0.0025
		Max.	17.2	0.544	0.201	190	15.2	14.7	1.52	746	0.111	0.004	0.025
		Avg.	7.468	0.217	0.070	42.004	8.216	7.013	0.521	361.459	0.045	0.004	0.017
		Std Dev	5.006	0.218	0.072	67.172	6.029	5.315	0.498	271.582	0.040	0.000	0.009
SW 924	Fly Ash	Min.	0.005	0.0025	0.0025	0.0025	0.025	0.0005	0	0.026	0.005	0.01	0.0025
Extract 1		Max.	0.122	0.114	0.089	0.167	0.128	0.014	0.022	1.22	0.005	0.02	0.108
		Avg.	0.027	0.035	0.029	0.041	0.044	0.005	0.009	0.256	0.005	0.012	0.039
		Std Dev	0.043	0.042	0.031	0.061	0.038	0.004	0.007	0.435	0.000	0.004	0.034
SW 924	Fly Ash	Min.	0.005	0.0025	0.0025	0.0025	0.025	0.0005	0.0075	0.0015	0.005	0.01	0.0025
Extract 2		Max.	0.033	0.15	0.012	0.118	0.148	0.0052	0.0075	1.2	0.005	0.01	0.0125
		Avg.	0.010	0.047	0.005	0.031	0.053	0.002	0.008	0.221	0.005	0.010	0.009
		Std Dev	0.010	0.061	0.004	0.044	0.046	0.002	0.000	0.439	0.000	0.000	0.005

TABLE 4-7
EXTRACTABLE METALS DATA FOR
THREE LABORATORY LEACHING PROCEDURES, VERSAR STUDY
PAGE THREE

LEGEND:

EP TOX = EP TOXICITY extraction procedure
TCLP = TOTAL CHARACTERISTIC LEACHATE PROCEDURE
SW 924 = Procedure for estimating monofilled solid waste leachate composition
SW 924 EX1 = First extract using SW 924 procedure
SW 924 EX2 = Second extract (on the same sample) using SW 924 procedure
Bottom/Fly = combined bottom ash and fly ash samples
Fly = Fly ash
Bottom = Bottom ash
Dup. = Duplicate (split) of the previous sample

Source: Versar Study (Volume V)

- The EP method appeared to extract copper and zinc more vigorously than the TCLP method, whereas the TCLP method extracted chromium, iron, manganese, nickel, and arsenic more aggressively than the EP method. In fact, the TCLP method was the only one to extract arsenic. The extraction efficiencies of EP and TCLP were approximately equal for cadmium, lead, and zinc.

- The concentrations of metals in SW-924-EX1 were generally greater than those in SW-924-EX2.

In the NUS Study, two fresh ash samples were collected from two codisposal facilities as they were arriving for disposal (NY and NC). These ashes were leached by the same methods as the Versar Study. Results for these two ashes samples are reported in detail in Volume VI of this report and in Tables 4-8 and 4-9, respectively. For comparison, the EP Toxicity Maximum Allowable Limit and the Primary Drinking Water Standards are given in the last two columns of each table.

Examination of the data presented in these two tables indicates that all EP Toxicity Maximum Allowable Limits were met except for lead. In one ash sample (NC), the EP Toxicity Maximum Allowable Limit of 5 mg/l (ppm) was not met by any of the three leaching methods, and in fact, exceeded it many folds. The lead levels were 49 mg/l (ppm) (EP), 240 mg/l (ppm) (TCLP), and 75 mg/l (ppm) (SW-924). For the second ash (NY) sample, the EP toxicity leachate for lead was only 3.17 mg/l (ppm).

Comparison of the aggressiveness of the leaching process between the EP and the TCLP indicates that for one ash (NC) sample, the TCLP leached consistently higher levels of metals, while for the second ash (NY) sample, the EP toxicity leaching procedures leached higher levels of cadmium and barium.

Comparison between inorganics in actual leachates from codisposal sites and monofills (Section 4.1) and in extracts produced by leaching procedures (Section 4.2) indicates that the levels of inorganic constituents, including metals in actual natural leachates were always lower than in leachates produced in the laboratory. The actual leachates always met the EP Toxicity Maximum Allowable Limits. The test-generated leachates, as discussed previously in this section, did not meet the EP Toxicity Maximum Allowable Limit for lead.

TABLE 4-8

INORGANIC CONTENT IN NY ASHES
AND IN EP TOXICITY, TCLP, AND SW-924
EXTRACTS, IN PPM

Contaminant	Ash	EP Toxicity	TCLP	SW-924	EP Toxicity Maximum Allowable Limit	Primary Drinking Water Standards
Arsenic	11.4	<0.02	0.203	Insufficient	5.0	0.050
Cadmium	14.8	0.195	0.155	Sample	1.0	0.010
Chromium	55.2	<0.02	0.270		5.0	0.050
Copper	226	ND	ND			
Iron	18,900	ND	ND			
Lead	630	3.17	9.58		5.0	0.050
Manganese	508	ND	ND			
Mercury	0.10	<0.02	<0.002		0.2	0.002
Nickel	144	ND	ND			
Selenium	<5	<0.05	<0.025		1.0	0.010
Zinc	1,510	ND	ND			
Barium	-	0.832	0.633		100	0.100
Silver	-	<0.02	<0.02		5.0	0.050

ND - Below the detection limit
Source: NUS Study (Volume VI)

TABLE 4-9

INORGANIC CONTENT IN NC ASH
AND IN EP TOXICITY, TCLP, AND SW-924
EXTRACTS, IN PPM

Contaminant	Ash	EP Toxicity	TCLP	SW-924	EP Toxicity Maximum Allowable Limit	Primary Drinking Water Standards
Arsenic	19.6	0.049	0.169	0.026	5.0	0.050
Cadmium	8.6	0.275	0.384	<0.02	1.0	0.010
Chromium	28.2	0.043	<0.1	<0.02	5.0	0.050
Copper	5,100	ND	ND	ND		
Iron	11,900	ND	ND	ND		
Lead	3,240	48.8	240	75.4	5.0	0.050
Manganese	352	ND	ND	ND		
Mercury	3.8	<0.002	0.044	<0.002	0.2	0.002
Nickel	498	ND	ND	ND		
Selenium	<5	<0.05	<0.025	<0.005	1.0	0.010
Zinc	3,750	ND	ND	ND		
Barium	ND	0.820	0.924	3.29	100.0	0.100
Silver	ND	<0.02	<0.1	<0.02	5.0	0.050

ND - Below the detection limit
Source: NUS Study (Volume VI)

Actual leachates from many MSW disposal sites, as reported in the literature and discussed as summarized in Table 4-1, also periodically did not meet the EP Toxicity Maximum Allowable Limit.

A recently published, EPA-sponsored study (SAIC) describes the collection of leachates from thirteen carefully selected hazardous waste disposal sites. Inorganics detected in the leachates from these hazardous waste sites were at much higher concentrations than in the leachates collected from the four municipal waste disposal sites, from the two NUS study codisposal sites (Volume VI), and from the Versar study monofills (Volume V).

5.0 ORGANICS IN LEACHATES FROM MSW DISPOSAL SITES, CODISPOSAL SITES, AND MONOFILLS AS WELL AS IN EXTRACTS

5.1 ORGANICS IN LEACHATES FROM MSW AND CODISPOSAL SITES

Tables 5-1 and 5-2 list ranges of organic compounds found in leachates collected from MSW disposal sites, as reported in the literature (Volumes II and III of this report). For comparison, the results obtained from the NUS study, where thirteen leachate samples collected from four MSW disposal sites and six leachate samples collected from two codisposal sites were analyzed for the entire list of Appendix IX compounds, are given in the last two columns of each table. The data presented in the last two columns were extracted from Volume VI of this report.

Examination of the data presented in these two tables indicates that numerous organic compounds, including many known or suspected carcinogens, are found in leachates from MSW disposal sites as reported in the literature.

The NUS sampling data used in this study originated from four MSW facilities and two codisposal facilities, none of which accepted industrial waste. All six facilities went into operation after RCRA was promulgated. For this reason, these data are by no means representative of MSW landfills in general.

The sites sampled by NUS, both the MSW and the codisposal sites, contained fewer compounds, and the compounds detected were present at significantly lower concentrations. Two probable reasons for this occurrence are that the selected sites were all constructed after RCRA regulations were enacted and that the selected sites do not accept industrial wastes for disposal.

Organic compound levels in leachates from the NUS-selected municipal disposal sites do not differ significantly from those collected from the codisposal sites.

TABLE 5-1

CONCENTRATIONS OF ORGANIC CONSTITUENTS
IN LEACHATE FROM MUNICIPAL WASTE LANDFILLS, IN µg/l (ppb)

Constituent	Range*	NUS Municipal	NUS Codisposal
Acetone	140-11,000	4-4,600	ND-1,500
Benzene	2-6,080	ND	ND
Bromomethane	10-170	ND	ND
1-Butanol	50-360	ND	ND
Carbon tetrachloride	2-398	ND	ND
Chlorobenzene	2-237	ND	ND
Chloroethane	5-860	ND	ND
Bis(2-Chloroethoxy)methane	2-25	ND	ND
Chloroform	2-1,300	ND	ND
Chloromethane	10-170	ND	ND
Delta BHC	0-5	ND	ND
Dibromomethane	5-25	ND	ND
1,4-Dichlorobenzene	2-37	ND	ND
Dichlorodifluoromethane	10-450	ND	ND
1,1-Dichloroethane	2-6,300	ND	ND
1,2-Dichloroethane	0-11,000	ND-16	ND
Cis-1,2-Dichloroethene	4-190	ND	ND
Trans-1,2-Dichloroethene	4-2,760	ND	ND
Dichloromethane	2-3,300	ND	ND
1,2-Dichloropropane	2-100	ND-230	ND
Diethyl phthalate	2-330	ND	ND
Dimethyl phthalate	4-55	ND	ND
Di-n-butyl phthalate	4-150	ND-23	ND
Endrin	0-1	ND	ND-250
Ethyl acetate	5-50	ND	ND

TABLE 5-1
CONCENTRATIONS OF ORGANIC CONSTITUENTS
IN LEACHATE FROM MUNICIPAL WASTE LANDFILLS, IN µg/l (ppb)
PAGE TWO

Constituent	Range*	NUS Municipal	NUS Codisposal
Ethyl benzene	5-4,900	ND	ND-15
Bis(2-ethylhexyl) phthalate	6-150	ND	ND
Isophorene	10-16,000	ND	ND
Methyl ethyl ketone	110-28,000	290-12,000	ND-2,200
Methyl isobutyl ketone	10-660	ND	ND
Naphthalene	4-68	ND	ND
Nitrobenzene	2-120	ND	ND
4-Nitrophenol	17-40	ND	ND
Pentachlorophenol	3-470	ND	ND
Phenol	10-28,800	ND-2,100	ND-2,100
2-Propanol	94-10,000	ND	ND
1,1,2,2-Tetrachloroethane	7-210	ND	ND
Tetrachloroethene	2-620	ND	ND
Tetrahydrofuran	5-260	ND	ND
Toluene	2-3,200	ND-1,100	ND-120
Toxaphene	0-5	ND-16	ND
1,1,1-Trichloroethane	0-2,400	ND	ND
1,1,2-Trichloroethane	2-500	ND	ND
Trichloroethene	1-1,120	ND	ND
Trichlorofluoromethane	4-100	ND-230	ND
Vinyl chloride	0-110	ND	ND
m-Xylene	21-79	ND	ND
p-Xylene + o-Xylene	12-50	ND-23	ND-290

*Source: Sobotka and Wisconsin Studies described and referenced in Literature Reviews Volumes II and III.
ND = Below detection limit

TABLE 5-2

CONTAMINANT CONCENTRATIONS FROM
LEACHATE OF MUNICIPAL LANDFILLS AND CODISPOSAL SITES
(Concentration in mg/l) (ppm)

Parameter	Lyon* Municipal Landfill	Meeker* Municipal Landfill	Rochester* Municipal Landfill	NUS Municipal Sites	NUS Codisposal Sites
Benzene[a]	0.036	0.270	0.54		
Butanol[a]	25	0.120	10.		
Chlorobenzene		0.060			
Cis-1,2-Dichloroethylene		0.190	0.47		
1,1-Dichloroethane[a]	0.046	0.035	0.026	ND-0.004	ND
1,2-Dichloroethane			0.006	ND-0.016	ND
1,2-Dichlorobenzene[a]	0.019	0.032	0.010		
1,4-Dichlorobenzene[a]			0.014		
Dichloromethane[a]	0.200	0.064	1.3		
1,2-Dichloropropane	0.002	0.013	0.081		
Ethanol[a]	110.		23.		
Ethyl Acetate	0.290	0.018	0.130		
Ethyl Benzene	0.015	0.820	0.250	ND	ND-0.015
Methyl Ethyl Ketone	0.650	9.8	27.	ND-12.0	ND-2.2
Methyl Isobutyl Ketone	0.087	0.410	0.710		
1-Propanol[a]	37.	0.076	11.		
2-Propanol[a]	41.	1.9	26.		
Tetrachloroethylene[a]			0.250		
Tetrahydrofuran	0.280	0.140	0.430		
Toluene[a]	0.180	0.390	0.6	ND-1.1	ND-0.12
Trans-1,2-Dichloroethylene[a]	0.0038	0.017	0.088		
Trichloroethane[a]	0.0076				
Trichloroethylene[a]	0.043	0.043	0.125		
Xylene[a]	0.092	0.32	0.198	ND	ND-0.29

*Source: Texas A&M University Report discussed and described in Volume II
(a) = Potential carcinogens
ND = Below detection limit

5.2 ORGANICS IN LEACHATES FROM MONOFILLS

Volume V of this report, the Versar Study, reported levels of organics in leachates collected from monofills. Table 5-3 summarizes the findings of this report in terms of compounds and concentrations. The number of times each compound was detected has also been reported in this table. Analyses were carried out for TOC, organic scan, and BNAs.

The quench water collected at each of the four sampled facilities contained a larger number of organic compounds and at significantly higher concentrations. The quench water contained phenol; 2-methyl phenol; 4-methyl phenol; dimethyl phenol; benzoic acid; naphthalene; acenaphthalene; phenantrene; butyl phthalate fluoranthene; pyrene; bis(ethylhexyl)phthalate; methyl butanoic acid; 1,2,4-trithiolane; 2-hydroxy benzoic acid; 4-hydroxy-4-methyl-2-pentanone; 1H; 3H-naphtho (1,8-cd) pyran-1,3-dion; 3-hydroxy-2methyl 4H pyran-4-one; hexanoic acid; methyl pentanoic acid; benzaldehyde; methyl pentanediol; 5-(hydroxymethyl)-2-2-furancarboxaldehyde; benzene propanoic acid; tetra decanoic acid; 2,2,4-trimethyl 1,3-purine dione; benzene acetic acid; and decanoic acid. Table 5-4 summarizes the levels of these organics in quench water, field leachates, and groundwater samples collected by Versar at monofills.

5.3 ORGANICS IN EXTRACTS FROM MWC ASHES

The EPA-sponsored Versar and NUS studies reported organic compounds in extracts generated in the laboratory by the EP, TCLP, or any other tests. These are reported in detail in Volumes V and VI of this report.

The ashes collected by NUS were leached by Versar in the same manner the Versar collected samples were leached. Analyses were conducted by Versar, as well. The Versar study has produced leachates which contained some base-neutral and acid extractables, as reported in Tables 5-5 through 5-7. The NUS ashes produced extracts that did not contain any of the base-neutral and acid extractable (BNA) compounds above the detection limits.

TABLE 5-3

RANGES OF LEACHATE CONCENTRATIONS OF ORGANICS FROM MUNICIPAL SOLID WASTE INCINERATOR RESIDUES (MONOFILLS) DETERMINED FROM ACTUAL LEACHATE FIELD SAMPLES IN mg/l (ppm)

Constituents	Range of Concentration	Number of Times Found*
Ethyl Hexyl Phthalate[1]	ND - 0.08	4 out of 9
Dimethyl Propane Diol[2]	ND - 0.120	4 out of 9
Biphenyl	ND - 0.051	2 out of 9
Hexa Tiepane[3]	ND - 0.082	1 out of 9
Thiolane[4]	ND - 0.400	2 out of 9
Benzaldehyde	ND - 0.008	1 out of 9
Sulfonylbis sulfur	ND - 0.011	1 out of 9
Number of Samples	**9**	

ND = Below Detection Limit
Source: Versar Study (Volume V)

1 Bis(2-ethyl Hexyl)phthalate (CAS 117-81-7)
2 2,2-Dinethyl-1,3-propanedial (CAS 126-30-7)
3 Hexathiepane (CAS 17233-71-5)
4 1,2,4-Trithiolane (CAS 289-16-7)

*Above Detection Limit

TABLE 5-4

ORGANIC CONSTITUENTS IN FIELD WATER SAMPLES

FIELD LEACHATES

Plant	Sample Description	TOC (mg/l)	Organic Scan (mg/l)	BNA Peaks Found (No.)	Ethyl Hexyl Phthalate 117817 (ug/L)	Dimethyl Propane Diol 126307 (ug/L)	Biphenyl 90437 (ug/L)	Hexa Thiepane 17233715 (ug/L)	Thiolane 289167 (ug/L)
B	East Side	189.0	<0.25	2					
B	Northeast Corner	204.0	<0.25	3		9			
B	North Side	273.0	<0.25	4		22			
C	Northwest Corner	379.0	<0.25	2					
C	Northeast Corner	187.0	2.5	8	12				
C	North Side	59.1	<0.25	1					
D	Southeast Corner	574.0	<0.25	21	7				
D	Northeast Corner	536.0	<0.25	22	80	110	51	82	400
D	Northeast Corner, Dup	567.0		24	37	120	51		140
	No.	9	8	9	4	4	2	1	2
	Min.	59.1	0	1	7	9	51	82	140
	Max.	636	2.5	24	80	120	51	82	400
	Avg.	340.9	NA	9.7	34.0	65.3	51.0	82.0	270.0
	Std. Dev.	195.4	NA	9.2	28.9	50.1	0.0	0.0	130.0

Plant	Sample Description	Benz-aldehyde 100527 (ug/L)	Sulfo-nylbis Sulfur 67710 (ug/L)	Unknown HCs (#)	Unknowns (#)
B	East Side				2
B	Northeast Corner				2
B	North Side				3
C	Northwest Corner		11		1
C	Northeast Corner	8		2	4
C	North Side				1
D	Southeast Corner			4	16
D	Northeast Corner			9	8
D	Northeast Corner, Dup			10	10
	No.	1	1		
	Min.	8	11		
	Max.	8	11		
	Avg.	8.0	11.0		
	Std. Dev.	0.0	0.0		

TABLE 5-4
ORGANIC CONSTITUENTS IN FIELD WATER SAMPLES
PAGE TWO

QUENCH WATER

Plant	Sample Description	TOC (mg/l)	Organic Scan (mg/l)	BNA Peaks Found (No.)	Phenol 108952 (ug/L)	2-Methyl phenol 95487 (ug/L)	4-Methyl phenol 106445 (ug/L)	Dimethyl phenol 105679 (ug/L)	Benzoic Acid 65850 (ug/L)	Naphtha-lene 91203 (ug/L)
A	Unit 2, 9/26	94.5	<0.25	29	65	6			36	8
A	Unit 1, 9/26	26.9	<0.25	8					260	
B	Unit 3, 9/28	77.3	<0.25	23	170	17			300	
B	Unit 4, 9/28, Dup	421.0	<0.25	20	380	40	92		2100	
B	Unit 4, 9/28	416.5	<0.25	20	380	44	94		2100	
C	Unit 2, 9/28	3.2	12.3							
C	Unit 2, 9/30	29.2	<0.25	5						
D	Unit 2, 10/3	165.0	<0.25	25	60	7	23		570	
D	Unit 2, 10/3, Dup	153.0		25	71	7			900	
D	Unit 2, 10/4	1228.0	<0.25	25	640	86		44	3800	
	No.	10	9	9	7	7	3	1	8	1
	Min.	3.2	0.125	5	60	6	23	44	36	8
	Max.	1228	12.3	29	640	86	94	44	3800	8
	Avg.	261.5	1.48	20.0	252.3	29.6	69.7	44.0	1258.3	8.0
	Std. Dev.	352.4	3.83	7.7	205.2	27.3	33.0	0.0	1219.0	0.0

Plant	Sample Description	Acenaph-thylene 208968 (ug/L)	Phenan-threne 85018 (ug/L)	Butyl Phthalate 84742 (ug/L)	Fluor-anthene 206440 (ug/L)	Pyrene 129000 (ug/L)	Ethyl Hexyl Phthalate 117817 (ug/L)	Methyl Butanoic Acid 116530 (ug/L)	Molecular Sulfur 10544500 (ug/L)	Thiolane 289167 (ug/L)
A	Unit 2, 9/26	6	6		6	5				
A	Unit 1, 9/26									
B	Unit 3, 9/28			3						
B	Unit 4, 9/28, Dup								29	
B	Unit 4, 9/28								130	23
C	Unit 2, 9/28									
C	Unit 2, 9/30							33		
D	Unit 2, 10/3						8			
D	Unit 2, 10/3, Dup									
D	Unit 2, 10/4									
	No.	1	1	1	1	1	1	1	2	1
	Min.	6	6	3	6	5	8	33	29	23
	Max.	6	6	3	6	5	8	33	130	23
	Avg.	6.0	6.0	3.0	6.0	5.0	8.0	33.0	79.5	23.0
	Std. Dev.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	50.5	0.0

TABLE 5-4
ORGANIC CONSTITUENTS IN FIELD WATER SAMPLES
PAGE THREE

Plant	QUENCH WATER Sample Description	2-Hydrox Benzoic Acid 69727 (ug/L)	Hydroxy Methyl Pentenone 80717 (ug/L)	Pyran Naphtho Dione 81845 (ug/L)	Hydroxy Methyl Pyranone 118718 (ug/L)	Hydro Pyranone 542280 (ug/L)	Hexanoic Acid 142621 (ug/L)	Methyl Pentanoic Acid 646071 (ug/L)	Benz-aldehyde 100527 (ug/L)	Methyl Pentane-diol 144194 (ug/L)
A	Unit 2, 9/26			6	11	11	22			
A	Unit 1, 9/26						10			
B	Unit 3, 9/28	40	26				30			
B	Unit 4, 9/28, Dup	50					58			
B	Unit 4, 9/28	42					37			
C	Unit 2, 9/28									
C	Unit 2, 9/30									
D	Unit 2, 10/3						45	17	22	17
D	Unit 2, 10/3, Dup						51	84		
D	Unit 2, 10/4				130		920	88		
	No.	3	1	1	2	1	8	3	1	1
	Min.	40	26	6	11	11	10	17	22	17
	Max.	50	26	6	130	11	920	88	22	17
	Avg.	44.0	26.0	6.0	70.5	11.0	146.6	63.0	22.0	17.0
	Std. Dev.	4.3	0.0	0.0	59.5	0.0	292.7	32.6	0.0	0.0

Plant	Sample Description	Furan Carbox-aldehyde 67470 (ug/L)	Benzene Propanoic Acid 501520 (ug/L)	Tetra Decanoic Acid 544638 (ug/L)	Methyl Purine Dione 58082 (ug/L)	Benzene Acetic Acid 103822 (ug/L)	Decanoic Acid 334485 (ug/L)	Unknown Org Acids (#)	Unknown HCs (#)	Unknowns (#)
A	Unit 2, 9/26							2		15
A	Unit 1, 9/26									6
B	Unit 3, 9/28									16
B	Unit 4, 9/28, Dup									13
B	Unit 4, 9/28									12
C	Unit 2, 9/28									
C	Unit 2, 9/30									4
D	Unit 2, 10/3	54	23	72	23			1	2	9
D	Unit 2, 10/3, Dup		12		22			1		17
D	Unit 2, 10/4					120	160	2	1	13
	No.	1	2	1	2	1	1			
	Min.	54	12	72	22	120	160			
	Max.	54	23	72	23	120	160			
	Avg.	54.0	17.5	72.0	22.5	120.0	160.0			
	Std. Dev.	0.0	5.5	0.0	0.5	0.0	0.0			

TABLE 5-4
ORGANIC CONSTITUENTS IN FIELD WATER SAMPLES
PAGE FOUR

GROUNDWATER

Plant	Sample Description	TOC (mg/l)	Organic Scan (mg/l)	BNA Peaks Found (No.)	Ethyl Hexyl Phthalate 117817 (ug/L)	Unknowns (#)
A	#1	3.4	<0.25			
B	#2	2.7	<0.25			
C	#3	80.9	<0.25	0		
C	#17	76.1	<0.25	2	9	1
C	#4	97.4	<0.25	0		
C	Production Well	2.0	<0.25			
	No.	6				
	Min.	2				
	Max.	97.4				
	Avg.	43.75				
	Std.	41.56				

NOTE:
Names of organic constituents abbreviated;
CAS numbers provided with constituent names

TABLE 5-5

RANGES OF EXTRACT CONCENTRATIONS OF ORGANIC CONSTITUENTS FROM MUNICIPAL WASTE INCINERATOR BOTTOM ASH FOR THREE LEACHING PROCEDURES (in mg/l) (ppm)

Constituents	Range of Concentrations			
	Deionized Water Extraction Procedure		Extraction Procedure	Toxic Characteristic Leaching Procedure
	First Extraction	Second Extraction		
Naphthalene	ND	ND	ND	ND
Methyl Naphthalene	ND	ND	ND	ND
Dimethyl Prodiol[1]	ND	ND	ND	ND
Methyoxy Ethane[2]	ND - 0.010	ND	ND - 0.012	ND - 0.022
Phenol	ND - 0.028	ND	ND	ND
E. Dim Dioxane[3]	ND	ND	ND	ND
Bis Oxy Ethanol[4]	ND	ND	ND	ND
Oleyl Alcohol[5]	ND	ND	ND	ND
Ethoxy Ethanol[6]	ND	ND	ND	ND
Cycloocta Decone[7]	ND - 0.150	ND	ND	ND
M. Furan Dione[8]	ND - 0.006	ND	ND	ND
Benzoic Acid	ND - 0.046	ND	ND	ND

ND = Below Detection Limit
1 2,2-dimethyl-1,3-propanediool (CAS 126-30-7)
2 1-methoxy-2-(methoxmethoxy) Ethane (9C1) (CAS 77498-88-7)
3 5-ethyl-2,2-dimethyl-1,3-Dioxane (9C1) (CAS 25796-26-3)
4 2,2-[1,2-ethanediglibis (oxy) bix-bis] Ethanol (CAS 112-27-6)
5 (2)-9 Octadecen-1-01 (CAS 143-28-2)
6 2-(2-(ethenyloxy)ethonxy)-Ethanol (CAS 929-37-3)
7 1,4,7,10,13,16-Hexa oxacyclooctodecane (CAS 17455-13-9)
8 3,4-dimethyl-2,5-Furadione (9C1) (CAS 766-39-2)

TABLE 5-6

RANGES OF EXTRACT CONCENTRATIONS OF ORGANIC CONSTITUENTS FROM MUNICIPAL WASTE INCINERATOR COMBINED FLY AND BOTTOM ASH FOR THREE LEACHING PROCEDURES IN mg/l (ppm)

Constituents	Range of Concentrations			
	Deionized Water Extraction Procedure		Extraction Procedure Test	Toxic Characteristic Leaching Procedure
	First Extraction	Second Extraction		
Naphthalene	ND	ND	ND-8	ND
Methyl Naphthalene	ND - 0.080	ND	ND-18	ND
Oleyl Alcohol[1]	ND - 0.088	ND	ND	ND
Methyoxy Ethane[2]	ND	ND	ND	ND
Methoxy Ethanol	ND	ND - 0.006	ND	ND - 0.013
Dimethyl Propdiol[3]	ND - 0.160	ND - 0.140	ND - 0.190	ND - 0.140
Phenol	ND	ND - 0.033	ND	ND
Bis Oxy Ethanol[4]	ND - 0.096	ND - 0.018	ND	ND
Ethoxy Ethanol[5]	ND - 0.310	ND - 0.390	ND	ND
Cycloocta Decone[6]	ND - 0.580	ND - 1.2	ND	ND
M. Furan Dione[7]	ND	ND	ND	ND
E. Dim Dioxane[8]	ND - 0.510	ND	ND	ND
Benz, Di Carboxy A	ND	ND - 0.002	ND	ND

ND = Below Detection Limit
Source: Versar Study (Volume V)

1 (2)-9 Octadecen - 1-01 (CAS 143-28-2)
2 1-Methoxy -2- (methoxy methoxy) Ethane (9C1) (CAS 74498-88-7)
3 2,2-Dimethyl-1,3-Propanedial (CAS 162-30-7)
4 2,2-{1,2-Etharediylbis (oxy) bis-] ethanol (CAS 112-27-6)
5 (2)-9 Octadecer-1-01 (CAS 143-28-2)
6 1,4,7,10,13,16-Hexaoxa cycloocta decane (CAS 17455-13-9)
7 3,4-Dimethyl-2,5-Furadione (9C1) (CAS 766-39-2)
8 5-Ethyl-2,2-dimethyl-1,3-Dioxane (9C1) (CAS 25796-26-3)

TABLE 5-7

RANGES OF EXTRACT CONCENTRATIONS OF ORGANIC CONSTITUENTS FROM MUNICIPAL WASTE INCINERATOR FLY ASH FOR THREE LEACHING EXTRACTION PROCEDURES in mg/l (ppm)

Constituents	Range of Concentrations			
	Deionized Water Extraction Procedure		Extraction Procedure Test	Toxic Characteristic Leaching Procedure
	First Extraction	Second Extraction		
Naphthalene	ND	ND	ND	ND
Methyl Naphthalene	ND	ND	ND	ND
Dimethyl Prodiol[1]	ND	ND	ND	ND
Methyoxy Ethane[2]	ND	ND	ND	ND - 0.01
Methoxy Ethanol	ND	ND	ND	ND - 0.01

ND = Below Detection Limit
Source: Versar Study (Volume V)

1 2,2-dimethyl-1,3-propanedial (CAS 126-30-7)
2 1-methoxy-2-(methoxy methoxy) Ethane (9C1) CAS 74498-88-7)

Examination of the Versar data reported in Tables 5-5 through 5-7 indicates that the results for the EP-prepared extracts showed that similar BNAs were detected in samples from each facility with approximately equal concentrations. Furthermore, every EP extract that had a quantifiable BNA-contained diethylphthalate, which was the predominant BNA. Phthalate esters, such as diethyl phthalate, are common plasticizers. This fact was also noted in the laboratory leachate blank samples and therefore may represent a background interference. The BNAs appeared to be slightly more abundant in the bottom/fly ash than in the fly ash. This is consistent with the observation that phthalate compounds were detected in the Versar-sampled bottom ash samples rather than fly ash samples (see Section 2.0).

A review of the TCLP-prepared leachate results showed the same trends described above for the EP-prepared extracts.

The results presented in Tables 5-3 through 5-7 for the SW-924 extracts showed that there was not a predominant BNA compound, that the bottom/fly ash and bottom ash contained slightly more leachable BNAs than the fly ash, and that there was essentially no difference between the first and second SW-924 extractions.

Upon comparing the results from the three different leaching procedures, the following observations were noted. First, the TCLP method appears to be more efficient for extracting BNAs than the EP method. However, for the compounds that were extracted by both procedures (e.g., diethylphthalate), the concentrations were approximately equal. Second, the extraction efficiency for SW-924 procedure appears to lie between the EP and TCLP methods. However, SW-924 procedures extracted totally different classes of BNA constituents than the EP and TCLP methods. Finally, for all three procedures, the combined bottom/fly ash and bottom ash contained slightly more BNAs than their corresponding fly ash. This fact suggests that the BNA compounds are associated with the coarser, heavier bottom ash materials or may be completely destroyed as the fly ash passes through high-temperature zones in the incinerator.

6.0 PCDDs AND PCDFs IN LEACHATES AND EXTRACTS

As discussed in Section 2.3, MWC ashes contain a variety of PCDD and PCDF homologs. Since the tetra homologs for both PCDDs and PCDFs are more toxic (the tetra 2,3,7,8 is the known most toxic), the EPA (1987) has developed an interim procedure of estimating the risk associated with exposure to mixtures of PCDDs and PCDFs by using the Toxicity Equivalency Factors (TEF), which essentially convert concentrations of each homolog to a 2,3,7,8-TCDD equivalent, based on toxicity.

Table 6-1 lists levels of PCDD and PCDF homologs found in fly ash, bottom ash, combined ashes, TCLP-generated leachates, actual field-collected leachates and quench waters as reported in the Versar Report (Volume V of this report) for the four facilities sampled in the course of the Versar Study. The 2,3,7,8-TCDD equivalents were calculated and reported in the bottom of each column, assuming conservatively that the total individual homologs consist entirely of the 2, 3, 7, 8 of that particular homolog. For example, for calculating the TEF of penta-CDD, the total penta CDD was assumed to consist entirely of 2,3,7,8 penta CDD. Since the acceptable level of 2,3,7,8-TCDD is 1 part per billion (ppb), the 2,3,7,8-TCDD equivalents are calculated in this unit (µg/kg for solids and µg/l for liquids).

A review of the PCDD and PCDF concentrations in the TCLP-prepared leachates showed that the extracted concentrations of PCDDs and PCDFs were approximately equal. Only hepta-CDD and octa-CDD homologs were detected in two fly ash leachates (Facilities A and B), and only the octa-CDD homolog was detected in one bottom ash leachate (Facility B). Similarly, the hepta-CDF and octa-CDF homologs were detected in one fly ash leachate (Facility B), whereas only the hepta-CDF homolog was detected in the Facility A fly ash leachate. The octa-CDF homolog was detected in only one bottom ash leachate (Facility B). Because the solid samples contained significantly more PCDD and PCDF homologs than the TCLP-prepared leachates, these observations indicate that the TCLP method is inefficient for extracting (i.e., leaching) PCDD and PCDF compounds in a waste ash matrix.

TABLE 6-1

CHLORINATED DIOXIN AND CHLORINATED DIBENZOFURAN LEVELS IN ASHES AND LEACHATES FROM MONOFILLS

Compound	Fly Ash (ng/g)	Fly/Bottom Ash (ng/g)	TCLP Leachates (ng/l)		Quench Water (ng/l)
			Bottom/Fly	Fly	
MONOFILL A					
2,3,7,8-TCDD	0.093-0.24	0.02-0.33	<0.038	<0.056	<0.08-<0.08
TOTAL TCDD	2.3-6.6	1.5-13	<0.038	<0.056	0.1-2
TOTAL PCDD	11-32	2.7-19	<0.023	<0.056	0.82-4
TOTAL HxCDD	18-35	1.9-11	<0.018	<0.026	0.66-2
TOTAL HpCDD	14-26	1.7-8.2	<0.028	0.11	0.58-1.9
TOTAL OCDD	11-31	0.84-3.7	<0.035	0.078	0.43-0.98
TOTAL Dioxin	64.3-116.7	8.69-54.9	0	0.188	2.59-10.88
2,3,7,8-TCDF	-	0.88-12	<0.031	<0.120	0.27-2.1
TOTAL TCDF	20-89	6.3-91	<0.031	<0.120	1.7-12
TOTAL PCDF	7.1-32	2.5-37	<0.013	<0.019	0.91-6.1
TOTAL HxCDF	14-96	1.3-18	<0.008	<0.015	0.51-3.1
TOTAL HpCDF	9.9-44	0.62-6.6	<0.013	0.049	0.36-1.2
TOTAL OCDF	1.4-4.0	0.18-1.3	<0.060	<0.081	0.27-0.27
TOTAL Furan	60.2-209.4	10.9-153.9	0	0.049	4.02-24.77
2,3,7,8-TCDD Equivalency (µg/kg or µg/l)	21-50	3.5-24	0.000	0.000	0.001-0.005

TABLE 6-1
CHLORINATED DIOXIN AND CHLORINATED DIBENZOFURAN LEVELS IN ASHES AND LEACHATES FROM MONOFILLS
PAGE TWO

Compound	Fly Ash (ng/g)	Bottom Ash (ng/g)	TCLP Leachates (ng/l)		Field Leachate (ng/l)	Quench Water (ng/l)
			Bottom Ash	Fly Ash		
MONOFILL B						
2,3,7,8-TCDD	0.13-0.63	<0.04-0.01	<0.076	<0.072	<0.06-0.28	<0.07-<0.07
TOTAL TCDD	6.5-18	<0.04-0.65	<0.076	<0.072	<0.06-6.6	<0.07-<0.07
TOTAL PCDD	84-139	<0.01-2	<0.027	<0 040	<0.05-25	<0.03-<0.05
TOTAL H_xCDD	123-322	<0.002-2.3	<0 015	<0.027	<0.02-22	<0.01-<0.04
TOTAL H_pCDD	93-435	<0.09-6.3	<0.120	0.036	0.009-21	<0.03-0.05
TOTAL OCDD	89-1,363	<0.16-29	0.091	0.11	0.14-14	0.06-0.13
TOTAL Dioxin	430-2,113	<0.27 - 40.25	0.091	0.146	0.149-88.6	0.06-0.18
2,3,7,8-TCDF	-	0.02-0.3	<0.040	<0.052	<0.05-3.7	<0.06-<0.08
TOTAL TCDF	48-107	0.06-1.3	<0.040	<0.052	<0.05-22	<0.06-<0.08
TOTAL PCDF	37 65	0.02-1.5	<0.013	<0.026	<0.02-17	<0.01-<0.04
TOTAL H_xCDF	41-241	0.02-2.5	<0.022	<0.020	<0.01-16	<0.01-<0.02
TOTAL H_pCDF	19-63	0.03-6.9	<0.043	0.063	0.05-9.4	<0.02-0.04
TOTAL OCDF	8 1-34	<0.04-3.7	0.054	0.89	0.05-1.9	<0.15-<0.30
TOTAL Furan	186-271.3	0.16-15.9	0.054	0.152	0.1-66.3	0-0.04
2,3,7,8-TCDD Equivalency (µg/kg or µg/l)	106-527	0.004-7.7	0.000	0.000	0.000 - 0.037	0.000 - 0.000

TABLE 6-1
CHLORINATED DIOXIN AND CHLORINATED DIBENZOFURAN LEVELS IN ASHES AND LEACHATES FROM MONOFILLS
PAGE THREE

Compound	Fly Ash (ng/g)	Bottom/Fly Ash (ng/g)	Landfill Composite (ng/g)	TCLP Leachates (ng/l)		Field Leachate (ng/l)	Quench Water (ng/l)
				Bottom Fly	Fly		
MONOFILL C							
2,3,7,8-TCDD	<014-3.9	0.12-0.78	0.07	<0.065	<0.094	<0.05-1.6	<0.17-<0.81
TOTAL TCDD	<0.14-43	1.3-14	1.2	<0.065	<0.094	<0.05-28	<0.17-0.59
TOTAL PCDD	<0.02-980	10-50	5.7	<0.067	<0.042	<0.03-93	0.26-5.9
TOTAL H_XCDD	<0.03-5,565	11-78	6.8	<0.022	<0.019	<0.02-130	1.1-10
TOTAL H_PCDD	<0.06-4,900	15-120	9	<0.049	<0.079	<0.02-172	1.5-19
TOTAL OCDD	<0.16-3,152	7.7-89	6.1	<0.100	<0.130	0.06-120	1.2-12
TOTAL Dioxin	0-12,018	48.9-350	28.8	0	0	0.06-543	4.06-47.49
2,3,7,8-TCDF	0.66-26	0.55-3.8	0.51	<0.064	<0.077	<0.08-11	0.14-0.55
TOTAL TCDF	3.8-169	3.4-24	2.4	<0.064	<0.077	<0.08-65	0.98-2.4
TOTAL PCDF	1.5-310	4.8-27	3.9	<0.020	<0.026	<0.02-64	0.76-4
TOTAL H_XCDF	0.22-2,353	6.3-35	4	<0.020	<0.014	<0.01-76	0.61-6.2
TOTAL H_PCDF	<0.03-666	4.8-36	3.3	<0.024	<0.030	<0.03-60	0.52-6.5
TOTAL OCDF	<0.15-362	1.4-8.4	0.81	<0.130	<0.100	0.04-15	0.25-1.4
TOTAL Furan	5.52-3,187	22.8-130.4	14.41	0	0	0.04-280	3.12-20.5
2,3,7,8-TCDD Equivalency (µg/kg or µg/l)	0.22 - 780	6.2 - 33	3.7	0.000	0.000	0.000 - 0.062	0.000 - 0.004

TABLE 6-1
CHLORINATED DIOXIN AND CHLORINATED DIBENZOFURAN LEVELS IN ASHES AND LEACHATES FROM MONOFILLS
PAGE FOUR

Compound	Fly Ash (ng/g)	Bottom/Fly Ash (ng/g)	Landfill Composite (ng/g)	TCLP Leachates (ng/l)		Field Leachate (ng/l)	Quench Water (ng/l)
				Bottom Fly	Fly		
MONOFILL D							
2,3,7,8-TCDD	0.37-0 83	0.04-0.07	0.15	<0.230	<0.071	<0.22-<0.26	1-17
TOTAL TCDD	5.1-19	<0.28-1.3	2.5	<0.230	<0.071	0.13-0.27	24-700
TOTAL PCDD	46-91	1.9-4	6	<0.060	<0.048	<0.22-0.4	80-650
TOTAL H_XCDD	49-106	1.4-3.4	4.1	<0.044	<0.022	2.1-2.2	72-500
TOTAL H_PCDD	37-81	1.4-3.3	4.2	<0.100	<0.038	8.2-8.8	77-450
TOTAL OCDD	35-113	1.2-2.6	3.9	<0 230	<0.140	23-25	53-330
TOTAL Dioxin	175.9-253.2	6.2-14.6	20.7	0	0	33 93-36 17	306-2,550
2,3,7,8-TCDF	-	0.41-0.76	1.3	<0.200	<0 048	0.37-0.4	14-110
TOTAL TCDF	36-93	2.3-5.1	11	<0.200	<0.048	2.9-3	91-640
TOTAL PCDF	27-47	1.6-4.7	7.7	<0 042	<0.016	2.3-2.4	83-560
TOTAL H_XCDF	21-115	1.2-4.1	5.3	<0.025	<0.013	1.9-1.9	81-490
TOTAL H_PCDF	3.8-80	0.81-2.6	2.7	<0.035	<0.020	1.2-1.3	59-310
TOTAL OCDF	3.1-9 8	0.21-0.59	0.61	<0.260	<0.015	0 81 0.84	16-75
TOTAL Furan	93.4-311.8	6.14-17.09	27.31	0	0	9.21-9.34	330-2,075
2,3,7,8-TCDD Equivalency (µg/kg or µg/l)	28 - 57	1.3 - 2 8	4.3	0.000	0.000	0.000 - 0.001	0.055 - 0.427

Furthermore, they indicate that only the highly chlorinated PCDD and PCDF species (i.e., hepta- and octa-) tended to be extracted by TCLP.

The field leachate sample results indicate that only minute quantities in the part per trillion levels of PCDDs (Figure 6-1) and PCDFs (Figure 6-2) were identified. This suggests that PCDDs and PCDFs are not mobile in the natural environment through aqueous transport pathways unless significant microbial activity produces organic acids or similar compounds which have the potential to make dioxins mobile (Sawell, 1987).

The PCDD results for the quench water (Figure 6-3) showed that the variability between shifts and units was relatively small compared to the variability between facilities. This suggests that the different combustion conditions and feed materials at each facility contributes to this variability. The quench water samples from Facility D contained the highest PCDD concentrations. There did not appear to be any correlations for the least or most abundant homologs, or for the 2,3,7,8-TCDD isomer.

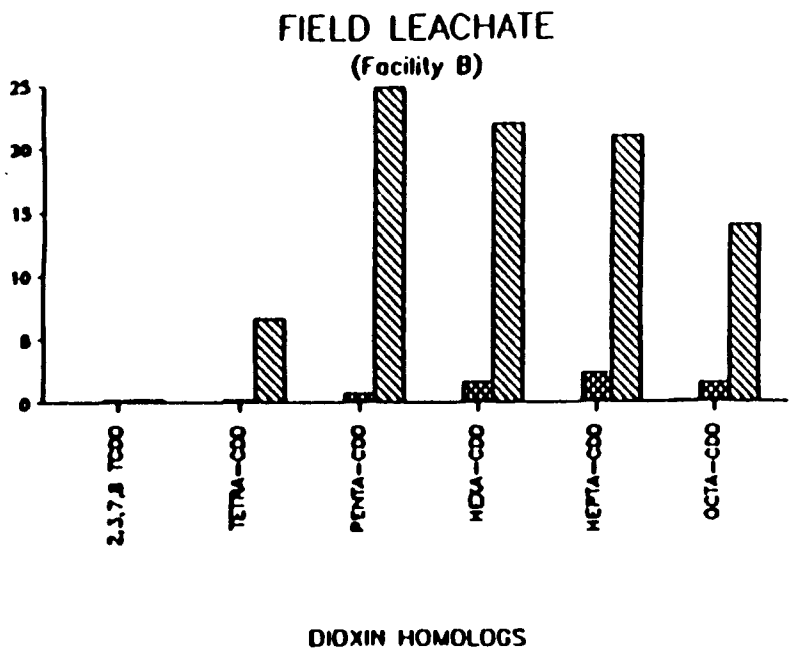
A review of the PCDF concentrations in the quench water (Figure 6-4) again showed that the variability between shifts and units was relatively small compared to the variability between facilities. The quench water from Facility D contained the highest PCDF concentrations. Again, there did not appear to be any trends for the least or most abundant homologs, or for the 2,3,7,8-TCDF isomer.

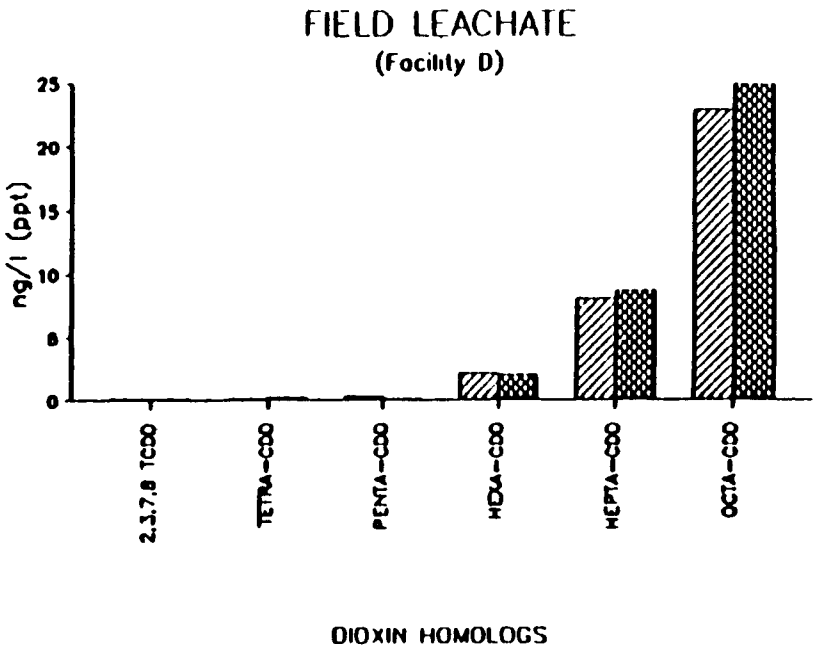
It should be noted that neither the quench water samples nor the field leachates samples were filtered prior to analysis. All of these samples appeared turbid, and thus contained suspended particulates. The analyses of these samples report total values, i.e., levels in the water samples and levels in the suspended solids. The variation in results reported for these samples may originate from differences in the amounts of solids found in these samples.

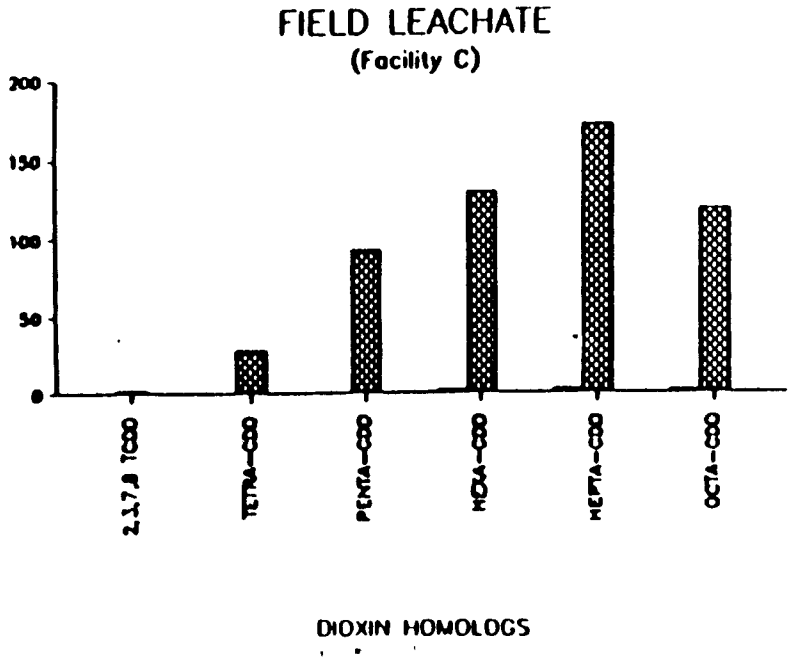
Due to the low solubility of these compounds in water, the reported values are probably mostly values of the suspended particulates.

Table 6-2 lists the concentrations of PCDD and PCDF homologs detected in the ashes disposed of in the two codisposal sites (NC and NY) sampled by NUS (Volume IV of

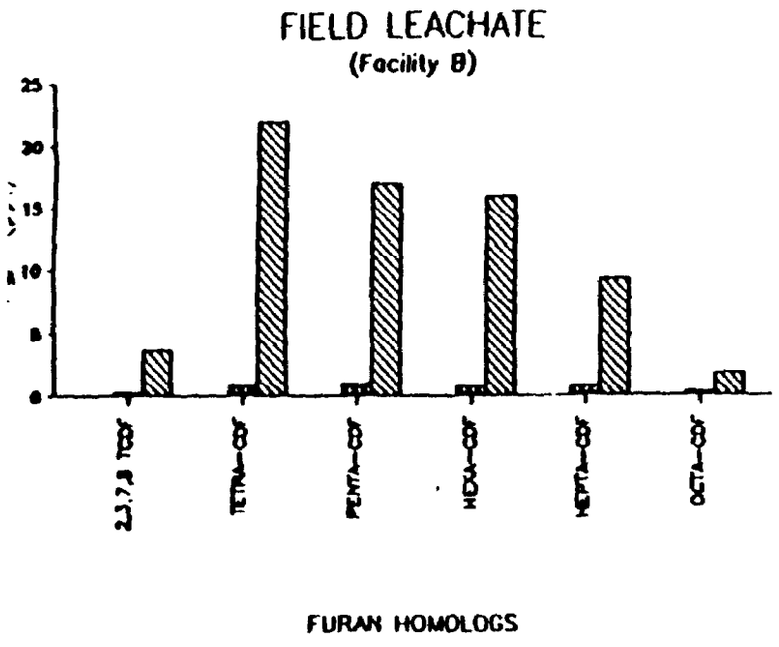
Concentrations of Dioxin Homologs in Field Leachates from the Three Facilities Sampled by Versar in ng/l (parts per trillion)

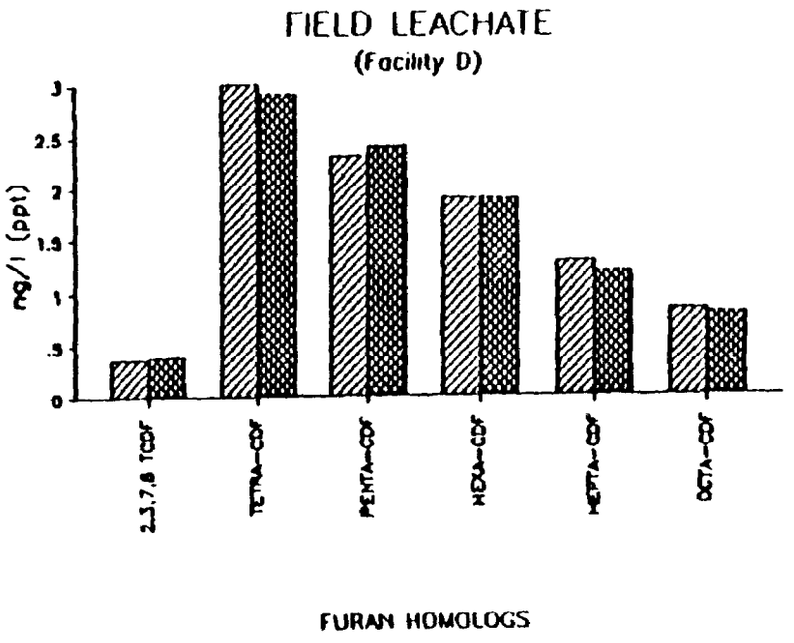


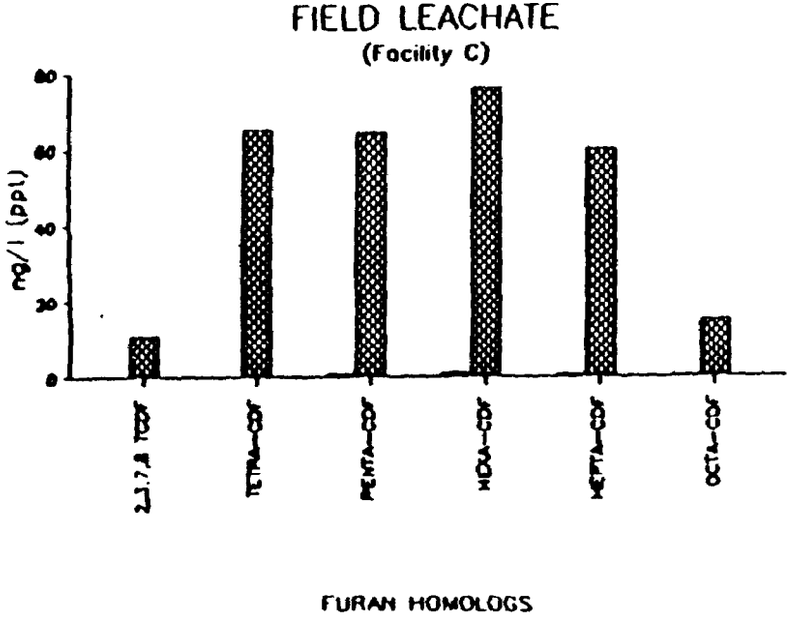




Note: Each bar represents an individual sample collected from an individual unit.



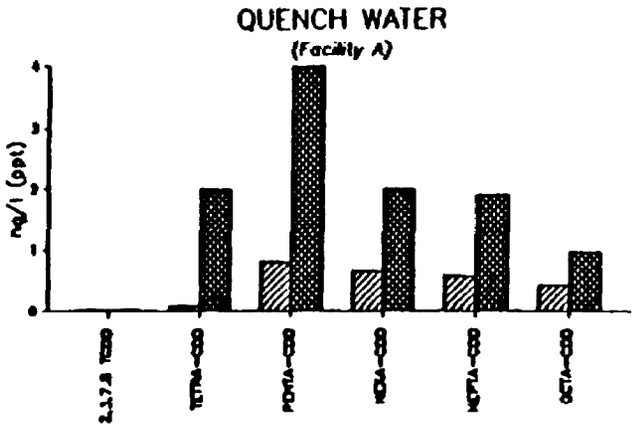


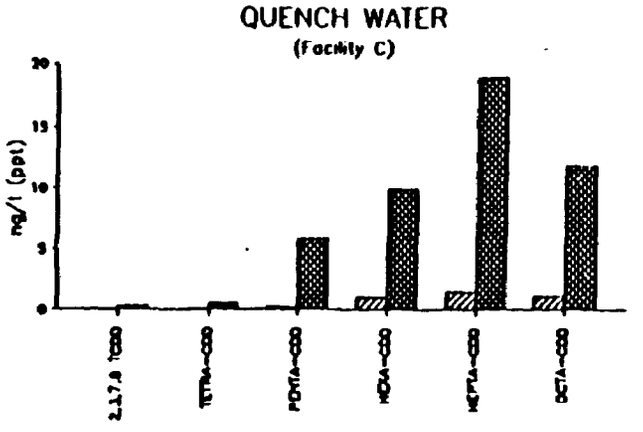


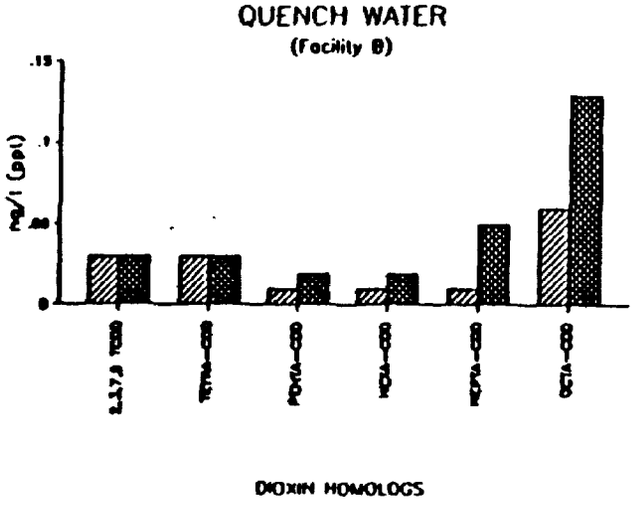
Note: Each bar represents an individual sample collected from an individual unit.

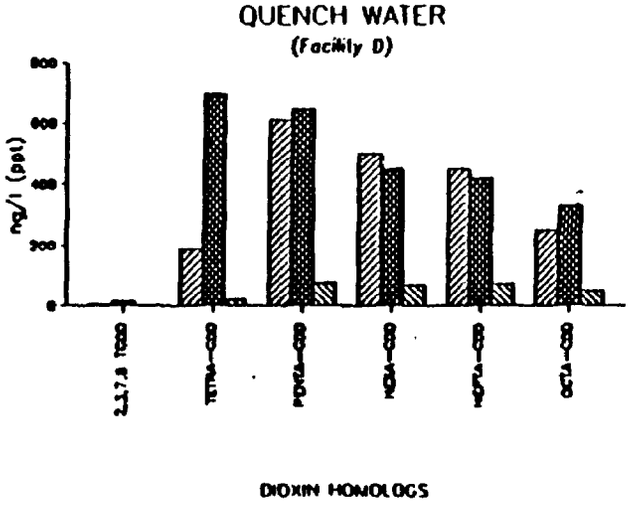
FIGURE 6-3

Concentrations of Dioxin Homologs in Quench Water from the Four Facilities Sampled by Versar in ng/l (parts per trillion)

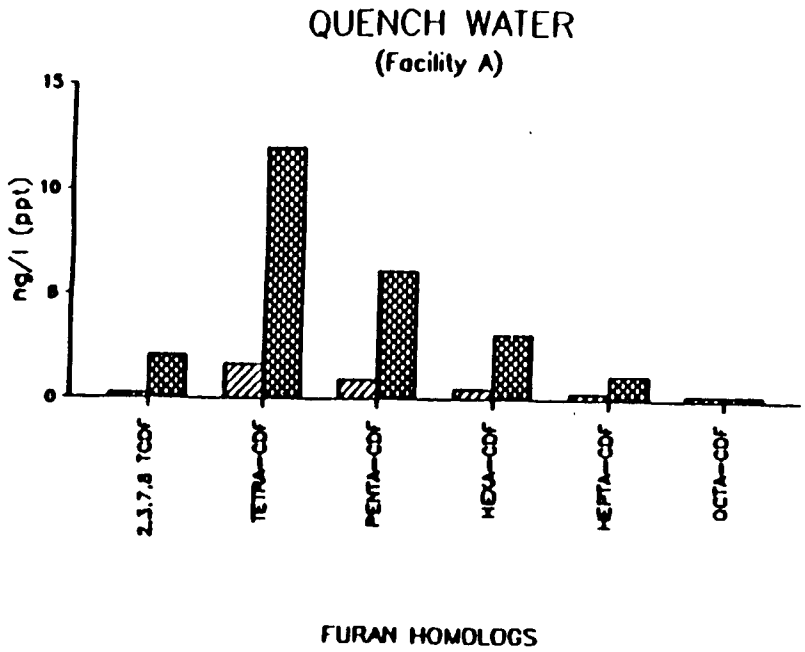


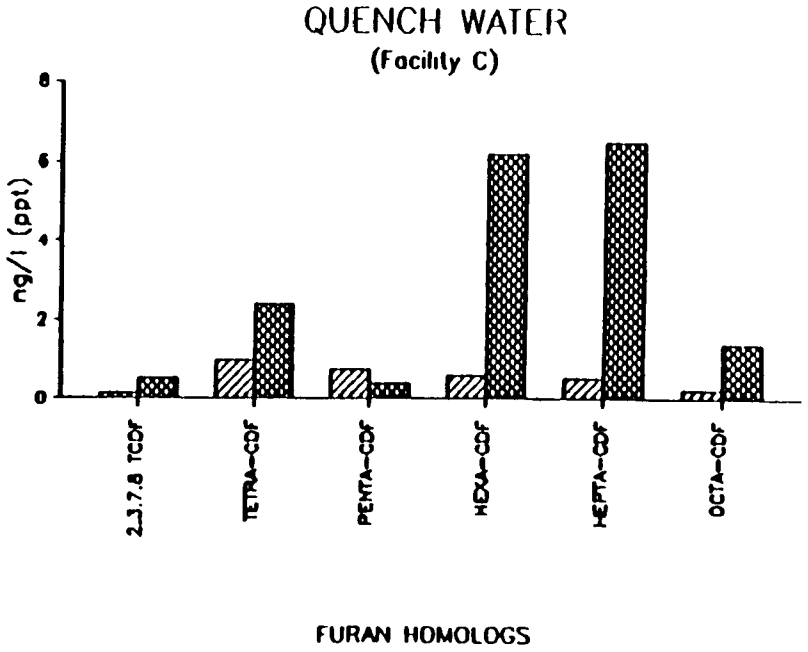


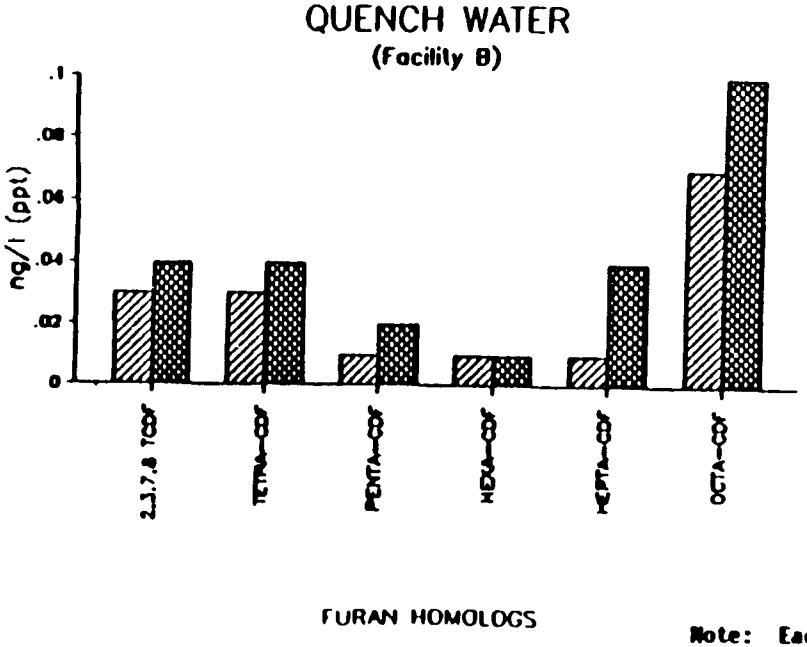


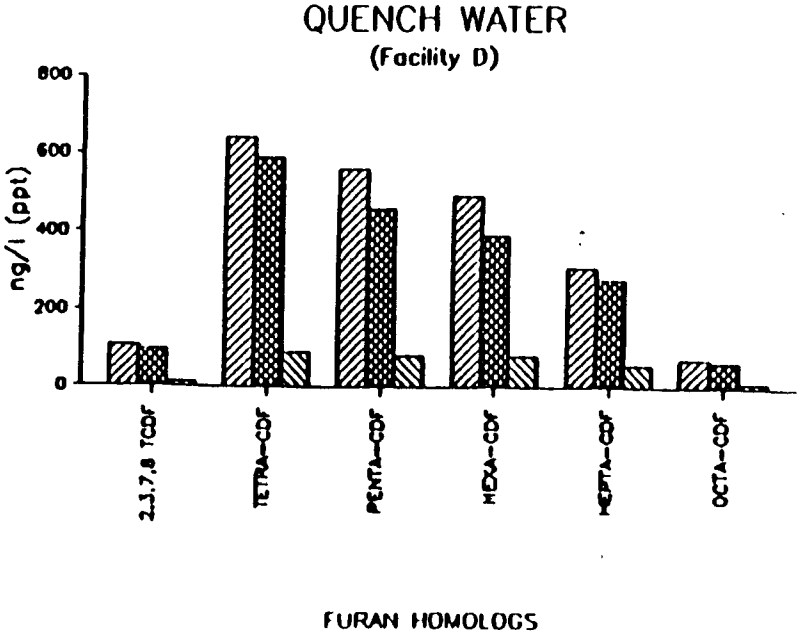


Note: Each bar represents an individual grab sample.









Note: Each bar represents an individual grab sample.

TABLE 6-2

CHLORINATED DIOXIN AND CHLORINATED DIBENZOFURAN LEVELS IN ASH AND LEACHATES FROM THE NC CODISPOSAL LANDFILL

Compound	Ash (ng/g) ppb	Leachates (ng/l) parts per trillion			
		Actual	TCLP	SW 924	EP-Tox
2,3,7,8-TCDD	ND	ND	ND	ND	ND
TOTAL TCDD	0.03	ND	ND	ND	ND
TOTAL PCDD	0.10	ND	ND	ND	ND
TOTAL H_XCDD	0.1	0.130	ND	ND	ND
TOTAL H_pCDD	0.18	0.770	ND	ND	0.021
TOTAL OCDD	0.14	15	ND	0.035	0.031
2,3,7,8-TCDF	0.07	ND	ND	ND	ND
TOTAL TCDF	0.56	ND	ND	ND	ND
TOTAL PCDF	0.29	0.035	ND	ND	ND
TOTAL H_XCDF	0.19	0.035	ND	ND	ND
TOTAL H_pCDF	0.11	0.085	ND	ND	0.012
TOTAL OCDF	0.02	0.054	ND	ND	ND
2,3,7,8-TCDD Equivalents ppb (µg/kg or µg/l)	0.27	0.001	0.000	0.000	0.000

ND = Below detection limit
Source: NUS Study (Volume VI)

TABLE 6-2
CHLORINATED DIOXIN AND CHLORINATED DIBENZOFURAN LEVELS IN ASH AND LEACHATES FROM THE NY CODISPOSAL LANDFILL
PAGE TWO

Compound	Ash (ng/g, ppb)	Leachates (ng/l) parts per trillion		
		Actual	TCLP	EP-Tox
2,3,7,8-TCDD	ND	ND	ND	ND
TOTAL TCDD	0.02	ND	ND	ND
TOTAL PCDD	0.12	ND	ND	ND
TOTAL H_XCDD	0.43	0.047	ND	ND
TOTAL H_pCDD	4.2	0.120	ND	ND
TOTAL OCDD	9.9	0.210	ND	0.033
2,3,7,8-TCDF	0.11	ND	ND	ND
TOTAL TCDF	0.46	ND	ND	ND
TOTAL PCDF	0.54	0.028	ND	ND
TOTAL H_XCDF	1.2	0.041	ND	ND
TOTAL H_pCDF	2.2	0.043	ND	ND
TOTAL OCDF	1.7	0.023	ND	ND
2,3,7,8-TCDD Equivalents (ug/kg or ug/l)	4.4	0.000	0.000	0.000

ND = Below detection limit
Source: NUS Study (Volume VI)

this report). PCDD and PCDF homolog concentrations in actual leachate samples, as well as in leachates generated by the EP, TCLP, and SW-924 methods are also given in these tables. Calculated 2,3,7,8-TCDD equivalents are included in the bottom of each column.

Review of the data presented in Table 6-2 indicates the following:

- 2,3,7,8-TCDD, the most carcinogenic homolog known, was not detected in the ashes, the actual leachates, or the extracts.

- The ashes contained ng/g (ppb) levels of total tetra, penta, hexa, hepta, and octa PCDDs and PCDFs.

- The NY ashes were a product of incomplete combustion, the beginning of the burn. As would be expected, the concentrations of most homologs are somewhat higher in these ashes.

- Extracts produced by the the TCLP procedure did not contain any of the PCDD or PCDF homologs.

- SW-924 was run on only one ash sample. This leaching procedure produced only 0.035 ng/l (parts per trillion) of the octa dioxin homolog. According to the EPA "Toxicity Equivalency Factors" (TEF) by which the individual homolog toxicity is converted to 2,3,7,8-TCDD equivalency, the multiplying factor for this octa homolog is 0.00. In other words, the octa homolog is treated as having no carcinogenic potential.

- The EP toxicity leaching procedures produced for one ash, 0.033 ng/l of the dioxin octa and for the second ash, 0.031 ng/l (part per trillion) of the dioxin octa, and 0.021 ng/l (part per trillion) of the dioxin hepta homologs. The TEF for H_pCDD is 0.001, which represents a very low level of carcinogenicity compared to 2,3,7,8-TCDD.

- The actual leachates collected at both codisposal sites contained very low concentrations of H_xCDD, H_pCD, OCDD, PCDF, H_xCDF, H_pCDF, and OCDF.

- Although the ashes from one site exhibited higher concentrations of most homologs because of incomplete combustion, the leachate did not exhibit the same trend. The leachates reflected previously disposed ashes present at the site rather than the analyzed ashes.

- The leachates from the two codisposal sites did not contain any tetra homologs.

- Wastes from MSW facilities have not been routinely subjected to the expensive testing for PCDDs or PCDFs. Neither have leachates from MSW facilities. However, according to a recent Canadian Government Publication, Ontario Ministry of the Environment: PCDDs and PCDFs: Scientific Criteria Document for Standard Development, No. 4-84, September 1985, dioxins and dibenzofurans were detected in actual solid waste found in municipal waste disposal sites. Such waste, the bulk of the codisposal site material, could contribute PCDDs and PCDFs to the leachates produced by these codisposal sites.

- Canadian studies suggest that incinerators, on a mass balance basis, are net destroyers of dioxins (Sawell, 1987).

7.0 CONCLUSIONS

The main conclusions of the information obtained through the literature reviewed for this study and from the two EPA-sponsored studies are reported in this section.

The main conclusions for the MSW and codisposal study (the NUS study) are as follows:

Conventional Parameters

- Water-quality parameters detected in the thirteen leachate samples collected at these four municipal waste sites were within the range of those reported in the literature for other sites. However, they did not show as much variation as does the published literature. The ranges reported in the literature are very wide for most parameters, covering several orders of magnitude; the pH ranged from acidic (3.7) to basic (8.5); The BOD, COD, and TOC values ranged from not determined (ND) to 720,000, 750,000 and 30,500 mg/l, respectively. The levels in leachates from the four sites sampled by NUS were at least one order of magnitude lower for BOD, COD, and TOC than values reported in the literature, and the pH was neutral to slightly basic, ranging from 6.98 to 7.8.

- Generally, there was no clear difference between the general water quality parameters of the thirteen leachate samples collected from the four municipal disposal sites and the six leachate samples collected from the two codisposal sites.

- Bacteria seem to be able to play an important part in the final water-quality characteristics of field leachates, as evidenced by the presence of ammonia in monofill leachates. The presence of 438 to 1,310 ppm of TOC and the 1,300 to 3,900 ppm of COD in the collected samples is indicative of substrate which may provide nutrients for bacteria. Both oxidizing and reducing bacteria can affect the quality of leachates in monofills.

Inorganics

- Concentrations of inorganic parameters (including metals) detected in leachates from the four municipal disposal sites were similar to levels reported in the literature for leachates from other municipal disposal sites. However, the higher levels of the metals reported in the literature exceeded the EP Toxicity Maximum Allowable Limit. Leachates from the four facilities sampled always met the EP Toxicity Maximum Allowable Limit. These four facilities were all constructed after the RCRA regulations were enacted, and these facilities do not accept industrial hazardous wastes.

- In general, there is no clear difference between the metal content in leachates from the codisposal sites and from the municipal disposal sites. This indicates that the neutral (pH 6.98 to 7.82) MSW-generated leachates do not promote leaching of metals from the MWC ashes. On the contrary, in the facilities we tested, they can provide dilution.

- The metal content in actual leachates collected from the codisposal sites was always lower than in test leachates (EP, TCLP, or SW-924). The actual leachates always met the EP Toxicity Maximum Allowable Limit; one ash sample exceeded the EP Toxicity Maximum Allowable Limit of 5 mg/l for lead when subjected to any of the three test methods.

- A recently published, EPA-sponsored study, "Composition of Leachates from Actual Hazardous Waste Sites," describes the collection of leachates from 13 carefully selected hazardous waste disposal sites. The metals detected in leachates from the hazardous waste sites were at much higher concentrations than in the leachates collected from the four municipal waste disposal sites and from the two codisposal sites.

- The pH in leachates from monofills, as reported in the literature, ranged between 8.04 and 8.3 and, in leachates from the monofills sampled by Versar, the range was between 7.44 and 8.58. The slightly lower pH values in leachates from the codisposal sites (7.2 to 7.3) may imply that the ashes have a somewhat neutralizing effect on the leachates generated by

municipal wastes. This may reflect a high initial wash-off of calcium-based compounds in the ash.

Organics

- Very few organic compounds, of the huge list of organics on Appendix IX, were detected in the leachates from either the municipal waste disposal sites or the codisposal sites. Only 11 volatile compounds, 4 semi-volatile compounds, and 5 pesticides were detected in these leachates. Concentrations of these compounds were very low. The volatile compounds cannot originate from the MWC ashes because volatiles are driven off at much lower temperatures than those in an incinerator.

- There is no noticeable difference in the number of organic compounds, or in the detected levels, between the leachates collected from the codisposal sites and the municipal disposal sites.

- Leachates generated by EP, TCLP, or SW-924 from ashes collected from the codisposal sites did not generate detectable semi-volatile compounds or PCBs.

- In the recently published, EPA-sponsored study in which leachates from 13 carefully selected actual hazardous waste sites were analyzed for the same compounds, leachates from these hazardous sites contained 42 organic acids, 43 oxygenated/heteroatomic hydrocarbons, 39 halogenated hydrocarbons, 26 organic bases, 32 aromatic hydrocarbons, and 8 aliphatic hydrocarbons. The levels of these detected compounds ranged from several parts per billion (ppb) to many thousands of parts per million (ppm).

- The leachates from the four municipal waste disposal sites were not analyzed for PCDDs or PCDFs. Only the actual leachates from the codisposal sites, the ashes from these sites, and the artificially generated leachates were analyzed for PCDDs and PCDFs. None of the analyzed samples contained 2,3,7,8-TCDD, which is the most toxic homolog known. The ashes contained ppb levels of total tetra, penta, hexa, and octa. The

TCLP procedure did not produce any PCDDs or PCDFs; the EP toxicity procedure and SW-924 produced part-per-trillion (ppt) levels of the octa and hepta homologs. The actual leachates contained part-per-trillion (ppt) levels of octa, hepta, and hexa levels of PCDDs and octa, hepta, hexa, and penta of PCDFs. Even when assuming conservatively that each total homolog type consisted of only the appropriate 2,3,7,8 homolog, the 2,3,7,8-TCDD equivalents were 0.00 µg/l. The ash at one site (NY), which was from the beginning of a run and did not go through complete combustion, contained somewhat higher PCDD and PCDF levels than the second site (NC) ash. A recent government of Canada publication claims that PCDDs are PCDFs are present in raw municipal waste. Before any conclusions are drawn regarding PCDD and PCDF levels in leachates from codisposal sites , leachates from raw municipal waste disposal sites should be analyzed for PCDDs and PCDFs as well.

The main conclusions from the monofill study (the Versar Study) are as follows for residue values:

- The variability of the contaminant concentrations between days, shifts, and units at any of the four sampled facilities was significant, a fact which indicates that slight changes in the incinerator feed material (i.e., the raw refuse) and /or the operating parameters significantly affected the quality of MWC residue. The variability of the contaminant concentrations between these facilities was extremely large (i.e., the standard deviations of the concentrations exceeded the average concentrations). This suggests that the variability of operating characteristics, facility design, and feed material composition between facilities has a significant impact on the resultant MWC residue quality. It may also imply that, despite compositing the analyzed samples, the heterogenetic nature of the ashes generally precludes obtaining representative "laboratory size" samples.

- In general, the weight ratio of bottom ash to fly ash was approximately 3 to 1 for the four facilities in this study. This ratio appears to be high and may reflect less than ideal operating conditions at the facilities sampled. Generally, fly ash makes up 10 to 20 percent of the total (Sawell, 1987).

- The quench water at all four facilities was discharged to the local wastewater treatment plant. Based on the analytical results for the quench water samples, this appears to be a suitable disposal technique.

- Generally, there did not appear to be a correlation between the operating characteristics of the sampled facilities and the metals concentrations in the residues. The variation in metal composition within each facility, each unit, and each shift is greater than the variation between the different units.

- The fly ash contained higher concentrations of all metals except copper and iron than the bottom ash. Therefore, combining the ash fractions effectively diluted the total metals concentrations of the fly ash.

- The fly ash consistently contained higher concentrations of PCBs, PCDDs, and PCDFs than the combined ash or bottom ash. However, the combined ash and bottom ash had higher concentrations of semi-volatiles than the fly ash.

- The contaminant concentrations of the disposed ash (i.e., the landfill perimeter composites) and the combined ash were not significantly different except for lead in one of two sampled facilities.

- The PCB concentrations were less than the 50 ppm limit established by the Toxic Substances Control Act (TSCA) for all solid samples. Therefore, the solid residues would not be classified as hazardous materials, based solely on their PCB content.

- In 27 percent of the fly ash samples, the 2,3,7,8-TCDD concentration exceeded the limit of 1.0 ppb established by the National Center for Disease Control for safe soil ingestion levels. This limit was not exceeded by any of the combined ash or bottom ash samples.

<u>For the Monofill Data:</u>

- Actual leachates from all sampled facilities met the EP Toxicity Maximum Allowable Limit.

- The concentrations of metals in the groundwater samples did not exceed the Primary or Secondary Drinking Water Standards. Some groundwater samples were not properly obtained and wells sampled were not located downgradient from the disposal facility in all cases.

- Based on chemical analysis of collected leachates, it can be assumed that bacterial activities were present in all sampled sites. The pH of the monofill leachates ranged between 7.44 and 8.58. These slightly to moderately basic waters can sustain bacteria, especially since the TOC levels ranged between 59 and 536 mg/l (ppm). Such bacteria can play a vital role in shaping the water quality of the monofill leachate. The presence of ammonia is evidence of anaerobic bacteria activity. The ammonia-nitrogen level ranged between 1.2 and 36 mg/l (ppm). For comparison purposes, the pH levels in the four NUS sampled MSW facilities ranged between 6.98 and 7.8; in the two codisposal sites, the range was between 7.2 and 7.3. The ammonia-nitrogen levels in the MSW leachates ranged between 53 and 580 mg/l (ppm); in the codisposal sites they ranged between 160 and 410 mg/l (ppm). The TOC levels in the MSW leachates ranged between 138 and 2,680 mg/l (ppm); in the codisposal site leachates between 436 and 1,310 mg/l (ppm). These data indicate that the leachates from these MSW codisposal landfills and monofills do not differ significantly in pH. The pH of the MSW facilities was neutral to slightly basic. The TOC levels and the ammonia levels indicate that anaerobic bacteria activities are taking place at all facilities.

- The neutral to basic pH conditions in the MSW facilities, the codisposal sites, and the monofills indicate an environment in which the solubilities of the RCRA-regulated metals are limited.

- The concentrations of PCBs, PCDDs, PCDFs, and semi-volatile compounds were negligible in the actual leachate samples and in the laboratory-prepared extracts. Therefore, these compounds appear to be relatively immobile in the natural environment.

the quality of leachates with time at a monofill where no new ashes are being brought in.

- Based on the limited, available data base it appears that codisposal of ashes and MSW may reduce the leached level of the conventional pollutants, the level of PCDDs and PCDFs and the levels of several metals. In the monofills the 2,3,7,8-TCDD equivalents ranged between 0.000 and 0.062 µg/l (ppb), while in the the codisposal sites the range was between 0.000 and 0.001 µg/l (ppb). Similarly, the levels of metals were lower in co-disposal facilities than in monofills. In the sampled codisposal sites, lead ranged between 0.01 and 0.27 mg/l (ppm); in the monofills the range was between 0.012 and 2.92 mg/l (ppm); cadmium levels in the codisposal sites ranged between not determined (ND) and 0.011 mg/l (ppm), while in the monofills the range was between ND and 0.044 mg/l (ppm). Similar differences are evident for each metal analyzed. Additional studies to determine the quality of leachates from codisposal sites and monofills could increase the confidence in this conclusion. However, because these lower concentrations appear to be primarily the result of dilution, the total mass of leached metals is likely to be substantially the same in monofills and co-disposal facilities handling the same quantity of ash. Furthermore, a co-disposal facility would have to be much larger than a monofill to handle an equivalent quantity of ash; thus, management practices that could be used at a monofill may not be feasible at a co-disposal facility.

- The rate of metal release from acidic fly ash may be reduced when the acidic fly ashes are mixed with the more basic bottom ashes for disposal in monofills. More studies are needed to verify this conclusion.

For the Leaching Results:

- The EP Toxicity Maximum Allowable Limit for cadmium was exceeded by 100 percent of the EP-prepared fly ash extracts. However, the cadmium EP Toxicity Maximum Allowable Limit was not exceeded by any of the EP-prepared combined ash or bottom ash extracts.

- The EP Toxicity Maximum Allowable Limit for lead was exceeded by 83 percent of the EP-prepared fly ash extracts and by 75 percent of the EP-prepared combined ash or bottom ash extracts.

- The EP and TCLP methods were more aggressive than the MWEP (SW-924) methods for extracting metals. The EP method appeared to be slightly more efficient than the TCLP method for leaching lead; however, the TCLP method appeared to be slightly more efficient than the EP method for extracting arsenic, chromium, and manganese. The extraction efficiencies of the EP and TCLP methods were approximately equal for the other metals. None of the laboratory leaching procedures were efficient for extracting organic base neutral compounds and PCBs.

- The TCLP was ineffective for extracting the organic constituents including PCDDs, PCDF, and semi-volatile compounds.

- Comparison of actual leachate data with the EP, TCLP, and SW-924 data indicates that the SW-924 results most closely represent the actual data, followed by the TCLP using extracting Fluid No. 1. The EP toxic procedure extracted significantly higher levels of metals than were found in the actual leachate.

- The fact that the analyzed quench waters contained higher levels of inorganics, PCDDs, and PCDFs than the actual leachates, and that the first leachate produced by SW-924 contained consistently higher levels of contaminants than the second leachate, implies that the leaching of contaminants from ashes should be decreasing with time, depending on the pH environment and other factors. This can be verified by monitoring

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