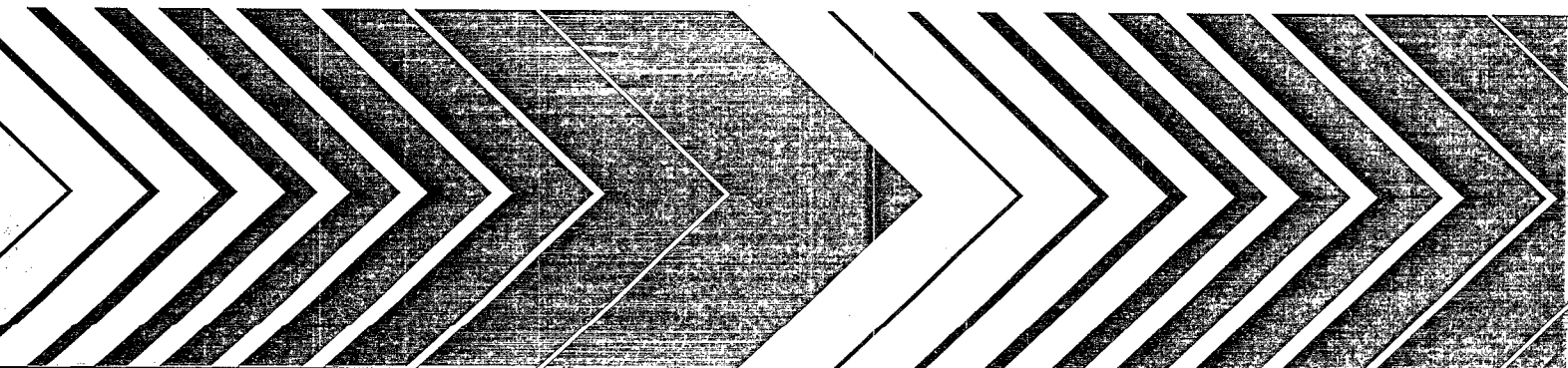**♨EPA**

Municipal Solid Waste Combustor Ash Demonstration Program "The Boathouse"

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MUNICIPAL SOLID WASTE COMBUSTOR ASH DEMONSTRATION PROGRAM
"THE BOATHOUSE"

by

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FOREWORD

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory is the Agency's center for investigation of technological and management approaches for reducing risks from threats to human health and the environment. The focus of the Laboratory's research program is on methods for the prevention and control of pollution to air, land, water and subsurface resources; protection of water quality in public water systems ; remediation of contaminated sites and ground water; and prevention and control of indoor air pollution. The goal of this research effort is to catalyze development and implementation of innovative, cost-effective environmental technologies; develop scientific and engineering information needed by EPA to support regulatory and policy decisions; and provide technical support and information transfer to ensure effective implementation of environmental regulations and strategies.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

E. Timothy Oppelt, Director
National Risk Management Research Laboratory

ABSTRACT

This report presents the results of a research program designed to examine the engineering and environmental acceptability of using municipal solid waste (MSW) combustor ash as an aggregate substitute in the manufacture of construction quality cement blocks. Approximately 350 tons of MSW combustor ash was combined with Portland cement to form standard hollow masonry blocks using conventional block making technology. The resultant stabilized combustor ash (SCA) blocks were used to construct a boathouse on the campus of the University at Stony Brook.

Periodically, over a thirty month period, air samples collected within the boathouse were examined and compared to ambient air samples for the presence and concentrations of suspended particulates, particulate and vapor phase PCDD/PCDF, volatile and semi-volatile organic compounds and volatile mercury. Analyses of the air samples indicate no statistical difference between the air quality within the boathouse when compared to ambient air samples. Rainwater samples following contact with the boathouse walls were collected and analyzed for the presence of trace elements. Results show that the SCA blocks retain contaminants of environmental concern within their cementatious matrix. Soil samples were collected prior to and following the construction of the boathouse and the results suggest that block debris generated during the boathouse construction was responsible for elevated concentrations of trace elements in surface soils. Engineering tests show that the SCA blocks maintain their structural integrity and possess compressive strengths similar to standard concrete blocks.

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TABLES

ABBREVIATIONS AND SYMBOLS

ASTM	American Society for Testing and Materials
BA	bottom ash
d	day
<dl	below detection limits
CA	combined ash
USEPA	U. S. Environmental Protection Agency
g	grams
GC/MS	gas chromatography/mass spectrophotometer
h	hour
H_2O_2	hydrogen peroxide
H_2SO_4	sulfuric acid
kg	kilograms
$KMnO_4$	potassium permanganate
L	liter
M^3	cubic meter
mg	milligrams
mL	milliliter
MPa	mega-pascal
MSW	municipal solid waste
MWC	municipal waste combustor
NA	not available
NS	not significant
PCBs	polychlorinated biphenols
PCDDs	polychlorinated dibenzo-p-dioxins
PCDFs	polychlorinated dibenzofurans
pg	picogram
ppm	parts per million
ppb	parts per billion
psi	pounds per square inch
TE	Toxic Equivalents
TSP	total suspended particulates
ug	micrograms
TCDD	Tetrachlorodibenzo-p-dioxins
HxCDD	Hexachlorodibenzo-p-dioxins
OCDD	Octachlorodibenzo-p-dioxins
TCDF	Tetrachlorodibenzofuran
HxCDF	Hexachlorodibenzofuran
HpCDF	Heptachlorodibenzofuran

ABBREVIATIONS AND SYMBOLS (continued)

OCDF	Octachlorodibenzofuran
VOC	volatile organic compound
°C	degrees Celsius
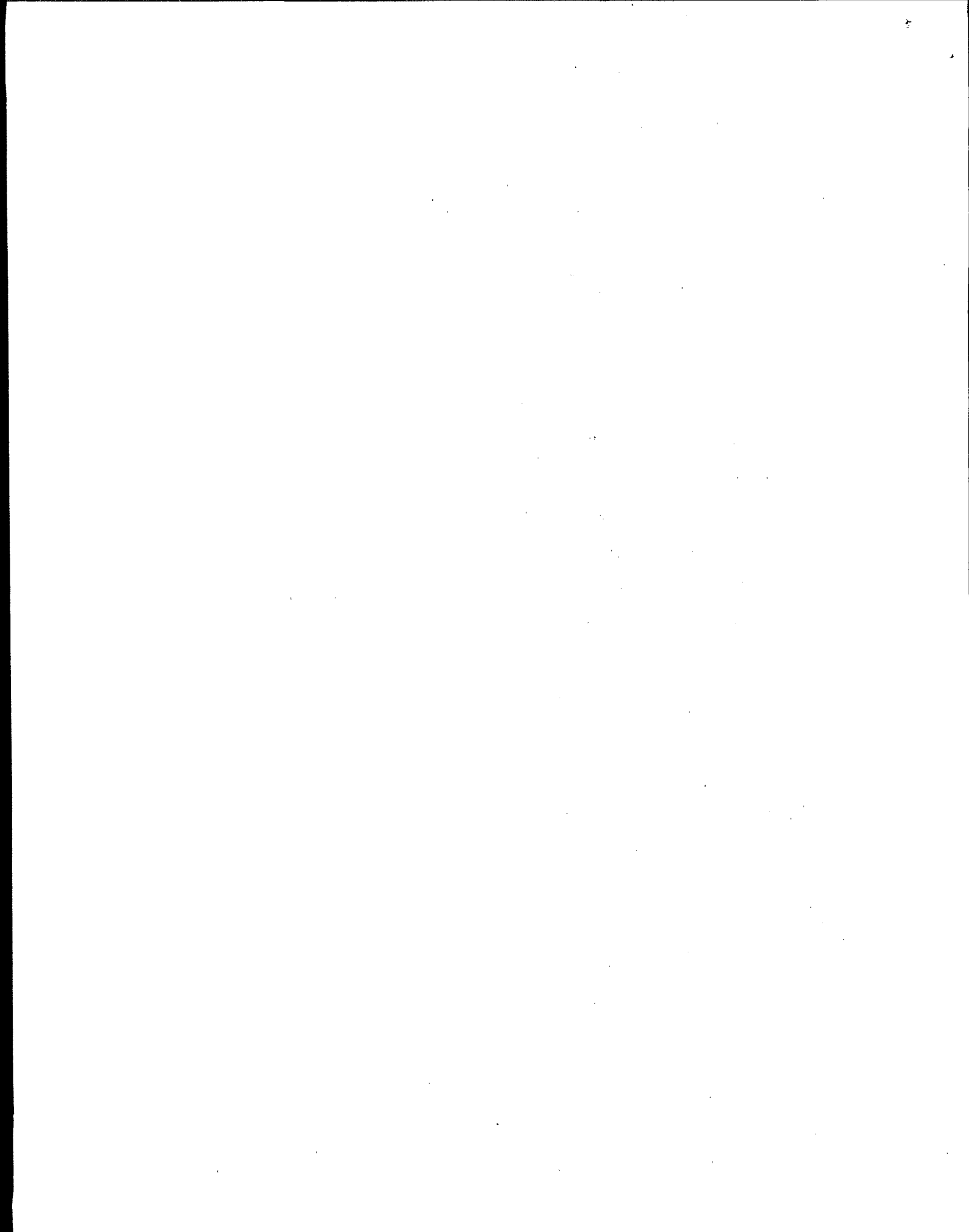
SECTION 1

INTRODUCTION AND BACKGROUND

CHANGES IN WASTE DISPOSAL STRATEGIES

In major urban areas across the United States (U.S.), landfilling of municipal solid waste (MSW) is rapidly declining. The lack of landfill capacity in concert with the potential for ground water pollution are major factors driving communities to alter their solid waste management strategies. No where is this problem more severe than in the Northeast U.S.. In the early 1980s, the New York metropolitan area collected eighteen million tons of solid waste each year, greater than 90% of which was landfilled (Schubel, 1985). In 1983, New York State passed the Environmental Conservation Law of New York, effective since December 18, 1990, resulting in the immediate closure of all Long Island landfills located in deep recharge zones and preventing new ones from being sited (Environmental Conservation Law of New York, 1983). The prohibition of landfilling, formally this region's primary form of waste disposal, the uncertain effectiveness of MSW composting, and the instability of current recycling markets greatly limits the region's waste disposal options. Due to the large volumes of waste collected and the lack of suitable landfill space, some Long Island municipalities turned to energy recovery incineration as a means of handling the ever increasing volume of municipal solid waste (Roethel, 1993).

An important obstacle to the acceptance of waste-to-energy facilities is the large volume of residual ash. With a diminishing number of landfills available to accept this combustion by-product, Long Island is faced with the dilemma of how to manage this material. Transporting combustor ash out-of-state is an expensive and potentially short-

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term solution to this problem. Development of environmentally acceptable, productive uses for the ash is an extremely attractive goal.

STABILIZATION OF MSW COMBUSTOR ASH

Since 1985, scientists at the Waste Management Institute (WMI) of the Marine Sciences Research Center at the University at Stony Brook have been assessing the feasibility of using stabilized MSW combustor ash in a variety of marine and terrestrial applications. To date, two artificial reefs have been constructed on the sea floor of Long Island Sound using blocks of stabilized combustor ash. Over the past six years, results showed there was no release to the environment of either organic or inorganic constituents of environmental concern from the stabilized combustion residue blocks placed into Conscience Bay (Roethel, 1993).

A second series of studies were initiated at Stony Brook to assess the potential use of MSW combustor ash as an aggregate substitute in the manufacture of construction quality cement blocks. Using combined ash, from a number of resource recovery facilities, scientists manufactured standard construction quality cement blocks, that either meet or exceed ASTM performance standards. As a component of this investigation, blocks were sent to Underwriters Laboratory, Northbrook, Illinois, for fire testing. Results showed the blocks fabricated using ash had fire resistant properties nearly identical to standard construction quality materials (Breslin and Roethel, 1989).

The third series of studies began in 1990 with the construction of "The Boathouse". This phase of the investigation furthered the structural testing of the ash blocks and extended the scope of the environmental and health impact assessment on a terrestrial setting. Research was conducted to measure changes in ash block chemistry, surrounding soil chemistry, rain water chemistry, air quality within "The Boathouse", and

the evaluation of long-term structural performance of the stabilized combined and bottom ash blocks.

ASH BLOCK PRODUCTION

In 1990, after demonstrating that MSW combustor ash could be effectively introduced as an aggregate in construction quality cement blocks, 14,000 stabilized ash blocks, fabricated using both bottom and combined ash, were manufactured at Barrasso & Sons Inc., a mason and building supply corporation, located in Islip Terrace, New York. Block fabrication employed conventional block making machines currently used by the industry. In 1991, on the campus of the University at Stony Brook, these ash blocks were used to construct The Boathouse (Figure 1).

Blocks were manufactured using bottom and combined ash from the Westchester waste to energy (WTE) facility, in Peekskill, New York. The combined ash used was a composite of approximately 15% fly ash and 85% bottom ash. Prior to block fabrication, iron was removed from the bottom and fly combustor ash, utilizing magnets at the Westchester WTE. The bottom ash and combined ash used for the construction of "The Boathouse" were collected during April 1990. The ash was not subject to a period of weathering to allow for salt removal, the formation of metal carbonates or the completion of hydration reactions.

"The Boathouse" was built from two different block mix formulations; bottom ash and combined ash. The difference between the two block designs was the type and proportion of ash, sand, and water incorporated into the mix. Both block designs contained 15% type II Portland cement, and 85% of an ash/sand mixture measured by dry weight. The bottom ash blocks contained A total of 55% bottom ash and 30% sand, whereas the combined ash blocks contained a total of 64% combined ash and 21% sand.
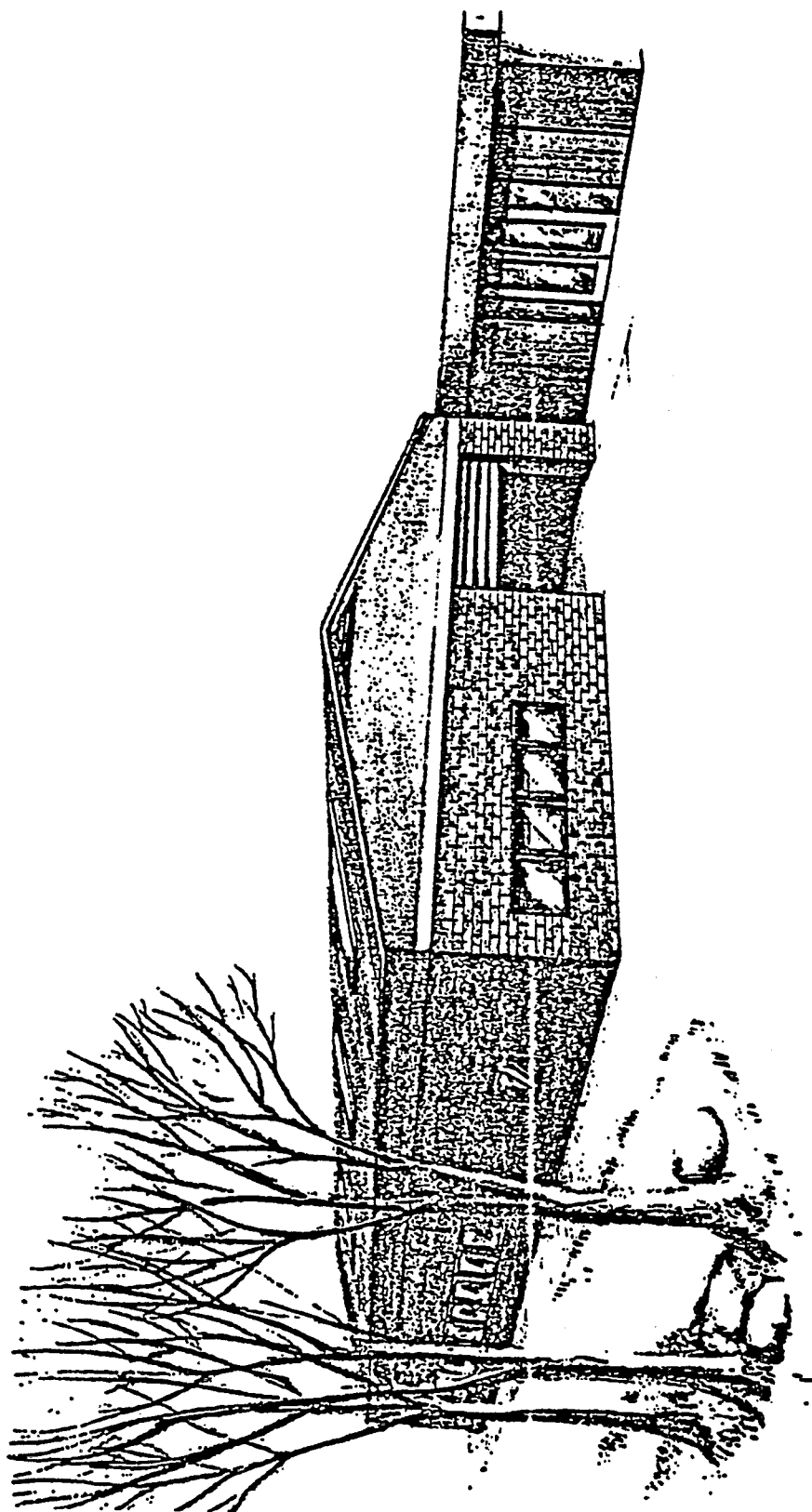
Figure 1. "The Boathouse".

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The block mix components (combined ash or bottom ash, sand and Type II Portland cement) were fed in weighed amounts from hoppers into a mixer. Water was then added to adjust the moisture content of the mix. The well mixed materials were then fed into the loader of the Besser Vibrapac block making machine. The block making machine used vibration and pressure to mold the mixture into blocks.

The block mold (20.3 cm x 20.3 cm x 40.6 cm, hollow core) rested on a steel pallet during the molding process and the material was fed into the mold box by vibration to achieve proper density and compaction. Shoes then descended on top of the mold to exert pressure; a second cycle of vibration began as the mold consolidated the material into blocks. After compaction, the mold lifted and the pallet holding the blocks emerged from the machine while a new pallet pushed under the mold box for the next molding cycle. The pallets of blocks were loaded on racks and cured for 24 h at 71 °C.

Standard concrete construction blocks were purchased from Barrasso & Sons Inc. for use as controls. These blocks were manufactured using 15% Type II Portland cement, sand, and natural aggregate.

CONSTRUCTION OF "THE BOATHOUSE"

"The Boathouse" was constructed to carry out a two year research project designed to test the structural integrity, environmental impact, effects on public health, and ambient air quality impacts associated with the use of combustor ash blocks in a practical application. The structure (Figure 1) measured 27 m long, 18 m wide, and 7 m tall. The western and northern exterior walls were made using bottom ash blocks, and the eastern and southern exterior walls were comprised of combined ash blocks. The interior walls of the structure were made of bottom ash blocks. "The Boathouse" interior was subdivided into five separate rooms. The entire building was constructed on a standard concrete pad and footings made using conventional concrete mixes.

Several precautionary steps were taken to minimize the possibility of any external environmental influences on "The Boathouse" interior. The building was constructed without heating or ventilation systems. Entry into "The Boathouse" was prohibited during sampling events. When "The Boathouse" was not being used for sampling, minimal entry was permitted for occasional storage activities. Some items of concern which were unknowingly stored within "The Boathouse" included; an outboard motor, lawn mower, and several small boats. The interior and exterior walls of "The Boathouse" were not painted to allow for maximum block exposure to the environment.

RESEARCH DESIGN

"The Boathouse" blocks were created to stabilize and prevent the release of contaminants within the incorporated combustor ash. To properly assess the effectiveness of stabilizing MSW incinerator ash contaminants in a concrete matrix, any changes in the known level of contaminants within the ash blocks must be quantified. If contaminants are found to be leaching from the ash blocks, all potential exposure pathways must also be evaluated. The most probable destinations of released contaminants would be the surrounding soil, ambient air within the structure, and rain water which comes in contact with the ash blocks. The environmental impact phase of this investigation focused on the examination of these three major potential pathways for contaminants to travel from "The Boathouse" blocks into the environment. The results of the environmental assessment of "The Boathouse" are then compared to a control site located 100 m northeast of "The Boathouse".

The combustor ash blocks must be able to withstand the physical stresses associated with weathering and use as building material for "The Boathouse" study to be an effective solution to combustor ash management. Therefore, physical tests commonly

used to evaluate ordinary construction quality cement blocks were also applied to the combustor ash blocks.

SECTION 2

MATERIALS AND METHODS

APPROACH

The components of this investigation comprise the assessment of the following:

1. Possible ash block influence on indoor air quality

2. Possible ash block influence on rain water run-off chemistry

3. Possible ash block influence on soil chemistry

4. Changes in ash block chemistry

5. Changes in ash block physical properties.

CONSTRUCTION OF TEST WALLS

Due to the impracticality of removing ash blocks directly from "The Boathouse" walls for experimentation, test walls were fabricated using ash blocks that remained after Boathouse construction. Three walls were erected; a bottom ash wall, a combined ash wall, and a standard cement block control wall. Prior to construction, the weights and dimensions of each block were recorded.

The three test walls were constructed side by side against the west wall of "The Boathouse" to expose them to the same environmental factors as "The Boathouse". Each wall was composed of sixty-four blocks, stacked eight blocks high and eight blocks across. The blocks were not mortared together in order to obtain accurate block weights, and also provide for easy removal during sampling events. Each wall rested against a wooden frame constructed of 5.1 cm x 10.2 cm lumber placed between the test walls and

"The Boathouse" wall. These frames prevented physical contact between the test blocks and "The Boathouse" wall and also enhanced the stability of the test walls. Each wall was built on a 20.3 cm wide plywood board which served as a firm base to stabilize the wall. For further stability, polyethylene rope was strung through the cores of each of the eight columns of blocks on each wall and the fastened to the wooden support frame. During each sampling event one column of eight blocks was removed from each of the three test walls. These blocks were then tested for physical and chemical changes.

BLOCK CHEMISTRY

Analyses of the major and minor chemical components of the bottom and combined stabilized ash, and control cement blocks were performed to estimate the leaching rates based on the changes in elemental concentrations and the period of time the blocks were permitted to weather.

To prepare the ash sample for analysis, three bottom ash blocks and three combined ash blocks were removed from their respective test walls every six months over an eighteen month period, for a total of four sampling events. Three cement control blocks were analyzed initially for comparison purposes. Each chemical analysis event was comprised of nine replicates of both bottom and combined ash blocks. Following structural testing, an 800 g piece of each block was kept and the rest discarded. Each piece of block was ground in its entirety to a particle size of 425 micron using a porcelain mortar and pestle previously acid washed for 48 h in a solution of 10% reagent grade hydrochloric acid (HCl), 10% reagent grade nitric acid (HNO_3), in distilled water. The ground ash was sifted through a 425 μm brass mesh screen previously rinsed with distilled water and acetone. Three replicate samples of each ground block were then prepared by first weighing three 0.5 g sub-samples into acid washed, non-reactive plastic 125 mL containers. Hydrofluoric/boric acid digestions of the powder were prepared for analysis

by atomic absorption spectrophotometry using procedures developed at MSRC (Roethel et al., 1986).

To chemically digest the 0.5 g samples, 10 mL of distilled de-ionized water were first added to the sample containers followed by 10 mL of reagent grade hydrofluoric acid. The resulting slurries were then mixed on a shaker table for 24 h. Following mixing, 70 mL of boric acid solution (15 g boric acid per 250 mL distilled de-ionized water) were added to each sample container, after which the slurries were placed on the shaker table for an additional 24 h. Finally, the samples were subjected to vacuum filtration using a 35 μ mesh filter. During filtration, 10 mL of distilled de-ionized water were used to rinse digested sample, which may have adhered to the container walls in the filtration apparatus. The resulting 100 mL of effluent was collected in an acid washed, 125 mL, plastic container for storage. Atomic absorption analyses were conducted using a Perkin Elmer, model 5000, Atomic Absorption Spectrophotometer (AAS) using both flame and a graphite furnace. Some metals analyzed with the graphite furnace required the inclusion of a matrix modifier to reduce matrix effects the digest solution may have had on percent recovery. Appendix A outlines the AAS methods and matrix modifiers associated with these analyses. Additional information pertaining to the analytical methodology can be found in the quality assurance document prepared for this investigation (WMI, 1990).

SOIL CHEMISTRY

To evaluate the extent of block leaching and/or physical erosion of the block's surfaces caused by weathering, soil samples were collected and analyzed. Soil samples were taken from the top 2 cm and at depths of 8, 14, and 20 cm adjacent to each of the four exterior walls of "The Boathouse". Similar samples were taken from a control soil site (CSS) located 100 m north-east of "The Boathouse". Soil samples were collected before and during construction of "The Boathouse". Soil samples collected following

construction were randomly selected along the exterior walls but typically at a distance of 30 cm from exterior wall. Construction activities such as block cutting and mortar mixing occurred at various locations surrounding the construction site and were not excluded as potential sampling sites. Three replicates were collected at every sampling site and depth, from May 1992 to April 1994 for a total of six sampling events. Soil samples were also collected from "The Boathouse" and control site at 2 and 20 cm during February 1987, June 1987, and October 1988 prior to Boathouse construction. During each sampling event, each soil sample was comprised of six replicates while soil samples collected at the control site were comprised of three replicates. Nitric acid digests of the samples followed by standard atomic absorption analysis were conducted. The analytical protocols employed for analysis were a modification of Method 3050 from SW-846, Test Methods for Evaluating Solid Waste, EPA Office of Solid Waste and Emergency Response, July, 1982. To maximize the recovery of metals from the soil samples, the digestion procedure was modified by the elimination of the intermediate filtration and centrifugation steps, and the elimination of any direct addition of concentrated HCl to the sample digests.

RAIN WATER CHEMISTRY

Leaching rates were also estimated by analyzing rain water which ran off a bottom and combined ash block as well as a cement control block. A blank was collected and analyzed to ascertain the chemical components of rain water without block contact. Samples were collected in 18.9 L non-reactive plastic pails, each containing one block broken into 70 to 80 pieces. Two collection pails were prepared for each sample type, for a total of eight samples (two bottom ash, two combined ash, two cement, two blank). Samples were collected every four months over a two year period, for a total of six sampling events.

Rain water exited through a hole bored in the bottom center of each pail into a sample collection bottle. Two replicates of each sample type were collected. The pH of each sample was recorded immediately following sampling in accordance with EPA Method 9040. Vacuum filtration through a 35 micron mesh was employed to remove particles that would otherwise interfere with atomic absorption spectrophotometer. Samples were then acidified to pH <2 using Ultrex HNO_3. Atomic absorption spectrophotometry was employed to test these samples for elemental Ca, Cd, Cu, Pb, and Zn.

AIR QUALITY

This component of the project consisted of four air experiments, each of which were conducted independently at two sampling sites at four month intervals over a two year period (six sampling events). An indoor site was located in the center of the main room of "The Boathouse", an outdoor control site was stationed approximately 15 m south of the main door of "The Boathouse". For each sampling event, individual air tests consisted of one replicate of both the indoor and outdoor tests run concurrently.

Samples were collected using a polyurethane foam (PUF) high volume sampler (NYS Department of Health, 1989) which has been modified and validated for the collection of polychlorinated dioxins and furans (PCDDs and PCDFs). Before alteration, the sampling apparatus contained an 20.3 cm x 25.4 cm, EPM 2000 0.3 micron filter in a standard holder with a high volume vacuum source. The modifications consisted of adding a threaded, cylindrical stainless steel extension to the throat of the holder. The 8 cm diameter extension contained a 12.5 cm long piece of polyurethane foam (pre-cleaned with acetone, toluene, hexane, vacuum dried) which was retained in place by a stainless steel support screen.

As air was pulled through a high volume vacuum source, airborne gaseous and particulate dioxins and furans were collected on the filter paper and PUF. Each sampling event lasted 24 h, during which time a total air sample of approximately 1000 M^3 was drawn. These samples were later analyzed at the Wadsworth Center of Laboratories and Research at the NYS Department of Health in Albany. The PCDDs and PCDFs were extracted by refluxing toluene through the filters for 24 h. Separation and identification was achieved through liquid and gas chromatography, and mass spectrophotometry.

Volatile Organic Compounds

The first of two methods employed to collect airborne volatile organic compounds was a Porapak-N cartridge. Porapak-N is a cavity rich polymer on which volatile organics are easily trapped if an air flow is directed over the material. For sampling, Porapak-N was placed within the center of a 30 cm long glass tube. Glass wool was housed within the tube to keep the Porapak-N from falling out. A vacuum pump was used to draw approximately 35 L of air through the Porapak-N over a five hour sampling period. The samples were then sent to the NYS Department of Health in Albany for analyses.

Methanol was used to flush the volatile organic compounds out of the Porapak-N cartridge. Separation and identification of the volatile organic compounds in the effluent was achieved using a gas chromatography system fitted with an electron capture detector, and a photoionization detector (NYS Department of Health, 1986).

The USEPA canister procedure (US Environmental Protection Agency, 1988) was used for the full range of volatile organics by MS/GC detection. Compendium Method T0-14, "The determination of volatile organic compounds in ambient air using Summa Passivated canister sampling and gas chromatographic analysis" was employed to verify the results of other collection and analytical procedures and expand on the number of organic compounds able to be detected.

Each of the two sampling sites was equipped with an apparatus housing two metal canisters evacuated to -30" Hg. The samplers contained an onboard computer which automatically allowed one canister to passively draw in air for 12 h, after which the second canister would open and draw in air for an additional 12 h. This procedure allowed for the collection of a 24 h air sample. The system was calibrated such that the canisters would reach atmospheric pressure at the end of the sampling event, during which time each canister collected approximately 6 L of air. Upon completion, the samples were sent to the NYS Department of Health in Albany for analyses.

Total Airborne Mercury

Airborne mercury was collected by drawing approximately 300 liters air through a potassium permanganate-sulfuric acid solution using a vacuum pump. This technique is in accordance with the New York State Department of Health (NYSDOH) protocol entitled "Determination of Ambient Levels of Mercury in Air). Following collection samples were frozen and shipped to the NYS DOH for analysis by way of cold vapor atomic absorption.

Suspended Particulates

Total suspended particulates were collected for the evaluation of suspended metals and salts using an EPM 2000 0.3 micron pre-filter fitted to the PUF sampler to be used for testing PCDDs and PCDFs. The samples were sent to the NYS Department of Health in Albany, to determine the amount of airborne particulate matter per cubic meter of air inside "The Boathouse" and at an outdoor control site.

STRUCTURAL CHARACTERISTICS

At three month intervals over a two year period, one column of eight blocks was removed from each of the three test walls to test for any significant changes in the block's physical characteristics. Structural testing was conducted at three month intervals over a twenty-one month period. Each event was comprised of eight replicates of compressive strength, dimensional stability and weight testing and three replicates of specific gravity and porosity testing.

Compressive Strength

The entire column of eight blocks from each of the three test walls (twenty-four blocks total) were transferred to the engineering department in the University at Stony Brook for structural testing in accordance with American Society For Testing and Materials (ASTM) method C39. Total block strength, measured in mega-pascals, was determined using a hydraulic press.

Specific Gravity and Permeable Pore Space

Three blocks, representative of an entire column of each of the three test walls were removed, and an 800-1600 gram piece was broken off each block. Specific gravity and permeable pore space were determined and recorded in accordance with ASTM method C642.

SECTION 3

AIR QUALITY RESULTS AND DISCUSSION

OVERVIEW

The air samples collected within "The Boathouse" were characterized as outdoor due to the nature of "The Boathouse" construction. The structure had no heating, or powered ventilation, permitting the building to conform to the changing outdoor ambient air conditions rather than maintaining the constant environment observed in conventional buildings.

DIOXINS AND FURANS

Tables 1 and 2 present the particulate and vapor phase concentrations of PCDDs and PCDFs measured from Hi-volume air sampling experiments conducted both inside the boathouse and at an outdoor control site. For five of the six sampling events, total PCDD/PCDF concentrations within the boathouse environment ranged between 0.19 pg/M^3 to 3.62 pg/M^3. The September 1992 sampling event resulted in a total PCDD/PCDF concentration of 17.86 pg/M^3. At the control site, for five of the six sampling events, total PCDD/PCDF concentrations ranged between 0.70 pg/M^3 and 4.00 pg/M^3. The May 1992 sampling event resulted in a total PCDD/PCDF concentration of 22.5 pg/M^3.

The results of a two-way analysis of variance ($\alpha=0.05$) comparing total individual PCDDs and PCDFs inside the boathouse to the outdoor control site with respect to time revealed that no statistically significant difference existed for any of the isomers.

Table 1. PCDD/PCDF concentrations (pg/M³) measured within "The Boathouse"

Analyte	INSIDE BOATHOUSE					
	Jan-92	May-92	Sep-92	Jan-93	May-93	Sep-93
2378 TCDD	<0.04	<0.05	<0.013	<0.001	<0.003	0.007
12378 PCDD	<0.04	<0.07	0.02	<0.001	<0.003	<0.006
123478 HxCDD	<0.06	<0.12	<0.007	0.002	<0.005	0.01
123678 HxCDD	<0.06	<0.11	0.026	<0.003	<0.005	<0.009
123789 HxCDD	<0.05	<0.11	0.02	<0.005	<0.004	0.008
1234678 HpCDD	0.151	<0.17	0.17	0.015	0.064	0.076
12346789 OCDD	1.05	0.762	0.55	0.23	0.23	0.25
2378 TCDF	<0.03	<0.04	1.1	0.007	0.014	0.02
12378 PCDF	<0.03	<0.05	0.89	<0.003	0.007	0.006
23478 PCDF	<0.04	<0.06	0.61	<0.004	<0.002	0.01
123478 HxCDF	<0.03	<0.06	0.41	<0.007	0.003	0.011
123678 HxCDF	<0.04	<0.06	0.19	<0.003	<0.003	0.008
234678 HxCDF	<0.04	<0.08	0.025	<0.002	<0.003	0.009
123789 HxCDF	<0.04	<0.07	0.007	<0.002	<0.003	0.008
1234678 HpCDF	0.077	<0.10	0.11	0.015	0.019	0.023
1234789 HpCDF	<0.07	<0.17	0.026	<0.002	<0.009	0.011
12346789 OCDF	0.156	<0.19	0.094	0.016	<0.010	0.028
OTHER TCDD	<0.04	<0.05	0.089	0.003	<0.003	0.007
OTHER PCDD	<0.04	<0.07	0.023	<0.002	<0.003	<0.006
OTHER HxCDD	0.138	<0.11	0.054	<0.002	0.019	0.025
OTHER HpCDD	0.167	0.284	0.16	0.082	0.046	0.114
OTHER TCDF	0.121	0.328	6	0.01	0.071	0.079
OTHER PCDF	0.201	0.225	6.8	<0.002	0.03	0.02
OTHER HxCDF	0.16	0.182	1.068	0.011	<0.003	0.023
OTHER HpCDF	0.032	<0.10	0.044	0.003	<0.003	0.007
TOTAL	2.903	3.621	17.86	0.186	0.361	0.502

Table 2. PCDD/PCDF concentrations (pg/M³) measured outside "The Boathouse"

Analyte	OUTSIDE BOATHOUSE - CONTROL SITE					
	Jan-92	May-92	Sep-92	Jan-93	May-93	Sep-93
2378 TCDD	<0.04	<0.09	<0.028	<0.016	<0.012	<0.014
12378 PCDD	<0.05	<0.13	0.002	<0.003	<0.013	<0.018
123478 HxCDD	<0.07	<0.23	<0.003	<0.011	<0.018	<0.027
123678 HxCDD	<0.07	<0.22	0.006	0.029	<0.017	<0.025
123789 HxCDD	<0.07	<0.21	<0.005	0.032	<0.015	<0.023
1234678 HpCDD	0.243	<0.36	0.067	0.29	0.094	0.16
12346789 OCDD	1.21	0.847	0.68	1.57	0.32	0.54
2378 TCDF	<0.04	1.067	0.033	0.052	0.033	0.028
12378 PCDF	0.079	1.006	0.006	0.016	0.018	0.016
23478 PCDF	0.051	0.496	0.009	0.035	0.023	0.029
123478 HxCDF	0.077	0.267	0.013	0.05	<0.010	0.028
123678 HxCDF	0.049	<0.12	<0.008	0.018	<0.01	0.022
234678 HxCDF	<0.05	<0.14	0.009	0.022	<0.012	0.027
123789 HxCDF	<0.05	<0.14	0.001	0.007	<0.011	<0.015
1234678 HpCDF	0.139	<0.19	0.045	0.11	0.027	0.14
1234789 HpCDF	<0.09	<0.32	0.009	0.011	<0.028	0.026
12346789 OCDF	0.172	<0.38	0.096	0.12	<0.046	0.11
OTHER TCDD	<0.04	<0.090	0.055	0.032	<0.012	<0.014
OTHER PCDD	<0.05	<0.130	0.027	0.011	<0.013	<0.018
OTHER HxCDD	0.205	<0.220	0.046	0.059	0.049	0.15
OTHER HpCDD	0.249	<0.460	0.063	0.3	0.086	0.21
OTHER TCDF	0.162	7.914	0.197	0.058	0.055	0.152
OTHER PCDF	0.458	6.392	0.077	0.089	0.069	0.115
OTHER HxCDF	0.246	0.885	0.046	0.053	0.026	0.103
OTHER HpCDF	0.044	<0.190	0.009	0.079	<0.003	0.034
TOTAL	4.004	22.49	0.764	1.383	0.70	1.394

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For this, and all subsequent statistical tests, "non-detects" were treated by using the appropriate detection limit in the statistical calculation. Detection limits were calculated as one-half the lowest concentration of the appropriate standard employed to generate a standard curve for the instrument.

However, the collective total of all isomers during any single sampling event was statistically greater at the outdoor control site for five of the six sampling events, while the collective total of any single isomer with respect to time exhibited no statistical differences.

PCDDs and PCDFs In "The Boathouse" vs. Other Studies

The toxicity and carcinogeneity of PCDD and PCDF isomers are extremely variable. For this reason the total concentration is not a reliable indicator of toxicity. It is common practice to assign each PCDD and PCDF isomer a toxic equivalency factor based on the relative toxicity of each isomer. 2,3,7,8-TCDD is considered the most toxic isomer among all the PCDDs and PCDFs and is justly given the largest toxic equivalency factor of 1 (Smith, 1990). Appendix A lists the toxicity factors associated with all the PCDD and PCDF homologs.

The 2,3,7,8-TCDD toxicity equivalent concentrations in "The Boathouse" and outdoor control site were calculated and the mean 2,3,7,8-TCDD toxicity equivalent concentration for the six sampling events was compared to the results of studies conducted in Niagara Falls, Utica (two sites) , and Albany NY (Table 3). The Niagara Falls site represented ambient outdoor air sampled from a highly industrialized urban area. One of the two Utica sites was representative of ambient outdoor air from a small city with light industry. The second Utica and Albany samples were collected indoors, in an office building and parking garage, respectively.

Table 3. Comparison of mean 2,3,7,8-TCDD toxicity equivalent concentrations (pg/M^3)

Analyte	Boathouse Sampling Site		Indoor Office Building	Parking Garage Heavy Traffic	Outdoor Urban Heavy Industry	Outdoor Urban Light Industry
	Inside	Control Site	Utica, NY	Albany, NY	Niagara Falls, NY	Utica, NY
Total TCDD	0.02	0.01	<0.18	<0.004	0.98	<0.05
Total PCDD	0.01	0.01	<0.34	<0.04	1.03	<0.07
Total HxCDD	0.05	0.10	<0.55	0.13	1.70	0.10
1234668 HpCDD	0.07	0.14	<0.77	0.69	2.40	0.30
Total OCDD	0.30	0.34	1.58	3.16	2.60	0.84
Total TCDF	1.29	1.63	8.81	3.37	3.30	5.87
Total PCDF	1.47	1.50	2.71	1.24	2.10	3.61
Total HxCDF	0.36	0.32	<0.26	0.36	2.00	0.46
Total HpCDF	0.06	0.11	<0.41	0.65	1.70	0.07
Total OCDF	0.03	0.03	<1.10	0.30	0.60	<0.12
Total PCDF+PCDD	3.65	4.19	13.1	9.90	18.41	11.25

Source: Smith, 1990

Total PCDD and PCDF toxic equivalency concentrations in "The Boathouse" and control site were less than observed in the results for each of the aforementioned comparative indoor and outdoor studies. The average total PCDD and PCDF toxic equivalency concentration inside "The Boathouse" and control site measured 3.65 pg/M^3 and 4.19 pg/M^3, while the office building and parking garage values totaled 13.10 pg/M^3 and 9.90 pg/M^3 respectively. The New York State Department of Health established a 2,3,7,8-TCDD toxicity equivalent concentration for indoor exposure of 10 pg/M^3 following the fire in the state office building in Binghamton, NY. (K. Aldous, personal communication). PCDD and PCDF toxic equivalency concentrations measured at the highly industrialized urban setting, 18.41 pg/M^3, and lightly industrialized urban site, 11.25 pg/M^3 were higher than observed in "The Boathouse" and control site.

VOLATILE ORGANIC COMPOUNDS

Of the forty-six VOCs sampled for, eleven were detected inside "The Boathouse" and twelve were detected at the outdoor control site. Except for methylene chloride, every compound detected inside "The Boathouse" was also observed at the outdoor control site. The compounds detected both inside "The Boathouse" and outdoor control site included chloroform, chloromethane, tetrachloroethene, ethylbenzene, m/p-xylene, o-xylene, carbon tetrachloride, benzene, 1,1,1-trichloroethane, and toluene. Hexane was detected only at the outdoor control site. The thirty-four VOCs which were not detected are listed in Table 4.

Of the eleven VOCs detected within "The Boathouse", only toluene and benzene were detected by both the canister and Porapak-N methods . The remaining nine analytes were detected by only one of the two sampling techniques.

Canister and Porapak-N Sampling Methods

The canister method was used to measure thirteen VOCs and the Porapak-N method was used to measure forty-four VOCs. The canister method measured chloromethane, methylene chloride, hexane, chloroform, 1,1,1-trichloroethane, carbon tetrachloride, benzene, trichloroethene, toluene, tetrachloroethene, ethylbenzene, m/p-xylene, and o-xylene. Eleven of the thirteen VOCs monitored using the canister method were also included in the Porapak-N method, while hexane and chloromethane, were unique to the canister method. Table 5 presents the range of concentrations measured during this investigation.

Table 4. Airborne volatile organic compounds not detected.

BROMOBENZENE	N-BUTYLBENZENE
BROMODICHLOROMETHANE	N-PROPYLBENZENE
BROMOFORM	O-CHLOROTOLUENE
CIS-1,2-DICHLOROETHENE	P-CHLOROTOLUENE
CHLOROBENZENE	SEC-BUTYLBENZENE
CIS-1,3-DICHLOROPROPENE	STYRENE
DIBROMOCHLOROMETHANE	TERT-BUTYLBENZENE
1,4-DICHLOROBENZENE	1,1,1,2-TETRACHLOROETHANE
1,3-DICHLOROBENZENE	1,1,2,2-TETRACHLOROETHANE
1,2-DICHLOROBENZENE	TRANS-1,2-DICHLOROETHENE
1,1-DICHLOROETHANE	TRANS-1,3-DICHLOROPROPENE
1,2-DICHLOROETHANE	1,2,3-TRICHLOROBENZENE
1,2-DICHLOROPROPANE	1,2,4-TRICHLOROBENZENE
1,1-DICHLOROPROPENE	1,1,2-TRICHLOROETHANE
ISOPROPYLBENZENE	TRICHLOROETHENE
4-ISOPROPYLTOLUENE (p-Cymene)	1,2,4-TRIMETHYLBENZENE
NAPHTHALENE	1,3,5-TRIMETHYLBENZENE

Analyses performed by the New York State Department of Health

Porapak-N Method Blanks

Of the forty-six VOCs sampled, four were present in the Porapak-N method blanks. These method blank detection's; chloroform, tetrachloroethene, 1,1,1-trichloroethane, and toluene were among the twelve VOCs detected both inside and outside "The Boathouse". The concentrations of the method blanks ranged between 0.01 to 0.70 ug/M^3, whereas the indoor Boathouse and outdoor control site concentrations for these same VOCs ranged from 1.1 to 47.0 ug/M^3 and 1.0 to 68.0 ug/M^3 respectively. The NYSDOH was unable to furnish the canister sample method blanks and therefore the VOC concentrations measured by this method must be considered upper limits rather than absolute values.

Table 5. Range of VOC concentrations.

Analyte ug/M^3	Detection Method	Inside Boathouse	Outdoor Control Site	Method Blank
Hexane	Canister	<2.0	29.9	<1.8
Chloroform	Porapak-N	4.5	1.0	0.01
Chloromethane	Canister	1.5	1.4 - 1.7	<1.4
Methylene Chloride	Canister	2.8	<2.0	<2.0
Tetrachloroethene	Porapak-N	1.5	1.0	0.01
Ethylbenzene	Canister	5.4 - 5.5	4.7	<2.2
M/P-Xylene	Canister	6.3 - 13.5	3.3	<3.0
O-Xylene	Canister	5.5 - 17.4	4.8	<2.6
Carbon Tetrachloride	Porapak-N	0.5 - 0.7	0.5 - 0.7	<0.005
Benzene	Can/P-N	2.5 - 9.2	2.0 - 4.7	<0.03
1,1,1-Trichloroethane	Porapak-N	1.1 - 24.0	1.0 - 2.7	0.01 - 0.2
Toluene	Can/P-N	3.0 - 47	2.8 - 68.0	0.01 - 0.7

VOCs Regulatory Standards

The American Industrial Hygiene Association (AIHA) uses the total VOC concentration as a guideline for assessing exposure limits. The AIHA found that total VOC concentration exceeding 5000 ug/M^3 can lead to symptoms of VOC poisoning (Hines, 1993). The total VOC load inside "The Boathouse" ranged from 4 ug/M^3 to 106 ug/M^3, and the outdoor control site ranged from 4 ug/m^3 to 69 ug/M^3. Both the indoor and outdoor data were negligible when compared to the 5000 ug/M^3 limit.

The Indoor air quality standards provided by the Occupational Safety and Health Association (OSHA) and American Conference of Governmental Industrial Hygienists (ACGIH) are listed in Table 6. The VOCs which were detectable both inside "The Boathouse" and at the outdoor control site were negligible when compared to the Threshold limit values set by OSHA and ACGIH.

Table 6. Indoor air quality standards for volatile organic compounds.

Units = ug/M³ TLV = Threshold Limit Value Pollutant	Inside "The Boathouse"	ACGIH Exposure Limits TLV	OSHA Exposure Limits TLV
HEXANE	BDL	176,000	17,600
CHLOROFORM	4.50	NA	NA
CHLOROMETHANE	1.50	NA	NA
METHYLENE CHLORIDE	2.80	NA	NA
TETRACHLOROETHENE	1.50	6,900	690
ETHYLBENZENE	5.35 - 5.53	434,000	43,400
M/P-XYLENE	6.35 - 13.5	434,000	43,400
O-XYLENE	5.50 - 17.4	434,000	43,400
CARBON TETRACHLORIDE	0.50 - 0.65	NA	NA
1,1,1-TRICHLOROETHANE	1.05 - 24.0	1,910,000	191,000
TOLUENE	3.00 - 47.0	188,000	18,800
BENZENE	2.50 - 9.20	319,000	31,900

Volatile Mercury

The National Institute of Occupational Safety and Health (NIOSH) considers mercury to be a carcinogenic hazard when detected above 50,000 ng/M³. Volatile mercury was detected during one of the six sampling events for both inside "The Boathouse" and outdoor control site. The concentration of mercury measured inside "The Boathouse" during May 1992 was 58 ng/M³, while the outdoor control site during January 1992 was measured at 87 ng/M³. Detection limits varied from 21 - 73 ng/M³ according to the volume of air sampled and sensitivity of the analytical procedures employed.

There was no significant difference ($\alpha=0.05$) between the mercury concentrations measured inside "The Boathouse" and the outdoor control site. All mercury concentrations were well below the NIOSH toxicity limit of 50,000 ng/M³.

Total Suspended Particulates

Total suspended particulate concentrations increased both inside "The Boathouse" and the outdoor control site from January 1992 to September 1992. Indoor concentrations ranged from 4.8 ug/M^3 and 24 ug/M^3, with the exception of a spike of 168 ug/M^3 in September 1992. The outdoor control site also experienced a spike in particulate concentration, of 120 ug/M^3, during September 1992, but otherwise maintained a concentration range from 44 ug/M^3 to 64 ug/M^3. On average, suspended particulate levels measured at the outdoor control site were higher than inside "The Boathouse" (Table 7).

Table 7. Total suspended particulate concentrations

| Sampling Events | Concentration (ug/M^3) | |
	Inside Boathouse	Outside Boathouse
Jan-92	8.9	44
May-92	24	61
Sept-02	168	120
Jan-93	4.8	64
May-93	11	NA
Sept-93	6.8	8.4

May 93 control sample was not available due to analytical problems

A determination of the slope of the best fit line of the TSP weights with time showed that no statistically significant changes in TSP existed inside "The Boathouse" and at the outdoor control site. A two-way ANOVA comparing the TSP data collected inside "The Boathouse" to the outdoor control site yielded no statistical differences between these two data sets (Table 8).

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Table 8. TSP significance testing in the Boathouse and Control sites.

t-test	Inside Boathouse	Outdoor Control Site
Slope	-0.0668	-0.0901
t-Statistic	2.42	1.62
t-Critical	2.57	2.78
Significance	N.S.	N.S.
Two-way ANOVA; Boathouse vs. Control		
F-Statistic: 0.63	F-Critical: 6.61	Significance: N.S.

F-Statistic: Results of a one-way model 1 ANOVA test for the significance of the regression. Critical values were obtained from a table of critical values of the F-distribution.

Slope: Slope of the best fit line obtained from regression analysis performed by the Least Squares method (Sokal, 1981).

t-Statistic: Results of a t-test where the null hypothesis states that the slope of a line equals zero: $h_0 \cdot M_1 = 0$. Critical values were obtained from a table of critical values of the t-distribution.

Significance: 95% significance level ($\alpha = 0.05$).

The average TSP loads, both inside "The Boathouse" and at the outdoor control site were well below the OSHA criteria of 5 mg/M^3, and below the ambient indoor air (117 ug/M^3) sampled within a building located near "The Boathouse" in an air quality study examining the screening of ash indoors (Roethel, 1992). Inside "The Boathouse", the TSP mean of 37.4 ug/M^3 fell well below the US Secondary National Ambient Air Quality Criteria for particulate matter annual average of 60 ug/M^3. A national survey was conducted in the early 1960s to determine the mean TSP concentrations for cities of varying sizes. The results of that survey are provided in Table 9. Unfortunately, this was the only large scale study conducted accounting for population size as well as suspended particulate concentrations. Since this study, the air quality of the individual cities surveyed have improved markedly (Stern et al. 1984).

Cheyenne, Wyoming and Honolulu, Hawaii measured annual TSP loads (35 ug/M^3 and 33 ug/M^3 respectively) less than observed in "The Boathouse" (37.4 ug/M^3). Twenty-six of the thirty-one cities listed had a maximum TSP greater than the maximum measured in the Boathouse (168 ug/M^3).

The TSP load of "The Boathouse" was well within air quality standards. More importantly, the data collected from "The Boathouse" was not statistically different from the air collected at the outdoor control site. The vast majority of TSP concentrations from comparable sites were either equal to or greater than "The Boathouse" TSP data. "The Boathouse" TSP data showed no indications of change with time, and was not statistically different from the outdoor control site.

Table 9. Particulate concentrations measured in major U.S. cities.

City	Annual Mean ($\mu g/M^3$)	Maximum ($\mu g/M^3$)
Charleston, West Virginia	174	684
Bakersfield, California	161	293
Philadelphia, Pennsylvania	148	261
Detroit, Michigan	143	323
St. Louis, Missouri	135	255
Baltimore, Maryland	133	296
Louisville, Kentucky	132	332
Chattanooga, Tenn.	131	347
Birmingham, Alabama	128	329
Phoenix, Arizona	128	297
New York City, New York	124	252
Denver, Colorado	117	230
Buffalo, New York	117	132
Chicago, Illinois	114	273
Columbus, Ohio	114	253
Los Angeles, California	113	235
Albuquerque, New Mexico	106	302
Dallas, Texas	89	390
Atlanta, Georgia	89	189
Salt Lake City, Utah	86	172
Kansas City, Kansas	83	148
New Orleans, Louisiana	82	401
Anchorage, Alaska	81	349
Washington, D.C.	72	216
Seattle, Washington	72	181
Columbia, South Carolina	70	142
Portland, Oregon	66	174
Jackson, Mississippi	62	113
BOATHOUSE CONTROL	59	120
Miami, Florida	45	100
INSIDE BOATHOUSE	37	168
Cheyenne, Wyoming	35	379
Honolulu, Hawaii	33	74

SECTION 4

RAIN WATER, SOIL AND ASH BLOCK CHEMISTRY

RAIN WATER CHEMISTRY

The pH and chemical composition of rain water following physical contact with Boathouse ash blocks was examined to quantify any potential contribution of heavy metals from "The Boathouse" blocks. Metal concentrations in the rain water samples were compared to conventional concrete blocks, other studies of water chemistry, and regulatory standards.

Sampling Procedure and Data Presentation

Rain water sampling consisted of four sample types; bottom ash blocks (BA), combined ash blocks (CA), ash-free cement blocks, and blanks. Two replicates of each of these four sample types were collected during each of the seven sampling events, distributed evenly over a twenty nine month period. Immediately following sample collection, the pH and volume of the rain water samples were recorded prior to chemical analyses. Chemical analyses consisted of calcium, cadmium, copper, and lead.

A series of statistical analyses were conducted to properly assess any potential significant differences and/or changes in rain water pH and chemistry which existed either within a single sample set or between two different sets of data. To quantify any significant changes for any rain data set as a function of time, a student t-test and best-fit line were performed. The slope of the best-fit line was calculated to determine significant increases or decreases in concentration. To assess any significant differences or

relationships which existed between two or more different sample types, a two-way analysis of variance (ANOVA) with replication was performed.

Rain water pH

The pH was measured to ascertain the degree of influence the ash blocks may have had on rain water chemistry. The pH of the BA and CA rain samples decreased from 10.2 to 6.7 and 10.3 to 6.2 respectively, while the cement rain samples decreased from 9.5 to 6.7 following twenty nine months of block exposure. The measured decrease in pH for the BA and CA rain water samples was not uniform, but a trend was observed. During this period the blank rain sample ranged from 4.9 to 6.9, with initial and final pHs of 5.3 and 5.8 respectively. Table 10 presents the pH and rainwater volume data.

Table 10. Mean pH and volume of rain water samples analyzed

Treatment	pH/Volume (mL)	Jan 92	May 92	Sep 92	Jan 93	Sep 93	Mar 94	May 94
Bottom Ash	pH	10.2 (0.2)	9.9(0.0)	8.3(0.2)	9.1(0.2)	8.5(0.1)	6.7 (0.2)	6.7(0.2)
	Volume	70 (10)	NA	460 (50)	2100(300)	60 (60)	520(140)	430 (60)
Combined Ash	pH	10.3 (0.0)	9.3 (0.2)	9.0 (0.1)	8.4 (0.2)	9.1 (0.0)	8.3 (0.1)	6.2 (0.1)
	Volume	150 (1)	NA	410 (120)	1600 (960)	230 (10)	865 (520)	1120 (760)
Cement	pH	9.5 (0.4)	8.1 (0.0)	7.6 (0.0)	8.1 (0.1)	8.6 (0.5)	7.0 (0.1)	6.7 (0.2)
	Volume	130 (100)	NA	300 (40)	1700 (810)	100 (50)	860 (240)	790 (40)
Blank	pH	5.3 (0.8)	6.2 (0.2)	5.5 (1.7)	4.9 (0.0)	6.9 (0.3)	5.5 (0.2)	5.8 (0.0)
	Volume	250 (160)	NA	720 (470)	1300 (980)	460 (270)	860 (600)	1130 (480)

Numbers in parentheses represents standard deviation
NA = Data not available due to analytical problems

A student t-test, and the slope of the best fit line performed for pH showed that the BA, CA, and cement block samples statistically decreased, while the blank samples exhibited no trend as a function of time.

A two-way ANOVA revealed that the pH of the BA and CA rain samples were not statistically different. However, the pH of the BA and CA rain samples were statistically greater than both the cement and blank rain samples. The pH of the cement rain samples were statistically greater than the blank rain samples.

The measured decrease in pH with time for all three block types indicated that the quantity of soluble alkaline salts available for leaching by each block has diminished with each rainfall event. The data suggest that soluble alkaline salts in the ash containing blocks were less available for leaching than they were in the cement control blocks.

Inorganic Composition of Rain water

Alterations in rain water chemistry were evaluated to determine the extent of inorganic leaching from the ash blocks as a function of exposure time. The rain water samples were each analyzed for a representative sub-set of the metals measured in the ash blocks. The rain water analyses (Table 11) consisted of calcium, copper, cadmium, and lead.

The results of a two-way ANOVA indicated that the calcium concentration in the cement rain water samples were statistically greater than the BA, CA, and blank rain water samples. Calcium content of the BA and CA rain water samples were not statistically different from the blank rain water samples. Calcium in the cement rain samples ranged from 9.5 to 25.6 mg/L, whereas the BA, CA samples ranged from 1.8 to 10.2 mg/L, with one outlier of 24.9 mg/L. Rainwater blank concentrations ranged between 0.3 and 1.9 mg/L with an outlier of 12.9 mg/L.

The results of a two-way ANOVA showed that no significant difference in cadmium concentration existed between the ash blocks, control blocks and blank rain water samples. Cadmium content of the CA block rainwater ranged from <0.3 to 2.1 ug/L, while the cement block rain water ranged from <0.3 to 2.6 ug/L.

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Table 11. Metal concentrations in rain water samples

Analyte	Treatment	CONCENTRATION							
		Jan 92	May 92	Sep 92	Jan 93	Sep 93	Dec 93	Mar 94	May 94
Ca (mg/L)	Bottom ash	2.5 (0.1)	1.8 (0.4)	4.7 (0.4)	2.6 (0.7)	2.2 (1.0)	6.7 (0.8)	7.6 (0.6)	10.2 (2.9)
	Combined Ash	3.0 (0.7)	4.1 (1.1)	6.0 (1.9)	3.7 (0.1)	4.1 (0.7)	5.1 (1.4)	9.2 (2.8)	24.9 (2.5)
	Cement	11.2 (4.7)	10.6 (2.6)	22.2 (4.4)	25.6 (3.9)	15.4 (6.3)	9.5 (0.8)	21.7 (1.4)	10.2 (0.9)
	Blank	1.9 (1.6)	0.3 (0.1)	12.9 (17.2)	0.4 (0.0)	1.7 (0.6)	1.4 (0.2)	0.5 (0.0)	0.6 (0.8)
Cd (μg/L)	Bottom ash	<0.3	5.1 (5.1)	<0.3	1.4 (1.4)	<0.3	2.1 (1.9)	<0.3	<0.3
	Combined Ash	<0.3	2.1 (0.6)	<0.3	1.7 (0.7)	<0.3	<0.3	<0.3	<0.3
	Cement	<0.3	<0.3	2.6 (3.3)	<0.3	<0.3	<0.3	<0.3	<0.3
	Blank	<0.3	<0.3	<0.3	1.2 (1.3)	0.3 (0.2)	<0.3	<0.3	<0.3
Cu (mg/L)	Bottom ash	0.6 (0.2)	0.7 (0.6)	0.54 (0.69)	0.51 (0.7)	0.55 (0.7)	<0.03	<0.03	<0.03
	Combined Ash	0.3 (0.02)	0.1 (0.02)	0.04 (0.02)	<0.03	0.05 (0.01)	<0.03	<0.03	<0.03
	Cement	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
	Blank	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Pb (μg/L)	Bottom ash	<2.5	17.9 (23.5)	<2.5	<2.5	<2.5	<2.5	<2.5	<
	Combined Ash	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5
	Cement	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<
	Blank	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5

Numbers in parentheses represents standard deviations.

Copper in the cement and blank rain water samples were measured at <0.03 mg/L for every sampling event. Copper concentration in the BA rain water ranged from <0.03 to 0.70 mg/L, while the CA rain water ranged from <0.03 to 0.30 mg/L. Copper release from the stabilized ash blocks appears to be a short term phenomenon concluding after the initial eighteen months of exposure.

The results of a two-way ANOVA indicated that the concentration of lead in the BA, CA, cement, and blank were not statistically different. The BA rain sample collected in May 1992 had a lead concentration of 17.9 ug/L. All remaining rain water samples were below the instrumentation detection limit of <2.5 ug/L. The single detected lead value of 17.9 ug/L value surpassed the USEPA drinking water limit for lead of 15 ug/L (USEPA, 1986). Since every sample measured <2.5 ug/L, the value of 17.9 ug/L was attributed to sample contamination or an analytical error.

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SOIL CHEMISTRY

The chemistry of soil surrounding "The Boathouse" was examined to quantify any potential contribution of heavy metals from the stabilized ash blocks. Soil samples were analyzed for a representative sub-set of the metals measured in the ash blocks. The soil metal analyses consisted of iron, calcium, cadmium, copper, lead, and zinc. The data from the two bottom ash wall soil sites (BASS) were combined to form one data set as were the two combined ash wall soil site (CASS) data. Only one control soil site (CSS) was used. The contribution of heavy metals from "The Boathouse" to the surrounding soil may have taken three forms:

- leaching from the blocks,
- block fragments deposited due to spalling, and
- the inclusion of ash block construction debris.

Normalization of Soil Chemistry Data to Iron

To directly compare any one soil sample against another soil depth, site or sampling event, the data were normalized to compensate for variations in soil chemistry between samples. Normalization between soil samples was achieved by analyzing iron, a conservative metal whose detectable concentrations were not affected by the varying chemical nature of the soil. All data collected were divided by the iron concentration to normalize the data, thus permitting comparisons among different soil types. The concentrations of iron at each soil depth and site as a function of exposure time are listed in Table 12.

Soil concentrations for calcium, cadmium, copper, lead, and zinc were each divided by the iron concentrations and multiplied by 100 to produce normalized data sets.

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All references to the soil data sets were expressed in accordance with the following expression:

$$[100 \text{ (metal concentration)}/\text{(iron concentration)}]$$

Table 12. Iron Concentrations (μg/g) measured in Pre and Post Construction Soil Samples

Treatment	Soil Depth	Pre-Construction			Post-Construction Concentrations (μg/g)					
		Feb 87	Jun 87	Oct 88	May 92	Sep 92	Jan 93	May 93	Sep 93	Apr 94
Bottom Ash	2 cm	10400 (2200)	8900 (500)	8300 (220)	10800 (2600)	10600 (1900)	7600 (1300)	8400 (630)	9400 (520)	6720 (385)
	8 cm	Not Analyzed			8600 (650)	7800 (970)	8600 (1200)	8500 (700)	10900 (890)	8260 (750)
	14 cm	Not Analyzed			8100 (900)	7800 (2100)	8000 (1200)	8500 (1000)	10800 (1300)	7970 (550)
	20 cm	8800 (210)	10900 (500)	8800 (480)	9000 (480)	8100 (590)	7200 (2500)	8400 (1330)	12400 (1700)	8420 (1120)
Combined Ash	2 cm	7800 (110)	7800 (900)	7800 (1200)	9400 (760)	7500 (2600)	8600 (1450)	9400 (830)	8300 (3700)	8310 (1140)
	8 cm	Not Analyzed			9700 (1060)	8400 (780)	8000 (1500)	9600 (360)	10200 (3400)	8860 (1310)
	14 cm	Not Analyzed			9300 (1100)	8000 (1100)	8500 (1400)	8900 (640)	9100 (1800)	7820 (1800)
	20 cm	7900 (440)	7900 (400)	8500 (280)	9200 (930)	7700 (1140)	9300 (3100)	8900 (1140)	10900 (1140)	9060 (1100)
Control Site	2 cm	8200 (250)	9600 (500)	7500 (600)	9200 (330)	8500 (1100)	7700 (1500)	8900 (800)	11600 (1600)	7775 (500)
	8 cm	Not Analyzed			9400 (920)	10100 (440)	14000 (2400)	8500 (2000)	13000 (950)	8460 (450)
	14 cm	Not Analyzed			9000 (1200)	8700 (420)	8200 (800)	8200 (600)	13000 (920)	8820 (530)
	20 cm	6500 (310)	7900 (200)	6200 (470)	8600 (490)	7400 (410)	8700 (1200)	8300 (1100)	9900 (580)	8010 (575)

Numbers in parentheses represents standard deviation.

The raw data for calcium, cadmium, copper, lead, and zinc are provided in appendix B.

The results of a two-way ANOVA comparing iron concentrations in soil from the pre-construction to the post-construction sample sets revealed that for the BASS and CASS, no statistical differences existed between the pre-treatment and post-treatment

data. At 20 cm depth, post-treatment CSS was statistically higher in iron than the pre-treatment CSS.

Iron at the pre-construction BASS ranged from 8,300 to 10,900 ug/g, while the post-construction site ranged from 6,720 to 12,400 ug/g. Iron at the pre- and post-construction CASS ranged from 7,800 to 8,500 ug/g and 7,500 to 10,900 ug/g respectively. At 2 cm, iron at the pre- and post- construction CSS ranged from 7,500 to 9,600 ug/g and 7,700 to 11,600 ug/g, while iron at 20 cm the pre- and post-construction CSS ranged from 6,200 to 7,900 ug/g and 7,400 to 9,900 ug/g respectively.

A two-way ANOVA comparing the BASS, CASS, and CSS with respect to depth revealed that the BASS and CASS data did not exhibit any statistical difference in iron concentration with respect to depth, while the CSS showed a statistical decrease with depth.

The results of a two-way ANOVA comparing iron content at the BASS and CASS to the CSS showed that the iron levels in soil at 8 and 14 cm depth from the BASS and CASS are statistically lower than the CSS. At 8 cm depth at the BASS and CASS iron ranged from 7,800 to 10,900 ug/g and 8,000 to 10,200 ug/g, while the CSS ranged from 8,460 to 14,000 ug/g. At 14 cm depth at the BASS and CASS iron ranged from 7,800 to 10,800 ug/g and 7,820 to 9,300 ug/g, while the CSS ranged from 8,200 to 13,000 ug/g.

Calcium Concentrations

The normalized calcium concentrations measured in and around "The Boathouse" are presented in Table 13. Normalized concentrations determined for the BASS, CASS and CSS ranged between 280 - 1.6, 100 - 1.6 and 5.1 - 0.6 (100 Ca/Fe) respectively.

A t-test performed on each of the soil data sets revealed that calcium concentrations in soil collected from the 2 cm BASS increased significantly ($\alpha = .05$), while samples from the 2, 8, 14 and 20 cm CASS significantly decreased as a function of time. Calcium content of the remaining BASS and all CSS exhibited no statistical correlation.

The results of a two-way ANOVA revealed that the calcium content in the BASS, CASS, and CSS decreased with respect to depth. The magnitude of the calcium gradient observed in the BASS and CASS was much greater than measured in the CSS.

The results of a two-way ANOVA comparing calcium concentrations at the BASS and CASS to the CSS revealed that the BASS and CASS at all measured depths were statistically greater than the CSS. The calcium concentration of the surface 2 cm of the BASS was statistically greater than the top 2 cm of the CASS. No statistical difference in calcium content existed in comparisons between the BASS and CASS for the 8, 14, and 20 cm samples.

Table 13. Normalized calcium soil concentrations

Treatment	Soil Depth	Post-Construction Normalized Concentration					
		May 92	Sep 92	Jan 93	May 93	Sep 93	Apr 94
Bottom Ash	2 cm	80 (24)	30 (8.3)	20 (2.3)	160 (30)	280 (230)	40 (21)
	8 cm	8.1 (1.5)	3.8 (0.5)	2.1 (0.4)	5.2 (0.5)	8.6 (10)	7.4 (3.3)
	14 cm	4.6 (2.9)	2.6 (0.9)	3.2 (2.0)	4.0 (0.7)	2.3 (0.6)	2.6 (0.5)
	20 cm	2.6 (0.5)	2.4 (0.3)	3.6 (2.4)	3.7 (1.4)	1.6 (0.3)	1.9 (0.5)
Combined Ash	2 cm	60 (5.6)	80 (50)	100 (9.6)	7.7 (1.1)	5.5 (0.5)	3.3 (2.0)
	8 cm	8.1 (2.3)	4.7 (1.0)	4.8 (1.2)	2.6 (0.4)	2.6 (1.9)	2.7 (1.5)
	14 cm	8.4 (5.7)	3.8 (0.4)	4.1 (1.0)	3.2 (0.4)	2.2 (0.5)	2.0 (1.5)
	20 cm	4.5 (0.5)	4.0 (1.0)	4.0 (0.8)	3.0 (0.7)	1.7 (0.7)	1.6 (0.8)
Control Site	2 cm	3.0 (0.7)	4.5 (0.8)	4.6 (1.0)	4.1 (0.8)	2.1 (0.2)	3.2 (0.4)
	8 cm	1.8 (0.5)	2.0 (0.3)	3.0 (0.9)	5.1 (1.1)	2.1 (0.3)	1.2 (0.1)
	14 cm	1.5 (0.3)	2.8 (0.1)	1.2 (0.7)	3.2 (0.4)	1.4 (0.3)	1.2 (0.3)
	20 cm	2.5 (0.9)	2.3 (0.1)	0.6 (0.2)	2.1 (0.8)	1.1 (0.1)	1.2 (0.4)

Numbers in parentheses represents standard deviation

Calcium is a major component in the Portland cement and ash used to fabricate the ash blocks, foundation and pad of "The Boathouse" blocks. The ash blocks had calcium concentrations ranging from 6 to 8%. Calcium's high solubility in water, in addition to its pre-dominance in the ash blocks made this element a likely candidate for leaching. Comparison of the calcium concentrations associated with the rainfall data with the surface soil chemistry reveal no correlation.

Cadmium Concentrations

A determination of significance for the slope of the best fit line performed on each of the soil data sets revealed that cadmium concentrations in soil collected from the 8 and 20 cm CSS statistically increased ($\alpha=.05$) with respect to time. Cadmium concentrations of all remaining soil samples was not statistically significant.

The results of a two-way ANOVA comparing cadmium concentrations in soil from the pre- to post-construction sample sets revealed that all post-placement soil data were statistically greater than the pre-construction data sets. At the BASS, the pre-construction cadmium content was measured <0.001 (100xCd/Fe), while the post-construction data ranged from 0.001 to 0.016 (100xCd/Fe). At the CASS, the pre-construction cadmium content ranged from <0.001 to 0.03 (100xCd/Fe), whereas the post-construction data spanned from 0.001 to 0.010 (100xCd/Fe). At the CSS, the pre-construction cadmium content ranged from <0.001 to 0.001 (100xCd/Fe), while the post-construction data ranged from 0.001 to 0.010 (100xCd/Fe) (Table 14).

The results of a two-way ANOVA comparing cadmium concentrations at the BASS, CASS, and CSS with respect to depth revealed that the CASS exhibited a decrease in cadmium with depth, while the BASS and CSS show no statistical change. The results of a two-way ANOVA comparing cadmium concentrations of the BASS and CASS to the CSS revealed that the 20 cm BASS contained less cadmium than the CSS, while the 2 cm CASS had a greater cadmium content than the CSS and BASS. Cadmium in the 20 cm

Table 14. Normalized cadmium soil concentrations

Treatment	Soil Depth	Pre-Construction			Post-Construction Normalized Concentrations					
		Feb 87	Jun 87	Oct 87	May 92	Sep 92	Jan 93	May 93	Sep 93	Apr 94
	2 cm	<0.001	<0.001	<0.001	0.004	0.005	0.003	0.005	0.004	0.003
					(0.002)	(0.002)	(0.001)	(0.038)	(0.078)	(0.001)
Bottom	8 cm		Not Analyzed		0.006	0.002	0.002	0.004	0.005	0.001
					(0.003)	(0.001)	(0.002)	(0.029)	(0.012)	(0.001)
Ash	14 cm		Not Analyzed		0.005	0.004	0.016	0.006	0.006	0.001
					(0.004)	(0.004)	(0.019)	(0.025)	(0.026)	(0.000)
	20 cm	<0.001	<0.001	<0.001	0.002	0.002	0.001	0.004	0.005	0.0005
					(0.001)	(0.002)	(0.000)	(0.040)	(0.022)	(.0002)
	2 cm	0.001	0.001	0.003	0.009	0.004	0.005	0.004	0.010	0.002
		(.002)	(0.004)	(0.001)	(0.005)	(0.002)	(0.001)	(0.014)	(0.017)	(0.001)
Combined	8 cm		Not Analyzed		0.008	0.002	0.002	0.004	0.005	0.001
					(0.005)	(0.001)	(0.001)	(0.052)	(0.013)	(0.001)
Ash	14 cm		Not Analyzed		0.002	0.002	0.002	0.004	0.006	0.001
					(0.001)	(0.001)	(0.001)	(0.049)	(0.018)	(0.001)
	20 cm	0.001	0.001	<0.001	0.004	0.007	0.001	0.005	0.004	0.003
		(0.000)	(0.010)		(0.001)	(0.007)	(0.001)	(0.037)	(0.039)	0.003
	2 cm	<0.001	0.001	0.001	0.007	0.002	0.001	0.003	0.005	0.001
			(0.002)	(0.001)	(0.011)	(0.001)	(0.000)	(0.014)	(0.019)	(0.000)
Control	8 cm		Not Analyzed		0.001	0.002	0.001	0.004	0.005	0.003
					(0.002)	(0.001)	(0.001)	(0.001)	(0.053)	(0.001)
Site	14 cm		Not Analyzed		0.001	0.010	0.001	0.004	0.005	0.001
					(0.000)	(0.012)	(0.000)	(0.030)	(0.046)	(0.001)
	20 cm	<0.001	0.001	<0.001	0.002	0.004	0.002	0.004	0.008	0.0005
			(0.002)		(0.002)	(0.001)	(0.001)	(0.006)	(0.063)	(.0001)

Numbers in parentheses represents standard deviations.

CSS ranged from 0.002 to 0.008 (100xCd/Fe), while the 20 cm BASS ranged from 0.001 to 0.005. Cadmium measured in the 2 cm CASS ranged from 0.004 to 0.010, while the 2 cm BASS and CSS ranged from 0.003 to 0.005 (100xCd/Fe) and 0.001 to 0.007 (100xCd/Fe), respectively.

Copper Concentrations

A determination of significance for the slope of the best fit line performed on each data set revealed that copper concentrations in soil collected from the 14 cm CASS statistically ($\alpha=.05$) decreased with respect to time. The remaining CASS samples, and all BASS and CSS data showed no statistical change in copper concentration as a function of time.

The results of a two-way ANOVA comparing copper concentrations in soil from the pre- to post-construction sample sets revealed that all CASS post-placement soil data were statistically greater than the pre-construction data sets. At the CASS, copper content of the pre-construction samples ranged from 0.04 to 0.09 (100xCu/Fe), while the post-construction samples ranged from 0.09 to 0.56 (100xCu/Fe) (Table 15)

Table 15. Normalized copper soil Concentrations

Treatment	Soil Depth	Pre-Construction			Post-Construction Normalized Concentrations					
		Feb 87	Jun 87	Oct 87	May 92	Sep 92	Jan 93	May 93	Sep 93	Apr 94
Bottom Ash	2 cm	0.08 (0.13)	0.20 (0.02)	0.08 (0.14)	0.25 (0.15)	0.22 (0.04)	0.20 (0.02)	0.29 (0.05)	0.49 (0.53)	0.16 (0.05)
	8 cm	Not Analyzed			0.29 (0.32)	0.13 (0.02)	0.11 (0.01)	0.14 (0.00)	0.07 (0.01)	0.06 (0.01)
	14 cm	Not Analyzed			0.10 (0.03)	0.14 (0.04)	0.12 (0.02)	0.15 (0.04)	0.06 (0.01)	0.05 (0.01)
	20 cm	0.07 (0.01)	0.05 (0.04)	0.08 (0.06)	0.15 (0.11)	0.12 (0.01)	0.17 (0.10)	0.15 (0.01)	0.06 (0.01)	0.06 (0.02)
Combined Ash	2 cm	0.08 (0.09)	0.07 (0.07)	0.09 (0.10)	0.25 (0.07)	0.28 (0.07)	0.56 (0.46)	0.26 (0.16)	0.20 (0.04)	0.10 (0.05)
	8 cm	Not Analyzed			0.24 (0.11)	0.12 (0.01)	0.11 (0.02)	0.15 (0.01)	0.14 (0.11)	0.07 (0.02)
	14 cm	Not Analyzed			0.26 (0.11)	0.13 (0.02)	0.10 (0.01)	0.15 (0.01)	0.11 (0.03)	0.05 (0.05)
	20 cm	0.08 (0.107)	0.04 (0.05)	0.08 (0.46)	0.14 (0.05)	0.14 (0.04)	0.09 (0.02)	0.15 (0.01)	0.09 (0.03)	0.06 (0.04)
Control Site	2 cm	0.08 (0.36)	0.07 (0.06)	0.10 (0.10)	0.12 (0.03)	0.11 (0.03)	0.11 (0.02)	0.17 (0.02)	0.07 (0.01)	0.07 (0.02)
	8 cm	Not Analyzed			0.10 (0.03)	0.11 (0.01)	0.06 (0.01)	0.18 (0.103)	0.07 (0.00)	0.07 (0.009)
	14 cm	Not Analyzed			0.10 (0.02)	0.12 (0.01)	0.08 (0.00)	0.15 (0.01)	0.07 (0.03)	0.05 (0.02)
	20 cm	0.07 (0.10)	0.05 (0.05)	0.07 (0.02)	0.22 (0.22)	0.11 (0.01)	0.08 (0.01)	0.14 (0.01)	0.06 (0.00)	0.04 (0.02)

Numbers in parentheses represents standard deviation

The results of a two-way ANOVA comparing copper content at the BASS and CASS to the CSS showed that the copper levels in the BASS at 2 cm, and in the CASS at 2, 8, and 14 cm were statistically greater than the CSS. No statistical differences in copper concentration were detected between the BASS and CASS sample sets.

Copper concentrations in the BASS and CASS at 2 cm ranged from 0.16 to 0.49 (100xCu/Fe) and 0.10 to 0.56 (100xCu/Fe) respectively, while the CSS ranged from 0.07 to 0.17 (100xCu/Fe). Copper content in the CASS at 8 cm spanned from 0.07 to 0.24, while the CSS ranged from 0.06 to 0.18 (100xCu/Fe). The CASS at 14 cm had a copper content ranging from 0.05 to 0.26 (100xCu/Fe), while the CSS ranged from 0.05 to 0.15 (100xCu/Fe)

The BASS and CASS copper gradient indicated the greatest impact of "The Boathouse" on copper concentration occurred in the surface soil, and decreased in intensity with depth. BASS to CASS comparisons yielded no statistical differences with respect to copper, suggesting that the BA and CA concrete products associated with "The Boathouse" equally impacted the soil.

Lead Concentration

A t-test performed on each of the soil data sets showed that lead in the 2 cm CASS statistically (α=.05) decreased with time. All remaining samples exhibited no statistical difference in lead concentration as a function of time

The results of a two-way ANOVA comparing lead concentrations in soil from the pre-construction to the post-construction sample sets revealed that post-construction 20 cm BASS and CASS, and the 2 and 20 cm CSS were statistically less than their respective pre-construction data sets (Table 16).

The results of a two-way ANOVA comparing lead concentrations in soil with respect to depth showed that the BASS, CASS, and CSS statistically decreased with depth. In addition, results of a two-way ANOVA comparing lead content at the BASS and CASS to the CSS showed that the lead levels in soil at 2 and 8 cm depths from the CASS are statistically lower than the CSS.

Table 16. Normalized lead soil concentrations

Treatment	Soil Depth	Pre-Construction			Post-Construction Normalized Concentrations					
		Feb 87	Jun 87	Oct 87	May 92	Sep 92	Jan 93	May 93	Sep 93	Apr 94
Bottom Ash	2 cm	0.13 (0.28)	0.12 (0.12)	0.08 (0.23)	0.19 (0.06)	0.21 (0.22)	0.12 (0.39)	0.18 (0.60)	0.09 (0.32)	0.11 (0.03)
	8 cm	Not Analyzed			0.30 (0.23)	0.04 (0.01)	0.05 (0.16)	0.13 (0.37)	0.08 (0.27)	0.11 (0.03)
	14 cm	Not Analyzed			0.09 (0.06)	0.07 (0.02)	0.09 (0.34)	0.05 (0.19)	0.06 (0.08)	0.08 (0.02)
	20 cm	0.09 (0.10)	0.10 (0.54)	0.09 (0.08)	0.08 (0.04)	0.05 (0.03)	0.08 (0.09)	0.07 (0.15)	0.06 (0.15)	0.08 (0.02)
Combined Ash	2 cm	0.09 (0.73)	0.09 (0.11)	0.10 (0.07)	0.20 (0.08)	0.13 (0.03)	0.33 (0.99)	0.07 (0.26)	0.11 (0.09)	0.09 (0.02)
	8 cm	Not Analyzed			0.05 (0.02)	0.07 (0.02)	0.06 (0.13)	0.06 (0.25)	0.12 (0.21)	0.09 (0.02)
	14 cm	Not Analyzed			0.11 (0.15)	0.02 (0.01)	0.05 (0.16)	0.10 (0.35)	0.15 (0.56)	0.13 (0.05)
	20 cm	0.13 (0.05)	0.11 (0.03)	0.07 (0.11)	0.04 (0.02)	0.04 (0.02)	0.04 (0.10)	0.07 (0.25)	0.08 (0.90)	0.05 (0.01)
Control Site	2 cm	0.44 (1.56)	0.42 (0.66)	0.28 (0.27)	0.17 (0.08)	0.24 (0.03)	0.20 (0.81)	0.16 (0.37)	0.08 (0.53)	0.03 (0.03)
	8 cm	Not Analyzed			0.13 (0.05)	0.16 (0.01)	0.10 (0.04)	0.15 (0.06)	0.16 (0.62)	0.17 (0.01)
	14 cm	Not Analyzed			0.06 (0.03)	0.10 (0.01)	0.12 (0.10)	0.14 (0.37)	0.06 (0.53)	0.08 (0.04)
	20 cm	0.33 (0.42)	0.24 (0.05)	0.10 (0.04)	0.07 (0.09)	0.08 (0.01)	0.05 (0.35)	0.08 (0.02)	0.07 (0.59)	0.06 (0.03)

Numbers in parentheses represents standard deviation

For the BASS, lead ranged from 0.09 to 0.21 (100xPb/Fe) at the surface 2 cm and 0.05 to 0.08 (100xPb/Fe) at 20 cm. Lead measured in the CASS ranged from 0.07 to 0.20 (100xPb/Fe) at the surface 2 cm and 0.04 to 0.080 (100xPb/Fe) at 20 cm. For the CSS, lead ranged from 0.03 to 0.24 (100xPb/Fe) at the surface 2 cm and 0.05 to 0.08 (100xPb/Fe) at 20 cm.

The statistical analyses show that lead concentration in all three soil sites decreased with depth. For each soil site, lead measured in the post-construction samples was either less than or equal to the pre-construction data. The statistical analyses gave no indication of elevated lead in soil due to the presence of "The Boathouse".

Zinc Concentration

A determination of significance for the slope of the best fit line performed on each of the soil data sets revealed no statistically ($\alpha=.05$) significant change in the zinc concentration as a function of time.

Results of normalizing the zinc data are presented in Table 17.

Table 17. Normalized zinc soil concentrations

Treatment	Soil Depth	Pre-Construction			Post-Construction Normalized Concentrations					
		Feb 87	Jun 87	Oct 87	May 92	Sep 92	Jan 93	May 93	Sep 93	Apr 94
Bottom Ash	2 cm	0.16 (0.02)	0.19 (0.26)	0.23 (0.41)	0.85 (0.23)	0.49 (0.11)	1.02 (0.38)	0.79 (0.11)	0.44 (0.12)	0.80 (0.33)
	8 cm	Not Analyzed			0.24 (0.03)	0.31 (0.03)	0.19 (0.02)	0.28 (0.09)	0.11 (0.06)	0.26 (0.10)
	14 cm	Not Analyzed			0.30 (0.22)	0.24 (0.08)	0.21 (0.03)	0.24 (0.05)	0.09 (0.06)	0.23 (0.06)
	20 cm	0.21 (2.05)	0.16 (0.08)	0.20 (0.25)	0.38 (0.37)	0.25 (0.04)	0.97 (1.36)	0.29 (0.05)	0.09 (0.07)	0.20 (0.02)
Combined Ash	2 cm	0.22 (3.00)	0.17 (0.18)	0.790 (0.31)	0.66 (0.04)	1.00 (0.81)	0.53 (0.07)	0.38 (0.17)	0.26 (0.16)	0.28 (0.05)
	8 cm	Not Analyzed			0.40 (0.10)	0.16 (0.04)	0.24 (0.04)	0.21 (0.07)	0.18 (0.13)	0.20 (0.06)
	14 cm	Not Analyzed			0.27 (0.04)	0.18 (0.07)	0.24 (0.06)	0.25 (0.03)	0.21 (0.04)	0.18 (0.03)
	20 cm	0.19 (0.11)	0.20 (0.53)	0.22 (0.14)	0.21 (0.05)	0.20 (0.05)	0.19 (0.03)	0.23 (0.05)	0.14 (0.07)	0.19 0.09)
Control Site	2 cm	0.24 (0.52)	0.24 (0.20)	0.27 (0.23)	0.23 (0.04)	0.34 (0.05)	0.27 (0.05)	0.27 (0.05)	0.14 (0.09)	0.28 (0.02)
	8 cm	Not Analyzed			0.20 (0.03)	0.31 (0.02)	0.17 (0.03)	0.23 (0.10)	0.11 (0.07)	0.21 (0.03)
	14 cm	Not Analyzed			0.15 (0.02)	0.33 (0.08)	0.15 (0.02)	0.32 (0.11)	0.13 (0.11)	0.16 (0.06)
	20 cm	0.23 (0.42)	0.20 (0.55)	0.23 (0.09)	0.17 (0.06)	0.28 (0.04)	0.13 (0.03)	0.24 (0.06)	0.11 (0.06)	0.11 (0.06)

Numbers in parentheses represents standard deviation

A two-way ANOVA comparing the concentration of zinc in soil from the pre- and post-construction samples showed that the post-construction 2 cm BASS was statistically greater than the pre-construction samples, all remaining comparisons showed no statistical difference in zinc concentration. In addition, the two-way ANOVA, comparing zinc levels

in the soil samples from the ash and control sites with depth, showed that the BASS, CASS, and CSS statistically decreased with respect to depth.

The results of a two-way ANOVA comparing the concentration of zinc in soil from both ash sites to the control site revealed that the 2 cm BASS and CASS were statistically greater than the CSS. The remaining soil comparisons exhibited no statistical difference in zinc concentration

All three soil sites exhibited a zinc decrease with depth, whereas only zinc at the 14 cm BASS and 2 and 8 cm CASS statistically decreased with time. The surface 2 cm BASS contained more zinc than the CSS and pre-construction samples, while the 2 cm CASS had more zinc than the CSS.

The statistical results indicated elevated zinc levels in the surface 2 cm of the BASS. The BASS and CASS exhibited several zinc decreases with time, while the CSS experienced no such changes, indicating that the zinc content at the BASS and CASS were influenced by "The Boathouse". The zinc content of the BA and CA blocks have not changed over the course of this investigation.

Heavy Metals in Boathouse Soil vs. Other Studies

"The Boathouse" and control site soil samples were compared to control soil from Calverton NY and to Calverton NY soil mixed with MSW compost from Pensbrook Pines Florida in October 1993 (Table 18). This soil-compost mixture was used to grow sod which was planted on the Boathouse soil in May 1994 (Breslin, 1993).

Cadmium, copper, lead, and zinc concentrations measured at the BASS and CASS were greater than measured at the Calverton control soil, while iron concentrations were less than the Calverton control soil. Cadmium and zinc measured at the CSS had concentrations greater than the Calverton control soil, while iron, copper and lead were observed to be lower than the Calverton control soil.

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Table 18. Metal concentrations from different soil types and locations

| Analyte (μg/g) | Bottom Ash Soil | Combined Ash Soil | Control Site Soil | Sampled 0-5 cm. depth, October 1993 | | | |
				Control Soil Calverton, NY		Pensbrook Pines, Fla. MSW Compost /Soil	
Iron	6,700-12,400	7,500-10,900	7,400-13,000	12,600	(3,400)	10,900	(3000)
Cadmium	0.04-2.3	0.09-1.5	0.04-0.78	0.16	(0.12)	0.63	(0.20)
Copper	4.3-100	4.4-100	3.3-20	45	(4.3)	75	(4.4)
Lead	5.6-52	3.6-40	4.6-21	25	(3.2)	70	(12)
Zinc	8.5-170	7.2-140	11-31	23	(4.9)	76	(22)

Source: Breslin, 1993

Cadmium, copper, and zinc concentrations measured at the BASS and CASS were greater than the Calverton soil-compost, while iron and lead were less than the Calverton soil-compost . All metals measured at the CSS were less than the Calverton soil-compost.

Four of the five metals measured in the Calverton soil and three of the five metals examined in the Calverton soil-compost had higher concentrations at the BASS and CASS. Two of the five metals measured in the Calverton soil and none of the five metals observed in the Calverton soil-compost had higher concentrations than the CSS.

Comparisons of "The Boathouse" soil to the CSS, Calverton soil, and Calverton soil-compost showed that "The Boathouse" soil was clearly influenced the ash blocks. The influence of "The Boathouse" blocks was great enough to raise the concentration of cadmium, copper, and zinc above the mixture of Calverton soil and Pensbrook Pines MSW compost. The sod placed on the soil surrounding "The Boathouse" was lower in concentration for cadmium, copper, and zinc, but higher in lead and iron.

Soil Regulatory Standards

The concentrations of cadmium, copper, lead, and zinc measured in soil collected 30 cm from each of "The Boathouse" walls were compared to the current NYS standards

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governing the acceptable metal concentrations of compost, sewage sludge, and septage for land application. "The Boathouse" metal data were also compared to the New Jersey (NJ) draft metal standards for residential and non-residential buildings (Table 19).

Table 19. Soil metal standards for various land applications

| Analyte (µg/g) | Bottom Ash Soil | Combined Ash Soil | Control Site Soil | NYS Land Application Criteria for: | | NJ Draft Soil Standards | |
				Class I Compost	Sewage Sludge and septage	Resident	Non-Resident
Cadmium	0.04-2.3	0.09-1.5	0.04-0.78	10	25	1	100
Copper	4.3-100	4.4-98	3.3-19.9	1000	1000	600	600
Lead	5.6-52	3.6-38	4.6-20.9	250	1000	100	600
Zinc	8.5-170	7.2-139	11-31	2500	2500	1500	1500

Source NYSDEC, 1993

Compost material with a "class I" rating for NYS can be distributed for use by the public, used on food chain crops and other agricultural and horticultural uses. All metals measured in "The Boathouse" soil were well within the metal criteria for class I compost (Table 19) (NYS DEC, 1993).

Sewage sludge and septage within NYS operational requirements may be used for land application so far as no crop for direct human consumption is grown on soil containing the material for at least eighteen months following application. All Boathouse soil metals were within the required metal criteria (NYS DEC, 1993).

The NJ soil standards consist of residential and non-residential metal criteria. All metals measured in Boathouse soil were well within the non-residential metal criteria. Except for cadmium at the BASS and CASS, all Boathouse metals were within the required residential metal concentrations. The cadmium limit for residential buildings is 1 ug/g. while the BASS maintained concentration from 0.04 to 2.3 ug/g and the CASS ranged from 0.09 to 1.5 ug/g.

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ASH BLOCK CHEMISTRY

Analyses of the major and minor chemical components of the bottom ash (BA) and combined ash (CA) blocks were performed to estimate the leaching rates based on the changes in elemental concentrations as a function of exposure time. Four groupings of elemental metal components were examined for ash block analyses. Measurements were recorded for calcium, aluminum, and iron, which are essential constituents to concrete block cementatious reactions and durability. The salts, magnesium, sodium, potassium, and calcium were examined because of their high solubility and potential leaching characteristics. Also monitored were copper, manganese, nickel, and zinc, which are non-toxic metals common to combustor ash. To assess potential environmental impact, known regulated metals including silver, arsenic, barium, cadmium, chromium, lead, and selenium were examined.

Metals are subdivided into one of three categories based on their concentrations. Major metals include those inorganic constituents with concentrations above 1000 ug/g. Minor metals are comprised of components which ranged in concentration from 100 ug/g to 1000 ug/g, and trace metals include all constituents below 100 ug/g.

Chemical Composition of Combustor Ash and Blocks

The constituents measured in the bottom and combined ash used in block fabrication are presented in Table 20. The major elements include iron, aluminum, zinc, lead, copper, and the salts; calcium, sodium, magnesium, and potassium. The minor metals consisted of barium, chromium, manganese and nickel. Arsenic and cadmium were present in trace amounts, whereas silver and selenium were never detected.

Table 20. Mean concentration and Std. Dev. of metals in MSW combustor ash

Analyte ($\mu g/g$)	Bottom Ash	Combined Ash
Fe	89100 (15400)	80200 (1900)
Ca	64700 (7250)	72000 (3340)
Al	51700 (3200)	5200 (3700)
Na	47800 (1850)	37500 (750)
Mg	10500 (400)	11800 (310)
K	7500 (60)	11100 (400)
Zn	6080 (220)	5370 (120)
Pb	3260 (750)	4070 (120)
Cu	2200 (340)	1600 (330)
Ba	730 (65)	870 (45)
Cr	250 (10)	220 (40)
Mn	130 (10)	930 (30)
Ni	130 (20)	140 (20)
As	20.4 (3.2)	<25
Cd	26.5 (3.1)	59.4 (10)
Ag	<5	<5
Se	<19	<25

Numbers in parentheses represents standard deviations.

The metal content of the bottom and combined ash samples (Table 20) were generally greater than the BA and CA blocks (Table 21). This concentration differential resulted from a dilution effect caused by the addition of Portland cement and sand to the ash during block fabrication. The BA and CA blocks contained 55% and 64% ash respectively. The concentration of inorganic constituents measured in the ash blocksshould have equaled either 55% or 64% of the inorganic material measured in the ash samples, plus any additional contribution from the sand and cement.

CHEMICAL COMPOSITION OF CONTROL CEMENT BLOCKS

For comparative purposes, metal concentrations were also determined for control cement blocks as presented in Table 22. Major metals measured in the cement blocks included aluminum, calcium, iron, potassium, magnesium, and sodium. Barium and

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Table 21 Mean and Std Dev. of inorganic concentrations (µg/g) measured in stabilized ash blocks

Analyte	Block Type	Pre-Exposure Nov 91	(sd)	May 92	(sd)	Nov 92	(sd)	May 93	(sd)	Nov 93	(sd)
Major Metals											
Ca	BA	79300	(6200)	70500	(2100)	73400	(4300)	68700	(7000)	66800	(9900)
	CA	60100	(7300)	71900	(1600)	74800	(3700)	61200	(11900)	69800	(8600)
Fe	BA	81100	(7300)	31700	(3600)	33700	(1400)	37400	(220)	39300	(7400)
	CA	38200	(1900)	23800	(7700)	23200	(8400)	26500	(9100)	41100	(8100)
Al	BA	30900	(2200)	24500	(830)	24100	(1300)	27000	(1000)	NA	
	CA	38600	(7200)	29400	(660)	29300	(1000)	30000	(1000)	NA	
Na	BA	16000	(2500)	13600	(380)	12400	(220)	15900	(4000)	NA	
	CA	35000	(17300)	12400	(750)	11800	(650)	10000	(2100)	NA	
Mg	BA	8600	(680)	5100	(170)	5600	(270)	4900	(1500)	7300	(730)
	CA	8200	(340)	8000	(290)	8400	(290)	11400	(3100)	11700	(1400)
K	BA	7500	(690)	5100	(340)	4900	(310)	5500	(890)	5600	(320)
	CA	7700	(190)	7500	(340)	7700	(320)	8600	(2100)	7200	(420)
Zn	BA	5300	(860)	1400	(140)	1200	(300)	1700	(150)	3000	(350)
	CA	3200	(240)	3200	(140)	3200	(270)	3600	(320)	5800	(1200)
Pb	BA	2800	(380)	1800	(510)	1500	(430)	1600	(360)	1400	(240)
	CA	2300	(290)	2100	(320)	2100	(250)	2100	(370)	2400	(350)
Minor Metals											
Cu	BA	830	(250)	720	(260)	650	(170)	690	(120)	510	(180)
	CA	1200	(400)	720	(80)	810	(100)	740	(150)	500	(160)
Mn	BA	760	(60)	530	(30)	550	(40)	570	(30)	500	(100)
	CA	550	(60)	520	(20)	530	(20)	550	(50)	550	(70)
Ba	BA	630	(70)	250	(20)	280	(40)	420	(50)	380	(140)
	CA	430	(30)	350	(20)	370	(40)	600	(70)	520	(120)
Trace Metals											
Cr	BA	70.2	(10.8)	70.8	(15.1)	75.1	(6.4)	86.8	(24.5)	77.2	(7.0)
	CA	77.9	(3.8)	86.0	(15.1)	80.6	(3.4)	110	(35.3)	74.7	(6.8)
Ni	BA	100	(10.0)	30.0	(4.9)	34.0	(5.0)	26.0	(4.2)	120	(15.4)
	CA	45.0	(3.9)	55.0	(11.0)	45.0	(7.0)	40.0	(2.9)	35.2	(10.1)
Cd	BA	27.1	(6.1)	10.3	(1.1)	11.5	(1.8)	8.9	(1.3)	11.9	(2.1)
	CA	33.3	(1.6)	33.5	(1.4)	35.2	(2.4)	32.9	(1.1)	35.2	(10.1)
As	BA	21.0	(4.7)	19.8	(11.1)	<4.1		<4.1		4.9	(2.6)
	CA	24.3	(4.2)	47.7	(13.6)	12.2	(0.7)	5.5	(1.4)	8.9	(3.1)
Ag	BA	<0.1		<2.2		<2.2		<2.2		<2.2	
	CA	<2.2		<2.2		<2.2		<2.2		<2.2	
Se	BA	<0.2		<2.2		<2.2		<2.2		<2.2	
	CA	<2.2		<2.2		<2.2		<2.2		<2.2	

Numbers in parentheses represents standard deviation

manganese were present in minor amounts, and chromium, copper, nickel, and zinc were present in trace amounts. Silver, arsenic, cadmium, lead, and selenium were never measured above the instrument detection limit.

Table 22 Mean Concentration and Std. Dev. of metals in control blocks

Analyte	Concentration(μg/g)
Ag	<1.1
Al	32300 (11100)
As	<5
Ba	190 (50)
Ca	23000 (6900)
Cd	<10
Cr	7.8 (1.3)
Cu	24 (12)
Fe	14500 (810)
K	5800 (1900)
Mg	1100 (380)
Mn	170 (10)
Na	28900 (3200)
Ni	8.6 (2.1)
Pb	<0.25
Se	<2.2
Zn	56 (13)

Numbers in parentheses represents standard deviation

Except for sodium, aluminum and potassium, all metal concentrations measured in the cement blocks were markedly lower than those found in the ash blocks. Sodium in the cement blocks was observed to be greater than in the BA blocks, measuring 28,900 ug/g in the cement blocks and ranging from 12,400 to 16,000 ug/g in the BA blocks. Sodium levels in the cement blocks were greater than those measured in the CA blocks for all but the pre-placement sampling event. The pre-placement CA block sampling event yielded an average sodium concentration of 35,000 ug/g with a standard deviation of 17,300 ug/g. Aluminum concentrations in the cement blocks were extremely variable, averaging 32,300

ug/g with a standard deviation of 11,100 ug/g, bringing this metal within the same concentration range measured for the BA and CA blocks. Potassium concentrations measured in the cement blocks overlapped those found in the BA and CA blocks. As in the BA and CA blocks, silver and selenium concentrations in the cement blocks were both below detection limit.

Chemical Composition of Blocks Following Exposure

Metal concentrations from pre-placement to two years of exposure are listed in Table 21. In general, major minor and trace constituents are similar to those observed in the combustor ash prior to stabilization. The variance among and between samples was significant thereby diminishing the ability to predict with any confidence the impact of exposure to the block's metal chemistry. The variance between data sets appears more significant for the stabilized bottom ash blocks when compared to the combined ash blocks.

The methods employed in the fabrication of the stabilized blocks may, in part, explain this observation. The cement block plant contracted to fabricate the stabilized ash blocks employed a batch mixing technique to blend the ash, natural aggregates and Portland cement. The ratio of the ingredients apparently could not be maintained constant as the different batches were blended. Some blocks apparently received differing amounts of ash which is believed to be reflected in the data set.

The substantial variability in the inorganic composition of the stabilized blocks reflects the inability of the commercial block plant to blend, with the necessary precision, the block's constituents.

SECTION 5

BLOCK PHYSICAL CHARACTERISTICS

OVERVIEW

An important aspect of the physical testing is that the experimental and control blocks were permitted to weather in what could be considered a worst case scenario. The blocks tested were not shielded from the elements by paint or any other protective coating which would limit the effects of weathering. The blocks comprising each test wall were not mortared together, thus permitting precipitation to easily pervade the blocks and accelerate weathering. The top of each test wall was not capped, which permitted precipitation to enter the cores of the uppermost layer of blocks and travel through the entire wall. Had these walls been built to acceptable commercial standards, much of the weathering effects would have been greatly reduced if not eliminated (Portland Cement Association, 1975).

COMPRESSIVE STRENGTH

To be of any use in construction, concrete blocks must have strength, the ability to resist force. These forces evolve from the applied loads and the weight of the concrete blocks themselves. For this reason, block strength is used a general indicator of quality (ASTM, 1978).

Because of applied loading, the dominant stress to concrete building blocks is compressive in nature. Compressive strength testing is used to determine the unit stress required for a concrete blocks to lose its structural integrity (ASTM, 1978).

Compressive strength testing is an indicator of other physical properties important in measuring the quality of a concrete block. Strong concrete is more impermeable to water and more resistant to erosion, but may incur a decline in porosity and increase in specific gravity resulting in greater susceptibility to cracking (ASTM, 1978).

The compressive strengths of all BA, CA and control blocks were expressed in mega-pascals (1 PSI = 6.894 kPa). Following 912 days of exposure, compressive strength of the BA blocks ranged from 8.1 to 15.6 MPa, with an initial strength of 11.9 MPa, and a final strength of 15.6 MPa. During this same time period, the CA blocks ranged from 7.5 to 13.1 MPa, with initial and final strengths of 8.7 and 13.1 MPa respectively. The cement control blocks showed a compressive strength range of 9.8 to 17.0 MPa, with initial and final strengths of 14.2 and 17.0 MPa respectively (Table 23).

Table 23. Mean and Std. Dev. of compressive strength (MPa) of boathouse and control blocks

	Nov 91	Feb 92	May 92	Aug 92	Nov 92	Feb 93	May 93	Aug 93	Nov 93
Bottom Ash	11.9 (3.02)	11.8 (1.86)	13.8 (2.27)	11.4 (1.93)	10.6 (2.34)	9.8 (1.72)	8.1 (1.86)	12.1 (2.75)	15.6 (1.94)
Combined Ash	8.7 (0.83)	8.5 (0.89)	9.0 (1.51)	9.6 (2.13)	9.0 (1.65)	8.0 (1.72)	7.5 (1.79)	9.7 (1.44)	13.1 (1.35)
Control	NA	14.2 (2.34)	12.6 (1.86)	12.0 (2.96)	11.1 (2.34)	9.8 (2.82)	11.5 (3.12)	11.9 (2.61)	17.0 (0.54)

The results of a two-way ANOVA comparing the compressive strengths of the BA and CA blocks to the control blocks indicate that the compressive strengths of the BA and control blocks were not statistically different. The compressive strength of the CA blocks was statistically lower than the BA and control blocks. In all cases, the ash blocks exceeded the 6.9 MPa compressive strength required by ASTM for load bearing construction quality cement blocks (Portland Cement Association, 1975).

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PERCENT PERMEABLE PORE SPACE AND SPECIFIC GRAVITY

Strength, durability, and permeability of hardened concrete are directly influenced by the relative amounts of the various forms and sizes of interstitial pores. Pores can exert their influence on the properties of concrete in various ways. The strength and elasticity of concrete are primarily affected by the total volume of the pores, not their size or continuity. The permeability of concrete is influenced by the volume, size, and continuity of the pores (ASTM, 1978).

The cement component of concrete usually contains purposely entrained and accidentally entrapped air voids. Purposely entrained air voids are used to maximize concrete resistance to freezing and thawing (ASTM, 1978).

Concrete can be visualized as consisting of a heterogeneous mixture of components, each component having its own characteristic pores. In terms of the other pores in concrete, the air voids may constitute from less than 1% to 10% or more of the total volume of the concrete. Approximately 85% of the concrete is aggregate, frequently heterogeneous, with an internal pore volume from almost 0 % to 20 % or more (ASTM, 1978).

Porosity of "The Boathouse" Block Aggregate

The presence of internal pores in the aggregate particles is associated with specific gravity, and the characteristics of these pores are important in the study of aggregate properties. The porosity of aggregate, its permeability, and absorption, influence such properties of aggregate as the bond between it and the cement paste, the resistance of the concrete to freezing and thawing, as well as its chemical stability and resistance to abrasion (Neville, 1990).

Assuming the BA, CA, and control blocks were manufactured under identical conditions, the aggregate of each block type was the only variable determining relative porosity. The control blocks were manufactured using an aggregate comprised of 100% sand. Sand is denser than bottom and combined ash, and therefore has relatively lower percent permeable pore space and absorptive properties. The control blocks were expected to have the lowest porosity of the three block types.

The BA block aggregate consisted of 55% bottom ash and 30% sand, while the CA block aggregate was comprised of 64% combined ash and 21% sand. The percent absorption of the bottom and combined ash used in "The Boathouse" blocks were 14.7% and 17.9% respectively. The combined ash was more absorptive than the bottom ash, indicating greater pore space. The CA block aggregate was comprised of 64% ash, while the BA block aggregate used only 55% ash, increasing the expected porosity of the CA blocks over the BA blocks. Based on the type and relative amount of aggregate used in block fabrication, the CA blocks were expected to yield the highest porosity, followed by the BA blocks and the cement control blocks respectively.

Boathouse Block Percent Permeable Pore Space

The percent permeable pore space of the BA and CA blocks ranged from 21.5 to 24.9% and 21.9 to 25.6% respectively, while the cement blocks ranged from 17.3 to 19.5 %. The results of a two-way ANOVA comparing the porosity of the BA, CA and control blocks to each other showed that the BA and CA blocks were greater than the cement blocks, but no statistical difference was observed between the BA and CA blocks (Table 24).

Table 24. Boathouse block percent volume of permeable pore spaces.

Block type	Nov 91	Feb 92	May 92	Aug 92	Nov 92	Feb 93	May 93	Aug 93
Bottom Ash	24.7 (1.5)	23.6 (1.0)	21.5 (0.9)	24.4 (0.7)	22.5 (0.7)	23.1 (0.1)	22.4 (0.9)	24.9 (0.4)
Combined Ash	24.2 (1.6)	22.7 (0.7)	21.9 (0.3)	24.8 (1.3)	24.6 (0.3)	25.2 (0.4)	24.4 (0.1)	25.6 (0.5)
Cement	18.6 (0.7)	19.2 (1.0)	18.4 (1.2)	18.9 (0.2)	18.5 (0.5)	19.5 (0.2)	18.4 (0.3)	17.3 (1.3)

Numbers in parentheses represents standard deviation

As expected, the control blocks had the lowest porosity. Unexpected, however, was the observation that the BA and CA block porosities were not statistically different. The percent absorption of the bottom and combined ash aggregates may have been similar enough such that the heterogeneity of the aggregate samples, in concert with the other aforementioned variables affecting porosity, caused the BA and CA block porosities to overlap.

A linear regression and t-test performed on each of the three block types exhibited that the BA blocks showed no significant change in pore space as a function of exposure time. The CA blocks displayed a statistically significant decrease and the control blocks exhibited an increase in porosity with time.

CHARACTERIZATION OF SPECIFIC GRAVITY

The specific gravity of hardened concrete is its weight compared to the weight of an equal volume of water, and is primarily determined by absorption (Portland Cement Association, 1975). Absorption is associated with the weight gain of partially dried specimens upon contact with or immersion in water. Factors significantly influencing absorption include the curing history, aggregate characteristics, air content, cement type, and fineness, specimen shape and size, and method of surface preparation (ASTM, 1978).

The absorption test is of value primarily as the basis of comparison of different concretes, the absorption in a gross manner being a function of the permeability and porosity of the specimen although influenced by many factors of test procedure (ASTM, 1978). Assuming the aggregate of each block type was the only variable determining relative absorption, the affects of aggregate on block absorption may be quantified.

Absorption is inversely proportional to specific gravity. The more absorptive a concrete specimen, the lower its specific gravity. Since the control blocks were expected to maintain the lowest percent pore space and absorption, these specimens should also have had the highest specific gravity. By this same reasoning, the BA blocks should have the next highest specific gravity, while the CA blocks were expected to have the lowest specific gravity of the three block types.

Boathouse Block Specific Gravity

The apparent specific gravity of the BA and CA blocks ranged from 2.47 to 2.69 and 2.50 to 2.58 respectively, while the cement blocks ranged from 2.59 to 2.67 (Table 25). The results of a two-way ANOVA comparing the specific gravity of the BA, CA, and control blocks to each other revealed that the control blocks were statistically denser than the ash blocks. The specific gravity of the BA blocks was statistically greater than that of the CA blocks.

A determination of the significance of the slope of the best-fit line for specific gravity revealed that the BA and control blocks statistically decreased with time, while the CA blocks statistically increased.

SUMMARY

The BA, CA, and control blocks each displayed a significant increase in compressive strength with respect to exposure time. The BA and control blocks displayed significant decreases in specific gravity and increases in porosity, while the CA blocks

Table 25. Apparent specific gravity of Boathouse blocks.

Block type	Nov 91	Feb 92	May 92	Aug 92	Nov 92	Feb 93	May 93	Aug 93
Bottom Ash	2.69 (0.04)	2.64 (0.01)	2.58 (0.03)	2.65 (0.01)	2.49 (0.04)	2.47 (0.02)	2.50 (0.03)	2.53 (0.00)
Combined Ash	2.53 (0.02)	2.52 (0.01)	2.50 (0.02)	2.56 (0.03)	2.55 (0.00)	2.55 (0.00)	2.54 (0.02)	2.58 (0.01)
Cement	2.67 (0.02)	2.66 (0.01)	2.63 (0.01)	2.61 (0.01)	2.62 (0.01)	2.59 (0.01)	2.62 (0.02)	2.62 (0.03)

Numbers in parentheses represents standard deviation

exhibited a significant increase in specific gravity, but no statistical change in porosity. These measured changes in both the ash and control blocks are not atypical and do not indicate any negative changes in the physical properties of the blocks with respect to exposure time.

SECTION 6

CONCLUSIONS

The conclusions associated with the investigation of "The Boathouse", an experimental building constructed with blocks of stabilized MSW combustor ash and the issues of environmental exposures due to the presence and weathering of the ash blocks can be partitioned into the following categories:

1. Air Quality Conclusions,

2. Soil Impact Conclusions,

3. Rainwater Conclusions,

4. Block Chemistry Conclusions, and

5. Structural Conclusions.

<u>Air Quality Conclusions</u>

TCDD toxic equivalent concentrations at the outdoor control site exceeded values measured inside "The Boathouse" for five of the six sampling events. The 2,3,7,8- TCDD toxicity equivalent concentration measured inside "The Boathouse" ranged from 0.07 to 2.09 pg/M^3 with one outlier of 17.68 pg/M^3 while at the outdoor control site values ranged from 0.39 to 3.14 pg/M^3 with one outlier of 18.87 pg/M^3. The New York State Department of Health established a 2,3,7,8-TCDD toxicity equivalent concentration for indoor exposure at a concentration of 10 pg/M^3 following the fire in the state office building in Binghamton, NY. (K. Aldous, personal communication).

The results of a two-way analysis of variance comparing individual PCDDs and PCDFs inside "The Boathouse" to the outdoor control site with respect to time revealed that no statistically significant difference existed for any of the isomers.

Ten of the eleven VOCs observed inside "The Boathouse" were also detected at the outdoor control site, indicating the major factors influencing VOC content in the air were the same for both sampling sites.

"The Boathouse" VOCs were well below standards provided by OSHA, ACGIH, and AIHA.

There was no significant difference between the mercury concentrations measured inside "The Boathouse" and the outdoor control site. All mercury concentrations were well below the NIOSH toxicity limit of 50,000 ng/m^3.

No statistically significant changes in TSP existed inside "The Boathouse" and at the outdoor control site. "The Boathouse" TSP load was not statistically different from the outdoor control site.

The average TSP loads, both inside "The Boathouse" and at the outdoor control site were well below the OSHA criterion of 5 mg/M^3. Inside "The Boathouse", the TSP mean of 37.4 ug/M^3 fell well below the US Secondary National Ambient Air Quality Criteria for particulate matter annual average of 60 ug/M^3.

Soil Impact Conclusions

Calcium exhibited a gradient with depth, but impact from "The Boathouse" increased the magnitude of that trend. The greatest impact of "The Boathouse" on surrounding soil occurred at the surface 2 cm, after which the effects dissipated with depth and concentrations significantly decreased with time.

Cadmium in the surface 2 cm of the CASS was greater than the underlying 8, 14, and 20 cm samples, and was also greater than the surface 2 cm of the BASS and CSS.

The CASS also exhibited a cadmium gradient with depth. "The Boathouse" may have had an impact on the cadmium levels measured in soil near the CA walls of the structure, while soil near the BA walls remained unaffected.

Contribution of copper existed from "The Boathouse" to the surrounding soil. The BASS and CASS copper gradient indicated the greatest impact of "The Boathouse" on copper concentration occurred in the surface soil, and decreased in intensity with depth.

Lead concentration in all three soil sites decreased with depth. For each soil site, lead measured in the post-treatment samples was either less than or equal to the pre-treatment data. The statistical analyses gave no indication of elevated lead in soil due to the presence of "The Boathouse".

Zinc concentrations were elevated in the surface 2 cm of the BASS. The BASS and CASS exhibited several zinc decreases with time, while the CSS experienced no such changes, indicating that the zinc content at the BASS and CASS were influenced by "The Boathouse".

Rain water Conclusions

The pH of the BA and CA rain samples decreased from 10.21 to 8.5 pH and 10.3 to 9.1 pH respectively, while the cement rain samples decreased from 9.5 to 8.6 pH following seventeen months of block exposure.

The BA and CA rain samples were not statistically different. However, the pH of the BA and CA rain samples were statistically greater than both the cement and blank rain samples.

The measured decrease in pH with time for all three block types indicated that the quantity of soluble alkaline salts available for leaching has diminished with each rainfall event. Comparisons between all rain water samples showed that the BA and CA blocks had a greater chemical contribution to the rain water pH than the control block.

The calcium concentration in the cement rain water samples were statistically greater than the BA, CA, and blank rain water samples.

No significant difference in cadmium concentration existed between the ash block and blank rain water samples.

The concentration of copper in the BA and CA rain water samples were statistically greater than the cement and blank rain water samples.

The statistical data exhibited leaching of copper from the ash blocks into the rain water samples. The BA rain water samples leached more copper than the CA rain water samples. The copper concentration in the CA rain samples significantly decreased with respect to exposure time, indicating that the copper available for leaching from the CA block declined.

The concentration of lead in the BA, CA, cement, and blank were not statistically different.

Block Chemistry Conclusions

Substantial variations were measured in the block chemistry as a function of time. Block fabrication was most likely responsible for this observation. The inability to blend the blocks ingredients in consistent proportions resulted in the differences in the chemical composition of the blocks.

Structural Conclusions

The compressive strengths of each block type revealed that the BA, CA and control blocks increased with time.

The compressive strengths of the BA and control blocks were not statistically different. The compressive strength of the CA blocks was statistically lower than the BA

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and control blocks. In all cases, the ash blocks exceeded the 6.9 MPa compressive strength required by ASTM for load bearing construction quality cement blocks.

The percent permeable pore space of the BA and CA blocks ranged from 21.5 to 24.9% and 21.9 to 25.6% respectively, while the cement blocks ranged from 17.3 to 19.5 %. The BA and CA blocks were greater than the cement blocks, but no statistical difference was observed between the BA and CA blocks.

Control blocks had the lowest porosity. Unexpected, however, was the observation that the BA and CA block porosity's were not statistically different. The percent absorption of the bottom and combined ash aggregates may have been similar enough such that the heterogeneity of the aggregate samples, in concert with the other aforementioned variables affecting porosity, caused the BA and CA block porosities to overlap.

A linear regression and t-test performed on each of the three block types exhibited that the BA blocks showed no significant change in pore space as a function of exposure time. The CA blocks displayed a statistically significant decrease and the control blocks exhibited an increase in porosity with time.

A determination of the significance of the slope of the best-fit line for specific gravity revealed that the BA and control blocks statistically decreased with time, while the CA blocks statistically increased.

The CA blocks displayed a positive slope for porosity and a negative slope for specific gravity with time. The BA and control blocks exhibited positive slopes for porosity and negative slopes for specific gravity with respect to time.

SECTION 7

REFERENCES

Agency for Toxic Substances and Disease Registry (ATSDR), 1989a. Toxicological Profile for Cadmium. ASTR/TP-88/08. U.S. Department of Health and Human Services. Atlanta, Georgia: U.S. Public Health Service.

Agency for Toxic Substances and Disease Registry (ATSDR), 1990b. Toxicological Profile for lead. ASTR/TP-88/17. U.S. Department of Health and Human Services. Atlanta, Georgia: U.S. Public Health Service.

American Society for Testing and Materials C29-78. (1983). Annual Book of ASTM Standards. Standard test method for unit weight and voids in aggregate. ASTM designation C29-78. Section 4, construction, Volume 04.02 concrete and mineral aggregates. American Society for Testing and Materials, Philadelphia, PA.

American Society for Testing and Materials C642 (1983). Annual Book of ASTM Standards. Standard test method for specific gravity, absorption, and voids in hardened concrete. ASTM designation C642. Section 4 construction, Volume 04.02, concrete and mineral aggregates. American Society for Testing and Materials, Philadelphia, PA.

American Society for Testing and Materials (1978). Significance of Tests and Properties of Concrete and Concrete-Making Materials. American Society for Testing and Materials, Philadelphia, PA. pp. 262-272.

Breslin, V. T. (1994). Personal contact. Marine Sciences Research Center, SUNY Stony Brook.

Breslin, V. T., Roethel F. J., and Schaeperkoetter. V. P. (1988). Physical and chemical interaction of stabilized incineration residue with the marine environment. Marine Pollution Bulletin. Volume 19, No. 11B. pp. 628-632.

Breslin, V. T., Roethel, F. J.. (1989). Utilization of Stabilized Incineration Residues. In: Procedures of the Seventh Annual Virginia Waste Management Conference. April 25-26, 1989. Marriott Richmond Hotel Richmond, VA. pp. 219-229.

Browning, E., 1961. Toxicity of industrial metal. Butterworths, London, England. pp. 160-161.

Camp, T.R. and R. Meserve (1974). Water and Its Impurities. Second Edition. Downden, Hutchinson & Ross, Inc.Stroudsburg, PA. pp. 120-126.

Chen, K.P. and H. Wu, 1962. Epidemiological studies on blackfoot disease:II: A study of source of drinking water in relation to the disease. Jour. Formosa Med. Assn., 61: 611.

Cook, J. (197). Environmental Pollution By Heavy Metals. International Journal of Environmental Studies. Gordon and Preach Science Publishers, Inc. and OPA Ltd. United Kingdom. Volume 9, pp. 253-266.

Dissanayake, C.B., Weerasooriya, S.V. (1985). Chemistry of Tap Water in Sri Lanka-- Implications on Health. International Journal of Environmental Studies, Volume 27. Gordon and Breach, Science Publishers, Inc. United Kingdom. p. 137.

Elkins, H.B., (1959). The Chemistry of Industrial Toxicology. Second Edition. Wiley & Sons, Inc. New York, NY. pp. 44-47.

Environmental Conservation Law of New York, Volume 2. Section 27.0704. (1983). Gould Publications, Binghampton, NY. pp. 27-15 - 27-15.4.

Hines, A.L., Tushar, K.G., Loyalka, S.K., and Warder, R.C. (1993). Indoor Air Quality and Control. PTR Prentice Hall. Englewood Cliffs, NJ. pp. 339.

Huff, J.E., Wassom, J.S. (1974). Health Hazards From Chemical Impurities: Chlorinated Dibenzodioxins and Chlorinated Dibenzofurans. International Journal of Environmental Studies. Volume 6. pp 13-17.

Long Island Regional Planning Board (1993). The Potential for Beneficial Use of Waste-to-Energy Facility Ash. Hauppage, NY. pp. 4-1.

McKee, J.E., and H.W. Wolf, 1963. Water quality criteria. State Water Quality Control Board, Sacramento California, Pub. 3-A.

National Academy of Sciences, 1972. Particulate Polycyclic Organic Matter, Committee on the effects of Atmospheric Pollutants. National Academic Press., Washington, D.C.

National Academy of Sciences, 1974a. Chromium. U.S. Government Printing Office, Washington , D.C.

National Air Pollution Control Administration, (1968). Air Quality Data from the National Air Sampling Networks, 1966. Durham, N.C.

National Air Pollution Control Administration, (1968). Air Quality Criteria for Particulate Matter. National Air Pollution Control Administration, Washington, D.C.

Ndiokwere, C. L. (1985). The Dispersal of Arsenic, Chromium, and Copper From a Wood Treatment Factory, and Their Effect on Soil, Vegetation and Crops. International Journal of Environmental Studies. Volume 24. Gordon and Preach Science Publishers, Inc. and OPA Ltd. United Kingdom. pp. 231-234.

Neville, A.M. (1990). Properties of Concrete. Third Edition. John Wiley & Sons, Inc., New York, NY.

New York State Department of Health. (1986). Volatile Organics in Air. NYS Dept. of Health, Wadsworth Laboratories, Albany, NY.

New York State Department of Health. (1989). Analysis of Ambient Air Using a PUF (Polyurethane Foam) Hivol Sample. NYS Dept. of Health, Wadsworth Laboratories, Albany, NY.

NYS Department of Environmental Conservation (1993). 6 NYCRR Part 360, Solid Waste Management Facilities. Revisions/Enhancements to New York State's Solid Waste Management Facilities. NYS Department of Environmental Conservation. Division of Solid Waste. Albany, NY. pp. 5-4.

Portland Cement Association (1975). Special Concretes, Mortars and Products. John Wiley & Sons, Inc. New York, NY, 294 pp.

Qureshi, S.A., Saksena, A.B., Singh, V.P. (1979). Acute Toxicity of Some Heavy Metals to Fish Food Organisms. International Journal of Environmental Studies. Volume 14. Gordon and Breach Science Publishers Inc. United Kingdom. pp. 325-327.

Roethel, F. J., Schaeperkoetter, V. P., Gregg, R. and Park, K. (1986). The Fixation of Incineration Residues, MSRC Working Paper #26. Marine Sciences Research Center, State University of New York, Stony Brook, NY.

Roethel, F. J. and V. T. Breslin, 1990. "The Environmental Effects Associated with a Boathouse Constructed Using Blocks of Stabilized MSW Combustor Ash." Marine Sciences Research Center, SUNY Stony Brook, NY.

Roethel, F. J. and V. T. Breslin, 1993. "Mobility of Dioxins, Furans and Trace Metals From Stabilized MSW Combustor Ash in Seawater." Marine Sciences Research Center, SUNY Stony Brook, NY.

Schubel, J. R. and H. A. Neal, 1985. Results and Conclusions of the Municpal Solid Waste Poilcy Forum, November, 1985 at MSRC, SUNY at Stony Brook, Stony Brook, NY. pp. 16.

Shu, G.Y., Liu, J.C. (1994). Content and Fractionation of Heavy Metals in Soils of Two Contaminated Sites In Taiwan. Environmental Progress. Volume 13. Number 2. New York, NY. pp. 89-93.

Singh, S.P. Rakipov, N.G. (1988). Effects of Cd, Cu, and Ni on Barley and Their Removal From the Soil. International Journal of Environmental Studies. Volume 31. Gordon and Preach Science Publishers, Inc. and OPA Ltd. United Kingdom. pp. 291-295.

Smith, R.M, O'Keefe, P.W., Aldous, K.M., Valente, H., Connor, S.P., Donnelly, R.J. (1990). Chlorinated Dibenzofurans and Dioxins in Atmospheric Samples from Cities in New York. Wadsworth Center for Laboratories and Research, NYS Department of Health. Albany, N.Y. pp. 1502-1506.

Sokal, R.R., Rohlf, F.J.. (1981). Biometry, The Principles and Practice of Statistics in Biological Research, Second Edition. W.H. Freeman and Company. San Francisco, CA.

Stern, A.C., Boubel, R.W., Turner, D.B., Fox, D.L., (1984). Fundamentals of Air Pollution. Second Edition. Academic Press, Inc. Orlando Fl. pp 530.

USEPA, (1981). Air quality Criteria for Particulate Matter and Sulfur Dioxides, Final Draft. United States Environmental Protection Agency, Research Triangle Park, NC.

United States Environmental Protection Agency. (1988). The Determination of Volatile Organic Compounds (VOC's) in Ambient Air using Summa Passivated Canister Sampling and Gas Chromatographic Analysis. Compendium Method T0-14. Quality Assurance Division, Environmental Monitoring Systems Laboratory, USEPA, Research Triangle Park, NC.

United States Environmental Protection Agency. (1976). Quality Criteria For Water. USEPA, Washington, D.C. 20460

United States Environmental Protection Agency. (1990). Characterization of municipal waste combustor ash, ash extracts, and leachates. EPA 530-SW-90-029A. USEPA, Washington, D.C. 20460

Van der Sloot, H.A., Woodhead, P.M.J., Hockley, D., and Roethel, F.J. (1991). The Long-Term Behavior of Stabelized Coal Ash In the Sea. Proceedings: Ninth International Ash Use Symposium. Volume 2: Stabilization and Aquatic Uses. American Coal Ash Association. Washington, D.C. pp. 53.

Waste Management Institute (WMI). (1990). Work/Quality Assurance Project Plan for Boathouse Incineration Ash Block Demonstration Program. Waste Management Institute, MArine Sciences Research Center, State University of New York, Stony Brook, New York 11794-5000.

APPENDIX A

Supplemental Analytical Data

Table A-1 AAS Analytical Techniques and Matrix Modifers

Metal	AAS Technique	Modifier
Ag	Furnace	PO_4
As	Furnace	Ni
Ba	Furnace	
Cr	Furnace	$Mg(NO_3)_2$
Pb	Furnace	$Mg(NO_3)_2$
Se	Furnace	Ni
Cd	Furnace	$PO_4/Mg(NO_3)_2$
Cd	Air/Acetylene	
Al	N_2O/Acetylene	
Ca	N_2O/Acetylene	o.5% La
Cu	Air/Acetylene	
Cr	Air/Acetylene	
Fe	Air/Acetylene	
K	Air/Acetylene	0.1% Na
Mg	Air/Acetylene	0.5% La
Mn	Air/Acetylene	
Na	Air/Acetylene	0.1% K
Ni	Air/Acetylene	
Pb	Air/Acetylene	
Si	N_2O/Acetylene	
Zn	Air/Acetylene	
Hg	Cold Vapor	

Table A-2. PCDD/PCDF toxicity factors.

Analyte	Toxicity Factor
2378 TCDD	1
12378 PCDD	0.5
123678 HxCDD	0.04
12379 HxCDD	0.04
123478 HxCDD	0.04
1234678 HpCDD	0.001
12346789 OCDD	0
2347 TCPF	0.1
12378 PCDF	0.1
23478 PCDF	0.1
123478 HxCDF	0.01
123678 HxCDF	0.01
234678 HxCDF	0.01
123789 Hx CDF	0.01
1234678 HpCDF	0.001
12346789 OCDF	0
OTHER TCDD	0.01
OTHER PCDD	0.005
OTHER HxCDD	0.0004
OTHER HpCDD	0.00001
OTHER TCDF	0.001
OTHER PCDF	0.001
OTHER HxCDF	0.0001
OTHER HpCDF	0.00001

APPENDIX B

Soil Concentrations

Table B-1. Soil calcium concentrations.

Treatment	Soil Depth	Post-Construction Concentrations (μg/g)					
		May-92	Sep-92	Jan-93	May-93	Sep-93	Apr-94
Bottom ash	2 cm	7600 (820)	3200 (315)	1340 (125)	9550 (1430)	23150 (15650)	2660 (1360)
	8 cm	710 (125)	305 (20)	180 (25)	455 (50)	940 (1060)	610 (290)
	14 cm	360 (220)	200 (55)	245 (155)	340 (40)	245 (65)	211 (52)
	20 cm	230 (40)	200 (25)	200 (20)	300 (90)	200 (45)	160 (40)
Combined ash	2 cm	5900 (910)	6000 (2450)	7300 (580)	725 (50)	540 (15)	297 (205)
	8 cm	775 (140)	390 (410)	375 (40)	255 (40)	180 (20)	250 (150)
	14 cm	800 (590)	305 (70)	340 (40)	290 (40)	205 (40)	170 (150)
	20 cm	405 (80)	315 (115)	345 (25)	280 (100)	185 (75)	148 (83)
Control site	2 cm	280 (60)	380 (50)	340 (20)	360 (70)	250 (20)	248 (34)
	8 cm	170 (40)	200 (40)	410 (60)	420 (40)	270 (40)	105 (15)
	14 cm	130 (20)	250 (20)	100 (60)	270 (50)	180 (40)	109 (27)
	20 cm	220 (90)	170 (10)	50 (20)	170 (60)	110 (10)	96 (38)

Bracketed numbers indicate standard deviations

Table B-2. Soil cadmium concentrations

Treatment	Soil Depth	Pre-Construction			Post-Construction Concentrations ($\mu g/g$)					
		Feb-87	Jun-87	Oct-88	May-92	Sep-92	Jan-93	May-93	Sep-93	Apr-94
Bottom ash	2 cm	<0.01	0.03 (0.01)	0.03 (0.01)	0.45 (0.14)	0.445 (0.25)	0.24 (0.10)	0.40 (0.17)	0.35 (0.12)	0.19 (0.04)
	8 cm	Not analyzed			0.47 (0.26)	0.17 (0.05)	↓0.18 (0.16)	0.35 (0.17)	0.49 (0.11)	0.11 (0.05)
	14 cm	Not analyzed			0.42 (0.33)	0.27 (0.22)	1.16 (1.29)	0.55 (0.33)	0.54 (0.28)	0.08 (0.03)
	20 cm	<0.01	<0.01	0.03 (0.01)	0.17 (0.10)	0.19 (0.15)	0.08 (0.05)	0.30 (0.23)	0.58 (0.38)	0.04 (0.02)
Combined ash	2 cm	0.02 (0.01)	0.05 (0.04)	0.24 (0.02)	0.77 (0.40)	0.405 (0.28)	0.395 (0.09)	0.42 (0.11)	0.735 (0.23)	0.14 (0.07)
	8 cm	Not analyzed			0.73 (0.43)	0.14 (0.09)	0.12 (0.09)	0.38 (0.19)	0.49 (0.37)	0.12 (0.07)
	14 cm	Not analyzed			0.22 (0.10)	0.15 (0.09)	0.21 (0.10)	0.36 (0.22)	0.47 (0.28)	0.09 (0.05)
	20 cm	0.04 (0.01)	0.05 (0.04)	0.03 (0.01)	0.33 (0.11)	0.49 (0.45)	0.1 (0.04)	0.42 (0.26)	0.47 (0.23)	0.22 (0.31)
Control site	2 cm	<0.01	0.08 (0.01)	0.06 (0.06)	0.67 (1.04)	0.17 (0.04)	0.11 (0.03)	0.28 (0.11)	0.52 (0.30)	0.90 (0.02)
	8 cm	Not analyzed			0.13 (0.15)	0.21 (0.03)	0.11 (0.10)	0.37 (0.03)	0.67 (0.50)	0.24 (0.11)
	14 cm	Not analyzed			0.06 (0.00)	0.91 (1.09)	0.12 (0.05)	0.33 (0.18)	0.60 (0.42)	0.06 (0.04)
	20 cm	<0.01	0.11 (0.03)	0.02 (0.01)	0.22 (0.21)	0.30 (0.08)	0.19 (0.08)	0.35 (0.07)	0.78 (0.36)	0.04 (0.01)

Bracketed numbers indicate standard deviations

Table B-3. Soil copper concentrations.

Treatment	Soil Depth	Pre-Construction			Post-Construction Concentrations (μg/g)					
		Feb-87	Jun-87	Oct-88	May-92	Sep-92	Jan-93	May-93	Sep-93	Apr-94
Bottom ash	2 cm	8.6 (2.9)	17.4 (0.1)	6.5 (0.3)	24.1 (12.1)	21.9 (0.4)	15.5 (3.2)	25.2 (3.3)	50 (70.0)	10.4 (3.2)
	8 cm	Not analyzed			24.5 (27.8)	10.3 (0.7)	9.5 (0.9)	11.8 (0.9)	7.1 (1.0)	4.8 (1.0)
	14 cm	Not analyzed			8.2 (1.7)	10.1 (1.6)	9.8 (2.1)	12.7 (2.6)	6.1 (1.2)	4.3 (1.0)
	20 cm	6.3 (0.2)	5.8 (0.2)	6.8 (0.3)	13.7 (10.1)	9.7 (0.2)	9.25 (0.6)	12.1 (0.8)	7 (0.3)	4.8 (0.9)
Combined ash	2 cm	6.1 (0.1)	5.8 (0.6)	7.1 (1.2)	25.0 (4.2)	24.6 (12.7)	50 (37.4)	23.8 (14.1)	18.9 (5.0)	8.8 (5.2)
	8 cm	Not analyzed			23.0 (9.6)	10.15 (0.3)	8.7 (0.8)	14.75 (1.1)	9.2 (1.4)	6.2 (2.5)
	14 cm	Not analyzed			25.1 (23.2)	10.0 (0.6)	8.1 (0.5)	13 (0.7)	9.7 (2.2)	4.4 (4.8)
	20 cm	6.0 (0.3)	3.5 (0.2)	6.8 (1.3)	12.7 (5.5)	10.1 (2.4)	7.4 (0.3)	13 (1.8)	9.25 (1.9)	5.4 (4.1)
Control site	2 cm	6.5 (0.9)	6.6 (0.3)	7.3 (0.6)	10.8 (3.2)	9.5 (1.2)	7.9 (0.5)	14.9 (3.4)	8.3 (0.6)	5.8 (1.7)
	8 cm	Not analyzed			9.3 (1.8)	11.2 (0.9)	8.7 (0.5)	16.0 (6.8)	9.3 (0.7)	6.3 (1.0)
	14 cm	Not analyzed			8.8 (0.8)	10.5 (1.1)	6.9 (0.6)	12.5 (0.5)	9.3 (4.3)	4.8 (1.0)
	20 cm	4.3 (0.3)	4.2 (0.1)	4.3 (0.1)	19.9 (21.0)	8.5 (1.3)	6.7 (0.2)	11.9 (2.5)	5.6 (0.6)	3.3 (1.0)

Bracketed numbers indicate standard deviations
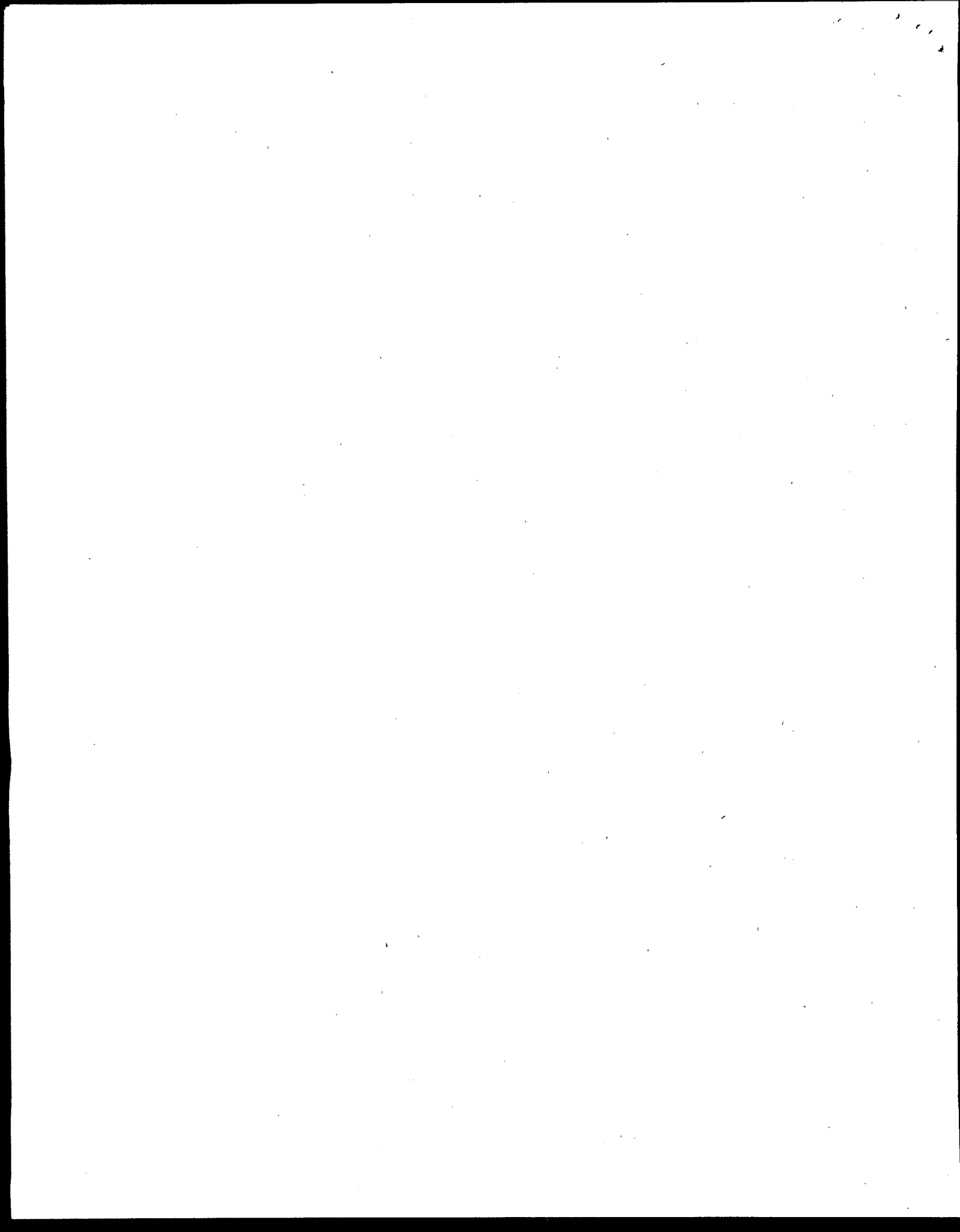
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Table B-4. Soil lead concentrations

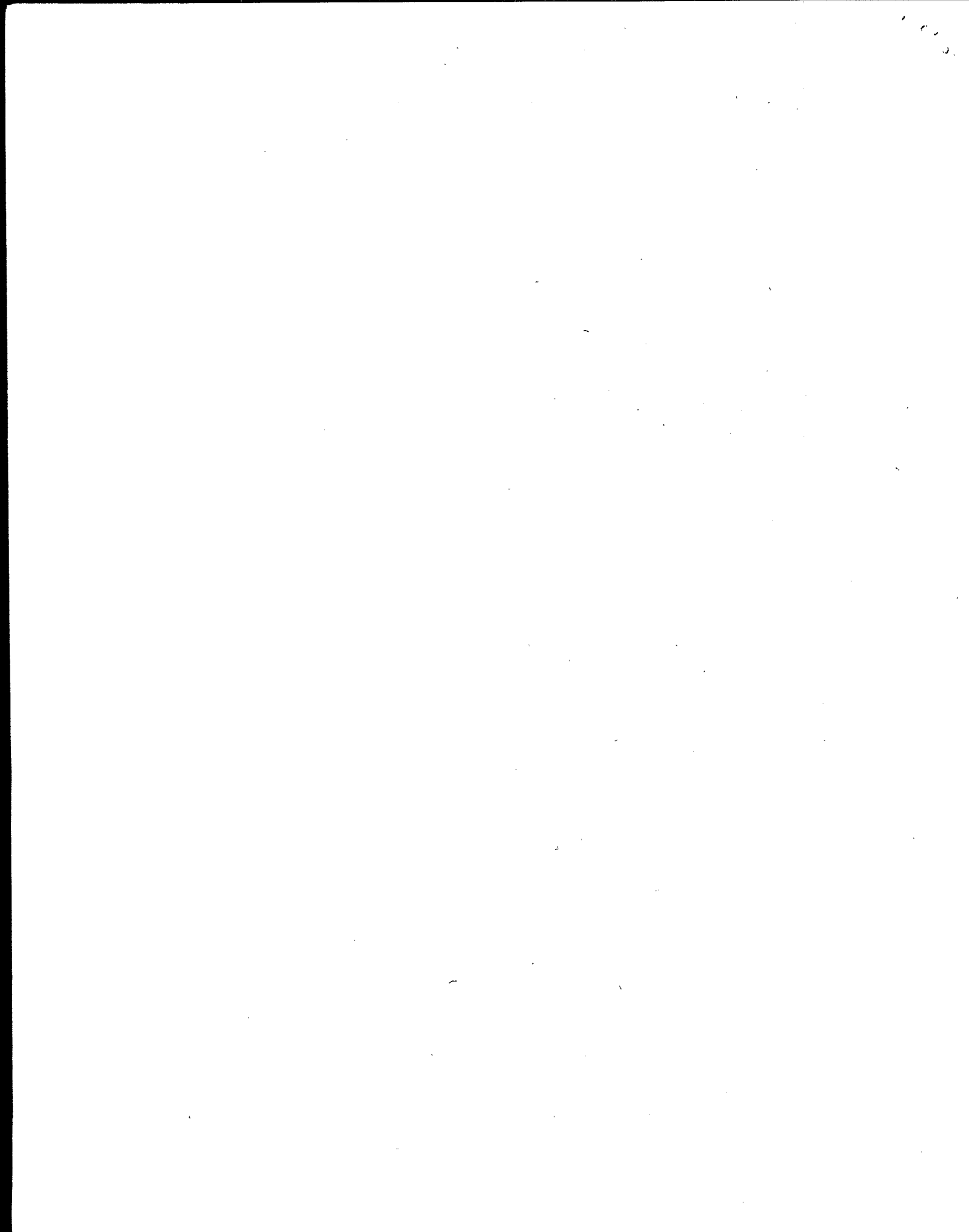| Treatment	Soil Depth	Pre-Construction			Post-Construction Concentrations ($\mu g/g$)					
		Feb-87	Jun-87	Oct-88	May-92	Sep-92	Jan-93	May-93	Sep-93	Apr-94
Bottom ash	2 cm	13.0 (6.2)	11.0 (0.6)	6.7 (0.5)	18.9 (1.5)	20.3 (18.8)	9.1 (4.0)	14.2 (2.9)	8.6 (5.8)	17.5 (6.2)
	8 cm	Not analyzed			26.1 (20.4)	2.8 (0.8)	4.2 (1.9)	10.3 (3.1)	8.3 (2.3)	8.6 (2.8)
	14 cm	Not analyzed			7.5 (4.8)	5.3 (1.2)	6.9 (3.8)	4.4 (1.6)	6.7 (1.0)	6.2 (1.5)
	20 cm	7.9 (0.2)	11.0 (2.7)	8.0 (0.4)	7 (3.5)	3.6 (2.8)	6.2 (1.6)	5.8 (1.9)	7.1 (2.6)	6.2 (1.0)
Combined ash	2 cm	7.1 (0.8)	7.0 (1.0)	7.5 (0.9)	18.8 (7.8)	10.8 (2.2)	20.6 (8.7)	6.7 (2.2)	8.4 (4.3)	7.2 (2.3)
	8 cm	Not analyzed			4.7 (2.3)	6.0 (1.1)	4.5 (1.8)	6.3 (0.9)	9.8 (8.8)	7.6 (1.6)
	14 cm	Not analyzed			11.6 (15.3)	1.8 (1.0)	4.5 (2.1)	9.3 (1.2)	13.1 (9.0)	9.1 (2.6)
	20 cm	9.9 (0.2)	9.0 (0.1)	6.0 (0.3)	3.6 (1.4)	2.9 (1.8)	3.95 (1.7)	6.15 (1.4)	8.4 (6.5)	4.5 (1.0)
Control site	2 cm	36.0 (3.9)	40.0 (3.3)	21.0 (1.6)	16.1 (8.2)	20.3 (0.3)	15.3 (12.2)	14.5 (3.0)	9.4 (8.4)	23.7 (1.1)
	8 cm	Not analyzed			12.1 (4.0)	16.1 (0.7)	13.6 (1.0)	12.5 (1.3)	20.9 (5.9)	14.2 (0.5)
	14 cm	Not analyzed			5.6 (1.9)	8.8 (1.5)	9.5 (0.8)	11.7 (2.2)	7.7 (4.9)	9.3 (0.3)
	20 cm	21.0 (1.3)	19.0 (0.1)	6.4 (0.2)	6.0 (6.2)	5.8 (0.8)	4.6 (4.4)	6.8 (0.2)	6.8 (3.4)	6.0 (0.8)

Bracketed numbers indicate standard deviations
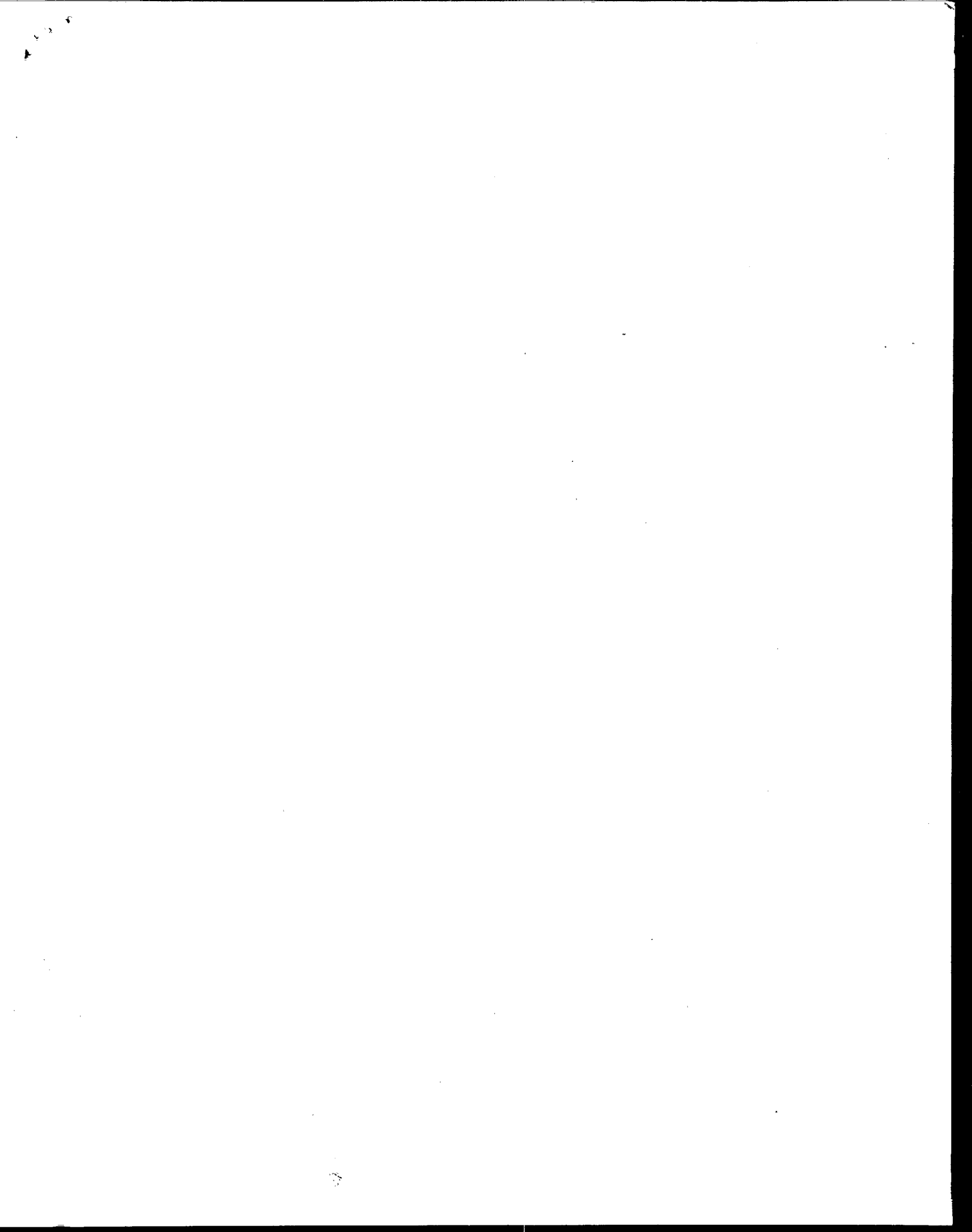
Table B-5. Soil zinc concentrations.

Treatment	Soil Depth	Pre-Construction			Post-Construction Concentrations (μg/g)					
		Feb-87	Jun-87	Oct-88	May-92	Sep-92	Jan-93	May-93	Sep-93	Apr-94
Bottom ash	2 cm	17.0 (0.4)	17.0 (1.3)	19.0 (0.9)	85.1 (10.6)	50.7 (2.7)	76.4 (22.0)	76.2 (12.7)	43.7 (12.5)	53.0 (19.9)
	8 cm	Not analyzed			20.2 (3.5)	22.8 (4.1)	16.1 (0.2)	23.3 (6.4)	7.85 (12.2)	21.1 (8.3)
	14 cm	Not analyzed			24.3 (18.7)	17.3 (2.0)	16.7 (0.9)	20.0 (5.2)	4.2 (10.6)	18.3 (4.9)
	20 cm	18.0 (4.3)	17.0 (0.4)	18.0 (1.2)	33.4 (31.1)	20.1 (2.0)	37.4 (40.4)	23.7 (3.2)	10.4 (11.0)	16.5 (2.6)
Combined ash	2 cm	17.0 (3.3)	13.0 (1.6)	55.0 (3.8)	57.5 (7.3)	69.7 (42.8)	40.2 (4.1)	35.1 (3.7)	24.8 (19.7)	7.2 (2.3)
	8 cm	Not analyzed			37.6 (10.2)	13.5 (3.5)	18.7 (0.6)	20.2 (5.7)	12.5 (13.1)	17.8 (4.1)
	14 cm	Not analyzed			25.5 (5.6)	14.2 (4.8)	20.0 (4.2)	22.0 (2.8)	17.9 (9.0)	14.0 (4.6)
	20 cm	15.0 (0.5)	16.0 (2.1)	19.0 (0.4)	18.6 (3.0)	15.1 (2.8)	16.5 (2.6)	20.5 (5.9)	13.8 (11.0)	17.0 (5.4)
Control site	2 cm	20.0 (1.3)	23.0 (1.0)	20.0 (1.4)	21.1 (3.3)	28.7 (2.8)	20.0 (0.4)	24.4 (4.8)	17.1 (12.7)	21.7 (0.7)
	8 cm	Not analyzed			18.6 (3.8)	31.2 (2.5)	23.0 (2.8)	18.8 (6.7)	14.2 (9.3)	18.2 (2.1)
	14 cm	Not analyzed			13.7 (1.6)	29.4 (8.7)	12.6 (1.3)	25.8 (7.2)	13.5 (18.6)	14.8 (0.07)
	20 cm	15.0 (1.3	16.0 (1.1)	14.0 (0.4)	15.1 (5.5)	20.9 (2.5)	10.8 (1.4)	19.4 (3.3)	11.1 (6.3)	12.5 (0.7)

Bracketed numbers indicate standard deviations