**FIELD STUDY OF DISPOSED WASTES
FROM ADVANCED COAL PROCESSES
DOE QUARTERLY TECHNICAL
PROGRESS REPORT**

November, 1991 to January, 1992

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1.0 OBJECTIVES

The Department of Energy/Morgantown Energy Technology Center (DOE/METC) has initiated research on the disposal of solid wastes from advanced coal processes. The objective of this research is to develop information to be used by private industry and government agencies for planning waste disposal practices associated with advanced coal processes. To accomplish this objective, DOE has contracted Radian Corporation and the North Dakota Energy & Environmental Research Center (EERC) to design, construct, and monitor a limited number of field disposal tests with advanced coal process wastes. These field tests will be monitored over a three year period with the emphasis on collecting data on the field disposal of these wastes.

There has been considerable research on the characteristics and laboratory leaching behavior of coal wastes -- a lesser amount on wastes from advanced coal processes. However, very little information exists on the field disposal behavior of these wastes. Information on field disposal behavior is needed (a) as input to predictive models being developed, b) as input to the development of rule of thumb design guidelines for the disposal of these wastes, and c) as evidence of the behavior of these wastes in the natural environment.

2.0 SUMMARY OF PREVIOUS WORK

This study is organized into four major Tasks. Tasks 1 and 2 were devoted to planing the Task 3 field study. Task 4 uses the results of the field testing to produce an Engineering Design Manual for the utilities and industrial users who manage wastes from advanced coal combustion technologies.

Task 1 identified and rated test design options. A Test Design Manual was prepared and submitted to METC in 1988. Specific test procedures suitable for each design option were identified under Task 2. These test methods were documented in a

Test Procedures Manual, submitted to METC in 1988. Also under Task 2, test sites were selected and site access was negotiated. Sites in Illinois and North Dakota were delayed at this stage, and the North Dakota site was dropped from consideration. Task 2 was completed and Final Test Plans were submitted to METC for three sites in 1988.

Task 3 progress for each of the test sites is summarized below.

2.1 Colorado

The test cell was constructed in June, 1989 with CFBC ash from a low sulfur western coal. The ash has low lime and sulfate content. Core samples were collected in June and December 1989, in March, June and December of 1990, and in June 1991. No groundwater or porewater samples have been recovered.

Cores strength is low to moderate (200 psi to 900 psi), with permeabilities of 2×10^{-3} to 3×10^{-4} . Laboratory leachates show moderate concentrations of calcium, sulfate, and other common ions. Trace element concentrations in test leachates are low compared to regulatory limits. No leachate has been generated at the site.

2.2 Ohio

Two test cells were constructed, in February and April of 1989, using LIMB ash from an Ohio coal with 2.4% sulfur. The ash has a high lime and sulfate content. Test case 1 (north cell) was constructed with 25% moisture; test case 2 was constructed with 38% moisture to optimize compaction. The wastes expanded, heaved, and fractured during the first year, particularly in the south cell. Mineralogical changes in the wastes with hydration and weathering are the primary cause. Core strength is moderate to low (2000 psi to <100 psi) and highly variable because of fracturing. Permeability varies from 3×10^{-3} to 5×10^{-5} cm/sec. Permeabilities are lowest in the north cell.

Large amounts of water were bound in the wastes in the first year as the waste saturated and hydrated. In the second year leachate migrated out of the south cell into downgradient wells. The leachate contains up to several thousand mg/L of sulfate, chloride, potassium, and sodium, with somewhat lower concentrations of calcium and silicon. Trace metal concentrations are generally low compared to regulatory limits, but a few samples show mobilization of metals.

Core samples were first collected in June, 1989, and quarterly and annual core sampling events have taken place according to schedule since that time. Water samples have been collected on a quarterly basis since October, 1989.

2.3 Illinois

The first Illinois test cell was completed in April, 1991, with BFBC ash from a Illinois coal with 3.1% sulfur. A large excess of limestone is used in the combustor; the ash is high in lime relative to most FBC wastes, containing up to 30% CaO. The ash also contains abundant sulfate, but has relatively low concentrations of typical coal ash constituents compared to other wastes included in this study. The two test cells planned for the second Illinois test case will evaluate the effects of added coal ash on cementitious reactions in the waste. Laboratory studies to define the proper mix of FBC waste and coal fly ash are in progress.

The initial cell was instrumented and sampled in June 1991. Water samples and additional cores were collected in August and November, 1991. No expansion has been noted at the site; the wastes are solidified and unfractured.

3.0 OBJECTIVES FOR THE CURRENT REPORTING PERIOD

The specific objectives for the reporting period of November, 1991 to January, 1992 were as follows:

- The 9th quarterly measurements at the Colorado site took place in December, 1991. Permeability and neutron absorption moisture content measurements were made and on site data was collected from the data logger;
- The 9th quarterly sampling at the Ohio site took place in November 1991. Permeability and moisture content measurements were made, and water samples were collected from the wells and lysimeters;
- The second quarterly core and water samples from the first Illinois test case were collected in mid November, and field data were collected from the data logger;
- Chemical analysis of all core and water samples continued; all chemical analyses except for some tests on Illinois second quarter cores are now complete;
- Preliminary testing for the second Illinois test case began after METC approval of the test plans, and
- EERC data on the second annual cores from Colorado and Ohio was received by Radian in early February. Some of these results are reproduced in this report, and a complete set of results for the first two years of testing at the Colorado and Ohio sites will be included with letter reports on these sites to be prepared during the next Quarter.

4.0 ACTIVITIES FOR THE REPORTING PERIOD

Mr. Andrew Covar took over the role of Program Manager for this project at Radian, replacing Mr. Gordon Page. Mr. Covar has approximately 20 years experience in waste management and environmental engineering. Mr. Weinberg continues as the Project Director.

4.1 Colorado Ute Site

Major element composition of ASTM leachates from the initial ash and cores collected from the test cells to date are shown in Figure 1. The graphed values are straight averages of concentrations in all samples collected during the same sampling

COLORADO ASTM LEACHATE CHEMISTRY

Initial ash and subsequent core compositions

Figure 1. Variation Over Time in the Average Concentrations of Calcium, Sulfate, Chloride, and Potassium in ASTM Leachates of Colorado Ash Samples. The Left Axis Shows Calcium and Sulfate Levels, the Right Axis Shows Chloride and Potassium Levels.

event; all data used in these plots has been previously reported. The ratio of fly ash to bottom ash in the test cells is approximately 12:1, and therefore fly ash ASTM leachate concentrations are used to represent initial ash concentrations.

Calcium concentrations in the ASTM leachates are lower in all cases than the initial ash composition, indicating that calcium, originally present as lime (CaO), is being incorporated into less soluble phases, such as ettringite or calcite. Leaching of soluble constituents from the FBC ash has not been an important mechanism at the Colorado site due to low rainfall. Sulfate in leachates has not changed significantly relative to the initial ash composition, although sulfate is also a major constituent of ettringite. There are no apparent trends in leachable chloride concentrations over time. Concentrations of potassium in ASTM leachates increased significantly following placement of ash in the cells, and have since remained fairly constant, indicating a gradual break-down of potassium-bearing phases. Leachate pH (not shown) dropped from 12.23 for the initial ash to a fairly constant average of 10.4 over the course of the two years of monitoring, suggesting a change from a lime buffered system ($\text{pH} = 12.4$) to an ettringite buffered system ($\text{pH} = 10.5$).

Trace element composition of ASTM leachate are shown in Figure 2. Again, the graphed values represent the averages of concentrations in all samples collected during the same sampling event. Data below the detection limit are considered equal to the detection limit for calculation purposes, giving "worse case" trace element concentrations. However, the overall trends remain constant regardless of treatment of data below the detection limit. Concentrations of barium, boron (not shown), molybdenum and zinc in leachates were always less than concentrations in initial ash leachates, suggesting incorporation of these elements into less soluble phases. Borate and molybdate substitution for sulfate in ettringite has been suggested as one mechanism for immobilizing these elements (1). However, selenium and vanadium oxyanions, which could also substitute for sulfate, were found in greater concentrations in ASTM leachates of core samples than in initial ash leachates. Vanadium was not found in concentrations

Trace Elements in Colorado Ash Leachates

NOTE: Values are straight averages from all samples taken during one event.
Values below the detection limit are considered equal to the detection limit.

Figure 2. Trends in Selected Trace Element Concentrations in ASTM Leachates of Colorado Ash Samples

above the detection limit (0.02 mg/L) in the initial ash leachates. Leachable lead was highest in ash samples taken six months after construction of test cells, but subsequently returned to the levels seen in the initial ash.

Physical properties data for the second year annual cores from the Colorado site are shown in Table 1. Moisture contents in the cover soils are low, ranging from about 5% to 20%, with an average of about 10%. The moisture content in the ash samples is generally higher, averaging about 20% with a range of 2% to 34%. Several very dry samples were collected from near the base of the test cell. Soils underlying the test cell have a lower moisture content than the ash, with values ranging from 6% to 14%. The higher average moisture content of the ash is probably largely attributable to the water bound in ettringite and other hydrated mineral phases in the ash.

The strength and permeability data for the second annual cores are shown in Figure 3, with data from the first year annual cores shown for comparison. All the cover and base soil samples were too poorly consolidated for strength or permeability testing, and only about half of the core samples from the ash could be tested because of fractures or poor consolidation. The 1991 samples have an average strength of 357 psi, for samples where measurements were taken, whereas the 1990 samples averaged 595 psi for samples on which strength could be determined, indicating a possible loss in compressive strength over time. Permeability measurements for the 1991 annual cores suffered from the same limitations as the strength analyses, and only about one half of the samples were recovered in an intact state suitable for analysis. The 1991 samples had an average permeability of 3×10^{-5} cm/sec, as opposed to 2×10^{-5} cm/sec in 1990 samples. This difference is within the data's range of variability, and may not represent any significant trend.

In situ permeability and moisture content measurements were made at the Colorado site in December, 1991. At this time data stored in the data logger for the meteorological station was also retrieved. Moisture contents in the waste appear to

Physical Properties of Colorado Annual Cores

Unconfined Compressive Strength

Where more than one result is available for a given depth, the average value is shown.

Core Permeability

Where more than one result is available for a given depth, the average value is shown.

Figure 3. Unconfined Compressive Strength and Permeability of Second Annual Colorado Cores

have risen somewhat; the moisture tension on the gypsum block installed in the FBC ash was down to 50 centibars. If rains continue in western Colorado this winter, the moisture tension may fall enough to allow some porewater to be sucked into at least the near-surface lysimeters. To date no porewater samples have been recovered from any of the lysimeters at the Colorado site.

4.2 Ohio Site

The sample location and matrix of all Ohio and Illinois chemical samples is shown in Table 2. Quarterly water samples were collected from the Ohio site in November, 1991. Analytical results for these samples are presented in Table 3. In situ permeability and moisture content measurements were also made in November, and meteorological data was collected from the data logger.

The shallow groundwater samples from downgradient of the initially wetted, south cell show a distinct trend of increasing concentrations of some ash-derived constituents, most notably chloride and sulfate. The upgradient and downgradient groundwater compositions over the last 2.5 years are shown in Figures 4 through 6. In each Figure, separate graphs are shown, each providing data for groundwater from a different depth interval. No trends which can be attributed to leachate migration into the groundwater are apparent downgradient from the initially dry north test cell.

A reanalysis of the chloride concentration in water from OHMW-6 from the August 1991 quarterly set of ground-water samples (sample ID OH-235) showed that the previously reported value of 10 mg/L was incorrect. The corrected value is 275 mg/L. This result, and the November, 1991 results confirm that there is consistent and continuing trend of increasing chloride concentration in this well. The concentration is now above the level seen in the deeper wells OHMW-4 and OHMW-5, so the chloride concentration in OHMW-6 appears more likely to be a result of ash-derived leachate than of mixing between shallow and deeper groundwater.

OHIO GROUNDWATER CHEMISTRY

Downgradient Wells--North Cell

Figure 4. Major Element Concentrations in Groundwater Samples from Wells Downgradient of the Ohio North Cell for All Sampling Events

OHIO GROUNDWATER CHEMISTRY

Downgradient Wells--South Cell

Figure 5. Major Element Concentrations in Groundwater Samples from Wells Downgradient of the Ohio South Cell for All Sampling Events

OHIO GROUNDWATER CHEMISTRY

Upgradient Wells

Figure 6. Major Element Concentrations in Groundwater Samples from Wells Upgradient of the Ohio Test Cells for All sampling Events

Porewater concentrations of most major and trace elements continue to decline in both test cells. The concentration trends of some of the major analytes in several of the lysimeters are shown in Figure 7. The trend of decreasing concentration over time is clearest for samples from OHLY-12, near the surface of the south cell. In OHLY-12 the concentrations of most of the major ions shown have decreased by approximately a factor of ten over the 2.5 years the LIMB ash has been in the landfill. Samples from the north cell and from the middle or lower portions of the south cell have a more stable porewater composition over time, and the concentrations of each analyte are generally higher than at the surface of the south cell. Poor sample recovery limits the available data for the north cell. None of the deeper lysimeters in the north cell has consistently produced water over the course of the field monitoring. The abrupt decline in the silicon concentration in OHLY-1 in the last set of measurements may be related to the appearance of thaumasite in the LIMB ash at this time (see further discussion below).

Semiquantitative x-ray diffraction analyses of the Ohio second annual cores were completed this quarter. The results are shown in Table 4. The new mineral phase which was noted in the Ohio LIMB wastes in the last Quarterly Report has been identified by Dr. G.J. McCarthy and his coworkers at NDSU using X-ray diffraction (the full text of Dr. McCarthy's report is attached as Appendix A). The new mineral is thaumasite, which can form a solid-solution series with ettringite where aluminum and sulfate in the ettringite are replaced by silicon and carbonate in the thaumasite. The nominal formula for phase-pure thaumasite is $\text{Ca}_6\text{Si}_2[(\text{SO}_4)_2(\text{CO}_3)_2](\text{OH})_{12} \cdot 24\text{H}_2\text{O}$. In most sources this formula for thaumasite is usually divided by two; this stoichiometry is used to emphasize the structural similarities to ettringite. Estimates of thaumasite abundance range as high as 58 % wt. for near surface samples from the initially wetted (south) cell.

Thaumasite formation in the LIMB wastes was identified as a possibility in the November, 1990 - January, 1991 Quarterly Technical Progress Report due to the high carbonate concentrations in some porewater samples, but at that time the occurrence of

Ohio Porewater Concentration Trends

Figure 7. Major Element Concentrations in Porewater Samples from Lysimeters Within the Ash in Both Ohio Test Cells

thaumasite had not been documented. In some cases thaumasite appears to form as a replacement of earlier ettringite (2), and calcite at near-freezing temperatures, but in the LIMB test cells there is no evidence for replacement based on the XRD results.

Thaumasite generally is found in the greatest abundance just beneath the soil cap and near the base of the test cells. Samples with more thaumasite do not contain any less ettringite; samples with less than 10 wt% thaumasite (n=7) average 35.86 wt% ettringite, while samples with at least 20 wt% thaumasite (n=6) average 38.5 wt% ettringite. Calcite contents of the samples appears to be similarly unaffected by thaumasite growth. Samples with the largest amounts of thaumasite have the least gypsum present. For samples with < 10 wt% thaumasite, gypsum averages 7 wt%, while for samples with ≥ 20 wt% thaumasite, gypsum averages 0.7 wt%.

Mass balance considerations, in particular the availability of aluminum and sulfate, will limit the overall abundance of ettringite and thaumasite in the LIMB wastes. Table 5 shows the minerals ettringite and thaumasite expressed in terms of the wt% of their chemical components in comparison to the LIMB ash composition as measured in the initial waste characterization. Hydration of the LIMB ash over time has lowered the effective concentration of components other than water as the solid phase water content has increased. The last column of Table 5 shows the effective composition of the LIMB ash after it has hydrated to a 30% water content in the solids, approximately corresponding to the amount of water bound in gypsum, ettringite and thaumasite in the wastes.

Table 5 illustrates that sulfate availability is likely to limit the formation of ettringite in the test cells after ettringite forms 55 wt% of the total. This is somewhat higher than the maximum amount of ettringite observed. Although thaumasite also contains sulfate, its formation should be favored under sulfate-limited conditions since it has a lower stoichiometric requirement for sulfate.

The sources and disposition of inorganic carbon in the test cells is not entirely clear. Figure 8 shows the concentration of inorganic carbon, as carbonate, in

Ohio LIMB Test Cells

Total Inorganic Carbon, mg/Kg

Figure 8. Total Inorganic Carbon Content of Cores From Both Ohio Test Cells

core samples from each test cell over the 2 years of monitoring to date. The south cell samples do not show any well developed trend, although the second year core samples have a more consistent, and generally higher, carbonate concentration than the first annual cores. The north cell has a more consistent carbonate concentration through the first year of monitoring, and a distinct trend of decreased carbonate in the upper portions of the test cell is apparent in the second annual samples.

These measured carbonate concentrations do not correlate with the abundance of thaumasite found in XRD measurements; no increase in total inorganic carbon is seen in areas where large amounts of thaumasite were detected. Likewise, calcite formation or dissolution does not appear to be responsible for the changes in north cell carbonate concentration. Calcite concentrations measured by XRD analysis of the wastes have generally been stable over the past two years, and account for approximately half of the total carbonate, with thaumasite and/or poorly crystalline materials presumably making up the difference. It is also unclear why carbonate concentrations are declining in the north cell rather than the south cell, which generally has a higher permeability and has undergone more extensive leaching than the north cell.

The physical properties data for the 1991 annual samples from the Ohio test cases is shown in Table 6. The moisture content of the LIMB wastes remains very high, especially just beneath the soil cap, due to the large amounts of combined water in the secondary minerals formed in the wastes, and its high porosity. Figures 9 and 10 show the strength and permeability data from the 1991 annual cores from the north cell and south cell respectively. Both strength and permeability are highly variable due to the extensive fractures in the landfilled material, and many samples were not recovered in a sufficiently intact state to permit analysis. Unconfined compressive strengths for the ash in the north cell (cores 2 and 4) vary between 50.7 psi and 2762 psi, averaging 1066 psi; the south cell (cores 6 and 8) range is from 152 psi to 1250 psi, averaging 864 psi. Soils in the test cell covers and beneath the test cells have strengths between approximately 40 psi and 175 psi. Most of the permeability data for the 1991 annual cores from

Physical Properties of North Cell Annual Cores

Figure 9. Unconfined Compressive Strength and Permeability of Annual Cores from the Ohio North Cell

Physical Properties of South Cell Annual Cores

Figure 10. Unconfined Compressive Strength and Permeability of Annual Cores from the Ohio South Cell

the south cell is not available at this time, but in general permeabilities in the LIMB ash range from 10^{-5} cm/sec to 10^{-6} cm/sec. Permeabilities in the cover soil and underlying soils are significantly lower than permeabilities measured on the ash cores, and range from approximately 10^{-7} cm/sec to 10^{-8} cm/sec.

4.3 Illinois Site

The second set of quarterly water samples was collected in November, 1991 and was analyzed in December, 1991. The results of these analyses are presented in Table 7. A comparison of the groundwater chemistry between the first and second sampling events (June and November of 1991, respectively) for both upgradient and downgradient wells is shown in Figure 11. Sulfate concentrations were consistently lower in the groundwater samples taken during the second sampling event. Chloride concentrations were likewise found to be generally lower in samples from the second event. In most cases, magnesium, calcium, and sodium did not exhibit significant differences in concentration between the two sampling events. Groundwater pH measurements (not shown) were similar for both dates, except in the case of the shallowest downgradient well. In this well, an increase of more than one pH unit (6.57 to 7.72) was observed from June to November.

Second quarter ASTM leachate data from the Illinois site are presented in Table 8. A comparison of major element concentrations in leachates from the initial ash and from cores taken from the test cell in June and November of 1991 is shown in Figure 12. Leachable sulfate, sodium and potassium concentrations have increased since placement of the ash in the test cell, indicating some degree of instability of phases containing these elements. Calcium and chloride concentrations in leachates from the two sets of cores have not changed significantly from those in initial ash leachates. The continued high calcium concentration suggests that $\text{Ca}(\text{OH})_2$ persists in the landfilled wastes at the Illinois site, whereas calcium hydroxide was quickly replaced by other minerals at the Colorado and Ohio sites.

ILLINOIS GROUNDWATER CHEMISTRY

Figure 11. Major Element Concentrations in Illinois Groundwater Samples

ILLINOIS ASH ASTM LEACHATE CHEMISTRY

Figure 12. Major Element Concentrations in ASTM Leachate of Ash from the Illinois Test Cell

Physical testing data for the initial waste and soil samples from the Illinois site is shown in Table 9. The soils generally are fairly dense clay soils with a moisture content between a 15% and 20% for shallow soils. The measured moisture contents place the soils near their plastic limit. Soil permeabilities have a wide range of measured values, from 1.5×10^{-4} cm/sec to 2.5×10^{-8} cm/sec. The first quarter measurements of unconfined compressive strength and permeability on core samples are shown in Figure 13. Strengths range from 250 psi to 505 psi, while permeability in the ash ranges from 1.2×10^{-6} to 6.2×10^{-5} cm/sec. Permeabilities in the underlying soil range from 10^{-4} to 10^{-7} cm/sec. Figure 13 also shows the results of in situ permeability tests at the Illinois site during the first two quarters of monitoring. First quarter measurements of in situ permeability, made in June, 1991, found values of 1.1×10^{-3} cm/sec to 2.9×10^{-3} cm/sec, considerably higher than values seen in the core samples. This same discrepancy between field and laboratory measurements was also seen at the Ohio site and is believed to be related to macroscopic fractures and pores which influence the field measurements, but not the smaller core samples. In August, 1991, when the next field measurements were made, in-situ permeabilities were unchanged, but in November, 1991, measurements of in situ permeability were significantly lower, ranging from 2×10^{-5} cm/sec to 2×10^{-4} cm/sec. This decrease in permeability suggests the continued development of cementing phases in the Illinois FBC wastes.

Initial laboratory testing on mixtures of the Midwest Grain FBC waste and fly ash from a near-by electric power plant burning an Illinois #6 coal is under way. Figure 14 shows both the relationship between the amount of moisture added to the FBC ash and the amount of water taken into the solid phase by hydration reactions and the moisture/density relations for the FBC ash. These tests show that approximately 40 wt% (dry basis) water is required to fully hydrate the ash, with approximately 21 wt% (dry basis) of that water actually bound into the solids. In order to obtain a 40 wt% moisture content, up to 75 wt% water addition may be required, since large amounts of steam are generated during the exothermic reaction of lime with water. Only water remaining in the wastes after cooling is shown here.

Illinois Site Physical Properties

Figure 13. Unconfined Compressive Strength and Permeability of Illinois Ash

Midwest Grain FBC Ash Testing

Figure 14. Relationship Between Water Added and Ash Hydration on Left and Between Moisture and Density on Right in Midwest Grain FBC Ash

The moisture/density relations shown in Figure 14 indicate that the optimum moisture content for compaction occurs at a moisture content slightly above the 40 wt% required for complete hydration of the wastes, with a free water (water not lost at 50 °C) content of approximately 23 wt%.

Figure 15 shows the variation in moisture/density relations as pulverized coal fly ash (PFA) is added to the FBC waste in different amounts. The first portion of the figure shows that the optimum total moisture content for compaction decreases as the proportion of FBC ash decreases, and that fly ash addition creates a higher density material. The smaller particle size of the fly ash, and the lack of reactive mineral phases account for the lower water demand of the fly ash mixtures. The second portion of Figure 15 shows that while the total water requirement for optimum compaction changes with fly ash addition, the amount of free water required for compaction is approximately 17 wt%, and is essentially unchanged for all mixtures containing fly ash.

The effect of reaction temperature on FBC ash hydration was also tested. FBC ash was hydrated using varying proportions of ice and water to control the temperature of reaction and to reduce the amount of water lost by steaming. Preliminary results suggest that the addition of ice did not interfere with the complete hydration of the FBC ash, but the ice also did not prevent boiling from occurring. Hydration of 1000g ash with 100g water and 400g ice still produced temperatures of 100°C within approximately 3 minutes, but only 115g water was lost to evaporation under these conditions, as opposed to approximately 170g water lost when 500g of water was added to 1000g FBC ash without ice.

5.0 PROBLEMS ENCOUNTERED

Economic conditions in the State of Illinois have forced severe cuts in the current year funding. The Illinois Department of Energy and Natural Resources (ENR) was forced to reduce their current year spending by \$1 million. This resulted in a

Midwest Grain FBC Ash/PFA Combinations

Figure 15. Variation in the Relationship Between Added Moisture and Density with the Addition of Varying Proportions of PFA to FBC Wastes

\$200,000 reduction in that agency's contribution to this program. Project sponsors at the Illinois ENR are still very supportive of the program and are hopeful that some or all of this funding may be restored in subsequent fiscal years. Contracts personnel are making needed changes to contracts documents in order to account for this change in contributor funding.

6.0 ACTIVITIES PLANNED FOR THE NEXT QUARTER

The following activities are planned for the period of February 1992 through April 1992:

- The 10th quarterly sampling at the Colorado site is scheduled for March, 1992. Permeability and in situ moisture content measurements will be made and on-site data collected from the data logger;
- The 10th quarterly sampling at the Ohio site is scheduled for February 1992. Permeability and moisture content measurements will be made, and water samples collected;
- Chemical analysis of samples will continue;
- The third quarterly core and water samples from the first Illinois test case will be collected in mid February, and other associated field measurements will be made;
- Preliminary testing of waste mixtures for the second Illinois test case will be completed;
- Radian will begin production of a short video presentation on the advanced coal wastes test program;
- EERC data will continue to be loaded onto the project database and reported as available. A complete set of results for the first two years of testing at the Colorado and Ohio sites will be included in letter reports on the two sites; and
- Preliminary Case Reports on the Colorado and Ohio test cases will be prepared during the next Quarter covering from results the first two and one half years of testing. These reports will include recommendations on the scope and costs of continued testing.

7.0

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Table 1

Physical Testing Data - Annual Colorado Ash Cores

=====											
SAMPLE DESCRIPTION		dry = Unconditioned wet = Conditioned		NP = Nonplastic FP = Poorly consolidated or Fractured material		IP = In Progress					
								- Atterberg Limits -			
		Unconfined									
Sample	Depth	Sample	Comp.	Unit	Dry	Moisture	Perm.	Particle	Liquid	Plastic	Plastic
ID	(ft)	Type	Strength	Weight	Density	Content		Specific	Limit	Limit	Index
=====											
=====											
1991 Annual Cores											
91JUNCO1-1	0-.5'	soil	FP			4.6	FP				
91JUNCO1-2	.5-1'	soil	FP			9.8	FP				
91JUNCO1-3	1-1.5'	soil	FP			13.5	FP				
91JUNCO1-4	1.5-2'	ash	246.7			29.9	FP				
91JUNCO1-5	2-2.5'	ash	FP			34.1	2.60E-05				
91JUNCO1-6	2.5-3'	ash	423.7			32.8	FP				
91JUNCO1-7	3-3.5'	ash	FP			31.4	5.70E-05				
91JUNCO1-8	3.5-4'	ash	258.8			33.3	FP				
91JUNCO1-9	4-4.5'	ash	FP			22.0	9.60E-05				
91JUNCO1-10	4.5-5'	ash	391.2			22.0	FP				
91JUNCO1-11	5-5.5'	ash	FP			23.5	1.80E-05				
91JUNCO1-12	5.5-6'	ash	354.6			23.5	FP				
91JUNCO1-13	6-6.5'	ash	FP			24.7	1.40E-05				
91JUNCO1-14	6.5-7'	ash	FP			12.3	FP				
91JUNCO1-15	7-7.5'	ash	FP			5.8	FP				
91JUNCO1-16	7.5-8'	ash	FP			3.8	FP				
91JUNCO1-17	8-8.5'	ash	FP			2.0	FP				
91JUNCO1-18	8.5-9'	ash	FP			26.2	FP				
91JUNCO1-19	9-9.5'	ash	FP			2.0	FP				
91JUNCO1-20	9.5-10'	ash	FP			17.4	FP				
91JUNCO1-21	10-10.5'	soil	FP			19.0	FP				
91JUNCO1-22	10.5-11'	soil	FP			14.7	FP				
91JUNCO1-23	11-11.5'	soil	FP			11.1	FP				
91JUNCO1-24	11.5-12'	soil	FP			10.0	FP				
91JUNCO1-25	12-12.5'	soil	FP			9.5	FP				
91JUNCO1-26	12.5-13'	soil	FP			9.1	FP				
91JUNCO1-27	13-13.5'	soil	FP			10.1	FP				
91JUNCO1-28	13.5-14'	soil	FP			9.4	FP				
91JUNCO1-29	14-14.5'	soil	FP			6.3	FP				
91JUNCO1-30	14.5-15'	soil	FP			10.1	FP				
91JUNCO1-31	15-15.5'	soil	FP			8.2	FP				
91JUNCO1-32	15.5-16'	soil	FP			9.5	FP				
91JUNCO1-33	16-16.5'	soil	FP			9.0	FP				
91JUNCO1-34	16.5-17'	soil	FP			13.5	FP				
91JUNCO1-35	17-17.5'	soil	FP			6.2	FP				

Table 1
(Continued)

=====											
SAMPLE DESCRIPTION			dry = Unconditioned wet = Conditioned		NP = Nonplastic FP = Poorly consolidated or Fractured material		IP = In Progress				

			Unconfined			- Atterberg Limits -					
Sample	Depth	Sample	Comp.	Unit	Dry	Moisture	Perm.	Particle	Liquid	Plastic	Plastic
ID	(ft)	Type	Strength	Weight	Density	Content		Specific	Limit	Limit	Index
=====											
1991 Annual Cores											
91JUNCO4-1	0-.5'	soil	FP			7.5	FP				
91JUNCO4-2	.5-1'	soil	FP			9.3	FP				
91JUNCO4-3	1-1.5'	soil	FP			19.4	FP				
91JUNCO4-4	1.5-2'	ash	221.8			34.3	FP				
91JUNCO4-5	2-2.5'	ash	FP			34.8	1.10E-05				
91JUNCO4-6	2.5-3'	ash	FP			35.0	FP				
91JUNCO4-7	3-3.5'	ash	532.3			32.5	FP				
91JUNCO4-8	3.5-4'	ash	FP			29.0	2.40E-05				
91JUNCO4-9	4-4.5'	ash	635.5			27.7	FP				
91JUNCO4-10	4.5-5'	ash	FP			20.8	1.30E-05				
91JUNCO4-11	5-5.5'	ash	227.2			30.3	FP				
91JUNCO4-12	5.5-6'	ash	FP			31.7	FP				
91JUNCO4-13	6-6.5'	ash	FP			26.1	7.90E-06				
91JUNCO4-14	6.5-7'	ash	FP			9.2	FP				
91JUNCO4-15	7-7.5'	ash	FP			9.1	FP				
91JUNCO4-16	7.5-8'	ash	FP			20.9	FP				
91JUNCO4-17	8-8.5'	ash	432.7			30.0	FP				
91JUNCO4-18	8.5-9'	ash	FP			26.9	3.20E-05				
91JUNCO4-19	9-9.5'	ash	204.0			21.5	FP				
91JUNCO4-20	9.5-10'	soil	FP			16.8	FP				
91JUNCO4-21	10-10.5'	soil	FP			17.1	FP				
91JUNCO4-22	10.5-11'	soil	FP			17.3	FP				
91JUNCO4-23	11-11.5'	soil	FP			17.7	FP				
91JUNCO4-24	11.5-12'	soil	FP			13.2	FP				
91JUNCO4-25	12-12.5'	soil	FP			5.8	FP				
91JUNCO4-26	12.5-13'	soil	FP			10.9	FP				
91JUNCO4-27	13-13.5'	soil	FP			10.4	FP				
91JUNCO4-28	13.5-14'	soil	FP			9.4	FP				
91JUNCO4-29	14-14.5'	soil	FP			8.0	FP				
91JUNCO4-30	14.5-15'	soil	FP			7.5	FP				
91JUNCO4-31	15-15.5'	soil	FP			8.4	FP				
91JUNCO4-32	15.5-16'	soil	FP			9.0	FP				
91JUNCO4-33	16-16.5'	soil	FP			9.5	FP				
91JUNCO4-34	16.5-17'	soil	FP			9.5	FP				
91JUNCO4-35	17-17.5'	soil	FP			9.0	FP				

Table 2

Sample Information Table

Location ID	Sample ID	Location	Matrix	Depth (ft)	Log date
Site: ILLINOIS					
91NOVIL02	91NOVIL02-01	In ash	Ash	0	12/02/91
91NOVIL02	91NOVIL02-03	In ash	Ash	2	12/02/91
91NOVIL02	91NOVIL02-05	In ash	Ash	4	12/02/91
91NOVIL02	91NOVIL02-07	In ash	Ash	6	12/02/91
91NOVIL02	91NOVIL02-09	In ash	Ash	8	12/02/91
91NOVIL02	91NOVIL02-10	In ash	Ash	9	12/02/91
91NOVIL02	91NOVIL02-11	Beneath ash	Soil	10	12/02/91
ILLY05	IL044	In ash	Soil porewater		11/17/91
ILLY06	IL045	In ash	Soil porewater		11/25/91
ILMW01	IL030	Downgradient	Groundwater	24	11/17/91
ILMW02	IL031	Downgradient	Groundwater	14	11/17/91
ILMW03	IL032	Downgradient	Groundwater	4	11/17/91
ILMW04	IL033	Upgradient	Groundwater	48	11/17/91
ILMW05	IL034	Upgradient	Groundwater	38	11/17/91
ILMW06	IL035	Upgradient	Groundwater	28	11/17/91
ILMW07	IL036	Downgradient	Groundwater	24	11/17/91
ILMW08	IL037	Downgradient	Groundwater	14	11/17/91
ILMW09	IL038	Downgradient	Groundwater	4	11/17/91
ILSW01	IL046	Downgradient	Surface water		11/17/91
ILSW02	IL047	Downgradient	Surface water		11/17/91
Site: OHIO					
OHLY01	OH269	In ash	Soil porewater	1	11/20/91
OHLY05	OH282	In ash	Soil porewater	6	11/21/91
OHLY11	OH271	In ash	Soil porewater	3	11/20/91
OHLY12	OH272	Beneath ash	Soil porewater	1	11/20/91
OHLY14	OH273	In ash	Soil porewater	3	11/20/91
OHLY15	OH274	In ash	Soil porewater	1	11/20/91
OHLY16	OH275	Beneath ash	Soil porewater	8.5	11/20/91
OHLY17	OH276	In ash	Soil porewater	4	11/20/91
OHLY20	OH277	Beneath ash	Soil porewater	9.7	11/20/91
OHLY21	OH279	In ash	Soil porewater	1	11/21/91
OHLY24	OH280	Beneath ash	Soil porewater	11	11/21/91
OHMW01	OH260	Downgradient	Groundwater	23	11/20/91
OHMW02	OH261	Downgradient	Groundwater	13	11/20/91
OHMW03	OH262	Downgradient	Groundwater	3	11/20/91
OHMW04	OH263	Downgradient	Groundwater	23	11/20/91
OHMW05	OH264	Downgradient	Groundwater	13	11/21/91
OHMW06	OH265	Downgradient	Groundwater	3	11/21/91
OHMW07	OH266	Upgradient	Groundwater	31	11/20/91
OHMW08	OH267	Upgradient	Groundwater	15	11/20/91
OHSW01	OH281	Downgradient	Surface water		11/20/91

Table 3A

Ninth Quarter Ohio Groundwater Data

Parameter	Units	OH260		OH261		OH262	
		Msr'd Val.	Det. Lim.	Msr'd Val.	Det. Lim.	Msr'd Val.	Det. Lim.
Anions							
Chloride	mg/L	200	.52			44	.26
Fluoride	mg/L	.78	.1	.41	.1	.38	.1
Sulfate	mg/L	500	1	890	1	820	.5
Elements by ICPEs or AA							
Aluminum	mg/L	ND	.2	ND	.2	ND	.2
Arsenic	mg/L	ND	.004	ND	.004	ND	.004
Barium	mg/L	.011	.01	.053	.01	.034	.01
Beryllium	mg/L	ND	.002	ND	.002	ND	.002
Boron	mg/L	.92	.6	ND	.6	ND	.6
Cadmium	mg/L	ND	.001	ND	.001	ND	.001
Calcium	mg/L	3.5	1	190	1	190	1
Chromium	mg/L	ND	.01	ND	.01	ND	.01
Cobalt	mg/L	ND	.01	ND	.01	ND	.01
Copper	mg/L	ND	.02	ND	.02	ND	.02
Iron	mg/L	.047	.04	ND	.04	ND	.04
Lead	mg/L	ND	.003	ND	.003	ND	.003
Magnesium	mg/L	3.4	1	130	1	170	1
Manganese	mg/L	ND	.01	.16	.01	.22	.01
Molybdenum	mg/L	ND	.05	ND	.05	ND	.05
Nickel	mg/L	ND	.02	ND	.02	ND	.02
Potassium	mg/L	25	3	7.9	3	6.5	3
Selenium	mg/L	ND	.005	ND	.005	ND	.005
Silicon	mg/L	3.2	1	6.3	1	6.9	1
Silver	mg/L	ND	.01	ND	.01	ND	.01
Sodium	mg/L	620	1	220	1	100	1
Strontium	mg/L	.22	.003	1.3	.003	.6	.003
Tin	mg/L	ND	.6	ND	.6	ND	.6
Vanadium	mg/L	ND	.02	ND	.02	ND	.02
Zinc	mg/L	ND	.02	ND	.02	ND	.02

Field measurements
Conductivity

ND = not detected NA = not applicable IS = insufficient sample

(Continued)

Parameter	Units	OH260		OH261		OH262	
		Msr'd Val.	Det. Lim.	Msr'd Val.	Det. Lim.	Msr'd Val.	Det. Lim.
Field measurements							
Redox (Eh)	mV	-165.1	NA	-6.8	NA	-12	NA
Temperature	degrees	15.7	NA	12.9	NA	14.8	NA
pH	pH units	10.25	NA	7.06	NA	6.69	NA

ND = not detected NA = not applicable IS = insufficient sample

Table 3A

(Continued)

Parameter	Units	OH263		OH264		OH265	
		Msr'd Val.	Det. Lim.	Msr'd Val.	Det. Lim.	Msr'd Val.	Det. Lim.
Anions							
Chloride	mg/L	230	.52	180	.52	460	1.3
Fluoride	mg/L	1	.1	.95	.1	.11	.1
Sulfate	mg/L	110	.1	120	1	610	1
Elements by ICPEs or AA							
Aluminum	mg/L	ND	.2	ND	.2	ND	.2
Arsenic	mg/L	ND	.004	ND	.004	ND	.004
Barium	mg/L	ND	.01	.035	.01	.063	.01
Beryllium	mg/L	ND	.002	ND	.002	ND	.002
Boron	mg/L	1	.6	1.2	.6	ND	.6
Cadmium	mg/L	ND	.001	ND	.001	ND	.001
Calcium	mg/L	7.4	1	20	1	290	1
Chromium	mg/L	ND	.01	ND	.01	ND	.01
Cobalt	mg/L	ND	.01	ND	.01	ND	.01
Copper	mg/L	ND	.02	ND	.02	ND	.02
Iron	mg/L	ND	.04	ND	.04	.75	.04
Lead	mg/L	ND	.003	ND	.003	ND	.003
Magnesium	mg/L	4.4	1	12	1	98	1
Manganese	mg/L	ND	.01	.02	.01	.43	.01
Molybdenum	mg/L	ND	.05	ND	.05	ND	.05
Nickel	mg/L	ND	.02	ND	.02	ND	.02
Potassium	mg/L	5.1	3	7	3	12	3
Selenium	mg/L	ND	.005	ND	.005	ND	.005
Silicon	mg/L	4.1	1	4.3	1	4.7	1
Silver	mg/L	ND	.01	ND	.01	ND	.01
Sodium	mg/L	570	1	480	1	180	1
Strontium	mg/L	.2	.003	.53	.003	1.1	.003
Tin	mg/L	ND	.6	ND	.6	ND	.6
Vanadium	mg/L	ND	.02	ND	.02	ND	.02
Zinc	mg/L	ND	.02	ND	.02	ND	.02
Field measurements							
Conductivity	umhos/cm	2034	NA	2080	NA	2740	NA

ND = not detected NA = not applicable IS = insufficient sample

(Continued)

Parameter	Units	OH263		OH264		OH265	
		Ms'd Val.	Det. Lim.	Ms'd Val.	Det. Lim.	Ms'd Val.	Det. Lim.
Field measurements							
Redox (Eh)	mV	-77.1	NA	-52.8	NA	27.4	NA
Temperature	degrees	13.4	NA	12.2	NA	12	NA
pH	pH units	8.29	NA	8.11	NA	6.53	NA

ND = not detected NA = not applicable IS = insufficient sample

Table 3A

(Continued)

Parameter		Units	OH266		OH267	
			Msr'd Val.	Det. Lim.	Msr'd Val.	Det. Lim.
Anions						
Chloride		mg/L	5.9	.052	3.9	.052
Fluoride		mg/L	.28	.1	.29	.1
Sulfate		mg/L	370	1	460	1
Elements by ICPEs or AA						
Aluminum		mg/L	ND	.2	ND	.2
Arsenic		mg/L	.0059	.004	ND	.004
Barium		mg/L	.047	.01	.017	.01
Beryllium		mg/L	ND	.002	ND	.002
Boron		mg/L	ND	.6	ND	.6
Cadmium		mg/L	ND	.001	ND	.001
Calcium		mg/L	77	1	110	1
Chromium		mg/L	ND	.01	ND	.01
Cobalt		mg/L	ND	.01	ND	.01
Copper		mg/L	ND	.02	ND	.02
Iron		mg/L	.044	.04	ND	.04
Lead		mg/L	ND	.003	.0034	.003
Magnesium		mg/L	ND	1	54	1
Manganese		mg/L	ND	.01	.048	.01
Molybdenum		mg/L	ND	.05	ND	.05
Nickel		mg/L	ND	.02	.028	.02
Potassium		mg/L	9.4	3	6.9	3
Selenium		mg/L	ND	.005	ND	.005
Silicon		mg/L	9	1	4.6	1
Silver		mg/L	ND	.01	ND	.01
Sodium		mg/L	160	1	120	1
Strontium		mg/L	.63	.003	2.3	.003
Tin		mg/L	ND	.6	ND	.6
Vanadium		mg/L	ND	.02	ND	.02
Zinc		mg/L	ND	.02	ND	.02
Field measurements		unhos/cm	1210	NA	1160	NA
Conductivity						

ND = not detected NA = not applicable IS = insufficient sample

(Continued)

Parameter	OH266		OH267	
	Msrd Val.	Det. Lim.	Msrd Val.	Det. Lim.
Field measurements				
Redox (Eh)	-257	NA	-19.3	NA
Temperature	13.9	NA	14.1	NA
pH	11.51	NA	7.27	NA

ND = not detected NA = not applicable IS = insufficient sample

Table 3B

Ninth Quarter Ohio Porewater Data

Parameter	Units	OH269		OH271		OH272	
		Msr'd Val.	Det. Lim.	Msr'd Val.	Det. Lim.	Msr'd Val.	Det. Lim.
Anions							
Chloride	mg/L	IS		390	1.3	42	.52
Fluoride	mg/L	IS		ND	.1	.23	.1
Sulfate	mg/L	IS		1700	2.5	310	1
Elements by ICPEs or AA							
Aluminum	mg/L	.34	.2	ND	.2	ND	.2
Arsenic	mg/L	ND	.004	ND	.004	.0044	.004
Barium	mg/L	.077	.01	.041	.01	.03	.01
Beryllium	mg/L	ND	.002	ND	.002	ND	.002
Boron	mg/L	ND	.6	ND	.6	ND	.6
Cadmium	mg/L	ND	.001	ND	.001	ND	.001
Calcium	mg/L	130	1	490	1	130	1
Chromium	mg/L	ND	.01	ND	.01	ND	.01
Cobalt	mg/L	ND	.01	ND	.01	ND	.01
Copper	mg/L	ND	.02	ND	.02	ND	.02
Iron	mg/L	ND	.04	ND	.04	ND	.04
Lead	mg/L	.0043	.003	.0032	.003	.0032	.003
Magnesium	mg/L	ND	1	ND	1	ND	1
Manganese	mg/L	ND	.01	ND	.01	ND	.01
Molybdenum	mg/L	.78	.05	.68	.05	.085	.05
Nickel	mg/L	ND	.02	ND	.02	ND	.02
Potassium	mg/L	990	3	590	3	33	3
Selenium	mg/L	.013	.005	.0089	.005	ND	.005
Silicon	mg/L	6	1	55	1	15	1
Silver	mg/L	ND	.01	ND	.01	ND	.01
Sodium	mg/L	300	1	160	1	11	1
Strontium	mg/L	2.4	.003	3.5	.003	.97	.003
Tin	mg/L	ND	.6	ND	.6	ND	.6
Vanadium	mg/L	ND	.02	.066	.02	ND	.02
Zinc	mg/L	ND	.02	ND	.02	ND	.02
Field measurements							
Conductivity	umhos/cm	6330	NA	32500	NA	678	NA

ND = not detected	NA = not applicable	IS = insufficient sample					

ND = not detected NA = not applicable IS = insufficient sample

(Continued)

Parameter	Units	OH269		OH271		OH272	
		Msr'd Val.	Det. Lim.	Msr'd Val.	Det. Lim.	Msr'd Val.	Det. Lim.
Field measurements							
Redox (Eh)	mV	-294.1	NA	-140.4	NA	-173.4	NA
Temperature	degrees	16	NA	13.8	NA	12.7	NA
pH	pH units	12.14	NA	9.35	NA	9.9	NA

ND = not detected NA = not applicable IS = insufficient sample

Table 3B

(Continued)

Parameter	Units	OH273		OH274		OH275	
		Msr'd Val.	Det. Lim.	Msr'd Val.	Det. Lim.	Msr'd Val.	Det. Lim.
Anions							
Chloride	mg/L	280	.52	110	.52	1400	2.6
Fluoride	mg/L	.11	.1	ND	.1	.12	.1
Sulfate	mg/L	1600	1	980	1	1900	5
Elements by ICPEs or AA							
Aluminum	mg/L	ND	.2	ND	.2	.24	.2
Arsenic	mg/L	.011	.004	.0078	.004	ND	.04
Barium	mg/L	.043	.01	.028	.01	.026	.01
Beryllium	mg/L	ND	.002	ND	.002	ND	.002
Boron	mg/L	ND	.6	ND	.6	ND	.6
Cadmium	mg/L	ND	.001	ND	.001	ND	.001
Calcium	mg/L	380	1	180	1	29	1
Chromium	mg/L	.016	.01	.011	.01	.065	.01
Cobalt	mg/L	ND	.01	ND	.01	ND	.01
Copper	mg/L	ND	.02	.053	.02	ND	.02
Iron	mg/L	ND	.04	ND	.04	ND	.04
Lead	mg/L	.0041	.003	.0035	.003	ND	.003
Magnesium	mg/L	1.3	1	ND	1	ND	1
Manganese	mg/L	ND	.01	ND	.01	ND	.01
Molybdenum	mg/L	.71	.05	.33	.05	1.5	.05
Nickel	mg/L	ND	.02	ND	.02	ND	.02
Potassium	mg/L	560	3	280	3	2900	30
Selenium	mg/L	.011	.005	ND	.005	.019	.01
Silicon	mg/L	33	1	54	1	100	1
Silver	mg/L	ND	.01	ND	.01	ND	.01
Sodium	mg/L	150	1	180	1	550	10
Strontium	mg/L	4.1	.003	2.5	.003	3.6	.003
Tin	mg/L	ND	.6	ND	.6	ND	.6
Vanadium	mg/L	.069	.02	.031	.02	ND	.02
Zinc	mg/L	ND	.02	.022	.02	ND	.02
Field measurements							
Conductivity	umhos/cm	3400	NA	2000	NA	9150	NA

ND = not detected NA = not applicable IS = insufficient sample

(Continued)

Parameter	Units	OH273		OH274		OH275	
		Msr'd Val.	Det. Lim.	Msr'd Val.	Det. Lim.	Msr'd Val.	Det. Lim.
Field measurements							
Redox (Eh)	mV	-119.5	NA	-128.7	NA	-293.9	NA
Temperature	degrees	14.6	NA	12.7	NA	19.4	NA
pH	pH units	9.07	NA	9.23	NA	12.11	NA

ND = not detected NA = not applicable IS = insufficient sample

Table 3B

(Continued)

Parameter	Units	OH276		OH277		OH279	
		Msr'd Val.	Det. Lim.	Msr'd Val.	Det. Lim.	Msr'd Val.	Det. Lim.
Anions							
Chloride	mg/L	410	1.3	150	1.3	140	.52
Fluoride	mg/L	ND	.1	ND	.1	.27	.1
Sulfate	mg/L	1700	2.5	1900	2.5	1500	1
Elements by ICPEs or AA							
Aluminum	mg/L	ND	.2	IS		ND	.2
Arsenic	mg/L	ND	.004	IS		.017	.004
Barium	mg/L	.054	.01	IS		.048	.01
Beryllium	mg/L	ND	.002	IS		ND	.002
Boron	mg/L	ND	.6	IS		7.4	.6
Cadmium	mg/L	ND	.001	IS		ND	.001
Calcium	mg/L	370	1	IS		510	1
Chromium	mg/L	.012	.01	IS		ND	.01
Cobalt	mg/L	ND	.01	IS		ND	.01
Copper	mg/L	ND	.02	IS		ND	.02
Iron	mg/L	ND	.04	IS		ND	.04
Lead	mg/L	ND	.003	IS		ND	.003
Magnesium	mg/L	ND	1	IS		68	1
Manganese	mg/L	ND	.01	IS		ND	.01
Molybdenum	mg/L	.86	.05	IS		.26	.05
Nickel	mg/L	ND	.02	IS		ND	.02
Potassium	mg/L	680	3	IS		180	3
Selenium	mg/L	.015	.005	IS		.021	.005
Silicon	mg/L	16	1	IS		24	1
Silver	mg/L	ND	.01	IS		ND	.01
Sodium	mg/L	220	1	IS		63	1
Strontium	mg/L	4.7	.003	IS		.82	.003
Tin	mg/L	ND	.6	IS		ND	.6
Vanadium	mg/L	.031	.02	IS		ND	.02
Zinc	mg/L	ND	.02	IS		ND	.02
Field measurements							
Conductivity	unhos/cm	3700	NA	IS		2750	NA

ND = not detected NA = not applicable IS = insufficient sample

(Continued)

Parameter	Units	OH276		OH277		OH279	
		Msr'd Val.	Det. Lim.	Msr'd Val.	Det. Lim.	Msr'd Val.	Det. Lim.
Field measurements							
Redox (Eh)	mV	-228.5	NA	IS		-27.5	NA
Temperature	degrees	15.4	NA	IS		11.2	NA
pH	pH units	10.93	NA	IS		7.48	NA

ND = not detected NA = not applicable IS = insufficient sample

Table 3B

(Continued)

Parameter	Units	OH280		OH282	
		Msr'd Val.	Det. Lim.	Msr'd Val.	Det. Lim.
Anions					
Chloride	mg/L	1300	2.6	7200	26
Fluoride	mg/L	.31	.1	.34	.1
Sulfate	mg/L	2400	5	8000	10
Elements by ICPEs or AA					
Aluminum	mg/L	ND	.2	ND	.2
Arsenic	mg/L	.0078	.004	.08	.04
Barium	mg/L	.07	.01	.046	.01
Beryllium	mg/L	ND	.002	ND	.002
Boron	mg/L	ND	.6	1.4	.6
Cadmium	mg/L	ND	.001	.0013	.001
Calcium	mg/L	700	1	150	1
Chromium	mg/L	.016	.01	.2	.01
Cobalt	mg/L	ND	.01	ND	.01
Copper	mg/L	ND	.02	ND	.02
Iron	mg/L	.21	.04	.05	.04
Lead	mg/L	ND	.003	ND	.03
Magnesium	mg/L	22	1	ND	1
Manganese	mg/L	.1	.01	ND	.01
Molybdenum	mg/L	.18	.05	5	.05
Nickel	mg/L	.027	.02	.023	.02
Potassium	mg/L	860	3	7600	30
Selenium	mg/L	.0056	.005	ND	.01
Silicon	mg/L	34	1	110	1
Silver	mg/L	ND	.01	ND	.01
Sodium	mg/L	500	1	3200	10
Strontium	mg/L	3.6	.003	6.2	.003
Tin	mg/L	ND	.6	ND	.6
Vanadium	mg/L	ND	.02	.11	.02
Zinc	mg/L	.023	.02	ND	.02
Field measurements					
Conductivity	u/mhos/cm	8050	NA	25000	NA

ND = not detected NA = not applicable IS = insufficient sample

(Continued)

OH280		OH282	
Parameter	Units	Msr'd Val.	Det. Lim.
Field measurements			
Redox (Eh)	mV	-129.5	NA
Temperature	degrees	15.7	NA
pH	pH units	9.18	NA
		-256.6	NA
		15.2	NA
		11.55	NA

ND = not detected NA = not applicable IS = insufficient sample

Table 4

X-Ray Diffraction Mineralogy of Ohio Ash

SAMPLE ID	Wt% Mineral by XRD						Sum
	Gp	Et	Tm	Ah	Qz	Cc	
North Cell							
91AUGOH6-4		36	29		2.5	4.1	71.6
91AUGOH6-6	9	35			3.2	8.6	55.8
91AUGOH6-8	5	42			2.9	7.8	57.7
91AUGOH6-11	4	38	20		3.1	6.4	71.5
91AUGOH8-3	9	28			6.1	5.6	48.7
91AUGOH8-5	7	37	16		3.1	5.7	68.8
91AUGOH8-7	7	34	9		3.1	7.8	60.9
91AUGOH8-9		34	29		3	4.9	70.9
South Cell							
91AUGOH2-2		30	58		3.2	5.6	96.8
91AUGOH2-4	12	39	4		3.3	6.5	64.8
91AUGOH2-6	8	43	11		2.8	6.9	71.7
91AUGOH2-8	9	39	19		3.3	7.2	77.5
91AUGOH4-3		47	36		3.1	7.8	93.9
91AUGOH4-4	10	36			3.6	6.5	56.1
91AUGOH4-6	6	37	9		3.6	6.4	62
91AUGOH4-8		46	26		3.7	7.8	83.5

MINERAL KEY

ANHYDRITE	Ah	CaSO ₄
CALCITE	Cc	CaCO ₃
ETTRINGITE	Et	Ca ₆ Al ₂ (SO ₄) ₃ (OH)12.26H ₂ O
GYPSUM	Gp	CaSO ₄ .2H ₂ O
QUARTZ	Qz	SiO ₂
THAUMASITE	Tm	Ca ₆ Si ₂ [(SO ₄) ₂ (CO ₃) ₂]OH12.24H ₂ O

Table 5

Weight Percents of Mineral Components¹

	Ettringite	Thaumasite	North Cell	North Cell Hydrated
Ca	19.2	19.3	31.7	22.2
SO ₄	23.0	15.4	18.0	12.6
Al	4.3	0	4.6	3.2
CO ₃	0	9.6	6.0	6.5 ²
Si	0	4.5	8.6	6.0 ³
H ₂ O	37.3	34.7	0	30

¹ The percentages shown do not add up to 100% because several inert major oxides are not counted; in addition oxygen and hydroxide are not included.

² Average measured total inorganic carbon concentration in 2nd year annual ash core samples. Approximately 4 wt% carbonate is estimated to be bound in calcite.

³ Approximately 20% of the total silicon is present as quartz, which is essentially unreactive. Some silicon and aluminum are also bound in mullite, which is unlikely to react.

Table 6

Physical Testing Data - Annual Ohio Ash Cores

=====											
SAMPLE DESCRIPTION			dry = Unconditioned wet = Conditioned		NP = Nonplastic FP = Poorly consolidated or Fractured material		IP = In Progress				
=====											
			Unconfined				- Atterberg Limits -				
Sample	Depth	Sample	Comp.	Unit	Dry	Moisture	Perm.	Particle	Liquid	Plastic	Plastic
ID	(ft)	Type	Strength	Weight	Density	Content		Specific	Limit	Limit	Index
			(PSI)	PCF	PCF	%	(cm/sec)	Gravity			
=====											
1991 Annual Cores											
91AUGOH2-1	0-1'	cap	FP			16.8	1.10E-07				
91AUGOH2-2	1-2'	ash	50.7			109.1	FP				
91AUGOH2-4	3-4'	ash	FP			7.0	FP				
91AUGOH2-6	5-6'	ash	1003.4			52.0	2.90E-06				
91AUGOH2-8	7-8'	ash	FP			72.4	FP				
91AUGOH2-11	10-11'	soil	FP			17.5	1.70E-08				
91AUGOH2-12,13	11-13'	soil	FP			18.4	1.30E-08				
91AUGOH2-15	14-15'	soil	85.3			13.9	FP				
91AUGOH2-17	16-17'	soil	FP			14.4	FP				
91AUGOH4-2	1-2'	cap	FP			60.0	2.00E-05				
91AUGOH4-3	2-3'	ash	FP			78.0	FP				
91AUGOH4-4	3-4'	ash	2761.8			56.3	FP				
91AUGOH4-6	5-6'	ash	448.6			50.6	1.90E-05				
91AUGOH4-8	7-8'	ash	FP			72.1	FP				
91AUGOH4-9	8-9'	soil	52.0			14.5	4.90E-08				
91AUGOH4-11	10-11'	soil	FP			11.9	1.20E-07				
91AUGOH4-13	12-13'	soil	159.2			10.8	FP				
91AUGOH4-15	14-15'	soil	FP			11.2	FP				
91AUGOH6-1,2	0-2'	cap	39.6			20.1	4.00E-07				
91AUGOH6-3,4	2-4'	ash	756.0			68.5	8.40E-08				
91AUGOH6-6	5-6'	ash	984.1			75.8	IP				
91AUGOH6-8	6-8'	ash				79.6	IP				
91AUGOH6-11	10-11'	ash				83.5	2.90E-06				
91AUGOH6-13	12-13'	soil	62.4			8.1	FP				
91AUGOH6-14	13-14'	soil	125.4			10.2	IP				
91AUGOH6-16	15-16'	soil	72.8			10.3	FP				
91AUGOH6-18	17-18'	soil	174.7			10.7	FP				
91AUGOH8-2	1-2'	cap	45.8			25.7	4.40E-06				
91AUGOH8-3	2-3'	ash	945.0			51.1	FP				
91AUGOH8-5	4-5'	ash	1250.0			62.0	IP				
91AUGOH8-6,7	5-7'	ash	1096.0			83.4	IP				
91AUGOH8-9	8-9'	ash	151.8			76.5	IP				
91AUGOH8-10	9-10'	soil	80.0			13.6	FP				
91AUGOH8-12	11-12'	soil	38.6			17.5	3.90E-07				
91AUGOH8-14	13-14'	soil	176.1			11.3	3.00E-08				
91AUGOH8-16,17	15-17'	soil	145.0			11.1	4.70E-08				
=====											

Table 7A

Second Quarter Illinois Groundwater Data

Parameter	Units	11030		11031		11032	
		Msr'd Val.	Det. Lim.	Msr'd Val.	Det. Lim.	Msr'd Val.	Det. Lim.
Anions							
Chloride	mg/L	25	.26	16	.052	54	.26
Fluoride	mg/L	.23	.1	.16	.1	.13	.1
Sulfate	mg/L	530	.5	1500	2.5	1400	2.5
Elements by ICPE or AA							
Aluminum	mg/L	ND	.2	ND	.2	ND	.2
Arsenic	mg/L	ND	.004	ND	.004	ND	.004
Barium	mg/L	.023	.01	.015	.01	.022	.01
Beryllium	mg/L	ND	.002	ND	.002	ND	.002
Boron	mg/L	1.3	.6	ND	.6	ND	.6
Cadmium	mg/L	ND	.001	ND	.001	ND	.001
Calcium	mg/L	190	1	450	1	420	1
Chromium	mg/L	ND	.01	ND	.01	ND	.01
Cobalt	mg/L	ND	.01	.013	.01	ND	.01
Copper	mg/L	ND	.02	ND	.02	ND	.02
Iron	mg/L	.61	.04	ND	.04	ND	.04
Lead	mg/L	ND	.003	ND	.003	ND	.003
Magnesium	mg/L	100	1	230	1	79	1
Manganese	mg/L	1.3	.01	6.9	.01	2	.01
Molybdenum	mg/L	ND	.05	ND	.05	ND	.05
Nickel	mg/L	ND	.02	.032	.02	ND	.02
Potassium	mg/L	6.7	3	4.3	3	15	3
Selenium	mg/L	ND	.005	ND	.005	.0062	.005
Silicon	mg/L	6.9	1	7.2	1	3.7	1
Silver	mg/L	ND	.01	ND	.01	ND	.01
Sodium	mg/L	120	1	71	1	110	1
Strontium	mg/L	1.5	.003	.93	.003	1.5	.003
Tin	mg/L	ND	.6	ND	.6	ND	.6
Vanadium	mg/L	ND	.02	ND	.02	ND	.02
Zinc	mg/L	ND	.02	ND	.02	ND	.02
Field measurements							
Conductivity	umhos/cm	1650	NA	2780	NA	2250	NA

ND = not detected NA = not applicable IS = insufficient sample

Table 7A

(Continued)

Parameter	Units	IL030		IL031		IL032	
		Msr'd Val.	Det. Lim.	Msr'd Val.	Det. Lim.	Msr'd Val.	Det. Lim.
Field measurements							
Redox (Eh)	mV	-19.1	NA	-17.9	NA	-66	NA
Temperature	degrees	13.7	NA	13.9	NA	14.3	NA
pH	pH units	6.87	NA	6.86	NA	7.72	NA

(Continued)

Parameter	Units	11033		11034		11035	
		Msr'd Val.	Det. Lim.	Msr'd Val.	Det. Lim.	Msr'd Val.	Det. Lim.
Anions							
Chloride	mg/L	23	.26	22	.26	25	.052
Fluoride	mg/L	.19	.1	.2	.1	.13	.1
Sulfate	mg/L	330	.5	330	.5	1400	2.5
Elements by ICPEs or AA							
Aluminum	mg/L	ND	.2	ND	.2	ND	.2
Arsenic	mg/L	ND	.004	ND	.004	ND	.004
Barium	mg/L	.021	.01	.017	.01	.023	.01
Beryllium	mg/L	ND	.002	ND	.002	ND	.002
Boron	mg/L	1.3	.6	1.3	.6	1.1	.6
Cadmium	mg/L	ND	.001	ND	.001	ND	.001
Calcium	mg/L	140	1	150	1	350	1
Chromium	mg/L	ND	.01	ND	.01	ND	.01
Cobalt	mg/L	ND	.01	ND	.01	.012	.01
Copper	mg/L	ND	.02	ND	.02	ND	.02
Iron	mg/L	.51	.04	.59	.04	ND	.04
Lead	mg/L	ND	.003	ND	.003	ND	.003
Magnesium	mg/L	75	1	78	1	200	1
Manganese	mg/L	.32	.01	.34	.01	1.8	.01
Molybdenum	mg/L	ND	.05	ND	.05	ND	.05
Nickel	mg/L	ND	.02	ND	.02	.028	.02
Potassium	mg/L	6.9	3	6	3	16	3
Selenium	mg/L	ND	.005	ND	.005	ND	.005
Silicon	mg/L	6.5	1	6.4	1	8	1
Silver	mg/L	ND	.01	ND	.01	ND	.01
Sodium	mg/L	160	1	160	1	150	1
Strontium	mg/L	1.4	.003	1.4	.003	2.5	.003
Tin	mg/L	ND	.6	ND	.6	ND	.6
Vanadium	mg/L	ND	.02	ND	.02	ND	.02
Zinc	mg/L	ND	.02	ND	.02	ND	.02
Field measurements							
Conductivity	umhos/cm	1715	NA	1560	NA	2740	NA

ND = not detected NA = not applicable IS = insufficient sample

Table 7A

(Continued)

Parameter	Units	IL033		IL034		IL035	
		Msr'd Val.	Det. Lim.	Msr'd Val.	Det. Lim.	Msr'd Val.	Det. Lim.
Field measurements							
Redox (Eh)	mV	-17.5	NA	-16.5	NA	-9.3	NA
Temperature	degrees	12.9	NA	12.7	NA	11.8	NA
pH	pH units	6.85	NA	6.64	NA	6.52	NA

(Continued)

Parameter	Units	IL036		IL037		IL038	
		Msr'd Val.	Det. Lim.	Msr'd Val.	Det. Lim.	Msr'd Val.	Det. Lim.
Anions							
Chloride	mg/L	40	.26	14	.13	15	.13
Fluoride	mg/L	.27	.1	.17	.1	.18	.1
Sulfate	mg/L	300	.5	1200	2.5	2700	5
Elements by ICPEs or AA							
Aluminum	mg/L	ND	.2	ND	.2	ND	.2
Arsenic	mg/L	ND	.004	ND	.004	ND	.004
Barium	mg/L	.025	.01	.026	.01	.017	.01
Beryllium	mg/L	ND	.002	ND	.002	ND	.002
Boron	mg/L	1.7	.6	ND	.6	ND	.6
Cadmium	mg/L	ND	.001	ND	.001	ND	.001
Calcium	mg/L	120	1	350	1	430	1
Chromium	mg/L	ND	.01	ND	.01	ND	.01
Cobalt	mg/L	ND	.01	ND	.01	ND	.01
Copper	mg/L	ND	.02	ND	.02	ND	.02
Iron	mg/L	1.3	.04	ND	.04	ND	.04
Lead	mg/L	ND	.003	ND	.003	ND	.003
Magnesium	mg/L	68	1	200	1	410	1
Manganese	mg/L	.44	.01	4.7	.01	4.5	.01
Molybdenum	mg/L	ND	.05	ND	.05	ND	.05
Nickel	mg/L	ND	.02	.026	.02	.034	.02
Potassium	mg/L	5.2	3	ND	3	10	3
Selenium	mg/L	ND	.005	ND	.005	.0052	.005
Silicon	mg/L	7.3	1	7.9	1	4.1	1
Silver	mg/L	ND	.01	ND	.01	ND	.01
Sodium	mg/L	150	1	50	1	68	1
Strontium	mg/L	1.3	.003	.36	.003	1.1	.003
Tin	mg/L	ND	.6	ND	.6	ND	.6
Vanadium	mg/L	ND	.02	ND	.02	ND	.02
Zinc	mg/L	ND	.02	ND	.02	.092	.02

Field measurements
Conductivity

NA

3810

NA

2490

ND = not detected NA = not applicable IS = insufficient sample

Table 7A

(Continued)

Parameter	Units	IL036		IL037		IL038	
		Msr'd Val.	Det. Lim.	Msr'd Val.	Det. Lim.	Msr'd Val.	Det. Lim.
Field measurements							
Redox (Eh)	mV	-25	NA	-17.2	NA	-6.8	NA
Temperature	degrees	13	NA	14.6	NA	15.1	NA
pH	pH units	7	NA	6.86	NA	6.67	NA

Second Quarter Illinois Porewater Data

Parameter	Units	IL044		IL045	
		Msr'd Val.	Det. Lim.	Msr'd Val.	Det. Lim.
Anions					
Chloride	mg/L	IS		500	2.6
Fluoride	mg/L	IS		.22	.1
Sulfate	mg/L	IS		2500	5
Field measurements					
Conductivity	umhos/cm	4290	NA	13000	NA
Redox (Eh)	mV	-248.8	NA	-237.8	NA
Temperature	degrees	18.1	NA	12.5	NA
pH	pH units	11	NA	11.18	NA

 ND = not detected NA = not applicable IS = insufficient sample

Table 8A

Second Quarter Illinois Ash ASTM Data

Parameter	Units	91NOVIL02-01		91NOVIL02-03		91NOVIL02-05	
		Msr'd Val.	Det. Lim.	Msr'd Val.	Det. Lim.	Msr'd Val.	Det. Lim.
Anions							
Chloride	mg/L	7.3	.026	130	2.6	49	.13
Fluoride	mg/L	.13	.1	.19	.1	.11	.1
Sulfate	mg/L	1200	5	1300	5	1200	5
Elements by ICPEs or AA							
Aluminum	mg/L	ND	.8	ND	.8	ND	.8
Arsenic	mg/L	ND	.004	ND	.004	ND	.004
Barium	mg/L	.18	.04	.21	.04	.2	.04
Beryllium	mg/L	ND	.008	ND	.008	ND	.008
Boron	mg/L	ND	2.4	ND	2.4	ND	2.4
Cadmium	mg/L	ND	.001	ND	.001	ND	.001
Calcium	mg/L	1200	4	1100	4	1200	4
Chromium	mg/L	.048	.04	ND	.04	ND	.04
Cobalt	mg/L	ND	.04	ND	.04	ND	.04
Copper	mg/L	ND	.08	ND	.08	ND	.08
Iron	mg/L	ND	.16	ND	.16	ND	.16
Lead	mg/L	ND	.003	.0051	.003	ND	.003
Magnesium	mg/L	ND	4	ND	4	ND	4
Manganese	mg/L	ND	.04	ND	.04	ND	.04
Molybdenum	mg/L	ND	.2	ND	.2	ND	.2
Nickel	mg/L	ND	.08	ND	.08	ND	.08
Potassium	mg/L	23	12	250	12	220	12
Selenium	mg/L	ND	.005	.012	.005	.0057	.005
Silicon	mg/L	ND	4	ND	4	ND	4
Silver	mg/L	ND	.04	ND	.04	ND	.04
Sodium	mg/L	8.2	4	200	4	160	4
Strontium	mg/L	10	.012	9.8	.012	8.4	.012
Tin	mg/L	ND	2.4	ND	2.4	ND	2.4
Vanadium	mg/L	ND	.08	ND	.08	ND	.08
Zinc	mg/L	1.6	.08	.15	.08	ND	.08
Field measurements							
Conductivity	umhos/cm	7200	NA	9000	NA	8800	NA
pH	pH units	12.64	NA	12.67	NA	12.62	NA

ND = not detected NA = not applicable IS = insufficient sample

(Continued)

Parameter	Units	91NOV102-07		91NOV102-09		91NOV102-10	
		Msr'd Val.	Det. Lim.	Msr'd Val.	Det. Lim.	Msr'd Val.	Det. Lim.
Anions							
Chloride	mg/L	69	.13	20	.13	9.2	.13
Fluoride	mg/L	.12	.1	.14	.1	.27	.1
Sulfate	mg/L	1100	5	1100	5	370	.25
Elements by ICPEs or AA							
Aluminum	mg/L	ND	.8	ND	.8	ND	.8
Arsenic	mg/L	ND	.004	ND	.004	ND	.004
Barium	mg/L	.2	.04	.19	.04	.12	.04
Beryllium	mg/L	ND	.008	ND	.008	ND	.008
Boron	mg/L	ND	2.4	ND	2.4	ND	2.4
Cadmium	mg/L	ND	.001	ND	.001	ND	.001
Calcium	mg/L	1200	4	1100	4	800	4
Chromium	mg/L	ND	.04	ND	.04	ND	.04
Cobalt	mg/L	ND	.04	ND	.04	ND	.04
Copper	mg/L	ND	.08	ND	.08	ND	.08
Iron	mg/L	ND	.16	ND	.16	ND	.16
Lead	mg/L	.0051	.003	.0052	.003	ND	.003
Magnesium	mg/L	ND	4	ND	4	ND	4
Manganese	mg/L	ND	.04	ND	.04	ND	.04
Molybdenum	mg/L	ND	.2	ND	.2	ND	.2
Nickel	mg/L	ND	.08	ND	.08	ND	.08
Potassium	mg/L	230	12	140	12	ND	12
Selenium	mg/L	.007	.005	ND	.005	ND	.005
Silicon	mg/L	ND	4	ND	4	ND	4
Silver	mg/L	ND	.04	ND	.04	ND	.04
Sodium	mg/L	170	4	83	4	17	4
Strontium	mg/L	5.8	.012	6.4	.012	2.1	.012
Tin	mg/L	ND	2.4	ND	2.4	ND	2.4
Vanadium	mg/L	ND	.08	ND	.08	ND	.08
Zinc	mg/L	ND	.08	ND	.08	.091	.08
Field measurements							
Conductivity	umhos/cm	8800	NA	7900	NA	6800	NA
pH	pH units	12.61	NA	12.4	NA	12.38	NA

ND = not detected NA = not applicable IS = insufficient sample

Table 8B

Second Quarter Illinois Soil ASTM Data

91NOV102-11

Parameter	Units	Msr'd Val.	Det. Lim.
Anions			
Chloride	mg/L	.82	.026
Fluoride	mg/L	.28	.1
Sulfate	mg/L	390	.25
Elements by ICPEs or AA			
Aluminum	mg/L	ND	.2
Arsenic	mg/L	ND	.004
Barium	mg/L	.033	.01
Beryllium	mg/L	ND	.002
Boron	mg/L	ND	.6
Cadmium	mg/L	ND	.001
Calcium	mg/L	110	1
Chromium	mg/L	ND	.01
Cobalt	mg/L	ND	.01
Copper	mg/L	ND	.02
Iron	mg/L	ND	.04
Lead	mg/L	.0093	.003
Magnesium	mg/L	23	1
Manganese	mg/L	ND	.01
Molybdenum	mg/L	ND	.05
Nickel	mg/L	ND	.02
Potassium	mg/L	ND	3
Selenium	mg/L	ND	.005
Silicon	mg/L	ND	1
Silver	mg/L	ND	.01
Sodium	mg/L	1.6	1
Strontium	mg/L	.15	.003
Tin	mg/L	ND	.6
Vanadium	mg/L	ND	.02
Zinc	mg/L	.28	.02
Field measurements			
Conductivity	umhos/cm	780	NA
pH	pH units	8.96	NA

ND = not detected NA = not applicable IS = insufficient sample

Table 9

Physical Testing Data - Preliminary Illinois Soils and Ash

=====										
SAMPLE DESCRIPTION			dry = Unconditioned wet = Conditioned		NP = Nonplastic FP = Poorly consolidated or Fractured material		IP = In Progress			
=====										
			Unconfined				- Atterberg Limits -			
Sample	Depth	Sample	Comp.	Unit	Dry	Moisture	Perm.	Particle	Liquid Plastic	Plastic
ID	(ft)	Type	Strength	Weight	Density	Content		Specific	Limit	Limit
			(PSI)	PCF	PCF	%	(cm/sec)	Gravity		Index
=====										
1991 Preliminary Samples										
Downgradient-North Cell										
ILMW1-1,2	0-2'	soil		FP	FP	13.2	FP	2.55	28	18
ILMW1-3,4	2-4'	soil		FP	FP	18.9	FP	2.67	30	20
ILMW1-5,6	4-6'	soil		FP	FP	17.3	FP	2.70	22	17
ILMW1-7,8	6-8'	soil	132.80	111.19	19.5	9.10E-08	2.68	27	16	11
ILMW1-9,10	8-10'	soil		FP	FP	18.3	FP	2.73	28	15
ILMW1-11,12	10-12'	soil	130.70	109.20	20.0	4.50E-08	2.72	28	15	13
ILMW1-13,14	12-14'	soil		FP	FP	22.3	FP	2.68	NP	NP
ILMW1-15,16	14-16'	soil	125.20	103.60	20.8	4.90E-08	2.71	28	17	9
Downgradient-South Cell										
ILMW7-1,2	0-2'	grvl		FP	FP	FP	FP	2.66	FP	FP
ILMW7-3,4	2-4'	grvl		FP	FP	FP	FP	2.69	FP	FP
ILMW7-5,6	4-6'	soil		FP	FP	14.6	FP	2.73	27	18
ILMW7-7,8	6-8'	soil	114.97	97.84	17.5	1.50E-04	2.70	29	18	11
ILMW7-9,10	8-10'	soil	129.77	113.04	14.8	1.60E-08	IP	30	17	13
ILMW7-11,12	10-12'	soil	127.20	114.08	16.9	6.90E-08	2.68	30	17	13
ILMW7-13,14	12-14'	soil	133.12	113.58	17.2	6.40E-08	2.70	31	15	16
ILMW7-15,16	14-16'	soil	135.20	114.48	18.1	2.50E-08	2.70	25	17	8
Upgradient										
ILMW4-16,17	15-17'	soil		FP	FP	13.7	FP	2.71	30	16
ILMW4-18,19	17-19'	soil		FP	FP	11.3	FP	2.70	36	23
ILMW4-20,21	19-21'	soil	117.66	103.21	14.0	1.80E-06	2.73	38	18	20
ILMW4-22,23	21-23'	soil	111.45	101.22	10.1	1.20E-06	2.73	44	21	23
ILMW4-24,25	23-25'	soil		FP	FP	9.4	FP	2.76	31	17
ILMW4-26,27	25-27'	soil	113.04	103.43	9.3	IP	2.75	34	17	17
ILMW4-28,29	27-29'	soil	125.42	115.81	8.3	7.20E-07	2.75	29	19	10
ILMW4-30,31	29-31'	soil		FP	FP	8.7	FP	2.71	32	22
ILMW4-32,33	31-33'	soil		FP	FP	12.2	FP	2.58	37	19
ILMW4-34,35	33-35'	soil	121.11	105.95	14.3	5.50E-08	2.68	34	19	15
ILMW4-36,37	35-37'	soil	106.69	100.09	6.6	1.10E-07	2.76	34	19	15
ILMW4-38,39	37-39'	soil	114.20	105.40	8.4	1.00E-07	2.54	31	21	10
Cell Base										
ILSS-1	N. cell	soil				10.0	FP	2.69		
ILSS-2	N. cell	soil				11.6	FP	2.72		
ILSS-3	N. cell	soil				13.7	FP	2.71		
ILSS-4	N. cell	soil				7.8	FP	2.73		
ILSS-5	S. cell	soil				8.8	FP	2.69		
ILSS-6	S. cell	soil				17.6	FP	2.68		
ILSS-7	S. cell	soil				12.3	FP	2.73		
ILSS-8	S. cell	soil				10.5	FP	2.70		

Table 9
(Continued)

=====											
SAMPLE DESCRIPTION			dry = Unconditioned wet = Conditioned		NP = Nonplastic FP = Poorly consolidated or Fractured material		IP = In Progress				
			Unconfined				- Atterberg Limits -				
Sample ID	Depth (ft)	Sample Type	Comp. Strength (PSI)	Unit Weight PCF	Dry Density PCF	Moisture Content %	Perm. (cm/sec)	Particle Specific Gravity	Liquid Limit	Plastic Limit	Plastic Index
=====											
1st Qtr. - North Cell											
91JUNIL1-1,2	0-2'	ash	434.6			33.0	6.20E-05				
91JUNIL1-3,4	2-4'	ash	249.3			34.4	2.10E-05				
91JUNIL1-5,6	4-6'	ash	309.9			42.9	2.90E-06				
91JUNIL1-7,8	6-8'	ash	FP			53.9	FP				
91JUNIL1-9,10	8-10'	soil	FP			15.9	1.40E-04				
91JUNIL1-11,12	10-12'	soil	FP			16.8	2.30E-07				
91JUNIL3-1,2	0-2'	ash	FP			37.3	FP				
91JUNIL3-3,4	2-4'	ash	283.0			36.3	FP				
91JUNIL3-5,6	4-6'	ash	FP			4.0	1.20E-06				
91JUNIL3-7,8	6-8'	ash	505.3			45.8	3.10E-06				
91JUNIL3-9,10	8-10'	soil	FP			17.2	FP				
91JUNIL3-11,12	10-12'	soil	FP			17.2	FP				

APPENDIX A

XRD Characterization and Reaction Modeling of Disposed Solid Wastes from Advanced Coal Processes

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NDSU Subcontract
Progress Report 1
January, 1992

Nature of this Report

This is the first of what will be a series of informal progress reports on mineralogical characterization by X-ray diffraction (XRD). They will be prepared, at irregular intervals, as some portion of the study is completed.

This report deals with: (1) identification of a new crystalline phase, thaumasite, formed after disposal in the Ohio test cell LIMB ash; (2) changes in our semi-quantitative XRD procedures necessitated by the appearance of thaumasite and other concerns about phase stability during the grinding step in specimen preparation; (3) results from the Ohio 2 year core samples; (4) characterization of leaching residue samples provided by Radian.

Thaumasite

A new crystalline phase was found last October during the initial XRD characterization of the year 2 core from the Ohio site. This phase has been identified unambiguously as the an ettringite-related phase thaumasite, which is characterized by having partial Si for Al substitution in the column structural unit and partial carbonate for sulfate substitution in the channel sites. The nominal, end member, compositions of thaumasite and *ettringite* are:

This formula thaumasite will usually be seen (in the XRD database, mineral compilations, cement chemistry literature) with half this formula, but this stoichiometry will be used to show the chemical and structural analogy to *ettringite*.

The key to identifying thaumasite was noting peaks too strong to be attributed to any other phase in the diffractograms of 91AUGOH2-2, the Ohio LIMB Year 2 sample from Core 2, 1-2 feet. The three diffractograms on the next page show a portion of this diffractogram (top), a diffractogram of a sample from this core having

only a small amount of thaumasite (middle) and a diffractogram calculated from the crystal structure of the mineral thaumasite (bottom). As noted below, it will turn out that some thaumasite was present in Year 1 samples also, but its peak heights were too small to permit unambiguous identification. Two of the strongest thaumasite peaks overlap with *ettringite* peaks and the third, at $23.4^\circ 2\theta$, is a direct overlap with a secondary peak of gypsum. In 91AUGOH2-2, the thaumasite had formed in such abundance, the gypsum was so scarce, and the low angle *ettringite* peaks were anomalously strong (compare the middle to the top diffractogram), that identification thaumasite was possible.

We consider the identification of thaumasite significant because it is the first crystalline phase to form that was not already present at the start of burial in the test cells. The implications could be profound, and numerous questions arise:

- Is thaumasite formed at the expense of *ettringite*?
- Does thaumasite formation improve consolidation and lower the permeability of the disposed waste?
- Is thaumasite more chemically durable in lower pH ground waters than *ettringite*?
- Is thaumasite the thermodynamically stable phase in the high-pH ($\text{Ca}(\text{OH})_2$ -buffered), carbonate containing, Ohio LIMB residue?
- How important is additional water input and/or bicarbonate/carbonate activity of this water to the formation of thaumasite?
- How important is the source of high-pH solubilizable silica to thaumasite formation? (In Ohio LIMB residue, this silica is present in fly ash glass, but in FBC residues the silica source is dehydroxylated clays.)
- In cement/concrete science, thaumasite is most often mentioned as a degradation product of carbonation of concrete. How much useful insight for our application is available in the concrete durability/degradation literature?

Insight on some of these questions will be obtained during interpretation of results from core mineralogy characterization. Most, however, are questions that are beyond the scope of the present subcontract and will have to be addressed on a time available basis.

Changes to XRD Analysis Procedures

Because thaumasite peaks overlap those of *ettringite* at low angles, we cannot continue to use the (100) peak at 9.2° for *ettringite* quantitation, as was done previously, or the (110) peak at 15.9° . The other strong *ettringite* peak is at 22.95° , but this overlaps partly with the thaumasite peak at 23.45° . We would also like to get an estimate of thaumasite abundance, and this latter peak is the only one

available for its quantitation. In the Ohio LIMB Year 2 core results that follow, we will use the pair of *ettringite* and thaumasite peaks near 23° to give a rough *estimate* of the abundance of these phases. Because of their overlap, the uncertainty in their compositions, and the lack of a pure thaumasite standard (we have calculated a Reference Intensity Ratio from the crystal structure of a mineral specimen), the should not be considered to be strictly quantitative.

We have cautioned from the beginning that our tabulated XRD results should be considered *semi*-quantitative at best. This new development makes any quantitative mineralogy results even more dubious. There are improved quantitative XRD analysis techniques (Rietveld QXRD, full profile analysis) that could be applied to this class of materials, but methods development alone would require both time and a level-of-effort that are beyond the scope of work of this subcontract. More importantly, the improvement in our understanding of the mineralogical and geochemical process would be modest at best.

The NDSU subcontract calls for determining the mineralogy of original and disposed residues and surrounding soils, with emphasis on changes in mineralogy after disposal and interactions with the local geochemical environment. The wide-ranging objective is long-term predictive modeling of the environmental and geochemical impacts of disposal. We can meet these objectives satisfactorily by looking at trends in intensities of key peaks for the phases of interest: reactants and products of geochemical reactions such as anhydrite, gypsum, portlandite, calcite, *ettringite* and thaumasite. The key peaks of reactive phases or newly formed phases can be roughly normalized to peaks of non-reactive phases such as quartz (see below). Most of our interpretations are based on these types of qualitative observations.

We have been concerned for some time that the additional milling, mixing and air exposure necessary for specimen preparation for the internal standard (Reference Intensity Ratio) method of quantitation was changing the relative abundance of some phases. This became especially obvious, and a critical issue, for the Illinois FBC materials with their highly reactive lime and portlandite. We modified our procedure to drop wet ethanol milling of each ash in the McCrone Micronizer Mill, which required hours to dry the sample prior to the XRD analysis. Now the grinding is done by hand, using minimal ethanol (some must be used to "quench" the hydration reactions) and minimal air exposure. Some carbonation of portlandite, may still be occurring during sample preparation and XRD analyses (with the Illinois residues), but this is the best we can do with existing equipment and procedures.

We will continue to utilize the semi-quantitative protocol, but, for the reasons just discussed, must provide a strong *caveat* against trying to use the reported weight percentages too rigorously. This *caveat* applies especially to *ettringite* and thaumasite, which have uncertain RIRs. The most reliable result is for quartz, which is also unreactive. If it can be assumed that quartz is homogeneously distributed (on the gram scale) in disposed materials (a considerable "leap-of-faith"), then analyses among cores and with time could be normalized to the its weight percentage.

Work is underway in our laboratories, supported at a low level by other sources, on improved quantitative XRD protocols for the crystalline phases in *ettringite*-forming materials. When these methods are available, they will be applied to this project also.

XRD Mineralogy of Year Ohio LIMB Core Samples

A table that gives the results of XRD mineralogical characterization of the Year 2 Ohio LIMB core samples supplied to NDSU follows. In line with the discussion above, we have supplied the complete data set instead of just the results of the semi-quantitative analyses. Only the reactive or product phases, plus quartz, are tabulated. (Some non-reactive mullite, hematite and magnetite were also present.) The analytical peaks are shown below the phase code. The first seven columns give the raw peak heights in counts/second in the rutile (Ru) internal standard mixes. (There was not anhydrite left in these samples.) The next two columns give heights for Ru and thaumasite (Tm) after subtracting weaker overlapped peaks (an Et peak under Ru and a Gp peak under Tm). The next set of columns is the peak height ratios of the phase of interest to Ru. The final group of columns is the semi-quantitative results using the Reference Intensity Ratio equation for each analyte (a):

$$\text{wt\% a} = \text{wt\% Ru/RIR}_a * I_a/I_{\text{Ru}} * 1.11$$

The wt% rutile is always 10% (the 1.11 factor corrects the result to a rutile-free sample) and the rutile RIRs of each analyte are Gp = 0.32, Et = 0.13, Tm = 0.105 (calculated), Ah = 1.11, quartz = 1.48, and calcite = 1.12.

Note that the sums of the crystalline phases total 90% and above is many of the samples. Such sums are probably too high, as mullite, hematite and magnetite and noncrystalline phases (e.g. residual fly ash glass) are not included. The weight percentages of *ettringite* and thaumasite may be overestimated because of peak overlap (summations of tails) and an inappropriate (for this crystallinity and composition) RIR of thaumasite.

Some observations, especially those involving thaumasite, are suggested from these results:

- Thaumasite is more abundant in the South Cell cores (where the additional water was added at emplacement), and is more abundant near the surface and at the soil-ash interface at the bottom of the cell;
- Ettringite does not appear to be less abundant where thaumasite is more abundant, suggesting that thaumasite is *not* forming at the expense of *ettringite*.
- Where thaumasite has formed in greatest abundance, gypsum is absent or present in reduced abundance, suggesting that gypsum is the source of the Ca and sulfate needed for thaumasite formation.

X-RAY DIFFRACTION MINERALOGY OF OHIO LIMB ASH ANNUAL SAMPLES

Sample	XRD Peak Height (counts/sec)										Ratios						Weight %					
	Gp	Et	Tm	Ah	Qz	Ru	Cc	Ru	Tm	corr.	Gp/ Ru	Et/ Ru	Tm/ Ru	Ah/ Ru	Qz/ Ru	Cc/ Ru	Gp	Et	Tm	Ah	Qz	Cc
11.6	22.9	23.5	25.5	26.7	27.5	29.4		corr.	corr.													
North Cell																						
91AUGOH6-4		120	77		96	321	118	283	77			0.42	0.27		0.34	0.42		36	29		2.5	4.1
91AUGOH6-6	65	102			107	281	215	248			0.26	0.41			0.43	0.87	9	35		3.2	8.6	
91AUGOH6-8	36	118			93	276	188	238			0.15	0.50			0.39	0.79	5	42		2.9	7.8	
91AUGOH6-11	30	116	54		105	295	167	258	48		0.12	0.45	0.19		0.41	0.65	4	38	20	3.1	6.4	
91AUGOH8-3	64	79			195	264	134	239			0.27	0.33			0.82	0.56	9	28		6.1	5.6	
91AUGOH8-5	50	108	47		103	282	143	247	37		0.20	0.44	0.15		0.42	0.58	7	37	16	3.1	5.7	
91AUGOH8-7	48	93	30		96	261	181	231	20		0.21	0.40	0.09		0.42	0.78	7	34	9	3.1	7.8	
91AUGOH8-9		93	64		94	264	115	234	64			0.40	0.27		0.40	0.49		34	29	3.0	4.9	
South Cell																						
91AUGOH2-2		120	187		148	382	194	344	187			0.35	0.54		0.43	0.56		30	58		3.2	5.6
91AUGOH2-4	96	127	31		122	318	182	277	12		0.35	0.46	0.04		0.44	0.66	12	39	4	3.3	6.5	
91AUGOH2-6	66	148	43		110	343	206	296	30		0.22	0.50	0.10		0.37	0.70	8	43	11	2.8	6.9	
91AUGOH2-8	64	116	57		112	288	181	251	44		0.26	0.46	0.18		0.45	0.72	9	39	19	3.3	7.2	
91AUGOH4-3		121	76		92	260	175	221	76			0.55	0.34		0.42	0.79		47	36	3.1	7.8	
91AUGOH4-4	73	105			121	286	166	252			0.29	0.42			0.48	0.66	10	36		3.6	6.5	
91AUGOH4-6	38	97	27		106	252	142	221	19		0.17	0.44	0.09		0.48	0.64	6	37	9	3.6	6.4	
91AUGOH4-8		134	62		121	291	196	248	62			0.54	0.25		0.49	0.79		46	26	3.7	7.8	

We are now looking back at diffractograms from all previous cores. Thaumasite has been found in 4 of 5 Year 1 South Cell core samples, but in generally lesser abundance than in Year 2 cores. Year 2 core 91AUGOH2-2 still has the greatest thaumasite abundance. Work is continuing with old diffractograms and with some samples that have been stored in the laboratory for 1-2.5 years.

Characterization of Ohio and Illinois Core Material from Radian Leaching Tests

Four core samples used in ASTM leaching tests at Radian Corporation laboratories were frozen (to stop hydration reactions) before and after the leaching tests and shipped to NDSU. Two were Ohio LIMB Year 2 and two were Illinois FBC 1st Quarter samples. They were kept frozen until XRD characterization was initiated.

The next four pages show the qualitative XRD diffractograms of each core sample before and after leaching. The diffractograms show that there were no dramatic differences in XRD mineralogy before and after leaching. The table below gives the semi-quantitative XRD results.

Sample	Gp	Qz	Et	Cc	Pl
	(semi-quantitative wt%)				
B91AUGOH1-6	13	3.9	39	7	
A91AUGOH1-6	2	3.4	40	4	
B91AUGOH1-8	10	2.9	50	7	
A91AUGOH1-8	5	2.8	53	10	
B91JUNIL4-1	23	7.8	28	5	14
A91JUNIL4-1	24	5.2	10	4	12
B91JUNIL4-3	28	5.9	23	4	13
A91JUNIL4-3	15	6.8	22	6	9

Prefix A = After leaching, B = Before leaching

Quartz is included in the table because it is nonreactive and should remain constant during the experiment (see discussion above). A large (> 20% relative) difference in the quartz analysis would indicate some problem with the sampling or the analytical procedures.

In the Ohio LIMB Core 1, No. 6 and 8 samples, there were changes in gypsum (Gp) and calcite (Cc) amounts, but little change in the amount of *ettringite*. The quartz results agreed well. There was a small amount of thaumasite in these core samples, with more in the No. 8 sample. The thaumasite peak height did not appear to change after leaching.

The mineralogy of the Illinois FBC Core 4 samples also remained the same after leaching. The quartz results were too far apart in the No. 1 sample, so we will not attempt to interpret the results quantitatively. The qualitative XRD diffractograms indicate little change in relative crystalline phase abundances, except for gypsum, which appeared to increase in 4-1 and decrease in 4-3.

In terms of modeling the activities of dissolved species in the leaching solutions, the controlling minerals should be ettringite, gypsum and calcite in the Ohio LIMB residues (one wonders if thaumasite is reactive enough in two days to control activities of silica species), and the same three plus portlandite in the Illinois FBC residues. The leaching procedure did not alter the mineralogy of the test specimens (with the possible exception of almost losing gypsum in OH 1-6). Some recrystallization of phases (portlandite and gypsum showed the most obvious effects), as evidenced by sharper peaks, indicated that at least some of the solid was interacting with the leachant and recrystallizing.

END

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