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The Impact of Weathering and Aging on a LIMB Ash Stockpile Material

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ABSTRACT

A 1,500 ton "temporary" storage pile of water conditioned LIMB ash by-product from the Ohio Edison Edgewater plant, Lorain, OH was constructed in July, 1991 at a coal company near New Philadelphia, Ohio. This "stockpile" was created for dry FGD by-product material to be held in reserve for a land application uses field demonstration project as part of a 5 year study titled "Land Application Uses of Dry FGD By-Product".

High volume, beneficial uses of dry FGD by-products, such as for mine reclamation and embankment stabilization, will require temporary stockpiling of the by-product. The purpose for constructing this pile was to study changes with time in the LIMB by-product material when exposed to weathering. We have extensively sampled and characterized this by-product material with respect to its chemical, mineralogical, physical, and engineering properties over a 2½ year period.

The normal amount of water to control fugative dust was added in the ash conditioner at the power plant while being loaded into dump trucks. The amount of water normally added in the conditioning process is close to the optimum moisture content of about 40-50 % on a dry weight basis, to construct a compacted road embankment or road base. Four environmental operating permits required for construction of the storage pile were obtained, three from Ohio EPA (air, water and solid waste), and one from the Ohio Division of Reclamation (revised reclamation area permit). There was no significant environmental impacts from storm runoff or leachate water from the LIMB ash stockpile during the initial 18 month period through December, 1992. After 2½ years of storage, the potential value of the LIMB material for use as a road embankment material or soil conditioner has declined significantly. Ettringite formation occurs. Aging allows the expansive reaction to take place before its potential use as compacted structural fill or embankment.

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INTRODUCTION

A 1,500 ton "temporary" storage pile of LIMB ash by-product from the Ohio Edison Edgewater plant was constructed in July, 1991, at a privately owned coal company, the Central Fuel Company, New Philadelphia, Ohio. Four environmental operating permits required for construction of the storage pile were obtained; three from Ohio EPA (air, water and solid waste), and one from the ODNR Division of Reclamation (revised reclamation permit). Costs of building the clay liner, berm, and drainage system required by these permits were donated by the Central Fuel Co.

This LIMB ash is a type of dry flue gas desulfurization (FGD) scrubber residual solid waste from the LIMB (Lime Injected Multistage Burner) clean coal combustion technology sponsored by the U.S. Department of Energy and The Ohio Coal Development Office. A comprehensive characterization study that involved fifteen dry FGD sources and over fifty samples including 14 LIMB samples has been completed and soon to be published by Electric Power Research Institute (EPRI).(1)

This stockpile study also involved characterization studies on chemical, physical, engineering, and leachate properties of LIMB flyash. Much of the interest in land application uses is due to the free or "available" lime content (about 12-22 %CaO) and high neutralizing value (about 500 - 700 tons of calcium carbonate equivalency per 1000 tons of dry FGD ash), and the soil conditioning value of gypsum content (30-40% $CaSO_4 \cdot 2H_2O$).

Stockpiling or temporary exposed storage may be necessary to accumulate sufficient quantities of material, but may be detrimental to the potential value for beneficial land application uses. The objective of this stockpile study was to determine the benefits and problems of exposed FGD storage for specific uses for agronomic soil conditioning, soil stabilization, and embankment construction.

Stockpile Construction and Moisture

A single pile was constructed with an initial residual moisture content that averaged approximately 17%. The normal amount of water to control fugative dust was added in the ash conditioner at the power plant while being loaded into the dump trucks. More water would have plugged the mixer conditioner. Our objective was to add enough water to be close to the optimum moisture content (OMC) for optimum compacted density i.e., to construct a compacted fill or road base. It turned out that the amount of water normally added in the conditioning process is close to the OMC, which is about 40 - 50 % on a dry weight basis.

It is important to note that during construction of the pile, efforts were made to minimize compaction of the LIMB ash by avoiding driving over it with the dump trucks or front end loader. The pile was constructed by placement with a large front end loader. Some compaction around the edges with the tires was unavoidable to stockpile the ash as high as possible.

Because of the chemical characteristics of the LIMB ash i.e., contains free lime (CaO) and anhydrous calcium sulfate ($CaSO_4$) it has a high demand for waters of hydration, also called combined water. An attempt was made to estimate the moisture content of LIMB by-product leaving the Lorain, Ohio Power Plant by measuring the total amount of water added and the wet ash weight of each truck load leaving the plant as described in Table 1. This amounted to an average of 43.5% water added (dry weight basis) and is based on 22 separate truckloads. This number is a good estimate but the measurements are not precise and an unknown fraction of added water was lost as steam vapor. About 43% of the 1,500 ton pile was water added at the power plant in the conditioning process.

Free moisture was also determined on samples collected upon delivery of the conditioned LIMB by-product to the storage pile to determine the initial pile moisture content as seen in Table 1. This average value of 17.5% residual moisture is lower than the water added values of 43.5% due in part to the reasons given above as well as chemical reaction of added water (hydration) with the by-product, and drying during transport and handling of the by-product.

TABLE 1

SUMMARY OF MEASURED PROPERTIES OF LIMB BY-PRODUCT PLACED IN STORAGE PILE

	Water Added	Moisture Content	Slaking Temperature	Free CaO	Calcium Carbonate Equivalent	Particle Density	Blaine Fineness	Bulk Density
Units	%	%	C^{o} 15 min^{-1}	% CaO	% $CaCO_3$	g cm^{-3}	cm^2g^{-1}	lb/cu ft.
Mean	43.5	17.5	8.2	21.4	46.	2.84	10,030	45.1
# of Samples	22	8	16	24	9	5	5	3
Range	31.0 - 53.5	7.5-35.2	6.5-13.7	11.4-25.5	27.3-48.2	2.83-2.87	9,790-10,460	44.5-45.5

A rain gauge was installed at the storage pile site and a precipitation record was kept . Rainfall during the summer and fall of 1991 was below average. The pile was monitored during all significant rainfall events since construction to the end of 1992. For the first 8 -9 months all rainfall was absorbed, and thus, there was no runoff events or leachate from the storage pile. Starting the spring of 1992 during significant rainfall events, there was some runoff water that was able to be sampled within the diked area for water quality as presented later in this report .

This stockpile study came right after a very thorough study by Radian Corp. for the U.S. Department of Energy (DOE) on Edgewater LIMB ash chemical, physical, and leachate properties and its placement in a natural geologic setting in two test cells starting in April,

1989. A report sponsored by the DOE on this and other test cells describes the aging effect in a test cell environment.(2)

Physical & Lime Neutralization Properties

Data on physical properties of the LIMB ash by-product in a dry condition are presented in Table 1. These include particle density, surface area, Blaine fineness, and bulk density. Available free lime content averaged about 21% CaO as per ASTM method C-25. Coming from a high temperature boiler the available lime is unhydrated or in the quicklime form. The acid-neutralizing capacity of the material is measured to account for the calcium and magnesium compounds that are capable of neutralizing soil acidity. These materials, referred to as a agricultural liming (aglime) material, are commonly made by crushing limestone or dolomite and are tested by method ASTM C-602 (reported as percent calcium carbonate equivalent, CCE). The LIMB ash by-product, based on 10 samples had a CCE content of about 50% $CaCO_3$.

After 3 and 6 months storage the free lime and CCE showed a decline particularly on samples near the surface, as seen in Table 3.

Total Chemical & Leachate Analysis

Leachate tests by both the ASTM 3987-85 water method (20:1, water:FGD) and the TCLP acetic acid extraction method #1311 are shown in Table 2 as conducted on the original dry LIMB ash (Sample EDG-LIM-14) which represents the material shipped to the stockpile. The ASTM results and TCLP results were less than primary drinking water standards (DWS) and are far lower than levels required for classification as non-toxic fly ash by the Ohio EPA Policy 4.07, which is 30 times DWS concentrations.

The major ions in the leachate were calcium, sulfate and hydroxide. Long term equilibrium solubility leaching tests on this sample are completed and seen in the Phase 1 report.(1) The total chemical analysis of the ash itself is also given in Table 2.

All the above data in Table 2 are very similar to that shown in two published studies on characterization of LIMB FGD by-products included in the LIMB Stockpile application. (6, 7). The data are also representative of reported values in the literature of stabilized/fixated forced oxidized FGD waste.(3)

Mineralogy of Original Unconditioned Ash

The major mineral phases in dry, unconditioned LIMB ash are quicklime (21%CaO), portlandite (5% $Ca(OH)_2$), calcite (15% $CaCO_3$) and anhydrite, also called anhydrous calcium sulfate, (25% $CaSO_4$). Minor mineral phases which occur in the coal fly ash component (totaling 28%) are quartz (SiO_2), hematite (Fe_2O_3), magnetite (Fe_3O_4), and mullite ($Al_6Si_2O_{13}$). Upon aging other mineralogical forms appeared most notably ettringite, as discussed later in this report. Ettringite is a form of calcium sulfo-aluminate ($Ca_6Al_2(SO_4)_3(OH)_{12}·26H_2O$), which has a high degree of hydration which helps explain the water absorbing properties of LIMB ash in addition to that due to hydration of quicklime and anhydrous calcium sulfate.

Moisture After 3 and 6 Months

The effects of weathering on chemical, physical and engineering properties of the storage pile material were determined by analyses of samples collected after 3, 6, 9, 18 and 30 months of storage. Results of the 3 and 6 month sampling period are given in Table 3. After 3 months the exposed pile had only a weak crust from cementation. After six months, the ash moisture content at the surface of the pile was about 70% (dry weight basis) and under 6 inches was 43-49%. The pile is very firm and easy to walk on because of the conditioning and subsequent cementation process. Water infiltration apparently was not significantly decreased by the crust formation since the rainfall events (>1 inch) of 4 and 13 December resulted in no surface runoff from the pile. The increase in moisture content from 17 to 70% during 6 months of exposure demonstrates the high capacity of the LIMB ash to absorb and react with water and prevent storm runoff and leaching.

Aged Material Characteristics from 9 to 30 Months

At 9,18, and 30 months in storage (aging) Table 3 shows data on moisture, free CaO, $CaCO_3$ equivalent (CCE), particle density, permeability, and bulk density. Chemical reactions of the pozzolanic and ettringite type decreased the acid neutralizing capacity in terms of $CaCO_3$ equivalency. The specific surface area (m2/g) increased dramatically from about 7 to 30, 45 and 55 m2/g at 9, 18, and 30 months respectively because of its chemical changes..

Storm Water Runoff Results: May 1992 to December 1992

The pile was constructed on an impermeable clay pad and surrounded by an impermeable clay berm. It was underlain with a network of perforated pipe leading to a discharge pipe outside the clay berm. Likewise, all surface runoff from the LIMB pile was directed to a discharge pipe outside the clay berm. Valves on both discharge pipes were kept closed at all times except for collection of water samples. Water samples for chemical analysis were collected from the surface runoff discharge pipe soon after a storm event. The volume to sample from was never more than 20 gallons. Surface runoff water was only allowed to drain from the bermed area at the time of sample collection. Drainage water was discharged into a drainage ditch which led to a holding pond on the Central Fuel site but was never enough to impact the pond.

As stated, the LIMB by-product has a large capacity for absorption of water, and to date no water has permeated the pile and entered the leachate water collection system. Likewise, in spite of significant rainfall during the above period (19 storm events of 0.5 inches or greater recorded rainfall), there was relatively little stormwater runoff and no samples from the buried perforated pipe. Absorption of water has resulted in the pile becoming very stable. There has been very little sloughing or erosion of material from the steep sides of the pile as seen in Figure 1 and the walls of sample collection pits dug into the sides of the pile did not collapse as seen in Figure 2. As stated, the pile is covered by a crust firm enough to support a person walking on the pile. This surface crust has prevented the discharge of any airborne fugative dust from the pile, even when the surface dries. The initial surface stabilization was likely due to cementing resulting from the conversion of anhydrous calcium sulfate ($CaSO_4$) to gypsum ($CaSO_4 \cdot 2H_2O$) and carbonation of quicklime to form calcium carbonate, $CaCO_3$. The permeability of the material was 4×10^{-4} cm/s as seen in Table 3.

Eight samples of runoff water were collected during the May to December period. Chemical analyses of these runoff samples are given in Table 4. The near neutral pH of these runoff samples, in spite of the very high pH of the fresh LIMB material (pH around 12), resulted from two factors. The first and most significant factor is that reaction of atmospheric CO_2 with a CaO and $Ca(OH)_2$ in the surface of the LIMB pile resulted in the formation of $CaCO_3$. This reduced the pH of the material in the pile surface to approximately 8.3 (the pH of free carbonates in equilibrium with atmospheric CO_2). Thus, runoff water interacted with material of a lower pH than that of the fresh LIMB ash or the LIMB ash deeper in the pile such as the acidic clay material used to construct the berm.

The chemistry of the runoff water is dominated by Ca and S (almost all in the form of SO_4^{2-}), as one would expect, given the high concentration of gypsum in the stockpiled material. These concentrations, however, are much lower than those of 20 to 1 water extracts of the LIMB material (1840 ppm Ca, 740 ppm S). This indicates that there is much less interaction of runoff water with the LIMB material in the stockpile than occurs in the standard ASTM water leachate extraction (ASTM D 3987-85) Runoff water concentrations of all trace elements were very low for all samples. Concentrations were always below drinking water standards and/or below analytical detection limits.

Discussion - Aging Effect on Beneficial Uses

Acid Neutralization Capacity

The chemical and mineralogical analyses during the 2½ year aging period showed the changes that occurred were due to further hydration, carbonation, pozzolanic, and ettringite reactions. As shown in Table 3, the free lime and calcium carbonates equivalent (CCE) declined with aging which deters from its potential valve as a soil liming material. The CCE originally was 45 -50% $CaCO_3$ but decreased to 25 - 50% in the first year of storage mostly due to ettringite formation. The free lime content dropped to a 1-2 % CaO.

The presence of ettringite in the aged material was confirmed by X-ray diffraction studies, as shown in Figure 3, on the 30 month old material. An attempt to quantify ettringite using thermal analysis was unsuccessful. The weight loss events resulting from the dehydration and dehydroxylation of ettringite occurred over a wide temperature range. Consequently, these events coincided with the decomposition of other reaction products commonly found in FGD by-products. Therefore, the thermal events associated with ettringite decomposition could not be defined without interference from other thermal transitions. No thaumasite ($Ca_6Si_2(CO_3)_2(SO_4)_2(OH)_{12} \cdot 24H_2O$) which is reported to be a decomposition product of ettringite, was found.(2)

Hydration:

FGD by-products from LIMB furnace sorbent injection and also fluid bed combustion units have unhydrated lime and anhydrite that are more reactive in waste stabilization than those that come from duct injection and spray dryer systems where by-products are hydrated during in-stream humidification. The unhydrated quicklime (CaO), and anhydrous calcium sulfate ($CaSO_4$), quickly hydrate and remove free water from the waste and give off heat (exothermic). As shown below, the quicklime will react to form portlandite, which is calcium hydroxide ($Ca(OH)_2$), and anhydrite will rapidly react to form calcium sulfate hemi-hydrate ($CaSO_4 \cdot ½ H_2O$) and subsequently gypsum ($CaSO_4 \cdot 2H_2O$), also called calcium sulfate dihydrate.

$$CaO + H_2O \rightarrow Ca(OH)_2$$

Portlandite or Hydrated Lime

$$CaSO_4 + 1/2\, H_2O \rightarrow CaSO_4 \bullet ½H_2O$$

Calcium Sulfate Hemi-hydrate

$$CaSO_4 \bullet ½H_2O + 3/2H_2O \rightarrow CaSO_4 \bullet 2H_2O$$

Gypsum or Calcium Sulfate Di-hydrate

Carbonation:

Calcite (calcium carbonate, $CaCO_3$) is formed by carbonation of the quicklime via reaction with the carbon dioxide (CO2) in ambient air and by hydrated lime reacting with the carbonate alkalinity equilibria system in the water content of the by-product.

$$CaO + CO_2 \rightarrow CaCO_3$$
$$Ca(OH)_2 + CO_3^{-2} \rightarrow CaCO_3 + 2\, OH^-$$

Pozzolanic Reactions:

Pozzolanic reactions between lime and the fly ash components (aluminum oxide, silica dioxide, and iron oxide) also consume free moisture and cause the waste material to harden and gain strength. These reactions occur in a high pH environment and are common place when portland cement or lime is mixed with Class F coal fly ash. Calcium silicate hydrate, calcium aluminate

hydrates, and calcium aluminumferro hydrates are formed. These reactions form glassy or noncrystalline (x-ray amorphous) phases characteristic of hydrated portland cement.

silica dioxide:

$$SiO_2 + Ca(OH)_2 + H_2O \rightarrow CaO\text{-}SiO_2\text{-}H_2O$$

calcium silicate hydrates

alumina:

$$Al_2O_3 + Ca(OH) + 2H_2O \rightarrow CaO\text{-}Al_2O_3\text{-}Ca(OH)_2\text{-}H_2O$$

calcium aluminate hydrates

iron oxide:

$$Fe_2O_3 + Al_2O_3 + Ca(OH)_2 + H_2O \rightarrow \underset{\text{calcium alumino-ferro hydrates}}{Ca(OH)_2 - Al_2O_3 - Fe_2O_3 - H_2O}$$

Ettringite Formation:

The gypsum form of calcium sulfate are able to further react with hydrated lime and the glassy alumino-silicate portion of fly ash in soil to form calcium sulfo-aluminate minerals of the ettringite group. More explicitly, the high pH solution solubilizes some aluminum, and it reacts with dissolved calcium and sulfate to form ettringite.

$$2Ca(OH)_2 + 3CaSO_4 \cdot 2H_2O + CaO \cdot Al_2O_3 + 30\,H_2O \rightarrow (CaO)_6Al_2(SO_4)_3 \cdot 32H_2O$$

Another molecular formula for ettringite is written as $3CaO\text{-}Al_2O_3 \cdot CaSO_4 \cdot 32H_2O$. This reaction uses 32 moles of water for every 3 moles of free CaO and 3 moles of $CaSO_4$ consumed and thus is a big contributor to compressive strength development and user of moisture.

Soil Engineering Uses

Dry LIMB ash, when mixed with water at optimum moisture content possesses cementitious properties. The 40% water added in conditioning the ash is approximately the optimum moisture content to form maximum dry density for stabilizing base construction. The unconfined compressive strength of the conditioned LIMB ash when tested at optimum moisture content reached strengths of 300 psi after a 28 day curing period .(1) Tests have shown that FGD material like LIMB ash can substantially improve the strength and the stiffness of a soil.(4,8)

The aging process allows for the cementitious reactions to take place before mixing to stabilize a soil or constructing a structure fill or embankment. Consequently, the aged material is much less cementitious. Unconfined compressive strengths on samples compacted from aged material are then about equal to a stiff clay, i.e. 30-50 psi. The lightweight or low bulk density of about 58 lbs per cu. ft. is interesting economically as potential lightweight and high volume structural fill per ton hauled.

However, because of ettringite formation the LIMB material will always be potentially harmful or damaging due to the expansive potential after the material has been compacted. LIMB ash samples after mixed to OMC exhibited swelling up to 90% after 800 days of saturated curing. (reference 8) Studies are showing that the stockpile aging process to be effective in preventing future expansion problems for use as structural fill may require additional watering in order to maintain adequate moisture. Lightweight plastic lining, i.e. visqueen, placed in the truck bed for each load to ease truck unloading that ends up in the ash stockpile prevents homogeneous moisture acclimation and saturation and thus must be avoided.

LIMB ash that has been well conditioned with water and then aged or stored to form ettringite such as exhibited by this stockpile should not have the severe expansion potential after being compacted for use in an embankment or structural fill. As shown in Figure 4, the stockpiled material at 6 months did not show significant swelling potential in a test where the specimen is maintained in saturation for about 200 days. If the storage pile is not uniformly of high moisture content, the ettringite potential swelling may always exist. More research is needed to positively reveal what moisture conditions and for how long are needed to prevent future expansion.

Conclusion & Summary

1) A description of the dry LIMB ash properties that were water-conditioned and constructed into a 1500T ash stockpile (storage pile) is presented herein in terms of water added, moisture contents, physical, mineralogical, chemical, and leachate properties.

2) About 43% of the 1500 tons is water added in the conditioning process. Moisture gains (surface only) after six months of exposure to rain are also reported herein. On average the initial residual moisture was 17% but the surface moisture level increased to 70% (dry weight basis or about 40% on wet weight basis). Below 6 inches the residual moisture increased to about 43-49% (dry weight basis or about 29-34% on wet weight basis).

3) The ASTM water and TCLP acidic leachate laboratory procedure yielded metal concentrations less than drinking water standards for important water quality parameters. This is due to very low levels of these metals in the LIMB ash.

4) Storm water runoff samples were not available the first ten months. For the next eight months there were eight storm events where samples could be collected and analyzed. Water quality test results showed only higher levels of calcium and sulfate. The pH was not above 7.8. No toxic metals were found. There was never a significant discharge from the clay diked storage pile.

5) During a 30 month period the stockpile was sampled for changes in physical, mineralogical, chemical, and engineering properties. Results showed a decrease in acid-soil neutralizing power (calcium carbonate equivalency) for beneficial use of soil conditioning and loss of free lime and resultant strength producing properties for soil stabilization. The conditioned LIMB ash largely converted to calcium silicates, calcium carbonate, and calcium sulfo-aluminate (ettringite). The aging allows for the expansive ettringite hydration reaction to take place before compaction in a structural fill or embankment beneficial use. More research is needed to confirm the aging and moisture content necessary to prevent expansion after compaction.

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TABLE 2

LIMB FGD ASH LEACHATE AND TOTAL CHEMICAL ANALYSIS

	LEACHATE ASTM 20:1	LEACHATE TCLP	TOTAL CHEMICAL ANALYSIS
SAMPLE I.D.	**LIM-14**	**N-VIRO**	**LIM-14**
SAMPLE DATE	**7-17-91**	**7-16 & 17-91**	**7-17-91**
	mg/L	mg/L	% or ug/g
Major Cations:			
Al	<0.11	0.15	3.60 %
Ca	1,842	3,670	33.68 %
Fe	<0.01	<0.01	5.32 %
Mg	0.07	0.12	0.60 %
Na	1.1	1.8	0.08 %
K	1.6	2.1	0.38 %
Si	0.12	0.15	5.74 %
Sr	2.58	2.21	0.03 %
Major Anions:			
F	3.4	--	--
Cl	54.4	64.8	--
SO_3	31.3	--	--
SO_4	1,872	1,590	--
S	740.7	605	5.77 % (17.3 % as SO_4)
Other:			
pH	10.63		
TDS (Total Dissolved Solids)	4,815		
			ug/g
Trace Metals:			
Sb	<0.06	<0.060	
As	<0.005	<0.005	55
Ba	0.231	0.26	100
Be	<0.002	<.002	4
B	3.93	5.78	230
Cd	<0.001	<0.005	1
Cr	<0.011	<0.011	33
Co	0.01	<0.01	20
Cu	<0.009	0.01	10
Pb	<0.093	<0.093	
Li	0.05	0.08	36
Mn	<0.053	<0.01	182
Hg	<.0002	<0.0002	
Mo	0.101	0.15	10
Ni	<0.01	<0.012	28
P	<0.108	0.054	300
Se	<0.005	<0.005	8
V	<0.029	0.049	9
Zn	<0.006	<0.006	54

TABLE 3

CHARACTERIZATION OF LIMB BY-PRODUCT AFTER 3, 6, 9, 18, & 30 MONTHS OF EXPOSED STORAGE

Sample ID	**Depth** cm	**Moisture Content** %	**Free CaO** %	**CCE** **%$CaCO_3$**	**Particle Density** g/cm^3	**Permability** cm/sec.	**Bulk Density** lbs/cu.ft
After 3 months:							
STO-01	0-5	25			1.24		
	50	33					
STO-02	0-70	10					
	70	12					
After 6 months:							
STO-03	0 - 15	43	--	--			
STO-04	0 - 15	73	--	--			
STO-05	0 - 5	70	12.4	51			
	15	49	1.2	49			
After 9 months:							
STO-06	150	62	--	--	0.70	1.4×10^{-4}	
STO-07	0		1.6	29.6	0.98	4.9×10^{-6}	
	90	45-49	7.7	34.3	--	(compacted)	
	150		19.1	50.5			
STO-08	30	19	--	--	0.66	--	
After 18 months:							
STO-09	0 - 5	62					
	30	102	6.5	22.2	0.6	4.0×10^{-4}	58.6
After 30 months:							
STO-10	0 - 5	62			0.6		
	30-50	52	2.0 (pH 11.2)	26	0.5		

Table 4

Chemical composition of stockpile runoff samples

ID	Date	Vol (L)	pH	Cond mmho/cm	Al ppm	As ppm	B ppm	Ba ppm	Be ppm	Ca ppm	Cd ppm	Co ppm	Cr ppm
SPRO-001	05/20/92	8	7.2	2.32	0.09	<0.08	2.363	0.023	<0.001	686.6	<0.003	<0.009	<0.004
SPRO-004	07/13/92	20	7.7	1.51	0.09	<0.08	2.042	0.011	<0.001	395.7	<0.003	<0.009	0.007
SPRO-007	07/30/92	40	7.2	0.94	<0.05	<0.08	1.216	0.010	0.001	237.2	<0.003	<0.009	<0.004
SPRO-008	08/28/92		7.4		0.14	<0.08	0.667	0.045	<0.001	143.4	<0.003	<0.009	<0.004
SPRO-010	09/23/92		7.8		0.10	<0.08	2.220	0.160	<0.001	655.0	<0.003	<0.009	0.010
SPRO-011	10/16/92		7.6		0.23	<0.08	0.334	0.065	<0.001	91.8	<0.003	<0.009	<0.004
SPRO-012	11/13/92	60	7.2	1.43	1.73	<0.08	1.014	0.002	<0.001	328.1	<0.003	<0.009	<0.004
SPRO-014	12/11/92		7.0		0.24	<0.08	0.353	0.162	<0.001	89.2	<0.003	<0.009	<0.004

ID	Cu ppm	Fe ppm	Hg ppm	K ppm	Li ppm	Mg ppm	Mn ppm	Mo ppm	Na ppm	Ni ppm	P ppm	Pb ppm	S ppm
SPRO-001	0.012	<0.011	<0.04	45.8	0.30	34.61	<0.001	0.128	11.55	0.027	<0.09	<0.04	500.6
SPRO-004	<0.007	<0.011	<0.04	23.3	0.06	10.97	0.001	0.113	4.54	0.022	0.44	<0.04	281.3
SPRO-007	<0.007	<0.011	<0.04	16.1	0.04	5.94	<0.001	0.051	2.49	<0.009	<0.09	<0.04	184.7
SPRO-008	<0.007	0.074	<0.04	11.3	0.03	8.38	0.009	0.031	16.67	<0.009	<0.09	<0.04	133.8
SPRO-010	0.010	0.060	0.05	49.9	0.09	18.81	0.010	0.100	16.31	<0.009	0.09	<0.04	496.9
SPRO-011	<0.007	0.167	<0.04	6.1	0.01	3.65	0.004	0.016	12.32	<0.009	<0.09	<0.04	81.1
SPRO-012	<0.007	<0.011	<0.04	16.7	0.04	9.58	<0.001	0.057	4.10	<0.009	<0.09	<0.04	272.1
SPRO-014	<0.007	0.350	<0.04	6.5	0.01	4.01	0.005	0.010	13.54	<0.009	<0.09	<0.04	79.9

ID	Sb ppm	Sc ppm	Si ppm	Sr ppm	V ppm	Zn ppm	F ppm	Cl ppm	SO_3 ppm	SO_4 ppm
SPRO-001	<0.165	<0.266	5.693	1.497	0.007	0.056	0.027	1.2	11.1	1363.1
SPRO-004	<0.165	<0.266	6.397	0.549	<0.006	0.006	0.022	<0.01	<0.01	809.4
SPRO-007	<0.165	<0.266	3.058	0.401	0.017	<0.005	<0.009	<0.01	<0.01	498.2
SPRO-008	<0.165	<0.266	2.429	0.280	<0.006	0.060	<0.009			332.7
SPRO-010	<0.165	<0.266	12.800	0.970	<0.006	2.000	<0.009			1563.8
SPRO-011	<0.165	<0.266	1.762	0.161	<0.006	0.034	<0.009			212.5
SPRO-012	<0.165	<0.266	4.882	0.507	<0.006	0.064	<0.009	2.2	<0.1	764.5
SPRO-014	<0.065	<0.266	1.833	0.169	<0.006	0.038	<0.009			208.3

Figure 1
Photograph taken 29 December, 1992 showing the integrity of the sides of the LIMB stockpile, and lack sloughing or erosion of material into the area between the pile and the clay berm.

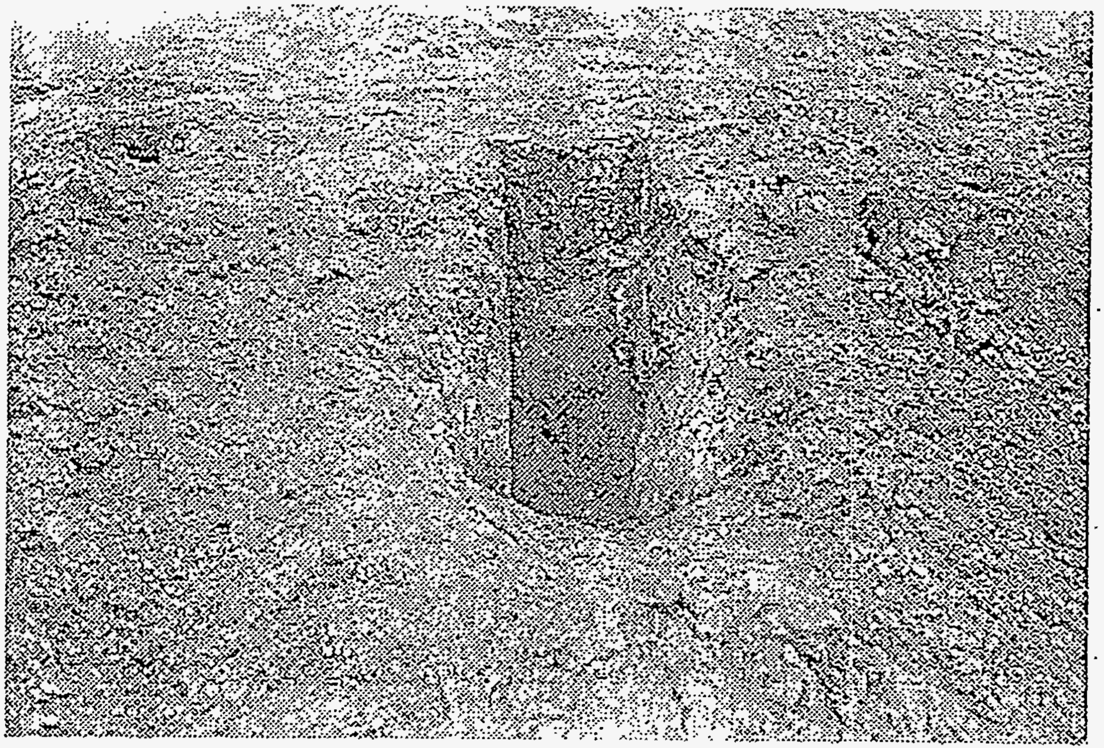

Figure 2
Photograph taken 29 December, 1992 showing the integrity of the sides of a sample collection pit excavated by back-hoe in May 1992.

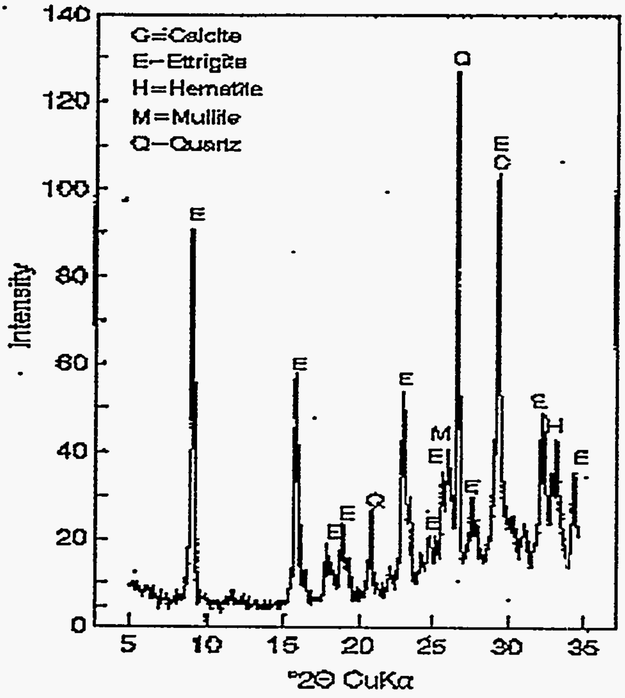

Figure 3
X-Ray diffraction pattern for LIMB ash after 30 months in a stockpile.

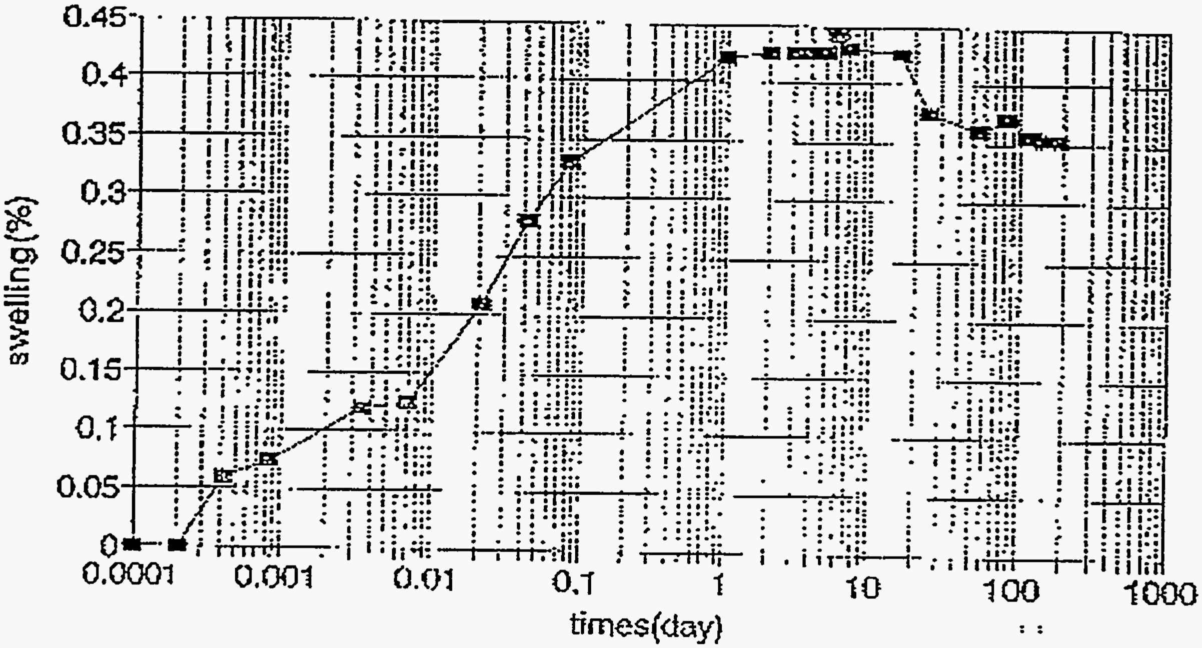

Figure 4
LIMB ash swelling test results of stockpile #4 samples after 6 months exposed storage.