# INVESTIGATION OF METAL AND NONMETAL ION MIGRATION THROUGH AN INACTIVE PHOSPHOGYPSUM STACK[1]

by

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Abstract. The Toxic Substance Control Act (TSCA) of 1976 authorizes the Environmental Protection Agency (EPA) to obtain production and test data from industries on selected substances and mixtures, and to regulate these substances when needed. Currently, phosphogypsum, a waste byproduct of phosphate ore processing, is being regulated under TSCA. To obtain a better understanding of the environmental effects caused by phosphogypsum stacks, the Tuscaloosa Research Center investigated the effects of a synthetic rainwater and a process cooling pond water on the mobility of metal and nonmetal ions through an inactive phosphogypsum stack in Florida. Twenty-one groundwater monitoring wells were installed in a 160 acre, 30 year old inactive phosphogypsum stack in the Central Florida Phosphate Mining District. The wells were placed in the stack in clusters of three, with the wells being 17, 27, and 37 ft deep, respectively. Well core samples were taken every 5 ft for characterization studies and column leaching tests. These wells were monitored monthly with samples analyzed for pH and metal and nonmetal ion concentrations. Two leach solutions, a synthetic rainwater to simulate natural rainfall and a phosphate plant process cooling pond water were used in the laboratory column leaching experiments. Leachate from these column leaching tests using phosphogypsum from the well cores was found to contain metal and nonmetal ions. Such tests indicate that metal and nonmetal ions contained in the phosphogypsum have the potential for migrating into surrounding surface waters and groundwater.

Additional Key Words: phosphogypsum, leaching, environmental impact.

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## Introduction

In the production of phosphate based fertilizers, an apatite $[Ca_5(PO_4)_3(F,Cl,OH)]$ concentrate is leached with sulfuric acid ($H_2SO_4$) in the presence of recycled dilute solutions of phosphoric acid ($H_3PO_4$). The apatite dissolves during the leaching step, producing $H_3PO_4$. The calcium and sulfate ions subsequently combine to form gypsum, commonly referred to as phosphogypsum (May 1984). The $H_3PO_4$ is separated by filtration and the phosphogypsum-water slurry, usually containing about 30 pct solids, is pumped to an impoundment where it is allowed to settle. As the gypsum settles, a small dragline removes some of it for raising the height of the dikes. By this process the gypsum settling impoundment, or "stack" as it is often called, increases in elevation. As a stack grows in height (up to 200 ft) the area of the settling impoundment decreases until a point is reached where the pond capacity becomes too small and the pumping height requires too much energy. At this point (approximately 30 years) the phosphogypsum stacks reach the end of their useful lives and they are ready to be closed. During the slurry process, any $H_3PO_4$ trapped in the filtrate (4 to 6 pct of the total extracted $H_3PO_4$) and unreacted $H_2SO_4$ end up in the slurry which goes to the stack also. Solutions associated with the slurry percolate through the stack into a cooling water pond which supplies water to the process plant. Water from the pond is also used in various plant operations (i.e., filtering the gypsum) and is subsequently recycled to the cooling water pond (Staff Bureau of Mines 1975).

As explained earlier, phosphogypsum is a by-product of phosphoric acid production. For each ton of phosphoric acid produced, approximately five tons of phosphogypsum must be stockpiled. To date, more than 600 millions tons have accumulated in Florida on approximately 5,000 acres and phosphogypsum is continuing to accumulate at an estimated rate of 30 million tons per year (FIPR 1992).

The environmental impact of the phosphogypsum stack and cooling water pond has received considerable attention. The potential migration of metal and nonmetal ions, including anions such as sulfate, has been discussed by various regulatory agencies. The final EPA National Emissions Standards for Hazardous Air Pollutants (NESHAP) ruling on phosphogypsum was issued in August 1992. The ruling effectively prohibits all utilization of phosphogypsum except for research purposes and requires that all phosphogypsum now stored in stacks plus all future phosphogypsum production remain in the stacks. The solid waste branch of EPA has also proposed regulation of phosphogypsum stacks and associated cooling pond systems. A primary concern of the solid waste division is the "pond water" associated with the phosphogypsum stack.

Another major issue currently under review is the procedure that should be used for closure of a phosphogypsum stack at the end of its use as a disposal area. To better define the migration of metal and nonmetal ions from a phosphogypsum stack, the Bureau of Mines Tuscaloosa Research Center, has investigated the effect of various solutions on metal migration. This paper describes the placement of monitoring wells to study the migration of ions in an inactive phosphogypsum stack. Column leaching tests using synthetic rainwater and process cooling pond water were also performed to determine the amount of metal and nonmetal migration.

## Experimental

A 2.0-in O.D. by 36-in long clear plexiglass tube was used as the leaching column (Standard Specifications for Transportation Materials and Methods of Sampling and Testing, (1982). A 750-g charge of phosphogypsum was used as the medium. Table 1 shows a size/screen analysis of the phosphogypsum sample. The phosphogypsum was from the inactive stack (P-21) in central Florida. The column was filled with the media and tamped until no additional settling occurred. The synthetic rainwater used was made up based on Rosler and Lange chemical composition of rainwater (Rosler 1972). The pH of this rainwater was 6.9.

Pore volumes were determined and the solutions analyzed for metal and nonmetal concentrations by Inductively Coupled Arc Plasma (ICAP). One pore volume is the amount of liquid it takes to completely saturate a known quantity of material. For the experiments described in this paper, one pore volume for 750 g of phosphogypsum was 250.0 mL. Five pore volumes were taken from each leached column. It took approximately 24 h to collect one pore volume of leachate.

TABLE 1.--Particle size/screen analysis for phosphogypsum

| Size, mesh | Weight, g | pct |
|---|---|---|
| +65 | 1.80 | 0.1 |
| -65/+100 | 33.18 | 20.0 |
| -100/+150 | 51.42 | 30.0 |
| -150/+200 | 35.19 | 21.0 |
| -200/+270 | 12.68 | 8.0 |
| -270/+325 | 4.36 | 2.9 |
| -325 | 30.13 | 18.0 |
| | 168.76 | 100.0 |

Density = 1.5 g/mL.

In January 1992, seven clusters of three wells each, totaling 21 wells, were installed in the 160 acre stack (P-21). The cluster wells were drilled to approximately 17, 27, and 37 ft deep and all boreholes were sampled at 5 ft intervals. The phosphogypsum drill cuttings were leached with a synthetic rainwater and a phosphoric acid plant process cooling pond water thus, simulating natural rainfall and active mining leaching of phosphogypsum stacks. The leachates from the ground-water wells and laboratory column leaching tests were analyzed for metal and non-metal ions. This data compares metal and non-metal concentrations of filtrates from monitoring well fluids at the field site with filtrates from laboratory column leaching tests. In addition, this data will be used to predict the impact of leachate from phosphogypsum stacks on the ambient surface and subsurface environments.

## Results and Discussion

Table 2 shows average Inductively Coupled Arc Plasma (ICAP) chemical analyses for the monitoring wells from the P-21 phosphogypsum stack for eight monthly collections during 1992.

Table 2 shows that the highest concentrations of metal ions were Al, Ca, K, Mg, and Na and for the non-metals the Cl, F, P, Si, and $SO_4$ were all relatively high. The phosphogypsum composite sample of drill cuttings contain significantly larger concentrations of these ions, as shown in table 3.

The depth of the groundwater in the P-21 site is not uniform throughout the inactive stack. This particular site was mined in the early 1960's from the surface using a dragline that cast the overburden into windrows. The windrows are oriented in a North and South direction. The cluster wells were placed in three separate windrows with the West well cluster placed three windrows from the center well cluster and the East well cluster two windrows from the center cluster (see fig. 1). The windrows are approximately 100 ft wide with the cluster wells being placed in the center of the windrow. The depth of each windrow is approximately 45 ft, filled with phosphogypsum. At the ground surface the spoil pile is cracked and vented with abundant vegetation of small trees and shrubs whereas, in the fill area of phosphogypsum, there is much less vegetation with grass being the primary flora. The western windrow has a 5.6 ft hydraulic head forcing water in a southerly direction. Finally, in the Eastern windrow there is a 3.2 ft hydraulic head pushing water in a southerly direction. The pH of all wells ranged from 3.4 to 5.7. If the windrows do in fact act as a barrier, then the direction of water flow is in a lateral southerly direction, however, if you look at the entire site and neglect the windrow barrier idea, the overall groundwater flow could be in a southwesterly direction where there is a 11.8 ft hydraulic head. Preliminary examination of the 8-month average data shown in table 1 and the data for the individual months does not permit a determination of the influence of groundwater flow on the ion concentrations.

Table 4 shows the chemical analyses of the synthetic rainwater and pore volumes from wells using cuttings from CC1 with synthetic rainwater as the leaching solution. Well CC1 is located approximately in the center and is one of the deepest wells in the P-21 phosphogypsum stack.

In table 4, very little migration of ions is occurring when synthetic rainwater is the leaching solution. The metals that leach out are Ca, K, Mg, and Na and the non-metals are Cl, F, P, Si, and $SO_4$. The data shows that the concentrations of these ions decrease in the first three pore volumes. The concentrations tend to level out in the last two pore volumes. This data agrees with previous phosphogypsum column leaching tests using synthetic rainwater as the leaching solution (Carter 1992). This occurs in almost every 5-ft section of core material. The pH changes very little starting at 6.9 and ending up at approximately 5.8.

A second series of tests were conducted using process cooling pond water as the leaching solution. The phosphate plant process cooling pond water normally has a pH range of 1.2 to 2.1. This process water is heavily concentrated with many metal and

TABLE 2.—ICAP analyses of monitoring wells fluid from the (P-21) inactive phosphogypsum stack

| Well | Metals, ppm | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | pH | Al | As | Ca | Cr | Cu | Fe | Hg | K | Mg | Mn |
| CS1[1] | 5.1 | 13.0 | 1.19 | 598 | 1.17 | 0.59 | 2.38 | 0.001 | 19.9 | 3.44 | 0.77 |
| CC1 | 5.7 | 4.9 | 1.12 | 509 | 1.12 | .50 | 49.8 | .001 | 17.9 | 24.8 | .46 |
| CN1 | 5.3 | 5.76 | .96 | 596 | 1.21 | .56 | 2.05 | .001 | 18.1 | 4.19 | .09 |
| CN2[2] | 4.9 | 12.7 | 1.28 | 600 | 1.08 | .52 | 1.30 | .001 | 17.7 | 3.70 | .05 |
| EN1 | 4.3 | 4.76 | .37 | 541 | .90 | .43 | 42.8 | .001 | 18.3 | 23.6 | .79 |
| EN2 | 5.5 | 4.5 | 1.35 | 584 | 1.06 | .49 | 15.9 | .001 | 19.2 | 22.0 | .24 |
| ES1 | 5.0 | 3.5 | .95 | 425 | 1.03 | .47 | 90.1 | .001 | 16.2 | 107.9 | .90 |
| ES2 | 3.4 | 4.2 | 1.30 | 403 | .90 | .43 | 53.2 | .001 | 18.1 | 41.4 | .66 |
| WN1 | 4.8 | 12.2 | 1.13 | 603 | 1.04 | .47 | 4.5 | .001 | 17.5 | 3.01 | .10 |
| WS1 | 5.1 | 3.1 | .75 | 579 | .82 | .40 | 17.2 | .001 | 14.5 | 2.91 | .37 |

| Well | Metals, ppm | | | | | | Non-metals, ppm | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Na | Ni | Se | Sr | Ti | Y | Cl | F | P | Si | $SO_4$ |
| CS1 | 13.0 | 0.79 | 0.005 | 3.95 | 0.39 | 0.22 | 24.3 | 42.2 | 23.6 | 52.3 | 1431 |
| CC1 | 47.0 | .60 | .001 | 1.09 | .33 | .20 | 24.3 | 13.5 | 10.4 | 33.2 | 1499 |
| CN1 | 47.0 | .52 | .001 | 2.94 | .38 | .22 | 24.7 | 27.7 | 22.7 | 51.4 | 1479 |
| CN2 | 9.4 | .93 | .001 | 3.77 | .35 | .19 | 19.6 | 38.9 | 27.7 | 51.5 | 1421 |
| EN1 | 40.0 | .67 | .001 | .53 | .33 | .17 | 19.2 | 13.9 | 6.43 | 39.9 | 1558 |
| EN2 | 39.9 | .70 | .001 | 1.81 | .33 | .19 | 22.9 | 16.9 | 9.54 | 44.2 | 1573 |
| ES1 | 76.3 | .78 | .001 | .11 | .34 | .18 | 23.8 | 12.5 | 6.36 | 17.4 | 1781 |
| ES2 | 26.6 | 1.05 | .001 | .48 | .29 | .19 | 20.4 | 10.2 | 16.90 | 37.6 | 1298 |
| WN1 | 10.4 | .61 | .001 | 3.54 | .34 | .18 | 19.0 | 29.8 | 35.30 | 58.3 | 1447 |
| WS1 | 10.6 | .42 | .001 | 1.18 | .30 | .16 | 19.8 | 13.8 | 39.20 | 53.9 | 1403 |

[1]All wells ending in a 1 are 37 ft in depth.
[2]All wells ending in a 2 are 27 ft in depth.

TABLE 3.—ICAP analyses of the phosphogypsum composite sample

| Metals, ppm | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Al | As | Ca | Cr | Cu | Fe | K | Mg | Mn | Na | Ni |
| 1300 | <300 | 190,000 | 72.5 | 195 | 940 | <1000 | <100 | 9.2 | 1700 | 245 |

| Metals, ppm | | | | Non-metals, ppm | | | | |
|---|---|---|---|---|---|---|---|---|
| Se | Sr | Ti | Y | Cl | F | P | Si | $SO_4$ |
| 0.413 | 550 | 200 | 20 | 138 | 5750 | 2450 | 92,000 | 356,000 |

- CN3
- CN2
- CN1 (160.8 elevation)

- WN3
- WN2
- WN1 (158.1 elevation)

- EN3
- EN2
- EN1 (164.3 elevation)

- CC3
- CC2
- CC1 (159.9 elevation)

- WS3
- WS2
- WS1 (152.5 elevation)

- ES3
- ES2
- ES1 (161.1 elevation)

- CS3
- CS2
- CS1 (157.2 elevation)

LEGEND

- WN - West Cluster North
- WS - West Cluster South
- CN - Central Cluster North
- CC - Central Cluster Central
- CS - Central Cluster South
- EN - East Cluster North
- ES - East Cluster South

N

FIGURE 1.- Well locations and piezometric elevations (feet) for the P-21 phosphogypsum stack

TABLE 4.--ICAP analyses of synthetic rainwater and pore volumes from well CC1 using synthetic rainwater as the leachate

| | | Metals, ppm | | | | | | | | | | | | | | | | | Non-metals, ppm | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | pH | Al | As | Ca | Cr | Cu | Fe | Hg | K | Mg | Mn | Na | Ni | Se | Sr | Ti | Y | Cl | F | P | Si | $SO_4$ |
| Synthetic rainwater | | 6.9 | 0.13 | 0.02 | 0.24 | 0.03 | 0.02 | 0.004 | 0.001 | 0.62 | 0.08 | 0.001 | 1.23 | 0.02 | 0.001 | 0.001 | 0.01 | 0.01 | 1.51 | 0.1 | 0.21 | 0.19 | 1.48 |
| Hole CC1 | Volume # | | | | | | | | | | | | | | | | | | | | | | |
| 0-5 ft | 1 | 5.6 | 4.50 | 0.002 | 651 | 0.35 | 0.53 | 0.17 | 0.001 | 11.3 | 2.60 | 0.13 | 16.4 | 0.36 | 0.001 | 3.69 | 0.47 | 0.12 | 10 | 23 | 39.5 | 83.7 | 1380 |
| | 2 | 5.5 | 5.88 | .002 | 656 | .35 | .15 | .17 | .001 | 10.6 | 2.64 | .1 | 13.3 | .78 | .001 | 3.84 | .32 | .11 | 10 | 24 | 38.2 | 83.2 | 1380 |
| | 3 | 5.5 | 7.98 | .002 | 662 | .35 | .16 | .14 | .001 | 9.3 | 2.09 | .03 | 5.79 | .65 | .001 | 3.50 | .42 | .16 | 10 | 28 | 21.7 | 81.3 | 1390 |
| | 4 | 5.7 | 6.29 | .002 | 680 | .35 | .16 | .23 | .001 | 5.6 | 1.32 | .03 | 5.34 | .20 | .001 | 2.69 | .38 | .16 | 10 | 40 | 10.4 | 81.5 | 1450 |
| | 5 | 5.8 | 5.46 | .002 | 655 | .58 | .15 | .27 | .001 | 5.6 | 1.64 | .03 | 6.34 | .41 | .001 | 2.48 | .30 | .13 | 10 | 26 | 11.1 | 80.6 | 1400 |
| 5-10 ft | 1 | 5.7 | 2.72 | .002 | 649 | .35 | .16 | .21 | .001 | 5.7 | 2.45 | .13 | 22.4 | .49 | .001 | 3.90 | .43 | .13 | 10 | 22 | 45.2 | 87.4 | 1370 |
| | 2 | 5.6 | 5.60 | .002 | 645 | .35 | .15 | .24 | .001 | 5.78 | 1.58 | .13 | 11.6 | .33 | .001 | 4.08 | .34 | .13 | 10 | 47 | 39.0 | 87.5 | 1390 |
| | 3 | 5.5 | 5.68 | .002 | 643 | .35 | .15 | .19 | .001 | 5.7 | 1.38 | .04 | 7.0 | .54 | .001 | 3.19 | .38 | .11 | 10 | 28 | 18.8 | 51.2 | 1380 |
| | 4 | 5.7 | 5.26 | .002 | 657 | .45 | .16 | .20 | .001 | 9.81 | 1.72 | .05 | 6.82 | .20 | .001 | 2.78 | .43 | .18 | 10 | 42 | 12.5 | 83.5 | 1410 |
| | 5 | 5.7 | 5.38 | .002 | 642 | .35 | .16 | .22 | .001 | 5.7 | 2.13 | .03 | 7.01 | .20 | .001 | 2.44 | .47 | .12 | 10 | 25 | 5.78 | 82.5 | 1380 |
| 10-15 ft | 1 | 6.0 | 2.07 | .005 | 648 | .45 | .15 | .19 | .001 | 13.5 | 3.11 | .17 | 31.5 | .26 | .003 | 4.50 | .39 | .14 | 10 | 32 | 52.4 | 93.7 | 1360 |
| | 2 | 5.6 | 4.80 | .008 | 654 | .35 | .16 | .15 | .001 | 8.9 | 1.95 | .18 | 20.4 | .39 | .003 | 4.80 | .42 | .13 | 10 | 24 | 53.8 | 91.7 | 1380 |
| | 3 | 5.6 | 5.81 | .002 | 642 | .35 | .16 | .23 | .001 | 8.79 | 1.76 | .07 | 8.32 | .79 | .001 | 4.47 | .31 | .15 | 10 | 23 | 25.6 | 84.3 | 1410 |
| | 4 | 5.6 | 6.57 | .004 | 646 | .64 | .16 | .18 | .001 | 5.7 | 1.44 | .02 | 6.26 | .20 | .001 | 4.06 | .38 | .10 | 12 | 25 | 19.3 | 81.8 | 1450 |
| | 5 | 5.7 | 5.81 | .002 | 653 | .35 | .16 | .18 | .001 | 7.82 | 1.47 | .01 | 9.23 | .34 | .001 | 3.68 | .39 | .10 | 10 | 24 | 11.6 | 82.4 | 1430 |
| 15-20 ft | 1 | 5.8 | 3.13 | .01 | 653 | .43 | .16 | .13 | .001 | 18.9 | 22.0 | .47 | 82.8 | .41 | .001 | 4.76 | .32 | .14 | 10 | 20 | 50.8 | 102.0 | 1590 |
| | 2 | 5.4 | 9.33 | .009 | 673 | .63 | .18 | .17 | .001 | 9.24 | 4.2 | .36 | 28.7 | .76 | .008 | 5.49 | .42 | .16 | 11 | 29 | 70.5 | 99.7 | 1450 |
| | 3 | 5.5 | 8.55 | .004 | 660 | .35 | .15 | .11 | .001 | 5.7 | 1.57 | .13 | 9.92 | .19 | .003 | 5.31 | .37 | .17 | 10 | 30 | 33.9 | 88.9 | 1430 |
| | 4 | 5.6 | 7.76 | .002 | 661 | .41 | .16 | .14 | .001 | 7.2 | 1.89 | .05 | 7.34 | .20 | .001 | 4.03 | .36 | .10 | 10 | 31 | 15.5 | 83.5 | 1470 |
| | 5 | 5.7 | 7.19 | .002 | 665 | .35 | .16 | .05 | .001 | 13.2 | 1.71 | .04 | 9.65 | .43 | .003 | 3.60 | .39 | .15 | 12 | 30 | 13.8 | 86.0 | 1460 |
| 20-25 ft | 1 | 5.6 | 6.95 | .02 | 650 | .35 | .42 | .19 | .001 | 11.5 | 21.0 | .49 | 74.5 | .89 | .03 | 4.93 | .40 | .12 | 13 | 28 | 48.8 | 102.0 | 1570 |
| | 2 | 5.4 | 12.5 | .01 | 656 | .35 | .53 | .28 | .001 | 9.64 | 7.36 | .34 | 31.9 | .65 | .02 | 5.32 | .49 | .16 | 10 | 35 | 46.7 | 92.5 | 1480 |
| | 3 | 5.5 | 11.2 | .007 | 636 | .35 | .28 | .17 | .001 | 7.94 | 1.77 | .08 | 9.24 | .71 | .007 | 4.08 | .47 | .13 | 10 | 34 | 15.3 | 80.0 | 1430 |
| | 4 | 5.6 | 8.46 | .004 | 664 | .54 | .31 | .18 | .001 | 6.41 | 2.11 | .03 | 6.58 | 1.08 | .004 | 3.59 | .43 | .13 | 10 | 30 | 10.9 | 81.1 | 1490 |
| | 5 | 5.7 | 6.31 | .004 | 653 | .53 | .23 | .15 | .001 | 5.7 | 1.73 | .06 | 7.47 | .34 | .004 | 3.24 | .50 | .15 | 11 | 29 | 6.35 | 81.1 | 1450 |
| 25-30 ft | 1 | 5.3 | 14.7 | .08 | 646 | .64 | .16 | .12 | .001 | 11.4 | 2.75 | .37 | 28.3 | .68 | .02 | 4.48 | .32 | .12 | 10 | 38 | 46.7 | 92.7 | 1440 |
| | 2 | 5.2 | 17.5 | .07 | 655 | .65 | .16 | .23 | .001 | 6.29 | 2.05 | .35 | 21.2 | .89 | .02 | 4.74 | .45 | .13 | 15 | 47 | 37.7 | 89.7 | 1440 |
| | 3 | 5.4 | 12.0 | .01 | 637 | .42 | .16 | .20 | .001 | 5.6 | 1.74 | .07 | 8.47 | .89 | .006 | 3.77 | .45 | .15 | 10 | 36 | 18.3 | 79.8 | 1410 |
| | 4 | 5.6 | 9.49 | .008 | 650 | .40 | .16 | .17 | .001 | 5.7 | 1.76 | .06 | 8.11 | .54 | .003 | 3.26 | .49 | .16 | 10 | 30 | 13.3 | 81.7 | 1460 |
| | 5 | 5.7 | 7.37 | .004 | 644 | .35 | .16 | .18 | .001 | 5.6 | 1.82 | .05 | 7.24 | .65 | .003 | 2.89 | .42 | .14 | 10 | 26 | 5.6 | 81.0 | 1430 |
| 30-35 ft | 1 | 5.2 | 14.7 | .162 | 653 | .34 | .15 | .25 | .001 | 7.1 | 1.22 | .54 | 34.0 | .65 | .02 | 4.78 | .31 | .05 | 14 | 43 | 43.6 | 102.0 | 1460 |
| | 2 | 5.2 | 19.5 | .118 | 662 | .35 | .15 | .25 | .001 | 5.9 | 1.27 | .41 | 21.9 | .22 | .02 | 5.12 | .34 | .05 | 10 | 46 | 39.1 | 92.4 | 1460 |
| | 3 | 5.4 | 12.5 | .02 | 665 | .35 | .15 | .16 | .001 | 5.9 | .87 | .07 | 8.1 | .28 | .006 | 4.16 | .30 | .07 | 10 | 35 | 20.2 | 81.5 | 1430 |
| | 4 | 5.5 | 8.96 | .01 | 688 | .35 | .15 | .28 | .001 | 8.54 | .87 | .03 | 7.82 | .19 | .003 | 3.62 | .20 | .06 | 10 | 30 | 14.0 | 81.6 | 1450 |
| | 5 | 5.7 | 7.69 | .008 | 668 | .35 | .15 | .31 | .001 | 5.9 | .87 | .03 | 6.3 | .20 | .004 | 3.14 | .33 | .07 | 10 | 27 | 13.4 | 81.6 | 1430 |

non-metal ions. In the construction of a phosphogypsum waste stack, this water is used as a transport mechanism to deposit phosphogypsum to the desired cell on the stack. Depending on the size of a stack, it may contain up to 8 to 12 cells where the phosphogypsum is slurried with the process cooling pond water and deposited, with the cooling pond water trickling or leaching through the stack from the top to the holding pond around the base.

From table 5, moderate leaching of metal and non-metal ions is occurring. This data coincides with previous phosphogypsum column leaching tests using mixed acid ($H_2SO_4$ and $H_3PO_4$) solutions to mimic process cooling pond water as the leaching solution (Carter 1992). The large concentrations of ions that are found in the pore volumes is due to the metals and non-metals in the cooling pond water. Almost at every depth of the core material the contaminants are percolating through the phosphogypsum. For the metals, Cr, Fe, K, and Na, there is a slight increase in concentrations and for the non-metals Cl and P there is a significant increase. In-depth analysis of the data from monitoring wells and leach column tests are continuing.

## Conclusions

Groundwater flow in the P-21 inactive phosphogypsum stack is determined to be in an overall lateral southwesterly direction due to the hydraulic gradient determined from the monitoring wells.

Column leaching tests using phosphogypsum as the medium showed metal and nonmetal ions were mobile when either synthetic rainwater or process cooling pond water were used as the leaching solutions. The majority of these ions are migrating out of the phosphogypsum in the first three pore volumes. The degree of ion migration is greater when the phosphogypsum is leached with process cooling pond water. This is due primarily to the makeup of this wastewater (i.e., very low pH and high concentrations of metal and nonmetal ions). This observation could have a great impact on phosphogypsum stack closure scenarios. Since the process cooling pond water enhances the leaching of the metal and nonmetal ions compared to that of the synthetic rainwater, the closure procedure could be accelerated by using this acidic process cooling pond water in the initial rinsing operation, followed by rinsing with water. This acid washing coupled with lime treatment of the leachate from the stack may be a viable technique for closure.

## Literature Cited


Carter, Jr. O. C. and B. J. Scheiner, Investigation of Metal and Nonmetal Ion Migration Through Phosphogypsum, Proceedings of the Symposium on Emerging Process Technologies for a Cleaner Environment, February 24-27, 1992, Phoenix, Arizona, Published by the Society for Mining, Metallurgy, and Exploration, Inc., Chapter 27, pp. 205-210.

Florida Institute of Phosphate Research (FIPR), Annual Report, 1992, 23 pp.

May, A. and J. W. Sweeney, Assessment of Environmental Impacts Associated with Phosphogypsum in Florida, The Chemistry and

TABLE 5.--ICAP analyses of process cooling pond water and pore volumes from well CC1 using a phosphate plant cooling pond water as the leachate

| | | Metals, ppm | | | | | | | | | | | | | | | | | Non-metals, ppm | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | pH | Al | As | Ca | Cr | Cu | Fe | Hg | K | Mg | Mn | Na | Ni | Se | Sr | Ti | Y | Cl | F | P | Si | $SO_4$ |
| Cooling pond water | | 1.2 | 420 | 2.23 | 1275 | 4.54 | 0.36 | 244.5 | 0.001 | 278 | 466 | 22.2 | 1988 | 1.23 | 0.02 | 32.2 | 7.45 | 2.3 | 100 | 11450 | 11550 | 2825 | 9520 |
| Hole CC1 | Volume # | | | | | | | | | | | | | | | | | | | | | | |
| 0-5 ft | 1 | 0.5 | 349 | 2.0 | 1490 | 10.7 | 1.6 | 418 | 0.001 | 401 | 452 | 21.0 | 2110 | 6.80 | 0.02 | 31.1 | 9.96 | 2.99 | 160 | 8200 | 11900 | 3120 | 6790 |
| | 2 | .4 | 390 | 2.4 | 1300 | 4.64 | 1.6 | 388 | .001 | 324 | 510 | 23.8 | 2120 | 8.56 | .03 | 34.3 | 9.44 | 3.43 | 230 | 8800 | 13500 | 3380 | 8010 |
| | 3 | .5 | 393 | 2.5 | 1120 | <3.9 | 1.6 | 349 | .001 | 319 | 515 | 23.8 | 1880 | 8.16 | .02 | 36.7 | 8.85 | 3.39 | 250 | 8700 | 13500 | 3260 | 8770 |
| | 4 | .4 | 425 | 2.5 | 1190 | 5.2 | 1.6 | 362 | .001 | 382 | 540 | 25.0 | 2080 | 3.78 | .02 | 37.7 | 9.47 | 3.35 | 270 | 8700 | 14000 | 3530 | 9680 |
| | 5 | .5 | 529 | 2.5 | 1330 | 8.69 | 1.6 | 379 | .001 | 427 | 560 | 25.6 | 2270 | 7.36 | .02 | 39.7 | 10.8 | 3.18 | 270 | 8900 | 14400 | 3680 | 9960 |
| 5-10 ft | 1 | .5 | 323 | 1.9 | 1530 | 5.43 | 1.6 | 282 | .001 | 417 | 416 | 19.2 | 1940 | 5.08 | .03 | 30.0 | 8.65 | 2.27 | 260 | 8400 | 10900 | 2860 | 5990 |
| | 2 | .4 | 424 | 2.3 | 1400 | 7.28 | 1.6 | 357 | .001 | 312 | 524 | 24.5 | 2200 | 10.9 | .02 | 34.8 | 10.6 | 4.49 | 250 | 9200 | 13800 | 3490 | 7680 |
| | 3 | .5 | 483 | 2.4 | 1240 | 6.91 | 1.6 | 370 | .001 | 456 | 560 | 25.4 | 2020 | 8.52 | .02 | 38.0 | 11.5 | 5.22 | 250 | 9400 | 14300 | 3500 | 8750 |
| | 4 | .4 | 474 | 2.4 | 1270 | 9.52 | 1.6 | 377. | .001 | 405 | 575 | 26.3 | 2170 | 6.14 | .03 | 3.89 | 12.3 | 4.77 | 240 | 9100 | 14600 | 3650 | 8600 |
| | 5 | .9 | 543 | 2.4 | 1300 | 4.88 | 1.6 | 362 | .001 | 334 | 522 | 24.2 | 2050 | 5.87 | .02 | 3.38 | 9.34 | 3.03 | 190 | 9100 | 13500 | 3340 | 9080 |
| 10-15 ft | 1 | 1.0 | 6.53 | 5.59 | 3340 | 6.05 | 2.7 | 189 | .001 | 324 | 438 | 21.5 | 1910 | 2.64 | .023 | 24.7 | 3.20 | .87 | 316 | 7830 | 12700 | 2340 | 2390 |
| | 2 | 1.3 | 2.62 | 6.19 | 4790 | 6.21 | 1.47 | 305 | .001 | 231 | 512 | 26.5 | 1920 | 3.14 | .029 | 22.4 | 2.43 | .55 | 302 | 8950 | 15800 | 2540 | 2080 |
| | 3 | .8 | 248 | 5.27 | 1850 | 6.80 | .72 | 435 | .001 | 345 | 526 | 25.4 | 2050 | 2.93 | .033 | 21.3 | 14.4 | 2.63 | 388 | 11800 | 14400 | 3150 | 5170 |
| | 4 | .94 | 365 | 7.25 | 1240 | 6.02 | .67 | 351 | .001 | 311 | 512 | 23.3 | 2070 | 2.96 | .029 | 30.5 | 9.59 | 2.90 | 390 | 11700 | 12800 | 3330 | 8750 |
| | 5 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| 15-20 ft | 1 | .8 | 48 | 5.53 | 1690 | 6.60 | 7.99 | 325 | .001 | 308 | 387 | 19.2 | 1700 | 2.64 | .026 | 16.7 | 6.97 | .87 | 288 | 7330 | 11100 | 2270 | 3230 |
| | 2 | .7 | 277 | 8.4 | 1690 | 7.09 | 10.00 | 393 | .001 | 325 | 505 | 23.9 | 1970 | 3.24 | .026 | 26.3 | 9.77 | 3.72 | 359 | 10300 | 13700 | 3030 | 5630 |
| | 3 | .68 | 471 | 4.94 | 1210 | 8.10 | 5.03 | 383 | .001 | 260 | 578 | 25.5 | 1950 | 3.69 | .026 | 35.5 | 9.16 | 4.88 | 345 | 11000 | 14400 | 3430 | 8020 |
| | 4 | .63 | 435 | 4.0 | 1240 | 6.45 | 3.35 | 366 | .001 | 391 | 555 | 25.2 | 2190 | 3.11 | .03 | 34.7 | 8.72 | 3.42 | 374 | 12200 | 13800 | 3560 | 8680 |
| | 5 | 1.41 | 421 | 4.82 | 1170 | 6.23 | 2.23 | 361 | .001 | 324 | 547 | 25.0 | 2120 | 3.18 | .029 | 34.0 | 8.39 | 2.98 | 403 | 13100 | 13600 | 3530 | 9790 |
| 20-25 ft | 1 | .8 | 229 | 4.6 | 1560 | 5.70 | 1.17 | 325 | .001 | 242 | 370 | 18.3 | 1680 | 2.04 | .04 | 24.9 | 7.09 | 1.60 | 302 | 8650 | 10100 | 2460 | 4050 |
| | 2 | .68 | 338 | 3.52 | 1470 | 6.87 | 1.99 | 379 | .001 | 298 | 475 | 22.1 | 1920 | 3.14 | .038 | 29.5 | 8.80 | 4.29 | 374 | 10800 | 12500 | 3000 | 6440 |
| | 3 | .65 | 443 | 7.44 | 1320 | 7.36 | 1.47 | 365 | .001 | 385 | 554 | 24.9 | 2220 | 2.62 | .033 | 38.2 | 8.66 | 3.63 | 402 | 12400 | 13900 | 3620 | 9020 |
| | 4 | 1.42 | 440 | 5.5 | 1240 | 8.07 | 1.55 | 363 | .001 | 355 | 564 | 24.9 | 2170 | 3.39 | .029 | 38.3 | 8.60 | 3.52 | 331 | 11700 | 13900 | 3590 | 8420 |
| | 5 | 1.42 | 401 | 6.39 | 1120 | 7.36 | 1.27 | 341 | .001 | 288 | 527 | 23.3 | 1900 | 2.72 | .027 | 34.2 | 7.91 | 3.16 | 316 | 12100 | 12900 | 3280 | 9430 |
| 25-30 ft | 1 | .7 | 310 | 4.98 | 1360 | 6.32 | 1.71 | 312 | .001 | 256 | 395 | 18.7 | 1710 | 2.90 | .037 | 29.2 | 7.41 | 2.62 | 287 | 9660 | 10300 | 2610 | 5490 |
| | 2 | .6 | 359 | 5.83 | 1290 | 6.48 | 1.52 | 345 | .001 | 304 | 452 | 20.9 | 1880 | 2.78 | .034 | 31.7 | 7.92 | 3.70 | 330 | 11000 | 11700 | 2950 | 6970 |
| | 3 | .61 | 449 | 6.0 | 1280 | 7.06 | 1.27 | 359 | .001 | 372 | 544 | 24.2 | 2180 | 2.94 | .029 | 38.4 | 8.41 | 3.36 | 359 | 12500 | 13500 | 3560 | 9120 |
| | 4 | 1.42 | 443 | 5.37 | 1210 | 8.02 | 1.56 | 361 | .001 | 365 | 552 | 24.4 | 2140 | 3.87 | .028 | 38.4 | 8.63 | 3.36 | 359 | 12600 | 13600 | 3540 | 9170 |
| | 5 | 1.43 | 417 | 6.39 | 1190 | 8.36 | 1.79 | 352 | .001 | 307 | 555 | 24.4 | 1970 | 3.38 | .027 | 35.1 | 8.47 | 3.36 | 345 | 11900 | 13600 | 3420 | 9300 |
| 30-35 ft | 1 | .85 | 304 | 6.56 | 1480 | 8.35 | 4.02 | 313 | .001 | 301 | 393 | 18.3 | 1660 | 3.40 | .03 | 27.9 | 7.78 | 2.29 | 288 | 8660 | 10200 | 2530 | 4400 |
| | 2 | .63 | 419 | 8.58 | 1300 | 8.01 | 2.82 | 370 | .001 | 302 | 509 | 22.8 | 1880 | 3.64 | .029 | 33.5 | 8.75 | 4.61 | 345 | 11500 | 12800 | 3130 | 7340 |
| | 3 | .57 | 421 | 7.08 | 1230 | 7.93 | 1.71 | 358 | .001 | 312 | 540 | 23.7 | 2010 | 3.74 | .028 | 35.3 | 8.40 | 3.72 | 331 | 12300 | 13200 | 3390 | 8960 |
| | 4 | .64 | 408 | 8.41 | 1300 | 7.74 | 1.45 | 348 | .001 | 391 | 540 | 23.5 | 2200 | 3.74 | .027 | 35.0 | 8.07 | 3.28 | 330 | 12700 | 13200 | 3560 | 9400 |
| | 5 | 1.06 | 415 | 7.27 | 1210 | 8.61 | 1.93 | 352 | .001 | 366 | 553 | 24.0 | 2150 | 3.38 | .031 | 35.5 | 8.56 | 3.29 | 359 | 12800 | 13400 | 3530 | 9390 |

NA - Not available.

Technology of Gypsum, ASTM STP 861, R. A. Kuntze, Ed., American Society for Testing and Materials, 1984, pp. 116-139.

Rosler, H. J. and H. Lange, Geochemical Tables, Table 150 - Chemical Composition of Rainwater, Elsevier Publishing Company, New York, 1972, pp. 437.

Staff, Bureau of Mines, The Florida Phosphate Slimes Problem, BuMines IC 8668, 1975, 41 pp.

Standard Specifications for Transportation Materials and Methods of Sampling and Testing, Part II TESTS, 13th Edition, American Association of State Highway and Transportation Officials, Washington, DC, 1982, pp. 771-776.