PREDICTION AND CONTROL OF ACID MINE DRAINAGE, EFFECTS OF ROCK TYPE AND AMENDMENT

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ABSTRACT

Prediction and quantification of acid mine drainage (AMD) from a given rock unit is in its infancy. Acid Base Accounting is the current procedure. It is a useful screening procedure and is designed to indicate whether a rock unit will or will not produce acid. In this sense, Acid Base Accounting is qualitative. Researchers at West Virginia University are developing a prediction method to estimate how much acid will be produced over the life of a rock unit's AMD production. The AMD prediction procedure can also evaluate the required rates and effectiveness of various AMD control amendments. This presentation discusses the WVU AMD prediction procedure in the context of historical approaches and indicates the mechanics and applications of this new technology.

INTRODUCTION

One of the enduring problems for the coal mining industry in the northern Appalachian basin has been the accurate prediction of acid mine drainage (AMD) from a particular property. This is necessary information as it significantly impacts the ultimate economics of the development. Nonetheless, presently applied technology for AMD prediction permits only very crude evaluations of the problem. As a consequence many developments are initiated with no clear idea as their long-term liabilities. Perhaps more significantly, many developments, in the absence of a reliable planning tool, create unnecessary problems.

Acid base accounting is the currently applied AMD prediction technology. It was developed to assist regulatory and industrial personnel estimate the acid producing potential of overburden prior to mining. The procedure has a number of shortcomings. It tends to underestimate AMD potential, it is subject to a wide variety of interpretations and not the least problematic is the sampling effort required to achieve reliable estimates of in situ pyrite and neutralizing capacity.

It may prove that emphasis on overburden characterization has been misplaced. This statement prepares the two primary hypotheses (and we stress HYPOTHESES) of this presentation:

1. Even in acid prone areas, spoils only produce AMD for a period of 15 to 20 years before produced water falls within compliance.
2. Pyritic refuse, roof rock and partings, unless inundated, can produce AMD on a timescale of centuries.

The Surface mining control and reclamation act of 1977 does not specifically distinguish mine spoil and coal cleaning plant refuse. Refuse is produced in a ratio of about 0.20 to 0.40:1 ton of clean coal. Mine spoil, on the other hand, results from surface mining operations and consists of cast overburden rock. It is a high volume material, produced at a rate of perhaps 5: 1 to 12: 1 ton of raw coal. While many strata are capable of producing acidity, much of the overburden volume which comprises spoil piles are neutral to slightly alkaline and contribute little to the formation of acid mine drainage (AMD).

Earlier work by Renton, et al. (1988) and Rymer, et al. (1988) described the Soxhlet Extraction procedure coupled with the SSPE/PSM model for predicting the acid producing potential of various refuse types. The model was verified against a series of northern West Virginia refuse piles and a high degree of fit was achieved between the model prediction and the observed AMD production rate. Stated simply, the characteristic AMD production curve for refuse rises sharply for between 5 and 9 years, declines sharply for similar period until leveling off at a production rate far in excess of compliance levels.

However pessimistic, this prediction has been supported by subsequent observations. Fortunately, refuse is a relatively low-volume material. Thus, our focus on further refuse research has been on treating it such that it does not produce AMD (e.g. phosphate treatment).

Many predominantly spoil dumps are strong, long-term AMD producers. With few exceptions, however, these dumps have also been used for disposal of refuse or similar materials such as partings and pit cleanings (hereinafter referred to as refuse) . Data produced by Schueck (1990) and Ackman (1990) have consistently pinpointed refuse piles within problematic AMD producing spoils.

Systematic evaluation of the AMD production for spoil vs. refuse is currently underway at West Virginia University. However, early results suggest that after less than 20 years spoil dumps, even those associated with major AMD problems, often produce water which is in compliance with regulations. The AMD production curves for these materials initially resemble those for refuse with peaks around year seven. In contrast with refuse, however, the decline in AMD production appears to continue downward rather than level out. Results of long-term monitoring of spoil and refuse sites reported by Meek (1991) support these findings.

These hypotheses, if proven correct, would have significant implications. Given success with phosphate, continuous water treatment may not be necessary at all.

The objective of this presentation is to describe a means of predicting the cost of a new mining operation in West Virginia with respect to AMD and associated treatment costs.

THE PROCEDURE

Following is a description of how the procedure would be applied to a new mining operation, one which is still in the planning stage. The procedure consists of three components:

1. IDENTIFY AMD PRODUCING ROCKS in the overburden and refuse. This is done by examining cores, taking samples of representative lithic units and subjecting them to accelerated weathering cycles in the laboratory. Simulated refuse can be obtained from conventional float-sink tests. This step identifies which rocks units require special attention.
2. APPLY THE SSPE/PSM MODEL to the resulting data indicating the duration of AMD production expected from each type material.
3. IDENTIFY REQUIRED AMOUNTS OF PHOSPHATE. AMD producing rock units identified in steps 1 and 2 are then treated with rock phosphate or other amendments in the laboratory and subjected to accelerated weathering. This task identifies the cost of controlling AMD in each of the problematic rock units.

Through this process the cost of controlling AMD production can be estimated with reasonable reliability. Three outcomes are possible:

A. Acid producing rock is widely disseminated through the overburden.
B. Acid producing rock is concentrated in the refuse.
C. No significant AMD is produced from any of the rock units.

If outcome A pertains then it is unlikely that it will be possible to handle the overburden so as to prevent AMD production. if outcome B is indicated then refuse can be treated with rock phosphate or another amendment as it leaves the prep plant on the conveyor belt. Outcome C needs no explanation.

THE SSPE/PSM MODEL FOR PREDICTING AMD

A mathematical model (SSPE/PSM) has been developed that relates AMD production and elimination rates and provides valuable insight into the long range behavior of refuse sites. The model predicts such field information as AMD producing longevity and water quality predictions. Two input variables are needed for the model: alpha, the oxidation rate constant for rock's pyrite and beta, the rate at which acid forming salts leach from the rock.

A project was funded in 1985 that allowed several refuse sites to be examined for water effluent chemistry in order to test the SSPE model. Due to the random nature of this field data direct formulation and regression techniques originally planned to calculate the beta value were of no use. Another technique had to be employed. Probability simulation, where a generation-discharge scenario could be simulated and brought under the governing principle of the Bateman equation was devised. This technique employed probability distributions of field data and utilized queue theory to simulate the sulfate ion generation-elimination phenomenon. This technique became known as PSM (Probability Simulation Modeling) . The end result was a technique known as SSPE/PSM modeling. Table 1 summarizes the results of one such prediction.

Table 1. Projected change in AMD from a northern West Virginia refuse pile generated by application of SSPE/PSM. The predictions and observed changes in water quality are given in ppm.

AMD PREDICTION USING SSPE/PSM

IONIC SPECIES	1982 OBSERVED	PROJECTED CHANGE	1985 OBSERVED	OBSERVED CHANGE
SULFATE	940	+80	1030	+90
IRON	58	0	48	-10
MANGANESE	0.5	0	0.4	-0.1
ACIDITY	510	+80	575	+65

Important points:

1. SSPE/PSM was developed for prep plant refuse disposed of in mountain top removal operations.
2. SSPE/PSM was tested only on eight refuse sites in northern WV. It needs to be tested with equal rigor on both spoil and refuse sites.
3. SSPE/PSM was developed for a single point source discharge scenario. It can be modified to include multiple discharge points. Although developed for existing refuse piles the technique has been modified to handle a "start from scratch" sequence.
4. SSPE/PSM was the first model developed for an AMD production-elimination scenario that was able to utilize "chaotic" field data and produce a field parameter (beta) that describes the system.
5. Field observations (peak ion concentration 8-12 years) are predicted by SSPE/PSM.

More recent applications of the AMD prediction procedure have evaluated long term performance on different types of spoil as well as treated refuse. The results indicate that acid producing sandstone is capable of significant AMD production but that the term of production is short. Sandstones are expected to complete their AMD producing lives within 14 to 25 years. Shales appear to be intermediate between sandstone and refuse, expending their AMD within 20 to 40 years. Refuse (including all shales in direct contact with the coal), as expected, continues to produce significant AMD over periods in excess of 60 years. Figure- 1 indicates the rate at which refuse is expected to produce AMD. The figure is calibrated in gallons of 20% NaOH required to neutralize the AMD from an acre foot of the rock unit over a 6 month period. Figure 2 indicates the AMD production from spoil shale and sandstone. All of these rocks are from the Kittanning sequence of the Allegheny Formation in north-central West Virginia.

In order to verify these predictions comparisons were made against a 12 year data base assembled at a mine in the same geologic sequence (Meek, 1991). Figure 3 is an overlay of these field observations and an SSPE/PSM prediction for the same rock. SSPE/PSM predicts peak AMD production earlier than observed but most observations fall on the prediction line. If these trends prove to be valid then a finite term for AMD production from spoil rock units can be estimated along with the total cost of water treatment.

The prediction procedure might also be used to estimate the effects of combining refuse types from different coal seams as might occur in a multiple seam mining operation. Figure 4 indicates AMD production over a 20 year period for a hypothetical mixture containing proportions refuse derived from the middle Kittanning, lower Kittanning, upper Clarion and lower Clarion seams.

From a regulatory perspective, it would suggest that AMD production and treatment be factored into the cost of the operation and that, to the extent possible, spoil dumps be kept free of refuse and that they be designed so as to drain into planned, central AMD treatment facilities. These facilities could then be scaled to meet the be needs of the drainage over the life of the operation, rather than added as an emergency response to unexpected AMD flows.

TREATMENT OF REFUSE TO PREVENT AMD

For the purposes of this presentation, refuse is considered all of the carbonaceous shales in immediate contact with coal. In surface mines these are called pit cleanings, rider coal or rash. In addition, the pit floor or seatearth is often a strong acid producer. In underground mining a good deal of the roof rock, seat earth and about 60% of the parting shales end up in the refuse pile at the prep plant. The remainder stays below ground in the unmined pillars, roof and floor rock according to the specific mine conditions. Unless permanently flooded, these carbonaceous shales which remain exposed underground will produce AMD indefinitely. Unlike spoil we cannot expect any pyritic refuse to stop producing AMD any time soon.

Figure 1. Predicted rate of AMD production from a northern West Virginia coal refuse. The Y axis is calibrated in gallons of 20% NaOH required over a 6 month period to neutralize the acidity generated by one acre-foot of rock.

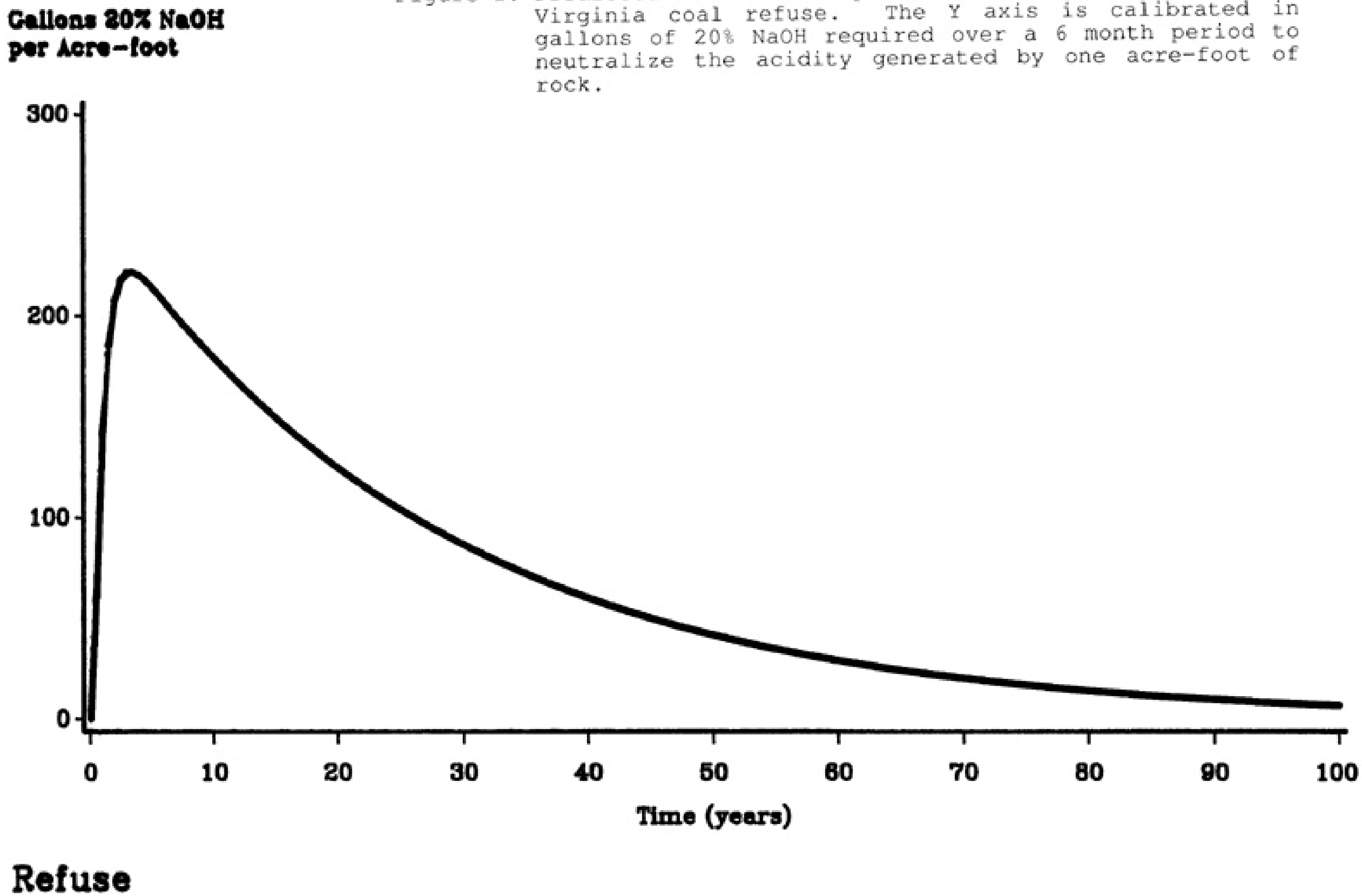


Figure 2. Predicted rate of AMD production from a northern West Virginia sandstone and shale. The Y axis is calibrated in gallons of 20% NaOH required over a 6 month period to neutralize the acidity generated by one acre-foot of rock.

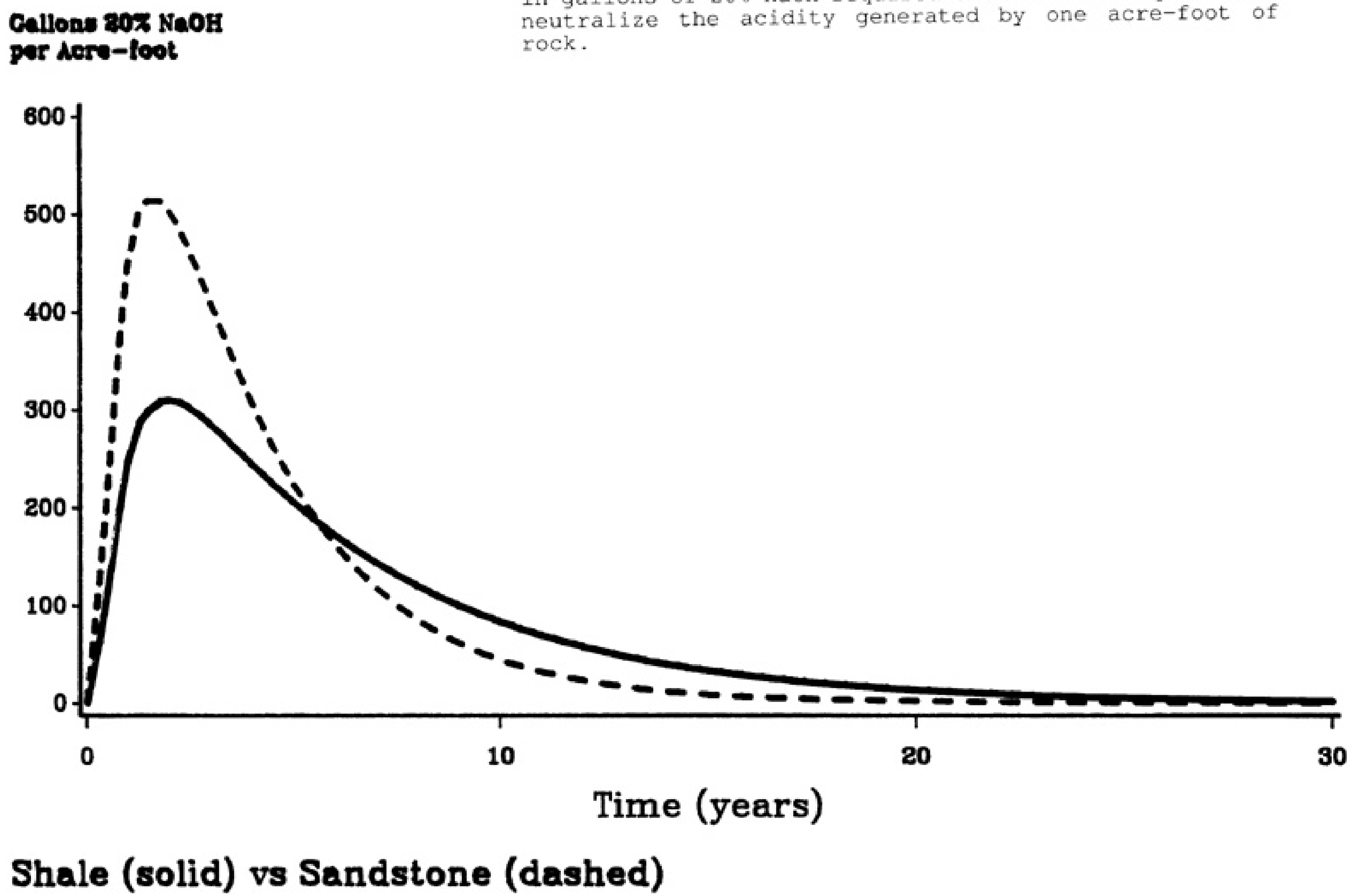


Figure 3 Predicted rate of AMD production from a northern West Virginia spoil (dotted line). The bells represent field observations.

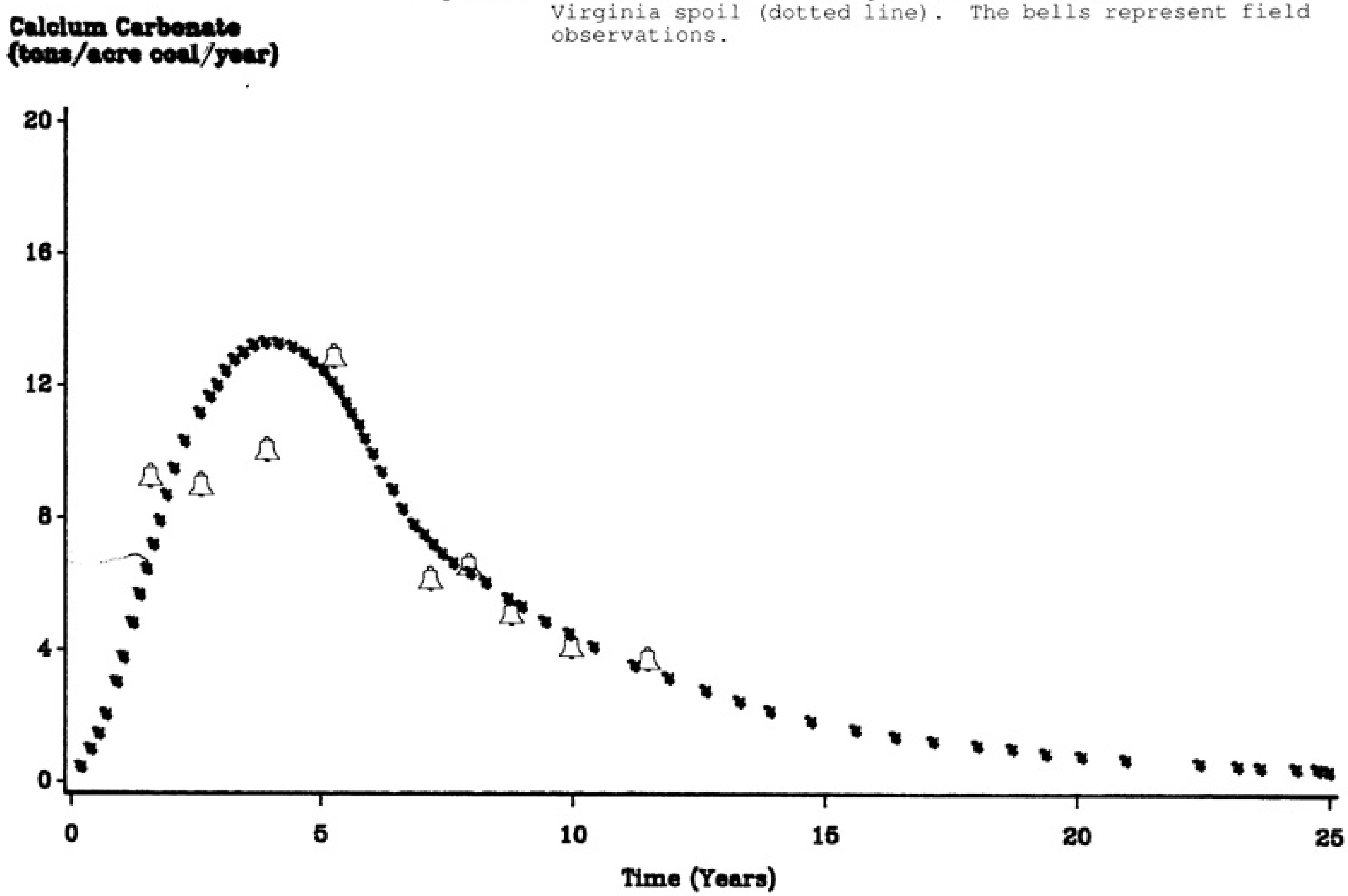
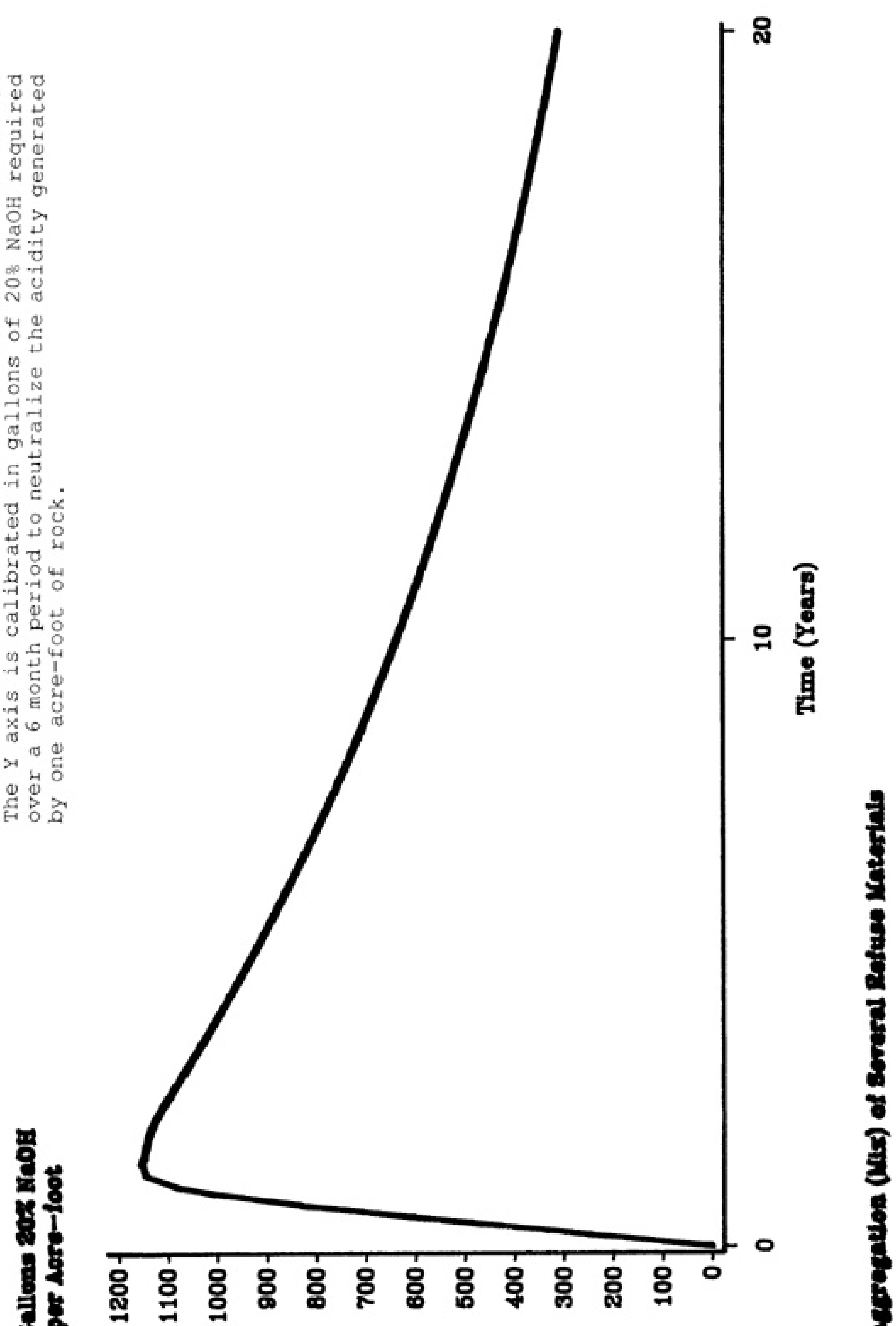


Figure 4. Predicted rate of AMD production from a composite West Virginia refuse derived from four different coal seams. The Y axis is calibrated in gallons of 20% NaOH required over a 6 month period to neutralize the acidity generated by one acre-foot of rock.



The WVU AMD prediction procedure permits evaluation of potential AMD ameliorants. Ameliorant in this sense indicates any material which, when added to the refuse will prevent AMD from leaving the pile. Ameliorants come in two basic types: neutralizing agents and oxidation controllers. Phosphate is regarded as an oxidation controller whereas lime is considered a neutralizer. Certain coal combustion ashes, may have mixed properties. Figure 5 shows the effect of commercial grade rock phosphate on AMD production when added to a southern West Virginia refuse at rates of 0, 2, 3, 4%. The results indicate a strong reduction in AMD with the best performance at 3%. Commercial grade rock phosphate costs about $50/ton at the phosphate mine. Phosphate waste rock, also produced at the same site sells for about $5/ton. Figure 6 shows the performance of phosphate waste rock when applied to the same coal refuse. Again, the 3% application rate yields the best results.

Phosphate, however, may not be effective on all types of refuse. Figure 7 indicates the effect of 0, 2, 3, 4% additions of commercial grade phosphate on a coal refuse from Kentucky. This refuse is particularly reactive. Even the 4% application rate failed to prevent AMD production. In addition to phosphate the same refuse was treated with the same amounts of an ash from a Circulating Fluidized Bed Combustion (CFBC) unit operated by a Northeastern Utility. Like most CFBC ash this one was rich in CaO. It was expected to delay AMD production until the CaO reacted and leached out of the refuse at which time AMD generation was expected. However, Figure 8 suggests that the response to CFBC ash is similar to that of phosphate. Continuing studies are underway to verify these results.

APPLICATION OF THE WVU AMD PREDICTION PROCEDURE

Following is an outline indicating how the procedure would be applied to a specific problem.

The procedure consists of three primary tasks:

1. IDENTIFY AMD PRODUCING ROCKS
2. APPLY THE SSPE/PSM MODEL
3. IDENTIFY REQUIRED AMOUNTS OF PHOSPHATE.

Each will be discussed below in detail.

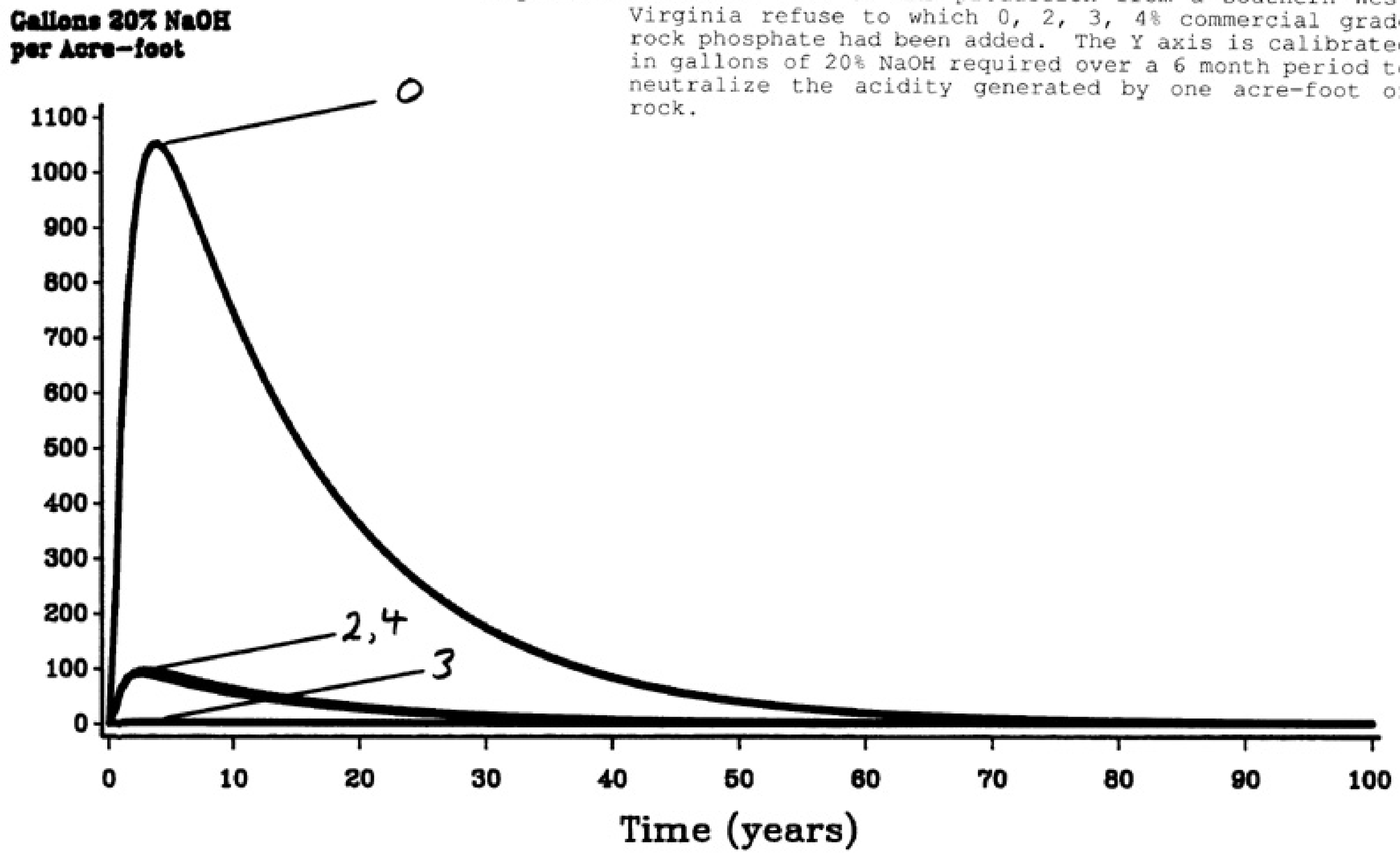


Figure 5. Predicted rate of AMD production from a southern West Virginia refuse to which 0, 2, 3, 4% commercial grade rock phosphate had been added. The Y axis is calibrated in gallons of 20% NaOH required over a 6 month period to neutralize the acidity generated by one acre-foot of rock.

Phosphate (Code 31)

Figure 6. Predicted rate of AMD production from a southern West Virginia refuse to which 0, 2, 3, 4% phosphate waste rock had been added. The Y axis is calibrated in gallons of 20% NaOH required over a 6 month period to neutralize the acidity generated by one acre-foot of rock.

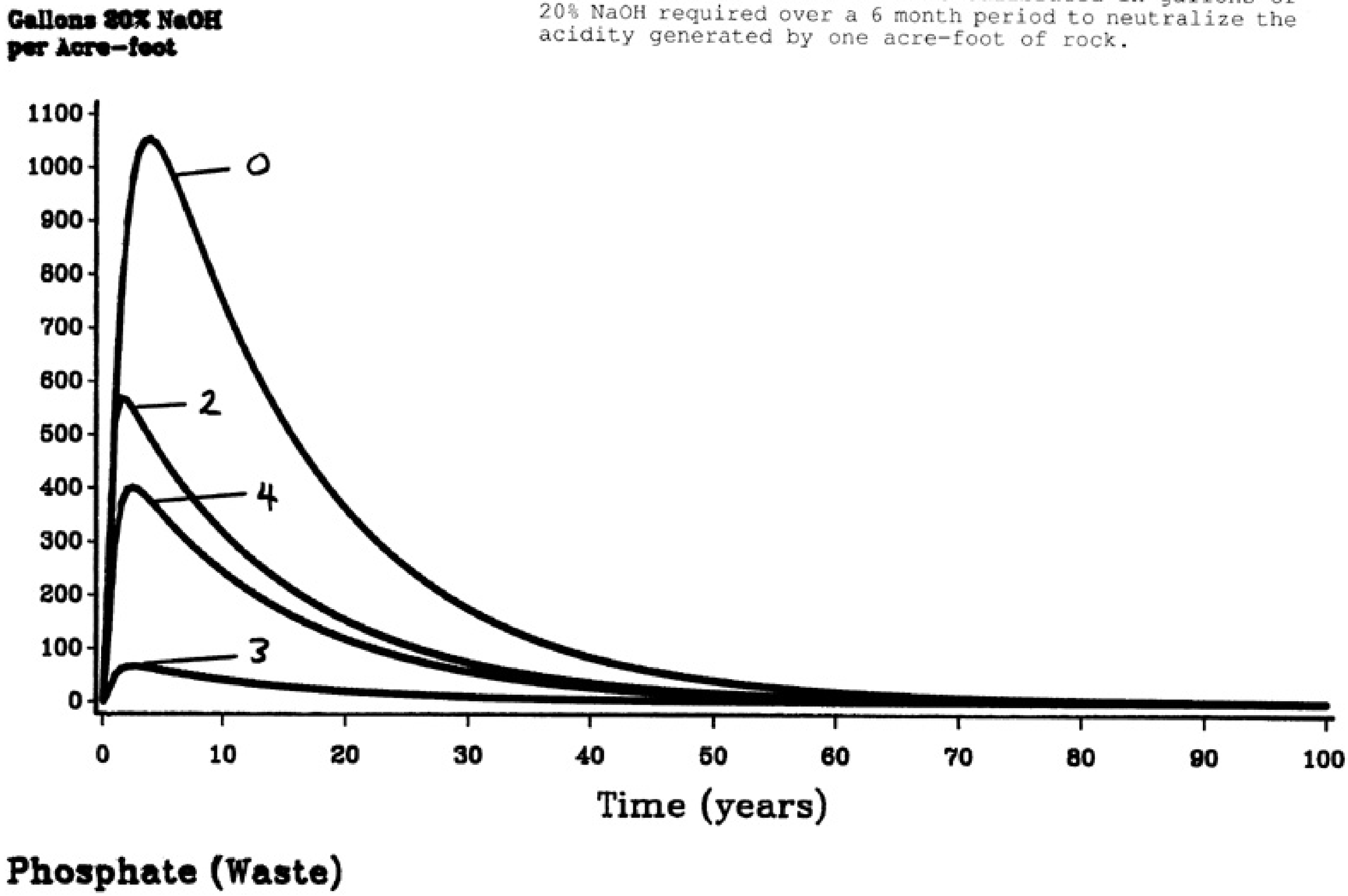
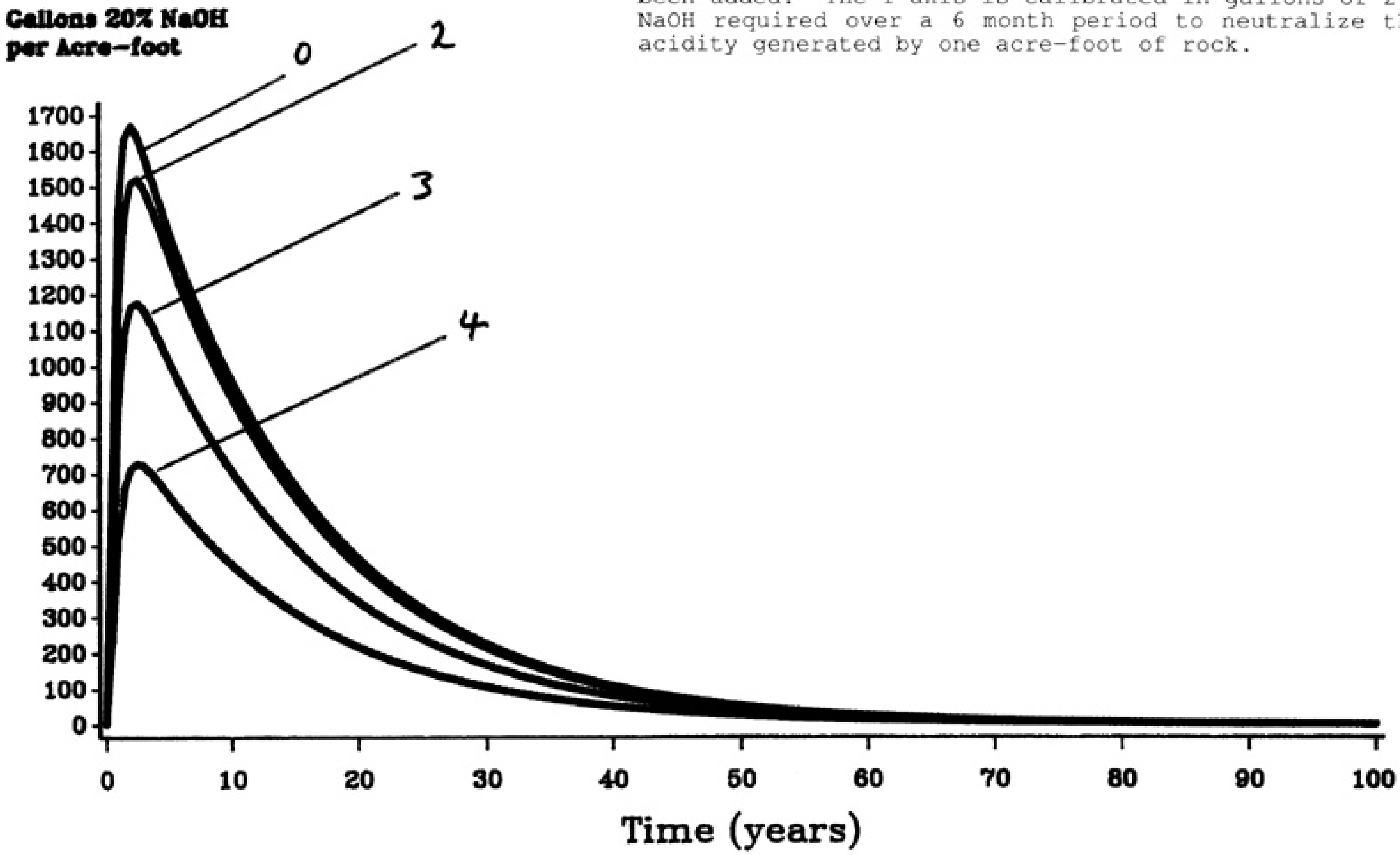
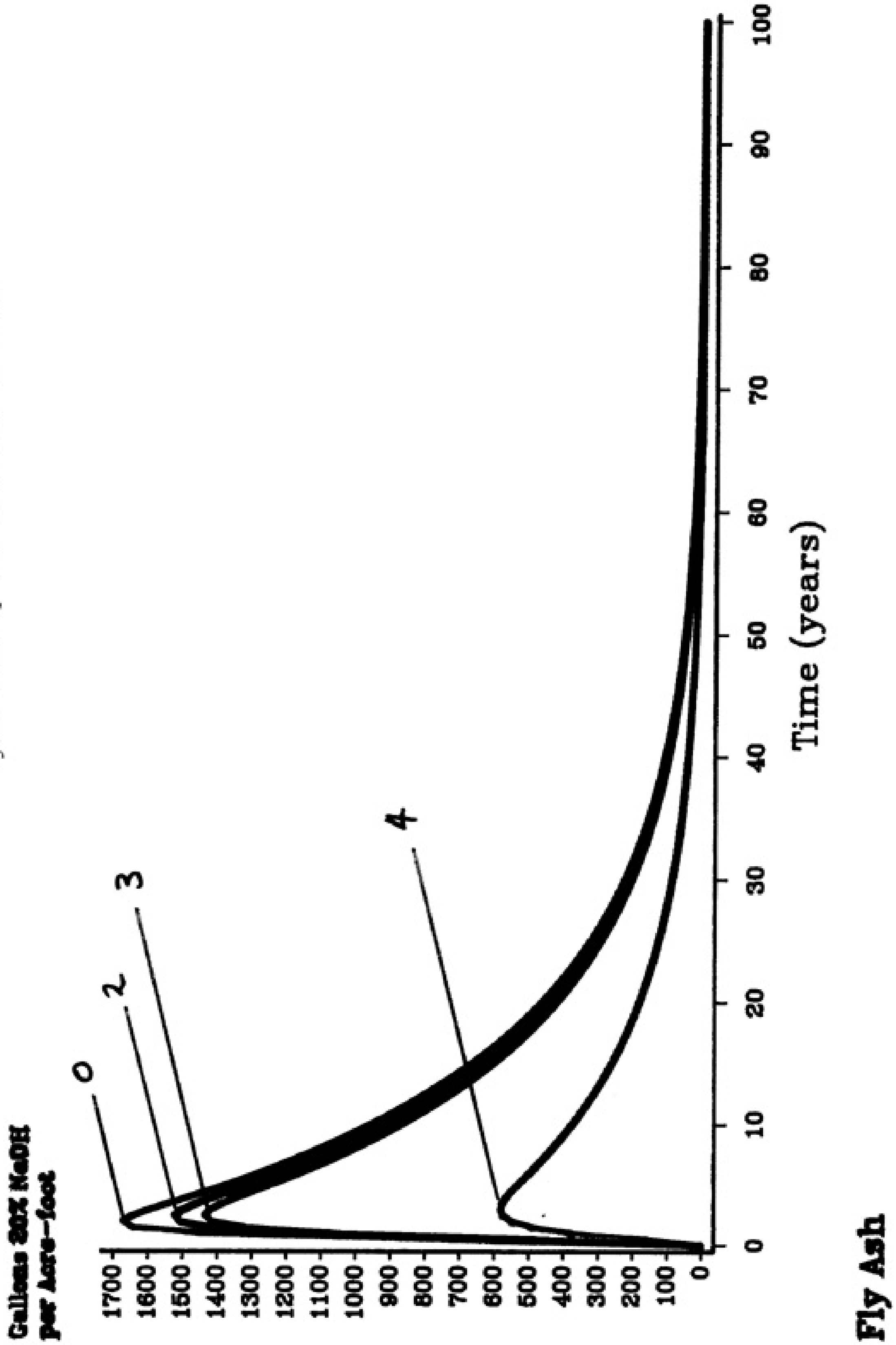


Figure 7. Predicted rate of AMD production from a Kentucky refuse to which 0, 2, 3, 4% commercial grade rock phosphate had been added. The Y axis is calibrated in gallons of 20% NaOH required over a 6 month period to neutralize the acidity generated by one acre-foot of rock.



Phosphate (Code 31)

Figure 8. Predicted rate of AMD production from a Kentucky refuse to which 0, 2, 3, 4% Circulating Fluidized Bed Combustion ash. The Y axis is calibrated in gallons of 20% NaOH required over a 6 month period to neutralize the acidity generated by one acre-foot of rock.



TASK 1. IDENTIFY AMD PRODUCING ROCKS in the overburden and refuse. This is done by classifying the various lithic units and identifying which are expected to be prone

to acid generation. Lithic unit classification is carried out by a geologist and it is based on examination of cores collected by the Company from the proposed property. Cores are collected and key lithic units are extracted for processing. In addition, simulated refuse can be obtained by the Company by washing the various coal measures in float/sink tests. The resulting simulated refuse and lithic units previously identified as potentially acid producing are subjected to accelerated weathering trials in the laboratory. This generates a reaction rate constant for each of the subject rock units which will serve as the alpha input variable in the SSPE/PSM model. This step identifies which rocks require special attention in the mine planning process.

The soxhlet extraction process takes ten weeks and samples are run in triplicate. Experience has shown that after this period all of the rock's pyrite has been oxidized and all of the weathering products have been leached out of the samples.

TASK 2. APPLY THE SSPE/PSM MODEL to the data resulting from Task 1. The model will indicate the amount, duration of quality of AMD production expected from each lithic unit. It requires only two input variables: Alpha, the reaction rate constant and beta, the leaching efficiency for a particular rock type.

Alpha is obtained in the previous step. Beta values are available for northern West Virginia refuses from previously studies. Beta values have been estimated for the various spoil types identified as having significant acid producing potential.

The SSPE/PSM model is on line at the West Virginia University Geology Department. The model operates on the Geology Department's VAX computer.

TASK 3. IDENTIFY REQUIRED AMOUNTS OF AMENDMENT. Phosphate application to refuse has been successful in laboratory soxhlet extraction trials, in outdoor 45 gallon drums over a period of five years and in outdoor 350 ton test piles. A series of 15,000 ton mine-scale field tests is presently under construction. Nonetheless phosphate technology cannot be said to be operationally tested and proven as yet. It is, nonetheless, the most attractive alternative for prevention of AMD in coal refuse. Phosphate is probably not the only material which could control AMD production. Alternatives can also be evaluated at this stage.

AMD producing rock units will be treated with rock phosphate in the laboratory and subjected to accelerated weathering. This task will identify the cost of controlling AMD in each of the problematic rock units.

Prior to proceeding with this step the research team will meet with Company representatives to discuss implications of the findings of Task 2 with respect to the mine planning process. For example, it will be possible to estimate the nature and complexity of the AMD which will be generated by the various rock units. It is expected that refuse will be the primary source for long term AMD production and the rock unit most likely to require special attention.

SUMMARY

Several technologies are emerging which have the potential to significantly improve our ability to quantify the extent of AMD hazard on a particular site and to identify the costs associated with treating resulting AMD. These technologies are still being developed and verified. In addition, alternative prediction methods are actively being developed and evaluated. The illustrations given in this presentation are primarily intended to show the potential applications of the prediction procedure. Most have yet to be rigorously verified.

Nonetheless, to the extent that comparisons have been made between field observations and predictions, the predictions achieved by the procedure have been encouraging.

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