PROCEEDINGS

of the

ILLINOIS MINING INSTITUTE

FOUNDED FEBRUARY, 1892

Ninety-Second Year

1984

Annual Meeting
SPRINGFIELD, ILLINOIS
October 4-5, 1984

JAMES D. CHADY

PRESIDENT, 1983-84

THE COAL MINER

True — he plays no grandstand role in life
But his importance is vital, great and just:
For without his toil in earth's caverns deep,
Civilization would soon crumble into the dust.
AD 1964 From his poem — Vachel Davis

(Dedicated on State Capitol Lawn, Springfield, Illinois, October 16, 1964)

IN MEMORY

of

All Deceased Members

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1963-64	E. T. MORONI, Old Ben Coal Corp., Benton, IL.
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1967-68	JOSEPH CRAGGS, Peabody Coal Co., Taylorville, IL.
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1970-71	R. F. DONALDSON, United Electric Coal Cos., Chicago, IL.
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1979-80	CHARLES E. BOND, Consolidation Coal Co., Springfield, IL.
1980-81	WALTER S. LUCAS, Sahara Coal Co., Inc., Harrisburg, IL.
1981-82	JACK A. SIMON, Illinois State Geological Survey, Urbana, IL
1982-83	H. ELKINS PAYNE, AMAX Coal Company, Indianapolis, IN
1983-84	JAMES D. CHADY, Old Ben Coal Company, Benton, IL

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PROCEEDINGS OF THE ILLINOIS MINING INSTITUTE

Ninety-Second Annual Meeting

Springfield, Illinois

Thursday and Friday, October 4-5, 1984

OPENING SESSION

The opening session of the 92nd Annual Meeting of the Illinois Mining Institute convened at 2:00 p.m., Thursday, October 4, 1984 in the Ford Room of the Holiday Inn East. James D. Chady, President of the Institute presided.

President Chady: The film entitled "To Catch a Cloud," which had been scheduled to be shown, is not available. The film that will be presented instead is entitled "Geology Is . . ." Dave Reinertsen will give you a little background on it.

Dave Reinertsen: The film was produced by the University of Illinois a number of years ago, and it tells something about the geologic make-up of Illinois. After we get beyond the animated portion of it we get a chance to see different parts of Illinois, some of the mineral industries in the state and, of course, the minerals that are produced and used by the citizens. There are some maps that will show where those particular mineral industries are located in the state. You will also find that there is some split image photography in the film, so there are some times when there are two or more things going on at the same time.

President Chady: On behalf of the Illinois Mining Institute and its officers, I would like to welcome you to the 92nd annual Institute meeting. I am Jim Chady, acting as your president this year, and I am very pleased that you so honored me. I have a few business announcements to make before we get into the technical sessions.

John Wooten of Peabody Coal Company will be our luncheon speaker, and he will discuss issues related to acid rain and how some of the potential problems arising from the proposed legislation will affect the coal mining industry. I am sure you are all aware that this evening at 5:30 to 7:30 in the Holidome we will have a fellowship hour.

The business meeting tomorrow is at 8:15, which is somewhat earlier than it has been in other years because of the long technical session. I think it's important that all of you try to make it to the business meeting as the Institute is in somewhat of a financial problem. The Executive Board has tried to come up with some ideas to keep us solvent in the oncoming years.

I think we have a very fine technical program for you this afternoon, and I would like to turn the meeting over to George May, General Manager of Monterey Coal Company of Carlinville for the remainder of the technical program. George.

George May: I, like Jim, also wish to welcome you to this session this afternoon. I believe you can see by the agenda, which you were given, that we have four very interesting papers. What I want to ask is that if you have any questions after the paper is given, will you please go to the microphones in the center of the aisle. The proceedings for these sessions are being recorded, and we want to get all questions recorded. Our first paper this afternoon is by Christopher T. Ledvina. Christopher has a Bachelor of Science degree in geology from the University of Illinois and a Master of Science degree in geology from Northeastern Illinois University. He has been associated with the Illinois State Geological Survey and has worked with Freeman United Coal Company as Assistant Superintendent. At the present time he is on leave from Old Ben Coal Company. The title of Christopher's paper is "Uses of Image Analysis in the Mining and Geological Sciences".

Christopher T. Ledvina: Thank you Mr. Chairman, thank you fellow members.

USES OF IMAGE ANALYSIS IN THE MINING AND GEOLOGICAL SCIENCES

CHRISTOPHER T. LEDVINA
Old Ben Coal Company (on leave)
Benton, Illinois

INTRODUCTION

What is image analysis? Image analysis is a fast, accurate, all-electronic technique that can be used to determine the surface area of objects or features represented on two-dimensional surfaces. Sources of material for image analysis include surface maps, contour maps, mine maps, photographs, and other types of flat-work. Image analysis can also be used to determine areas from microscopic flat-work such as microscope slides, thin sections, and polished sections.

Image analysis is not new; the technique has been around in one form or another for at least twenty years. It has not, however, found broad applications in the fields of mining or geology; fields in which it could have a large number of applications. The technique also is not a "computer" technique, although it does lend itself well to computerization.

Why is it important to determine areas? Maps or photographs are accurate representations or models of real-life situations. If we can measure areas on these representations, we know their real areas simply by multiplying by a scale factor. Suppose we had a surface quadrangle map of some area. On this type of map, contour lines show the elevation of the land forms and colored areas delineate woods or bodies of water. If we are able to read areas from this type of map, we could find the number of acres at a certain elevation or the number of acres (or square miles) covered by woods or water.

Suppose we had a map of an underground coal mine. If we could read areas accurately from this type of map, we could determine the number of square miles involved in mining operations. If we could read the area occupied by pillars versus the area occupied by entries and cross-cuts, we could find the volumes and tonnages of coal mined or unmined, percent recovery, and even tons of refuse produced.

Using the areas read from maps, plus thickness information, not only is it possible to find various tonnages from individual mines, but it is also possible to calculate coal reserves.

If we had a map showing contour lines of coal thickness, such as one that would result from exploratory drilling, we could easily find the reserves within the map area. We could use image analysis to find the area covered by each contour interval or thickness category. Using these area determinations along with the thickness information and the scale factor of the map, some simple arithmetic yields total tons in the reserve as well as tons in each thickness category.

Area determinations in microscope work are used primarily in petrography. In a thin-section for example, when viewed under polarized light, different mineral species appear as different colored areas. By determining the areas occupied by each mineral species, the composition of the rock (or coal) sample can be determined (Chao, et.al., 1983).

Not only is image analysis uniquely suited to finding areas, but it can be used to count numbers of objects and determine their size distributions. This feature is particularly useful in petrography for determining grain size distributions in samples (Harvey and Steinmetz, 1971). It is also useful in determining pillar size distributions from mine maps.

OPERATION

How does image analysis work? First, let's look at the equipment. At the heart of most image analyzing systems is a television camera (Figure 1). The television camera "sees" the source material and sends a signal to processing and control circuitry. Out of the control unit, areas and counts are indicated on a meter. The control unit also sends a signal to a video monitor that allows the operator to see what's going on. Figure 2 shows what a typical image analyzing system looks like, in this case, it is the one at the Illinois State Geological Survey.

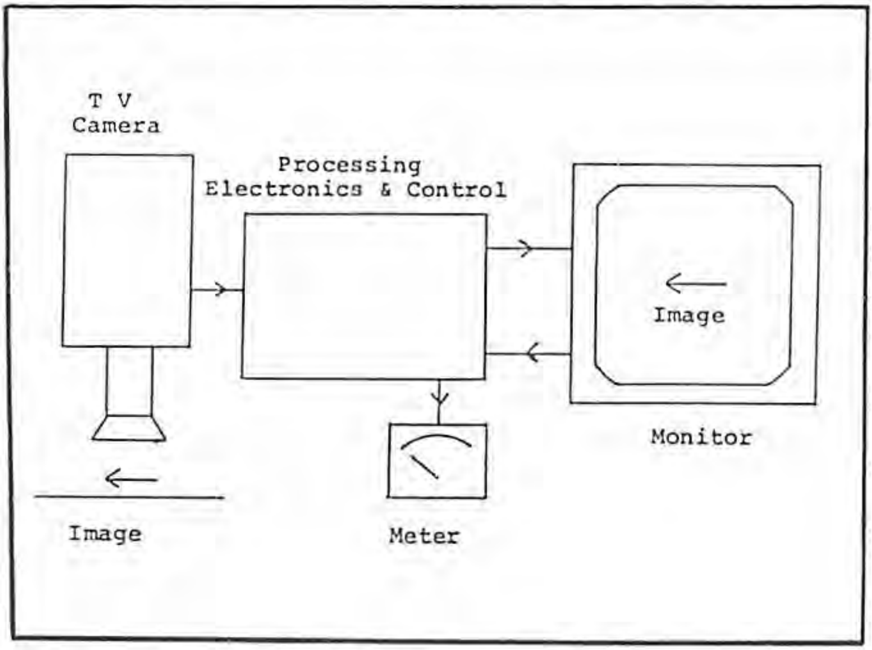

Fig. 1 – Block diagram of image analyzing system.

In area determinations, the analyzer generates and displays a square or rectangular reference image whose dimenstions are fully adjustable. The reference image is superimposed onto the image of the source material (Figure 3). From the scale of the source, we know exactly how much area is covered by the reference (height x width). Unknown areas displayed within the reference occupy some percentage of it's area. Therefore, the area of the unknown equals the percent of area covered by the unknown times the area covered by the reference. The meter on the analyzer is set to equal one hundred percent with the reference image displayed. Controls on the analyzer are then set to display only objects within the reference. The percent of area covered by the objects is then read from the meter. After some simple calculations, the area of the unknown objects is determined simply and accurately.

To prepare material for analysis, some work is usually required. So the TV camera can "see" them, unknown areas or areas of interest must contrast with surrounding areas. In the case of macroscopic work such as maps, if interest areas do not have sufficient contrast, they must be colored or inked in. In microscopic work, interest areas can be high-lighted by staining or illuminating in polarized light. Large work may in some cases have to be subdivided.

Fig. 2 – Image analyzing system at the Illinois State Geological Survey. To the far left is the processing and control unit. The meter, where areas and counts are read, is located in the lower center. The monitor is to the right. The source material is placed on the platform in the upper center.

OTHER METHODS FOR FINDING AREAS

To appreciate the value of image analysis, let's take a brief look at other methods of determining areas. Using a mine map as an example, let's say we wanted to determine the area occupied by pillars versus the area occupied by entries and cross-cuts. We could roll a planimeter around the outline of the pillars and find their area that way. If the mine map was large and the pillars intricate, it would take many tens of hours to find their areas. We could plot points around the pillars using an X-Y digitizer and use a computer to generate grid cells to find areas (Treworgy and Bargh, 1982). With this technique we would have to plot so many thousands of points to achieve any degree of accuracy that over a large map, the task would literally be impossible.

We might consider mathematical functions to determine the areas of the pillars, such as the formulas for the areas of squares, rectangles, triangles, and circles. This method would take forever with one or two pillars, let alone a map full of them. Finally, we could use the tour de force method of cut and weigh. We could weigh the map on a laboratory balance, then cut the pillars out and weigh the map again. By comparing the percentage relationship between the two weights, we could find areas. This method would obviously be impossible with any map larger than one covering a few pillars, but in a way resembles the way image analysis works. The difference is that the comparison of areas in image analysis is done optically and electronically. Now, let's take a look at some real-life examples using image analysis.

Fig. 3 – Reference image superimposed on a mine map. Since the reference image is a square or rectangle, the scaled area it covers is easy to calculate. When the analyzer is reading areas or counts, only contrasting objects within the reference are reflected in the readings. Thus areas are expressed as a percentage of the reference.

EXAMPLE ONE – CALCULATION OF COAL RESERVES

Figure 4 shows a thickness map of a hypothetical coal reserve covering two townships and containing forty six thousand eighty acres. The map is divided into thickness categories and is much like the type of map that could result from exploratory drilling. In this example, we wish to determine total reserves and the reserves in each thickness category.

To prepare the map, it is subdivided into segments and the thickness categories are inked-in to provide contrast. In this case, simple Xerox copies were made of the map and the categories were inked with India ink. Each category was analyzed separately to find its percentage of the total area.

The percent black to white, which is read from the meter, times the total area yields the acres in the thickness category. This acreage times 1800 tons per acre per foot of coal yields tonnage in the category. Of course, the tonnages are totalled to give the total number of tons in the reserve. The results are summarized in Table 1.

In this example, a simple hypothetical map was chosen so we could check the accuracy of the technique by the cut and weigh method. As it turns out, the image analyzing system under-read the area by 852.4 acres for an error of 1.8 percent. This is certainly an acceptable tolerance for most work and could be improved with better system calibration. Now let's look at an example with some real-life unknowns.

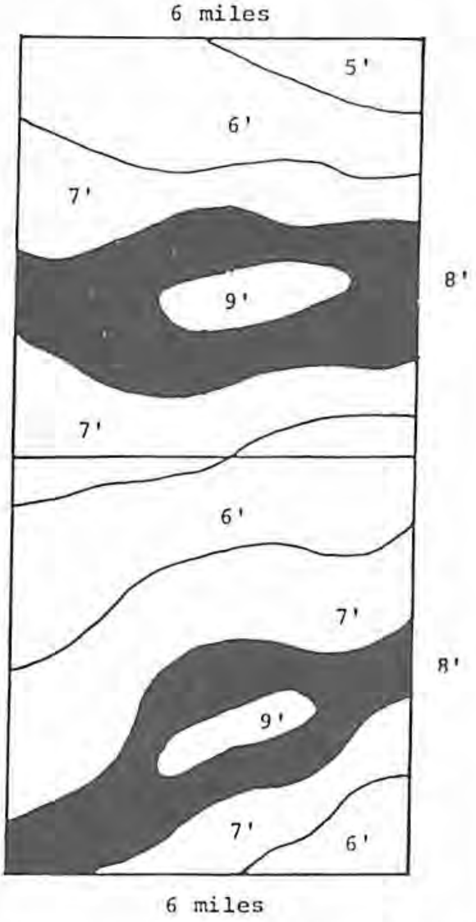

Fig. 4 – Hypothetical coal reserve showing thickness intervals used in Example One. The eight-foot interval is inked in for analysis.

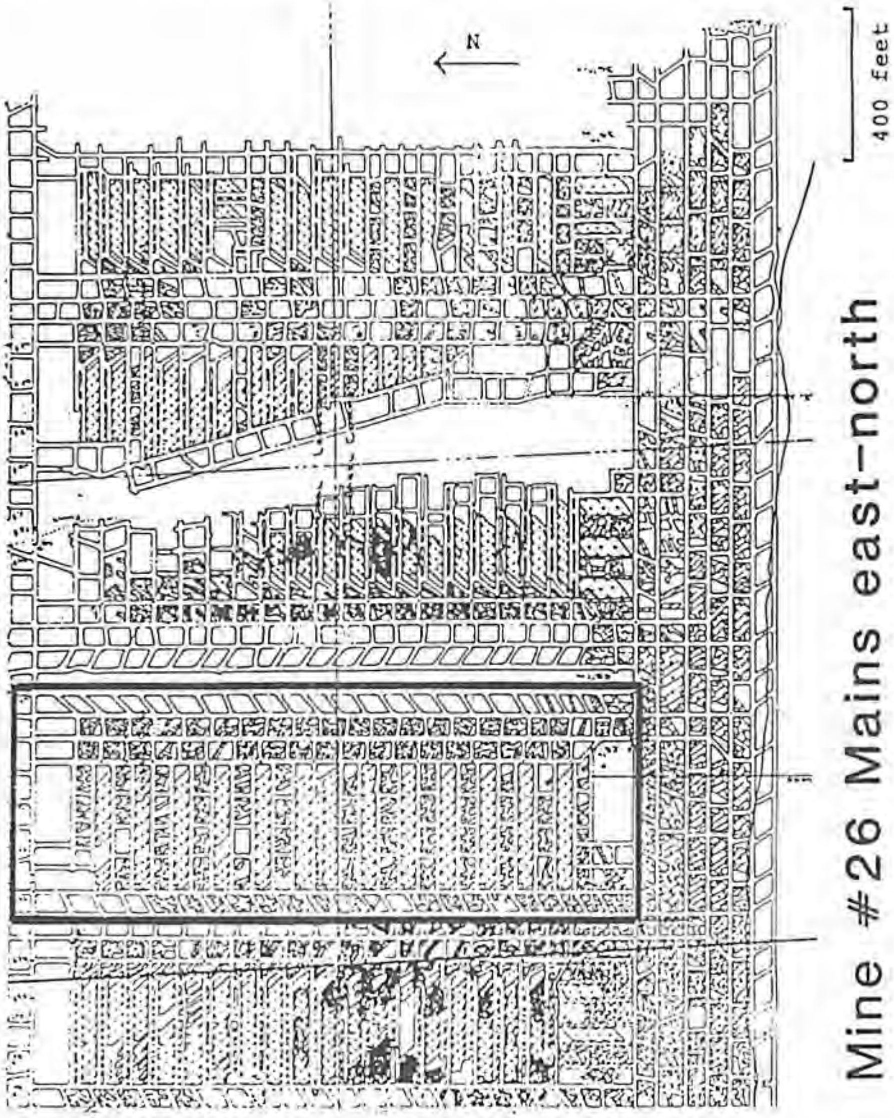

Fig. 5 – Portion of blueprint map of Old Ben Coal Company's Mine No. 26. The panel selected for study is in the boxed in area.

EXAMPLE TWO – TONNAGES FROM THE MAP OF A MINED-OUT PANEL

Figure 5 shows a portion of Old Ben Coal Company's Mine No. 26 at Sesser, Illinois. The panel we wish to study is shown in the boxed-in area. This example is interesting because it not only shows the usefulness of image analysis, but it demonstrates that a lot of information is contained in an accurately drawn mine map.

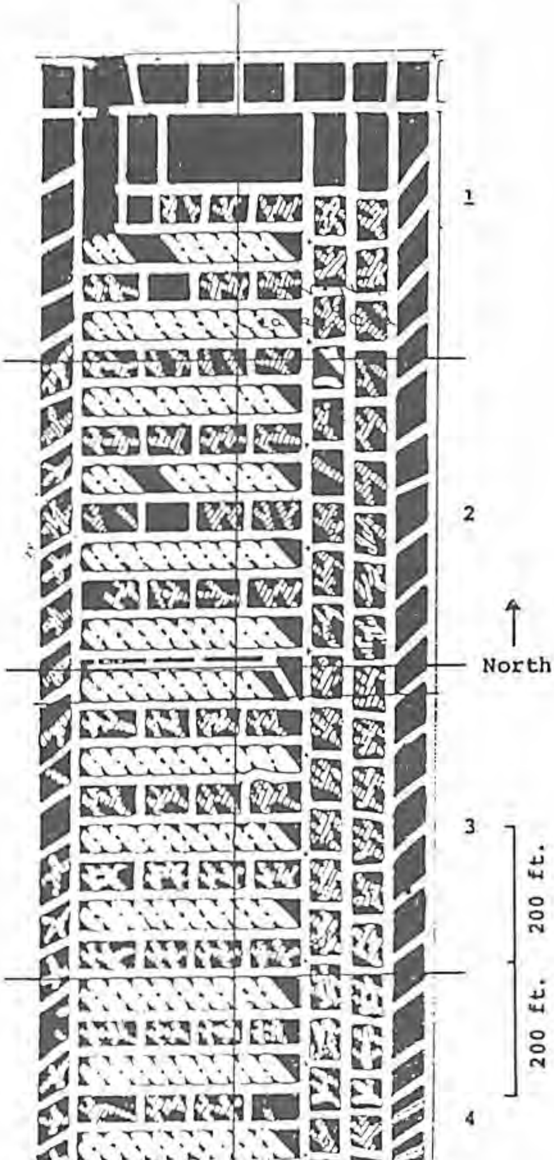

Fig. 6 – Study panel inked in and divided into segments for analysis. The limited aperature size on the analyzer requires division of larger types of work. Inking provides the required contrast.

In this example, we wish to determine the tons mined, tons left unmined, percent recovery, and the tons of refuse generated during the mining cycle.

To prepare the map for analysis, we have taken an enlarged version, inked in the pillars for contrast, and sub-divided the map by outlining segments (Figure 6). From the scale of the map, we know the area covered by each segment. To obtain thickness information that will allow us to determine volumes, which will lead to tonnages, we need to take a look at the mining profile of the panel.

The profile (Figure 7) was made from measurements taken in the panel and shows a cross-section typical of areas mined by ripper-type continuous miners used in this mine. Notice the top coal left for roof support, the "blue band" [a characteristic shale parting found in the Herrin (No. 6) Coal of the Illinois Basin], and the amount of floor mined as part of the mining cycle. From this profile, we know that for each square foot of continous miner travel, we mined 5.83 cubic feet of coal, .16 cubic feet of blue band, and .83 cubic feet of floor.

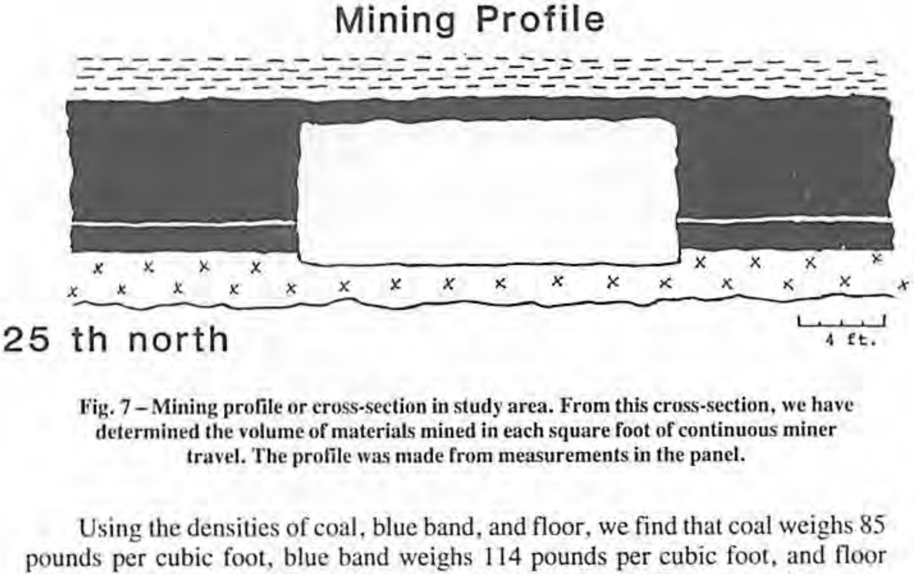

Fig. 7 – Mining profile or cross-section in study area. From this cross-section, we have determined the volume of materials mined in each square foot of continuous miner travel. The profile was made from measurements in the panel.

Using the densities of coal, blue band, and floor, we find that coal weighs 85 pounds per cubic foot, blue band weighs 114 pounds per cubic foot, and floor weighs 140 pounds per cubic foot. Armed with these volumes and weights, we find that the total in-place tonnage in the panel was 313,650 tons. From analysis, we find the percentage of black to white (unmined area to mined area). One segment as it appeared on the monitor is shown in Figure 8.

From the scale of the map and using the percentages from analysis, we have calculated the area of continuous miner travel. Using the volumes and weights for the various materials, we have proceeded to calculate the amounts of each mined or unmined, for the entire panel. These tonnages are summarized in Table 2.

Using the data from Table 2, we can see that a considerable amount of coal was left as top coal and in chain pillars, barrier pillars, stumps, and fenders. We can also see that a considerable amount of extraneous material was handled as part of the mining cycle. We find that the overall percent recovery for the panel was a disappointing 46.3 percent. We also find that the refuse generated by the mining cycle was 17.1 percent by volume or 21.5 percent by weight.

One might glance at the mine map in Figure 6 and conclude that we did a pretty good job of extracting the reserve. But via image analysis, we can see that even with pillar extraction, a lot of coal was left. Just as bad is that the mining cycle generated a fair amount of refuse from the floor. These are just a few of the reasons why our company is mining much more effectively with longwalls. Not only do we improve the percent recovery by as much as 30 percent, but we have almost eliminated the unintentionally mined floor and have improved safety as well.

In this example, we could have used image analysis to find out more than just tonnages. We could have determined things as diverse as areas blocked by roof falls, areas and volumes of air courses, areas versus mining costs; we could even have calculated royalty payments. Image analysis is thus particularly useful in engineering and economic studies.

Now, let's take a look at an example in which an image through a microscope is analysed.

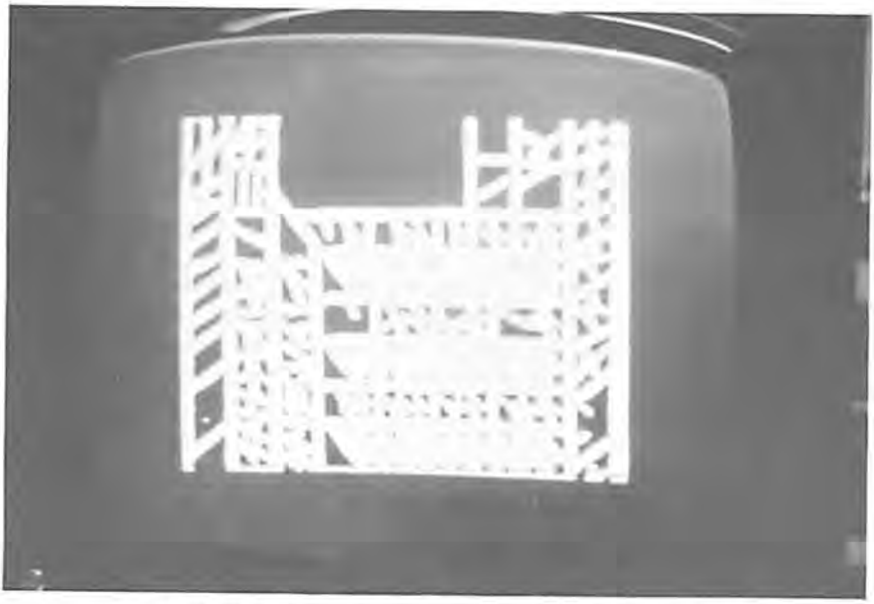

Fig. 8 – One segment in Example Two as it appears during analysis.

EXAMPLE THREE – PETROGRAPHY OF MINE ROOF SHALES

This final example is from Freeman United Coal Mining Company's Orient Mine No. 6, Waltonville, Illinois. Here, we will be determining the percentage of bituminous material in the roof shales of this mine. Although we will not go into the details of it, the amount of bituminous material in the roof shales has a direct affect on roof stability at Orient No. 6 (Ledvina, 1976). Image analysis provides a tool for accurately determining the amount of bituminous material.

The mineral matter (quartz and clays) in the shales is nearly transparent while the bituminous material shows as black or opaque specks. To find the percentage bituminous material, we determine from analysis the percentage black (bituminous) versus the percentage white (mineral). These percentages yield percent by volume directly.

The volume percentages coupled with the density of coal (representing bituminous material) and the density of shale (representing mineral matter) yield the percent bituminous material by weight. Taking sample one, for example, shows fifty eight percent white versus forty two percent black. These percentages represent percent bituminous material by volume. The volume percentages translate into sixty nine percent mineral versus thirty one percent bituminous material by weight. The other three samples could be similarly analyzed.

COUNTING AND SIZE DISTRIBUTIONS

Figure 9 shows a portion of a simplified mine map. The map shows a grouping of several different pillar sizes. When viewed by the image analyzing system, with the controls switched to the count mode, the system displays counting ticks in place of objects on the monitor. The meter on the system then can be set to read numbers of objects instead of areas. The controls on the analyzer can be adjusted to eliminate certain sized objects from the count in steps. Using this feature, size distributions can be determined. Figure 10 is a histogram showing the size distribution of pillars in the map in Figure 9.

Counts and size distributions are useful in engineering studies such as subsidence studies, roof control studies, or studies involving mining plans. Also, in microscope work, we could use the counting and sizing functions to determine number of grains, grain size distributions, and compositions in thin-sections. Thus, we could have analyzed the samples in Example Three in more detail.

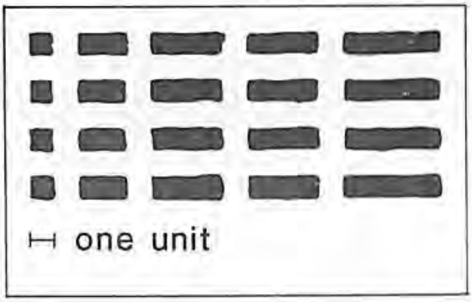

Fig. 9 – Simplified portion of mine map showing a population of different-sized pillars.

ADDITIONAL FEATURES, THE STATE OF THE ART, AND NEW DIRECTIONS

With a little imagination, it is not hard to come up with many additional uses for image analysis. One particularly useful function is a direct offshoot of the counting and sizing functions. This is using image analysis for orientation studies. Orientation studies have direct applications in petrography, for example, to detect preferred orientations of grains in rock samples. Other orientation work may involve the study of maps to detect trends in roof falls over mined areas.

Since image analyzing systems can count objects based on their maximum dimensions, counts can be taken of objects with the data source oriented in various directions. By comparing the counts statistically in each direction, preferred orientations become readily apparent.

Another useful function possible with image analysis is in studies of complimentary areas. Suppose we had a map that had a number of dark objects scattered over a light-colored field. Simply by flicking a switch, the image analyzing system can be set to read either the light areas or their compliments, the dark areas.

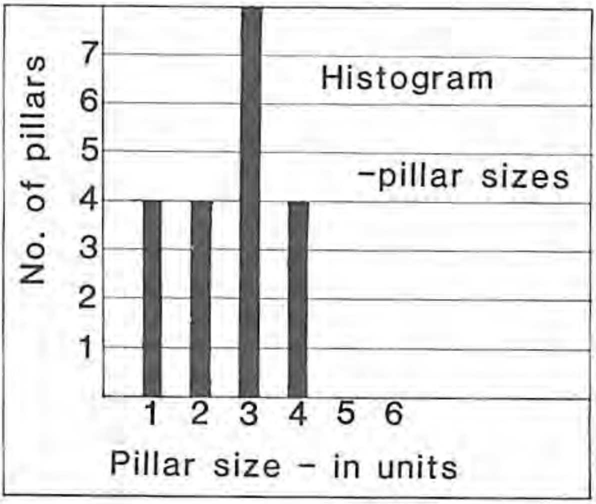

Fig. 10 – Histogram of pillar size distribution. Although highly simplified for illustrative purposes one can imagine what the distribution of pillar sizes might be like using a much more complicated example. Similar distributions could be determined for many other parameters from a variety of data sources.

To allow rapid analysis of large flat work, the TV camera can be mounted on a frame, fitted with a zoom lens, and positioned so work can be viewed from above. With this arrangement, large work can be analyzed without as much subdividing. It must be remembered however that there is a limit on accuracy as the size of objects in the data source decreases.

Table 1 – Tonnages from Example One as determined by image analysis.

Interval	Tons
9 feet	34,713,360
8 feet	177,500,160
7 feet	207,567,360
6 feet	140,590,080
5 feet	11,404,800
Total tons	571,775,760

Table 2 – Tonnages and percent recovery from Example Two as determined by image analysis.

Tons left as pillars	143,496.0
Tons left as top coal	24,900.6
Tons mined (floor)	34,176.0
Tons mined (blue band)	5,563.5
Tons mined (coal)	145,253.4
Percent recovery	46.3%

Image analyzing systems can be teamed with small digital computers simply by feeding the meter output through a stage of analogue/digital conversion and then into a mini-computer. This type of arrangement allows programming ability to be added to analysis and makes easy work out of the arithmetic that often has to be used in area or counting studies. Data compilation and statistical interpretation becomes much easier. The data derived from analysis can also be accessed by other systems, and information from cumbersome maps, photos, or microscope slides can be stored on disk or tape.

In general, most image analyzing systems are monochromatic, but they can discern color to a limited degree by gray tonal value. Most multi-colored sources such as maps or photos can be broken down into series of gray tonal values. The control unit on the analyzer can eliminate objects from counts or area studies by their gray tonal value. Thus existing maps can be analyzed without inking in interest areas. To simplify the explanation, this feature was not used in the examples, but could have been used, especially in the first example on reserve calculations to avoid separate inking and analysis of each thickness category. The problem with selection by gray tone equivalents is that two or more colors may have the same gray tonal value. This is where color image analysis really pays off. Some of the newer systems have full color capability so existing color maps are easy to analyze with little or no preparation. In petrographic work, different components that appear as different colored areas in thin sections under polarized light are easy to separate and analyze.

In applications of image analysis, one aspect that we have not discussed at all is its application in surface mining. Surface applications include the calculation of tonnages of coal and spoil, soil volumes, size of seeded areas, or mining costs. Area determinations from contour maps of elevation can aid in reclaiming land and its restoration to original contour.

AVAILABILITY AND COSTS

Image analyzing systems are available from a number of manufacturers, mostly the major optical companies. Some of the most diverse systems are from Carl Zeiss Optical, which has devoted a lot of their resources to the refinement of the technique. A fairly simple system that uses a magnetic board and pen instead of a TV camera is shown in Figure 11. This system features a paper strip printer, programming ability, and relatively low cost – around $10,000. Very sophisticated systems with full color capability and built-in computers run in the $30,000 to $40,000 range. Some of the more sophisticated systems are designed mostly for microscopic work only. In general, systems are getting less expensive with time. Often, used systems are easy to find.

Fig. 11 – Image analyzing system at Northeastern Illinois University. This system is not a video-type system. It reads areas and determines counts using a pen and magnetic board. This system, made by Carl Zeiss, features a digital display and paper tape printer.

CONCLUSION AND ACKNOWLEDGEMENTS

Image analysis offers to the mining and geological sciences a method to save time and extract extra information from data sources. In this paper, each of the examples took less than one-half hour to prepare and analyze. This time could be cut considerably by using some more sophisticated features of image analyzing systems. Although image analysis has been used primarily in medical, biological, and metalurgical fields, it is hoped that this paper will serve to encourage its use more in our fields of mining and mining geology.

For all their kind and patient help in making this presentation possible, I owe a lot to my friends and colleagues in the coal industry of Illinois. Special thanks go the Illinois State Geological Survey, especially Richard Harvey and Heinz Damberger, students and staff at Northeastern Illinois University, especially Robert Doehler, Albert Forslev, Charles Shabica, Hansa Upadhyay, and William Tong, my colleagues at Old Ben Coal Company and Sohio, especially Jeff Moriarty and Andy Koch, friends at Freeman United Coal Mining Company, Paul Weir Company, and of course, my wife, Nancy.

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Question from floor: Your examples of the underground mine maps are totally hand drawn. The measurements are actually in the surveyor's book, and the pictorial part on the mine map itself is hand drawn. Is image analysis nothing more than a calculated guess?

Christopher Ledvina: The section foremen are given either a 1" = 500' or 1' = 100' mine map to work with, and they have to mark their cutting progress at the end of each shift. There is a grid system on each of those maps, and the section foremen have to draw in their cuts, the lifts, the depths of crosscuts, and the depths of entries with the grid system so that the mine maps are fairly accurate. Now, some companies do not draw mine maps as well as the maps we are using here. Some companies just block out square blocks for pillars and draw in straight lines for entries or crosscuts, but certainly at Old Ben our maps are drawn accurately. What I am saying is that basically they are still hand drawn. The features are there to back up the hand-drawn maps. The image analysis itself is not a calculated guess of a mine map. It is basically accurate, but it is only as accurate as the people are. You still have to have the pictures to back you up. I will admit that there probably is some artistic license to drawing things as they are. If you consider the size of a panel, the way I see it, any errors in the drawing abilities of a section foreman probably tend to balance themselves out. It's the best information available.

Keep in mind that topographic maps are guesses too, because of what happens to the bumps and depressions that are smaller than the contour interval. We have to work with the best data we have available, and there are few other ways to count the production of an individual panel. Certainly I wouldn't trust buggy counts or shuttle car counts, and installing belt scales isn't particularly practical. Looking at the mine map may be the only way to get an accurate guess of production for a particular panel.

Remark from floor: I was just questioning its application in that particular area.

Christopher Ledvina: I see your point though, and it's a good one too. Any other questions? Thank you very much.

George May: Our next speaker is Paul J. Ehret. Paul has a Bachelor of Science and a Master's degree from Southern Illinois University at Edwardsville. He has spent time working with the Illinois State Geological Survey on subsidence problems, and now he is the environmental specialist for the Illinois Department of Mines and Minerals in the Land Reclamation Division. The title of his paper this afternoon is "Subsidence Control Planning for Regulatory Compliance in Illinois".

SUBSIDENCE CONTROL PLANNING FOR REGULATORY COMPLIANCE IN ILLINOIS

PAUL J. EHRET
Illinois Department of Mines & Minerals
Land Reclamation Division
Springfield, Illinois

INTRODUCTION

I would like to start out this presentation with a story which somewhat reflects the situation in regard to subsidence and the regulations. It occurred while I was attending the American Mining Congress Convention in St. Louis in May, 1981. At the convention I sat in on a technical session regarding the SMCRA regulations. One of the presentations was given by a lawyer working in Washington representing the coal industry. His topic of discussion dealt with issues that are presently controversial and that are foreseen to be controversial in the future. Some of the issues he discussed included valid existing rights, grandfathering, and about a half dozen or so other topics.

Considering my area of interest I was more than a little surprised that he did not mention subsidence. After his presentation I spoke to him to ask if he was familiar with the subsidence regulations and how subsidence looked as far as a future issue of concern. He indicated that he was familiar with the subsidence regulations, but felt there was little in them that should stir controversy.

The point of this story is that subsidence has been somewhat of the sleeping giant of the regulatory program and until most recently has been ignored by more than one individual.

To a large degree this is what this discussion is about. In fact, perhaps a better title for this presentation may be "How to avoid being blindsighted by a subsidence regulation." One thing I am not going to do is stand here and quote regulations. Most here are probably well versed on them. What I do feel I can offer is a discussion of future issues that lie ahead for the industry based on observations from my perspective of the regulations after over two years under the permanent program.

PLANNED AND UNPLANNED SUBSIDENCE

Basically, from a regulatory standpoint subsidence is viewed in two extremes; one, concerns the removal of all subjacent support, which equates to planned subsidence in a predictable and controlled manner, or two, unplanned subsidence in which support of the surface is provided along with documentation of maximum mine stability.

After reviewing in detail 38 underground mine permit applications it is my feeling that many applications for planned subsidence lack good planning, and many unplanned subsidence applications lack good documentation as to the stability of their mine plans. Obviously, much of this can be blamed on the newness of the regulations. Surface miners have had over 20 years to adjust to an escalating progression of regulatory requirements upon their operations. The adjustment to regulations for underground operations as severe as SMCRA had to be done virtually overnight.

Under these circumstances the industry has for the most part responded satisfactorily in meeting the requirements of the regulations. I would like to take this opportunity to give my Department a compliment in its approach to implementing the regulations. I believe we have implemented a very complex and difficult program with as little pain as possible and have still maintained our regulatory mandate.

However, and this is a very important however, in regard to what has been done so far, the industry in the future must be far more dynamic in its approach to meeting the regulations. The alternative which was spoken of earlier, is running the risk of being unprepared for the critical requirements of the regulations.

NEW DEVELOPMENTS IN REGULATIONS

Although the letter of the regulations may not change, it is not unrealistic to expect the requirements needed to address those regulations, through a normal evolutionary process will begin to focus on critical areas requiring more detail work and investigation. Also, on the favorable side of this process, some of the non-essential work will be eliminated or substantially reduced. The first evidence you may see of this is when the Department develops its new UM-1 application. The development of the new application will be based on the Department's observations and experiences thus far into the permanent program. Hopefully, the new UM-1 will be ready within a year or so.

A hint of some of the things to be prepared for can be seen in part in the Department's modifications letters, permit findings, and conditions. Basically, the level of detail in planning and analysis for planned subsidence mining and the documentation of "maximum mine stability" for unplanned subsidence will be emphasized.

PUBLIC AWARENESS

An additional factor, which will have far reaching effects, is public awareness of the regulations. As people who live in the areas in which you mine become more aware of the regulations and surface owner right provisions of the law, the need to satisfactorily address public concerns as an element of the regulations will require more preparation and better planning on the part of the operator.

A point, which all of you can perhaps appreciate, is that of the 38 underground mine permit applications filed since the start of the permanent program, only three public hearings were requested and only two were held. The other request came after the 80th day deadline and was requested by a county outside of the five-year shadow area limit. Of the other two hearings subsidence was the primary issue in only one.

In several years we will be entering the second permit application phase, or as significant revisions are submitted it can be anticipated that you will see applications much more highly scrutinized by the public and in all probability a significant increase in requests for informal conferences and public hearings. This should be true particularly for planned subsidence operations and room and pillar mines that may be experiencing surface stability problems.

A point that all operators must understand is that because of the strong public review aspects of the regulatory program your permit applications and particularly the subsidence control plan, aside from its technical requirements, is very much a public relations document. As of yet this fact is not often realized by industry. It is obvious that many of the subsidence control plans are put together without an appreciation of this fact. They may be done by a staff engineer experienced in working on production or MSHA standards and, these public concern aspects may not necessarily be understood. Additionally, although our regulations can in no way interfere with the safety provisions of MSHA, the purpose of our regulations serve a very different purpose and the two should not necessarily be viewed as having the same intentions. In production areas MSHA is concerned with the shorter term goal of protecting the miners in active areas, while my Division is concerned for the longer term goal of maintaining the ground surface long after the mines are abandoned.

UNDERSTANDING THE REGULATIONS

As part of my application review I always attempt to place myself in the surface owner's position of trying to understand what is being said and how the mine plan and subsidence control plan relates to protecting the surface owners property rights under SMCRA. You may have noticed the nature of many of the subsidence modifications questions in this regard. Much effort is spent to eliminate vague, ambiguous or contradictory language and statements to help facilitate public understanding.

The propensity for general or vague permit application statements is recognized. The desire not to commit to something until you are sure of the final repercussions is only natural. However, it should be understood that is exactly what a subsidence control plan requires. It is a written commitment to the Department and the public that states an operator has devised through planning and quantitative analysis a well conceived plan for the control of subsidence and its impacts.

ANTICIPATING FUTURE DEMANDS

In regard to meeting these future needs I am happy to see that several operators have foreseen many of these problems and are taking farsighted approaches in order to take on these challenges. I would strongly encourage all operators to take this approach rather than to react to a situation through crisis management.

Also, in the realm of anticipating future demands, as I am sure you are aware, the Illinois Coal Association (ICA) and the Farm Bureau have been working together to bring research funds for subsidence studies from the Bureau of Mines for fiscal year 1986. Although the direction of this research presently is not known or even if money will be available, my Department, the ICA, and the Farm Bureau together with the State Geological Survey are working to develop an area of focus which it is felt would be most beneficial. We are hopeful that the Bureau of Mines will be willing to use the available collective knowledge that presently exists in industry and the Survey to produce meaningful research.

Obviously, however, the focus of this study cannot address the individual priorities of each operator. Therefore, operators are going to have to do much more on their own to gather data to document and quantify the soundness of mine and subsidence control plans. The importance of developing and maintaining a current detailed data base in regard to both surface and subsurface conditions cannot be over-emphasized. The key to managing your operations in response to the future demands of subsidence regulations will be from this data base. It will give you the ability to perform quantitative analysis of your mine plans with less reliance on existing empirical methodologies. I don't necessarily want to down-play the usefulness of empirical methods, but rather to place an expanded emphasis on investigation and data development. The data you develop today will greatly assist the analysis you must do in the future to acquire subsequent permits.

REDUCE COSTS OF OPERATIONS

Finally, the incentive for doing a good job in response to challenges the subsidence regulations place on operators goes beyond just doing what is necessary to get a permit, but to reduce costs of operations. With the regulations such as they are the cost of subsidence prevention and mitigation must be recognized as a cost of operations as it has never been before. The room and pillar miners that can provide the greatest stability per ton of coal mined will do well in reducing the long-term effects of subsidence as a cost of operations.

Planned subsidence miners who apply sound predictive techniques to avoid or minimize damages, where possible, and where not possible, to develop the most effective mitigation plan will also find costs reduced. It is a good idea to keep the good-will of the people of areas in which your mines are located. This is a factor that cannot be overrated.

George May: Thank you Paul. Are there any questions for Paul?

Question from floor: Paul, I'm not an engineer, but I have a little philosophical problem with the concept of "planned subsidence". It seems to me that when you take three to eight feet of horizontal strata out of the earth, something is going to happen at some point in time down the road. How do you assure control of subsidence short of backfilling or some process whereby you replace what you took out?

Paul Ehret: I think this is something that has been somewhat of a misconception. The regulations have never said that you cannot have subsidence even in the case of "unplanned subsidence". I think that the regulations recognize that this is an eventuality of the mining process. However, they have come up with the concept of "mine stability": when you mine coal you should do the best job possible under the circumstances to provide good support of the surface. I think all of us recognize that it will not necessarily stop subsidence from occurring, but maybe more could be done than is being done to guarantee the integrity of the surface or to at least attempt to guarantee the integrity of the surface. It by no means says that you cannot have subsidence. Obviously, if you are going to do room-and-pillar mining, you are going to get subsidence eventually somewhere. It does not mean it would not be quantifiable. It's never measured when it occurs, and you can't really predict it. Basically its trying to attempt to get a handle on that. I think a lot of people have had the same concern.

Question from floor: But does that translate inevitably into a percent of extraction? Is that basically what we are talking about?

Paul Ehret: I don't think everything fits into a nice little category, but I think that is what the regulations are trying to do. There are two extremes in the regulations. Either you take all the support or you leave proper support. And what I think they are trying to eliminate is the part in between. When you are taking out a lot of coal, and not leaving sufficient support you are almost guaranteeing subsidence. You've thus got a situation where you have a lot of subsidence that can't be predicted, so what you are trying to do is provide as good a support as you can to keep that type of subsidence to a minimum. And whether or not that goal is achievable, I don't know. The mining techniques they are using now obviously provide a lot better support than the old ones. However, the problem is that the types of mining that are being done right now don't have the longevity to allow you to look back and tell which mining technique worked properly. The only thing I think you can do is attempt to quantify some of these things. In many cases a lot of owners and operators complain that a particular theory doesn't apply to their situation. What I am saying is that to get a permit the industry is going to have to start spending more effort on something that they can quantify rather than use the empirical methods that they have been using for 30 years.

Remark from floor: I suggest that it is very, very difficult to quantify the type of thing you are talking about even with any given percent of extraction. The question is whether it is going to happen 50 years, 100 years, or 150 years down the line. I think those are the types of things we're dealing with, and I think it's almost impossible for an operator in the unplanned subsidence area to meet this type of requirement.

Paul Ehret: Well, I don't necessarily say that just because you don't think you can do it, you shouldn't accumulate data and try to work on the process. I disagree with that. I think that attempts are going to have to be made; cases are going to have to be argued. Things are going to have to be done to show that the industry is doing a good job. Basically, it's going to come down to accountability. If problems start to arise from a particular mining operation, why is there a problem? I think that's what it comes down to. The operators are going to have to show that they are doing a good job. What they're doing in many cases, quite frankly, is covering up for things that might come down in the future. The company should have good engineering and have all this information to show that under the circumstances they did as good a job as possible. That's not saying that they will stop subsidence, but they should show that they're doing a good job rather than saying that we don't have any information. And that's really what it comes down to.

Remarks from floor: I would like to make some comment on the mining education for many years. It always bothered me that we have a system that sets up conveyor belts and shuttle cars, and then somebody mines the coal. They leave about 50 percent of that resource in the ground and create a problem for future generations. I agree with the previous gentleman, that if you mine room-and-pillar, someday you are going to have subsidence. There is going to be an affect on the surface. Is your agency working on efforts to control subsidence and maximize extraction?

Paul Ehret: We had a recent meeting, as I alluded to earlier, with the U.S. Bureau of Mines, and one of the things that the Bureau wants to do is to longwall-mine under central Illinois cornfields. Nobody has even contemplated doing something like that before. We are receptive to that sort of activity, if it is well conceived. I don't think we would permit it just out of hand. There has got to be a lot of other factors that are involved. In other words, if you do that, can it be mitigated? Can the ground be restored? I think that is the important factor now. But I would say, that rather than leave 50 percent of the coal, I would rather see it all taken, quite frankly, under a lot of circumstances. There is that in-between area, of maybe 75 percent extraction that generates a lot of subsidence that you can't account for. Either you have to apply good support or you take it all. I think that one of the things that the people who wrote this law tried to do is push everybody into high extraction. The question is that in central Illinois can you do high extraction mining properly? We are receptive to high extraction mining, if there are certain things that can be done in the area of litigating subsidence damage.

Remarks from floor: I have traveled in Europe, particularly in Poland, and I saw them backfilling where seams are about 9 feet thick. They use longwall mining, and then they backfill with sand. I think this is a reflection of a society that mines a lot of their reserves. We heard earlier in the film of the great reserves in Illinois, but it's not always going to be that way in future generations. I think it behooves us as mining people and professionals to do the things today that will not create the problems tomorrow.

Paul Ehret: Yes. I think that is an extremely important point. I'm up here in a certain way, issuing a challenge to the coal industry to be imaginative. I think we're so set in a pattern that makes us say, "We've mined that way for 30 years." Who says you've got to mine that way for the next 30 years? Show a little initiative, take all the coal, and come up with something else. I don't think you can deny that unless something radically changes, there are going to be some tremendous costs in mitigation. If you can produce more coal and keep your costs down, you are going to be far ahead of the game.

George May: Thank you Paul. Moving ahead here, our next speaker is Mr. Roger Missavage. Roger has a B.S. in engineering, mechanics, and materials from Southern Illinois University. He is currently a Master's student, also at Southern Illinois University, and he is working on a mining engineering degree. He is Director of the Computer-aided Research and Instruction Laboratory for the College of Engineering and Technology at Southern Illinois University. Today he is going to talk about "A Ground-Control Analysis of Multiple-Seam Room-and-Pillar Coal Mining".

Roger Missavage: Thank you. My co-author is Dr. Chugh, also from Southern Illinois University. Today I would like to talk about multiple seam mining in the Illinois Basin.

A GROUND CONTROL ANALYSIS OF MULTIPLE SEAM ROOM-AND-PILLAR COAL MINING IN ILLINOIS

ROGER J. MISSAVAGE
YOGINDER P. CHUGH
Department of Mining Engineering
Southern Illinois University
Carbondale, Illinois 62901

INTRODUCTION

The term "multiple seam underground mining" refers to extraction of two or more seams at different horizons or two or more lifts in a single thick seam. The mining in different horizons may be done simultaneously or in a sequence. Multiple seam mining is extensively practiced in Europe and some Asian countries and to a lesser extent in the United States. It can increase the marketability and effective utilization of the available resource and aid conservation by reducing losses. Furthermore, it can extend the useful life of surface facilities such as railroad spurs, load-out equipment, shops, office buildings, hoisting equipment, etc. and thus reduce the unit cost of production.

Concurrent multiple seam underground mining is currently not being practiced in Illinois, although it was practiced about 40 years ago on a limited scale in mining the Springfield (No. 5) and Herrin (No. 6) Coals in Williamson County. Currently two mines are mining a second seam in areas where the other seam was mined. There exists a significant potential for such mining in the state, and several mining companies are considering concurrent multiple seam mining in several mines.

This study was undertaken with the overall objective of evaluating 1) the areas in Illinois where multiple seam mining may be practiced based on area geology and coal seam characteristics, and 2) whether such mining would be possible based on ground control considerations. This study was restricted to feasibility of partial extraction room-and-pillar mining, and it was designed to answer specific questions such as 1) what is the minimum interburden thickness that will have minimal interaction in multiple seam mining? and 2) what effect, if any, will staggering of pillars in the two coal seams have on the interaction? These questions are very important because of the multiple seam mining potential under prime agricultural lands, which may not be subsided, and the possibility of non-concurrent mining or the use of different mining methods or mining plans in the two seams.

MULTIPLE SEAM MINING POTENTIAL IN ILLINOIS

Over 70 percent of the State of Illinois is underlain by coal. This coal is a part of the Illinois Basin which covers most of Illinois, western Indiana, and western Kentucky. The vast lateral extent of the seams and the relatively small amount of geological disturbance in the basin make possible large highly productive mines. While more than twenty seams have been mined in the basin the majority of the production (78 percent) has been from the Herrin (No. 6) Coal (No. 11 Coal in western Kentucky and Herrin Coal in Indiana) and the Springfield (No. 5) Coal (No. 9 Coal in western Kentucky and Springfield Coal V in Indiana). In general, both seams are not thick enough for underground mining in the same area under present-day economics, but in thirteen counties (Figure 1) in southeastern Illinois both seams are more than 42 inches thick. Within this area, reserves are estimated to be about 36.3 billion tons in both seams (Missavage, private communication, 1984). The overburden above the No. 6 Coal varies from 150 to 1000 feet (Figure 2), and the interburden thickness between the two seams varies from 20 to 120 feet. In addition to a variation in seam thickness between the seams the sulfur content also varies for the two seams. Since the potential market for high-sulfur coal is limited, simultaneous mining of both seams and the subsequent blending of coal may reduce the sulfur content of the thicker seam and thus increase the marketability of the coal. Therefore, the authors think that a significant potential exists for multiple seam mining in the basin and it should be exploited.

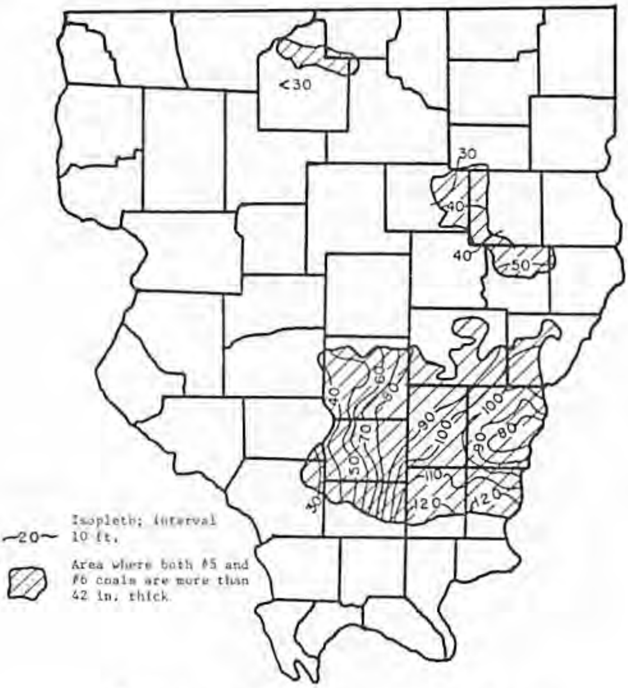

Fig. 1 – Interburden thickness in the study area.

The distinct features of the basin are prime farmland, thick underclays, large percentage of shales in the overburden, and high tectonic stresses. Since much of the basin is considered prime farmland and much of it is drained by gravity tiles, subsidence must be kept to a minimum and therefore may preclude the widespread use of longwall mining. The No. 6 Coal is underlain by a weak water-sensitive underclay that ranges from a few inches to more than ten feet in thickness. The underclay at times can have a mudlike consistency and compressive strengths of less than 300 psi (Rockaway 1980). This soft layer causes floor heave and foundation failures of the pillars. High tectonic stresses have been shown to cause problems in the Beckley coal bed (Aggson 1978), and high stresses in excess of 3000 psi (Aggson 1978) have been reported near the basin.

The area most likely to adopt multiseam mining is northern Saline, eastern Franklin, and Hamilton counties. They are characterized by moderate to high-sulfur No. 6 Coal, low-to moderate-sulfur No. 5 Coal, interburden spacings ranging from 70 to 120 feet, overburden thicknesses ranging from 400 to 800 feet, and seam thickness ranging from 42 to 66 inches in both seams. The mines may employ simultaneous mining of both seams to avoid the problems associated with water and gas accumulation and also to allow the blending of the coal to improve the marketability.

Fig. 2 – Overburden thickness in the study area.

GROUND CONTROL ANALYSIS OF MULTIPLE SEAM MINING

OVERALL APPROACH

Finite Element Modeling (FEM) was utilized to analyze interactions in multiple seam partial extraction mining under geologic conditions typically encountered in the counties that are most likely to practice such mining.

The analyses involved determining stress distribution around the mine openings in both seams together. Though this was truly a three-dimensional problem, it was simulated as a two-dimensional plane strain problem due to the large amount of computer time required and due to the complexity of analyzing the results of a three-dimensional analysis. Two dimensional linear elastic analysis using the FEM computer programs BMINES developed by the Bureau of Mines was used in the study. The computed stresses were used in calculating a point by point safety factor in the rock mass surrounding the mine openings. The safety factor was defined as the shear stress at the point divided by the maximum allowable shear stress at that point. The maximum allowable shear stress at the point was calculated based on the non-linear (Parabolic) Torre failure envelope. The safety factor contour plots were prepared to assess both the overall stability and the interaction of mining in both seams.

The FEM studies were conducted to evaluate the effects of varying parting thickness, roof type, thickness of the underclay, and lateral stresses. Three mining geometries were considered to simulate development entries, panel entries with columnization of pillars, and panel entries with staggering of pillars.

PREVIOUS STUDIES

A review of past studies on the subject was recently presented by Eghartner (1982) and Barko (1982). Studies on ground control analysis of multiple seam mining in the U.S. are rather sparse. Thirty eight case histories of multiple seam mining and encountered ground conditions were analyzed to develop empirical observations. Most of these case histories were from eastern U.S. and none were from the Illinois Basin. Of the 38 case histories, mining of the upper seam preceded mining of the lower seam in 32 cases. Among the 38 case histories, 16 cases were considered stable and 22 were considered unstable. This does not necessarily mean that 60 percent of all multiseam mining situations were unstable. It is probable that most of the studies were done in mines having ground control problems.

Eghartner (1982) attempted to correlate overall stability to several geometric parameters such as interburden spacing, extraction ratio, percent sandstone in the interburden, and number of layers in the interburden.

Theories of how mining in two seams interact can be divided into two categories: arching and subsidence. Arching theories presented by Peng and Chandra (1980), Britton (1980), and Haycocks et al. (1982) involve the region around the mine opening where stresses are redistributed due to the mine opening. The presence of the pressure arch around single mine openings is accepted by most mining engineers. Arch heights extend upward and downward a distance of anywhere from 3 to 5 times the seam height (Britton), 50 times seam height (Peng and Chandra 1980), and to twice the opening width (Holland). Interaction occurs when the arches from the two seams coincide. Arch height of 50 times seam height is accepted for longwall mining and twice the opening width for room-and-pillar mining. This would correspond to arch heights of 40 to 60 feet for the Illinois Basin and minimum interburden spacing of 80 to 120 feet. Wilson and others (1976) suggested that the interaction effects are complex and no single theory can explain the phenomenon. He suggested that in certain cases, mining of the second seam could increase the stability rather than reduce it. In the United Kingdom entries in lower seams are driven directly below the gob of longwall panels in the upper seam to take advantage of the interaction. As seen from the histogram in figure 3, interburden spacing alone is not a good measure of stability when mining two seams. Haycocks and others (1982) also tried to correlate layering, interburden stiffness, and ratio of upper to lower seam extraction to opening stability but met with little success.

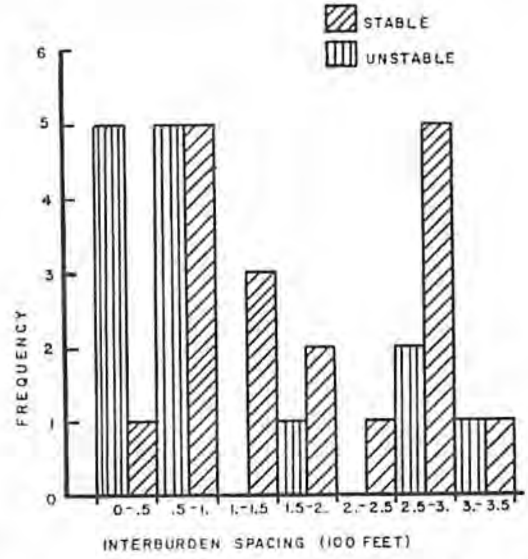

Fig. 3 – Histogram of case histories versus interburden spacing.

A few studies in the recent past (Eghartner, 1982 and Barko, 1982) have attempted to analyze interactions in multiple seam mining using analytical techniques. Eghartner (1982) used photoelastic modeling to measure the extent of disturbance caused by a single pillar on an elastic floor. He used several models varying the size of the pillar, stiffness of the floor, and stress distribution on the pillar. Using the results of the photoelastic study, he inferred the depth to which the natural stress field would be disturbed beneath pillars in the upper seam. He concluded that with a single pillar on an elastic floor the depth was greater with softer or layered interburden. This is consistent with observations made from the case history data. One limitation to this analysis is that the pressure bulbs extend more than a pillar width beyond the edge of the pillar. The pressure bulbs from adjacent pillars will therefore interact with each other. The photoelastic analysis conducted by Eghartner (1982) would therefore not be directly applicable to room-and-pillar mining. The application of his studies is limited to longwall mining or to the effect of barrier pillars in longwall mining.

Eghartner also used FEM to measure the height/depth of interaction. A two-dimensional plane strain linear elastic layered model was used. The boundary conditions on the model were pins on the base and rollers on both sides. Therefore, the horizontal stress was limited to one-third the vertical stress. The thickness and stiffness of the strata overlying the coal seam were varied. The arch height was defined as the distance to which the principal stresses varied by at least five percent from the natural stress field. As the stiffness of the overlying strata increased, the height of the pressure arch increased. This is in contradiction to what is expected from analysis of the case history data. Either the effect of high lateral stresses is significant or the height/depth of the pressure arch does not correlate with seam stability.

Barko (1982) also used FEM to analyze the stability when mining multiple seams. The approach was quite different from that used by Eghartner (1982). Barko used the stresses from the FEM analysis to calculate point by point safety factors based on the Coulomb-Navier (linear) failure criterion. The model was a two-dimensional plane strain with roller boundary conditions on the bottom and both sides. The extent of interaction was measured as the distance between an arbitrary safety contour (usually 20 or 60) at the upper coal seam. He used several different models that varied the mine geometry, but all models limited horizontal stresses to one third of the vertical stress. Very large safety factors (10-100) and the method of measuring interaction makes one somewhat cautious about the results obtained in this study. One conclusion is especially circumspect. He noted a decrease in the failure in the upper seam until the interburden increased to 52 feet beyond which the extent of failure in the upper seam rapidly increased. The increase in failure with increasing interburden spacing is not consistent with the case history data or intuition. Because of the limitations of the studies discussed above, the present study was initiated.

FINITE ELEMENT MODELING OF MULTIPLE SEAM MINING IN ILLINOIS

Two dimensional linear elastic analyses were conducted using the program BMINES (Revision 2, 12/1972) written for the Bureau of Mines by Agbabian Associates. A typical model of multiple seam mining geometry under Illinois conditions is shown in Figure 4. The symmetric columnized model consists of ½ pillar, ½ opening, and one full opening and one full pillar in each seam. The model is capable of simulating up to 9 layers extending 30 ft. below the No. 5 Coal to 45 ft. above the No. 6 Coal. Each layer was assumed to be homogenous and isotropic. Material properties for different layers were based on over 400 laboratory strength tests for rocks in the Illinois Basin Coal Field tested in the Department of Mining Engineering Geotechnical Laboratories. The geotechnical properties of different layers utilized in the analyses are given in Table 1. Vertical pressures of 600 psi were applied at the upper model boundary to simulate a 400-foot mining depth of the No. 6 Coal. Analyses were made with lateral pressures of 600, 1800, and 3000 psi ($m = 1, 3, 5$). The extraction ratios varied from 36 percent to simulate main entries to 70 percent to simulate working panels. An additional model was constructed to simulate staggering of pillars. Staggers of 10 percent and 20 percent were used to simulate errors in surveying, and 100 percent was used to simulate

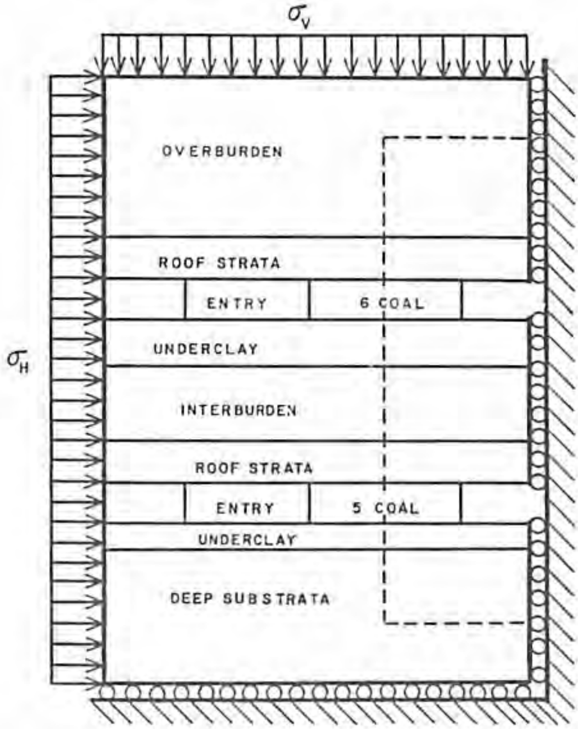

Fig. 4 – Schematic diagram of the panel FEM model. The data from the area enclosed in dashed lines were used for the safety factor calculations.

cases where pillar geometry in the previously mined seam is unknown. The nature of the interburden and immediate roof material was varied from a soft shale to limestone to simulate the extremes throughout the basin. Interburden thickness varied from a minimum of 25 feet to a maximum of 115 feet.

All models utilized plane strain quadrilateral elements with aspect ratios of less than 2.5 to 1 in the regions of high stress concentration or high stress gradients. Outside these regions aspect ratios were never greater than 4 to 1. The models consisted of 1520-2400 nodes and 1440-2260 elements with the smallest elements 1 ft. square next to the opening.

The stress data for model elements were analyzed for point by point safety factors using a parabolic yield envelope and laboratory strength data scaled by a factor of two. Contour plots of safety factors were prepared, and comparisons were made for openings only in the No. 5 and No. 6 Coals to openings in both seams to evaluate interactions due to multiple seam mining.

RESULTS AND DISCUSSION

Figure 5 is an example of analysis with 25 feet of shale interburden. The immediate roofs of the No. 5 and No. 6 Coals is also composed of soft shales. Note that the failed area (safety factor below 1.0) extends between the two seams. The shear failure starts along the rib of the No. 5 Coal and propagates upward to the No. 6 Coal. The interaction between the two seams is quite apparent in this example.

Figure 6 represents a similar analysis except that the interburden is now 85 feet. In this case the interaction is minimal, and therefore, the stability of either mine opening is unaffected by the other.

Figure 7 shows analysis with full stagger of pillars and an interburden of fifty feet and a lateral pressure of 1800 psi. The interaction in this example is minimal. Note the reduced size of the 2.0 safety factor contour above the No. 5 Coal pillar. The asymmetry is due to a stagger of 20 feet and a pillar width of 22 feet.

Several additional similar analyses were conducted to evaluate the effects of a strong stiff layer in the interburden, varying amount of pillar stagger in the two seams, and varying roof and floor conditions. The results of all analyses can be summarized as follows:

1) Interaction between mine workings in the upper and lower seam is predominant where interburden between two seams is 75 ft. or less. For interburden thickness varying between 50-75 ft., the interaction is relatively small. In other words, if the openings are stable while mining a single seam, the openings will also be stable if both seams are mined.

2) A massive stiff layer in the interburden reduces the interaction between the seams. For example, if the 25-ft. interburden has a 15-ft. layer of limestone in it, the minimum safety factor in the interburden is 3.0 as compared to 0.8 when the interburden is composed of soft shales. This is similar to the results reported by Haycocks (1982).

3) The underclay thickness does not significantly affect the degree of interaction. For example, increasing the underclay thickness from 2 ft. to 7 ft. with 50 ft. of interburden does not change the stability of the interburden. The effects of weak floor on stability due to weak floor is limited to the seam above it.

4) High lateral stresses seem to have little effect on the interaction. When the lateral stress is increased from 200 PSI ($m = 1/3$) to 1800 PSI ($m = 3$) the minimum safety factor in the interburden increased from 1.0 to 1.5. The high horizontal stress field seems to lower the pressure arch. If either seam is stable in the high horizontal stress field when mined individually, then both seams would be stable when mined together. Also no increase in stability was observed when the openings were staggered. This is due to the shallow arch height in room-and-pillar mining.

5) Staggering of pillars has little effect as compared to columnization. Other than slightly distorting the stress field, staggering does not affect the overall stability with interburdens of 50 feet or more. This allows independent sizing of pillars and entries in each seam to meet the roof and floor conditions of that seam.

Additional studies are currently being planned to include interaction effects due to multiple seam mining in high extraction areas such as retreat mining and longwall mining.

Table 1 – Material Properties Used in FEM Models and Safety Factor Calculations

Material	Density lb/ft^3	Poisson's Radio	Elastic Modulus x 10^6 PSI	Bulk Modulus x 10^6 PSI	Shear Modulus x 10^6 PSI	Compressive Strength (PSI)	Tensile Strength Strength (PSI)
Cover Rock	150	.25	.3	.2	.12	2000	120
Hard Roof Shale above No. 6	140	.15	.6	.2837	.2609	2000	180
Soft Roof Shale above No. 6	155	.15	.6	.2837	.2609	800	80
No. 6 Coal	85	.25	.3	.2	.12	3500	10
Underclay	150	.35	.05	.0555	.0185	450	10
Interburden Shale	140	.20	.3	.1667	.125	3500	200
Limestone	165	.10	2.25	.9375	1.0227	15000	1300
Hard Roof Shale above No. 5	140	.15	.6	.2837	.2609	8000	400
Soft Roof Shale above No. 5	150	.15	.3	.1429	.1304	3000	300
No. 5 Coal	85	.20	.3	.1667	.125	3500	10

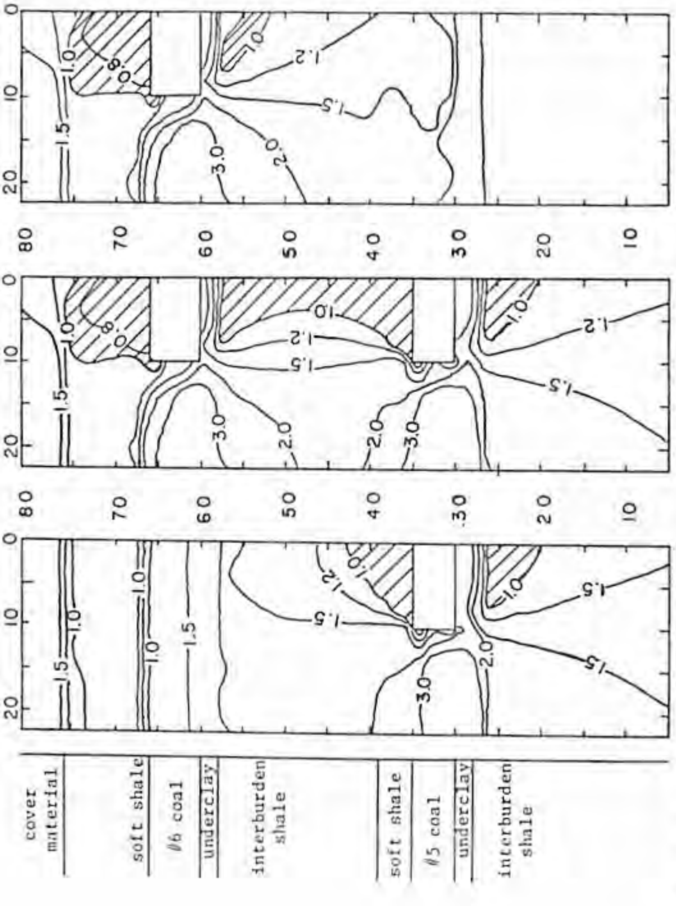

Fig. 5 – Safety factor contours with interburden 25 ft. and m = 3. Areas with safety factors less than 1.0 are shaded.

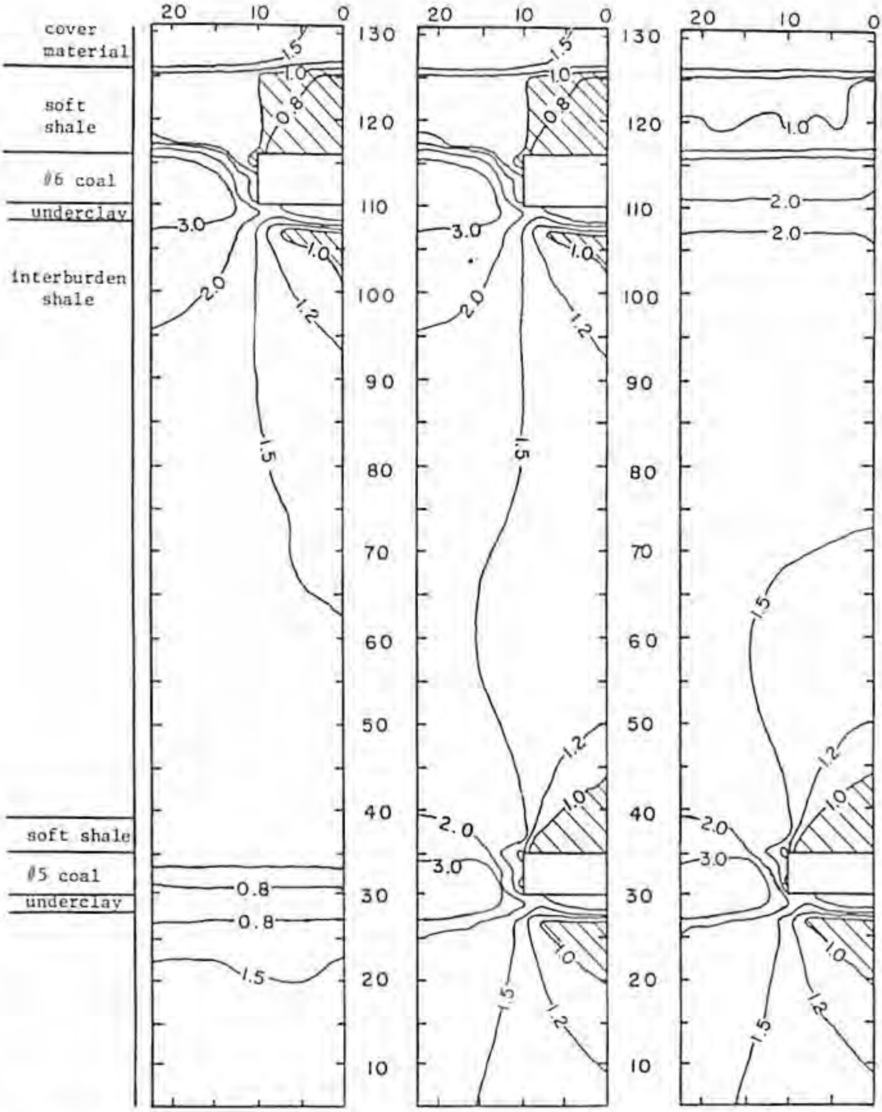

Fig. 6 – Safety factor contours with 75 feet of interburden and m = 3. Areas with safety factor less than 1.0 are shaded.

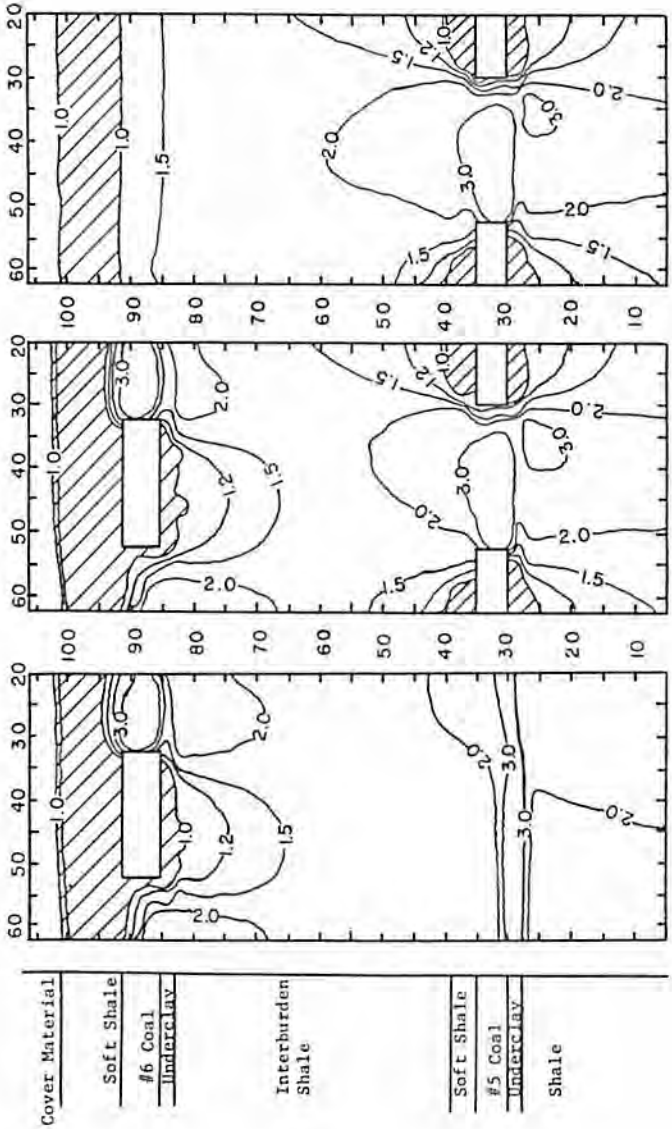

Fig. 7 – Safety factor contours with interburden of 50 ft. and m = 3. Areas with safety factors less than 1.0 are shaded.

ACKNOWLEDGEMENTS

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George May: My next speaker is Jack Nawrot. Jack has a B.S. degree from Blackburn College and an M.A. from Southern Illinois University of Carbondale. His paper today is "Enhancing Reclamation through Selective Slurry Disposal".

Jack Nawrot: I supervise the reclamation research portion of the Cooperative Wildlife Research Laboratory at Southern Illinois University. Dr. Klimstra, who began our program 35 years ago, supervises everything including what we call the "Bugs Bunny Program". Our lab started about 35 years ago doing reclamation research, and one of the main objectives of most of our research demonstration projects on mined lands is to provide very good opportunities for fish and wildlife habitat enhancement.

ENHANCING RECLAMATION THROUGH SELECTIVE SLURRY DISPOSAL

JACK R. NAWROT, S. C. YAICH, and W. D. KLIMSTRA
Cooperative Wildlife Research Laboratory
Southern Illinois University
Carbondale, Illinois 62901

INTRODUCTION

Current reclamation requirements require four feet of soil or other material be used as final cover on those slurry impoundments not capable of supporting vegetation. As experienced by many operators, implementation of this requirement is often expensive and extremely difficult due to problems of cover availability and surface stability. In many cases, operators cover portions of ponds, particularly the fine-grained silt/clay zone, that are capable of supporting vegetation without supplemental soil. Also, cover soil must be borrowed from an adjacent site resulting in creation of a problem to resolve a problem. This is especially important when slurry sites are in quality agricultural regions.

Examples exist throughout Illinois and Indiana of entire slurry ponds or portions of ponds exhibiting after a period of time a capability for supporting vegetative cover (Figure 1). Such plant communities vary from wetland and moist-soil

Fig. 1 – Favorable zones of many slurry ponds are often colonized by wetland species such as cattails (*Typha* spp.) and wild millet (*Echinochloa* spp.).

plants associated with seasonally inundated and saturated silt/clay soil types (Figure 2) to upland herbaceous and woody cover associated with drier coarse-grained slurry constituents. Extensive investigation of factors affecting the natural establishment of vegetation on slurry impoundments suggests that saturation and distance from the discharge point played important roles in controlling the acid-producing potential of slurry (Nawrot 1981, Nawrot and Yaich 1982a). Patterns of vegetation establishment on inactive ponds indicate that harsh phytotoxic conditions are concentrated in zones immediately surrounding discharge points.

Unfortunately, most slurry disposal operations utilize single-point discharge systems which result in concentrated and elevated accumulations of acid-producing coarse-grained pyritic materials at the point of discharge in the impoundment. Downslope from the discharge point acid-producing potential decreases rapidly if turbulent flow, or short-circuiting, does not resuspend and transport pyritic constituents farther. Although favorable or non-acid producing zones may characterize lower portions of recently inactivated ponds, oxidation and acidification, which begins near site of discharge, can adversely affect most slurry surfaces. Downslope transport of fine-grained pyritic materials and acid runoff ultimately reinforce the regulatory viewpoint that entire slurry ponds are acid producing.

The first step in recognizing the reclamation potential of selective slurry processing to produce a non-acid soil substitute is to appreciate that slurry is not necessarily a waste product of the coal benefication process. Often carbon recovery from slurry is considered economically feasible, and preparation engineers and mine management have addressed the problems of quality characterization and

Fig. 2 – Seedbed preparation, nutrient application, and supplemental planting of adaptable wetland species can enhance existing vegetation in favorable silt/clay zones.

identification of cleaning technology that accommodate carbon separation from other byproducts. Similarly, identification and separation of non-acid constituents from pyritic materials at given sites would seem technologically and economically feasible. While the reaction of management and engineers is to view selective handling as costly or logistically complicated, selective separation of slurry components already occurs as a natural process within many slurry impoundments. Because of this fact, efforts should be made to capitalize on existing favorable conditions within slurry impoundments, as well as investigate and develop practices that will enhance and refine segregation and selected placement of pyritic materials.

CURRENT SLURRY DISPOSAL PRACTICES – LIMITATIONS AND PROBLEMS

Most current slurry disposal practices utilize stationary single-point discharges resulting in differential distribution of slurry constituents due to interaction of flow velocity, particle size, and specific gravity. Slurry distribution from single-point discharges is characterized by physical and chemical gradients established between the high discharge and low decant ends of the basin (Table 1). Typical slurry distribution resulting from single-point discharge systems minimizes the extent of the non-acid producing zone.

Under normal conditions, zonation of an unmanaged disposal system results in 15 to 20 percent of the basin acreage being an extreme acid-producing Discharge Zone (Nawrot and Yaich 1982b). Net neutralization deficits in excess of 100 tons $CaCO_3$ eq/1,000 tons/acre mandates 4 feet of soil to comply with current regulatory requirements or flooding to prevent oxidation.

The immediately adjacent Intermediate Zone represents a transition from extreme acid-producing potentials of the Discharge Zone to marginal neutralization deficits treatable with incremental applications of agricultural limestone (25 to 40 tons/acre). Although the Intermediate Zone may be but 20 to 25 percent of a pond, vegetation establishment without soil cover is difficult and requires considerable labor and expense for limestone application. Just as high water tables and unstable conditions contribute stability problems when covering this Zone with soil, limestone application by conventional means, even with low ground pressure spreaders such as Big Wheels and Big A, may be impossible. Consequently, less productive, and more expensive (limestone applications @ $30 to $60/ton) practices are required, such as aerial limestone applications using fixed-wing aircraft and helicopters, liquid limestone application with hydroseeders, and pneumatic placement of fine-grained limestone. In addition to these cost factors, the naturally occurring calcareous slurry components that settle out in the Discharge Zone at rates exceeding 150 tons $CaCO_3$ eq/1,000 tons/acre should be capitalized on in reclamation planning. Depositing available calcareous materials with coarse pyrite fractions in the Discharge Zone while purchasing limestone and spreading at great expense on adjacent downslope areas is evidence of inadequate attention given preplanned slurry disposal and reclamation. Vegetation establishment without soil cover in the Intermediate Zone can be difficult because of need for limestone application; however, transporting or blending of the naturally occurring calcareous slurry

Table 1 – Slurry Impoundment – Management Zones; Generalized characterization of pre-evaluation site conditions and reclamation considerations.

Reclamation Management Zone	Water Table (AMWT)[1]	RECLAMATION CONSIDERATIONS				
		Revegetation Factors (Phytotoxicity/Nutrients)	Direct Revegetation Potential	Site Preparation	Amendments	Vegetation
High/ Discharge Cone	3.0-15.0'	Texture: Coarse-grained Soil Moisture: Droughty Acidity: Excessive total potential acidity (60-200 tons $CaCO_3$/acre deficiency at discharge zone; decreasing acidity downslope. Nutrients: pH limited	Poor Feasibility: Excessive liming required; application rates and potential acidity are limiting. Covering may be only feasible solution for areas with excessive acidity.	Cover (≥1') toxic materials in immediate vicinity of discharge cone. Stability analysis required. Optional: Direct lime and seed less toxic downslope portion.	Soil cover and limestone: 20-60 tons/acre limestone and 1,600 cu yds cover/ acre-foot. Neutralize only: Direct lime and seed (40-120 tons $CaCO_3$/acre).	Drought tolerant pasture/ prairie grasses and woody shrubs; shallow rooting depth will limit species selection. Nurse crop establishment for organic matter enhancement with interplanting of perennials.
Intermediate	1.5-3.0'	Texture: Coarse-fine; stratified Soil Moisture: Dry surface (0-6" to saturated subsurface (01.5'). Acidity: Total potential acidity may be high (50-80 tons $CaCO_3$/acre deficiency) at upper portion, decreasing downslope. Nutrient: pH limited in surface horizon; low in saturated root zone (below 1.5').	Moderate Feasibility: liming and leaching may be required to obtain initial vegetation establishment through leaching of accumulated acid surface salts.	Limestone application and incorporation limited to specialized low ground pressure equipment, hydroseeder, aerial and pneumatic application.	Lime amendment (20 to 60 tons $CaCO_3$/acre) may be required on upper zone.	Annual nurse/mulch crop and perennial grass and shrubs on mesic sites. Moist soil annuals and perennials at lower elevations of zone.
Low-Shallow Saturated Substrate	0.5-1.5'	Texture: Fine textured silts and clays Soil Moisture: Moist surface (0-6") over a shallow saturated substrate (1.5'). Acidity: Total potential acidity decreasing to moderate levels (10-40 tons/acre $CaCO_3$/ acre), with no active acidity in saturated subsurface. Nutrient: pH limited in upper horizon; low to moderate P and K in saturated zone.	Good Feasibility: Shallow saturated substrate provides adequate moisture and and prevention of pyrite oxidation to facilitate direct planting of adapted hydrophyte rootstock.	Initial nurse crop (millet) establishment on scarified surface followed by temporary water level increase (0.5'-0.8') to enhance seedling survival.	Lime amendment (10-20 tons $CaCO_3$/acre may be required for upper zone. Temporary inundation of millet and hydrophytes would preclude need for liming.	A diversity of moist-soil annuals and perennial hydrophytes can be directly established on the slurry surface - lowland trees and woody shrubs can be used to enhance diversity through the zone.
Low-Seasonally Inundated	0.0-0.5'	Texture: Very fine textured silts and clays. Soil Moisture: Annual saturation. Acidity: Limited acid potential (0-30 tons $CACO_3$/acre) with little or no active acidity due to saturation and inundation. Nutrient: Low to moderate P and K availability.	Excellent Feasibility: Extensive saturated zone and seensonal inundation provides natural leaching and ideal site conditions for hydrophyte establishment (from both seed and rootstock).	Handplanting required for all areas due to surface instability.	Lime amendment not necessary if moist-soil and wetland vegetation are the principal species.	Moist soil annuals and perennials adapted to seasonal inundation. Volunteer establishment may contribute significantly after initial stabilization.
Permanently Impounded	0.00-−15'	Permanent Water - 0.1-15.0'. Acidity: Buffering capacity should maintain circumneutral conditions.	Excellent Feasibility: Permanent inundation of silt/clay substrate provides ideal conditions for establishment of submerged and emergent wetland species.		Management and amendment of entire upslope slurry system generally precludes additional amendment needs.	Shoreline emergents, floating aquatics, and rooted submergents can be established to provide cover diversity and waterfowl foods as well as functional attributes of sediment filtration.

[1] Elevation above mean water table.

component lost in the Discharge Zone can contribute to an acceptable acid-base balance. Disposal management practices, which enhance the coarse-grained limestone recovery, can be designed so as to simultaneously reduce the fine-grained pyritic component that adversely affects the Intermediate Zone. Disposal practices, which contribute to pyrite reduction or calcite enhancement, can transform an acid-producing Intermediate Zone to a zone capable of supporting vegetation without soil cover.

The lowest management zones (Low and Impounded) of slurry impoundments represent the maximization of selective separation of favorable slurry constituents that can be expected to occur naturally in an unmanaged single-point discharge system. By the time the discharge flow has reached the lower zones of the pond, the silt- and clay-sized fractions of shale, clays, coal, and calcite represent the predominant slurry constituent in suspension. Consequently, if ponding depth and retention time are maximized and scouring or short-circuiting is prevented, only the finest-grained pyrite, or pyrite entrapped in other constituents, will enter this zone of favorable silt/clay substrates.

Ponds where resuspension and scouring of pyrite have not occurred are characterized by positive net neutralization potentials, with values as high as 32 tons/acre of excess calcium carbonate. It is these segments with positive acid-base balances and high water tables that have colonized by native wetland vegetation. These zones represent 35 to 50 percent of the pond acreage and provide the most dramatic results in recent experimental practices where wetland habitat development was implemented as a cost effective reclamation alternative (Nawrot and Yaich 1982b). Soil conditions associated with the silt/clay fraction in the Low and Impounded zones are so favorable, that reclamation needs only to diversify and enhance wetland plant communities which rapidly colonize this desirable substrate. In fact, the only constraints to developing quality wetlands result from limited quantities of ecotypically adapted wetland plant materials and too little watershed or inadequate freeboard for seasonal and/or permanent inundation. Slurry disposal management to maximize and increase moist soil and inundated wetland zones requires preplanning that provides for adequate watershed and sufficient embankment freeboard. Also important are water level control capabilities to capitalize on favorable properties of silt/clay slurry constituents to support productive wetland habitats.

SLURRY DISCHARGE MANAGEMENT – PREPLANNING TO PREVENT PROBLEMS

There have been frequent invitations from the coal industry to characterize existing impoundments and evaluate the potential for slurry reclamation without soil cover. After study of more than 1,900 acres of slurry impoundments and results of more than 28,000 chemical analyses, it is obvious that slurry disposal and management technology is making little or no progress. Because slurry is a by-product of processing coal and industry treats it as waste, there is perpetuation of the negative stereotype that slurry is acid-producing and requires 4 feet of soil cover for regulatory compliance.

Mine superintendents maintain production levels, preparation engineers ensure coal quality, and mine engineers plan and survey new ponds when old ponds are filled. Consequently, ultimate slurry pond reclamation responsibility often rests with individuals not involved in planning and designing disposal systems. Understandably, the "waste product" environmental engineers or reclamation personnel are required to handle often offers little or no opportunity for implementation of reclamation alternatives other than 4 feet of cover. In the absence of preplanning and implementing slurry discharge/disposal management practices, the acid stereotype is enhanced, and industry does not fully benefit from minimized slurry reclamation costs.

The main objective of discharge management is to selectively distribute slurry constituents to improve physical, chemical, and topographic characteristics of impoundments. Fortunately, many practices that enhance reclamation feasibility of an inactive impoundment also improve sediment settling and hydraulic efficiency of an active impoundment. Disposal practices designed to selectively place slurry constituents capitalize on specific gravity differences of target constituents such as coarse and fine-grained pyritic and calcareous materials, fine and coarse-grained coal fragments, and fine-grained silt/clay constituents. Increasing sediment retention time and decreasing flow velocity results in an increased surface acreage covered by silt- and clay-sized slurry fractions, and a decrease in acid-producing discharge acreage.

Although current disposal practices result in differential gravitational settling, the degree of differential settling and separation of slurry constituents produces a zonation that seldom achieves the full potential of selective placement. The non-acid producing silts and clays settle out in the decant zone where permanent inundation precludes the need for covering (soil or water) these materials. Ideally, the fine-grained materials should be used to cover acid-producing pyritic materials which settle out closer to the discharge point. The velocity and location of the discharge should be managed to eliminate extensive deposition of pyritic materials above the final ground water elevation. Coarse-grained discharge constituents should ideally remain below the water table and below the silt- and clay-sized fraction. Discharge velocity and ponding depths should be carefully managed to prevent short-circuiting and excessive flow velocities which might resuspend and distribute pyritic materials throughout lower zones. Discharge and decant locations and elevations should be designed to prevent steep topographic gradients that result in detrimental scouring and resuspension of pyritic materials under conditions of insufficient ponding depth.

Design and management of slurry impoundments to selectively place constituents could utilize many techniques practiced by the U.S. Army Corps of Engineers in dredged material containment and placement (Gallagher et al. 1978, Johnson and McGuinness 1975, Montgomery 1978). Many options (e.g., energy dissipators, multiple discharge points and manifolds, floating discharge point and baffles, multicell design, etc.) are available to improve disposal practices and final slurry distribution. However, significant improvement in coal mine slurry impoundments could be made through relatively simple planning and management of existing discharge systems. The sequential movement of discharge points to place pyritic materials below the final water elevation would be the first step in minimizing adverse effects of above grade discharge materials mounds. A final placement of the discharge point to reduce flow velocities and short circuiting, and maintenance of increased ponding depth and sediment retention time can maximize the capping of previous discharge points with the favorable silt and clay fraction.

SLURRY DISCHARGE MANAGEMENT – FIELD DEMONSTRATIONS

Although pre-planning and implementation of site specific discharge disposal that selectively separates slurry constituents has not yet been carried to completion, the Cooperative Wildlife Research Laboratory is collaborating with industry in two full-scale reclamation demonstrations. Management practices at two Illinois mines where accidental and partial implementation of designed slurry handling have occurred may reduce the need for soil cover by 75 percent. While these preliminary management demonstrations have not yielded the most optimal results in separation of pyritic constituents or minimization of potential acid-producing slurry acreage, the level of accomplishment has been extremely encouraging. As a result, there is obvious interest by mine management personnel to pursue similar practices at other suitable sites. In addition, both the site specific experience and general principles demonstrated have served as a focus for fine-tuning and outlining comprehensive planning for future slurry discharge management.

Cyclone Processing for Pyrite Reduction

A potentially attractive slurry management technique to reduce pyritic sulfur content was demonstrated by chance at a surface mine in southern Illinois. As premature filling of an 80-acre slurry impoundment necessitated a reduction in solids input, two 24-inch classifying cyclones were installed on the main slurry line. This maximized return water flow to the preparation plant and reduced further input volume to only the fine overflow fraction. The fine-textured cyclone overflow materials were discharged over previously deposited slurry forming a silt/clay cap ranging in thickness from 6 to 38 inches. As laboratory personnel had already initiated establishment of a 10-acre wetland plant propagation area in the lower zones of this pond (Figure 3), the scope of the project was expanded to investigate the feasibility of using the silt/clay cycloned cap as a substitute for soil cover for the potentially acid-producing upper pond zones.

Suitability of the silt/clay cap as a non-acid producing cover substitute was supported by acid-base balance analyses of the cyclone overflow materials when compared to the coarse-grained pyritic underflow; the fine-grained silt/clay materials had undergone a 69 percent reduction in pyritic sulfur (relative to raw slurry). Pyritic sulfur had been reduced from approximately 1.9 percent in raw slurry to 0.63 percent in fines. However, concurrent with the cyclone reduction in coarse-grained pyrite, desirable coarse-grained calcareous materials also were reduced by 65 percent in the overflow silt/clay cap. Consequently, although the overall acid-base balance of the cyclone fines constituted a "non-acid producing" value (i.e., 32 tons neutralization potential versus 20 tons potential acidity), this cap material cannot be assumed free of potential acid "hotspots". While the cyclone

Fig. 3 – Non-acid producing cyclone overflow materials provided saturated substrates ideally suited for establishment of desirable wetland species such as hardstem bulrush *(Scirpus acutus)* (top) and sweet flag *(Acorus calamus)* (bottom).

effectively reduced pyritic sulfur, loss of the coarse-grained calcareous component unfortunately produced a slurry with reduced buffering capacity. Field evaluation of any actual acid production will be necessary to determine if cycloning produces a silt/clay cap acceptable as a soil substitute.

After one and a half growing seasons, both the 20 acres of wetland species and approximately 60 acres of upland grass-legume cover have performed exceptionally well. In fact, during August 1984 when most hay crops in southern Illinois appeared drought stressed, the red-top *(Agrostis alba)*, creeping foxtail *(Alopecurus arundinaceus)*, and white sweet clover *(Melilotus alba)* cover showed vigorous growth. Hopefully, these favorable growth conditions will persist despite indication of occasional hotspots or marginal acid-base balances.

While cycloning to reduce pyritic sulfur has produced dramatic results, this initial effort must be expanded and refined to improve and to ensure quality cap materials. Further, it must be appreciated that the effort at one mine must be evaluated before application at other sites, as regional differences in the quality of roof, floor, and parting materials are as variable as given coal seams and associated mining techniques as well as coal preparation practices. Unquestionably, the use of the cyclone demonstrated the possibility of a process that may contribute to reduction in acid-producing potential. Because of important economic benefits of a soil cover substitute contributed by components of slurry, preparation and reclamation engineers must now work together to ensure that the full potential of this technology is pursued.

The cyclone system responsible for reducing pyritic sulfur in the above 80-acre cell was not specifically designed to enhance reclamation potential of overflow components. However, with modification of current cyclone designs used by metals processing industries, operational characteristics might be significantly improved to enhance neutralization capability to further reduce acid potential. Evaluation of current design specifications of available cyclones, as well as determination of optimal characteristics (i.e., apex diameter, vortex finder length and diameter, feed concentration and volume, etc.) suggest it is feasible to develop a system that can optimize separation of non-acid slurry constituents from run-of-mine slurry feed.

After separation of slurry into non-acid cover materials and pyritic wastes, many opportunities exist for development of innovative and cost-effective reclamation alternatives. The non-acid constituent could be used as a final cover for pre-May 1978 impoundments or as a soil substitute for post-law impoundments. Sequential disposal using cycloned separates (i.e., covering previous pre-law impoundments and capping acid-producing cycloned separates) has the potential for nearly complete elimination of a soil cover, reducing an expensive and difficult aspect of slurry pond reclamation.

To fully capitalize on the potential of cyclone processing, pre-planning is essential. Analyses are needed for run-of-mine slurry feed representative of geological and operational conditions associated with each mine site. Delineation of percent composition of acid and non-acid constituents within various size fractions will be important in assessing the applicability of this technique to reduce pyrite. To more readily meet the objectives for reclamation it is recommended that preparation engineers initially approach slurry processing only as a pyrite reduction and neutralization potential enhancement process. Efforts to combine fine coal recovery with pyrite reduction constrain the effectiveness and simplicity of the cyclone process, as multi-stage processing will be required to deal with two slurry constituents of distinct specific gravities. Collaboration with design engineers of cyclone equipment manufacturers can provide additional hydraulic engineering expertise to identify existing cyclone systems and necessary modifications to achieve a practical and functional slurry processing system. Equally important, input of soil scientists is needed to ensure that cyclone processing produces an acceptable non-acid cover component capable of supporting the intended post reclamation use, whether it be wetland habitat development or agronomic practices such as pasture or hay production.

DISPOSAL MANAGEMENT FOR SELECTIVE SEPARATION

A second field demonstration of slurry discharge management recently produced promising results at a surface mine in northwestern Illinois. Capitalizing on the principle that slurry constituents of different specific gravity and particle size settle out naturally in response to physical factors associated with Stoke's Law (i.e., flow velocity, pond morphology, and detention time), efforts were made to enhance the discrete settling process by management of both the sequence and placement of the discharge point location. Most importantly, those discharge practices that were to be minimized or eliminated were those that frequently contribute to undesirable topographic gradients and the distribution of acid-producing components throughout the pond surface.

Major emphasis was placed upon sequential movement of a floating slurry discharge line around the pond perimeter to achieve a level topography and prevent deposition of coarse-grained pyritic slurry constituents above the final pool elevation. Maintenance of adequate ponding depth was a key factor in maximizing the settling efficiency for coarse pyritic material and preventing short-circuiting and subsequent scouring of pyritic materials downslope over the non-acid silt/clay sized slurry fraction. These simple management practices were implemented with the initial intention of enhancing the effectiveness of the natural settling process so that the extent of the acid-producing Discharge and Intermediate Zones could be minimized.

Subsequent placement of discharge points and water level management in the final stages of the discharge management plan were designed to cover previous acid-producing discharge areas with favorable silt/clay cap materials. However, premature termination of mining activities prevented completion of slurry discharge management as originally planned. Despite the inability to complete the silt/clay capping process, the laboratory continued the physical and chemical site evaluations to delineate the distribution of previously deposited slurry constituents. Although reclamation of the 80-acre impoundment through wetland development would have to be reduced in scope, it was hoped that an alternative to the plan for covering the entire impoundment with 4 feet of soil was possible.

After implementation of discharge management practices for approximately 7 months of disposal, 10 discharge points had been established. Post-disposal investigations identified distinct and abrupt textural, chemical, and topographic segregations within short (100-300 feet) distances from slurry discharge points. In general, two distinct chemical and textural classes were observed. Primarily coarse-grained ($>$ 200 mesh) pyritic materials, shales, sand, coal, and calcareous components were concentrated from the point of discharge extending approximately 200 to 600 feet downslope where non-acid producing silt/clay slimes (i.e., $\geq$60 percent silt and clay) settled out in less turbulent discharge flows. The favorable silt/clay constituents comprised a distinct mud flat similar to seasonally inundated zones of natural wetlands.

Unlike most unmanaged slurry ponds where high discharge velocities and scouring transport pyritic materials throughout much of the pond profile, sampling along discharge gradients and paired samples of naturally deposited adjacent coarse and fine-textured slurry materials dramatically illustrated the principle of selective slurry separation with even minimal discharge management practices. High potential acidity values (e.g., $>$ 100-200 tons $CaCO_3$ eq/1,000 tons) and neutralization potential values (e.g., 40-100 tons $CaCO_3$ eq/1,000 tons) were concentrated at the points of discharge in association with coarse-grained materials. As discharge velocity decreased, downslope concentrations of both coarse-grained pyritic and calcareous constituents decreased gradually until rapid abrupt decreases in potential acidity (e.g., $<$ 20 tons $CaCO_3$ eq/1,000 tons) were reflected in the final transition to the silt/clay zones.

Maintenance of adequate ponding depth and regulation of discharge point locations resulted in silt/clay slime deposits characterized by 60 to 98 percent reductions in potential acidity values (relative to discharge areas). Acid-base balances with minimal neutralization deficits (i.e., 5-10 tons $CaCO_3$ eq/1,000 tons) and excess neutralization potentials of 3 to 13 tons $CaCO_3$ eq/1,000 tons indicated the need for little or no limestone amendments for about 50 percent of the 80-acre impoundment.

Evaluation of watershed characteristics, slurry infiltration rates, and macro- and micro-nutrient status of the silt/clay slurry constituents indicated the suitability of pursuing a wetland/wildlife habitat reclamation alternative for the lower 40 acres of the 80-acre pond. Because this reclamation alternative would be delayed until final plans were completed and regulatory approval received, remedial measures (straw bale barriers) were taken to prevent pyritic materials in the Discharge and Intermediate areas from eroding downslope prior to completion of soil covering.

While not being able to complete this discharge management plan was disappointing, the dramatic reduction in pyritic sulfur resulting in the elimination of soil cover for the proposed 40-acre wetland/wildlife area was extremely encouraging. Even as soil covering continued on the acid-producing Discharge and Intermediate Zones, desirable wetland species have begun the natural colonization process on the silt/clay wetland substrate, clearly demonstrating the potential of selective slurry disposal as a cost effective alternative for regulatory compliance.

ADDITIONAL SITE SPECIFIC DEMONSTRATIONS ARE NEEDED

While slurry management technology is still more of an art than a science, experience gained through additional applications of those hydraulic, physical, and chemical principles governing the selective separation process will demonstrate the importance of addressing site specific conditions when expanding and implementing these practices by the mining industry. Regulatory acceptance of selective processing as a reclamation alternative should not be based upon the assumption that all slurry can be rendered non-acid producing, but, that all slurry constituents, similar to overburden, are not acid producing.

Therefore, to gain regulatory acceptance it will be the responsibility of the operator to demonstrate the most effective technique(s) to remove or selectively process the acid-producing pyritic component. Pre-planning slurry reclamation as part of the coal cleaning and disposal engineering process will ensure that slurry is no longer treated only as an acid-producing waste, but a potential recoverable soil resource.

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George May: Do you have any questions for Jack?

Question from floor: Did you look at trace metal uptake in the vegetables that you are growing there?

Jack Nawrot: People always ask about that. There wasn't a problem with it because in order for trace elements, such as zinc and copper, to be mobilized, generally the soil has to have low pH. In order to grow vegetables, we had to have a pH of about 5.8, so we never have to analyze the watermelons, cucumbers, or other vegetables. People have eaten them and have had no ill effects. The data are living proof that it's safe. But every pond is different. Everybody has the misconception that a slurry pond is made of waste material, and the minute you mention waste material people think of toxic waste and heavy metals. It really isn't the case in most of our Midwestern and Illinois slurry ponds.

Question from floor: Jack, what kind of reaction are you getting from your former colleagues and regulators as to the permanent use of slurry for reclamation?

Jack Nawrot: Maybe they would like to answer for themselves, I'm not sure. The turn of events that helped us is that now everybody is screaming about saving wetlands. When we started this thing a wetland was something you drained and grew corn and soybeans on. So now you have to save the wetlands and show this as a desirable land use. I think that there are a lot of advantages to having wetlands.

I know that within Illinois, at the Sunspot Mine for example, we've had a nice wetland up there. Through the variance we can have a chance at demonstrating that type of thing, and we've been working on that as an experimental practice in Indiana right now. Like I said, if you look at our native wetlands and then you look at the wetlands in slurry ponds, you have equally as diverse vegetation and good water quality. So there is no question that we can produce what is a diminishing resource here in the Midwest through using slurry ponds as wetland development areas.

Remark from floor: I commend your work, and I think your wetland study is worth the effort. Reclamation is very important. But regarding the management of this disposal of slurry, whenever you move from one spot to another you ruin the potential of going back at a later date and reclaiming the slurry for fuel content. Our experience in Indiana has been that when you keep the point of entry to one particular spot you will have your coal separated in a natural sequence. Thus, I concur with what you say with regard to the particle size, the deposition of pyritic material, and so forth.

Jack Nawrot: We've found that in all the pre-reclamation characterization studies where there was a single point discharge, the coal was about 800 to 1,000 feet out, and the silt and clay was further. Moving the point of discharge and mixing the silt-clay with the coal materials will interfere with subsequent carbon recovery. The thing that probably would be more of a disadvantage to you as far as carbon recovery would be to have to dig through a 4-foot soil cover to go get what you had to cover in 1984. So there's an advantage in what we're proposing too. Even if you mixed it, it might work over a larger portion of the pond. We take samples and talk to the preparation people and cyclone engineers and tell them to extract the pyrite from the slurry pond so that we can develop favorable soil. For some soil types we would just as soon have that coarse-textured coal material mixed with the calcitic material as a complete soil type rather than wasting the coal or the limestone that occurs naturally in slurry. We would just as soon have that mix without the pyrite, because if you got rid of the pyrite, you would be a step ahead of the coal recovery process later on anyway.

George May: Are ther any other questions?

Question from floor: Have you had any reaction for increased need for liners, and has there been any consideration of the effects of pyrite materials on the groundwater?

Jack Nawrot: Well, that is the situation now. You can always typify the basic pond with a cross-section as shown up there. You have an acid-producing discharge area that's above the water table. That's where the undesirable acid-producing material is located. It is best to get below the water, and we achieve that in our overall reclamation plan. Then we pull the calcitic material out and distribute it in the lower ⅔ of the pond where we have marginal potential acidity. Overall we develop a better soil system as far as acid-base balance is concerned. We have a saturated environment below the surface as well as a well-blended surface component. So we'd end up with probably a better overall scheme, and the question about pond water is just that. You've been approached by somebody that said, "Well if your slurry is below the water table then you'll have acid contamination in the groundwater." That one diagram that showed saturated substrata is fairly representative of the groundwater of most of the ponds we've sampled. Every time we sample groundwater and we get to that saturated zone, we'll find a few of what we refer to as the nation's worst slurry pond in southern Illinois. We find pH's of 6.8 to 7.2 and above from 18 inches to 7 feet down in that pond. If you pull that material out and expose it to the air, it will acidify. Since the slurry is flooded, it hasn't acidified for 20 years. It's the surface-aerated zone that acidifies.

George May: Thank you Jack. I wish to thank all of you for coming and attending the session this afternoon. This concludes our papers. Also, let me once more give all the speakers a hand for extremely well-presented talks (Fig. 1).

At this time the session is adjourned.

Fig. 1 – Speakers in the technical session of Thursday afternoon. The speakers are (from left to right): technical chairman – George May, Jack Nawrot, Christopher Ledvina, Paul Ehret, and Roger Missavage.

MORNING SESSION

The Friday morning Business and Technical Sessions convened in the Ford Room, Holiday Inn East, Springfield, Illinois at 8:15 a.m., October 5, 1984. President James Chady presided.

BUSINESS SESSION

President Chady: The first order of business this morning will be the Secretary/Treasurer's report as given by Heinz Damberger.

SECRETARY-TREASURER'S REPORT

Heinz Damberger: Good morning. I'm sorry we had to schedule this business meeting so early, but our technical session is longer than usual. Let me first briefly report on our status of membership and attendance. Yesterday we had 697 people attending. There are 23 students in addition. We expect that there will be some additional people registering today so the total will be probably somewhere around 800. Last year at the close of the day on Thursday, we had 784, so we are about 80-90 people short of last year's attendance. We had about 50 students last year, so the total attendance last year was 847. *(The total attendance in 1984 was 739 including 26 students.)*

I have some copies of the audited financial statement here. If any of the members want to review it, they may do so. The financial statement has been audited and approved by the Auditing Committee. Basically it shows a reduction in our assets by close to $4,000. That is a substantial deficit that we show in this past fiscal year. We've been showing deficits for several years now, so the Board decided that something will need to be done. Actually this year's deficit looks a little larger than it actually is because we are cutting off earlier than usual. Therefore, we haven't gotten quite a few of the checks for the advertising in last year's *Proceedings*. We estimate that this is close to $1,500, so the deficit will be less than what is shown. The Board yesterday decided that next year we will charge $3.00 attendance fee or registration fee in addition to the membership fee. This is for one year only. We want to see how things are developing, and hopefully we will not need to charge this fee in the future. It is primarily to defer costs of the meeting and in particular the fellowship hour, which costs about $6,000. This should generate about $2,000 to $2,500. Also we decided that we would raise the charge for advertising in our *Proceedings* by about 10 percent rounded off to the nearest $5. That again should generate something like $2,000 to $2,500. This will be implemented for the 1985 *Proceedings*, so we will be generating income in 1986 from this decision. We have not changed our fees for quite a number of years. It has been the same for about 5 years. Also, the Board was debating whether the meeting should be moved from Springfield closer to the coal fields and thus increase the attendance. Certain members of the Board were asked to check into the facilities in Mt. Vernon and Marion. We'll also check out the convention facilities here because one of the ideas is that we might want to add exhibitors to our meeting. The facilities should have enough space to have exhibitors in connection with our annual meeting. This is just in an exploratory stage. And lastly, the Secretary was asked to hold down expenses as much as possible. You may have noticed some of this yesterday during our fellowship hour.

I think this about concludes the report. I'll certainly be willing to field any questions at this point. As I said, if you are interested in looking at the financial report, it is available here. Thank you.

President Chady: Thank you Heinz. The next order of business is the Nominating Committee Report for the slate of officers for next year, which will be presented by M. E. Hopkins.

NOMINATING COMMITTEE

M. E. Hopkins: I am substituting for Dale Walker, Chairman of the Committee. The Committee consists of Dale Walker, George May, and myself. The Committee has chosen the following members for presentation at this time: Robert Izard for President; David Beerbower of Freeman United for First Vice-President; Mack Shumate for Second Vice-President; for four members of the Executive Board – Ron Morris of Sahara; Gordon Roberts of Monterey; Joseph Schonthal, Jr. of J. Schonthal and Associates (a third generation of board members); Taylor Pensoneau of the Illinois Coal Association; and a real hard choice for Secretary/Treasurer, Heinz Damberger.

President Chady: Thank you Hoppy. Would there be any nominations from the floor? Then would someone make a motion that these nominations be accepted?

IMI Member: I so move.

President Chady: Is there a second? All in favor say "aye". Opposed? That approves the slate. Doc, who is the chairman of the Honorary Life Membership Committee, is not here. This year we have two outstanding gentlemen who have been selected for Honorary Life Membership. They are Gene Moroni formerly with Old Ben Coal Company, and Minor Pace who has been with Inland Steel Company. The next order of business is the Scholarship Committee Report, George Eadie, Chairman.

SCHOLARSHIP COMMITTEE REPORT

George Eadie: Besides myself the Scholarship Committee consists of Jim Yancy from Freeman United Coal and Kevin Brooks from Consolidated Coal Company. The Committee this year again requested the Board to provide the same funds for scholarships for the coming year that were provided this year, and the Board has approved. This year the Board allocated $5,600 to five schools and as is our tradition, we will ask each of these schools to give us a brief report on what's going on in their program. Some people aren't here yet so I will have to change the order of presentation and ask Professor Sprouls to start by giving the report on his school, Indiana State University at Evansville.

Professor Sprouls: Indiana State at Evansville describes its location. We are a branch campus of Indiana State University at Terre Haute, presently with 3,800 students, which includes about 250 in engineering technology. This includes the disciplines of civil, electrical, mechanical, and mining engineering technology. The $750 received from the Illinois Mining Institute provides two scholarships: Our recipients were David Weaver, who is a senior, and William Peters, who is a junior, in a four-year mining engineering technology program. We wish to thank the Illinois Mining Institute for making this scholarship money available to these deserving students.

George Eadie: Thank you Eric. The report of the University of Wisconsin at Platteville will be given by Dr. John Krogman.

John Krogman: Thank you George. We were allotted $750 again by the Illinois Mining Institute, and once again we divided that among three students. This year's recipients are Jeff Van Zummeren, who is a senior from Waupaca, Wisconsin; Kirk Hillman, who is a senior from Wisconsin Dells, Wisconsin; and John Jones, who is also a senior from Platteville, Wisconsin. On behalf of those students and my department chairman, Bob Reeder, I would like to thank the Illinois Mining Institute for their continuing support of our program which helps us in recruiting students to our four-year mining engineering program. Thank you very much.

George Eadie: Thank you John. The Southern Illinois University is one of the schools this year that has a new department head. To give that report for Southern Illinois University is Dr. Paul Chugh, Chairman of the Mining Engineering Department.

Paul Chugh: Thank you George. $1500 were allocated to the Department of Mining Engineering for scholarships by the IMI. We gave three scholarships of $500 each based on academic merit. The three students were seniors in either the mining engineering program or mining technology program. They have all graduated. Tom Roscetti, who was the scholarship holder for the mining engineering program, is currently pursuing his Master's program in the Department of Mining Engineering at SIU-C. We are really proud to have Tom with us, and I will be introducing him to you at the luncheon meeting again. The other two scholarship holders were Mr. Michael Storm and Mr. John Dozier. I have prepared a three-page flier about the department, and it is on the back table. I would appreciate it if you would take a flier and learn a little more about the department. We have appreciated the support of the IMI in the mining engineering and mining technology programs at SIU-C, and we hope this support will continue in the future. Thank you.

George Eadie: Thanks Paul. The new Department Head at the University of Missouri at Rolla, Dr. Charles Beasley. Dr. Beasley has been at Rolla for a year now and will give a report on the University of Missouri-Rolla.

Charles Beasley: We do want to tell you that we really appreciate the support that you've given to the school, and as a department chairman, having looked over the record of support, this is very much an enviable record. It goes back about 92 years, and I understand in your by-laws you even spoke to the needs for support of student programs at that time. You've carried through with it since that time, so I don't know if anyone in the country can match you at that duration and level of support. We are very appreciative of that. Our student holders of the awards are here with us this morning, and I would like to have both of them stand up. One is

Mr. Bruce Yoder, and the other is Mr. Mike Savage. Both of these men are juniors, and both coincidentally, are the sons of engineers. Although we didn't get their fathers in the right profession, had they studied harder we would have gotten one out of metallurgy and one out of aerospace-electrical engineering. These two students also illustrate something else that I think is very important for you to know. One, Mike Savage, is a co-op student who is largely supporting himself as he puts himself through school. It takes a lot of time and effort to do that as you fellows who are in co-ops know. Bruce, on the other hand, is a participant in our mine-rescue team. That is an activity that gets no credit, but requires a lot of practice time. They are going to compete next weekend against a lot of company teams in a rescue competition that we hold annually now at Missouri at our practice mine. You're all, by the way, invited on October 11th to that competition. So both are taking a lot of time outside of class to do other activities, and we appreciate their efforts.

Let me share another piece of good news with you. We are ground-breaking on October 18th for our brand new $21,000,000 Mineral Engineering Building. Finally, the legislature saw things the same way the mining industry does, so we are getting the Mineral Engineering Building under way at that time. It will supplement our experimental mine and Rock Mechanics and Explosive Research Center, which we're all very proud of on our campus.

Let me share another piece of good news of what support like yours can do. This very morning a shuttle went up again, and I heard the voice of a fellow who grew up in a small mining camp in southern West Virginia, the same mining camp that I grew up in, as a matter of fact, Bragg, West Virginia. Commander Johnny McBride is flying this morning. He grew up in the same house a few years later, that I grew up in. It's the kind of support that you men supply that gets people through school. Thanks again for your kind support.

George Eadie: Thank you very much Chuck. The community college programs are represented this morning. The Wabash Valley College program will be presented by Mr. John Howard.

John Howard: The Wabash Valley mining program is in its fourth year, and we have expanded from one location in Mt. Carmel to five additional locations. The scholarship monies were divided equally to provide one scholarship to one student in each of the six mining technology sites that we have in Illinois. The recipients are: Mr. Steve Timming from the Mt. Carmel facility, who works for Old Ben; Mr. Mike Waite from the Centralia-Kaskaskia mining site; Mr. Mike Liles from Lincoln Land Community College; Mr. George Pepovich; Mr. John Wards from the Southeastern Illinois facility; and Mr. Todd Bohlen from our college in Marion. And I might add that during this time of the relatively limited opportunities – the scholarship recipients appreciate the bright news probably more than at any other time. On behalf of the faculty, staff, administration, and students for all these community colleges, I thank the Illinois Mining Institute for its support. Thank you.

George Eadie: Thank you John.

These college representatives in the last couple of years have been driving up in the morning, and I suspect they've been caught by the change in time of the business meeting. I'm sure that they will be at the luncheon meeting. I want to thank the members of the Scholarship Committee and the Institute for their support during the past year. Would all the students in the room please stand up.

We will see you at the luncheon. Thank you very much. That concludes the Scholarship Report.

President Chady: Thank you George for your report on this whole worthwhile function of the IMI. It was decided at the Board meeting yesterday that even though we did have a financial problem, we certainly weren't going to try to cure it by cutting down on the scholarships. That's why we have asked that for next year we will have the $3.00 registration fee in addition to the dues for those who attend the meeting. Our greatest source of revenue comes from our advertising that is in the *Proceedings* every year. That is a group that tirelessly works on this project through the year to sell this advertising in order to get the annual report out each year. Is Lanny Bell, Chairman of the Advertising Committee here? Well if Lanny comes in we'll ask him to give the report from the committee.

TECHNICAL SESSION

President Chady: If you will have a seat, we will begin our technical session. I would like to welcome all of you to the morning session of the technical program.

The Chairman of this morning's session is George Land, who is the Director of Technical Assessment for Amax Coal Co. We have a fine program lined up for you this morning, and I hope you all enjoy it. George.

George Land: Thank you. One thing he didn't tell you and that I am going to tell you is that if you will look at the program you will see that we've got a very tight schedule this morning. We have seven papers scheduled for 2½ hours, and that means we are going to have to move right along. As you also can tell by looking at the program, our first four papers have to do with fine-coal cleaning or characterization methods, research, and the ways to improve the product by the so-called deep coal cleaning. I am hoping we will have time for questions, but if we don't, I'm sure that if you have any questions, the speakers will be glad to talk to you after the meeting. Without further ado, I will get at this business of being a program chairman. Our first speaker comes to us from the U.S. Department of Energy, the Pittsburgh Energy Technology Center. His name is Carl P. Maronde. He is a graduate of the University of Pittsburgh with a B.S. in mining engineering. He went to work with the U.S. Department of Energy when he got out of school. He's been there since then doing research in coal preparation under Al Beaubrock whom many of you know. He is well qualified to address us on the subject of "Fine Coal Beneficiation – Current Practices, New Directions." Mr. Maronde.

Carl Maronde: Thank you George. I would like to thank you all for showing up this morning. Coal preparation has evolved over the years from simplistic methods of removing impurities from coal to a very costly, complex technology requiring sophisticated instrumentation.

FINE COAL CLEANING: CURRENT PRACTICES, NEW DIRECTIONS

ALBERT W. DEURBROUCK
Division Director
Coal Preparation Division

CARL P. MARONDE
Mining Engineer

Pittsburgh Energy Technology Center
U.S. Department of Energy
Pittsburgh, Pennsylvania

INTRODUCTION

Over the years, coal preparation has evolved from a simplistic method for removing liberated impurities from coarse coal to a complex technology requiring sophisticated instrumentation and control to assure rejection of pyrite and other mineral matter from finely ground coal.

The first recorded attempt to wash coal mechanically occurred in Saxony in about 1830, when a hand-operated movable-sieve jig was used to stratify heavy mineral matter from the lighter coal. Today, coal is almost universally cleaned by mechanical methods, although some hand picking is still practiced because of unique local conditions. As shown by the statistics in Table 1, conventional coal-cleaning devices, such as jigs, dense-medium vessels, dense-medium cyclones, and concentrating tables, all clean large tonnages of coal. While these devices are relatively efficient, they are generally limited to cleaning only the coarser sizes of coal ($>$ 0.5 mm), and it is known that both recovery and quality of product can be improved significantly through size reduction to liberate the mineral matter and pyrite associated with the coal.

FINE COAL CLEANING OF LOWER FREEPORT COAL

An excellent example of the pyritic sulfur liberation attainable through size reduction is shown in Figure 1. Here, a sample of Lower Freeport coal from Pennsylvania was riffled into five aliquots and crushed to the different sizes shown. Each of these samples was then float-sink tested at both 1.30 and 1.60 specific gravity (sp.gr.). The sample crushed to 1½-inch top size had 1.4% pyritic sulfur in the float 1.60 sp.gr. fraction. Crushing to ⅜-inch top size provided little pyritic sulfur release, as shown by the fact that the 1.60 sp.gr. float product still contained 1.3% pyritic sulfur. However, crushing to 14 mesh showed a very significant liberation of pyritic sulfur, the product containing 0.6%. Further crushing

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DISCLAIMER – Reference in this report to any specific commercial product, process, or service is to facilitate understanding and does not necessarily imply its endorsement or favoring by the United States Department of Energy.

Table 1 – Mechanical cleaning of bituminous coal and lignite, by type of equipment – 1978 (thousand short tons)

Type of Equipment	Total
Wet Methods:	
Jigs	104,811
Concentrating Tables	23,549
Classifiers	6,153
Launders	1,358
Dense Medium Processes:	
Magnetite	65,823
Sand	7,765
Calcium Chloride	924
Flotation	10,068
Pneumatic Methods	4,330
Grand Total[a]	224,780

[a]Data may not add to totals shown due to independent rounding.
Source: Form EIA-7

to 48 mesh provided a product containing 0.3% pyritic sulfur – again, a very significant reduction in pyritic sulfur content. Further reduction to 200 mesh provided only an additional 0.1% reduction in the pyritic sulfur content.

Although no operator is crushing his total preparation plant feed to ⅜-inch top size today, undoubtedly some operators have considered the implication of doing this. However, how many operators have considered beneficiating a ROM coal crushed to minus 14 mesh, or minus 48 mesh, or minus 200 mesh? Yet, this dramatic departure from conventional beneficiation practice may be necessary to produce specification coals for an ever more discriminating and expanding market, a market that currently seeks a very low-sulfur fuel and is beginning to realize the merits of low mineral-matter content.

So where does the coal preparation engineer go from here? What flow sheet configuration might he consider? And, what equipment and processes will he use?

Such flow sheets will likely contain a precleaning circuit in which the high mineral matter content fraction will be removed. And it may be expedient, on a coal-dependent basis, to scalp off a coarse-size clean coal fraction before crushing the coal for impurity liberation. Thus the required capacity of the fine coal beneficiation circuit would be reduced with minimal effect on final product quality or recovery.

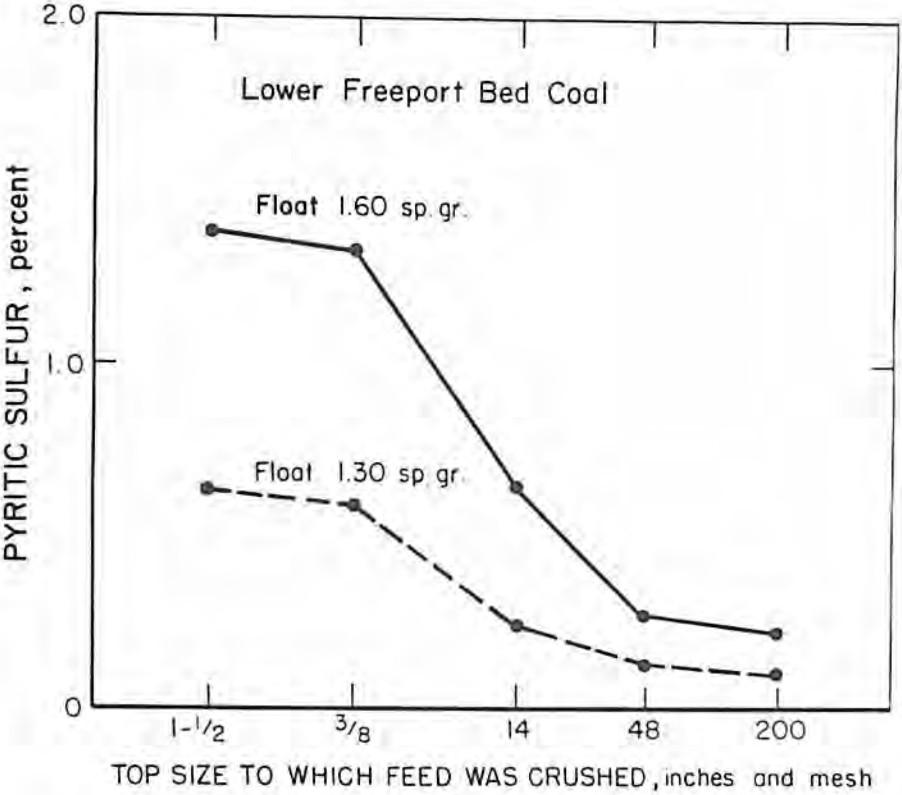

Fig. 1 – Effect of crushing on pyritic sulfur liberation.

Figure 2 shows a flow sheet using such an approach. Here the raw coal would be crushed to a nominal top size and washed in a jig at 1.70 sp.gr. The primary refuse draw would be rejected, the secondary draw might logically be crushed to some finer top size and rewashed. The jig float-coal product would then be deslimed to remove as much of the collodial-size clay as possible. This desliming process may use a combination of screens and two or three stages of classifying cyclones to reject only the minus 10-micron material from the process stream. This reject would be high in ash and sulfur, and would contain little carbonaceous material. The deslimed coal would be crushed to 500 microns and pumped to a classifying cyclone, where it would be split at approximately 100 microns (150 mesh). The plus-100-micron material would go to a dense-medium cyclone circuit, washing at a nominal 1.3 to 1.4 sp.gr., thus producing a clean coal and a middlings product. The classifying cyclone overflow material would go to a two-stage flotation circuit called coal-pyrite flotation (Figure 3). Stage 1 would be conventional froth flotation, where the coarser pyrite and the liberated mineral matter would be rejected. The froth would then be repulped and pumped to the second stage of flotation, where a hydrophilic colloid, such as starch, would be added to depress the coal, and a xanthate would be added to float the pyrite.

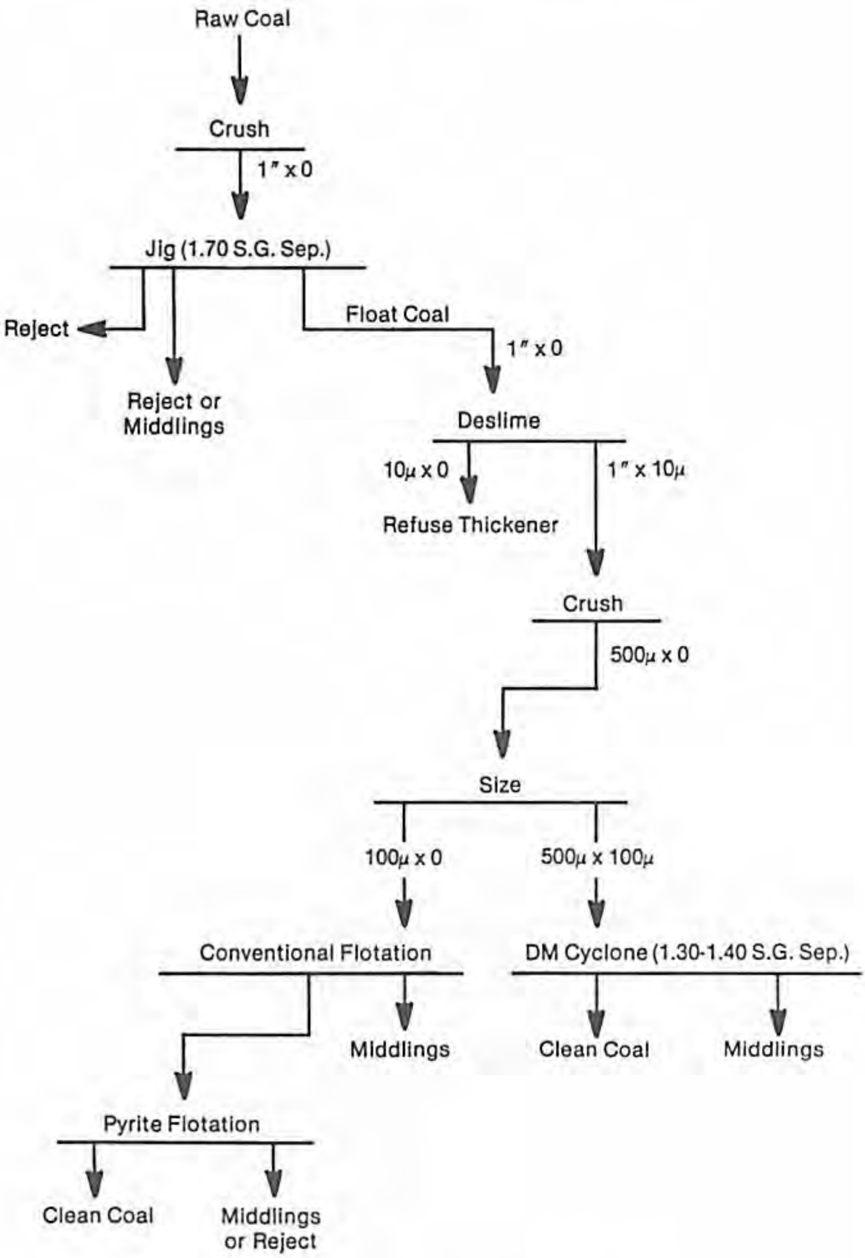

Fig. 2 – Flow chart for advanced coal cleaning circuit.

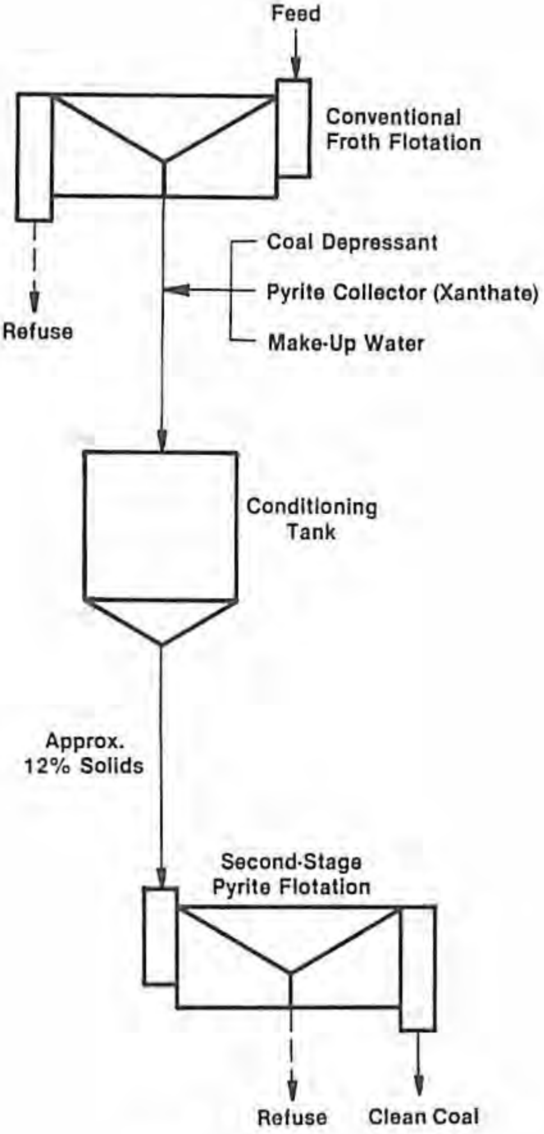

Fig. 3 – Coal-pyrite flotation circuit.

Obviously, many variations of this flow sheet would be considered depending on the washability analysis of the feed coal and the end-use market requirements for the product.

Interestingly, the proposed flow sheet does not involve any exotic new equipment or processes but rather a shift in emphasis to the fine-coal-cleaning circuit. Such preparation plants will cost considerably more to build and operate, and the final products, both clean coal and refuse, will present unique problems in handling, storage, and disposal. However, using such schemes, significant reductions in ash and sulfur content of Midwest Region coals could be realized immediately while new, more selective techniques are being developed.

Such exotic preparation plants will be designed to produce at least two and perhaps three salable products, depending on the coal and the available markets. The primary product (a low-sulfur-, low-mineral-content coal) would be used as a utility coal or feedstock for a coal-water slurry. The secondary product, of a somewhat higher sulfur and ash content, would be suitable as a fuel for a fluidized-bed combustion boiler. Markets for ultralow ash and sulfur products would include fuels for diesels or gas turbines.

The equipment and processes for providing these ultraclean coal products logically fall into three categories:

(1) Currently available technology that, through circuit modification, would be capable of providing final clean-coal products of lower pyrite and mineral-matter content, including jigs, wet concentrating tables, dense-medium vessels and cyclones, and froth flotation.

(2) New physical and physicochemical technologies currently being developed. These would include agglomeration, electrostatics, high-gradient magnetic separation, true-heavy-liquid cyclones, and advanced flotation techniques.

(3) Chemical coal-cleaning technologies, including the Gravimelt process and the Microwave process, that can remove organic sulfur as well as mineral matter from coal.

CURRENTLY AVAILABLE TECHNOLOGY

Jigs employ particle stratification resulting from a pulsating fluid action to effect a separation. Two types of jigs are available: the baum-type jig used for cleaning plus-¼-inch material, and the Batac jig used for cleaning material in the ¾-inch to 200-mesh size range.

Wet concentrating tables use differential motion and gravitational flow to stratify coal on a ribbed table. It is commonly applied to the washing of nominal ⅜ inch by 0 raw coal. However, it is also suitable for, and has been applied to, the washing of material as fine as 28 mesh by 0. The wet concentrating table has been shown to provide significant pyrite rejection down to 400 mesh [1].

Dense-medium vessels and dense-medium cyclones use a medium made up of finely ground magnetite particles suspended in water to effect a separation based on particle density. The sense-medium vessel is used to treat plus-¼-inch material, while the dense-medium cyclone typically cleans the ¼-inch x 28-mesh size fraction. The dense-medium cyclone has also been shown to be an effective coal-cleaning device, providing extremely sharp separations when washing feeds as fine as 150 mesh [2]. However, as the size of the particle to be separated approaches the size of the magnetite particles in the medium, the efficiency of the separation deteriorates rapidly.

Froth flotation is a physicochemical process for beneficiating the by-zero material. The process uses a difference in the surface properties of the coal and its associated impurities to effect a separation. A feed slurry is fed into an aerated tank, where hydrophobic coal particles become attached to, and are buoyed to the surface by finely dispersed air bubbles and are collected as a clean coal froth product. The mineral matter, being hydrophilic, is wetted by water and remains in suspension to be carried off as the tailings product.

For flotation to be most effective, reagents such as oils (collectors), and surfactants (frothers) must be added to the pulp. The collector reagent adsorbs on the coal surface and renders it more hydrophobic while the frother reagent facilitates the production of a stable froth capable of carrying the coal to the surface of the pulp. Conventional froth flotation of coal has been in use in the United States for more than 50 years, although it has only been since the 1960s that flotation has gained any semblance of acceptance.

NEW TECHNOLOGY

FLOTATION

While conventional flotation will successfully reduce the mineral matter content of a coal, it has limited effect on the pyritic sulfur content, as pyrite tends to float almost as well as coal. Because of the limited pyrite rejection achieved by coal flotation, researchers have been looking for ways to remove finely disseminated or locked pyrite particles from coal. This work led to the development of a two-stage reverse-flotation process. The process, called coal-pyrite flotation, was described earlier. While this technique has not yet been used in a full-scale commercial plant, laboratory results on a wide suite of coals containing liberated pyrite showed excellent results, and the commercialization of the process will inevitably occur as more coal is crushed to a fine size for pyrite liberation [3,4].

Another new flotation technique is the Advanced Fuels Technology (AFT) process. Using different chemicals and a deeper tank configuration, the process is able to clean lower rank coals, such as those found in the Midwest, better than conventional froth flotation techniques [5].

The AFT process uses a patented chemical-bonding method of absorbing polar (fatty acids) reagents onto the coal particle surfaces. This treated slurry is then sprayed through a nozzle onto the surface of the water-filled beneficiation tank. The force of the spraying action through the nozzle applies intense shear to the chemically treated slurry, breaking apart any floccules of mineral matter and coal. As the slurry spray hits the water, the aerated hydrophobic coal particles stay on the surface as a thick froth, while the hydrophilic mineral matter disperses into the water.

The chemical-bond attachment of air to coal via the AFT process is claimed to be more permanent than the physical-adsorption bond normally associated with coal flotation. In addition, the surface-formed froth produced by the spraying method is cleaner because the aerated coal particles need not be buoyed upward through a tank of water laden with mineral matter. Also, it is claimed that AFT's use of deep tanks and countercurrent water flow assures a cleaner product with minimal coal loss.

While selective agglomeration has been practiced on a limited scale for many years, it is now emerging with a new look. This technology includes processes such as oil agglomeration and the Otisca-T process. These processes, like flotation, rely on the hydrophobicity of the coal to separate it from the hydrophilic mineral matter.

Many different agglomerating agents have been applied successfully, including various oil fractions, heptane, pentane, perchloreothylene, and freon. Liquid CO_2 is presently being tested at the University of Pittsburgh. The Otisca-T process, one of the more developed processes and one of the best known, uses freon. Results of beneficiating two coals using the Otisca-T process are shown in Table 2 [6]. Unlike oil agglomeration, the Otisca-T process rejects pyrite, thus affecting a reduction in overall sulfur content.

It should be noted that selective agglomeration techniques are particularly efficient in treating the finest size coal and provide relatively low-moisture content products, an important consideration as the percentage of coal fines being treated increases.

True heavy-liquid cycloning of by-zero material is currently the focus of much attention. The liquid most commonly used is freon; and for the last 3 years the Department of Energy has been funding a program at Atisca Industries, Ltd. to investigate Freon cycloning [7,8]. Figure 4 shows a hypothetical physical layout of Otisca's cyclone circuit. Table 3 shows selected results from Otisca's testing using a 2-inch cyclone. Separations on a 28 mesh x 0 feed coal produced probable errors of 0.065 to 0.204.

ELECTROSTATICS

During World War II, an energy-hungry Germany used electrostatics to clean coal, even though the production capacity was low and costs were high. After the war, when coal processors were again faced with normal economic constraints, electrostatic separation fell out of favor. And though re-evaluated at frequent intervals, the technique was considered unattractive for commercial application.

The quickened interest in coal cleaning in the mid 1970's, however, resulted in renewed efforts to commercialize this technology. An organization called Advanced Energy Dynamics (AED) cleverly solved the principal problem of the electrostatic separator – its low capacity [9]. They observed that when the speed of rotation was increased sufficiently to attain a reasonable product capacity, a severe dust cloud formed at the point of material introduction on the roll, thus destroying the effectiveness of the separation. They recognized that the dust was the result of fine particles not being able to reach the drum and becoming entrained in an air layer created by the velocity of the drum. By putting a "doctor blade" on the drum to remove the air layer just before the introduction of the feed coal, they found that the particles were able to reach the drum surface at higher rotational speeds with

Table 2 – Otisca-T Processing of Washery Plant Fine-Size Raw Coal

	Pittsburgh Bed		Peerless Bed	
	Feed	CC	Feed	CC
Ash				
Percent	5.7	0.5	14.9	0.9
Lb/10^6 Btu	4.0	0.3	11.5	0.7
% Reduction/10^6 Btu	—	70.2	—	94.2
Total Sulfur				
Percent	1.24	0.82	1.08	0.80
Lb/10^6 Btu	0.87	0.64	0.83	0.53
% Reduction/10^6 Btu	—	38.0	—	36.1
Wt. Yield, %		93.0		N/A
Btu Yield, %		95.0		90.0

Table 3 – Typical True-Heavy-Liquid Cyclone Performance

Cyclone Diameter:	2 inches
Feed Coal Size:	28 mesh x 0
Feed Coal Ash:	30.0% (Average Value)
Cyclone Pressure Drop:	85 psi
Feed Solid Concentration:	20%

	Test A	Test B	Test C
Moisture (Wt. %):	1.5	10.0	10.0
Surfactant OT-100 (LB/Ton):	0	0	10
Clean Coal Yield (Wt. %):	77.3	78.8	70.1
Clean Coal Ash (Wt. %):	13.8	18.2	7.2
Reject Ash (Wt. %):	83.4	66.7	83.8
S.G. of Separation (Wt. %):	1.74	1.84	1.68
Probable Error (Ep):	0.139	0.204	0.065

minimal dust cloud formation and limited impairment of performance. AED further refined its process by incorporating an ionizer in the system to ensure a steady flow of feed coal to the drum.

The AED system includes two stages of electrostatic separation. The first stage is conventional technology called Model FC for treating fine-size material. Table 4 shows typical results on a suite of coals using the Model FC unit: ash reductions ranged from 30% to 45%, and sulfur reductions ranged from 18% to 40% at Btu recoveries of 87% to 95%. The second stage is a newly developed electrostatic separation method called Model UFC for treating the ultrafine-size material. Figure 5 shows the results of treating a sample of the Herrin (No. 6) Coal of Illinois using the two-stage electrostatic process. All of these tests for the Models FC and UFC were done on a laboratory scale.

Table 4 – Advanced Energy Dynamics test results

	Ash (%)*			Total Sulfur (%)*				
Coal Seam	Feed	Product	% Reduction	Feed	Product	% Reduction	% Yield	% Btu Recovery
Kentucky No. 13	18.9	10.3	46	1.42	1.46	(+)3	83	90
Herrin (No. 6)	22.7	14.9	34	4.15	3.29	21	75	87
Herrin (No. 6)	24.0	20.2	16	5.57	4.33	22	80	89
Herrin (No. 6)	23.2	14.1	39	3.53	2.60	26	80	89
Colchester (No. 2)	24.2	13.2	45	4.61	3.41	26	82	95
Fleming	35.1	24.1	31	4.69	3.72	21	71	87
Bee Veer	23.3	15.0	36	6.90	3.96	43	82	93

* Dry Basis

Presently, a field trial of the Model FC system is under way at the Pickway Station Power Plant of the American Electric Power Service Corporation. The feed to the power plant is ground to its normal size of approximately 70% minus 200 mesh. Approximately 10 tons an hour of this material are diverted to the electrostatic separator circuit. The separator is a grounded, 10-foot-long, 14-inch diameter drum revolving at 360 revolutions per minute. The pyrite and mineral matter, having good electrical conductivity, lose their charge and drop off of the roll quickly. The coal, however, sticks to the drum and is scraped off later. The system is producing three products: a clean coal, a middlings that can be recycled, and a reject.

HIGH-GRADIENT MAGNETIC SEPARATION

A novel method for cleaning fine-size coal is high-gradient magnetic separation (HGMS). This technique exploits the difference in the magnetic susceptibility of weakly paramagnetic pyrite and mineral matter components associated with the diamagnetic coal. While these differences in magnetic susceptibilities have long been recognized, they were generally felt to be too small to be effectively utilized

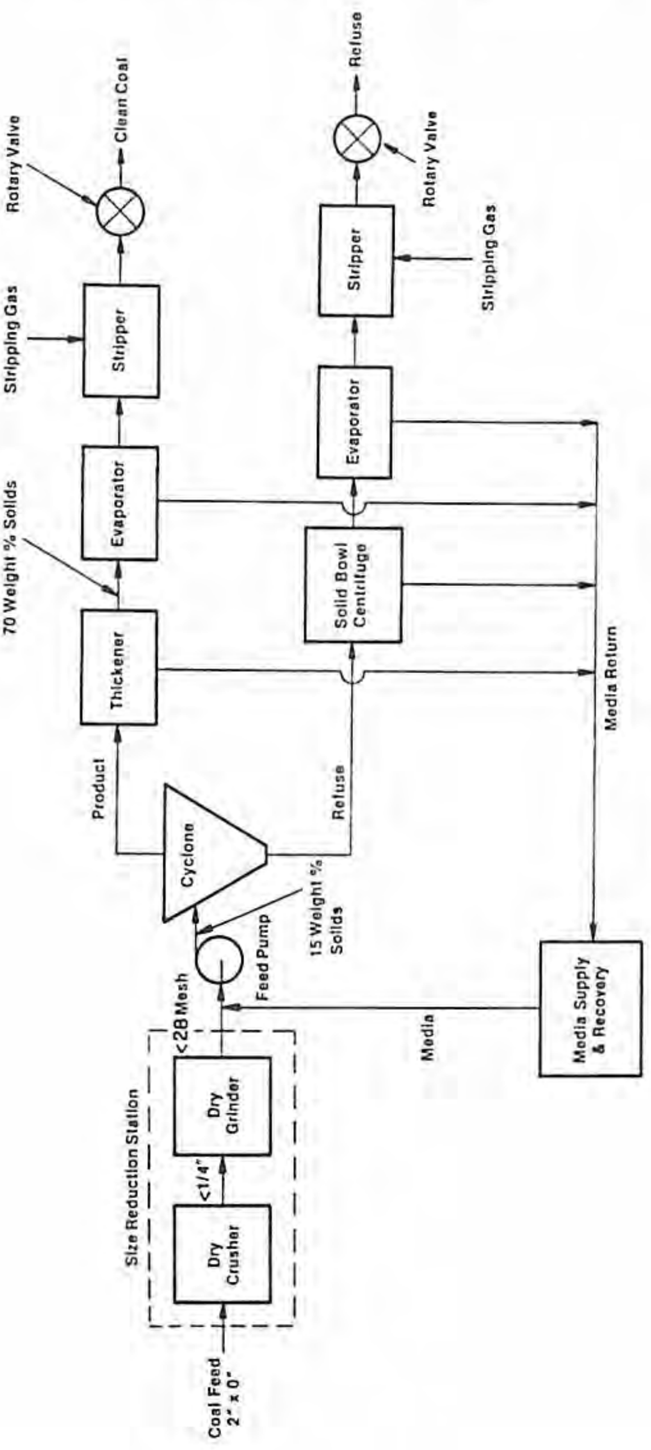

Fig. 4 – True-heavy-liquid cyclone circuit.

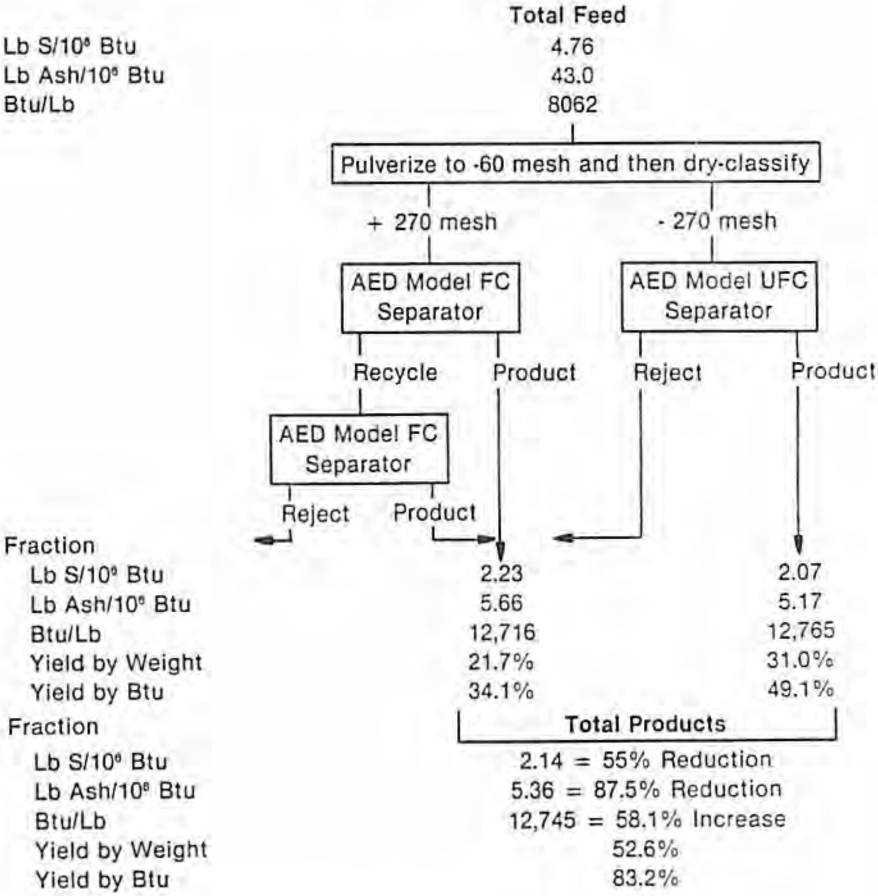

Fig. 5 – Results of Advanced Energy Dynamics two-stage coal-cleaning system on Herrin (No. 6) Coal of Illinois.

in a commercial separating process. However, the development of the HGMS technique provided a mechanism for beneficiating weakly magnetic particles. HGMS is capable of producing separations in either a wet or a dry mode. The HGMS separator, Figure 6, is composed of a solenoidal magnet that generates a uniform magnetic field throughout the working volume within the solenoid. This volume is packed with a matrix of ferromagnetic material, such as steel wool or expanded metal. The matrix material greatly distorts the magnetic field in its vicinity, thereby creating large magnetic field gradients. As feed passes through the matrix, the paramagnetic particles (pyrite and mineral matter) are captured and adhere to the matrix while the diamagnetic coal passes out through the top of the matrix [10].

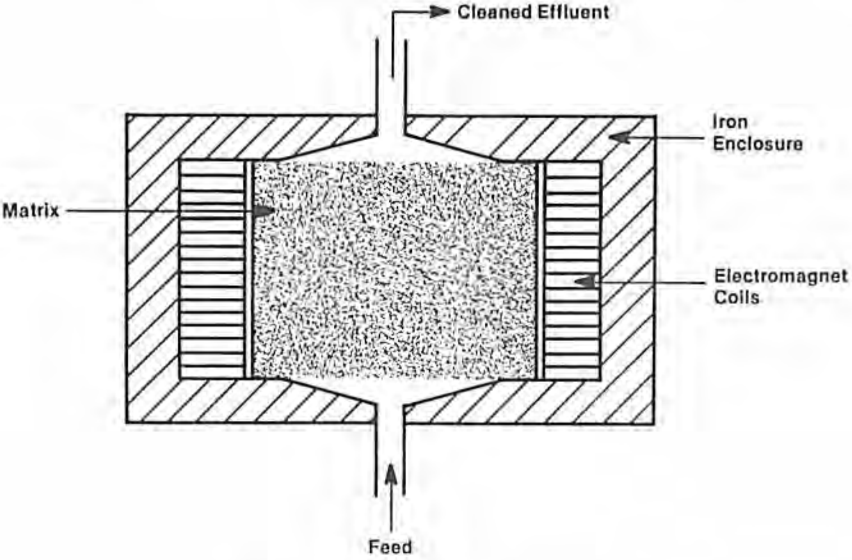

Fig. 6 – High-gradient magnetic separator.

Currently, a carousel-type unit is treating approximately 1 ton per hour of flotation feed at the Paradise Plant of the Tennessee Valley Authority. Figure 7 depicts a wet carousel high-gradient magnetic separator. This type of separator employs a rotating ring divided into compartments that are packed with a matrix. As each compartment enters an elongated solenoid, a slurry is fed into it through slots in the iron casing of the solenoid. After the compartment passes through this feeding zone, and while it is still within the magnetic field, it is rinsed to free nonmagnetic particles from the matrix. Then the compartment leaves the magnet, and a flush removes the magnetic particles.

CHEMICAL CLEANING TECHNOLOGIES

The chemical treatment of coal is unquestionably a very costly and complex alternative to physical beneficiation. However, it holds forth the promise of providing a final clean-coal product that can meet the New Source Performance Standards for sulfur emissions and will contain minimal mineral matter. There are at least two processes being actively developed at this time – the TRW Gravimelt Process and the General Electric Microwave Process. Only the Gravimelt Process will be described because its development is somewhat more advanced. Both processes utilize molten caustic as a reactant to remove sulfur and mineral matter from coal.

In the Gravimelt Process, 14 mesh x 0 physically beneficiated coal is fed into a molten bath of sodium hydroxide and potassium hydroxide. Organic and pyritic sulfur, and most of the mineral matter in the coal react with and are dissolved in the

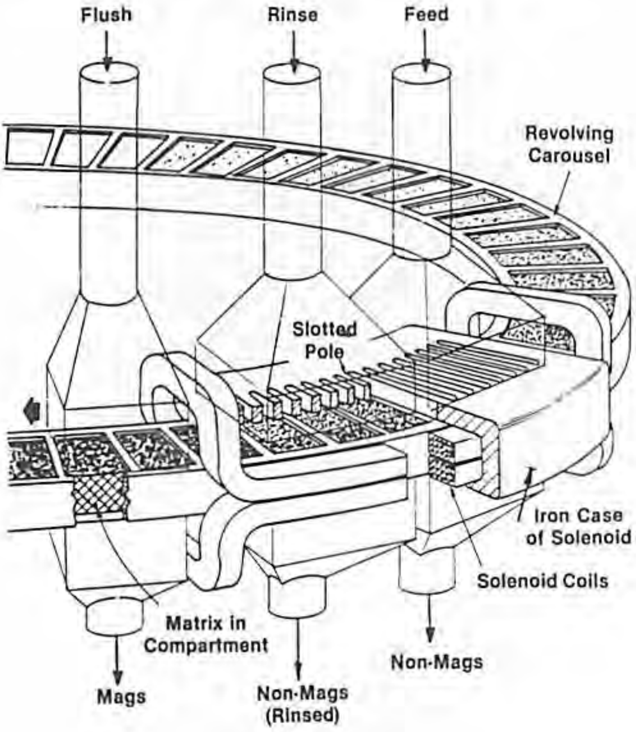

Fig. 7 – Carousel high-gradient magnetic separator.

molten caustic. The residence time in the reactor is from 60 to 240 minutes. The reacted coal is water-washed in a counter-current flow vessel and filtered. The water-wash filtrate is sent to the regeneration system. The filtered coal is acid-washed and filtered to remove any residual caustic. The acid-wash filtrate is treated with lime to precipitate dissolved mineral matter. The Gravimelt Process is currently at the bench-scale stage of development. Table 5 shows some current typical results [11]. The cost of the Gravimelt Process has been estimated to be from $32 to $44 per ton [12].

The cost of chemical coal cleaning is obviously quite high, but it must be remembered that the final product is a premium fuel. Its use could eliminate the need for SO_2 scrubbers and eliminate or significantly reduce particulate emission control costs. Trace element contents of the product coal will be minimal. When the product is used as a fuel in utility boilers, many benefits will accrue. On-line reliability will increase because of reduced erosion and corrosion problems in the boiler. Operating and maintenance costs on units such as the pulverizer will be reduced significantly. Ash and sludge disposal costs will be almost eliminated. Furthermore, this fuel may challenge oil for such new markets, such as coal-fired diesels or gas turbines. Thus while the costs of chemically cleaned coal may seem unrealistically high, recognize the potential benefits to be derived from using such a coal.

Table 5 – TRW Gravimelt Process results for U.S. coals

Coal		Analysis, dry basis			lb SO_2	lb Ash
		Sulfur,%	Ash,%	Heat content, Btu/lb	10^6 Btu	10^6 Btu
Kentucky No. 9	Feed	3.93	22.8	10795	7.28	21.2
	Product	0.37	0.3	13359	0.55	0.2
Kentucky No. 11	Feed	3.51	7.3	13182	5.33	5.5
	Product	0.52	0.2	13530	0.77	0.2
Herrin (No. 6)	Feed	3.45	11.9	12342	5.60	9.7
	Product	0.28	0.1	13518	0.40	0.1
Pittsburgh	Feed	3.12	10.7	12907	4.83	8.3
	Product	0.55	0.4	13801	0.80	0.3
Lower Kittanning	Feed	5.24	13.6	12931	8.11	10.5
	Product	0.64	0.4	14420	0.89	0.3

CONCLUSION

Coal remains the lowest cost and most bountiful domestic fossil energy resource in the United States. Through utilization of the best currently available coal beneficiation technologies, and continued development and adoption of new technologies, the broader acceptance of coal as a major source of domestic energy is assured.

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George Land: Thank you Carl. We have time for about 2 questions.

Jack O'Donnell: I have several question for Carl. Does the HGMS you referred to use a wet or dry process? Secondly, who's doing the work on liquid CO_2 as a medium?

Carl Maronde: It is either wet or dry. However, it appears that we do have a wet mode that gives somewhat improved results. There are some problems created by trying to package HGMS using dry particles. There tend to be very fine-sized particles in the coal that almost destroy some of the separation. I think that answers your first question. The University of Pittsburgh is working on liquid CO_2. They have been under contract to us for the last year, and they are still testing at a very small scale. However, they are moving along, and I am looking for very good results from this work. I think it's going to be an interesting application.

George Land: One more question.

Joe Fitzpatrick: I am from Western University. Have the economics of the reverse flotation of the pyrite removal improved since the developmental work at DOE, and would that suggest that commercial development would be possible for this? You mentioned there is no commercial-sized equipment for reverse flotation or for the two-stage pyrite rejection process. Could you comment on that?

Carl Maronde: Well I don't think that there is any significant change in the economics of the process. However, from when this process was first developed, I think that there has been a significant change in the coal market. The fact that you can remove some of the pyrite out of the flotation material can make a significant difference in the product. It's going to open many different kinds of markets. Did I answer your questions?

George Land: Sorry, we're going to have to cut it off here and go on. The next speaker on the program is George Land, Director of Technology Assessment, AMAX Coal Company. My topic is "Cleanability Characteristics of Finely Ground Illinois Basin Coal." Now you heard Carl telling you some of the techniques you would use, and he showed you one chart showing the difference between liberation of ash on what I believe depended on size and specific gravity. I have a few graphs that I will use. In the last 3 or 4 minutes I am going to show a series of slides of polished sections of coal particles at different gravities. You can see how much mineral release there has been and how much mineral matter is still in some of the micron and sub-micron particles of coal.

CLEANABILITY CHARACTERIZATION OF FINELY GROUND ILLINOIS BASIN COALS

GEORGE W. LAND, P.E.
Director, Technical Assessment
AMAX Coal Company
Indianapolis, Indiana

INTRODUCTION

Characterization of the cleanability of coal by time honored washability test methods has for the most part, been confined to coal sizes larger than 28 mesh particularly for "steam" coals. Published data on washability of coals generally do not contain float and sink information on minus 28 mesh coal. If the data cover 1½" x 0, for example, there is usually a footnote explaining that the sample contained x percent of minus 14 mesh, 28 mesh, 60 mesh, or even 100 mesh, which was removed before the sample was subjected to float sink determination.

With the advent of interest in using relatively high-density coal-and-water mixtures as replacement for fuel oil in steam generation, has come an interest in cleanability of fine sizes, i.e., particle sizes in the minus 100 to 200 mesh range.

The mineral impurities in coal are present as discrete particles of various sizes ranging from inches to submicrons in dimension. Breakage of coal produced by mining operations and comminution of the mined product to produce cleaning plant feed liberate particles of the mineral inclusions. The separation of coal and mineral matter, which have substantially different specific gravities and surface properties, can then be accomplished by any of several techniques, the choice of which depends upon the particle size and the aforementioned differences in gravity and surface properties.

PARTICLE SIZE REDUCTION

At AMAX we became more interested in the cleanability of coals as influenced by particle size reduction about three years ago as we began to develop our own expertise in the field of preparation of coal-and-water mixtures to be used as boiler fuel. It seemed to us that a logical place to start our investigations was to determine the extent to which we could liberate and remove mineral matter from our coals after they were ground to minus 200 mesh, the standard pulverized coal size. We were interested in determining the maximum reduction we might achieve in both ash and sulfur values as a result of the "fine" coal cleaning. Consequently, we began a program of characterizing coals from selected producing mines and principal reserve areas. To date we have investigated nine coals, five from the Illinois Basin and four from Appalachia.

As you would expect there are significant differences in cleanability of coals from these areas.

PREPARATION AND SELECTION OF SAMPLES

Exact definition of those differences cannot be addressed from the data we developed in our studies for we did not have that in mind as we carried out our investigations. For example, in four of our five Midwestern samples we started with coal from our preparation plants that had been cleaned in jigs at a gravity of about 1.65. The other Midwestern sample and the four Appalachian samples were raw ROM coal.

The feed to the jig plants is approximately 5" x 0. After washing, the plus 2-inch material is crushed to minus 2-inch and added to the natural 2" x 0. The mixture is our finished product. On the average, it contains about 4 percent misplaced, i.e., plus 1.65 gravity, material.

I've gone into this detail about the four washed coal samples because I want to broaden the data base for this paper, which presents information on the liberation of mineral matter resulting from reducing coal particle sizes before cleaning. To do this I am using data published in USBM RI 8118, "Sulfur Reduction Potential of U.S. Coals", 1976, by Cavallaro, Johonston and Deurbrouck, as well as information on the average quality of the products from our Midwestern mines.

Seven of the nine coal seams covered in our study are also included in RI 8118. By selecting the RI 8118 data for the appropriate seam samples identified as being from the same counties from which our samples came, and making some reasonable assumptions as to the relevance of the data in RI 8118 and the AMAX samples, we can extend the range of size versus liberation characteristics from 5" x 0 to 200 mesh x 0 for the four washed coal samples.

The other three seams included in RI 8118 and our study were not taken from the same counties. The paired samples for the Lower Kittanning, Pittsburgh No. 8, and the Springfield (No. 5) Coal of Illinois (AMAX Wabash Mine) showed such substantial differences in percent float, Btu recovery, float ash, and sulfur that comparisons of mineral matter liberation by increased comminution are confused and inconsistent. Therefore, for these three coals only the liberation characteristics shown by our study are included in this report.

RESULTS OF WASHABILITY STUDIES

Figures 1 through 4 are standard washability plots showing ash and recovery versus specific gravity for the coals included in both the RI 8118 and AMAX studies and for which coal samples come from the same counties in each study. Figures 5 through 9 show the washability curves determined by AMAX for the other samples included in this study.

Figures 10 through 13 are curves produced from data given in RI 8118 showing the percent reduction in ash, pyritic sulfur, total sulfur and pounds of SO_2 per million Btu for the 28 samples of Illinois Basin coal covered in that report. Included in those charts are curves showing the reductions attained by crushing the washed Delta Mine sample (approximately F1.65) to 6 mesh x 0, 100 mesh x 0 and 200 mesh x 0. The percentage reduction for these curves is based on the assumption that the starting point, that is the original head sample ash before reduction in size or treatment in the cleaning plant, was 16.6 percent, the ash value of the RI 8118 sample average for samples from Williamson and Saline Counties.

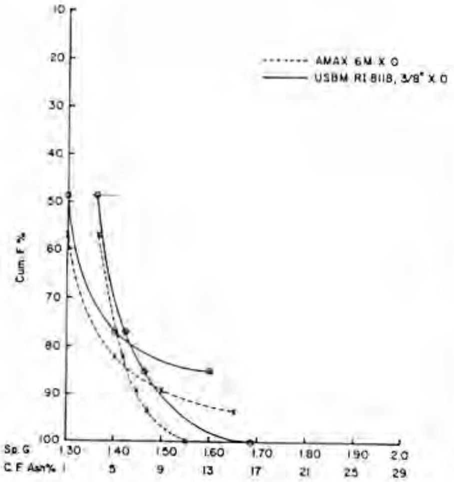

Fig. 1 – Washability of Herrin (No. 6) Coal from Delta Mine, Illinois showing ash and recovery versus specific gravity.

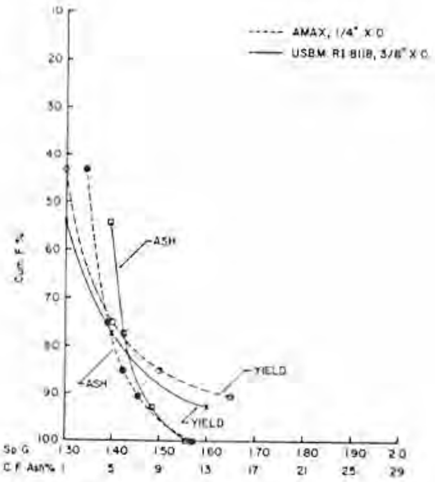

Fig. 2 – Washability of Seelyville Coal (III) from Chinook Mine, Indiana.

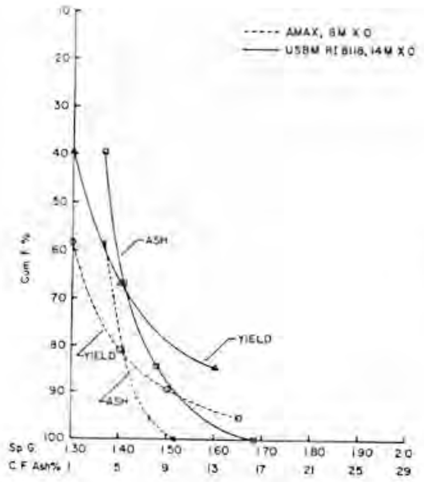

Fig. 3 – Washability of Herrin (No. 6) Coal from Leahy Mine, Illinois.

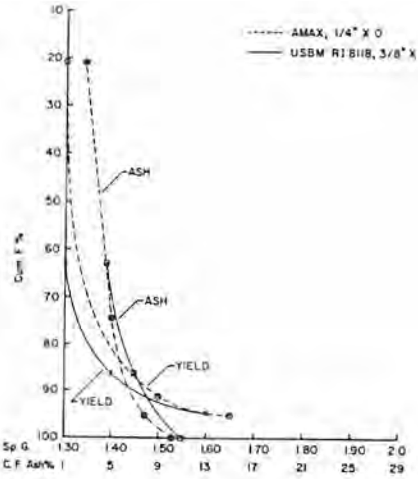

Fig. 4 – Washability of Danville Coal (VII) from Minnehaha Mine, Indiana.

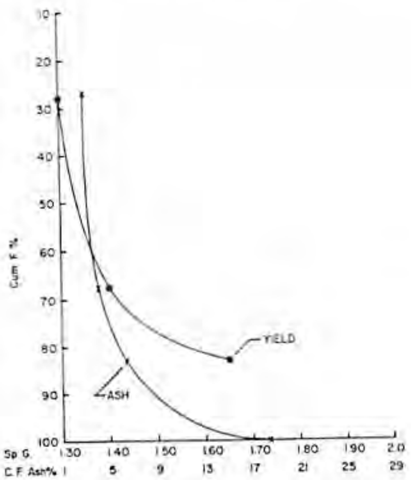

Fig. 5 – Washability of Springfield (No. 5) Coal from Wabash Mine, Illinois for ⅜" x 0 size.

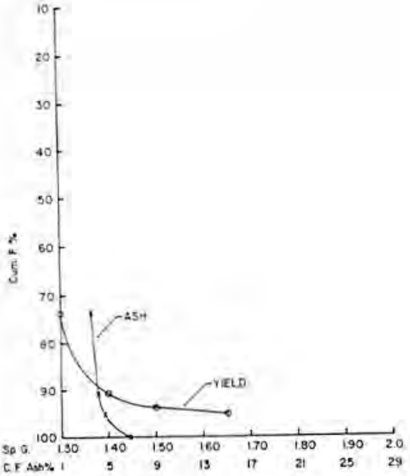

Fig. 6 – Washability of Pittsburgh (No. 8) coal for ¼" x 0 size.

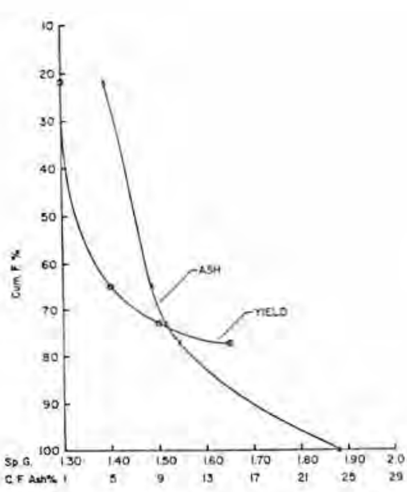

Fig. 7 – Washability of Lower Kittanning coal for ¼" x 0 size.

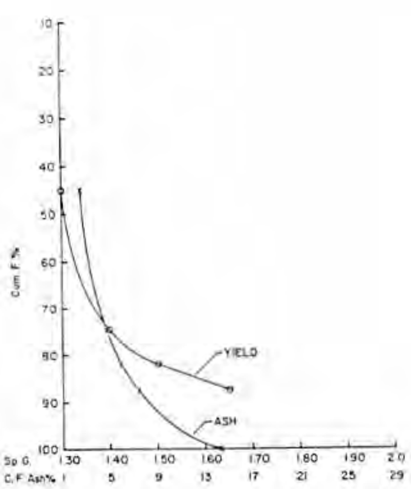

Fig. 8 – Washability of Sewell coal for ¼" x 0 size.

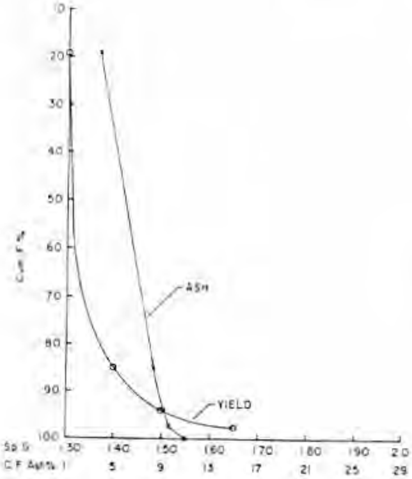

Fig. 9 – Washability of Sewanee coal for ¼" x 0 size.

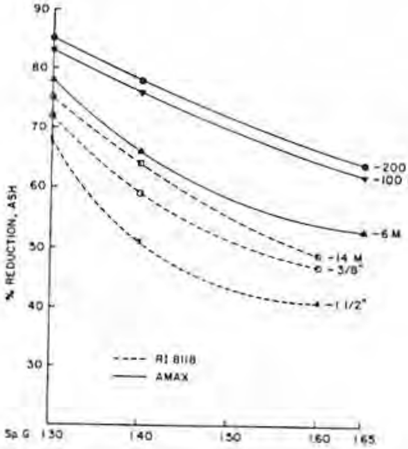

Fig. 10 – Percentage reduction of ash for Herrin (No. 6) Coal, Delta Mine.

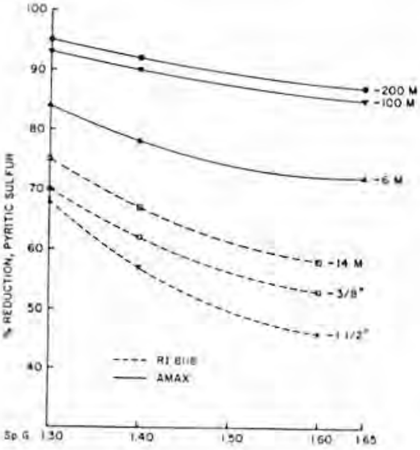

Fig. 11 – Percentage reduction of pyritic sulfur for Herrin (No. 6) Coal, Delta Mine.

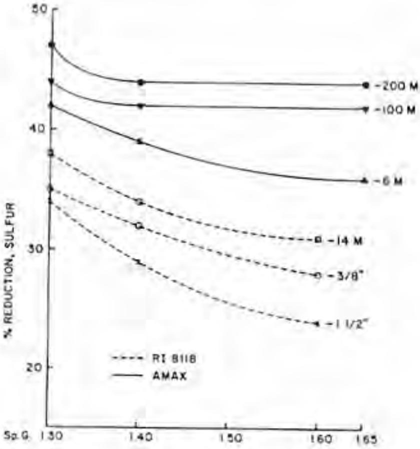

Fig. 12 – Percentage reduction of sulfur in Herrin (No. 6) Coal, Delta Mine.

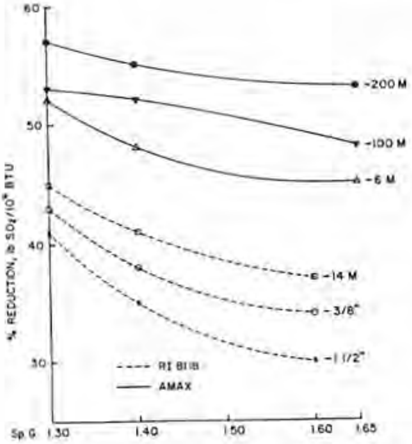

Fig. 13 – Percentage reduction, lb. $SO_2/10^6$ Btu, for Herrin (No. 6) Coal, Delta Mine.

The AMAX data for the sample of the Herrin (No. 6) Coal of Illinois show clearly how ash reduction increases with decreasing particle size. To put it another way: the smaller the average particle size, the lower the cumulative float ash for each gravity.

Table 1 presents data illustrating those statements for coal from the Delta Mine. Section A presents the actual ash values of the various cumulative float fractions for the different sizes. Part B shows the percentage reduction from the ash value of the head sample as shown in RI 8118. In Part C the percentage reduction is from the ash value of the commercially washed coal, which was the actual head sample for the AMAX work. Because this sample is a float sample of approximately 1.65 specific gravity, the percentage reduction values are not as large as those of the raw head sample from RI 8118.

We have made the same analysis for the three other washed coal samples as shown in Tables 2, 3, and 4. Similar comparisons of values and percent reduction of total sulfur, pyritic sulfur and pounds of SO_2 per million Btu as well as ash for all of the samples have also been made and are shown in tables in the Appendix to this paper. For five of the coals, reductions in values are based only on head sample values determined from the AMAX samples. Percent weight and Btu recovery for all samples are included in the Appendix.

We can summarize all of these data by saying that actual values of ash and sulfur for any given specific gravity of separation are decreased substantially as the average particle size is reduced. I'm sure all of you knew that, but perhaps you weren't aware of the magnitude of the potential reductions in ash and sulfur that exist as the result of size reduction before cleaning.

To go back to the coal from the Delta Mine, for an example, the average ash of the as-mined coal delivered to the jigs is approximately 25 percent. Product from the plant has an average dry ash of 10.9 percent – a reduction of 56 percent.

A. % CUMULATIVE FLOAT ASH

Size →	RI8118 Sample			AMAX Sample		
	1-1/2"X0	3/8"X0	14mX0	6mX0	100mX0	200mX0
F 1.30	3.7	3.4	3.3	3.6	2.8	2.5
F 1.40	7.1	5.9	5.4	5.7	4.0	3.7
F 1.60/1.65*	8.7	7.5	7.7	7.8*	6.3*	5.9*

B. % ASH REDUCTION FROM RAW COAL[1]

Size →	1-1/2"X0	3/8"X0	14mX0	6mX0	100mX0	200mX0
F 1.30	78	80	81	78	83	85
F 1.40	57	64	66	66	76	78
F 1.60/1.65*	48	55	54	53*	62*	64*

C. % ASH REDUCTION FROM COMMERCIALLY WASHED COAL[2]

Size →	1-1/2"X0	3/8"X0	14mX0	6mX0	100mX0	200mX0
F 1.30				67	74	77
F 1.40				48	63	66
F 1.60/1.65*				29*	42*	46*

---

[1] Head ash from RI8118 16.6% (raw coal)

[2] Head ash from AMAX 10.9% (washed coal)

Table 1 – Ash versus particle size for various specific gravities for Herrin (No. 6) Coal, Delta Mine, Illinois.

A. % CUMULATIVE FLOAT ASH

Size →	RI8118 Sample			AMAX Sample		
	1-1/2"X0	3/8"X0	14mX0	1/4"X0	100mX0	200mX0
F 1.30	4.7	4.8	4.3	2.7	1.7	1.8
F 1.40	6.6	6.0	5.8	4.6	3.9	4.0
F 1.60/1.65*	9.3	8.4	7.9	7.2*	5.8*	5.8*

B. % ASH REDUCTION FROM RAW COAL[1]

Size →	1-1/2"X0	3/8"X0	14mX0	1/4"X0	100mX0	200mX0
F 1.30	58	57	62	76	85	84
F 1.40	41	46	48	59	65	64
F 1.60/1.65*	17	25	30	36*	48*	48*

C. % ASH REDUCTION FROM COMMERCIALLY WASHED COAL[2]

Size →	1-1/2"X0	3/8"X0	14mX0	1/4"X0	100mX0	200mX0
F 1.30				78	86	85
F 1.40				62	68	67
F 1.60/1.65*				40*	52*	52*

---

[1] Head ash from RI8118 11.2% (raw coal)

[2] Head ash from AMAX 12.0% (washed coal)

Table 2 – Ash versus particle size for various specific gravities for Seelyville Coal (III), Chinook Mine, Indiana.

A. % CUMULATIVE FLOAT ASH

	-----RI8118 Sample------			-----AMAX Sample------		
Size →	1-1/2"X0	3/8"X0	14mX0	8mX0	100mX0	200mX0
F 1.30	4.4	3.7	3.6	3.2	2.2	1.7
F 1.40	7.8	6.4	5.3	5.3	3.6	2.8
F 1.60/1.65*	9.5	8.4	8.1	7.5*	6.0*	5.2*

B. % ASH REDUCTION FROM RAW COAL[1]

F 1.30	73	77	78	80	87	90
F 1.40	52	61	68	68	78	83
F 1.60/1.65*	42	49	50	54*	63*	68*

C. % ASH REDUCTION FROM COMMERCIALLY WASHED COAL[2]

F 1.30				67	77	82
F 1.40				44	62	72
F 1.60/1.65*				21*	37*	46*

---

[1] Head ash from RI8118 16.3% (raw coal)

[2] Head ash from AMAX 9.5% (washed coal)

Table 3 – Ash versus particle size for various specific gravities for Herrin (No. 6) Coal, Leahy Mine, Illinois.

A. % CUMULATIVE FLOAT ASH

	-----RI8118 Sample------			------AMAX Sample------		
Size →	1-1/2"X0	3/8"X0	14mX0	1/4"X0	100mX0	200mX0
F 1.30	6.4	4.9	2.9	2.6	1.2	1.3
F 1.40	8.1	6.0	5.7	5.0	2.8	2.7
F 1.60/1.65*	8.8	8.2	7.9	7.9*	5.7*	5.3*

B. % ASH REDUCTION FROM RAW COAL[1]

F 1.30	40	54	73	79	89	88
F 1.40	24	36	47	53	74	75
F 1.60/1.65*	18	23	26	26*	47*	51*

C. % ASH REDUCTION FROM COMMERCIALLY WASHED COAL[2]

F 1.30				75	88	87
F 1.40				51	73	74
F 1.60/1.65*				23*	44*	48*

---

[1] Head ash from RI8118 10.7% (raw coal)

[2] Head ash from AMAX 10.2% (washed coal)

Table 4 – Ash versus particle size for various specific gravities for Danville Coal (VII), Minnehaha Mine, Indiana.

Cumulative Float Pyritic Sulfur %

	-----RI8118 Sample[1]-----			-----AMAX Sample[2]-----		
Size →	1-1/2"X0	3/8"X0	14mX0	6mX0	100mX0	200mX0
F 1.30	.50	.39	.40	.35	.16	.12
F 1.40	.75	.60	.58	.48	.22	.17
F 1.60/1.65	.95	.75	.79	.61	.33	.28

---

[1] Head sample 2.17% pyritic sulfur (raw coal).

[2] Head sample 1.21% pyritic sulfur (washed 1.65 specific gravity).

Table 5 – Pyritic sulfur versus particle size for various specific gravities for Herrin (No. 6) Coal, Delta Mine, Illinois.

Cumulative Float, Pyritic Sulfur %

	-----RI8118 Sample[1]-----			-----AMAX Sample[2]-----		
Size →	1-1/2"X0	3/8"X0	14mX0	1/4"X0	100mX0	200mX0
F 1.30	.97	.81	.52	.55	.16	.12
F 1.40	1.18	1.06	.86	.97	.42	.28
F 1.60/1.65	1.49	1.32	1.14	1.18*	.63*	.44*

---

[1] Head sample 1.65% pyritic sulfur (raw coal).

[2] Head sample 1.85% pyritic sulfur (washed coal)

Table 6 – Pyritic sulfur versus particle size for various specific gravities for Seelyville Coal (III), Chinook Mine, Indiana.

	Cumulative Float Pyritic Sulfur %					
	RI8118 Sample[1]			AMAX Sample[2]		
Size →	1-1/2"X0	3/8"X0	14mX0	8mX0	100mX0	200mX0
F 1.30	.53	.43	.40	.45	.20	.11
F 1.40	.85	.66	.58	.53	.27	.14
F 1.60/1.65*	1.22	.85	.82	.58*	.34*	.22*

---

[1] Head sample 2.27% pyritic sulfur (raw coal).

[2] Head sample 1.06% pyritic sulfur (washed coal)

Table 7 – Pyritic sulfur versus particle size for various specific gravities for Herrin (No. 6) Coal, Leahy Mine, Illinois.

	Cumulative Float Pyritic Sulfur %					
	RI8118 Sample[1]			AMAX Sample[2]		
Size →	1-1/2"X0	3/8"X0	14mX0	1/4"X0	100mX0	200mX0
F 1.30	.32	.26	.14	.02	.01	.01
F 1.40	.34	.29	.20	.02	.01	.01
F 1.60/1.65	.38	.32	.24	.03*	.02*	.02*

---

[1] Head sample .85% pyritic sulfur (raw coal).

[2] Head sample .14% pyritic sulfur (washed coal)

Table 8 – Pyritic sulfur versus particle size for various specific gravities for Danville Coal (VII), Minnehaha Mine, Indiana.

When that 10.9 percent ash 2" x 0 coal is crushed to minus 6 mesh, the 1.65 specific gravity cumulative float for this size has a dry ash of 7.8 percent, and if the size is reduced to minus 200 mesh, the dry ash for the 1.65 float is 5.9 percent. This final value represents a reduction of 76 percent from the original 5" x 0 raw run of mine feed. For sulfur, the equivalent numbers are: washer feed, 3.8 percent; product, 3.1 percent; for product crushed to minus 6 mesh the float 1.65, 2.3 percent; crushed to minus 200 mesh the float 1.65 is 2.0 percent. This latter value represents a reduction of 47 percent.

Pyritic sulfur makes up a little over half of the 3.8 percent total raw sulfur. Values are: raw feed 2.0 percent; washed product 1.4 percent; crushed to minus 6 mesh, 0.61 percent; minus 200 mesh, 0.28 percent for the 1.65 float. This is a reduction of 86 percent.

The other coals show similar reductions as average particle size is reduced. Tables 5 through 8 contain the pyritic sulfur information on the washed Illinois Basin coals.

What about reduction in pounds of sulfur dioxide per million Btu? Can any of the Illinois Basin coals be cleaned to "compliance" quality? Or rather, do any of them have the potential of being cleaned to 1.2 lb. SO_2 per million Btu or less by fine grinding before cleaning? Take a look at Table 9 for an answer.

Table 9 shows the pounds of sulfur dioxide per million Btu for a cumulative float fraction of each coal after reduction to 200 mesh x 0. The comparison is shown for the 1.40 F rather than 1.30 F because the potential Btu recovery for some of the coals is very low at 1.30 F. However, all of them showed potential Btu recovery of 62 percent or more (with most over 70 percent) for a 1.40 float product. The results indicate that two of the Illinois Basin coals, the Springfield (No. 5) Coal of Illinois and Danville Coal (VII) of Indiana, have the potential for being cleaned to the "compliance" level, and that all showed substantial reduction potential for SO_2 emissions.

Coal	% Btu Recovery 1.40 Float	Head lbs. $SO_2/10^6$ Btu	lbs. $SO_2/10^6$ Btu 1.40 Float
Delta	83	4.8*	2.8
Chinook	76	6.4*	3.8
Leahy	79	5.0*	3.5
Minnehaha	73	0.6*	0.4
Wabash	62	2.9**	1.0
Pittsburgh #8	94	6.2**	3.1
Lower Kittanning	71	5.1**	1.1
Sewell	79	0.9**	0.9
Sewanee	77	2.2**	1.1

---

*Washed coal samples (approximately 1.65 F). Approximate raw feed values are: Delta, 6.2; Chinook, 7.2; Leahy, 6.7; and Minnehaha, 2.1.

**Raw coal samples.

Table 9 – Pounds of SO_2 per million Btu and percent Btu recovery for minus 200 mesh cumulative 1.40 float.

CONCLUSION

The data we developed in this briefly reported characterization study indicate that it should be possible to produce feed for a high-density coal and water mixture with less than five percent dry ash from several Illinois Basin coals. Recovery, while obviously lower for those coals cleaned to a 1.40 specific gravity, appears to be at a level that should satisfy economic requirements for competitive use of the mixtures with fuel oil when used for steam generation.

If sulfur emission requirements are at a 1.2 lb. per million Btu level, the number of acceptable Illinois Basin coals will be small.

APPENDIX

	% TOTAL SULFUR[1]					
	RI8118 Sample			AMAX Sample		
Size →	1-1/2"X0	3/8"X0	14mX0	6mX0	100mX0	200mX0
F 1.30	2.0	1.9	1.9	2.1	2.0	1.9
F 1.40	2.2	2.1	2.0	2.2	2.1	2.0
F 1.60/1.65*	2.4	2.2	2.2	2.3*	2.1*	2.0*
	Lb. $SO_2/10^6$ Btu[2]					
F 1.30	2.9	2.8	2.8	3.0	2.9	2.7
F 1.40	3.4	3.1	3.0	3.2	3.0	2.8
F 1.60/1.65*	3.7	3.4	3.3	3.4*	3.2*	2.9*

---

[1] Head sample from RI8118 3.6%, AMAX 3.1%

[2] Head sample from RI8118, 6.2 lb., AMAX, 4.8 lb.

Table 1 – Total sulfur and pounds of sulfur dioxide per million Btu versus particle size for various specific gravities for Herrin (No. 6) Coal, Delta Mine.

	% TOTAL SULFUR[1]					
	RI8118 Sample			AMAX Sample		
Size →	1-1/2"X0	3/8"X0	14mX0	3/8"X0	100mX0	200mX0
F 1.30	3.8	3.8	3.3	3.0	2.7	2.8
F 1.40	4.1	4.1	3.7	3.8	3.0	2.7
F 1.60/1.65*	4.3	4.2	3.9	3.8*	3.0*	2.7*
	Lb. $SO_2/10^6$Btu[2]					
F 1.30	5.6	5.7	4.9	4.2	3.8	3.8
F 1.40	6.3	6.1	5.6	5.0	4.1	3.8
F 1.60/1.65*	6.8	6.5	6.1	5.6*	4.4*	4.0*

---

[1] Head sample from RI8118 4.5%, AMAX 4.1%

[2] Head sample from RI8118, 7.2 1b., AMAX, 6.4 1b.

Table 2 – Total sulfur and pounds of sulfur dioxide per million Btu versus particle size for various specific gravities for Seelyville Coal (III), Chinook Mine, Indiana.

	% TOTAL SULFUR[1]					
	RI8118 Sample			AMAX Sample		
Size →	1-1/2"X0	3/8"X0	14mX0	8mX0	100mX0	200mX0
F 1.30	2.6	2.6	2.6	2.8	2.5	2.4
F 1.40	2.8	2.7	2.7	2.8	2.5	2.4
F 1.60/1.65*	3.0	2.8	2.8	2.8*	2.5*	2.4*
	Lb. $SO_2/10^6$Btu[2]					
F 1.30	3.8	3.8	3.8	4.1	3.6	3.4
F 1.40	4.3	4.1	4.0	4.2	3.7	3.5
F 1.60/1.65*	4.9	4.4	4.4	4.2*	3.8*	3.5*

---

[1] Head sample from RI8118 1.9%, AMAX 1.3%

[2] Head sample from RI8118, 6.7 1b., AMAX, 5.0 1b.

Table 3 – Total sulfur and pounds of sulfur dioxide per million Btu versus particle size for various specific gravities for Herrin (No. 6) Coal, Leahy Mine.

	% TOTAL SULFUR[1]					
	RI8118 Sample			AMAX Sample		
Size →	1-1/2"X0	3/8"X0	14mX0	1/4"X0	100mX0	200mX0
F 1.30	0.8	0.8	0.6	0.3	0.4	0.4
F 1.40	0.8	0.8	0.7	0.3	0.3	0.3
F 1.60/1.65*	0.9	0.8	0.7	0.3*	0.3*	0.3*
	Lb. $SO_2/10^6$ Btu[2]					
F 1.30	1.2	1.1	0.8	0.4	0.5	0.5
F 1.40	1.2	1.1	0.9	0.4	0.4	0.4
F 1.60/1.65*	1.3	1.2	1.1	0.4*	0.4*	0.4*

---

[1] Head sample from RI8118 1.3%, AMAX 0.4%

[2] Head sample from RI8118, 2.1 lb., AMAX, 0.6 lb.

Table 4 – Total sulfur and pounds of sulfur dioxide per million Btu versus particle size for various specific gravities for Danville Coal (VII), Minnehaha Mine, Indiana.

	% Ash[1]		
Size →	1/4"X0	100mX0	200mX0
F 1.30	3.0	2.0	2.3
F 1.40	4.2	3.9	3.8
F 1.65	6.4	6.4	6.7
	% Total Sulfur[2]		
F 1.30	0.9	0.7	0.7
F 1.40	0.9	0.8	0.7
F 1.65	1.0	0.9	0.7
	% Pyritic Sulfur[3]		
F 1.30	0.25	0.10	0.07
F 1.40	0.20	0.12	0.08
F 1.65	0.39	0.20	0.16
	Lbs. $SO_2/10^6$ Btu[4]		
F 1.30	1.1	1.0	1.1
F 1.40	1.3	1.2	1.0
F 1.65	1.5	1.3	1.1

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[1] Head sample 6.4%
[2] Head sample 1.3%
[3] Head sample 1.16%
[4] Head sample 2.2 lb.

Table 5 – Ash, total sulfur, pyritic sulfur, and pounds of sulfur dioxide per million Btu versus particle size for various specific gravities for Springfield (No. 5) Coal, Wabash Mine, Illinois.

	% Ash[1]		
Size →	1/4"X0	100mX0	200mX0
F 1.30	3.6	2.3	2.0
F 1.40	4.1	3.2	3.1
F 1.65	4.7	3.6	3.6
	% Total Sulfur[2]		
F 1.30	2.3	2.4	2.4
F 1.40	2.6	2.4	2.3
F 1.65	3.1	2.5	2.4
	% Pyritic Sulfur[3]		
F 1.30	0.24	0.05	0.06
F 1.40	0.56	0.11	0.17
F 1.65	0.98	0.21	0.27
	Lbs. $SO_2/10^6$ Btu[4]		
F 1.30	3.2	3.2	3.2
F 1.40	3.6	3.3	3.1
F 1.65	4.2	3.4	3.2

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[1] Head sample 6.5%
[2] Head sample 3.6%
[3] Head sample 2.17%
[4] Head sample 5.6 lb.

Table 6 – Ash, total sulfur, pyritic sulfur, and pounds of sulfur dioxide per million Btu versus particle size for various specific gravities for the Pittsburgh (No. 8) coal.

	% Ash[1]		
Size →	1/4"X0	100mX0	200mX0
F 1.30	4.6	3.0	3.1
F 1.40	8.4	6.0	5.6
F 1.65	10.7	9.2	9.3
	% Total Sulfur[2]		
F 1.30	0.9	0.9	0.8
F 1.40	1.3	1.0	0.8
F 1.65	1.5	1.1	0.9
	% Pyritic Sulfur[3]		
F 1.30	0.16	0.07	0.06
F 1.40	0.58	0.20	0.13
F 1.65	0.83	0.34	0.26
	Lbs. $SO_2/10^6$ Btu[4]		
F 1.30	1.2	1.2	1.0
F 1.40	1.8	1.4	1.1
F 1.65	2.2	1.6	1.3

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[1] Head sample 24.0%
[2] Head sample 3.2%
[3] Head sample 2.27%
[4] Head sample 5.2 lb.

Table 7 – Ash, total sulfur, pyritic sulfur, and pounds of sulfur dioxide per million Btu versus particle size for various specific gravities for the Lower Kittanning coal.

Size →	1/4"X0	100mX0	200mX0
	% Ash[1]		
F 1.30	2.5	1.9	1.7
F 1.40	4.7	3.6	3.5
F 1.65	7.3	5.9	6.0
	% Total Sulfur[2]		
F 1.30	0.6	0.7	0.7
F 1.40	0.6	0.7	0.6
F 1.65	0.6	0.6	0.6
	% Pyritic Sulfur[3]		
F 1.30	0.02	0.01	0.01
F 1.40	0.02	0.01	0.01
F 1.65	0.02	0.01	0.01
	Lbs. $SO_2/10^6$Btu[4]		
F 1.30	0.8	0.9	0.9
F 1.40	0.8	0.9	0.9
F 1.65	0.9	0.9	0.8

---

[1] Head sample 13.8%
[2] Head sample 0.6%
[3] Head sample 0.05%
[4] Head sample 0.9 lb.

Table 8 – Ash, total sulfur, pyritic sulfur, and pounds of sulfur dioxide per million Btu versus particle size for various specific gravities for the Sewell coal.

Size →	1/4"X0	100mX0	200mX0
	% Ash[1]		
F 1.30	3.7	2.0	1.9
F 1.40	8.3	5.2	4.7
F 1.65	9.7	8.2	7.5
	% Total Sulfur[2]		
F 1.30	0.8	0.7	0.8
F 1.40	1.0	0.8	0.8
F 1.65	1.2	1.0	0.9
	% Pyritic Sulfur[3]		
F 1.30	0.12	0.05	0.03
F 1.40	0.36	0.14	0.10
F 1.65	0.52	0.25	0.18
	Lbs, $SO_2/10^6$Btu[4]		
F 1.30	1.1	1.0	1.0
F 1.40	1.5	1.2	1.1
F 1.65	1.8	1.4	1.2

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[1] Head sample 10.5%
[2] Head sample 1.5%
[3] Head sample 0.70%
[4] Head sample 2.2 lb.

Table 9 – Ash, total sulfur, pyritic sulfur, and pounds of sulfur dioxide per million Btu versus particle size for various specific gravities for the Sewanee coal.

	---F 1.30----		---F 1.40----		---F 1.60----		---F 1.65----	
	Wt %	Btu %	Wt %	Btu %	Wt %	Btu %	Wt %	Btu %
ILLINOIS #6, DELTA								
1-1/2"X0*	39.1	45.1	77.4	86.1	86.3	94.4		
3/8"X0*	48.9	56.4	77.1	86.7	85.2	94.2		
14mX0*	42.4	48.7	70.9	80.4	84.1	93.3		
6mX0	58.3	63.7	82.3	87.1			93.7	97.6
100mX0	57.7	68.8	76.0	82.9			91.8	97.5
200mX0	56.3	62.4	75.6	82.7			91.7	93.5
INDIANA #3, CHINOOK								
1-1/2"X0*	47.5	51.0	77.2	81.2	95.0	97.6		
3/8"X0*	54.1	58.0	77.4	82.0	93.0	96.0		
14mX0*	33.4	35.9	79.0	83.6	91.8	95.0		
1/4"X0	43.5	48.8	75.0	82.1			90.7	96.3
100mX0	18.9	21.4	76.4	83.8			90.4	96.9
200mX0	9.8	11.4	68.1	76.4			88.6	97.0
ILLINOIS #6, Leahy Mine								
1-1/2"X0*	37.2	42.2	76.2	84.0	87.1	94.2		
3/8"X0*	44.6	51.0	74.4	83.0	85.7	93.6		
14mX0*	39.5	52.0	66.8	75.5	84.5	92.6		
8mX0	58.2	62.6	80.9	85.7			95.2	97.8
100mX0	50.3	54.9	77.6	83.1			93.6	97.5
200mX0	34.7	38.0	72.6	78.6			92.6	97.4
INDIANA #7, MINNEHAHA								
1-1/2"X0*	70.8	74.1	91.3	94.0	95.9	98.0		
3/8"X0*	62.8	69.6	86.3	90.2	94.7	97.4		
14mX0*	34.0	37.0	79.6	84.4	93.6	96.8		
1/4"X0	21.1	23.1	74.6	79.6			95.5	98.6
100mX0	3.3	3.7	71.7	78.2			92.6	97.7
200mX0	2.3	2.6	65.8	72.6			91.6	97.9
ILLINOIS #5, WABASH								
1/4"X0	28.1	34.0	67.7	80.8			83.0	96.6
100mX0	12.4	15.3	60.1	72.9			81.1	95.5
200mX0	5.7	6.7	51.0	61.6			82.0	95.7
PITTSBURGH #8								
1/4"X0	73.7	77.0	90.7	94.0			95.2	98.0
100mX0	70.1	73.9	91.2	95.1			94.5	98.0
200mX0	53.6	56.5	89.4	93.6			94.5	98.2
LOWER KITTANNING								
1/4"X0	21.6	28.3	64.8	80.3			77.3	93.8
100mX0	25.2	33.9	58.1	75.4			75.6	94.0
200mX0	22.8	31.1	53.8	71.0			74.6	93.8
SEWELL								
1/4"X0	45.1	52.2	74.9	85.6			87.8	96.0
100mX0	48.1	55.6	72.0	81.5			87.3	96.3
200mX0	38.4	44.6	69.8	79.2			87.5	96.4
SEWANEE								
1/4"X0	19.3	21.0	84.9	88.1			97.1	98.8
100mX0	34.8	38.4	74.7	79.7			95.4	98.2
200mX0	30.8	34.1	72.1	77.2			89.0	98.1

*Data from USBM RI8118

Table 10 – Weight and Btu recovery cumulative float for various sizes, RI 8118 and AMAX samples.

George Land: I will take maybe one or two questions at the most. Anybody have a question?

Paul Chugh: My name is Paul Chugh and I am from SIU. Your initial washability data has shown that float materials at 1.3 had roughly 1 to 5 percent ash. Did I read it correctly?

George Land: On a couple of those coals we got down close to 1 percent. The problem is that with some of the coals, there was practically no 1.30 S.G. float, but a large amount of 1.40 float material. If you looked at that last table, which compared before and after pounds of SO_2 per million Btu, I used a 1.40F and showed the percent Btu recovery for that gravity. The indications are that we were getting efficient recovery. A 1.30 would have given me a lower SO_2 value but, even then none of them would have been in compliance. I didn't use 1.30 because some of them had less than 3 or 4 percent 1.30F material.

Paul Chugh: Did you say 3 or 4 percent?

George Land: For 1.30, yes. some of them had 30 or 40 percent, but a couple of them had less than 5 percent, so by choosing 1.40 float, we found they all had at least 60 percent, and some of them had as high as 80 percent.

Paul Chugh: What was the sulfur in the 1.30 float?

George Land: The sulfur in the Illinois coals was still above 1.5 percent in the ones that we looked at, except for the Springfield (No. 5) Coal.

George Land: Our next speaker is Dr. Sinha from Southern Illinois University. Dr. Sinha's academic and professional qualifications are in mining engineering, electrical engineer, and coal preparation. He has a Doctorate in mining engineering. In England, he worked with longwall operations before he came to the United States. He also worked in Canada. He was with Penn State for a while, then worked for Peabody, and he's been with Southern Illinois University since 1975. He is going to talk about "Desulfurization Potential of Illinois Basin Coal". Dr. Sinha.

DESULFURIZATION POTENTIAL OF ILLINOIS BASIN COAL

A. K. SINHA
Associate Professor
Department of Mining Engineering
Southern Illinois University
Carbondale, Illinois

ABSTRACT

Rapid growth in the thermal coal market, which the industry has enjoyed until recently, is projected to resume soon and continue in the foreseeable future. Most of the increase in the thermal coal market is expected to occur in the areas close to Midwestern coal fields, southeastern United States, and western Europe where the Illinois coals have best prospects for competing. Besides, the Midwestern coal fields have all the elements necessary to become an important exporter of thermal coal provided the coal is desulfurized and prepared to meet the environmental restrictions and the specifications of utility customers. While the Environmental Protection Agency (EPA) does not generally permit the utilization of even high BTU coal containing more than 0.8 or 0.9 percent sulfur within the United States, the utility companies in other countries usually require high BTU coal containing not more than 1.5 percent sulfur to minimize the cost of fuel utilization and meet their local environmental standards.

High quality thermal coal can be prepared to compete in the utility markets by desulfurizing the high BTU Midwestern coal and blending it with low-sulfur western coal which is usually low in BTU content. Sulfur in coal occurs in organic and inorganic forms. The inorganic sulfur in Illinois coals is almost exclusively pyrite which can be liberated and removed from the coal by physical coal cleaning devices, such as hydrocyclones, concentrating tables, or froth flotation cells. Several research projects have been conducted at Southern Illinois University in recent years which indicate that Illinois Basin coals can be significantly desulfurized by conscientious application of such devices. The total sulfur in Illinois coals is generally comprised of about 1 percent organic sulfur, and the remainder is in pyrite. The total sulfur in a sample of southern Illinois coal was very economically and successfully reduced from 3.57 percent to 1.5 percent utilizing a concentrating table. A similar result was obtained with a hydrocyclone. In a project accomplished recently, the total sulfur in samples of coal obtained from ten selected high-sulfur coal mines operating in Illinois was successfully reduced by froth flotation from as high as 5.3 percent to less than 1.4 or even 1.25 percent in each case. These results were later verified by tests conducted in an industrial-size froth flotation pilot plant. Some of the details of these tests are presented and discussed.

INTRODUCTION

It is well known that the high BTU Midwestern coal, of which there is a very large reserve in the United States, has great potential for competing in the utility markets here at home and abroad provided that the coal is desulfurized to meet the environmental restrictions. While the Environmental Protection Agency (EPA) does not generally permit the utilization of even high BTU coal containing more than 0.8 or 0.9 percent sulfur within the United States, utility companies in other countries often require high BTU thermal coal containing less than 1 or 1.5 percent sulfur to minimize their cost of fuel utilization and meet their local environmental standards. According to the recent estimates (1), the areas where substantial increase in utility coal demand is being projected to occur lie closer to the Illinois Basin. It was concluded at the congressional field hearings conducted in 1981 (2), that the Illinois Basin has many of the elements necessary to emerge as an important exporter of the thermal coal to the growing markets abroad provided that the coal is adequately desulfurized. The low BTU Western coal is not able to penetrate the utility markets in Europe or southeastern United States due to the high costs of transportation.

The sulfur in Illinois coals occur in both organic and inorganic forms. The organic sulfur, which is derived from decaying vegetable matter and is chemically bonded, can not be liberated or physically separated from the coal. The inorganic sulfur, which is primarily pyrite or sulfate and occurs in veins, lenses, or nodules, can be liberated and removed from the coal by physical coal cleaning methods. A major portion of the total sulfur in most U.S. coals occurs in the form of pyrite (3). Illinois Basin coals contain on an average 3.57 percent total sulfur, out of which 2.06 percent is pyritic, 0.08 percent is sulfate, and 1.46 percent is organic sulfur. Recent research data indicate that the Illinois Basin high-sulfur coals generally contain about 1 to 1.5 percent organic sulfur, the remainder being primarily pyritic sulfur.

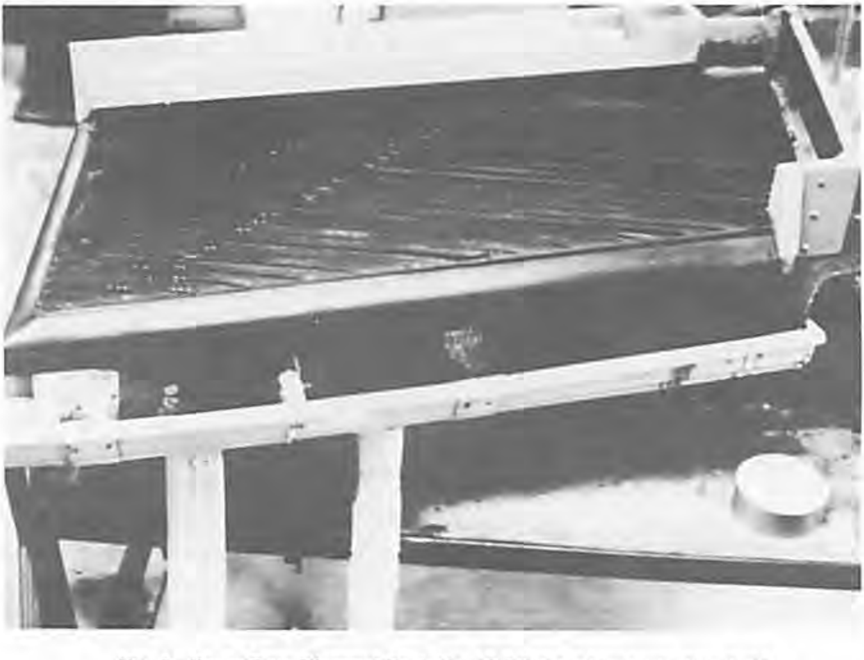

Fig. 1 – Super Duty Diagonal-Deck No. 15-S Deister Concentrating Table.

DESULFURIZATION POTENTIALS

Pyrite is much harder than coal. It is liberated when coal is ground to a fine size. Research conducted at Southern Illinois University indicates that the pyrite in Illinois coals generally attains almost complete liberation when ground finer than 100 or 200 mesh (4). Considerable liberation, however, is attained in the coarser sizes. Pyrite is over three times heaver than coal. Therefore, it can be separated from coal by gravitational coal cleaning techniques such as the shaking table or the cyclone. Surface properties of pyrite particles are also considerably different from those of coal particles. Therefore, it can be separated from coal also by such other techniques as the froth flotation. Three research projects were recently conducted in the Department of Mining Engineering at Southern Illinois University under the direction of the author to study the desulfurization potentials of Illinois Basin coals.

A research project was conducted for a M.S. thesis in which a series of tests were systematically conducted to desulfurize a sample of coal using a single deck industrial type shaking table, Deister Model 15-S, which is shown in Figure 1. The sample used for this study was a channel sample obtained from Herrin (No. 6) Coal in southern Illinois. It contained 3.57 percent sulfur and 11.17 percent ash which represents an average Herrin Coal in southern Illinois. The data so obtained were analyzed with the help of a statistical computer model to optimize the table operating parameters. A series of tests was then conducted with the optimized values of the table operating parameters. Figure 2 presents the result which clearly shows that a sample of coal from the Herrin Coal can be desulfurized to recover over 92 percent of the coal with a sulfur content of 1.55 percent, when the concentrating table is operated with optimized values of the table operating parameters and the sample is ground to minus 35 mesh in size (5). It represents a total sulfur reduction of over 56 percent and pyrite removal of over 85 to 90 percent.

Another research project was conducted under the direction of the author in which a six inch, commercial type hydrocyclone, Krebs model D-6B-227, was utilized for desulfurizing a sample of high-sulfur coal obtained from a coal mine operating in southern Illinois. Figure 3 shows the experimental set up. The coal sample contained 4.67 percent sulfur and 14.46 percent ash. A series of tests were conducted and the data so obtained were analyzed utilizing a nonlinear statistical computer model to optimize the values of the operating parameters of the cyclone for maximum reduction in sulfur. Figure 4 presents the test results as well as the predictions made by the computer (6). Pyritic sulfur reduction of as high as about 62 percent with approximately 54 percent recovery of coal was obtained with the single stage operation of the hydrocyclone. The computer, however, predicted that over 70 percent reduction in pyritic sulfur should be obtainable in a single stage operation if the cyclone is operated with optimized values of its operating parameters. Dense-media cyclones are considered superior to a hydrocyclone for the removal of pyrite from coal. However, the feasibility of desulfurization of high-sulfur coal with multi-stage cyclone operations and dense-media cyclones remain the topics for further research.

Both coal and pyrite display natural flotability in a froth flotation cell. However, the coal floats much faster than the pyrite. An extensive research project was recently concluded under the direction of the author which was conducted with funds provided by the U.S. Department of Energy. Ten representative channel samples of high-sulfur coal were obtained from carefully selected coal mines operating in the different areas in Illinois. A series of bench scale tests were conducted on each sample utilizing a Denver, D-size, froth flotation cell to optimize the froth flotation system operating parameters for maximum reduction in sulfur. The rate of flotation of coal was accelerated by the use of kerosene as collector, and the pyrite was suppressed by the use of cyanide. All the tests were conducted at a pH of 7.0. The data so obtained were analyzed utilizing a nonlinear statistical computer model to optimize the froth flotation system operating parameters for maximum reduction of sulfur in each sample. A series of bench tests was then conducted with the optimized values of the froth flotation system operating parameters on each sample to verify the predictions made by the computer. Finally, a series of

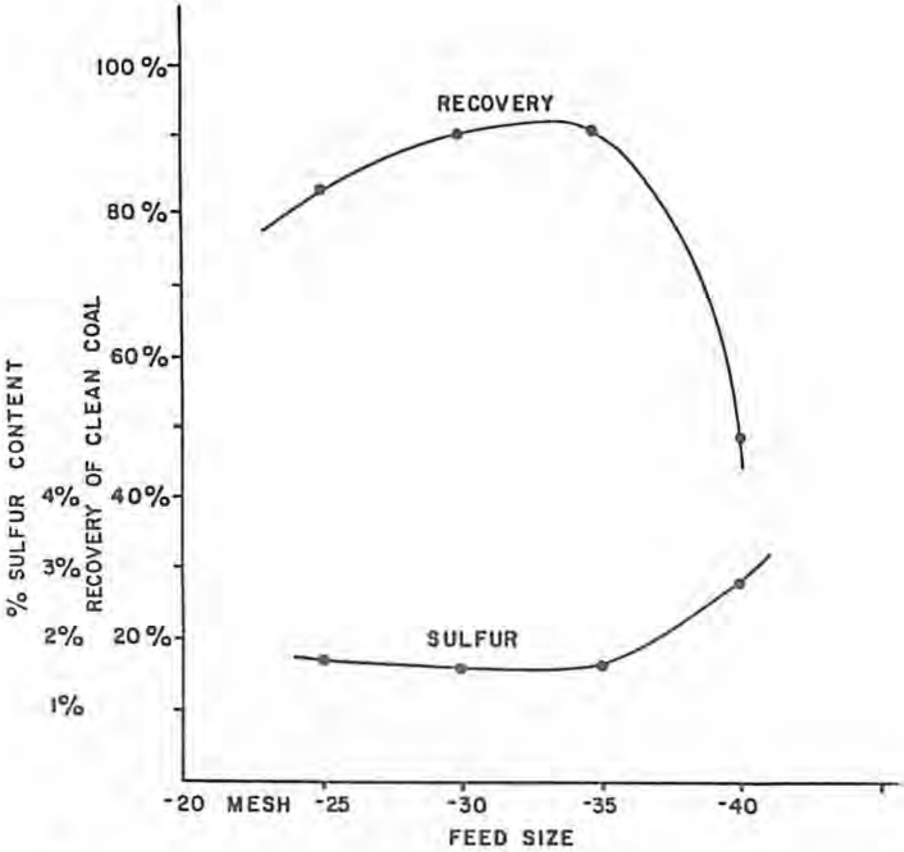

Fig. 2 – Desulfurization and coal recovery by shaking table. Rate of flow of dressing water =6.9 liter/minute, longitudinal slope=0.4°, cross slope=3.2°.

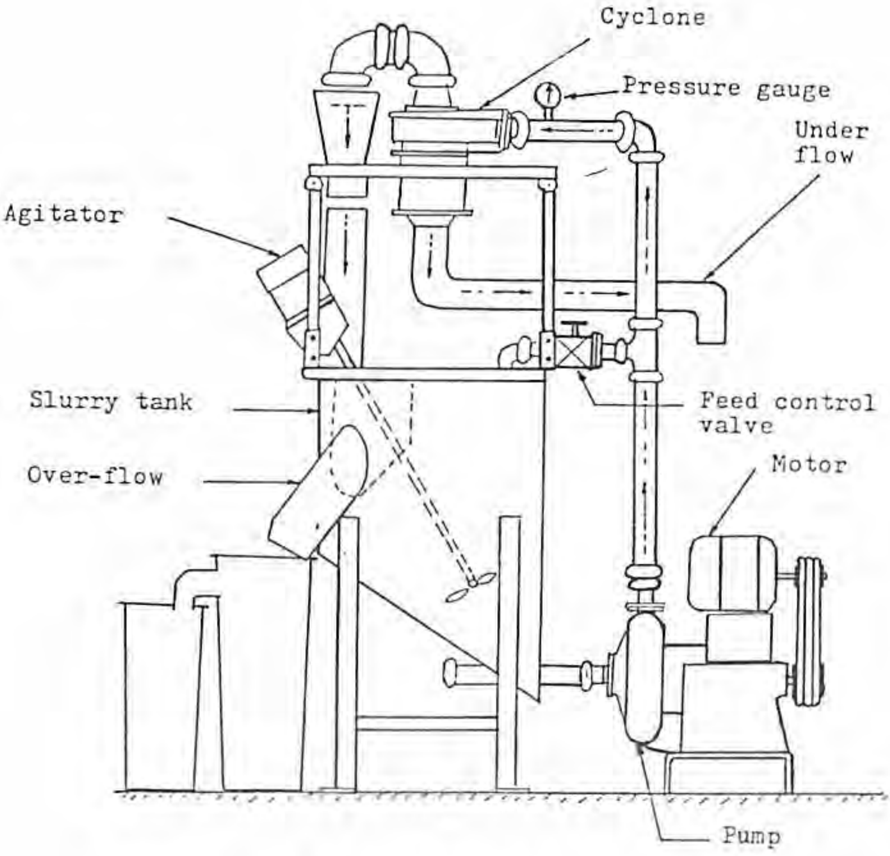

Fig. 3 – Experimental setup of the hydrocyclone.

tests was conducted on each sample on a pilot plant scale utilizing an industrial size, Denver No. 8, froth flotation pilot plant shown in Figure 5. The tests were conducted with a continuous flow to simulate a practical froth flotation system. Table 1 presents a summary of the results of the pilot plant study. The total sulfur in some of the samples dropped to less than 1.4 percent in the concentrate from as high as 5.25 percent in the feed with a recovery of coal of over 82 percent. A reduction in ash of 64 percent was obtained in the desulfurization process. It seems quite obvious from the results that over 85 percent recovery of coal with sulfur content of less than 1.5 percent in the concentrate is obtainable in high-sulfur Illinois coals by the use of single stage froth flotation (7).

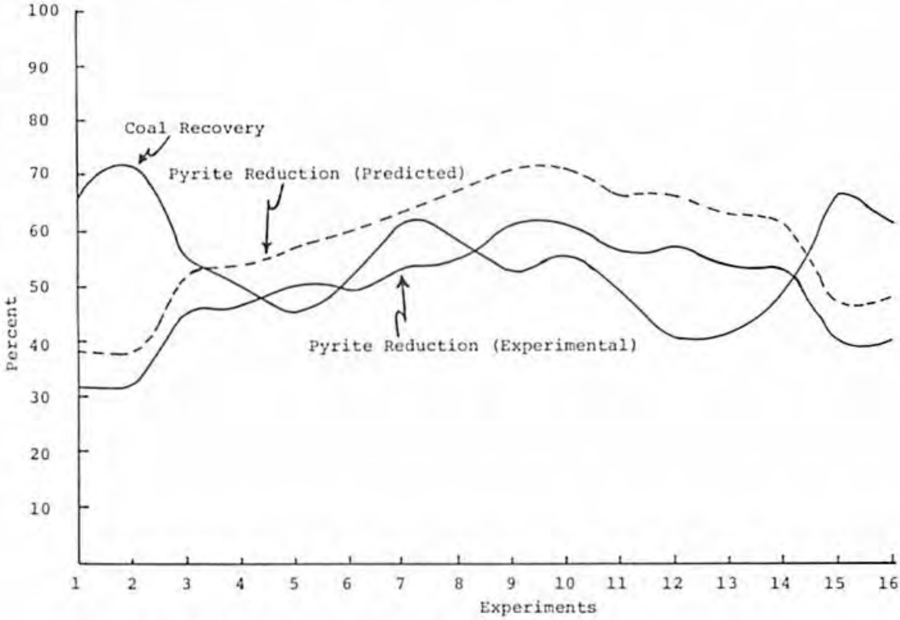

Fig. 4 – Coal recovery and pyrite removal by single stage hydrocyclone.

Fig. 5 – Froth flotation pilot plant.

Table I – Summary of Pilot Plant Test Results

Sample	Initial Sulfur %	Sulfur In Concentrate %	Total Sulfur In Tailings %	Reduction In Total Sulfur %	Yield Of Clean Coal %	Recovery Of Coal %	Ash In Feed %	Ash In Conc. %	Red. In Ash %
A	4.25	1.38	18.75	67.5	83.5	86.0	29	11.6	60
B	3.92	1.56	9.95	60.2	77.1	78.6	21	10.5	50
C	3.56	1.72	9.75	51.7	77.1	78.6	23	11.5	50
D	4.475	1.62	15.275	63.8	79.1	81.5	21	10.25	51.2
E	2.125	1.36	7.52	36.0	87.6	88.2	12	7.7	36
F	3.525	1.46	11.90	58.6	80.2	81.9	17	8.5	50
G	4.00	1.46	12.80	63.5	85.1	87.4	21	9.0	57
H	2.75	1.50	8.50	45.5	82.1	83.2	13	9.0	31
K	5.25	1.40	19.80	73.3	79.1	82.3	18	6.5	64
L	3.50	1.62	11.67	53.7	81.3	82.9	11	4.8	56.4

CONCLUSIONS

The test results obtained to date indicate that high-sulfur Illinois coals generally contain about 1 percent organic sulfur, the remainder of the sulfur existing in the pyrite. The pyrite in Illinois coals is almost completely liberated when ground to minus 100 mesh in size. Over 90 percent of the pyrite can be removed from Illinois coals without any appreciable loss of coal by conscientious application of relatively inexpensive devices such as the concentrating tables or single stage froth flotation. It is apparent from the test results that coal concentrates with less than 1.4 or 1.3 percent sulfur and over 85 percent recovery of coal is obtainable from high-sulfur Illinois coals in industrial coal preparation plants. However, overgrinding of coal is neither technically advisable nor economical. Hence, a run of mine coal should be desulfurized in coarse sizes as much as possible. It is only the middling products, which are pyrite particles locked with coal, that must be ground to liberate the refuse material. The coal fines, when desulfurized, may be pelletized to minimize transportation problems, unless the desulfurization procedures are performed at the power plant site, or hydraulic transportation of the fines is resorted to. Modern utility boilers use pulverized fuel which is coal ground to about 70 percent passing through 200-mesh sieve. Hydraulic transportation pipe lines require coal feed which has to be ground to minus 14-mesh in size with 16 to 23 percent by weight passing through 325-mesh sieve.

An Illinois Basin coal, upon being desulfurized, can be blended with a low-sulfur Western coal to produce an EPA compliance quality coal to compete in the utility coal markets abroad. Appreciable potential thus exists for desulfurization of an Illinois coal to render it competitive in the utility coal markets here at home and abroad. A coal desulfurization procedure would add to the cost of coal preparation, but the additional cost would be more than off-set by the additional revenue created by the increase in price of coal due to the improvement in its quality. The penalty paid by a company for not meeting the coal quality specification of a customer can be minimized or even eliminated through the application of a suitable coal desulfurization scheme.

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George Land: Dr. Sinha got through in time so we can take one or two questions. Okay, let's proceed then with the next speaker. We have one more paper about fine-coal cleaning. Joanna Buckentin is an Assistant Minerals Engineer at the Illinois State Geological Survey. She received her education at the University of Arizona. She has her B.S. in metallurgical engineering and an M.S. in mineral processing engineering from Montana Tech. She is going to tell us of some of the work that is going on at the Geological Survey. The title of her paper is "Research for Ash and Pyrite Reduction by Fine Coal Cleaning." Joanna.

RESEARCH FOR ASH AND PYRITE REDUCTION BY FINE COAL CLEANING

J. BUCKENTIN, R. R. RUCH, L. CAMP
Minerals Engineering Section
Illinois State Geological Survey
Champaign, Illinois 61820

ABSTRACT

Research was performed to compare a new fine coal cleaning process, the Illinois State Geological Survey Aggregate Flotation process, with the more traditional processes of Froth Flotation and oil agglomeration. Tests were performed on a run of mine coal ground to fine sizes. Results revealed that oil agglomeration is effective in removing mineral matter from coal but is expensive due to the high oil dosages needed (200-250 pounds of oil per ton of coal). Froth flotation demineralizes coal well when particle sizes are coarser than 200 mesh, but the process performs less effectively at finer sizes. As originally envisioned, the ISGS Aggregate Flotation process demonstrated an ability to recover combustible material even at fine sizes. However, process selectivity was poor. Changes were made in the process and it was then successful in cleaning a coal from 39 to 7 percent ash and from 2.0 to 0.8 percent pyritic sulfur.

George Land: Thank you Joanna. We now have about 7 minutes of that original 10 minutes we were going to have for questions. Let's start with questions for Joanna first and then for anybody else on the program. Does anybody have a question for Joanna?

We'll throw it open for general questions. Does anybody have any questions for any of the first four speakers?

Our next speaker is someone whom I think most of you in the coal business know from some association with the Department of Energy and Natural Resources. Terri Moreland comes to us today from the Department of Energy and Natural Resources. She was educated at Western Illinois University and has a Master's degree and a Bachelor's degree. She has been working for the Department for 4 years, and today she is going to talk to us about "State Efforts to Improve Markets for Illinois Coal." Terri Moreland.

Terri Moreland: I welcome this opportunity to speak to you today about the State of Illinois' efforts to increase the marketability of its coal. First, because we think that what we are doing is important and we like to talk about it, and second; because you, as representatives of the mining industry, are pretty much interested in many of the same things that we are. However much the citizens of this state have invested in the coal industry in Illinois, we know that your investment, your stake, and ultimately your risk, is far greater. Even though you have the biggest stake in the future of Illinois coal, the State of Illinois as a whole has a very real and very significant interest in the health of your industry. In order to understand that interest, I think it is important to look at the coal industry in the context of the total state picture. Of course, coal has played a very important part in Illinois history.

Terri Moreland did not submit her paper for publication in the Proceedings.

George Land: Thank you Terri. Do we have any questions for Terri from anybody in the audience? If not, we'll proceed with our program. Our next talk about one of those projects that Terri mentioned has to do with the Allis-Chalmers KILnGAS project with which many of you are familiar I'm sure. The program shows that Jim Deacon was going to be here to talk to us about it, but Jim couldn't make it. He sent a very able replacement by the name of Don Loomis, who is going to talk to us. Don received his education at the University of Wisconsin. He has been involved in the KILnGAS program for a long time. He helped to engineer, design, and construct the microplant that was operated at Oak Creek. This led to the final design of the plant that was built at the Wood River Station of Illinois Power, and he has been very much involved in the construction and operation of that plant. Don Loomis.

Don Loomis: On behalf of Allis-Chalmers we are pleased to participate in your 92nd IMI annual convention. We've been involved with this KILnGAS technology for quite a while. I am very pleased to have an opportunity to go out once in a while and talk to others about different experiences that we have had. I personally believe that we together have common ground which can be mutually beneficial not only to the coal mining industry, but also to the State of Illinois. You can see that we're on the threshold of significant changes that can have a long-term impact on not only our company and its business but also the coal mining industry. My feeling is that the application that we just discussed and reviewed is only the beginning for a new use of high-sulfur coal. I think that as we look over some of the problems that were discussed here this morning there is probably a place for a lot of the processes that are under development at this time. We hope to carve out a niche for our company to supply equipment. Thank you.

THE *KILnGAS* PROCESS AND ITS COMMERCIAL APPLICATION TO HIGH-SULFUR COALS

DON W. LOOMIS
Proposal Manager
Allis-Chalmers Coal Gas Corporation
P. O. Box 512
Milwaukee, WI 53201

INTRODUCTION

There is growing interest in coal as one of the nation's primary energy resources, and with good reason. The United States, as a whole, is estimated to have 1,730 billion short tons of identified coal resources. Enough of this is recoverable to potentially satisfy most of the country's electric power generation needs for the next 200 years. Of this vast reserve, Illinois has been blessed with approximately 181 billion tons, with 30 billion tons being recoverable reserves of bituminous coal. This places Illinois in the enviable position of having one quarter of the nation's total recoverable bituminous coal reserves. Other positive factors for Illinois coal are:

- Higher heating value when compared to Western coals,
- Major markets nearby,
- Excellent transportation network, and
- Relatively low production cost.

Yet, with all these positive factors, Illinois coal sales are declining, or, at best, not increasing (Table 1). The basic reason is that Illinois coal has a high-sulfur content. Many states have passed environmental regulations that make it expensive and difficult to use high-sulfur coal. And, there is a growing concern that future legislation may be even more restrictive.

Allis-Chalmers is in the process of commercializing a new coal technology that is aimed specifically at large-volume utilization of high-sulfur coal in an economical and environmentally attractive manner. Demonstration of this technology, being conducted at East Alton, Illinois, is supported by Allis-Chalmers, 12 utilities, EPRI, and the State of Illinois. The initial market for the technology, called the KILnGAS process, is anticipated to be in the electric utility industry, because of its traditionally heavy reliance on coal. The Illinois electric utilities, for example, consumed more than 31 million tons in 1983, which accounted for over 86 percent of all coal used in the state that year (Table 3).

Significantly, comparison of Illinois coal shipped to all utilities (Table 2) with Illinois coal production trends (Table 1) shows that in 1983, almost 89 percent of all coal mined in Illinois went to electric utilities both in and out of state. Table 4 presents a detailed breakdown of all coal shipped to Illinois steam-electric plants, which shows that the primary loss to Illinois coal mining is the low-sulfur coals coming from Colorado, Wyoming, and Montana.

Table 1 – Illinois Coal Production Trends

Year	Short Ton in 1000's
1983	56,841
1982	60,275
1981	51,865
1980	62,543

Source: *Quarterly Coal Report,* DOE/EIA-0121 (83/4Q). April, 1984.

Table 2 – Illinois Coal Shipped to Utilities

Year	Short Ton in 1000's	%
1983	50,557	-2.1
1982	51,619	

Source: *Cost and Quality of Fuels for Electric Utility Plants 1983* DOE/EIA-0191 (83), June 1984.

Table 3 – Distribution of Coal Delivered in Illinois During 1983

	Short Ton in 1000's	%
Electric Utilities	31,404	86.4%
Coke Plants	1,608	4.4%
Other Industrials	2,897	8.0%
Residential/Commercial	423	1.2%
	36,332	100.0%

Source: *Quarterly Coal Reporter,* DOE/EIA-0121 (83/4Q). April, 1984.

The incentives for utility industry support for coal gasification lie in the recognition of the need for a competitively-priced and environmentally-acceptable alternative fuel to oil, natural gas, and state-of-the-art coal-based sulfur removal technologies. In addition, the utility industry is interested in the flexibility offered by the KILnGAS process to feedstock selection, namely, the ability to use high-sulfur coal as a fuel. The industry recognizes that transportation accounts for two-thirds of the cost of Western coal, and transportation costs are also vulnerable to annual increase and inflation. Likewise, the utility industry, typically a long-range planner, is comfortable with the vast coal reserves safety contained within the U.S. borders.

The incentives for the State of Illinois participation in the KILnGAS program are from a different perspective. In addition to recognizing the necessity of promoting "clean air" technologies, the state has viewed the KILnGAS technology as a means of protecting and expanding their existing coal markets. For example, even a single gasification plant for a nominal 500 MW power plant would consume approximately 1.0+ million tons of coal per year – operating at 60 percent capacity – with a corresponding coal market value of $30 million (in 1984 dollars). The potential for a reasonably quick trend reversal due to the state's investment is obvious.

The State of Illinois also recognized that the KILnGAS technology offers a means of protecting its consumers from rapidly escalating electricity costs – which could occur from deregulation of natural gas and rapid jumps in oil prices, as happened in the late 1970's. Another difficult situation has been the delays and escalated cost for completing nuclear power plant projects, which in the end may result in increased electric power cost. The bottom line is that electricity is an important factor in maintaining the economic competitiveness of industries operating in the state or those considering locating there.

Finally, the State of Illinois recognized that successful commercialization of the technology would create new employment opportunities for its citizens and revenue streams for the state. It is estimated, for example, that a single 500 MW capacity KILnGAS gasification combined-cycle plant could create more than 1200 jobs – including construction and related industries, operators and maintenance personnel, and mining-related workers (Table 5).

Table 4 – 1983 Coal Shipped to Illinois Steam-Electric Plants of 50 MW or Larger

District	State	Short Tons (in 1000's)	$/Short Ton	Total ($ in 1000's)	% Total Tons
8	KY	1,048.6	52.76	55,324.1	3.4%
9	KY	769.1	35.53	27,326.1	2.5%
10	IL	16,365.2	33.23	543,815.6	52.4%
11	IN	1,554.5	32.64	50,738.9	5.0%
16	CO	63.2	54.35	3,434.9	0.2%
17	CO	569.3	55.29	31,476.6	1.7%
19	WY	8,049.0	58.77	473,039.7	25.7%
22	MT	2,841.0	49.03	139,209.0	9.1%
Total		31,259.9	42.37	1,324,364.9	100%

Source: *Cost and Quality of Fuels for Electric Utility Plants, 1983*
DOE/EIA-0191 (83), June 1984.

Table 5 – Job and Investment Impact of a Single KILnGAS Combined Cycle 500 MW Plant Built in Illinois

Coal (M Ton/Yr.)	1.25
Mining Jobs	500
Construction Jobs	75
KILnGAS Operators	180
Service Jobs	510
Total Jobs	1,265
Mine Investment (1984 $)	$55 MM
KILnGAS Plant Investment (1984 $)	365 MM
Total Investment (1984 $)	$420 MM

KILnGAS COMMERCIAL MODULE

The KILnGAS coal gasification technology has been under development by Allis-Chalmers Corporation since 1970, as shown by the schedule (Figure 1). The company's coal gasification feasibility evaluation reached a major milestone in 1976 when eleven electric utility companies joined with Allis-Chalmers to fund the engineering development program. Pilot plant (60 tpd) design, fabrication and operation, large-scale gasifier components development, coal-feed testing, and commercial plant studies constituted the major program efforts lasting three years.

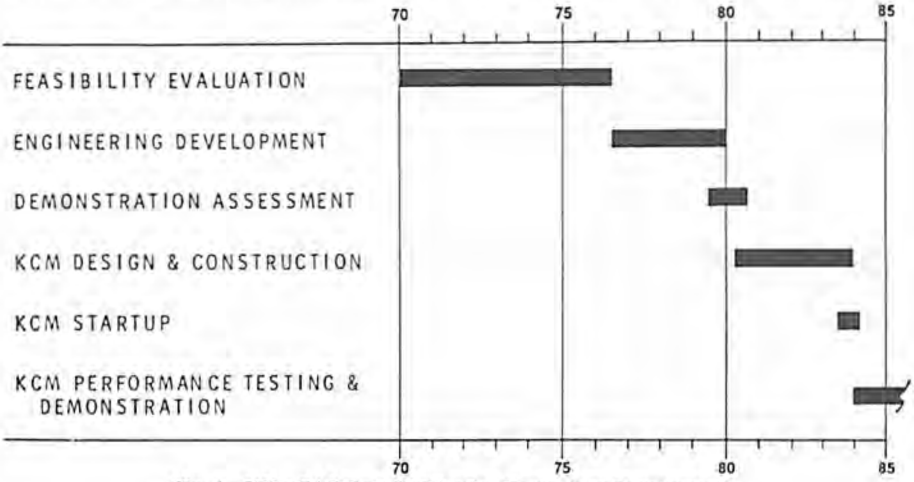

Fig. 1 – KILnGAS Coal Gasification Technology Development

The Demonstration Assessment activities consisted of third-party technology evaluation, demonstration plant site selection, preliminary design of the gasification plant, and funding solicitation. These tasks lasted about one year.

During October of 1980 Allis-Chalmers started construction of the coal gasification plant, referred to as the KILnGAS Commercial Module (KCM). Funding for this project was provided by Allis-Chalmers, the State of Illinois, and twelve electric utility companies. During June 1983, plant start-up functional tests were initiated for completed individual systems and groups of systems.

PLANT DESCRIPTION

The KILnGAS plant is located adjacent to Unit No. 5 of the Wood River Generating Station, in East Alton, Illinois, as shown in Figure 2. (The gasification plant is located in the left-center foreground area.) Coal, from supply yards beyond the switchgear, is transported on existing power plant conveyors, through the utility building to the gasifier day bin, which is enclosed in the tall structure separated from the power plant. (In Figure 2 the structure enclosing the coal day bin stands in front of the tallest stack.) The long, lower, narrow building, connected to the coal tower, encloses the pressurized rotary kiln, designed for gasifying coal. Gas cooling, heat recovery, gas cleanup and other process systems are located adjacent to the gasifier building.

The gasifier operating pressure is 60 psig; fuel gas delivery of the gasification plant to Unit No. 3 is 409 million Btu/h.

Fig. 2 – Aerial View of KILnGAS Commercial Module

Project Test Objectives

Concerns for electric utility power generation and distribution needs related to operation and future growth provided the basis for the project test objectives:

To show that the gasification plant can:

- Operate in an electric utility load-following environment.
- Use operating plant personnel with conventional skill levels.

To establish a data base for:

- Design performance of the various process units.
- Evaluating operational economics and
- Designing future larger-scale units, 2000 tons to 5000 tons per day coal feed.

The overall goal of Allis-Chalmers is to position itself for design and sales of future KILnGAS plants with normal commercial performance and equipment warranties.

THE KILnGAS PROCESS

The KILnGAS system is an air-blown coal gasification system for supplying Low-Btu Gas (LBG) for utility electric-power generation. The system uses a rotary kiln for gasification and incorporates gas cleaning, cooling, and sulfur removal to provide environmentally acceptable fuel for combustion in gas turbines and boilers.

The primary element in the KILnGAS system is the rotary gasifier kiln that is ported and pressurized. Coal, without pretreatment (no grinding, classification, or slurrying), is introduced into the gasifier (on the left in Figure 3) and, as a result of the kiln's inclination, rotation, and tumbling action, passes through the unit. The

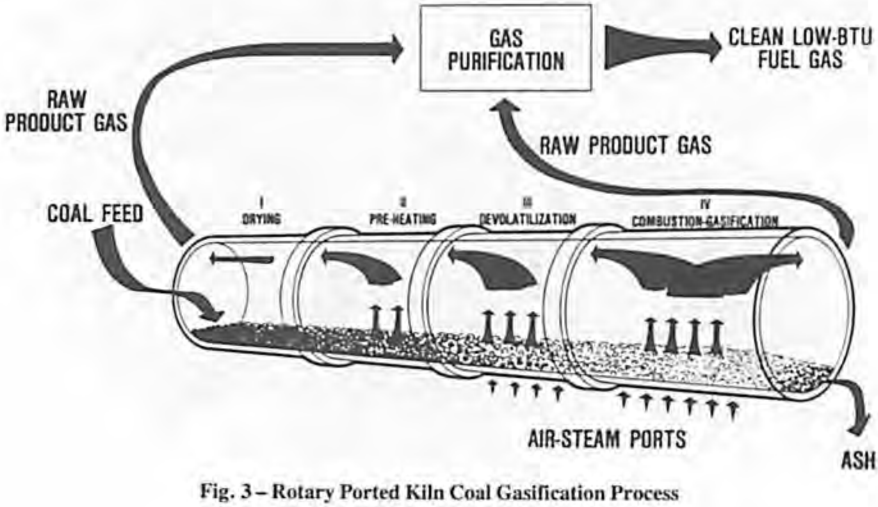

Fig. 3 – Rotary Ported Kiln Coal Gasification Process

coal progresses through the gasifier and is subjected to four successive process steps – drying, preheating, devolatilization, and gasification; the remaining ash solids are discharged. Gasification reactants, steam, and compressed air, are supplied under the coal bed to the partially-devolatilized coal and to the char in the downstream half of the rotary kiln through ports which are axially positioned along the gasifier shell. Independent air/stream quantity and mixture control are provided for each of six ported zones in the downstream half of the gasifier. This arrangement permits adjustment of the air-stream mixture along the gasifier axis to satisfy changing process conditions.

Referring to the KILnGAS system block diagram, Figure 4, the ash remaining after gasification is discharged into the lock hopper system, where it is first quenched with water and reduced to atmospheric pressure. The ash is then hydraulically conveyed to an ash pond.

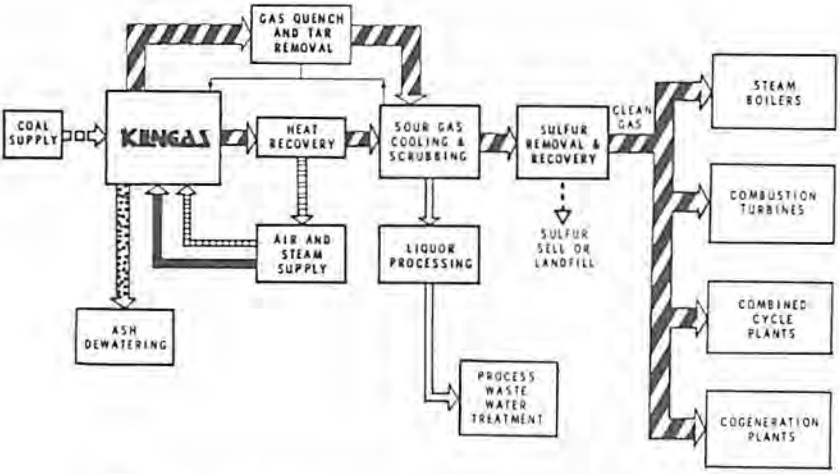

Fig. 4 – KILnGAS Commercial System – Process Flow Block Diagram

The gasifier feed-end off-gas passes through a refractory-lined cyclone to remove entrained particulates. These particulates, containing a high percentage of unreacted carbon, are reintroduced into the gasifier with the coal feed. The 1000°F gases leaving the cyclone are quenched, scrubbed, and cooled to approximately 200°F. Condensed coal tars, heavy oils, and particulates are separated from the wash liquors and are recycled back to the gasifier.

The gasifier discharge-end off-gas passes through a refractory-lined cyclone to remove entrained particulates. These particulates, having a lower carbon content than those on the feed-end, are disposed with the gasifier ash. The 1900°F off-gas is cooled to approximately 300°F in the Discharge-End Heat Recovery (DEHR) system, which generates steam for gasification. The DEHR off-gas, following scrubbing and cooling to approximately 200°F, is merged with the feed-end gas stream. These combined streams are cooled to 100°F and scrubbed. The

100°F gas passes through a sulfur recovery system which removes the hydrogen sulfide gas and recovers elemental sulfur. This is done by absorption in an alkali liquor using a three-stage jet-venturi scrubber. After H_2S absorption, the liquor is let down to atmospheric pressure, transferred to oxidizer tanks, and sparged with air. The oxygen in the air reacts with the liquor to regenerate the solution for recirculation. Elemental sulfur is formed and floats to the top of the liquor contained in the oxidizer tanks, where it is skimmed off and subsequently washed and centrifuged for landfill disposal or heated, melted and transported by railroad tank cars to point-of-sale.

Following H_2S removal, the desulfurized gas passes through a final polishing scrubber to remove any trace material carryover from the sulfur removal system. The clean fuel gas can then be piped to any of the end users shown in Figure 4.

Gasification plant operations are controlled by a central computer, which has two processing units and a redundant back-up system, that takes over if the primary system fails. Data logging has been incorporated into the control system to provide continuous gathering of plant process performance information. These data are used for on-line process control.

THE KCM TEST PROGRAM

OVERVIEW

Initial start-up of the gasifier using anthracite having low ash, tar and sulfur content was accomplished in mid-1983. As operating experience was gained, fuel feed was changed to the design coal, Herrin (No. 6) Coal. Performance testing and parallel development of the data acquisition system was initiated in the second quarter of 1984, and is currently in progress. Follow-on demonstration testing will be performed over a period of 60 days to simulate commercial service.

After start-up, some system modifications were made, which resulted in operating simplifications in the areas of:

- Tar recycle,
- Tar and water separation, and
- Solids feed.

These modifications have potential for capital cost reductions relative to future commercial large-scale plant design. Other engineering accomplishments in the area of plant function were also realized.

Performance testing progressed to the point where the plant received its Illinois EPA operating permit in June of this year. The test data acquired, to date, are consistent with that used as a basis for large-scale plant design having coal-feed capacities to 5000 short tons per day.

KCM PERFORMANCE TESTING

Performance testing, currently underway, has reached operating levels corresponding to 65% load at 45 psig. Most of the performance work has been near mid-load, approximately 55 percent. During plant operation, fuel gas is regularly fired in the Illinois Power Unit No. 3 boiler. Some performance test results achieved to date include:

- *Environmental compliance.* Plant air emission data required for an operating permit were obtained by an independent contractor. The data provided the basis for filing an operating permit application request to the Illinois EPA, which was subsequently granted for a two-year period.
- *Fuel gas higher heating value (HHV).* Generally the gas HHV is in agreement with the design value of approximately 158 Btu/SCF.
- *Heat recovery.* High-temperature heat recovery operation, 1900°F to 300°F yielded steam generation at 130 percent of its capacity rating, suggesting that the design appears conservative. However, longer operation is required to assure that depositions on the heat transfer surfaces can be controlled by "soot blowing" to maintain performance.
- *Process condensate and wastewater treatment.* Liquor processing, ammonia stripping, and pH control, have yielded wastewater that is treatable by the Alton Municipal Treatment Plant. No upsets have been experienced at the treatment plant; their effluent continues to meet standards. Phenol content is at 30 percent of the design value.
- *Sulfur removal.* Hydrogen sulfide removal rates of 99 + percent have been measured. The ratio of H_2S to organic sulfur is 11:1. Both results are in agreement with design.
- *Turndown.* The gasifier with its reservoir of heated solids, heat losses minimized by refractory-lined walls, and off-gas temperatures of 1900°F and 1000°F relative to much higher temperatures in other gasification systems are contributing operational factors enabling broad process turndown. To date operation as low as 20 percent design rate has been achieved with no evidence of control problems.

In addition, noteworthy functional test accomplishments have been realized in the areas of tar recycle, tar/water separation, solids feed, gasifier off-gas biflow operation, gasifier seal performance, and start-up time.

Longer term operation at full load is required to be more specific in describing additional performance test results. However, preliminary analysis of available data indicates process performance is consistent with that required for future larger-capacity KILnGAS plants. There is no evidence of technology problems, and problems related to the hardware have been amenable to engineering design and modifications.

FUTURE PLANS

While the KILnGAS program has progressed well towards meeting its key objectives, a conservative market such as the electric utility industry requires extensive performance demonstration and confirmation of economic, reliability, and environmental forecasts before commercially adopting such new technologies.

These assurances can only be provided through sustained long-term operation of the plant at significant production levels under a variety of actual utility load conditions.

Future plans include operation of the KCM plant for a 60-day performance test during the balance of 1984, with extended demonstration operations anticipated throughout 1985.

George Land: Thank you Don. Do we have any questions for Don? If you don't have any, before I introduce the next speaker, I have a message here for Ron Sanderson of Rend Lake College. He was not here with his students at the time we had the business meeting, and I have been asked to suggest to Ron that perhaps he could introduce his students at this time.

Lee Wilson: Ron had to leave the room for just a moment. I'm Lee Wilson. I teach at Rend Lake College, and these are the students. Brian Smith is on my right, and this is Greg Thompson from Pinckneyville, Illinois.

George Land: I'm going to ask for the Center for Research on Sulfur in Coal to remind people in the audience of a 3-day meeting in Champaign-Urbana October 30th through November 1st. The second annual contractors technical conference, is sponsored by the Center. There will be technical papers presented giving the results of last year's work by the various investigators. It is going to be held at the Round Barn Center. If you need information call the Center at (217) 333-9241, and they will give you more details. But I think all interested spectators from the coal industry are invited to attend that meeting.

We will now listen to the next report on another one of the new technologies that was mentioned this morning by Terri. And this is fluidized bed combustion which has received a lot of publicity lately. Our speaker on that subject is going to be Ladd Seaberg, President of Midwest Solvents Company, Inc. Mr. Seaberg has had a distinguished career in the industrial world. He got his Bachelor of science and chemical engineering degrees from Texas University and spent most of his active working career with Midwest Solvents or one of their subsidiary companies. He is now President of Midwest Solvents Company of Illinois in Pekin, Illinois. He is a member of a number of different boards including one bank. He is going to talk to us about "Cogeneration with Fluidized Bed Combustion" and installation in Pekin. Mr. Seaberg.

COGENERATION WITH FLUIDIZED BED COMBUSTION

LADD M. SEABERG
President, Midwest Solvents Company, Inc.
Atchison, Kansas 66002

INTRODUCTION

Midwest Solvents Company is a grain processing company located in Pekin, Illinois. We have two production facilities, the one in Pekin and another plant located in Atchison, Kansas. The Pekin, Illinois site is composed of a 50-acre plant site along the Illinois River that was formerly owned by the American Distilling Company. It was purchased by the Midwest Solvents Company in 1980 and converted from a whiskey operation to a distillery that produces high-quality industrial alcohol, beverage alcohol (including gin and vodka), and recently we added a plant where we extract wheat protein from wheat flour. This is called vital wheat gluten which is used in the baking industry for fortifying breads and is also used in the meat industry.

We are very large users of energy, both electrical and thermal energy for such unit operations as distillation, evaporation, and cooking. When we first purchased the plant, we had the forecast from the local utilities that energy charges would go up only approximately 15%-20% per year. Shortly after we started up the plant, as you can guess, energy charges went up at least 200% during a very short period. Therefore, we were faced with a big decision on what to do as far as supplying energy to our plant. With this very high cost of natural gas, we were forced to make a change to a lower cost of supply of energy. Pekin is very close to coal supplies so we quickly started investigating as to what type of technology to burn coal would be best for us as an energy source.

SELECTION OF FLUIDIZED-BED COMBUSTION

Fluidized-bed combustion is very new and very experimental. We became aware that the Department of Energy and Natural Resources of the State of Illinois had funds available for such experimental work to prove technologies. We made application for these funds to aid us in evaluating a new technology that would not only help us, but would also help other industries in Illinois if we could prove this technology worked.

There are several reasons why we selected fluidized-bed combustion.

1. It would put us in compliance – as far as environmental restrictions, we were in a nonattainment area for sulfur dioxide in Pekin, Illinois – so we knew that we had to meet very rigid parameters as far as sulfur dioxide requirements on emissions control. Fluidized-bed combustion does meet this requirement. quirement.

2. We also wanted a method that would remove the sulfur without humidifying the gasses because we had already been recovering heat from our gas

boilers to aid us in drying the animal feed in our feed recovery system of our dryhouse. We wanted to maintain this plant efficiency of utilizing boiler flue gasses.

We evaluated different types of fluidized-bed combustion – the so called first generation, the bubbling-bed design, and even second generation boilers. We decided upon the bubbling-bed design because, while it is still experimental, there was more information available on this design for coal application than for the circulating-bed design. We visited boilers in Georgetown, near Washington, D.C. and in Kentucky and observed the somewhat severe problems in those designs. In working with Foster Wheeler Corporation – I won't say they fully assured us – but certainly they made improvements upon those problems at those locations. So, we were off and running with a bubbling-bed design boiler.

We also decided to install cogeneration at the same time. For a very small capital requirement, relative to the total project, cogeneration could be installed for a good return for the amount of the investment.

Our previous boiler room had three gas boilers, 80,000 lbs./hr. (175 lb. pressure boilers). Those boilers are still in place, and we keep them on standby for times that we are doing maintenance or we have any upsets with the fluidized-bed boiler.

CONSTRUCTION OF BOILER

The construction for this project was somewhat constrained in the sense that we were fitting it into our existing boiler house to minimize the capital required for a totally new structure, and all of the components for the boiler had to be moved into the building.

The boiler was somewhat modular in design. The boiler was shipped in large pieces, such as the floor structure, water walls, and the top of the boiler – in pieces that would fit through the side door of the building. The tubes were preshaped so that only an interconnection had to be made between the upper and lower drums.

The groundbreaking for the project was in June of 1983. The summer and fall of the year were very busy getting the outside construction done before bad weather would set in. The boiler stack was erected very early in the project. Part of the old foundation for the previous coal boilers that were used at the American Distilling Company prior to 1972, was usable for the new stack. The baghouse structure and all the other components such as the economizer and the ash storage silo were installed outside during the fall. Winter set in about the time that we put the ash storage silo in place.

Winter set in during January, but construction continued inside the building with installation of the main supply air ducts to support the fluidized-bed combustion. The floor of the boiler was moved into place and the walls were put into place – all this construction took place while severe cold weather occurred outside.

NEW FEATURES OF INSTALLATION

There are many novel features to this bubbling-bed, fluidized-bed boiler compared to previous installations. The inbed tubes were installed at a lower angle of 12½° compared to previous boilers. This will, hopefully, stop erosion. Also, the tubes were treated with applications of fins, pins, and tiny balls to prevent erosion and the tubes themselves were chromized to provide a nice hard surface to prevent erosion. All these measures, so far, look very good in stopping any erosion that might occur. Future inspections, of course, will tell us if we have stopped all erosion.

The walls of the boiler in the fluidized-bed area are also treated with small attached balls and refractory material to curb erosion.

Some of the existing coal-handling equipment that had been used prior to 1972 was still usable and only required refurbishment to be put back into service. A coal dump station, a bucket elevator, and a belt conveyer with tripper conveyor installed to drop coal and/or limestone down into the storage bins, which were also in place, greatly helped the economics of the project.

In the spring, coal weigh-belt feeders were installed to take the coal from the existing bunkers to the stoker roto-flippers that inject the coal into the boiler. Also, limestone is supplied to the boiler by an incline conveyor which volumetrically meters the small pebbles of limestone into the firebox. By midspring this system was complete along with the final installations of the turbine generator in the turbine room. Also the computer control system, manufactured by Fisher-Provox, was completed in the spring.

STARTUP OF INSTALLATION

The final insulation was applied to the boiler in the spring, although some external piping was not completely insulated at the time of the startup of the boiler. In mid-May, everything was ready for the startup of the equipment. Natural gas was used to preheat the bed material to a temperature of approximately 1,000°F. Then, coal was added and combustion started shortly thereafter. The gas fire was shut off and combustion was sustained with the addition of coal. The fire inside the boiler is a very vigorously agitated combustion with sparks flying and much turbulence.

A three-month inspection of the boiler was conducted in September of 1984 with extremely good results. The in-bed tubes were carefully inspected to look for any indications of severe wear that might have occurred like on earlier boiler designs. We were very pleased to note that the fins, pins, and balls did not show any appreciable wear at all. They looked to be in ideal shape. The superheater, which is a convective superheater, even had its red primer-paint coat, on the tubes. It showed no signs of erosion at all.

The boiler operation has been going on for about three months of continuous service to date, and the economics for the project look excellent at this time. Our savings over natural gas are about $200,000 per month. The cogeneration of electricity is done for roughly $.01-$.02 per kw hour.

CONCLUSION

We are extremely pleased with the operation of the boiler to date. We have found that we are presently using 60 percent of the capacity of the boiler because, while the boiler was being constructed and planned, numerous energy-efficient projects were completed at Midwest Solvents. For that reason we are only producing half of the electricity from the cogeneration plant that we thought we would be producing. Of course, we are only producing 60 percent or half of the steam. We are very pleased with this efficiency because this will allow us to increase the capacity of the plant and get an ideal economic advantage with this low-cost thermal energy since the two highest cost factors in producing our products are raw material, or grain, and energy.

So, we are extremely pleased that we started the project when we did, and we look forward to many years of good service with our fluidized-bed boiler along with cogeneration of electricity.

George Land: Thank you Mr. Seaberg. Are there any questions?

Lou Miller: I'm Lou Miller of the Indiana Geological Survey. Do you have any data regarding the lowest quality material that you can burn in terms of Btu?

Ladd Seaberg: One consideration on this design of the boiler and the bubbling bed was that you do not have the latitude of fuel supply that you do in a later generation boiler, the so-called circulating boiler, for instance. About anything you can shove in the boiler will burn. With bubbling-bed design the sizing, but not so much the Btu consideration, is very important. We have to burn mostly a compliance grade of coal or a so-called stoker grade 1¼ inch or less. We pay particular attention to the amount of fines because if we get too many fines in the coal, they will tend to carry out on the belt of the boiler before you get complete combustion.

George Land: Are there any other questions? I'm glad you all came, and we'll see you at the luncheon.

Fig. 1 – Speakers in the technical session of Friday morning. The speakers are (from left to right): Carl P. Maronde, Terri Moreland, Don Loomis, Ladd Seaberg, A. K. Sinha, George Land, and Joanna Buckentin. George Land was also chairman of the session.

LUNCHEON MEETING

The annual Institute Luncheon Meeting convened at 12:20 p.m. in the Ford Room of the Holiday Inn East. Approximately 150 members and guests were in attendance. President James Chady presided.

President Chady: Welcome to the 92nd annual luncheon of the Illinois Mining Institute. I would first like to take this opportunity to thank our speakers who presented their papers at the technical sessions yeserday afternoon and also to thank the two chairmen of the technical sessions. I would like to introduce the guests at our head table today. To my extreme right, George Land with AMAX; Buster Roberts, Inland Steel; Brad Evilsizer, Director of Mines and Minerals; the next gentleman we will introduce a little later; Doc Harrell with Freeman United; and Bob Izard with Midland. On my far left Lanny Bell with Roberts and Schaefer; the next gentleman we will introduce later; Terri Moreland with the Illinois Department of Energy and Natural Resources; and John Wooten of Peabody Holding Company, who will be our speaker today. I would also like to recognize Betty Conerty and the group that does so much work for the Institute sitting at this table over here. A special thanks goes to Heinz Damberger, our Secretary/Treasurer who does so much for the Institute.

We have a number of scholarship winners and students in our audience today, and I would like their faculty representatives to introduce them. Dr. Charles Beasley from the University of Missouri at Rolla.

Charles Beasley: Our two scholarship holders are Mr. Bruce Yoder and Mr. Mike Savage (Fig. 1).

Fig. 1 – Students from University of Missouri-Rolla who attended the IMI meeting. They are: (left to right, kneeling) Todd Grounds, Dan Marley, Steve Johnson, Charles Siegel and Michael Savage and Bruce Yoder (recipients of IMI scholarships); (standing) Jim Stratton, Kurt Oakes, Scott Giltner, Jon Clark, Aron Miller, and Mark Odum.

President Chady: Dr. Paul Chugh of Southern Illinois University.

Paul Chugh: Our two scholarship winners are Tom Rosetti and Tom McGee (Fig. 2).

President Chady: Indiana State University – George Eadie.

George Eadie: Our scholarship holders were unable to attend.

President Chady: John Krogman from the University of Wisconsin at Plattville had to go back. Would the students stand if they are here.

President Chady: Ron Sanderson with Rend Lake College.

Ron Sanderson: We have with us today Lee Wilson, Brian Smith, and Greg Thompson (Fig. 3).

President Chady: John Howard, Wabash Valley College.

John Howard: Our scholarship recipient is Mike Liles (Fig. 4).

President Chady: Are there any students whom I've failed to recognize? Several weeks ago a member of the IMI died. He was Norman Syljebeck, who had been Vice-President of Purchasing for Freeman United Material Service Corporation for many years. Until his retirement three years ago, he was very active on the Advertising Committee of the IMI. Betty informed me that he did plan to be here as she received his check for dues and the luncheon several weeks ago. Would you please stand for a moment of silence for Norman and other members who have died.

Thank you. A very important part of this program is to recognize those individuals who have dedicated a large portion of their life to the advancement of the Illinois Mining Institute and the coal industry. At this time I would like to ask Doc Harrell, Chairman of the Honorary Membership Committee, to come forward.

Fig. 2 – Students from Southern Illinois University-Carbondale, who attended the IMI meeting. They are: (left to right, kneeling) Theera Honghirun, Vinod Lall, Kausik Sinha, Emilio Escobar; (standing) Thomas McGee and Thomas Roscetti (recipients of IMI scholarships), Roger Missavage, Sachin Shankar, and Stephen Ober.

Fig. 3 – Dr. Ron Sanderson (right) of Rend Lake College and his students who attended the IMI meeting. (Left to right) Lee Wilson, Greg Thompson, and Brian Smith.

Fig. 4 – Dr. John Howard (right) of Wabash Valley College and Mike Liles, recipient of IMI scholarship.

CERTIFICATES OF HONORARY LIFE MEMBERSHIP

Doc Harrell: Thank you Jim. Institute members, guests. It is a great pleasure on behalf of the Illinois Mining Institute to present this Certificate of Honorary Life Membership to my good friend, Gene Moroni, whom I have known and worked with for many years. I know Gene is well known to all of you older members, but just for the record, Gene and Wilma have four children. Gene graduated from the University of Illinois in 1940 with a B.S. degree in mining engineering. Upon his graduation he worked as an engineer for Island Creek for three years, then with Franklin County Coal Corporation for a short while as a surveyor. After that he was with Sinclair Coal as a field engineer until 1944. From 1944 to 1951 he was with Consolidated Coal of St. Louis, later to become known as Bell and Zoller or Zeigler as we know it today. From April of 1951 through May 1953, he was with CW & F Coal Company, later to become known as Freeman United Coal Mining Company. He worked there as a face boss. For the following two years he was with Bell & Zoller in western Kentucky as Chief Engineer. Then he was promoted to General Superintendent. On September 1, 1958, he became Superintendent of Coal Processing at the Dixieanna Mine in West Virginia until September, 1959. At that time Old Ben promoted and moved him to Benton as Manager of Mines. He continued in that capacity until January, 1969, when he was made Vice-president of Underground Mining. In 1971, he was again promoted to Vice-president of Operations, and in May of 1978 he became Senior Vice President of Mining for Old Ben from which he retired effective February 1, 1981. During the last few years of employment he lived in Chicago and now lives a life of luxury in Herrin, Illinois.

Gene has worked tirelessly for the Illinois Mining Industry. He was president of this Institute in 1963-1964, served on many committees during the years, and has been on the Board. Gene has made it his personal responsibility, officially and unofficially, to help this Institute which he still continues to do today. I have been a friend of Gene's for many years, and I want to say this to you. As you all well know, he is a fine gentleman, and he certainly deserves this award that we are presenting to him. It's a pleasure, Gene, for me to present this (Fig. 5). Congratulations.

Gene Moroni: Thank you Doc. And I want to thank the members of the Institute.

Doc Harrell: I want to say that Gene has certainly been a help to all of us, and he's done a great job. I would like to say this to you though, Wilma: you sure did have a hard time keeping him working.

President Chady: Thank you Doc. Next, I'd like to ask Buster Roberts to come up for a presentation.

Buster Roberts: The Selection Committee felt there were two gentlemen who were very deserving of recognition today and most of you know the second person who is being honored today with an Honorary Membership. We recognize his contribution to the industry and to the various areas of his interests. E. Minor Pace is at the head table again today. Minor Pace came from Virginia originally, received his mining engineering degree, and went on to get a graduate degree in ventilation at West Virginia University. He was in the service overseas as a captain and came

Fig. 5 – Gene Moroni (left) receives Certificate of Honorary Membership from Doc Harrell.

Fig. 6 – Buster Roberts (left) presents Certificate of Honorary Membership to Minor Pace.

to the industry right after the war. He went through the various stages of promotions up to Executive Vice-president, and he retired in 1980. I have to say though, he's not quite living the life of luxury. He's working at least half time with a private venture that he's involved in, so he won't quit yet.

In the area of some of his professional activities, he has been active in Kentucky where he was located before he came to Illinois and was Vice President of the Kentucky Mining Institute. He is also a past President of this Institute, having served in 1972 and 1973. He has been quite active in the AIME, and last year received two very prestigious awards at the national convention in Los Angeles – the Erskine Ramsey Medal and the Percy W. Nichols award. He has also been Chairman of the SME-AIME Coal Division and on the Board of Directors of the AIME among other duties in that organization. In the civic area he has been quite active and continues to be quite active. One of his present jobs right now is that of being on the Police Commission in Mt. Vernon as well as having a number of other jobs. So, it is a distinct pleasure for me after so many years of long and close association with Minor, to recognize him and present him with this certificate of Honorary Membership (Fig. 6). Minor.

Minor Pace: Thank you Buster and members of the Illinois Mining Institute. You have one of the finest institutes that I know of in the nation and I think we have an outstanding organization. This is a double honor for me because it's a great honor to be on the same footing as Gene Moroni who I consider to be one of the greatest coal miners with whom I've had the pleasure of association through the years. Let me congratulate you. Thank you.

President Chady: I would like to introduce our speaker for this afternoon. His topic will be "Acid Rain Control – Will Emerging Technologies Get a Chance?" John Wooten graduated with a B.S. in mechanical engineering from the University of Missouri in Columbia and received an M.S. in civil engineering and environmental and sanitary engineering in 1978 from the University of Missouri at Rolla. He worked 7 years with Union Electric Company and the last five years with Peabody. He is a member of the American Society of Mechanical Engineers, Air Pollution Control Association, Kappa Alpha Order, and Environmental Committee of the National Coal Association. He is also Chairman of the St. Louis Section of Air Pollution Control, the Illinois Coal Association, Research and Development and Air Pollution Control Committee, and the Air Sub-committee of the National Coal Association. John Wooten (Fig. 7).

Fig. 7 – Luncheon speaker, John Wooten.

ACID RAIN CONTROL: WILL EMERGING TECHNOLOGIES GET A CHANCE?

JOHN M. WOOTEN
Director, Research and Technology
Peabody Holding Company, Inc.
St. Louis, Missouri

INTRODUCTION

Ladies and gentlemen, it is indeed a pleasure to appear before you today to discuss an issue that will have a great deal to do with the marketability of Illinois coal – acid rain control. I am certain that each of you has heard your share of talks on acid rain, so let me veer from the standard presentation and address whether emerging technologies for burning coal or for reducing emissions will get a chance to be utilized for acid rain control.

Rightly or wrongly, acid rain or acid deposition, a more technically correct term, has been characterized as resulting from two precursor pollutants – sulfur oxides and nitrogen oxides.

As you may be aware, a number of acid deposition control bills have been introduced in both Houses of Congress. Most of these bills require major reductions (50 percent or more) in utility SO_2 emissions. These major SO_2 emission reductions are to be achieved at the earliest by 1990 and the latest by 1995. Once you decide to proceed, it takes approximately four years to design, procure, construct, and start up a utility-sized emission control system. Therefore, to achieve the required sulfur dioxide or nitrogen oxide emission reductions at existing power plants, the utilities will be required to reach a decision between 1986 and 1990 based on those technologies, which either are or will have been demonstrated on a utility scale (100 megawatts electric or greater) and at an acceptable cost.

CONTROL OPTIONS FOR EXISTING FACILITIES

The control options available to existing facilities are limited; fuel switching and retrofitting flue gas desulfurization systems, or scrubbers as they are commonly known, are the only techniques that have been demonstrated to achieve the required level of control. The question I would like to address today is: "Do these two control options . . . fuel switching, with its inherent unemployment impact, or retrofitting scrubbers, with their significant capital costs . . . represent the best alternatives for reducing SO_2 emissions from existing power plants; or should the commercialization of promising new technologies be accelerated by providing increased federal funding so that these techniques will be available in the 1986-1990 time frame?"

I believe that (1) in many instances fuel switching and scrubbers represent undesirable control options, and (2) the federal government must assist the private sector to ensure timely development of the more promising technologies thereby reducing or eliminating the unemployment and excessive cost impacts associated with present options.

EMERGING TECHNOLOGIES

However, I think it is only appropriate to point out that one other ingredient is essential, and that ingredient is time. It takes at least four years to install a proven precursor control system of any magnitude. Emerging technologies, such as advanced coal cleaning, limestone injection multistage burner (LIMB), atmospheric fluidized bed combustion (AFBC), and dry SO_2 scrubbing of high-sulfur coal – will not be commercially demonstrated for large-scale utility applications in time to be of use in complying with a 1990 deadline set forth in some of the bills. This will be true even if unlimited funding was available because it is impossible to complete an installation, much less any testing, by the end of 1986.

While we may speak of promising technologies, it is important that you and the members of Congress realize, that good engineering design takes time. Implementation schedules must be realistic. Simply stated, if acid rain control legislation does pass, it must not preempt the use of emerging technologies. Compliance dates in the late 1990's would represent a reasonable target if – and the "if" is so important – if these emerging technologies are adequately funded by the public and private sectors.

You have heard discussed this morning one emerging technology, "KILNGAS", currently undergoing commercial demonstration. I would like to address my remarks to four areas of technology I mentioned earlier by briefly describing them and their present state of commercialization.

MAJOR POLLUTANTS

The direct combustion of coal using conventional furnace technology produces three major pollutants: particulate matter, sulfur dioxide, and nitrogen oxide. Two of these pollutants, sulfur dioxide and nitrogen oxide, are precursors for acid deposition and coincidentally are difficult and expensive to control at high removal levels. Sulfur dioxide results from the conversion of the sulfur in the coal during combustion, while NO_x results primarily from the high temperature conversion of the nitrogen in the combustion air as it passes through the furnace. The nitrogen found in the coal itself can also be converted to NO_x, however, it usually does not contribute significant amounts to the total NO_x emission concentration.

Since the amount of SO_2 emitted is a direct function of the amount of sulfur in the coal, control strategies include removal prior to combustion (pretreatment), during combustion, or after combustion (post combustion). NO_x, on the other hand, can be controlled by either lowering combustion temperatures or limiting the time the combustion air is subjected to higher temperatures.

PHYSICAL COAL CLEANING

Physical coal cleaning is a process that is capable of removing sulfur from coal prior to combustion and is widely practiced today by coal producers. Its value as a cost-effective means to reduce SO_2 emissions is recognized. The one major drawback is that the removal rates are relatively low compared to the combustion or post combustion technologies since only the inorganic sulfur is reduced.

The Department of Energy has recognized the importance of physical coal cleaning research and development and has funded much work in this area. In fiscal year 1985, the control technology and coal preparation program of DOE will contain a new effort to determine whether advanced coal cleaning technologies have the potential for use as acid rain precursor control options.

LIMESTONE INJECTION MULTISTAGE BURNER

A technology for removing sulfur dioxide during combustion involves the injection of a sorbent into the boiler, either with the coal or separately. The sorbent, which usually is a sodium or calcium based material, reacts with the sulfur dioxide to form a sulfate particle that can be removed from the combustion gases by the particulate control equipment.

Research on sorbent injection has been ongoing since the early 1970's with only limited success. Generally, poor SO_2 removal has resulted when lime or limestone has been used. In addition, because a foreign non-combustible substance is being injected into the boiler, it can cause the boiler's operational characteristics to change. For example, there may be more slagging, and fouling may increase. Also, since additional particles enter the combustion gases, the particulate control devices may need to be upgraded. These potentially adverse operational effects may not be warranted by the low SO_2 removal achieved.

In recent years, however, a variation of the sorbent injection technology has emerged that has the potential to achieve moderate SO_2 removal (50-60 percent). This technology, known as limestone injection multistage burner or LIMB, is being researched by the U.S. Environmental Protection Agency and the private sector.

LIMB has much to offer as an acid precursor control technology. First, it is a retrofit technology, which theoretically can be applied to a large percentage of the existing utility and industrial boilers at a cost one-half that associated with existing post combustion technology (flue-gas desulfurization systems or scrubbers). Second, unlike a scrubber, LIMB can reduce both SO_2 and NO_x emissions. Thus, it addresses both major acid rain precursors. LIMB technology, however, still has a number of technical problems that must be resolved before it can be considered commercially available.

The coal program budget of the Department of Energy for fiscal year 1985 does not contain funding for LIMB research. To date, the federal research and development effort on LIMB has been done by the U.S. Environmental Protection Agency at its industrial environmental research laboratory in Research Triangle Park, North Carolina. The program plan calls for 50/50 co-funding by EPA and the private sector to design, construct and demonstrate LIMB technology on a wall-fired boiler by 1988 and on a corner-fired boiler by 1990.

The U.S. Environmental Protection Agency and the State of Ohio recently announced that Babcock and Wilcox will be the prime contractor to test LIMB technology on the 105 MW Ohio Edison Edgewater Plant. The program will cost $18 million.

FLUIDIZED BED COMBUSTION

Fluidized bed combustion, FBC, is a combustion technology that is new for utility appliations, but it has been used a good deal for industrial applications in Europe and the U.S. The technology involves the burning of coal in a bed of limestone particles. Air is injected beneath the bed suspending the burning coal/limestone mixture so that it resembles a fluid. Sulfur dioxide is captured by the limestone, producing calcium sulfate particles which are drawn off the bed with the ash. NO_x emission levels also are significantly reduced because the combustion temperature is approximately one-half that of a conventional boiler.

There are a number of FBC demonstration projects being conducted in the U.S. today. The largest of these is the atmospheric fluidized bed combustion (AFBC) demonstration being conducted by the Tennessee Valley Authority, Duke Power, the Electric Power Research Institute, and the State of Kentucky. Peabody recently announced its intention to commit up to $4 million to this project. The demonstration plant will be constructed at an existing TVA plant site in Paducah, Kentucky, beginning in early 1986, with completion scheduled for mid-1989. Following initial start-up and shakedown, a nominal four-year test program will be initiated.

The Department of Energy has increased the fiscal year 1985 funding level for the combustion systems program area to include $15 million for the development of the start-up and operational test plans for the Paducah project. An additional $15 million is to be made available in fiscal year 1986. The total fiscal year 1985 combustion systems funding request is for $17.5 million, which leaves only $2.5 million for additional combustion work.

Two other planned fluidized bed demonstrations are the circulating AFBC project being undertaken by Colorado-Ute Electric Association at its Nucla Station, and the conversion of a boiler to AFBC by Northern States Power company at its Black Dog Station.

Colorado-Ute proposes to use a significantly different AFBC design, a circulating fluidized boiler (CFB). Rather than burning the coal/limestone mixture in a fixed bed, the air is injected at a much higher rate which, in turn, expands the bed throughout the entire combustion chamber and causes the solid combustion products to be entrained in the combustion gases. The solid combustion products are then removed from the gas and recycled to the boiler. This recirculation offers the potential for improved combustion efficiency and more complete utilization of limestone.

Colorado-Ute expects to order the CFB boiler in late 1984, initiate construction by mid-1985, begin operating the system in early 1988, and complete a two-year test program by early 1990. To date, this project has not been targeted to receive any federal funding. Peabody has committed $2 million to this project.

Northern States Power is also taking a unique and important approach to demonstrating AFBC technology. They are proposing to convert an existing conventional coal-fired boiler to an AFBC boiler. Procurement of the boiler conversion package is expected to occur by mid-1984, and construction is to be completed by early 1986. A preliminary survey of installed utility capacity in the U.S. has indicated that approximately 150 boilers, totaling over 20,000 MW, could be converted in this manner. This is equivalent to approximately one-third of the capacity which would be required to retrofit scrubbers by H.R. 3400, the Waxman Sikorski Acid Rain Control Bill.

DRY FLUE GAS DESULFURIZATION

The development of flue gas desulfurization (FGD) processes that produce a dry discharge or sludge have only recently been applied to utility-sized facilities. There currently are 6 operational utility systems, 7 under construction, and 4 for which contracts have been awarded. These 17 dry FGD units represent 6,873 megawatts of scrubbed capacity or 6.5 percent of the total scrubbed capacity in the U.S. None of these installations utilize high-sulfur coal (sulfur content greater than 2.5 percent be weight) even though the technology has the potential for lower installed cost, lower maintenance, and energy requirements. In addition, the technology generates a dry sludge making disposal easier. It is also easier to operate because it is a simpler technology than wet scrubbing.

Dry scrubbing has been applied to industrial boilers burning high-sulfur coal. One such installation is a boiler at Argonne National Laboratory near Chicago, Illinois that produces 170,000 pounds of steam per hour. SO_2 removal efficiencies in excess of 90 percent have been achieved on a 3.5 percent-sulfur coal. In addition, a dry FGD system installed at the Northern States Power Company's Riverside Station in Minneapolis has been tested on 3 percent-sulfur coal. The tests were short term, however, 90 percent SO_2 removals were demonstrated.

The potential operational and economic benefits of dry FGD and the industrial and utility test experience warrant that this technology be demonstrated on a utility-sized boiler burning high-sulfur coal.

I think you can see from this discussion that there are a number of technologies out there that, given the time and funding, will get their chance. I would like to leave with you at least a partial solution to this dilemma.

DOE'S TRADITIONAL RESEARCH ROLE

Traditionally, the Department of Energy was limited in its involvement in energy research to the initial stages of basic research through pilot plant proof of concept work. The private sector then takes those technologies that appear most promising through the process development and commercialization stages. This results in complete development of only those projects that are both technologically as well as economically viable.

Under the normal economic cycle of events, I support the traditional roles of both DOE and the private sector. However, when the normal economic cycle is disrupted by legislative initiates such as acid deposition control, available technologies become unacceptable, and there is not ample time for fulfilling the traditional roles of technology development. As a result, complementary legislative initiatives to demonstrate more acceptable technologies are required. In addition, in the field of coal combustion or coal conversion, the technical as well as economic risks can easily exceed the capabilities of the private sector. When the traditional cycle of technology development is circumvented, as will be the case with acid deposition control legislation, DOE must be provided the means to move beyond its traditional research role and assist the private sector in developing the technological response within the required time frame.

Peabody, along with others, has been working on a way to provide DOE with just such a means. The concept was first introduced in the provisions of H.R. 5593, The Clean Coal Production and Utilization Technology Demonstration Act. The concept has now found its way into the Senate Appropriations Committee's Interior and Related Agencies Appropriations Bill that passed the Senate on September 26. The amendment rescinds funds and makes other changes in the use of appropriations for the Synthetic Fuel Corporation. A clean coal technology reserve of $750 million would be established for conducting clean coal technology demonstration activities. Specifically, the purpose of this section is to

(1) Identify emerging clean coal technologies that may be commercialized in the near term for reducing emissions from new and existing coal-burning power plants and from industrial coal uses; and to

(2) Determine what incentives, including financial assistance the federal government should provide to assure the earliest practicable commercial availability of these emerging clean coal technologies.

Examples of such emerging clean coal technologies include, but are not limited to, the following: (1) advanced coal preparation and cleaning; (2) limestone injection multistage burners; (3) flue gas desulfurization processes that produce only dry discharges; (4) regenerable flue gas desulfurization; (5) furnace retrofit of in-boiler sulfur control technology; (6) atmospheric fluidized bed combustion systems of a size appropriate to the electric utility market; (7) repowering applications of a pressurized fluidized bed in a large oil-fired boiler; (8) phosphoric acid fuel cell systems using coal-derived gas; (9) coal-fired gas turbines in second-generation combined-cycle systems; and (10) low cost, easily replicable, sources of fuel gas for multimarkets.

Proposed projects solicited under this provision should be large enough to demonstrate commercial feasibility of the technology or, if not, at least permit rapid scaleup to commercial size.

The Secretary of Energy, within 60 days of enactment, is to solicit statements of interest in proposals for projects employing clean coal technologies, no later than April 15, 1985, The Secretary shall submit a report to Congress identifying the proposals and his intent to provide incentives of financial assistance.

So if these provisions are enacted into law, and if realistic compliance deadlines are enacted, or even if no acid rain legislation were enacted, emerging technologies for improving the marketability of Illinois coal will be given a much needed boost to get their chance to be commercially demonstrated.

President Chady: Thank you John, for your very informative presentation on the subject that's uppermost in all of our minds in the coal industry. I failed to mention in the introduction that John is the Director of Research and Technology for Peabody Holding Company.

It says on the program that at this time I present the gavel to the President Elect. I would like to introduce your president for next year, Bob Izard.

Bob Izard: Thank you Jim. Ladies and gentlemen, honored guests, my first act as the new president is to get Jim back up here. On behalf of the Illinois Mining Institute we would like to thank you for a job well done this year. As a little remembrance of your term as president we would like to present you with this souvenir gavel (Fig. 8). Thank you Jim.

The second thing I would like to do is say how honored I am to have joined Jim as president of this fine organization and also to join Gene Moroni and Minor Pace, who were both past presidents. And the third thing I should do is to say that if there is no more business, let's adjourn the meeting until next year.

Fig. 8 – President Elect Bob Izard (left) presents souvenir gavel to President James Chady.

CONSTITUTION AND BY-LAWS*

ARTICLE I.

Name and Purpose

The Illinois Mining Institute has for its object the advancement of the mining industry by encouraging and promoting the study and investigation of mining problems, by encouraging education in practical and scientific mining, and by diffusing information in regard to mining that would be of benefit to its members.

ARTICLE II.

Membership

Section 1. Any person directly engaged or interested in any branch of mining, mining supplies, mining appliances, or mining machinery may become an active member of the Institute. Any persons desiring to become a member of the Institute shall fill out a blank for that purpose giving name, residence, age and occupation. This application shall be accompanied by the current year's dues as established by the Executive Board. Each application for membership shall be reviewed by the Executive Board, who may investigate as to the qualifications of the applicant, and shall be authorized to elect to membership and issue a certificate of membership to such applicant subject to ratification at the regular meeting of the Institute.

Section 2. Honorary Member — Annually, one or more members recommended by a committee and approved by the Executive Board who has rendered outstanding service to the Illinois Mining Institute, and thereby to the coal industry of the state may be elected as an Honorary Member with dues being waved.

Section 3. The annual dues for active members shall be determined by action of the Executive Board. Any person in arrears on October 1, of the current year, after having been sent two notifications of dues, shall be dropped from membership. Members in arrears for dues will not receive the printed proceedings of the Institute.

Section 4. Any active member may become a life member by the payment of twelve times annual dues and shall be exempt from further payment of dues.

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*Last changed during 91st annual meeting, October 1983.

ARTICLE III.

Officers

Section 1. The officers shall consist of a President, First Vice-President, Second Vice-President, Secretary-Treasurer, twelve Executive Board members, and one ex-officio member, the current director of the State of Illinois Department of Mines and Minerals. The services of all officers shall be without compensation.

Section 2. Nominations for officers and the Executive Board shall be made by a nominating committee of three (3) appointed by the President at least thirty days before the annual meeting, provided that anyone can be nominated on the floor of the meeting for any office for which an election is being held.

Section 3. The President, First Vice-President, Second Vice-President, and Secretary-Treasurer shall be elected by ballot, annually, at the regular meeting and shall hold office for the ensuing year.

Four Executive Board members shall be elected by ballot, annually, at the regular meeting and shall hold office for the ensuing three years.

Section 4. In case of death, resignation, or expulsion of any officer, the Executive Board may fill the vacancy by appointment until the next regular meeting, when the vacancy shall be filled by regular election. In case of a vacancy in the office of President, the duties shall devolve upon the First Vice-President.

Section 5. The Executive Board shall consist of the officers, the 12 elected Board members, and the ex-officio member.

ARTICLE IV.

Duties of Officers

Section 1. The President shall perform the duties commonly performed by the presiding officer and chairman and shall, with the Executive Board, exercise a general supervision over the affairs of the Institute between sessions.

Section 2. The First Vice-President shall preside in the absence of the President and perform all the duties of the President. The Second Vice-President shall perform all duties of the First Vice-President in the absence of First Vice-President.

Section 3. The Secretary-Treasurer shall keep a record of each meeting, shall read and file all resolutions and papers that come before the Institute, sign all orders for money, and shall purchase necessary supplies.

The Secretary-Treasurer shall keep a true record of all money received and payments made on account of the Institute; shall pay out no money except on personally signed order, and shall retain these orders as vouchers; shall give bond in such sum as the Institute may provide, the premium on said bond being paid by the Institute.

The Secretary-Treasurer shall act as editor-in-chief for the Institute and may furnish the newspaper and other periodicals such accounts of our transactions and discussions as are proper to be published. The Secretary-Treasurer's own judgment is to prevail in such matters unless objection is lodged at a regular meeting or by the Executive Board.

The retiring President shall act ex-officio in any capacity for ensuing year.

Section 4. The President shall appoint an auditing committee annually to audit the accounts of the Secretary-Treasurer, and said audit shall be submitted to the annual meeting of the Institute.

Section 5. The Executive Board shall perform the duties specifically prescribed by this constitution; it shall supervise the expenditures and disbursements of all money of the Institute, and no expenditure other than current expenses shall be authorized without first having the approval of the Executive Board, and shall perform such other duties as may be referred to them by regular or special meeting of the Institute.

Section 6. The Executive Board may delegate work responsibility to Institute committees, appointed by the President, for conducting selected business of the Institute, but with all actions being subject to Executive Board approval.

ARTICLE V.

Meetings

Section 1. The annual meeting shall be held in the fall of each year and on such days and in such places as may be determined by the Executive Board of the Institute. Notice of all meetings shall be given at least thirty days in advance of such meetings.

Section 2. Meetings of the Executive Board shall be held on the call of the President, or at the request of three members of the Executive Board, the president shall call a meeting of the board.

ARTICLE VI.

Amendments

Section 1. This Constitution may be altered or amended at any regularly called meeting by a majority vote of the members present, provided notice in writing has been given at a previous annual meeting of said proposed change of amendment.

ARTICLE VII.

Order of Business

At all meetings, the following shall be the order of business:

(1) Reading of minutes.
(2) Report of Executive Board.
(3) Report of officers.
(4) Report of committees.
(5) Election of new members.
(6) Unfinished business.
(7) New business.
(8) Election of officers.
(9) Program.
(10) Adjournment.

ARTICLE VIII.

Dissolution

In the event of complete dissolution of the Institute, the cash assets of the Institute will be distributed to universities where the Institute has provided past scholarships, on an equal basis, for support of scholarships in Mining Engineering. Equipment will be donated to any not-for-profit organization that the Executive Board may determine to be worthy recipients.

ILLINOIS MINING INSTITUTE

HONORARY MEMBERS

BALL, CLAYTON G., 1500 Hinman Ave., Evanston, IL 60201

BOTTOMLEY, J. A., Consulting Engr., Sahara Coal Co., Inc., Box 330, Harrisburg, IL 62946

BROECKER, CLETUS A., Consultant, 7253 Dean Rd., Indianapolis, IN 46240

CONERTY, BETTY, Admin. Asst., Illinois Mining Institute, 615 E. Peabody Dr., Champaign, IL 61820

CONWAY, C. C., 1140 Tom Gurney Dr., Winter Park, FL 32789

CRAGGS, JOE, (Retired), Peabody Coal Co., RR 3,Box 47A, Taylorville, IL 62568

GARWOOD, THOMAS L,(Retired),Freeman United Coal Mining Co., 1009 S. Main St., Benton, IL 62812

HALBERSLEBEN, PAUL, Consultant, Sahara Coal Co., Inc., Box 330, Harrisburg, IL 62946

HAYDEN, CARL T., V. Pres., Sahara Coal Co., Inc., 3 First National Plz., Suite 3050, Chicago, IL 60602

HOPKINS, M. E., Dir., Geology, Peabody Development Co., Box 14222, St. Louis, MO 63178

MAC DONALD, J. W., Consultant,501 W. Reed St., Benton, IL 62812

MORONI, E. T. (GENE), (Retired), Old Ben Coal Co., Box 477, Herrin, IL 62948

NUGENT, FRANK, Chairman, Chief Exec. Officer, Freeman United Coal Mining Co., 300 W. Washington St., Chicago, IL 60606

PACE, E. MINOR, (Retired), Inland Steel Coal Company, 700 Lake Park Drive, Mt. Vernon, IL 62864

PERRINE, NATE G, Pres, Nate Perrine Sales Co, Box 481, Collinsville, IL 62234

SCHONTHAL, JOSEPH, President, J. Schonthal & Associates, Inc., Box 807, Highland Park, IL 60035

SIMON, JACK A., (Retired), IL State Geological Survey, 615 E. Peabody Dr., Champaign, IL 61820

ILLINOIS MINING INSTITUTE

LIFE MEMBERS

BALL, CLAYTON G., 1500 Hinman Ave., Evanston, IL 60201

BELL, J. H., 331 River Dr., Tequesta, FL 33458

BOWMAN, F. T., Pres., Bowdil Co., Box 470, Canton, OH 44701

BROWNING, J. ROY, Attorney, 208 S. La Salle St., Chicago, IL 60604

COLNON, STUART, 6665 N. Ocean Blvd., 2B, Ocean Ridge, FL 33435

CRAGGS, JOE, (Retired), Peabody Coal Co., RR. 3,Box 47A,Taylorville, IL 62568

FLETCHER, ROBERT, J. H. Fletcher & Co., Box 2143, Huntington, WV 25722

FLETCHER , WILLIAM, Dir., J. H. Fletcher & Co., 1630 Sheridan Rd., Apt. 10N,
Wilmette, IL 60091

GEBHART, BARTON R., 2773 E. Avenida De Posada, Tucson, AZ 85718

GORDON, GLENN B., 2405-C Patriot Way, Greensboro, NC 27408

GOSSARD, A. G., 12419 Green Valley Dr., Oklahoma City, OK 73120

HALBERSLEBEN, PAUL, Consultant, Sahara Coal Co., Inc., Box 330, Harrisburg,
IL 62946

JENKINS II, WILLIAM J., Pres., Ridgetop Enterprises, Inc., 9216 Clayton Rd.,
St. Louis, MO 63124

KALIA, HEMENDRA N., 2348 E. Cleft Dr., Columbus, OH 43221-1852

KARNES, RALPH E., Maintenance Foreman, Consolidation Coal Co., 1311 Elm St.,
Hillsboro, IL 62049

KOERBER JR., FRED, Owner, Koerber Drilling Contractor, 424 North Hickory St.,
Du Quoin, IL 62832

LEDVINA, CHRISTOPHER T. (CHRIS), Old Ben Coal Co., 5415 N. Sheridian Rd.,
Suite 5511, Chicago, IL 60640

LINDSAY, GEORGE C., Gen. Mgr., Coal Mining & Processing, 300 W. Adams St.,
Chicago, IL 60606

MANCI, SAMUEL L, Sales Rep,Long-Airdox Co, 214 Tartan Dr, Henderson, KY 42420

MARTIN, CHARLES EDWARD, Mgr., Human Resources, Roadmaster Corp., Box 344,
Olney, IL 62450

MICHAEL, DAVID G., Vice Pres., Gen. Mgr., Michael-Walters Industries, Inc.,
Box 34066, Louisville, KY 40232

MORGAN, GEORGE H., Hydraulics Div., Brake Supply, 309 Springhaven Dr.,
Evansville, IN 47710

MORONI, E. T. (GENE), (Retired), Old Ben Coal Co., Box 477, Herrin, IL 62948

NUGENT, FRANK, Chairman, Chief Exec. Officer, Freeman United Coal Mining Co.,
300 W. Washington St., Chicago, IL 60606

PEABODY JR., STUYVESANT, Pres., Willson Hardware Co., 1649 N. Military Trl.,
W. Palm Beach, FL 33406

POLING, GILBERT, Pres., Evansville Elec. & Mfg. Co., 600 W. Eichel Ave., Evansville, IN 47707

RYAN JR., J. T., Chairman of Board, Mine Safety Appliances Co., 600 Penn. Center Blvd., Pittsburgh, PA 15235

SCHONTHAL, JOSEPH, Pres., J. Schonthal & Associates, Inc., Box 807, Highland Park, IL 60035

SCHUBERT, R. R., Vigor & Billings (in care of), Box 1239, Ashland, KY 41101

SHIMKUS, ERVIN L., Safety Mgr., Peabody Coal Co., 44 Greentrail Dr., Chatham, IL 62629

SHIMKUS, TONY, Legal Dept., Peabody Coal Co., 111 White Dr, Marissa, IL 62257

WALKER, HAROLD L., 2110 Belmore Ct., Champaign, IL 61820

WEARLY, WILLIAM L., Chairman of Board, Ingersoll-Rand Co., Woodcliff Lake, NJ 07675

WEIR, CHARLES R., 9534 Normandy Ave., Morton Grove, IL 60053

WEIR, J. P., Pres., Paul Weir Co., 20 N. Wacker Dr., Chicago IL 60606

ILLINOIS MINING INSTITUTE

ACTIVE MEMBERS

ACTON, WILLIAM A., Const. Engr., Freeman United Coal Mining Co., 108 Horrell Ave., West Frankfort, IL 62896

ADAMS, JOE J., Hillsboro Coal Co., Box 539, Hillsboro, IL 62049

ADAMS, RICHARD W.(DICK), V. Pres., Sverdrup Corp., 801 N 11th St., St. Louis, MO 63101

AHRENS, WILLIS, Sales, Joy Manufacturing Co., 422 Westhaven Dr., CENTRALIA, IL 62801

AITKEN, WILLIAM P., Dooley Bros., 3100 Blackberry, Mt. Vernon, IL 62864

ALBON, DEAN E., Tech. Mgr., Sontec Co., P.O. Box 514, Benton, IL 62812

ALDERSON, MARY ANN, Owner, L & M Buckles, RR 1, Box R-49, Virden, IL 62690

ALDRIDGE, BILL, Midway Equipment, Inc., R.R. 2, Box 28, Alton, IL 62002

ALEXANDER JR., DAVID R., V. Pres., Sales, Gauley Sales Co., Drawer C, Hico, WV 25854

ALIUCCI, FLOYD B., Gen. Mgr., Labadie Coal Co.,111 Larkspur Dr., Huntington, WV 25705

ALLAN, THOMAS D., State Mine Inspector, State of IL, 511 E. Walnut St., Gillespie, IL 62033

ALLEN, GEORGE P., Service, Bowdil Co., 7617 Pittsburg Ave., N.W., North Canton, OH 44720

ALLEN, JIM, P.S.S.R.,Capitol Machinery Co Inc,Box 2008,Springfield, IL 62705

ALLEN, RODNEY G., Safety Dir., Freeman United Coal Mining Co., Box 100, West Frankfort, IL 62896

ALLEN, THOMAS, Asst. Shift Mine Mgr., Monterey Coal Co., R.R. 1, Box 91A, Germantown, IL 62245

ALTERMITT, BILL, Engr., HANCOR, Inc., P.O. Box 1047, Findlay, OH 45840

ALTORFER, D. A., Pres., Capitol Machinery Co., Inc., P.O. Box 2008, Springfield, IL 62705

AMBLER, ROBERT R., Storekeeper, Peabody Coal Co., 606 E. Cleveland, Taylorville, IL 62568

AMBRA, STEPHEN P., V. Pres., Construction, Gunther-Nash Mining Construction Co., 2150 Kienlen Ave., St. Louis, MO 63121

AMOS, JOHN W., Deister Concentration Co., Box 1, Fort Wayne, IN 46801

ANDERSON, A. DALE, Independent, Box 2488, Mt. Vernon, IL 62864

ANDERSON, JAMES P., (Retired), Sahara Coal Co., Inc., P.O. Box 330, Harrisburg, IL 62946

ANDERSON, MICHAEL E., Proj. Engr., Inland Steel Coal Co., 529 S. 19th St., Mt. Vernon, IL 62864

ANIXTER, ALAN B., Pres., Anixter Bros., 4711 Golf Rd., Skokie, IL 60076

ARCHBOLD, N. L., Prof. & Chairman, Western IL University, Dept. of Geology, Macomb, IL 61455

ARHAR, ERNEST B., V. Pres., Mining Industry Services, Inc., 1300 N. 16th St., Herrin, IL 62948

ARMES, WILLIAM C., Asst. Mine Mgr., Monterey Coal Co., 1009 E. Clark, Littchfield, IL 62056

ARMOUR, MICHAEL K., Warehouse Supv., Freeman United Coal Mining Co., R.R.2, Box 124A, Raymond, IL 62560

ARN JR., R. DALE, Sales Mgr., Midway Equipment, Inc.,2380 Cassens Dr., Fenton, MO 63026

ARNESON, N. ARNE, Pres., Arneson Timber Co., 1600 S. Warson Rd., St. Louis, MO 63124

ARNETT, GREGORY K., Civil Engr., Freeman United Coal Mining Co., Box 570, Canton, IL 61520

ARNOLD, DAVE, Prep. Engr., Sahara Coal Co., Inc., Mine #6, Box 330, Harrisburg, IL 62946

ARNOLD, JOHN M, V. Pres., Peabody Coal Co., 32 Williamsburg Rd., Creve Coeur, MO 63141

ARNOLD, THOMAS, United Mine Workers of Amer., RR 1, Waggoner, IL 62572

ARTIME, JOE R., Sales Engr., Okonite Co., 10411 Clayton Rd., Le Chateau Village 309, Frontenac, MO 63131

ARVIEW, JOHN, Instructor, Wabash Valley College, Coal Mine Technology, Shattuc Rd., Centralia, IL 62801

ASBRIDGE, LLOYD S., Shift Mine Mgr., Peabody Coal Co., Mine #10, 309 W. Vine St., Taylorville, IL 62568

ASBURY, DAVID M., Technical Service Engr., Wire Rope Corporation of America, 609 N. Second, St. Joseph, MO 64502

ASHBY, JAMES A. (JIM), Gen. Mgr., Fairmont Supply Co., 1525 Herbert St., Mt. Vernon, IL 62864

ASHBY, MILTON, Pres., Ashby Electric Co., Inc., Box 55, Sebree, KY 42455

ASHBY, W. CLARK, Prof., Dept. of Botany, SIU, Carbondale, IL 62901

ASHE, ROBERT D., Parts Sales Mgr., Ingersoll-Rand Mining Machinery, Box O, Benton, IL 62812

ATKINS, PAUL D., Dist. Mgr., Acme Machinery, Box 462, 306 N. Vicksburg St., Marion, IL 62959

AUE, FRANCIS, Mine Mgr,Inland Steel Coal Co,204 Laurel Ave,Du Quoin, IL 62832

AUGENSTEIN JR., V. E., Pres., Victory Hydraulics Div., ACI, Ltd., Box 8, Lewistown, IL 61542

AUGHENBAUGH, N. B., Dean, School of Mineral Engineering,University of AK, Fairbanks, AK 99701

AUSTIN, WILLIAM T., Wire Rope Engr., U.S Steel Corp., Box 67, Oakland City, IN 47660

BAILIE, C. C., Consultant, 305 W. Reed, Benton, IL 62812

BAIR, DEAN, Mgr., Off. of Coal Commerce, State of IL, 222 S. College St., Springfield, IL 62706

BAIRD, BILLIE V., V. Pres., Saturn Machine & Welding Co., Inc., Box 273, Sturgis, KY 42459

BAIRD, NORVAL E., Saturn Machine & Welding Co. Inc,Box 273, Sturgis, KY 42459

BAIRD, WILLIAM R., Pres., Saturn Machine & Welding Co., Inc., Box 273, Sturgis, KY 42459

BAKER, JON W., Flanders Elec. Motor Service, 201 Vaux St., Zeigler, IL 62999

BAKOWSKI, EDWIN C., Engr., IL EPA, Mine Pollution Control Program, 2200 Churchill Rd., Springfield, IL 62706

BALDWIN, ROBERT A., Secy.-Treas., Sherwood-Templeton Coal Co., Box 24306, Indianapolis, IN 46224

BALINT, MIKE L., V. Pres., Sales-Mktg., Ingersoll-Rand Mining Machinery, 4201 Lee Hwy., Bristol, VA 24201

+*BALL, CLAYTON G., 1500 Hinman Ave., Evanston, IL 60201

BALL, JAMES B., Sales, American Mine Res., Inc.,Box 1628, Bluefield, WV 24701

BANOVIC, EDWARD J., Foreman, Freeman United Coal Mining Co., R.R. 1, Box 111, Litchfield, IL 62056

BANOVIC, JOHN J., United Mine Workers of America, 1919 Bright Leaf Ct., Silver Spring, MD 20920

BARBER, JAMES A., Int. Sales Mgr., Allis-Chalmers, Suite 101, One Smoke Tree Plz., N. Aurora, IL 60542

BARBOUR, DEWAYNE D., Branch Mgr., National Mine Service Co., Box 1766, Mt. Vernon, IL 62864

BARGANZ, RON, IL EPA, Mine Pollution Control Program, 2200 Churchill Rd., Springfield, IL 62706

BARKER, KENNETH E., Maint. Supt., Freeman United Coal Mining Co., Box 100, West Frankfort, IL 62896

BARLOW, CRAIG B., Sr. Engr., Monterey Coal Co.,Box 496, Carlinville, IL 62626

BARNES, F. A., 1524 W. Wood St., Decatur, IL 62522

BARNHART, DICK, Gen. Mine Mgr., AMAX Coal Co., Inc., Sun Spot Mine, Box 336, Vermont, IL 61484

BARRINGTON, JAMES R., Safety Inspector, Monterey Coal Co., 317 S. Ring, Virden, IL 62690

BASTIEN, BLAINE, Proj. Engr., Inland Steel Coal Co.,Box 566, Sesser, IL 62884

BAUER, ROBERT A. (BOB), Asst. Geologist, IL State Geological Survey, 615 E. Peabody, Champaign, IL 61820

BAUGHAN, JR., R. ROGER, Branch Mgr., Sales, Marathon Industries, Inc., 1110 Casey St., Mt. Vernon, IL 62528

BAWEL, FRED, Freeman United Coal Mining Co.,Box 100, West Frankfort, IL 62896

BAXTER, FRANK L., Sales Mgr., Midco Sales&Serv.,Box 28729,St. Louis, MO 63146

BAYLESS, GERALD A, Gen. Supt,Consolidation Coal Co,RR 2, Greenville, IL 62246

BEAL, LARRY, Sales, Sentry Mine Supply, Box 516, West Frankfort, IL 62896

BEARD, EMERY, Reclamation Engr., Sahara Coal Co., Inc., Box 330, Harrisburg, IL 62946

BEARDSLEY, JAN A., Dist. Mgr., Nalco Chemical Company, 514 Earth City Expy, Suite 231, Earth City, MO 63045

BEASLEY, CHARLES A., Univ. of MO, Rolla, 101A Mining Bldg., Rolla, MO 65401

BEATTY, R. O., Sales Mgr., Capitol Machinery Co, Inc., Box 2008, Springfield, IL 62705

BEAUMONT, JAMES M., Owner, Beaumont Lumber Co., Box 652, Effingham, IL 62401

BEAUMONT, JOHN G., Pres., G. L. Beaumont Lumber Co., Box 3, Cowden, IL 62422

BECHMANN, DIANE M., Industrial Serv. Engr., Central Illinois Public Service Co., 711 S. 9th St., Mattoon, IL 61938

BECK, ROBERT E., Prof. of Law, Southern IL University Law School, Southern IL University, Carbondale, IL 62901

BECKER, CHARLES O., Nicor Mining, Inc., Box 83, Naperville, IL 60566

BECKMAN, FRANCIS, Prep. Foreman, Consolidation Coal Co., R.R. 1, Cripple Creek Rd., Apt. 4, Pinckneyville, IL 62274

BEDUHN, RICHARD, Sales Engr., Durex Products of IN, Inc., P.O. Box 485, Windfall, IN 46076

BEEMER, BRUCE A., Sales Engr., Brusco-Rich, Inc., 10621 Liberty Ave., St. Louis, MO 63132

BEERBOWER, DAVID A., Supt., Crown III, Freeman United Coal Mining Company, Box 100, West Frankfort, IL 62896

*BELL, J. H., 331 River Dr., Tequesta, FL 33458

BELL, LANNY, Purchasing Agent, Roberts & Schaefer Co., 120 S. Riverside Plz., Chicago, IL 60606

BELL, LARRY PHILLIP, AMAX Coal Co., Inc., P.O. Box 144, Keensburg, IL 62852

BENNETT, JAMES E, FMC Corp., MHE Div, 125 Windsor Dr., Suite 128, Oak Brook, IL 60521

BENNETT, JOHN C., Pres., Peabody Coal Co., IL Div., 301 Greenhaven Dr., Belleville, IL 62221

BENNETT, JOHN S., Vistaulic Company of America, 1516 Greenfield Rd., Evansville, IN 47715

BENNETT, PHILLIP, Dist. Sales Mgr., Ingersoll-Rand Mining Machinery, Box 513, Marion, IL 62959

BENOWICZ, CASMER A., Sr. Consultant, Christian, Roge & Assoc. Chicago, 770 S. Palm Ave., Sarasota, FL 33577

BENS, BILL, Sales, Hicks Oils & Hicks Gas, Inc,Miller&Hickory Sts., Du Quoin, IL 62832

BENSON, JOHN H., Pres., John Benson Electric Co., 1708 N. 8th St., St. Louis, MO 63102

BERGER, ROY S., AVP, Centerre Bank,NA, One Centerre Plz., St. Louis, MO 63101

BERGNER, JOHN, Dist. Sales Repr., Columbia Steel Casting Co., Inc., Box 323, Hales Cors., WI 53202

BERT, RICHARD A. (DICK), Sales Rep., Driltech, Inc., 810 Valley View Dr., Downers Grove, IL 60516

BERTA, JOSEPH Q., Mgr. I. & E. R., Consolidation Coal Co., 2476 S. Estes Ct., Lakewood, CO 80227

BETLER, KENNETH W, Mgr. Serv. Center,Ingersoll-Rand Mining Machinery,Box 110, Taylorville, IL 62568

BHAGWAT, SUBHASH B., Mineral Economist, IL State Geological Survey, 615 E. Peabody Dr., Champaign, IL 61820

BIGGS,JIM,Norris Screen & Mfg, Inc.,614 S. Wickham Ave., Princeton, WV 24740

BILDERBACK, JAMES E., V. Chairman of Board, Centrifugal & Mechanical Industries, Inc., 146 President St., St. Louis, MO 63118

BIONE, JULIUS, Safety Dir., Zeigler Coal Co.,520 N. 9th St., Herrin, IL 62948

BISHOFF, STEVEN M., Proj. Engr., Freeman United Coal Mining Co., Box 100, West Frankfort, IL 62896

BLACKMORE, GERALD, Pres.,Old Ben Coal Co.,333 W Vine St., Lexington, KY 40507

BLAIR, J. T., Warehouse Superv., Peabody Coal Co., Eagle Mine #2, Box 527, Shawneetown, IL 62984

BLAIR JR., SHERMAN, Sales, C E Tyler, Inc., 1210 Mallard Dr., Elgin, IL 60120

BLEVINS, RONALD R., V. Pres., Gauley Sales Co., 468 Hunting Creek Rd., Canonsburg, PA 15317

BLEVINS, TOM, Resident Engr., Inland Steel Coal Co., R.R. 2, Box 1280, Bluford, IL 62814

BLOSS, DONALD J. (DON), Sales Rep., Midco Sales & Service, 11475 Page Service Dr., St. Louis, MO 63146

BOATRIGHT, JIM, Prep. Mgr., AMAX Coal Co., Inc., Box 167, Marion, IL 62659

BOBENAGE, JOHN P., V. Pres., Gen. Mgr., Classic Coal Corp., 1604 Matthew Ln., Marion, IL 62959

BOEHM, FRANK J., Pres., F. J. B., 11710 Admin. Dr., St. Louis, MO 63146

BOGAARD, H. W., Prep. Plant Supt., Inland Steel Coal Co., Mine #2, R. R. 4, Mc Leansboro, IL 62859

BOLLIER, CHARLES, Dir.-Operation Support, Peabody Coal Company, Mine No. 10, 423 Arrowhead Dr., Troy, IL 62294

BOMKAMP, WILLIAM, Top Shop Foreman, Monterey Coal Co., 411 Cedar St., Gillespie, IL 62033

BOND, CHARLES E., Consolidation Coal Co., 67 Pine Cove, Springfield, IL 67203

BOOHER, STEVEN E., Dist. Sales Mgr., UST Inc., 312 Admiral, Godfrey, IL 62035

BORDER, WILL, Area Sales Supervisor, Joy Manufacturing Co., P. O. Box 1269, Mt. Vernon, IL 62864

BORST, R. A., Warehouse Manager., Joy Manufacturing Company, P. O. Box 1269, Mt. Vernon, IL 62864

+BOTTOMLEY, J. A., Consulting Engr., Sahara Coal Co., Inc., Box 330, Harrisburg, IL 62946

BOURNONVILLE, M. L., Sales Mgr.-Propietary Equip., Mc Nally Pittsburg, Inc., P.O. Drawer D, Pittsburg, KS 66762

*BOWMAN, F. T., Pres., Bowdil Co., Box 470, Canton, OH 44701

BOWMAN, JAMES C. (JIM), A. L. Martin & Co., 4807 W. Main, Suite 200, Belleville, IL 62223

BOWMAN, MARION O., Supt., Inland Steel Coal Co., R.R. 4, Benton, IL 62812

BOYD, JAMES W., Pres., John T. Boyd Co., 400 Oliver Bldg., Mellon Sq., Pittsburgh, PA 15222

BOYER II,CHARLES M., Research Engr., U.S. Steel Corp., 1 Tech Center Dr., Monroeville, PA 15146

BOYERS, BERNIE, V. Pres., Underground Surface Pollution Control, Inc., 357 Blue Sky Pky., Lexington, KY 40509-9419

BOYETT, CHARLES R., Repair Foreman, Freeman United Coal Mining Co., R.R 2, Carlinville, IL 62626

BRADSHAW, MIKE, Sales, Clipper Co., 548 S. Main St., Madisonville, KY 42431

BRADY, WILLIAM J., Pres., Brady's Mining & Supply Co., 11793 Lackland Rd., Creve Coeur, MO 63141

BRADY, C. ED, Gen. Mgr., Capitol Plbg. & Htg. Supply Co., 1900 S. 8th St., Springfield, IL 62704

BRANDLEIN, WALTER E., Purchasing Agent, Roberts & Schaefer Co., 120 S. Riverside Plz., Chicago, IL 60606

BRANDT, W. A., Lafayette Coal Co., 15 Spinning Wheel Rd., Suite 426, Hinsdale, IL 60521

BRANDT, HARRY, Mgr. D.C. Div., Mohler Armature & Electric Inc., 2355 Eby Rd., Boonville, IN 47601

BRANNON, JOHN E.,Consultant, Brannon Enterprises Inc., 1912 W. Rendleman St., Marion, IL 62959

BRANNON, JOHN P., Pres., Brannon Enterprises, Inc., 1912 W. Rendleman St., Marion, IL 62959

BRASEL, RONALD G., Sales Mgr., Truck & Mine Supply Co., 11 S. Kentucky Ave., Evansville, IN 47711

BRATCHER, HAROLD,Driver Salesman,Joy Manufacturing Co, RR 1, Texico, IL 62889

BRAXMEIER SR., THOMAS A., Gunther-Nash Mining Construction Co., 2150 Keinlen Ave., St. Louis, MO 63121

BREDEL, DANIEL, Purchasing Dept., Monterey Coal Co., R.R. 4, Rt. 108 E., Carlinville, IL 62626

BRENDEL, JAMES B., Gunther-Nash Mining Construction Co., 2150 Kienlen Ave., St. Louis, MO 63121

BRENTZ, STEVEN M.,Sales Rep,Exxon Chemicals Americas,7777 Bonhomme,Suite 909, Clayton, MO 63105

BRENTZ, DAVID W., Mktg. Mgr., Johnson Screen Div. UOP, Inc., P.O. Box 43118, St. Paul, MN 55164

BRENTZ, H. W.(BILL), Sales Engr, Mc Nally Pittsburg, Inc., 298 N. 1st Ave., Farmington, IL 61531

BREWER, B. K. (KEN), Mng. Industry Specialist, Westinghouse Electric Corp., P.O. Box 28540, St. Louis, MO 63146

BREWER, JOE R., WABCO Construction & Mining Equip., 2301 N.E. Adams St., Peoria, IL 61639

BRIANZA, LEO, Sales, Central Ill. Steel Co., Box 75, Carlinville, IL 62626

BRIDWELL, JAMES G., Emeritus, Southern IL University, 725 St. Louis St., Edwardsville, IL 62025

BRINES, MARK, Mgr., Engrg., AMAX Coal Co., Inc., Box 144, Keensburg, IL 62852

BRINSON, RICHARD L., Branch Mgr., Cummins Mid-States Power Co., P.O. Box 348, Normal, IL 61761

BRITTON, RANDY Sales Rep., National Mine Service Co., Mt. Vernon, IL 62864

BROCHU, RENE R.,Dist. Sales Mgr, American Cyanamid Co., Rt 1 Morgan Hill Rd., Morgan, PA 15064

BROCKHAUS, DOUGLAS A., Head, Tech. Serv., Monterey Coal Co, 6 Greenridge Dr., Carlinville, IL 62626

+BROECKER, CLETUS A., Consultant, 7253 Dean Rd., Indianapolis, IN 46240

BROWN, ALEX (SANDY), Product Support Mgr., Capitol Machinery Co., Inc., P. O. Box 2008, Springfield, IL 62705

BROWN, DAVE, Pres., Midwest Supply, Inc., P.O. Box 330, Sturgis, KY 42459

BROWN,DOUGLAS E., Gen. Mgr.,Raw Materials, Inland Steel Co.,30 W. Monroe St., Chicago, IL 60603

BROWN, GARY W., Mine Manager, Freeman Coal Mining Co., Crown III, R. R. 1, Box L-131, Virden, IL 62690

BROWN, GORDON, Partner, Hillsboro Coal Co., Box 539, Hillsboro, IL 62049

BROWN, HAROLD C., (Retired), 1301 Purdue Ave., University City, MO 63130

BROWN, STEVE, Elec. Sales Dept., Valley Electric Supply, 15 Sassafras Ct., Mt. Vernon, IL 62864

BROWN, WALLACE, (Retired)., 1949 Ramada Blvd., #1, Collinsville, IL 62234

*BROWNING, J. ROY, Attorney, 208 S. La Salle St., Chicago, IL 60604

BROWNING, TRUMAN, Div. Elect. Engr., Peabody Coal Co., Box 545, Greenville, KY 42345

BRUCE, BRENDA, Jennmar Corp., 907 Highland St., Benton, IL 62812

BRUCE, GARY C.,Plant Supt.,Jennmar Corp., 907 Highland Ave., Benton, IL 62812

BRUMBAUGH JR., OWEN E., V. Pres.,Allen & Garcia Co., 300 W. Adams, Suite 422, Chicago, IL 60606

BRUNSON, LAWRENCE E.,Pres.,Lawrence E. Brunson Co,300 Brookes Dr., Suite 200, Hazelwood, MO 63042

BRYAN, ROBERT C., Dist. Sales Mgr., Wire Rope Corporation of America, 9337 N. Harding, Evanston, IL 60203

BRYANT, DENNIS WARD, Dir., Planning-Engrg., AMAX Coal Co., Inc., Box 967, Indianapolis, IN 46206

BUBANOVICH, TOM, Chief Industrial Engr., Freeman United Coal Mining Company, Box 100, West Frankfort, IL 62896

BUCHANAN JR., GORDON, 1630 Sheridan Rd., Apt. 4B, Wilmette, IL 60091

BUCK, TED, Sales Mgr., Midway Equipment, Inc., R.R. 2, Box 220A, Carterville, IL 62918

BUCKENTIN, JODI, Asst. Mineral Engr., IL State Geological Survey, 615 E. Peabody Dr., Champaign, IL 61820

BUDZAK, PAUL,Freeman United Coal Mining Co,138 W. Webster Ave,Benton,IL 62812

BUFFINGTON, DON, W. M. Hales Co., Hwy. 85 E., Madisonville, KY 42431

BUIST, G R, Pres., Midway Equipment, Inc., 2380 Cassens Dr., Fenton, MO 63026

BUNTON, JERRY P, Trainman,MO-PAC Railroad, 316 W. South St,Du Quoin, IL 62832

BUNTON, MIKE, Board Member, United Mine Workers of Amer., Dist.12, Du Quoin, IL 62832

BURCHETT, MARK A., Branch Mgr.,Bruening Bearings, Inc.,4037 Clarks River Rd., Paducah, KY 42002

BURDETT, GARY, Valico, Inc., Box 333, Bluffs, IL 62621

BURDETTE, JOSEPH D., Mgr., Polyurethane Prod., Celtite, Inc., 412 E. Maiden, Washington, PA 15301

BURGESS, DENNIS R., Gen. Mine Mgr., Inland Steel Coal Co., R.R. 2, Box 312, Benton, IL 62812

BURKE, JAMES E, Pres, Wescott Steel, Inc., 425 Andrews Rd., Trevose, PA 19047

BURKE, KIM A., Chief Engineer, Underground Mines, Old Ben Coal Comp., 500 N. Du Quoin St., Benton, IL 62812

BURKETT, KEN, Outside Sales, Mine Supply Co., Box 754, Mt. Vernon, IL 62864

BURKHOLDER, JIM, Dist. Sales Rep,Hancor, Inc, RR 4,Box 120, Spencer, IN 47460

BURNER, JAMES B., Pres., Nicor Mining, Inc., Box 83, Naperville, IL 60566

BURNS, EARL W., 1237 Pinecrest Ln., H, Manchester, MO 63011-5471

BURRIS, DANE, Foreman, Peabody Coal Co., R.R. 3, Box 89, Auburn, IL 62615

BURTON, TERRY, Mgr. Prod. Cen. & E. Oprs., Inland Steel Coal Co., Box 566, Sesser, IL 62884

BUSHONG, JOHN R., Sales Rep., Power Torque Co., Box 1016, Sesser, IL 62884

BUTLER, BILL J., Sales&Serv., Pennzoil Products Co, Box 325, Energy, IL 62933

BUTLER, EARL, Mine Electrical Maint. Mgr., AMAX Coal Co., Inc., Leahy Mine, Box 165, Campbell Hill, IL 62916

BUTLER, MICK, Prep. Plant Repairman, Freeman United Coal Mining Co., U.M.W.A., 522 W. Washington St., Girard, IL 62640

CALDER, A. WILLIAM,Joy Manufacturing Co, 1 Oxford Centre,Pittsburgh, PA 15219

CALDWELL, JUD, Sales Engr., Joy Manufacturing Co., 7026 Ayer Dr., Madisonville, KY 42431

CALDWELL, MICHAEL R. (MIKE), Mining Engr., Paul Weir Co., 20 N. Wacker Dr., Chicago, IL 60606

CALLAHAN, GENE, Sales Rep, Michigan Industrial Hardwood, 1851 Front, Box 612, Whiting, IN 46394

CAMP, LARRY R., Assoc. Sup. Chemist, IL State Geological Survey, 212 Applied Research Lab., Champaign, IL 61820

CAMPANELLA, AUGUST A., Gen. Mgr., Mainline Power Product Co., P.O. Box 306, West Frankfort, IL 62896

CAMPBELL, BILL G., V. Pres., Personal Safety Equipment Co., P.O. Box 1048, Henderson, KY 42420

CAMPBELL, JAMES F., Old Ben Coal Co., Vine Center, 333 W. Vine St., Lexington, KY 40507

CAMPELL, JOHN A. L., Dir, Engr. & Tech. Sup., Kerr-Mc Gee Coal Corporation, Box 25861, MT-2202, Oklahoma City, OK 73126

CARDWELL, SUE, Pres., Reclamation Services Unlimited, 12 Hartland Ave., Madisonville, KY 42431

CARLEY, GERALD K., Purchasing Agent, Freeman United Coal Mining Co., 300 W. Washington St., Chicago, IL 60606

CARLSON, ROBERT A., Nalco Chemical Co., 502,514 Earth City Expy., 231, St. Louis, MO 63045

CARR, BILL, Sales, Kiefer Electrical Supply, R.R. 3, Benton, IL 62812

CARR, ROBERT J., Sales Engr.,Industrial Process Equipment Co,2812 Locust St., St. Louis, MO 63103

CARRELL, J. CRAIG, Prog. Coord., Coal Tech. Lab, Southern IL University, Coal Research Center, Carbondale, IL 62901

CARTER, LEE, Consulting Engr., 622 Belson Ct., Kirkwood, MO 63122

CARTER, TOM L., Sales Mgr., Alken-Ziegler Carbide Products, 225 E. Beaumont, Greenville, IL 62246

CASPER, VICTOR E, Ind. Sales Rep.,Cummins MO, Inc., 7210 Hall St., St. Louis, MO 63147

CASTRALE, ARDUINO, Plant Supt., Inland Steel Co., R.R. 1, Box 430, West Frankfort, IL 62896

CAUDLE, RODNEY, Assoc. Prof. Mng. Engr. Dept., Southern IL University, Carbondale, College of Engineering, Carbondale, IL 62901

CAUTHEN, WILEY M., V. Pres., Engr., Transgulf Pipeline Co., P.O. Box 44, Winter Park, FL 32790

CAVANAUGH, MICHAEL, Safety Superv., Monterey Coal Co., 807 N. Adams, Gillespie, IL 62033

CAVENEY, EARL E., (Retired), R.R. 1, Pawnee, IL 62558

CAVINDER, MARK, Old Ben Coal Co., 111 Philip Rd., Christopher, IL 62822

CHADY, JAMES D., Gen. Supt., Old Ben Coal Co., 201 W. Park, Benton, IL 62812

CHAMNESS, FRANKIE, Asst. Gen. Mgr.-S. Div., Zeigler Coal Co., P.O. Box 1, Sparta, IL 62286

CHAMNESS, MARCEL, V. Pres., Operations, Zeigler Coal Co., P.O. Box 547, Coulterville, IL 62237

CHANDLER, G. RUFFIN, Off. Mgr., Kerco, Inc., P.O. Drawer 665, Madisonville, KY 42431

CHAPMAN, RANDY, Mining Serv. Engr., American Cyanamid Co., 919 S. Main St., Princeton, IN 47670

CHARD, STEVE, Dept. of Agric., Div. of Nat. Resources, State Fairgrounds, Springfield, IL 62706

CHASE, DAVID, Graham Equipment Co., Inc., P.O. Box 5758, Evansville, IN 47715

CHAUVIN, BEN, Shift Mine Mgr, Monterey Coal Co, Box 12-Q, New Baden, IL 62265

CHENOWETH, CHERI, IL Water Survey, 605 E. Springfield 169 Water Resources Bldg., Champaign, IL 61820

CHOU, CHEN-LIN, Asst. Geologist, IL State Geological Survey, 615 E. Peabody Dr., Champaign, IL 61820

CHRISTIAN, CHARLES, Dir., Sales, Dick Corp., Box 10896, Pittsburgh, PA 15236

CHRISTOPHERSEN, JOHN A., Deister Concentrator Co.,Box 1, Fort Wayne, IN 46801

CHUGH, YOGINDER P., Prof., Southern IL University, Dept. of Mining, Carbondale, IL 62901

CIMA, GREG, Secy.-Treas., Cima Electrical & Mine Services, P.O. Box 66, Thompsonville, IL 62890

CLARK, C. E. (GENE), Sales, J. H. Fletcher & Co., 104 Edgewood Pk., Marion, IL 62959

CLARK, RICHARD R. (DICK), V. Pres., AMAX Coal Co., Inc., P.O. Box 967, Indianapolis, IN 46206

CLARK, TOM, AMAX Coal Co., Inc., 222 S. 2nd St., Grayville, IL 62844

CLARKE, FORBES R., Director of Maintenance, Freeman United Coal Mining Co., Box 570, Canton, IL 61520

CLAYTON, DANNY, Engr., Sahara Coal Co., Inc., Box 330, Harrisburg, IL 62946

CLEGG, KENNETH E., Coal Geologist, Box 112, Urbana, IL 61801

CLEM, NEAL, Sales, M.A.T. Industries, Box 250, West Frankfort, IL 62896

CLINTON, JEFF, Sales Rep., Marathon Industries, 1110 Casey St., Mt. Vernon, IL 62864

COCHRAN, OLLIE (AL), Evansville Electric & Mfg. Co., Inc., Box 4717, Evansville, IN 47711

COFFEY, NATE, Prep Mgr, AMAX Coal Co, Inc.,Box 967, Indianapolis, IN 46206

COLEMAN, RANDALL S., Sales Mgr., Johnston & Chapman Co., 2925 Carroll Ave., Chicago, IL 60612

COLEMAN, ROBERT D, Sales Rep,Oberjuerge Rubber Co,Box 519, St.Louis, MO 63166

COLIJN, WALTER S., Industrial Eng., Zeigler Coal Co., 2306A Carlisle Dr., Champaign, IL 61821

COLLINS, DON, Dist. Mgr., Ford Steel,2475 Rock Island Blvd.,Maryland Heights, MO 63043

*COLNON, STUART, 6665 N. Ocean Blvd., 2B, Ocean Ridge, FL 33435

COLOMBO, RAY, Asst. Gen. Mgr.,Northern Div., Zeigler Coal Co., Box 542, Coulterville, IL 62237

COMBS, HARRY, Supt., AMAX Coal Co., Inc., Box 144, Keensburg, IL 62852

+CONERTY, BETTY, Admin. Asst., Illinois Mining Institute, 615 E. Peabody Dr., Champaign, IL 61820

CONNELLY, BOB, Sales Rep., Capitol Machinery Co., Inc., Box 2008, Springfield, IL 62705

CONROY, PETER J., 448 Elm Park, Elmhurst, IL 60126

+CONWAY, C. C., 1140 Tom Gurney Dr., Winter Park, FL 32789

COOLIDGE, LIZA (KLEIN),Environ. Specialist, Turris Coal Co, Box 21, Elkhart, IL 62634

COOPER, DARLENE M., Health & Safety Tech., Monterey Coal Co., Box 496, Carlinville, IL 62626

COOPER, MAX, AMAX Coal Co., Inc., Box 967, Indianapolis, IN 46206

COOPER, SAM N., Prep. Electrician-Mng. Tech., Turris Coal Co., Box 21, Elkhart, IL 62634

COOPERIDER, STAN, Capitol Machinery Co., Inc., Box 2008, Springfield,IL 62705

CORRELL, JOHN R., Mgr. Health & Safety, AMAX Coal Co., Inc., Box 967, Indianapolis, IN 46206

COSTELLO, ALLEN, Div Eng., Zeigler Coal Co, Noll Mine, Coulterville, IL 62237

COSTELLO, TOM, Quarry Supply Prod., Ltd., Box 420, Rochelle, IL 61068

COURSON, RICHARD, Pres, Courson Coring & Drilling, RR 1, Box 38A, St. Peter, IL 62880

COX, OLLIE D., Maintenance Planner, Monterey Coal Co., #1 Mine, 1408 N State, Litchfield, IL 62056

CRAFT, REX R., Resident Engr., AMAX Coal Co., Inc., RR 1, Box 1708, De Soto, IL 62924

+*CRAGGS, JOE,(Retired),Peabody Coal Co.,RR 3, Box 47A, Taylorville, IL 62568

CRAGGS, JOSEPH D., Environment Tech., Peabody Coal Co., R.R. 3,Box 47C, Taylorville, IL 62568

CRAIG, WILLIAM, Lab. Technician, AMAX Coal Co., Inc., 200 E. Patrick, Marion, IL 62959

CRAVENS, BENNIE, Sales, Royal Brass & Hose,Box 1412, Mt. Vernon, IL 62864

CRELLING, JOHN C., Dept. of Geology, Southern IL Univ., Carbondale,IL 62901

CRISMORE, LEO C, Partner, Cartwright-Crismore, RR 2,Box 30, Gasport, IN 47433

CROOKS, JACK, AMAX Coal Co., Inc., Wabash Mine, Box 144, Keensburg, IL 62852

CROSS, MATTHEW J, Engr., Monterey Coal Co., Box 496, Carlinsville, IL 62626

CULLEN, WILLIAM P, Marketing Repr.,E.I. Du Pont Co, 1973 Grampian Hills Dr., Madisonville, KY 42431

CUNETTO, JOSEPH, Rec. Parts Mgr., Constr. Machinery Corp., Rt.4, Sunset Harbor, Marion, IL 62959

CURL,JOHN R.,Industrial Engr., Central IL Public Service Co., 104 E. 3rd St., Beardstown, IL 62618

CURTIS, DALE L., Industrial Serv. Engr., Central Illinois Public Service Co., 711 S. 9th St., Mattoon, IL 61938

CURTIS, SAM,Freeman United Coal Mining Co,507 Broadway,Johnstn City, IL 62951

DALLAS, A. V. (TONY), Sales, H. A. Petter Supply Co., R.R. 11, Box 352, Paducah, KY 42001

DAMATO, JOHN W., V. Pres Land&Explor.,Diamond Shamrock Corp,1200 1st Security Plz., Lexington, KY 40507

DAMBERGER, HEINZ H., Head, Coal Section, IL State Geological Survey, 615 E. Peabody Dr., Champaign, IL 61820

DANA, ROBERT A., Manager of Mining Sales, Bridon American Corp., R.R. Box 67, Oakland, IN 47660

DANKO, J. ROBERT, Gen. Supt., Mine #10, Peabody Coal Co., 302 Summit St., Taylorville, IL 62568

DANKO, JOHN, Chief Electrician,Peabody Coal Co.,Box 432,Taylorville, IL 62568

DANNER, STEPHEN K., Asst. Geologist, IL State Geological Survey, 615 E. Peabody Dr., Champaign, IL 61820

DAVIS, DOUG, ASST. SALES MGR., MICHAEL-WALTERS INDUSTRIES, INC., 6200 Dutchman Ln., Suite 103, Louisville, KY 40205

DAVIS, GENE L., Sales, Kerco, Inc., Drawer 665, Madisonville, KY 42431

DAVIS, PHILIP G., Sr. Proj. Engr., Old Ben Coal Co., 500 N. Du Quoin St., Benton, IL 62812

DAVIS, PHILIP K., Prof. & Chairman, Dept. of Engineering Mechanics & Materials, Southern IL University, R.R. 4, Box 199, Carbondale, IL 62901

DAVIS, TOM, Pres., Mining Related Products, Box 1133, Madisonville, KY 42431

DAWE, RUSSELL T., (Retired), Inland Steel Coal Co., Box O, Valier, IL 62891

DE MARIS, PHILIP, IL State Geological Survey, 615 E. Peabody Dr., Champaign, IL 61820

DE RUSHA, GLENN E., V. Pres., Mng., Michael Baker Corp.,4301 Dutch Ridge Rd., Box 280, Beaver, PA 15009

DEAN, GEORGE, Safety Mgr., Peabody Coal Co., 119 S. Bess, Marissa, IL 62257

DEERING, JIM, Sales,B F Goodrich,15649 Century Lake Dr,Chesterfield, MO 63017

DEERING, RICHARD A., Sales Rep., Power Torque, Inc., 303 W. Franklin, Sesser, IL 62884

DEMPSEY,RANDALL,Area Engr,N IL, Peabody Coal Co,Box 14495,St. Louis, MO 63178

DENMAN, PAUL, Peabody Coal Co., 86 Lou Rosa, Collinsville, IL 62234

DENNY, FRED G., Owner, Equality Mining Co., 10 Dogwood, Harrisburg, IL 62946

DENNY, JEFFREY G., Peabody Coal Co., 10 Dogwood, Harrisburg, IL 62946

DEVER, JIM, Engine Div., Construction & Mining Service, Inc., Box 2086, Fairview Heights, IL 62208

DEVER, JON, Assoc. Mng. Engr., Turris Coal Co., Box 21, Elkhart, IL 62634

DIAL, EMERY N., Engr., Monterey Coal Co., 146 Red Bud, Wood River, IL 62095

DICKASON, DAN B., Sales Engr.,Wedge Wire Corp., 34 N Highland, E.,Mt. Vernon, IL 62864

DICKERSON, BRIAN M., Pres., Dickerson Aerial Surveys, Inc., 107 N. 10th St., Lafayette, IN 47901

DILLARD, FRANK L., Chief Engr., Midwest Mining & Constr.Co., Rt.4, Box 483, Marion, IL 62959

DILLBACK, CHARLIE, Sales Rep., Ashby Elec.Co., Inc., Box 55, Sebree, KY 42455

DILLMAN, CHRIS, Mgr., Royal Brass & Hose Co., Hwy. 37 N., Benton, IL 62812

DOBBINS, BARBARA, Dir., After-Market Sales, Thyssen Mining Equipment Division, 202 E. Main St., Stanley Bldg., Suite 102, Marion, IL 62959

DOBROVOLNY, JERRY S., Prof. & Head, Dept. of General Engineering, Univ.of IL, Urbana, IL 61801

DODD, LEE W., Electrical Superv., Monterey Coal Co., 903 W. Monroe, Auburn, IL 62615

DODD, PHILIP, Engr. Manager ,AMAX Coal Co.,Inc., Delta Mine,Box 167, Marion,IL 62959

DOLL, ROGER, Mng. Engr., Turris Coal Co., Box 21, Elkhart, IL 62634

DOOLEY, E. F., Dooley Bros., 1201 S. Washington St., Peoria, IL 61602

DOOLEY, R. A., Pres., Dooley Bros., 1201 S. Washington St., Peoria, IL 61602

DOOLEY, THOMAS J., V. Pres., Sontec Co., Box 514, Benton, IL 62812

DORLEY, HERBERT A., Service Repr., National Mine Serv. Co., 514 S.Grand St., Nashville, IL 62263

DORRIS, FULFORD, Storekeeper, Associated Supply Company, 200 S. Taft St.,West Frankfort, IL 62896

DOTSON, GAIL, Construction Machinery Corp., 803 S. 20th St., Herrin, IL 62948

DOTSON, JOHN D, Electrical Engr, Freeman United Coal Mining Co., 415 W. Adams, Auburn, IL 62615

DOUGLASS, PETER M., V. Pres., Hart-Crowser & Associates, Inc., 1910 Fairview Ave., E., Seattle, WA 98102

DOZIER, JOHN O., Oberjuerge Rubber Co., Box 519, St. Louis, MO 63166

DRAKULIC, JOHN A., Sales Engr., Huwood-Irwin Co., Box 409, Irwin, PA 15642

DRENNEN, DAVE, Mng. Engr., 3M, Inc.,887 Claymark Way,305, Henderson, KY 42420

DRIER, JAMES A., WABCO, 2301 N.E. Adams St., Peoria, IL 61639

DRURY, DAVID M., Health & Safety Tech., Monterey Coal Co., R.R. 3, Box 251, Carlinville, IL 62626

DRURY, FRED C., Exec. V. Pres., Econex, Inc, 618 S West St, Wheaton, IL 60187

DRYDEN,JOSEPH L,Production Mgr,Bixby-Zimmer Engineering Co, 961 Abingdon St., Galesburg, IL 61401

DU BOIS, GEORGE F., Pres., George Du Bois,Inc,Box 23958A, St. Louis, MO 63119

DUANE, JIM, Sales Mgr., T. A. Pollack Co., 200 S. Taft St., West Frankfort, IL 62896

DUANE, LEN, Sales Engr., V. R.-Wesson Div., Fansteel, Inc., Box 366, West Frankfort, IL 62896

DUFFIE, DON, Engr. Coordinator, Freeman United Coal Mining Co., Box 570, Canton, IL 61520

DUGAN, DIXIE, Wescott Steel, Inc., 7766 Meadow Ln., Newburgh, IN 47630

DUGGER,LARRY,Sales,Woodruff Supply Co,628 Lincoln Ave,Madisonville,KY 42431

DUKES, W. W., Exec. V. Pres., Sherwood-Templeton Coal Co., 501 Merchants Bank Bldg., Terre Haute, IN 47801

DUNCAN, RALPH W,Sales Rep.,Brake Supply Co.,Inc,Box 447, Evansville, IN 47703

DUNCAN, S. W., Pres., Duncan Foundry & Machine Works, Inc., Box 433, Alton, IL 62002

DUNHAM, ED, Susman Wiping Materials Co.,420 E Desoto Ave.,St. Louis, MO 63147

DUTCHER, LINDA A.F., Geol. Consultant,Box 128, Carbondale, IL 62901

DUTCHER, RUSSELL R, Prof & Dean, College of Science,Admin.,Southern IL Univ., Carbondale, IL 62901

DYTZEL, ERNEST L. (JACK), Sales, EIMCO Corp.,Box 588, Madisonville, KY 42431

DZIUBAN, STEVEN E., Box 546, Valley View, PA 17983-0546

EADIE, GEORGE R., Prof., Mng. Engr. Tech., IN State University, Evansville, 8600 W. University Blvd., Evansville, IN 47712-3534

EADS, B. F., Pres., Monterey Coal Co., Box 496, Carlinville, IL 62626

EARLEY, VIRGIL G., Sales, J Schonthal&Assoc.,212 Poplar St., Sesser, IL 62884

EDDY, JACK, Asst. Supt.,Peabody Coal Co.,Eagle Mine #2, Box 527, Shawneetown, IL 62984

EGGERS, WILLIAM H. (BILL), Mgr., Distb. Sales, Long-Airdox, 4 Charleroi Pl., Lake St. Louis, MO 63367

EGGLESTON, GENE, Asst. Mgr., Brad Ragan, Inc.,Box 2728, Springfield, IL 62702

EGLI, ERICH, Chief Engr., Sahara Coal Co.,Inc, Box 330, Harrisburg, IL 62946

EHRET, PAUL J., Land Reclamation Div., Rm. 204, IL Dept. of Mines & Minerals, 227 S. 7th St., Springfield, IL 62706

EISON, WALTER E. (MONK), Pres., Western Kentucky Energy Eq., Inc., Box 81, Madisonville, KY 42431

ELFRING, STEVE, Product Engineer, Conoco, Inc., 11605 Studt Ave., Suite 118, St. Louis, MO 63141

ELLERBUSCH, RON, Mt. Vernon Industrial Elec., Box 1027, Mt. Vernon, IL 62864

ELLIS, GORDON B., Branch Mgr.,Bearing & Supply Headquarters, 328 S. 10th St., Mt. Vernon, IL 62864

ELLIS, JOHN, H. A. Petter Supply Co., Box 2350, Paducah, KY 42001

EMLING, DALE H., Pres., D. H. Emling Co., 7800 E. Union Ave.,Suite 420, Denver, CO 80237

ENGELKE, PHIL, Sales, Erico Jones Company, 506 Hillsboro Ave., Edwardsville, IL 62025

ERHART, PAMELA, Coal Mining & Processing, 300 W. Adams St., Chicago, IL 60606

ERICKSON, RON, T.J. Gundlach Machine Div, Rexnord, Inc., Box 385, Belleville, IL 62222

ERWIN, RON, Prep. Dir., Zeigler Coal Co.,Box 547, Coulterville, IL 62237

ESTEP, ROBERT, Sales Rep., Baker Mine Service, Box 775, Benton, IL 62812

EVANS, WILLIAM H., Sales Rep., Gooding Rubber Comanpy, 411 E. Plainfield Rd., La Grange (Countryside), IL 60525

EVILSIZER, BRAD, Dir., IL Dept. Mines & Minerals, 704 Stratton Office Bldg., Springfield, IL 62706

EWIGLEBEN, DONALD C., Mgr., State Aff., Midwest, AMAX Coal Co., Inc, BOX 967, Indianapolis, IN 46206

FABER, JAMES W., AMAX Coal Co., Inc., Box 967, Indianapolis, IN 46206

FALLIS, JOHN, Foreman, Freeman United Coal Mining Co., Box 263, Waltonville, IL 62894

FALTER, MICHAEL D., Sales, S & S Distributors, Box 186, Farina, IL 62838

FARMER, JERRY, Sales, Hendrick Screen, Box 369, Owensboro, KY 42302

FARMER, William T. (BILL), Sales Rep., M-R-S Mfg. Co., 500 Industrial Dr., Prairie View, IL 60069

FARRIS, W. DALE, Scientific Photographer, IL State Geological Survey, 615 E. Peabody Dr., Champaign, IL 61820

FATHAUER, DENNIS, Superv., Wooddell Logging,Inc., Box 1095, Mattoon, IL 61938

FAY, THOMAS E., Marcal Rope & Rigging, Inc., Box 477, Alton, IL 62002

FEIG, BILL, Service Repr., National Mine Service Co., 403 South St., Ewing, IL 62836

FEISTE, VERNOLD, Assoc. Prof. Elec. Engrg., Southern IL University, School of Engineering & Technology, Carbondale, IL 62901

FELDMAN, P. J., Dist. Mgr., Goodyear Tire and Rubber Co., 8544 Page Blvd., St. Louis, MO 63114

FELLER, ALLAN G., Client Serv. Mgr., Michael Baker Jr., Inc., 1313 Raven Dr., Pittsburg, PA 15243

FENSOM, KENT,Fleet-Heavy Duty Sales Repr., Fram Corp.,5269 Parker, St. Louis, MO 63139

FIELD, GEORGE W., Coal Consultant, 3746 E. 83rd St., S., Tulsa, OK 74137

FILMONT, THEODORE T., Sales, Sun Refining & Marketing Co., 385 Mason Ridge, St. Charles, MO 63301-7290

FINK, JACK C., Plymouth Rubber Co., Inc, 1637 Brett St., Pittsburgh, PA 15205

FITZGERALD, JOHN E., Sales Engr., AZTEC, Energy & Power Transmission, Inc., 5023 Chase Ave., Downers Grove, IL 60515

FITZPATRICK, JOSEPH A., Prof., Civil Engrg., Northwestern University, Northwestern University, Evanston, IL 60201

FLETCHER, ERNEST R,Mine Supt.,Freeman United Coal Mining Co.,130 S Henderson, Virden, IL 62690

*FLETCHER, ROBERT, J. H. Fletcher & Co., Box 2143, Huntington, WV 25722

*FLETCHER, WILLIAM, Dir., J. H. Fletcher & Co., 1630 Sheridan Rd., Apt. 10N, Wilmette, IL 60091

FLOWERS, BILL, Sr. Master Mech.,AMAX Coal Co.,Inc, Box 336, Vermont, IL 61484

FLOYD, ADRIAN B., Supt., #1 Mine, Monterey Coal Co., 101 Oakbrook Dr., Carlinville, IL 62626

FORD, JOHN, V. Pres., Ford Steel, 2475 Rock Island Blvd., Maryland Heights, MO 63043

FORMAN, CHARLES V., Traffic Distr.Mgr., Freeman United Coal Mining Company, Box 261, Industry, IL 61440

FORMAN, JOHN S,(Retired) Pres.,Mt. Olive&Staunton Coal Co,1760 St. Denis St., Florissant, MO 63033

FORSE, HERB E.,Pres.,JMD Co,Box 173,5401 Progress Blvd.,Bethel Park, PA 15102

FOSTER, ELDON C., Staff Engr., Kerr-Mc Gee Coal Corporation, Box 25861, Oklahoma City, OK 73126

FOSTER, I. O., Dist. Mgr., Commercial Testing & Eng. Co., 16130 VanDrunen, South Holland, IL 60473

FOWLER, SCOTT K., Shell Oil Mining, Box 2906, Houston, TX 77252

FOX, CHRIS, Sales,Marcal Rope&Rigging,Box 477, 100Central Ave.,Alton,IL 62002

FOX, JAMES M., Engr., Tabor Machine Co., 908 Taylor, Mt. Vernon, IL 62864

FOX, JOHN M., Research Asst., IL State Geological Survey, 615 E. Peabody Dr., Champaign, IL 61820

FRANKE, WILLIAM D.,Pres.,Bi-State Rubber Inc,Box 9440,St. Louis,MO 63117-0440

FRASER, JAMES D., V. Pres., Sales-Mktg., T. J. Gundlach Div., Rexnord, Inc., Box 385, Belleville, IL 62222

FREASE, JERRY E., Plant Mgr., Pattin-Marion,1003 S. Court St.,Marion,IL 62659

FREDERICK, JAMES P., Turris Coal Co., Box 21, Elkhart, IL 62634

FREEMAN, MARVIN, Office Mgr., Consolidation Coal Co., R.R. 2, Box229A, Mulberry Grove, IL 62262

FREESEN, ROY, Pres., Valico, Inc., Box 333, Bluffs, IL 62621

FRITZSCHE, KEN, Safety Inspector, Freeman United Coal Mining Company ,R.R. 3, Box 110, Auburn, IL 62615

FRUIT, HOMER G., Leahy Mine Mgr., AMAX Coal Co., Inc., 37 Pinewood, Carbondale, IL 62901

FULTON, JAMES F,Dir.,IL Field Off.,US Office of Surface Mining,600 E. Monroe, Springfield, IL 62704

FUSTIN, KENNETH, Asst. Mine Mgr., Peabody Coal Co., 315 Wagon Wheel Ln., Chatham, IL 62629

GAFFNEY, GEORGE F.,Dist. Mgr.,Okonite Co,10411 Clayton Rd.,St. Louis,MO 63131

GAINES, GARY, Sales, Melville B. Hall, Inc., 3001 Spruce, St. Louis, MO 63103

GALEENER, CHRIS, Sales, Bruening Bearing, Inc., 437 N. 9th St., E. St. Louis, IL 62201

GAMSTER, SCOTT K., Pres., Reaco Battery Service Corp., Hwy. 37 S., Rt.1, Johnston City., IL 62951

GARBIN, THOMAS L, Employee Relatns Mine Coordr., Monterey Coal Company, 1605 24th St., Highland, IL 62249

GARCIA, STEPHEN J., AMAX Coal Co., Inc., Wabash Mine, P.O. Box 144, Keensburg, IL 62852

GARDNER, L. J., Mgr. Sales, Sigmaform Corp., 3902 Terra Trace Ct., Evansville, IN 47715

GARRISON, GARY G., Div. Engr. Mgr., Peabody Coal Co., P.O. Box 530, Taylorville, IL 62568

GARRISON, HOWARD LELAND, Freeman United Coal Mng. Co., Crown III, UMWA, R.R.1, Box L125, Virden, IL 62690

+GARWOOD, THOMAS L.,(Retired),Freeman United Coal Mining Co.,1009 S.Main St., Benton, IL 62812

GAUDIANO, RONALD M., V. Pres., Engr., AMAX Coal Co., Inc., 32 Timber Ln., Brownsburg, IN 46112

*GEBHART, BARTON R., 2773 E. Avenida De Posada, Tucson, AZ 85718

GENT, L. D., Exec. V. Pres., John T. Boyd Co,Oliver Bldg.,535 Smithfield St., Pittsburgh, PA 15222

GENTER, D. L., Pres., Duquesne Mine Supply, 2 Cross St., Pittsburgh, PA 15209

GERLER, WARREN C., Contracting Engr., Roberts & Schaefer Company, 120 S. Riverside Plz., Chicago, IL 60606

GERTH, STEPHEN A,Pres,Truck&Mine Supply Co,Drawer 4438, Evansville, IN 47711

GESKE SR., FRANK L., Pres., Mine Service Co., Inc., R.R. 2, Box 416, Anna, IL 62906-9635

GIANATO, JOHN, Gen. Sales Mgr., Pemco Corp., Box 511, Bluefield, VA 24605

GIBBS, ROBERT C., Central Illinois Public Service Co., 104 E. 3rd St., Beardstown, IL 62618

GIBSON, WESLEY H., Sales Rep., Goodyear Tire & Rubber Co., 8544 Page Blvd., St. Louis, MO 63114

GILES, WILLIAM E., Chief Mech. Engr., Freeman United Coal Mining Co. Box 62, Girard, IL 62640

GILLEN, GEORGE M. B., Owens Mfg. Co., Box 1749, Bristol, VA 24203

GILLES, STEVE, Sales, Bixby-Zimmer Engineering Co., P.O. Box 248, Elberfeld, IN 47613

GILLETTE, GARY, Director,Parts Sales,Midco Sales&Service,Box 28729,St. Louis, MO 63146

GILMAN, BILL, Mgr., Mc Laughlin Mfg. Co., Box 303, Plainfield, IL 60544

GILMARTIN, D. LEO, (Retired), Peabody Coal Co,RR 2, Box 102A,Marissa,IL 62257

GINNARD, KEN, Geologist, Paul Weir Co., 20 N. Wacker Dr., Chicago, IL 60606

GIORDANO, PATRICK, Farmland Protection, IL Dept. of Agric., Div. of Nat. Resources, IL State Fairgrounds, Springfield, IL 62706

GIOVANDO, ROBERT G.,Proj Mgr,Old Ben Coal Co,500 N Du Quoin,Benton, IL 62812

GIVEN, CHARLES R. (DICK), Dist. Mgr., E. US, Dresser Security Mining,Box 560, Carmi, IL 62821-0560

GLEN, SHERIDAN (RUSTY),Arch Mineral Corp.,200 N. Broadway,St. Louis, MO 63102

GLOVER, THOMAS O., US Bureau of Mines, 2401 East St., NW, W616 Columbia Plz., Washington, DC 20241

GLUSKOTER, HAROLD J.,Research Superv, Exxon Production Research Co.,Box 2189, Houston, TX 77001

GOLDEN, FRANK, State Mine Inspector, IL Dept. of Mines & Minerals, RR 1, Box 19, Herod, IL 62947

GOLDMAN, SIDNEY A., Pres., Central Iron & Metal Co, 1100 S. 9th St., Box 1180, Springfield, IL 62705

GOLDMAN, TOM, (Retired), Sahara Coal Co, Inc, 1809 4th St, Eldorado, IL 62930

GOLDSTEIN, MICHAEL (MICKEY), Asst. Mgr., Azcon Corp., Box 61, Madison, IL 62060

GOOD, KURT E., Engr., Monterey Coal Co., Box 94, Albers, IL 62215

*GORDON, GLENN B., 2405-C Patriot Way, Greensboro, NC 27408

GORDON, JAMES R., V. Pres., Sales, Mine Equipment Co., 2304 Industrial, Dr., Mt. Vernon, IL 62864

GOSS, JAMES F., Sr. Geologist, AMAX Coal Co., Inc., 389 S. St. Clair St., Martinsville, IN 46151

*GOSSARD, A. G., 12419 Green Valley Dr., Oklahoma City, OK 73120

GOTHARD, RAMON A., Peabody Coal Co., R.R. 2, Box 261, Freeburg, IL 62243

GRASSINGER, JOE, Sales Mgr., Giles Armature & Elec., 1901 Julianne Dr., Marion, IL 62959

GRAY, DENNIS R, Territory Mgr., Western Diesel Services, Inc., 118 Deer Creek, Rochester, IL 62563

GRAY, RALPH J., Ralph Gray Services, 303 Drexel Dr., Monroeville, PA 15146

GREATHOUSE, RONALD, Sales Dir., Polygem, Inc, 188 S Barron, Bensenville, IL 60106

GREEN, RALPH J., (Retired), Consolidation Coal Co., RR 2, Box 674, Du Quoin, IL 62832

GRIESEDIECK, HENRY, Gen. Mgr., American Pulverizer Co., 5540 W Park, St Louis, MO 63110

GRIFFIN, JACK P., Mgr.-Systems Process Div., Heyl & Patterson, Box 36, Pittsburgh, PA 15230

GRIFFITHS, CARL D., Mine Supt., Sahara Coal Co., Inc., Walnut & Vine Sts., Harrisburg, IL 62946

GRIMM, JAMES W., Supt., Elm Mine, Midland Coal Co., Box 8, Trivoli, IL 61569

GRISSINGER, LEE A, Asst. Gen Mgr, Wedge Wire Corp., Box 157, Wellington, OH 44090

GROSS, D. JAMES, Vice President, Chief Engr., Roberts & Schaefer Company, 120 S. Riverside Plz., Chicago, IL 60606

GROSS, JAMES W., Asst. Mine Mgr., Monterey Coal Co., RR 1, Plainview, IL 62676

GROSSKOPF, JOHN W., Engineer., Freeman United Coal Mining Company, Box 100, West Frankfort, IL 62896

GROVES, GARY, Sales, Kerco, Inc., Drawer 665, Madisonville, KY 42431

GUCCIONE, JOE, Territory Sales Mgr., Lincoln Lubrication, 1295 Jackson Ln., Florissant, MO 63031

GUESS, JIM, Brake Supply Co., Inc., Box 447, Evansville, IN 47703

GUEST, TERRY, Safety Tech., Sahara Coal Co,Inc,Box 330, Harrisburg, IL 62946

GUILFOILE, JOSEPH F., Dist. Mgr., Midwest Steel Corp,1107 22nd St.,Box 1243, Granite City, IL 62040

GULLEY, THURMAN, Mine Supt.,Sahara Coal Co.,Inc,Box 338, Harrisburg, IL 62946

GULLIC, ROBERT C. (BOB), Asst. Chief Engr., Sahara Coal Co., Inc., Box 338, Harrisburg, IL 62946

GURLEY, JEFFREY P, Safety Dept, Peabody Coal Co,RR 1,Box 108,Sparta, IL 62286

HAAG, GERALD, (Retired), Jeffrey Mining Machinery Division, Dresser Ind., 9505 S. Point La Salles's Dr., Bloomington, IN 47401

HAAS, CHARLES J., Prof. Mng. Engr., University of MO, Rolla, Rock Mechanics Research Center, Rolla, MO 65401

HACKLEY,KEITH,IL State Geological Survey,615 E. Peabody Dr,Champaign,IL 61820

HAENTJENS, R. P., V. Pres., Barrett, Haentjens & Co.,225 N Cedar St.,Box 488, Hazelton, PA 18201

HAGENBUCH, LEROY G., Pres., Philippi-Hagenbuch, Inc., 7424 W. Plank Rd., Peoria, IL 61604

HAIR, RICHARD T,Mining Industry Conslt,184 Briarwood Loop,Oak Brook, IL 60521

HAKE, WILLIAM D., Chief Engr.,Surf. Mines,Old Ben Coal Co,RR 3, Oakland City, IN 47660

++HALBERSLEBEN, PAUL, Consultant, Sahara Coal Co., Inc., Box 330, Harrisburg, IL 62946

HALES JR., HERBERT F., Pres., W. M. Hales Co., Box 65, Danville, IL 61832

HALEY, GENE, V. Pres., Bearing Headquarters Co., 1304 Ashby Rd., St. Louis, MO 63132

HALL, BOB, Mine Mgr., Peabody Coal Co., 805 Pauline, Taylorville, IL 62568

HALL, JAMES A,V. Pres,Mktg.-Mng. Div.,W. R. Grace & Co.,3400 Inter First Two, Dallas, TX 75270

HALL, R. W. (ROB), Sales Rep., Armco, Union Wire Rope, 1440 Farmington Ct., St. Louis, MO 63141

HALLBERG, JEFFREY C., Mng. Engr., Kiefer Electrical Supply Co., R.R.3, Benton, IL 62812

HAMMOND, JOHN P., State Mine Inspector, IL Dept. of Mines & Minerals,Box 109, Rushville, IL 62681

HAMMOND, KENNETH R., Peabody Coal Co., 323 W. Glen, Glen Carbon, IL 62034

HANCOCK JR., DELVIN O., Commerical Testing & Engineering Co., Box 752, Henderson, KY 42420

HANFT, ALLAN L., Chief Engr., Brazil Coal & Clay Corp., 9291 Fordham St., Indianapolis, IN 46268-1280

HANLEY, TERRY, Sales Rep., Ingersoll-Rand Mining Machinery, Box 513, Marion, IL 62959

HARGRAVES, GEORGE E., Mng. Engr., AMAX Coal Co., Inc., R.R. 2, Box 105, Marion, IL 62959

HARRELL, M. V. (DOC), V. Pres., Freeman United Coal Mining Co., 123 S 10th St., Mt. Vernon, IL 62864

HARRIS, JAMES D, Anixter-Cable Service, Box 427, Country Club Rd., West Franklin, IL 62896

HARRIS, TROY, Instructor, University of MO, Rolla, 1022 Morrell St., Rolla, MO 65401

HARRISON, WARREN L., Frontier-Kemper Constructors, Inc., Box 6548, Evansville, IN 47712

HART, RONALD L., Maintenance Foreman, Monterey Coal Co., #1 Mine, RR 1, Box 90, Virden, IL 62690

HARTING, RICH, Dist. Mgr., Bearing Headquarters Co., 3689 E. Broadway, Alton, IL 62002

HARTLINE, CURTIS RAYMOND, Pres., C. R. Hartline Co., Inc., 2121 Lakeview, Madisonville, KY 42431

HARVEY, RICHARD D., Geologist, IL State Geological Survey, 615 E. Peabody Dr., Champaign, IL 61820

HASTINGS, TOM, T. J. Gundlach Machine Div., Rexnord Inc., Box 385, Belleville, IL 62222

HATFIELD, REO, Michael-Walters Industries, Inc., Box 458, Kenova, WV 25530

HAUBOLD, RICH, Mine Examiner, Freeman United Coal Mining Co., Box 185A, Pawnee, IL 62558

HAWKINS, JOE, Dist. Repr., Truck & Mine Supply, Box 4438, Evansville, IN 47711

+HAYDEN, CARL T., V. Pres., Sahara Coal Co., Inc., 3 Fisrt National Plz., Suite 3050, Chicago, IL 60602

HAYNES, FRANK C, Sales, Bearing Headquarters Co, 3689 E Broadway, Alton, IL 62002

HAYS, LARRY G., Fairmont Supply Co., 1525 Herbert St., Mt. Vernon, IL 62864

HEAD, GEORGE, Pres., Ruttmann Construction Co, Box 120, Upper Sandusky, OH 43351

HEALEY, GEORGE D., Proj. Engr., Inland Steel Coal Co, Box 566, Sesser, IL 62884

HEALY, JOHN M., V. Pres., Partner, Hanson Engineers, Inc., 1525 S. 6th St., Springfield, IL 62703

HEIDINGER, GEORGE H., Peabody Coal Co., R.R. 1, Box 299, Sparta, IL 62286

HEIL, RAY, Purchasing Agent, Peabody Coal Co., Box 176, MARISSA, IL 62257

HELD, ALAN D. (BUD), Sales, Mid-Continent Pipe & Supply Co.,Inc,15 Ridge Rd., Centralia, IL 62801

HELFRICH, GEORGE,Sales,Sentry Mine Supply Co,Box 516,West Frankfort, IL 62896

HELLER, CHRIS, Maintenance Foreman, Monterey Coal Co., #1 Mine, R.R. 2, Carlinville, IL 62626

HELMEN, GLOER (BUD), Mohler Armature & Electric, Inc., 2355 Eby Rd., Boonville, IN 47601

HELWIG, W. O., Chairman of Board, Helwig Carbon Products,Inc,2550 N 30th St., Milwaukee, WI 53210

HEMMERICH, WAYNE,Safety Tech.,Sahara Coal Co,Inc,Box 330,Harrisburg, IL 62946

HENDRICKS, CHARLES, Sahara Coal Co., Inc., Box 330, Harrisburg, IL 62946

HENK, WALTER E., Division Operations Mgr,Gooding Rubber Co,Box 477, Benton, IL 62812

HENKEN, DON, Sales, Maintenance, S & S Distributors,Box 186,Farina, IL 62838

HENRY, BOB, Foreman, Monterey Coal Co., 60 Memorial Ct., Highland, IL 62249

HERBERT, RANDY, Asst. Sales Mgr., D & E Tool Co., 21 Sunset Dr., Mt. Vernon, IL 62864

HERMAN, DR. RICHARD G., Research Scientist, Lehigh University, Sinclair Laboratory, Bldg. #7, Bethlehem, PA 18015

HICKS, C. W., Pres., Hicks Oils & Hicks Gas, Inc., IN Div., Roberts, IL 60962

HICKS, STEVEN, Engr., Consolidation Coal Co., Box 598, Pocahontas, VA 24635

HICKS, TOM, Div. Mgr., Rite-Crete Concrete Products, 680 Lincoln Ave., Madisonville, KY 42431

HIERBAUM, JOHN L., Sales, Mine Safety Appliances Co., 3586 Foxwood Dr., Murrysville, PA 15668

HIGGINS, GEORGE, Freeman United Coal Mining Co., Bailey Ln., Benton, IL 62812

HIGGINS, PATRICK K., Parts Mgr., Jeffrey Mining, Box 348, Litchfield,IL 62056

HILL, JOHN M., Supply Superv., Kenellis Energies, Inc,Box 194, Harco,IL 62945

HILL III, J. B.(JERRY),Sales Engr., Johnson Div., UOP, 3500 Tangle Brush, 46, Woodlands, TX 77380

HILLIARD, CHARLES F., Aero-Metric Engineering, 1415 East Central Road, Arlington Heights, IL 60005

HILLIS, DAVID E., Account Mgr., Cummins Mid-State Power, U.S. 51 & I 55, Normal, IL 61761

HINCHEE, BETTY, Minesafe Electronics, Box 281, Sturgis, KY 42459

HINDERT, GEORGE L.,Spec. Metal Fabr.,St. Louis Blow Pipe Div.,1948 N 9th St., St. Louis, MO 63102

HINES, ROGER L., Services, Joy Manufacturing Co., Mt. Vernon, IL 62864

HINZ, BILL,Chief Elect,Freeman United Coal Mining Co,Box 337,Virden, IL 62690

HITCHINGS, DAVID, Maintenance Foreman, Freeman United Coal Mining Co.,R.R.2, Raymond, IL 62560

HOCHSCHEID, ROBERT E., V. Pres., Krebs Engineers, 205 Chrysler Dr,Menlo Park, CA 94025

HOFFMANN, JOHN O., Shift Maintenance Foreman,Monterey Coal Co.,204 Debra Dr., Albers, IL 62215

HOGLUND, HAP, Weld Shop Foreman, Capitol Machinery Co., Inc., Box 2008, Springfield, IL 62705

HOLDERFIELD, JOE, Fabick Machinery Co., Box 166, Marion, IL 62959

HOLLAND, GARY, Pres., Ajax Engineering Corp., Box 409, Shawneetown, IL 62984

HOLLAND, JOHN D., Ajax Engineering Corp., Box 409, Shawneetown, IL 62984

HOLLOWAY, ROBERT W., Dir. of Eviron. Off., Arch Mineral Corporation, R.R. 1, Percy, IL 62272

HOLMES, RON,Sales,Mine Equipment & Mill Supply Co,RR 1,Box 79,Dawson Springs, KY 42408

+HOPKINS, M. E.,Dir., Geology, Peabody Development Co., Box 14222, St. Louis, MO 63178

HOPKINS, THOMAS P., Sales, Fairmont Supply Co., 6044 Magnolia Dr., Newburgh, IN 47630

HOPPER, LARRY J.,Sales Mgr.,Heyl & Patterson,Inc,Box 36, Pittsburgh, PA 15230

HOPWOOD, JACK W., Midwest Reg. Sales Mgr., WEMCO, 100 St. Louis St., Rm. 306, Edwardsville, IL 62025

HORTON, EUGENE, V. Pres., Atkinson Industries,Inc.,Box 268,Pittsburg,KS 66762

HORTON, RICHARD E., Sales Rep., Guyan Machinery Co., R.R. 2, Box 8, Mahomet, IL 61853

HOUSER, ROBERT W., Commercial Testing & Engineering Co.,1919 S Highland Ave., Lombard, IL 60148

HOWARD, DAN G., Sales Rep., U.S. Steel Corp., Box 67, Oakland City, IN 47660

HOWARD, JOHN L., Northern Superv., Wabash Valley College-Coal Mining Technology, 281 E. Jackson St., Virden, IL 62690

HOWARD, JOHN MICHAEL,Sales Mgr,St. Louis Energy,311 Laura,Farmington,MO 63640

HUCKABY, HUCK, Asst. Director, IL. Department of Mines & Minerals, 704 Stratton Off. Bldg., Springfield, IL 62706

HUFF, W. L. (BILL), Mgr., Material Control, AMAX Coal Co., Inc., Box 967, Indianapolis, IN 46206

HUFFER, WILLIAM D., Prod. Mgr., Fan Div., Peabody ABC Corp., Box 77, Warsaw, IN 46580

HULL, CLARENCE, Electrician, Freeman United Coal Mining Co., R.R. 3, Box 109, Auburn, IL 62615

HUNT, JOHN E., Supt., Peabody Coal Co., Box 14495, St. Louis, MO 63178

HUNT, TY, PMA, Turris Mine, 4143 Pickfair, Springfield, IL 62703

HURLEY, JACK,Pres,Centrifugal & Mechanical Industries, Inc,146 President St., St. Louis, MO 63118

HURST, ROBERT J., V. Pres., Explor., Geo-Con, Inc., R.R. 4, 305 Fifth Ave., Princeton, IN 47670

HURTTE, JAMES E., Peabody Coal Co., 1108 W. Poplar, Taylorville, IL 62568

HURTTE, RAYFORD, (Retired), Peabody Coal Co., 1100 Poplar St., Taylorville, IL 62568

HUTCHCRAFT, JIM,Sales Rep,Sentry Mine Supply,Box 516,West Frankfort, IL 62896

HYMEL, BILL, Superv. Purchasing Off. Serv., Turris Coal Co., Box 21, Elkhart, IL 62634

INABNIT, DAN, Mine Mgr., Freeman United Coal Mining Co., RR 2,Girard,IL 62640

INMAN, ROBERT H., 502 Broadmoor, Chesterfield, MO 63017

ISAACS, L. WAYNE, Mine Engr.,Kerr-Mc Gee Coal Corp,Box 278, Galatia, IL 62935

IWASYSZYN, TED, Vice President, Civil Serv., C. M. I.,Inc.,146 President St., St. Louis, MO 63118

IZARD, ROBERT M., V. Pres., Operations, Midland Coal Co., Box 159, Farmington, IL 61531-0159

JACKSON, AARON D., Mine Engr.,Kerr-Mc Gee Coal Corp.,Box 278,Galatia,IL 62935

JACKSON, ED, Plant Mgr., Turris Coal Co., Box 21, Elkhart, IL 62634

JACKSON, HARVEY D., Sales, Royal Brass & Hose Co.,Hwy. 37,N, Benton, IL 62812

JACKSON, ROYCE, Sales, Rees Mine Supply Sales, Inc., Box 127,Du Bois,IL 62831

JACOBSON, RUSSELL J.,Asst. Geologist,IL State Geological Survey,Coal Section, 615 E. Peabody Dr., Champaign, IL 61820

JAENKE, C. T., Sales Mgr., Cummins MO, Inc., 7210 Hall St.,St. Louis,MO 63147

JAHRAUS, JOE, Sales, S & S Distributors, Box 186, Farina, IL 62838

JAMES, CHARLES W., Mgr., Central Electric Co., Box 621, Fulton, MO 65251

JAMISON, GEORGE F., Assoc. Partner, Hanson Engineers, Inc.,1525 S. Sixth St., Springfield, IL 62703

JANKOUSKY, CHARLES,Proj Engr,Freeman United Coal Mining Co.,702 Sheridan Dr., Benton, IL 62812

JARMAN, DWAYNE L., Shop Foreman, Monterey Coal Co., R.R. 1, Box 40,Mt. Olive, IL 62069

JENKINS, JACK D., 1601 Dewey, Marion, IL 62959

*JENKINS II, WILLIAM J., Pres., Ridgetop Enterprises, Inc., 9216 Clayton Rd., St. Louis, MO 63124

JENNINGS, EARL A., Instructor, Wabash Valley College, 423 E. Center, Girard, IL 62640

JOCKISCH, LEE W., Reclamation Mgr., AMAX Coal Co., Inc., R.R. 1, Box 109, Lewistown, IL 61542

JOHNSON, CHARLES W., V. Pres., Viking Chain Div., N. Star Casteel Products, 185 Maple Dr., Chicago Heights, IL 60411

JOHNSON, DAVID E., Assoc. Geologist, Mapco, Inc. 1800 S. Baltimore Ave., Tulsa, OK 74119

JOHNSON, D. J., Rend Lake College, R.R. 1, Ina, IL 62846

JOHNSON, FLOYD W., Maintenance Foreman, Monterey Coal Co., R.R. 2, Box 87A, Bunker Hill, IL 62014

JOHNSON, J. N., Mgr., Twin Mills Timber & Tie Co., 1200 N. Douglas St., West Frankfort, IL 62896

JOHNSON, SAM, Sales, Dooley Bros., R.R. 2, Box 320, Johnston City, IL 62951

JOHNSON, STEVE, Engr., Sahara Coal Co., Inc., Box 330, Harrisburg, IL 62946

JOHNSON, T C (TEG),EASTERN SALES MGR.,MARION POWER SHOVEL,617 W. CENTER ST., MARION, OH 43302

JOKERST, JERRY, Farrar Pump & Machinery Co.,1701 S. Big Bend Blvd.,St. Louis, MO 63117

JONES, AARON U., V. Pres., Operations, Mining Controls, Inc., Box 1141, Beckley, WV 25801

JONES, CARL, Instructor, Rend Lake College., R.R. 1, Ina, IL 62846

JONES, DON, Mgr., Mine #1, Inland Steel Coal Co., Box 566,Sesser,IL 62884

JONES, J. ROBERT (BOB),Sales,H A Petter Supply Co.,Box 2350,Paducah,KY 42001

JONES, JACKIE W., Kerco, Inc., Drawer 665, Madisonville, KY 42431

JONES, LOY D., Sales Mgr., Cummins Mid-States Power, Inc., Box 41317, Indianapolis, IN 46241

JONES, RICHARD,Asst Mine Mgr.,Monterey Coal Co.,112 N. Wilson,Girard,IL 62640

JONES, ROBERT E., State Mine Inspector, IL Dept. of Mines & Minerals, R.R.1, Benton, IL 62812

JORDAN, ALEX, Top Boss, Peabody Coal Co., 333 Henrietta, Divernon, IL 62530

JOSENDALE, JOHN, Dist. Mng. Mgr., Leschen Wire Rope, 10785 Indian Head Industrial Blvd., St. Louis, MO 63132

JUENGER, CLYDE E., Supt., Randolph Prep., Peabody Coal Co., Box 46, Marissa, IL 62257

JUST, ZBIGNIEW,Sr Proj Engr,Thyssen Mining Equipment Division,202 E Main St., Stanley Bldg., Suite 102, Marion, IL 62959

JUSTICE, GEORGE H., Sales Mgr., Peabody ABC Corp., Box 77, Warsaw, IN 46580

JUSTICE, HENRY B., Pres.,Du Quoin Iron & Supply Co.,Box 181,Du Quoin,IL 62832

JUSTICE, JAMES H. (JIM), Sales, Du Quoin Iron Supply Co., Box 181, Du Quoin, IL 62832

JUSTICE,MARY E,V. P., Du Quoin Iron & Supply Co., Box 181, Du Quoin, IL 62832

KACHIK, DAVID J, V. Pres., Paul Weir Co., 20 N. Wacker Dr., Chicago, IL 60606

KAISER, F. X., Serv. Engr., Peabody Coal Co., Box 14495, St. Louis, MO 63178

*KALIA, HEMENDRA N., 2348 E. Cleft Dr., Columbus, OH 43221-1852

KALKA, DALE A., Foreman, Monterey Coal Co., 509 N. High, Carlinville,IL 62626

KARLOVSKY JR., JERRY, Chief Mng. Engr., National Mine Service Co., Greenup, KY 41144

*KARNES, RALPH E., Maintenance Foreman, Consolidation Coal Co., 1311 Elm St., Hillsboro, IL 62049

KASHMERICK, RICHARD D., Territory Mgr., Donaldson Co., Inc., 800 Ruth Dr., St. Charles, MO 63301

KATH, STEWART M., Pres., Reid-Holcomb Supply, Inc., R.R. 2, Box 238A, Carterville, IL 62918

KATZ, BEN, AMAX Coal Co., Inc., Box 967, Indianapolis, IN 46206

KAUFFMAN, JERRY,Mc Lanahan Corp., 200 Wall St., Hollidaysburg, PA 16648

KEE, GEORGE B., Sales, Special Mine Services, Inc., 503 W. Cline St., Marion, IL 62959

KEE, VERNON, Sales, Austin Powder Co., Mine Tool Div., 700 W. 11th St., Johnston City, IL 62951

KELLER, ROBERT T., V. Pres., Mainline Power Products Company, Inc., Box 306, West Frankfort, IL 62896

KELLEY, JAY HILARY, Pres,Kelastic Mine Beam Company,307 S. Pennsylvania Ave., Greensburg, PA 15601

KELLY, JOSEPH M., Old Ben Coal Co., 500 N. Du Quoin St., Benton, IL 62812

KELM, GEORGE, Pres., Sahara Coal Co., Inc., 3 First National Plz.,Suite 3050, Chicago, IL 60602

KELSEY, AL, Sales Engr.,IL. Bearing Co.,1350 Finley Ct.,Mt. Zion,IL 62549

KELTON, GERALD P., Staff Engr., Krebs Engineers,1205 Chrysler Dr.,Menlo Park, CA 94025

KELTON JR., SAM W., Regional Mgr, Hercules, Inc,1 Energy Center, 300 E. Schuman Blvd., Naperville, IL 60566

KENNEDY, JACK, Pres,Jack Kennedy Metal Products,Box 38, Taylorville, IL 62568

KENNEDY, LARRY, National Mine Service Co., P.O. Box 1766, Mt. Vernon,IL 62864

KENNEDY, WILLIAM, Pit Mgr., Jack Kennedy Metal Products, Box 38, Taylorville, IL 62568

KENSEK, MICHAEL L., Wabash Valley College, Box 2415, Vincennes, IN 47591

KERN, FRED, Regional Mgr., Ingersoll-Rand Mining Machinery, Box 2863, Pittsburgh, PA 15230

KESTER JR., WILLIAM M., Sr. Engr. Superv., AMAX Coal Co., Inc., Box 967, Indianapolis, IN 46206

KEYS, NICK, Mobil Oil Corp., Mining & Coal Div., Box 17772, Denver, CO 80217

KIBLER, WILLIAM L., Operations Coordinator, Western Fuels Assoc., Inc., Brushy Creek Mine, R.R. 2, Box 74, Galatia, IL 62935

KIELY, ED, C. L. Smith Industrial Co., 1311 S. 39th St., St. Louis, MO 63110

KIESSLING, FRANK J., Mgr. Cen. Sales Reg., Dravo Engineers, 1900 E. Golf Rd., M-100, Schaumburg, IL 60631

KILE, DAVID L., Mgr., Chicago Industrial Rubber Co., 862 Industrial Dr., Elmhurst, IL 60126

KILLMAN, MIKE, Purchasing Agent, Sahara Coal Co., Inc., Box 330, Harrisburg, IL 62946

KIMBLE, LARRY, Asst. Serv. Mgr., Capitol Machinery Co., Inc., Box 2008, Springfield, IL 62705

KIMELTON, JAMES E., Buyer, Inland Steel Coal Co., Box 566, Sesser, IL 62884

KING, THOMAS G.,Dist. Mgr.,Austin Powder Co.,Box 278, Madisonville, KY 42431

KING, WILLIAM C. (BILL), Vice President, King, Miles & Associates, 6611 Old Stone House Dr., Newburgh, IN 47630

KIPPENBERGER, RON, Midway Equipment, Inc., 2380 Cassens Dr., Fenton, MO 63026

KIRCHNER, DENNIS, Central Illinois Public Service Co., 607 E. Adams St., Springfield, IL 62701

KIRK, W. R., Da-Co Machine Co., Barbour St., [illegible] 2, Providence, KY 42450

KIRKLAND, WAYNE, Sales, Bridon American Corp., Tiger Brand Wire Rope, 5457 Landview Dr., Newburgh, IN 47630

KIRKPATRICK, BILLY, Field Repr., Joy Manufacturing Co., R.R. 6, Mt. Vernon, IL 62864

KISSINGER, STEVE, Anixter-Cable Service, Box 427,Country Club,West Frankfort, IL 62896

KLOTZ, RONALD, Shift Maintenance Foreman, Monterey Coal Co., R.R. 2, Box 626, Sorento, IL 62086

KNIGHT, GREGORY R., Power Transmission Specialist, Bearings, Incorperated, 2727 Washington Blvd., St. Louis, MO 63103

KNIPPING, BRENDA, Pres., Central Petroleum Co., Box 506, Centralia, IL 62801

KNOWLES, TOM, Supervisor Mobile Equipment, Freeman United Coal Mining Co., 940 N. Eigthth Ave., Canton, IL 61520

KOCUREK, PAUL J.,Resident Engr,Freeman United Coal Mining Co.,505 Western, Taylorville, IL 62568

KOEHL, KENO W., Sr. Planning Engr., AMAX Coal Co., Inc., Box 967, Indianapolis, IN 46206

*KOERBER JR,FRED,Owner,Koerber Drilling Contractor,424 N Hickory St,Du Quoin, IL 62832

KOESTERER, MICHAEL (MIKE), Sales Engr., Joy Manufacturing Co., 13 Innsbruck, Belleville, IL 62221

KOKINDA, JAMES E., Goodall Rubber Co., 2330 E. Franklin, Evansville, IN 47711

KOLVEK, M. W. (MIKE), Sales Engr., Erwin Industries, Inc., Box 752, Fairmont, WV 26554

KOSANKE, ROBERT M., US Geological Survey, Mail Stop 919, Box 25046, Denver, CO 80225

KRAZER, RALPH G., (Retired), 1733 Smith Dr., Abilene, TX 79601

KRESS, EDWARD S., Pres., Kress Corp., Illinois St.,Box 368,Brimfield,IL 61517

KRESS, RALPH H., Exec. V. Pres., Kress Corp.,IL Street, Box 368, Brimfield, IL 61517

KRIETEMEYER, NORMAN, Truck Driver, Evansville Electric & Mfg. Co., Box 4717, Evansville, IN 47711

KROGMAN, JOHN A., Dept.-Mng. Engrg.,Univ. of WI,Platteville,Ottensman Hall, Platteville, WI 53818

KRUEGER, P. ANDREE (ANDY), Sales Representive,Chicago Industrial Rubber Co, 423 Southside Ave., St. Louis, MO 63119

KRUG, FRANK, Superv., AMAX Coal Co., Inc., Wabash Mine, Box 144, Keensburg, IL 62852

KRUPNIK, LINDA Z.,Engrg. Coordinator,Monterey Coal Co,Box 94,Albers, IL 62215

KRUSE, CARL W., Senior Research Scientist, IL State Geological Survey, 615 E. Peabody Dr., Champaign, IL 61820

KULASH, EDWARD J., Engr. Asst., Turris Coal Co., Box 398, Riverton, IL 62561

KUTZ, BILL, Service Engineer, Centrifugal & Mechanical Industries, Inc., 146 President St., St. Louis, MO 63118

KYLE, BOB,Sales Rep.,Brad Ragan, Inc.,15314 Von Achen Dr.,Chilicothe,IL 61523

LAFFEY, LARRY R.,V. Pres.,Laffey Equipment Co.,Box 16285, St. Louis, MO 63105

LAIR, LANCE H., Sales Engr., Foster Co., 10452 Baur Blvd., St. Louis,MO 63132

LAMB, JOHN L., Oberjuerge Rubber Co., Box 519, St. Louis, MO 63166

LAMBERT, KEITH, Minesafe Electronics, Box 281, Sturgis, KY 42459

LAND, GEORGE W., Dir. Tech. Assessment, AMAX Coal Co., Inc., Box 967, Indianapolis, IN 46206

LANE, RICHARD R., Owner, Land & Mineral Acquisition, Box 7, Virden, IL 62690

LANGAN, JAMES T., (Retired), Roberts & Schaefer Co., 7107 N. Overhill, Chicago, IL 60631

LANGE, LEONARD J., Wescott Steel, Inc., 425 Andrews Rd., Trevose, PA 19047

LANGE, ULRICH O., Pres., Hemscheidt America Corp.,Box 500,Pittsburgh,PA 15230

LANZEROTTE, JOHN T., Shift Mine Engr., Monterey Coal Co., 445 E. Second, Trenton, IL 62293

LARNED, GARDNER, Pres., Berry Bearing Co., 4242 S. 1st Ave., Lyons, IL 60534

LARSON, JOHN C., Sales Rep., MI Industrial Lumber, 1851 Front St., Box 612, Whiting, IN 46394

LASWELL, RON, Pres., Coal, Inc., R.R. 25, Box 243, Terre Haute, IN 47802

LATTINA, ALAN, Serv. Engineer, Centrifugal & Mechanical Industries, Inc., 146 President St., St. Louis, MO 63118

LAUER, BRIAN K., Missouri-Illinois Tractor & Equip. Co., Inc., 5920 N. Lindbergh Blvd., Hazelwood, MO 63042

LAURENT, EDWARD L., Rep., Diatec Polymers, R.R. 2, Box 350, St. Anne,IL 60969

LAWRENCE, DAVID W., Exec. V. Pres., Gooding Rubber Co., Box 729, La Grange, IL 60525

LAYNE, E. B., Mgr. Corp. Safety, Old Ben Coal Co., 500 N. Du Quoin St., Benton, IL 62812

LECOCQ, GERALD WAYNE, Pres., Wayne Sales, 8215 N. Green River Rd., Evansville, IN 47711

*LEDVINA, CHRISTOPHER T. (CHRIS), Old Ben Coal Co., 5415 N. Sheridian Rd., Suite 5511, Chicago, IL 60640

LEE, DOUGLAS, (Retired) Consultant, 635 Fawn Ct., Mt. Zion, IL 62549

LEE, JAMES, Freeman United Coal Mining Co., 2464 Arrowhead Dr., Springfield, IL 62702

LEEDS, JAY, Dist.Sales Mgr.,NIPAK Inc.,7514 Appletree Way,Louisville,KY 40228

LEHMAN, ROBERT C., Safety Tech., Sahara Coal Co., Inc., Box 330, Harrisburg, IL 62946

LEIGHTON, MORRIS W., Chief, IL State Geological Survey, 615 E. Peabody Dr., Champaign, IL 61820

LEMMONS, SHARON K., Claims Mgr., Lynch Coal Operators Reciprocal Assn., Box 715, Terre Haute, IN 47808

LESTER, HENRY, Dir.-Planning & Admin., Old Ben Coal Co., 500 N. Du Quoin St., Benton, IL 62812

LICK, BOB, Coal Mining & Processing, 300 W. Adams St., Chicago, IL 61531

LIGGETT, MICHAEL, Purchasing Agent, Du Quoin Iron & Supply Company, Box 181, Du Quoin, IL 62832

LILLY, PETER B., Gen. Mgr., Kerr-Mc Gee Coal Corp., Galatia Mine, Box 727, Harrisburg, IL 62946

*LINDSAY, GEORGE C., Gen. Mgr., Coal Mining & Processing, 300 W. Adams St., Chicago, IL 60606

LINHARDT, E.H., Sales, Rome Cable Corp., 75 Worthington Dr., Maryland Hts., MO 63043

LINK, WILLIAM R., Buyer, Monterey Coal Co., Box 496, Carlinville, IL 62626

LIPPENCOTT, THOMAS W., Contracting Engr., Roberts & Schaefer Company, 120 S. Riverside Plz., Chicago, IL 60606

LITTLE, JONATHAN L., Sales Engr., Heyl & Patterson, 809 Oakland, Mt. Vernon, IL 62864

LITTLEFIELD, KENNETH, Sr. Pres., B & L Industrial Systems, Inc., Box 1223, Granite City, IL 62040

LOCK, TIMOTHY P., Dist. Sales Mgr., Leschen Wire Rope Co., 1220 Capitol Dr., Addison, IL 60101

LOCKIN, GEORGE W. (BILL), (Retired), Inland Steel Coal Co., R.R. 2, Benton, IL 62812

LOLAN, DONALD J, Sales Rep., Midco Sales & Service, Box 28729, St. Louis, MO 63146

LOMELINO, VICKY S., Safety Clerk, Monterey Coal Co., 736 W. Madison St., Girard, IL 62640

LONG, TED C., Sales, Hughes MPD, 573 Oak St., Madisonville, KY 42431

LOUNSBURY, RICHARD E., Environ. Coordinator, Monterey Coal Co., 111 Oakbrook Dr., Carlinville, IL 62626

LOVINGOOD, D. L., Serv. Engr., Central Illinois Public Service Co., Box 566, Mattoon, IL 61938

LUCAS, WALTER S., V. Pres., Sahara Coal Co., Inc., Box 330, Harrisburg, IL 62946

LUKENS, AL, Mktg., Century Hulburt, Inc., Box 161, Marion, IL 62959

LUMM, DON K., IL State Geological Survey, 615 E. Peabody Dr., Champaign, IL 61820

LUNDIN, A. M., Dist. Sales Mgr., Mine Safety Appliances, 1000 Nicholas Blvd., Elk Grove Village, IL 60007

LYMAN, ROBERT M, Geologist, Elk River Resources, Inc, Box 10388, Knoxville, TN 37919

LYON, DAVID L., Mng. Engr., Zeigler Coal Co., R.R. 7, Box 538,Marion,IL 62959

LYTLE, JOHN M., Center for Research on Sulfur in Coal, 615 E. Peabody Dr., Champaign, IL 61820

+MAC DONALD, J. W., Consultant, 501 W. Reed St., Benton, IL 62812

MALONE, JAMES (PAT), Mgr., Jake's Tire Co., 1001 N. Court, Marion, IL 62959

*MANCI, SAMUEL L,Sales Rep.,Long-Airdox Co.,214 Tartan Dr.,Henderson,KY 42420

MARCHANT, DANIEL L., Asst. District Sales Manager, E. I. Du Pont Company, 1250 Executive Park, Suite 301, Geneva, IL 60134

MAROSCHER, GUS, General Manager & Director,Thyssen Mining Equipment Division, 202 E. Main St., Stanley Bldg., Suite 102, Marion, IL 62959

MARTIN, ANDREW G,Mng. Engr.,Monterey Coal Co.,420 E. 18th St.,Tuscon,AZ 85701

MARTIN, BERNARD DEAN, State Mine Inspector, IL Dept. of Mines & Minerals, 616 N. Silver, Taylorville, IL 62568

*MARTIN, CHARLES EDWARD, Mgr., Human Resources, Roadmaster Corp., Box 344, Olney, IL 62450

MARTIN, DARIN W,Environ.&Reclaim. Tech.,Old Ben Coal Co.,500 N. Du Quoin St., Benton, IL 62812

MARTIN, ROBERT W., Mgr,Purchasing,Zeigler Coal Co,2700 River Rd.,Des Plaines, IL 60018

MARTIN, STEVE, Sales Engr., Davidson, Inc., Mining Div., 2321 Commercial Ct., Evansville, IN 47711

MARTING, MATTHEW, Dist. Rep., Mac Whyte Wire Rope Co., 184 Doorack Ln., Kirkwood, MO 63122

MASSER, BRUCE, Superv., AMAX Coal Co., Inc., Wabash Mine, Box 144, Keensburg, IL 62852

MASSIE, SUE, Exec. Dir., Abandoned Mined Lands Reclamation Council, IL Dept. of Mines & Minerals, 100 N. 1st St., Springfield, IL 62701

MASTERS, FRANK R., Proj. Engr.,Monterey Coal Co.,Box 496,Carlinville,IL 62626

MASTERS, JODI H., Coal Prep. Engr., Monterey Coal Co., Box 496, Carlinville, IL 62626

MATTHEWS, TOM, Sales Rep.,L. B. Foster Co.,1750 S. Brentwood Blvd.,St. Louis, MO 63144

MATUSKA, DAN, Engr., Century Hulbert, Inc., Box 161, Marion, IL 62959

MAUCK, HARVEY B., Owner, Deep Valley Coal Co., 1107 N. Logan Ave., Danville, IL 61832

MAXTED, ED, Sales, Reid-Holcomb Supply, Inc., R.R. 2, Box 238, Carterville, IL 62918

MAY, BILLY, Mohler Armature & Electric, Inc., 2355 Eby Rd., Boonville, IN 47601

MAY, GEORGE L., Gen. Mgr., Monterey Coal Co., Box 496, Carlinville, IL 62626

MAYHALL, DICK H., Hwy. Equip. Superv., Peabody Coal Company, 41 Ivan Ct., Fairview Heights, IL 62208

MC CLANAHAN, MIKE, SII Smith-Gruner, Box 603, Oakwood, VA 24631

MC COMMONS, STEVE, Engr., Inland Steel Coal Co., Box 566, Sesser, IL 62884

MC CONNELL, MICHAEL, Gen. Sales Mgr., Vincent Brass & Aluminum Company, 2150 S. 59th St., St. Louis, MO 63110

MC COY, LARRY, Sales Mgr., Esco Corp., 1017 Griggs St., Danville, IL 61832

MC COY, LARRY E., Dist. Sales Mgr., National Mine Service Co., Box 497, Madisonville, KY 42431

MC COY, ROBERT E., Gunther-Nash Mining Construction Co., 2150 Kienlen Ave., St. Louis, MO 63121

MC CURDY, JOHN, Asst. Plant Supt, Inland Steel Coal Co., Box 566, Sesser, IL 62884

MC DANIEL, O. KENNETH, Acct. Mgr., Amoco Oil Co., 2825 W. Briarcliff Ln., Peoria, IL 61604

MC DOWELL, NEAL A., Sales Rep., Rudd Construction Equipment Co, Inc., Box 3935, Evansville, IN 47737

MC GINNIS, JOHN S., V. Pres., Sales, Ingersoll-Rand Mining Machinery Group, R.R. 3, Box 70, Cedar Bluff, VA 24609

MC GREEVY, WM. E., Sales Mgr., Roland Machinery Co., 816 Dirksen Pky, Springfield, IL 62708

MC KEE, LARRY E., Engr., Bixby-Zimmer Engineering Co., 961 Abingdon St., Galesburg, IL 61401

MC KELVEY, BOB, Proj. Engr., Old Ben Coal Co., 208 Patricia Ln., West Frankfort, IL 62896

MC KINNEY, HAROLD LEE, Sales Rep., Pace International Corp., Box 2586, Carbondale, IL 62902

MC LAIN, JOHN C., Arch Mineral Corp., 200 N. Broadway, St. Louis, MO 63102

MC LANAHAN, MICHAEL W., Sales Mgr., Mc Lanahan Corp., 200 Wall Street, Hollidaysburg, PA 16648

MC NALLY, R. PATRICK, C. L. Smith Industrial Co., 1311 S. 39th St., St. Louis, MO 63110

MC NULTY JR., JAMES E., V. Pres., Paul Weir Co., 20 N. Wacker Dr., Chicago, IL 60606

MC WHORTER, P. L., V. Pres., Sales & Mktg., Jeffrey Mining Machinery Div., Dresser Ind., Box 1879, Columbus, OH 43216

MC WILLIAMS, ARCHIE, Shop Mgr., General Electric Co., 151 Fisher Ct., Eldridge, IA 52748

MEANS, LARRY D., Mgr. Tech. Serv. Engr., Wire Rope Corporation of America, Box 350, 609 N. 2nd St., St. Joseph, MO 64502

MEDLEY, JACKSON, V. Pres., Engr., Kress Corp., Box 368, Brimfield, IL 61517

MEIER, DANA G., Sr. Proj. Engr., AMAX Coal Co., Inc., Box 967, Indianapolis, IN 46206

MEISTER, WILLIAM G., Geologist Engr., Turris Coal Co.,Box 21,Elkhart,IL 62634

MEKELBURG, THOMAS, Head of Product Quality, Monterey Coal Co.,Box 496 (Headquarters Office), Carlinville, IL 62626

MELCHOR, M. JOSEPH, Gunther-Nash Mining Construction Co., 2150 Keinlen Ave., St. Louis, MO 63121

MELLERT, ROBERT M., Engrg. Asst., Freeman United Coal Mining Co., Box 570, Canton, IL 61520

MELVIN, BURTON, M.A.T. Industries, Inc,Franklin Cnty Industrial Park,Box 454, West Frankfort, IL 62896

MELVIN, RICHARD E., Pres., M.A.T. Industries, Inc., Franklin County Industrial Park, Box 454, West Frankfort, IL 62896

MELVIN, ROBERT L. (BOB), State Mine Inspector, IL Dept. of Mines & Minerals, R.R. 1, Box 336, West Frankfort, IL 62896

MESSMER, JERRY, Centrifugal & Mechanical Industries, Inc., 146 President St., St. Louis, MO 63118

METZGER, DAN R., Pres., D. R. Metzger,Inc.,475 W. 55th St.,La Grange,IL 60525

METZROTH, LARRY, Arch Mineral Corp., 200 N. Broadway, St. Louis, MO 63102

*MICHAEL, DAVID G., Vice President, Gen. Mgr., Michael-Walters Industries, Inc., Box 34066, Louisville, KY 40232

MICHAEL, GLEN E., Sales Mgr., DQI Supply, R.R. 2, Box 261, Pana, IL 62557

MIDGETT, DON, Sales, Gauley Sales Co., Box 312, Marion, IL 62959

MILES, GARY (JACK), Sales Mgr.,Sasser Electric Co,Box 622,Wytheville,VA 24382

MILLER, DAVID B., Sr. Planning Engr., AMAX Coal Co., Inc., Box 967, Indianapolis, IN 46206

MILLER, DEAN, T. J. Gundlach Machine Div., Rexnord, Inc.,Box 385, Belleville, IL 62864

MILLER, DONALD, Supt., Joy Manufacturing Co., 3201 Jamison Blvd., Mt. Vernon, IL 62864

MILLER, JOHNNY, Chief Engr., Construction & Mining Services, Box 2086, Fairview Heights, IL 62208

MILLER, LOUIS V., Chemist, IN Geological Survey, 611 N. Walnut Grv., Bloomington, IN 47401

MILLER, RANDY B., Electrical Engr., Inland Steel Coal Co., R.R. 1, Box 74, Waltonville, IL 62894

MILLER, RICHARD, Mgr., Marcal Rope & Rigging, Box 477, Alton, IL 62602

MILLER, RICK, Sales, Mohler Armature & Electric, Inc.,RR 1,Lynnville,IN 47619

MILLER, PERRY F., Sales Mgr., Guyan Machinery Co., Box 150, Logan WV 25601

MILLER JR., R. G., Pres., Roberts & Schaefer Co., 120 S. Riverside Plz., Chicago, IL 60606

MILLER SR., MARCUS, Drilling-Blasting Superv.,AMAX Coal Co.,Inc,1020 E. Gate, Marion, IL 62959

MILLIGAN, EMERY, Pres., Elem Corp., 805 S. Aikman St., Marion, IL 62959

MILLIGAN, GARY, Plant Foreman, Sahara Coal Co., Inc., 1004 E. Gregory, Marion, IL 62959

MINER JR., JAMES A., Pres., Kerco, Inc.,Drawer 665, Madisonville, KY 42431

MINOR, LINDELL R., Serv. Superv., Ingersoll-Rand Mining Machinery, Box 596, Benton, IL 62812

MINTON, JAMES M., Mine Surveyor, Old Ben Coal Co., 500 N. Du Quoin St., Benton, IL 62812

MISSAVAGE, ROGER J., Dir. Computer Aided Res. & In, Southern IL University, Carbondale, 207 S. 7th St., Herrin, IL 62948

MITCHELL, CARL W., Sales, Austin Powder Co., Rt. 4, Box 220, Marion, IL 62959

MITCHELL, CHAS. ROBERT(BOB), Mgr Purch & Engrg Serv, Inland Steel Coal Co., Box 566, Sesser, IL 62884

MITCHELL, ED, Sales, Ajax Engineering Co., Box 409, Shawneetown, IL 62984

MITCHELL, JOHN D., State Mine Inspector, IL Department of Mines & Minerals, 218 Elm St., Zeigler, IL 62999

MITCHELL, R. W., Mgr., Engrg., Kerr-Mc Gee Coal Corp., Box 25861, MT-202 Oklahoma City, OK 73126

MITCHELL, WILLIAM G (BILL),Sales Mgr.,Missouri-Illinois Tractor & Equip. Co., 5920 N. Lindbergh Blvd., Hazelwood, MO 63042

MOESER, AL, Mktg. Mgr., Mng., Victaulic Co. of America, 5232 E. Maplewood Pl. Littleton, CO 80121

MOFFETT, PHILIP J., WI Power & Light Co., 222 W. Washington, Madison,WI 53700

MOHLER, SCOTT, Pres., Mohler Armature & Electric, Inc., 2355 Eby Rd., Boole, IN 47601

MOHLER, WILLIAM A,Mohler Armature & Electric Inc.,2355 Eby Rd.,Bille,IN 47601

MOLISKE, LAVERN, Chief Belt Foreman,Freeman United Coal Mining Co.,Crown III, 1206 Roosevelt Rd., Taylorville, IL 62568

MONARCH, DENNIS D., Sales Rep., Gooding Rubber Co., Box 477, Benton,IL 62812

MOODY, G. G. (GREG), Maintenance Supt., Monterey Coal Co., R.R. 2, Box 42C Gillespie , IL 62033

MOODY, GARY W., Purchasing Agent,Midland Coal Co.,Box 159,Farmington,IL 61539

MOONEYHAM, ROBERT, Instructor, Rend Lake College,RR 2,Box 289,West Frankfort, IL 62896

MOORE, JOHN R., Asst. Supt.-Maintenance, Inland Steel Coal Co.,804 Water St., Johnston City, IL 62951

MOORE, MARVIN R., AMAX Coal Co., Inc., Wabash Mine,Box 144,Keensburg,IL 62852

MORAN JR., E. S., Sr. Vice Pres., Lively Mfg. & Equip. Co,Box 339,Glen White, WV 25849

MORELAND, FLOYD C., Sales Engr., Mc Nally Pittsburg, Inc., Box 235, Evansville, IN 47702

MORGAN, BEN, Sales, J. Schonthal Assoc., Inc., 411 E. Main St., Morganfield, KY 42437

*MORGAN, GEORGE H., Hydraulics Div., Brake Supply, 309 Springhaven Dr., Evansville, IN 47710

MORGAN, JAMES L., Du Quoin Iron & Supply Company, Box 181, Du Quoin, IL 62832

MORGAN, JOHN D., 420 W. Mill St., Girard, IL 62640

MORGAN, JOHN H., Geologist, Box 36, West Frankfort, IL 62896

MORGAN, MARK D., Supt.-Maintenance, Mine #1, Inland Steel Coal Co., Box 566, Sesser, IL 62884

MORGAN, RICHARD E., Regional Sales Mgr., V. R.-Wesson Div., Fansteel, Inc., Box 11399, Lexington, KY 40501

MORLOCK, R J, Pres.,Commerical Testing & Engineering Co, 1919 S Highland Ave, Suite 210-B, Lombard, IL 60148

+*MORONI, E. T.(GENE),(Retired), Old Ben Coal Co., Box 477, Herrin, IL 62948

MORRILL, DAVID S., Freeman United Coal Mining Co., R.R. 4, 213 Lawndale Ct., Metamora, IL 61548

MORRIS, GEORGE, Sr. Proj. Engr., Peabody Coal Co., R.R. 3,Nashville,IL 62263

MORRIS JR., GEORGE, Asst. to Pres., Midwest Mining, Knellis Energies, Inc., 617 E. Church St., Harrisburg, IL 62946

MORSE, JAMES (JIM), Sales Engr., Gardner-Denver Mining & Construction,Box 58, Florissant, MO 63032

MORSE, KENT, Sales, Bruening Bearings, Inc., 2703 E. Broadway, Alton,IL 62002

MORSE, RONALD E., Safety Dir.,Sahara Coal Co.,Inc,Box 330,Harrisburg,IL 62946

MORTON, HARRY C., Sr. Staff Advisory,Monterey Coal Co.,307 E. 1st. South St., Carlinville, IL 62626

MOSELEY, CLAYTON, Kerco, Inc., P.O. Drawer 665, Madisonville, KY 42431

MOSS, HERSCHEL, Truck & Mine Supply, Inc., Box 4438, Evansville, IN 47711

MOTTERSHAW, DICK, Safety Coordinator, Monterey Coal Co., 205 Oakland Ave., Carlinville, IL 62626

MOTTET, JAMES L., Sr. Planning Engr., AMAX Coal Co., Inc.,Delta Mine,Box 167, Marion, IL 62959

MOUSER, H. D., President, Mine Equip. & Mill Supply Co., R.R. 1, Box 79, Dawson Springs, KY 42408

MUELLER, JEFFREY D., Engrg. Mgr., Leahy Mine, AMAX Coal Co., Inc., Box 165, Campbell Hill, IL 62916

MULHERN, JAMES M., Sr. Engr., Monterey Coal Co., P.O. Box 496, Carlinville, IL 62626

MULLINAX, CHARLES R., General Mgr., Henry A. Petter Supply,2800 Broadway St., Paducah, KY 42001

MULLINS, W. H., Vice President, Engineer, Freeman United Coal Mining Company, 1019 Election Dr., Benton, IL 62812

MULLINS, LEONARD C., Serv., National Mine Service Co., R.R. 4,Benton,IL 62812

MULLINS, RICHARD A., (Retired), R.R. 4, Box 48, Princeton, IN 47670

MULLINS JR., HENRY S., Sales Engr., Dosco Corp., 1020 N. Eisenhower Dr., Beckley, WV 25801

MURPHY, E. LOUIS, 74 Quail Valley, Princeton, WV 24740

MURPHY, JOHN D., V. Pres., Alloy Sling Chains, Inc., 1416 W. 175th St., E. Hazelcrest, IL 60429

MURPHY, LAWRENCE V., Sales Rep., Sligo, Inc.,5 Book Ln.,Jacksonville,IL 62650

MURPHY, JOE, Foreman, Capitol Machinery Co.,Inc,Box 2008,Springfield,IL 62705

MURRAY, FREDERICK N., Consultant, 3734 E. 81st Pl., Tulsa, OK 74136

MURRAY, MICHEAL D., Esco Corp., 1017 Griggs St., Danville, IL 61832

MURRAY, ROBERT E., Exec. V. Pres.-Operations, North American Coal Corp., 12800 Shaker Blvd., Cleveland, OHIO 44120

MURRAY, WILLIAM, Dir., Underground Mng., Kerr-McGee Coal Corp., Box 25861, Oklahoma City, OK 73126

MUSCARELLO, FRANK G., Sales Mgr., Anixter Bros., 2230 Brummel Pl., Evanston, IL 60202

NAIRN, JAMES P., Staff Geologist, Gai Consultants, Inc., 570 Beatty Rd., Monroeville, PA 15146

[illegible] B., Geologist,Freeman United Coal Mining Co,Box 1587,Mt. Vernon, [illegible]

NASH, BILL, Supt., Coal, Inc., R.R. 3, Linton, IN 46149

NEEDHAM, BOB, Parts Mgr., Capitol Machinery Co., Inc., Box 2008, Springfield, IL 62705

NELSON, THOMAS D.,Dir. of Commerical Dev.,Inland Steel Coal Co.,30 W. Monroe, Chicago, IL 60603

NELSON, W. JOHN, Associate Geologist, IL State Geological Survey, 615 E. Peabody Dr., Champaign, IL 61820

NEMECEK, MONA L., Geologist, AMAX Coal Co., Inc., 4849 Hillside Ave., Indianapolis, IN 46205

NERI, E. D., Electrical Engr., Monterey Coal Co.,Box 496,Carlinville,IL 62626

NEUBAUER, ROBERT J., V. Pres., Coal, IL Central Gulf Railroad, 233 N. Michigan Ave., Chicago, IL 60601

NEWMAN, FREDERICK G., Consulting Geologist,R.R. 1,Box 151A,Gillespie,IL 62033

NICHOLSON, HAROLD (NICK), Sales,Reaco Battery,Rt. 1, Hwy. 37 S.,Johnson City, IL 62951

NIEBRUEGGE, PAUL E., Sales, Helwig Carbon Products, Inc.,2 Glen Crossing Rd., Edwardsville, IL 62025

NIELSEN, BILL, Sales Rep., Giles Armature & Electric Works, Inc., Box 70, Marion, IL 62959

NOEL, WILLIAM, Dist. Mgr., Long-Airdox Co., Box 479, Benton, IL 62812

NOEL JR., WILLIAM E., Sales Engr., National Mine Service Co,1329 Ritchey Dr., Marion, IL 62959

NORRIS, DALE W., Prep. Plant Mgr.,Kerr-Mc Gee Coal Corp,Galatia Mine,Box 727, Harrisburg, IL 62946

NORRIS, GENE, Pres., Mgr., Norris Screen & Mfg., Inc., 614 S. Wickham Ave., Princeton, WV 24740

+*NUGENT, FRANK, Chairman,Chief Exec. Officer,Freeman United Coal Mining Co., 300 W. Washington St., Chicago, IL 60606

NUGENT, JOHN T,Sales Mgr.,Freeman United Coal Mining Co,300 W Washington St., Chicago, IL 60606

NUTTER, THOMAS B., Head, Mng. Engrg., Monterey Coal Co., Box 496, Carlinville, IL 62626

NYSTROM, LEONARD T., Dist. Mgr., Okonite Co., 10411 Clayton Rd., Suite 309, Frontenac, MO 63131

O'BRYAN, DAVE, Consultant, R.R. 2, Box 376A, Linton, IN 47441

O'TOOLE, HAROLD A., Dist. Sales Mgr., Mach. Div., Camber Corp,7854 Owens Dr., Newburgh, IN 47630

OAKLEY, KENNETH W., Branch Mgr., Woodruff Supply Co., Inc., R.R. 1, Benton, IL 62812

OBERHELLMAN JR., T. A., V. Pres., Mktg., Stephens-Adamson, Inc,Ridgeway Ave., Aurora, IL 60507

ODLE, HAROLD E., Safety & Health Mgr., Kerr-Mc Gee Coal Corp., Galatia Mine, Box 727, Harrisburg, IL 62946

OETGEN, THOMAS L. (TOM), Freesen, Inc., Box 277, Bluffs, IL 62621

OGLESBY, DONALD D., Partner, Hanson Engineers, Inc., 1525 S. 6th St., Springfield, IL 62703

ORLANDI, WILLIAM T., Asst. to Supt.,Freeman United Coal Mining Co, Crown III, Box 716, Farmersville, IL 62533

ORLANDI, WILLIAM J., Carbon Coal Co., 124 S. Boardman, Gallup, NM 87301

ORTH, ED, Sales, Hicks Industrial Oils, Box 626, Pekin, IL 61554

OSWALD, ROBERT B., (Retired), Midland Coal Co.,5422 Greenmont,Peoria,IL 61614

OTT, ANDY K., Mine Mgr., Freeman United Coal Mining Co., 18 Helston Pl., Hillsboro, IL 62049

OTT, PHILIP R., Asst. to Supt., Freeman United Coal Mining Co., R.R. 2, Hillsboro, IL 62049

OWEN, DAVID R., Maintenance, Freeman United Coal Mining Co.,Crown III,R.R. 2, Box 183, Waverly, IL 62692

OYLER, JERRY, Warehouse Mgr.,Peabody Coal Co.,R.R. 2,Box 20,Freeburg,IL 62243

+PACE, E. MINOR,(Retired),Inland Steel Coal Co.,700 Lake Park Dr.,Mt. Vernon, IL 62864

PACKARD, CHARLES E., V. Pres., Sales, Mc Nally Pittsburg Manufacturing, Inc., Drawer D, Pittsburg, KS 66762

PADDOCK JR., FREDERICK W., Reg. Manager. Engineer, Consolidation Coal Co., 12755 Olive Blvd., St. Louis, MO 63141-6267

PADGETT, JEFFREY T., Sr. Geologist, Monterey Coal Co., Box 496, Carlinville, IL 62626

PALMER, JAMES E., Sigma Consultants, Box 1035, Mattoon, IL 61938

PALMER, K. W., 2321 Dodge Dr., Daytona Beach, FL 32018

PARKER, NEAL M., V. Pres., Explor. & Devel., Arch Mineral Corp., 200 N. Broadway, St. Louis, MO 63102

PARKINS, RICHARD S.,Sr Proj Engr,Old Ben Coal Co,RR 2,Box 142,West Frankfort, IL 62896

PARSON, JOHN H., Sales Engr., Durex Products, Inc., 2800 Algoma Ter., Waukesha, WI 53186

PATALSKY, RAY M., Staff Engr., LTV Steel Corp., 6801 Brecksville Rd., Independence, OH 44131

PATE, CHARLIE, Safety Superv., Monterey Coal Co., 104 Lakeview Dr., Carlinville, IL 62626

PATE, ROBERT, Inspector at Large, 1 Lexington Manor, Harrisburg, IL 62946

PATTERSON, W. TOM, V. Pres., White County Coal Corp., Box 152,Carmi,IL 62821

PATTON, KENNETH R., Sales, Mainline Power Products Co,Box 306,West Frankfort, IL 62896

PAYNE, H. ELKINS, Sr. V. Pres., AMAX Coal Co., Inc., Box 967, Indianapolis, IN 46206

*PEABODY JR., STUYVESANT, Pres., Willson Hardware Co., 1649 N. Military Trl., W. Palm Beach, FL 33406

PEACH, LANNY, Surf. Foreman, AMAX Coal Co., Inc., Wabash Mine, Box 144, Keensburg, IL 62852

PECORI, SERGIO, Assoc. Partner, Hanson Engineers, Inc., 1525 S. 6th St., Springfield, IL 62703

PENSONEAU, TAYLOR, V. Pres., IL Coal Association, 212 S. 2nd St., Springfield, IL 62701

PEPPERS, RUSSEL A., Geologist, IL State Geological Survey,615 E. Peabody Dr., Champaign, IL 61820

PERIGO, LEE, Sales Engr.,C L Smith Industrial Co,1311 S. 39th St.,St. Louis, MO 63110

PERKS, ALAN V., Peabody Coal Co., TSM Central Shop, IL Div. E. E., R.R. 2, Box 85, Marissa, IL 62257

+PERRINE, NATE G., Pres., Nate Perrine Sales Co., P.O. Box 481, Collinsville, IL 62234

PERRY, ROD, V. Pres., Senior Conflow, Box 265, Clinton, PA 15026

PERTILE, R. K., V. Pres., Operations, Turris Coal Co.,Box 21,Elkhart,IL 62634

PETERS, DAVE, Sales, Capitol Machinery Co., Inc., P.O. Box 2008, Springfield, IL 62705

PETERS, JOHN W., Sr Staff Engr,Kerr-Mc Gee Coal Corp,Box 25861,Oklahoma City, OK 73126

PETERSON, PATRICK J., Ventilation Engr., Freeman United Coal Mining Company, 1515 Dodds, Mt. Vernon, IL 62864

PETTER, ROBERT P.(BOB),V. Pres.,Gen. Mgr.,Henry A. Petter Supply Co,Box 2350, Paducah, KY 42001

PETTIT, LARRY G., Sales, Royal Brass & Hose Co., Hwy. 37 N., Benton, IL 62812

PFIFER, JAMES L., Staff Mng. Engr,Kerr-Mc Gee Coal Corp,Galatia Mine,Box 727, Harrisburg, IL 62946

PFINGSTEN, CHARLES R, V. President,Western Diesel Services,1424 Ashby Rd., St. Louis, MO 63132

PHIFER, STEVEN C., Proj. Engr., Freeman United Coal Mining Co., 605 E. Henry, Staunton, IL 62088

PHILLIPS, GIL, Sales & Serv., MEMCO, 2304 Industrial Dr., Mt. Vernon,IL 62864

PIERCE, FRANK, Asst. Shift Mine Mgr., Monterey Coal Co., 1522 Main St., Highland, IL 62249

PIERPOINT, CHARLES H., Conn-Weld Industries, Inc., Rt. 1, Woodlawn, IL 62898

PINNELL, THOMAS W., State Mine Inspector,IL Dept. of Mines & Minerals,Box 73, Farmersville, IL 62533

PISANESCHI, PETER R., Monterey Coal Co., Box 496, Carlinville, IL 62626

PITCHFORD, ROBERT, Belt Boss, Freeman United Coal Mining Co., Box 66, Thayer, IL 62689

PITROLO, EDWARD R., Engrg. Coordinator, Monterey Coal Co., Box 496, Carlinville, IL 62626

PLEASANT, JAMES T, Sales, Line Service Co., Rt. 1, Box 298-C, Hwy. 41 N., Madisonville, KY 42431

PLUCIENIK, JERRY, Midwest Steel Div., Box 1243, Granite City, IL 62040

PLUMMER, EARL, Sales & Mktg. Mgr., Bridon American Corp., R.R. 3, Box 67, Oakland City, IN 47660

*POLING, GILBERT, Pres., Evansville Elec. & Mfg. Co., 600 W. Eichel Ave., Evansville, IN 47707

POLINO, SAMUEL G., Mng. Engr.,Zeigler Coal Co,606 Cypress Ln.,Sparta,IL 62286

POLITO, MARCO A., V. Pres., Sales, B. P. Tracy Co., 919 Fulton St., Pittsburgh, PA 15233

POLLACK, TOM, Associated Supply Co., 200 S. Taft St., West Frankfort,IL 62896

POND, ROBERT A,Frontier-Kemper Constructors,Inc.,Box 6548,Evansville,IN 47712

POOR, BOB L., Sales, Du Quoin Iron Supply Co., Box 181, Du Quoin, IL 62832

POPP, JOHN T., Acquistions Geologist, NERCO Coal Co., 4225 Malsbary Rd. , Cincinnati, OH 45242-5509

POTTS, RUSSELL A., Monterey Coal Co., 702 W. Jefferson, Auburn, IL 62615

POUNDSTONE, SCOTT L., Regional Sales Mgr.-Equip.,Robert & Schaefer Company, 120 S. Riverside Plz., Chicago, IL 60606

POWELL, RICHARD E. (RICH), Dir. of Permitting, Arch of Illinois, Inc., Captain Mine, Percy, IL 62272

POWELL JR., MAX, V. Pres., Mktg.,Long-Airdox Co.,Box 640,Mt. Vernon,KY 40456

PRATHER, LARRY, Gen. Mine Mgr., AMAX Coal Co.,Inc.,Box 144,Keensburg,IL 62852

PRESLER, DONALD P., Sales Rep., Oberjuerge Rubber Co., Box 519, St. Louis, MO 63166

PRICE, CHARLES E., Mine Mgr., Monterey Coal Co., Box 496,Carlinville,IL 62626

PRICE, JOHN D., Maintenance Foreman, Peabody Coal Co., R.R. 2, Box 166, Coulterville, IL 62237

PRICE, SUSAN A.,Admin. Superv.,Monterey Coal Co.,Box 496,Carlinville,IL 62626

PRITCHARD,MICHAEL, Engr.,Old Ben Coal Co.,500 N. Du Quoin St.,Benton,IL 62812

PRUDENT, JOHN E., Supt., Mine #1,Inland Steel Coal Co,Box 566,Sesser,IL 62884

PRUNTY JR., M. E.,Exec. V. Pres.,Roberts & Schaefer Co,120 S. Riverside Plz.,
Suite 500, Chicago, IL 60606

PTASNIK, LEE, Mine & Process Service, Inc., Box 484, Kewanee, IL 61443

PUKALL, CRAIG,Sales Rep,Ingersoll-Rand Mining Machinery,Box O,Benton,IL 62812

PURDY, KENNETH H.,Sales,Mine Equipment & Mill Supply Co,520 Meadows Hill Dr.,
Dawson Springs, KY 42408

QUENON, ROBERT H., President, Peabody Holding Company, Inc., 301 N. Memorial,
St. Louis, MO 63102

RAETZ, RON, Mine Supt., Peabody Coal Co., River King U/G #1, R.R. 2,Box 260R,
Freeburg, IL 62243

RAJARAM, DR. V., Mgr. Mng., Engineers International Inc,98 E. Naperville Rd.,
Westmont, IL 60559-1595

RAMER, RALPH W., Pres., Screenco, Inc., 3003 Brainard Rd.,Pepperpike,OH 44124

RAMSEY, P. DOUG, Engr., Sahara Coal Co., Inc., Box 330, Harrisburg, IL 62946

RANZ, FRANK, Engr. Mgr.,Roberts & Schaefer Co.,120 S. Riverside Plz.,Rm. 500,
Chicago, IL 60606

RASSEL, PAUL J., Sales, Ford Steel Co., 2684 Waterford Ct., Aurora, Il 60505

RAY, JAMES S., Sales, Bruening Bearings, Inc., Box 3159, Paducah, KY 42001

RAY, STEVEN D., Accounting & Serv. Head, Monterey Coal Co., 109 Bradley Dr.,
Carlinville, IL 62626

REA, RICHARD, Sr. Coal Prep. Engr., Old Ben Coal Co., 500 N. Du Quoin St.,
Benton, IL 62812

READY, DALE, Owner, Ready Drilling Co., R.R. 1, Box 201B, Mason, IL 62443

REED, CHARLES E. (CHUCK),V. Pres.,Kerco,Inc.,Drawer 665,Madisonville,KY 42431

REED, KERT E., Secy.-Treas., Kerco, Inc., Drawer 665, Madisonville, KY 42431

REES, BEN H., Sales, Rees Mine Supply Sales, Inc.,Box 296, Du Quoin, IL 62832

REIDELBERGER, BYFORD CARL, Supt., Zeigler Coal Co., Box 72, Murdock, IL 61941

REILLY, MICHAEL K., Pres., Zeigler Coal Co., Box 66913,A.M.F. O'Hare,IL 60666

REINERTSEN, DAVID L.,Geologist,IL State Geological Survey,615 E. Peabody Dr.,
Champaign, IL 61820

REISINGER, RICHARD W., Mng. Engr., Peabody Coal Co., 2804 West Blvd., Apt. 5,
Belleville, IL 62221

RENNER, RAY, 305 Oliver Lee Dr., Belleville, IL 62223

REQUARTH, DAVID L., Foreman, Peabody Coal Co., RR 2,Box 17,Edinburg,IL 62531

RESNIK, WILLIAM L,Sales Rep,Pattin-Marion Div.,Eastern Co.,1003 S. Court St., Marion, IL 62959

REYNOLDS, JACK E,Mgr.,Illinois Bearing Co.,1620 Hubbard Ave.,Decatur,IL 62526

REYNOLDS, ROBERT J., Sr. Geologist, AMAX Coal Co., Inc., 3323 Rex Dr., N., Indianapolis, IN 46222

RHOADES, R. (DICK), Mgr., Conoco, Inc.,101 E. Plaza Blvd.,Evansville,IN 47715

RHODES, GARY WAYNE, Civil Engr.,Law Engineering Testing Co, 2749 Delk Rd, SE, Marietta, GA 30067

RHODES, JOHN T., Div. Mgr., Gauley Sales Co., 807 W. 11th St., Johnston City, IL 62951

RHODES, THOMAS P.,Prep. Engr.,Georgia Iron Works Co,Inc,400 N. Michigan Ave., Belleville, IL 62221

RHYE, WAYNE, Gen. Supt., White County Coal Co.,Box 62, Providence,KY 42450

RICE, FRED, Eastern Underground Div., Peabody Coal Co., Box 1981, Henderson, KY 42420

RICE, ROBERT D., #1 Mine Resident Engr., Monterey Coal Co.,Box 496, Carlinville, IL 62626

RICE, THOMAS F., Mine Mgr., Monterey Coal Co., 456 E. 3rd, Trenton, IL 62293

RICHTER, LANNY LEE, Mgr.-Mng. Engrg., Old Ben Coal Co., 333 W. Vine St., Lexington, KY 40507

RICHTER, PAUL T., Dist. Mgr,Mine Safety Appliances Co,2053 Congressional Dr., St. Louis, MO 63141

RIGNEY, LEVI E., Mgr. Operations, AMAX Coal Co., Inc., 7938 Sunfield Ct., Indianapolis, IN 46224

RIPOLI, DOMINICK J., Mine Engr., Inland Steel Coal Company, 2910 Lime St., Mt. Vernon, IL 62864

RIPPE, PETER J., National Accounts Manager, American Cyanamid Company,Box 14, Oak Hill, WV 25901

RITCHEY, JAMES A., Foreman, Freeman United Coal Mining Co., 713 E. Dean, Virden, IL 62690

RIVA, RUDY, Foreman, Freeman United Coal Mining Co., Box 190,Kincaid,IL 62540

ROACH, DAVE, Sales, Jeffrey Manufacturing Div., 207 E. Elm,Gillespie,IL 62033

ROBARE, PHILLIP, System Support Analyst, Apollo Computer Inc.,Woodfield Lake, Suite 334, Schaumburg, IL 60195

ROBERTS, E. E. (GENE), Dist. Engr., Continental Conveyor & Equip. Company, 5455 Jeffries Ln., Newburgh, IN 47630

ROBERTS, E. H., Mgr., Mines, Inland Steel Coal Co., Box 566, Sesser, IL 62884

ROBERTS, GARY A., Vice President, Sales, Freeman United Coal Mining Company, 300 W. Washington, Chicago, IL 60606

ROBERTS, GORDON L., Mine Supt., Monterey Coal Co., Box 94, Albers, IL 62215

ROBERTS, KEITH, Safety Engr., Kerr-Mc Gee Coal Corp., Galatia Mine, Box 727, Harrisburg, IL 62946

ROBINETTE,LARRY,Mine Tech,Turris Coal Co.,Box 153,Williamsville,IL 62693-0153

ROBINSON, CHARLES E., Nalco Chemical Co., 3006 Taylor Ave., Apt. 55, Springfield, IL 62703

ROBINSON, CHAS. L., Operations Planning Coord., Monterey Coal Co., Box 94, Albers, IL 62215

ROBINSON, DENNY, Chief Electrician, Peabody Coal Co., R.R. 2, Box 213, Freeburg, IL 62243

ROBINSON, LEROY, State Inspector, State of IL, R.R. 1, Box 289, Carterville, IL 62918

ROBINSON,ROBERT A,Proj. Engrg.Geologist,Shannon&Wilson Inc.,1105 N. 38th St., Seattle, WA 98103

ROESCH, JOSEPH A., Sales, Mississippi Lime Co., 7 Alby St., Alton, IL 62002

ROHDE, CHUCK, Dist. Mgr., Long-Airdox Co., 2813 Lime Ave.,Mt. Vernon,IL 62864

ROLAND, EARL, PRES., Roland Machinery Co., Box2879, 816 N. Dirksen Pky., Springfield, IL 62708

ROLAND, RAYMOND E., Roland Machinery Co., Box 2879, 816 N. Dirksen Pky., Springfield, IL 62708

ROLAND, W. D., Sales, Mc Junkin Corp., 802 S. Adams, Henderson, KY 42490

ROLL, JOHN L., Reclamation Engr., Freeman United Coal Mining Co., Box 570, Canton, IL 61520

ROLLINSON (PHEE), JANE A., Sales Repr., Central Petroleum Co., Box 506, Centralia, IL 62801

RONAN, JOHN, Proj. Engr., Old Ben Coal Co., 500 N Du Quoin St,Benton,IL 62812

ROPER, ROGER D., Mgr. of Ventilation,Zeigler Coal Co,Mine #5,Murdock,IL 61941

ROPER, WILLIAM D., Sr. Engineer, Peabody Coal Company, 50 Jerome Lane, Fairview Heights, IL 62208

ROSEN, JIM, Susman Wiping Materials Co,420 E. De Soto Ave, St. Louis,MO 63147

ROSEN, MARK, Pres., Susman Wiping Materials Co,420 E. De Soto Ave.,St. Louis, MO 63147

ROSKO, RONALD, State Mine Inspector, IL Dept. of Mines & Minerals, Box 216, Witt, IL 62094

ROTHLUEBBERS, ROBERT, Sales, Johnson Screens, R.R. 2, Box 147, Coulterville, IL 62237

ROWE, BRUCE G., Mine Inspector, Inland Steel Coal Co,RR 4,Mt. Vernon,IL 62864

ROWLAND, STEVE S., Mine Supt., Kerr-Mc Gee Coal Corp., Galatia Mine, Box 727, Harrisburg, IL 62946

ROWLEY, GERALD, Asst. Storekeeper, Peabody Coal Co., 100 E. Vine, Taylorville, IL 62568

ROWNEY, CLYDE E., Safety Superv., Monterey Coal Co., 739 Fort Henry Dr., Belleville, IL 62221

RUCH, RODNEY R., Chemist, IL State Geological Survey, 615 E. Peabody Dr., Champaign, IL 61820

RUCKMAN, GENE, O.T.R. Sales,Jake's Tire Co.,1001 N. Court St.,Marion,IL 62959

RUE, ORLIE J., Div. Ind. Engr,Central IL. Public Service Co,1800 W. Main St., Marion, IL 62959

RUFENBARGER, STEPHEN, Exec. V. Pres., Peabody ABC Corp,Box 77,Warsaw,IN 46580

RUFF, L. LEON, 1329 Medinah Ct., Winter Park, FL 32792

RUIZ, FRANK E., Project Engineer, Freeman United Coal Mining Co.,Box 100, West Frankfort, IL 62896

RUSAK, RICHARD S., Sales Rep., Rowe & Sons, Inc., 3005 W. Franklin Blvd., Chicago, IL 60612

RUSH, HAROLD E., AMAX Coal Co., Inc., 1203 Hawkins Rd., Fairfield, IL 62837

RUSSELL, SUZANNE J., Shell Oil Company, Box 60775, New Orleans, LA 70160

RUSSELL, TERRY, Counselor, Wabash Valley College, John A. Logan College Coal Mng. Tech., Carterville, IL 62918

RUSSELL, WILLIAM (BILL), Mgr., Line Service Co., Box 61,Madisonville,KY 42431

RYAN, CHUCK, Sales, Mine Safety Appliances Co., 1940 S. Pasfield, Springfield, IL 62704

RYAN, PATRICK M., Dir. Health & Safety, AMAX Coal Co., Inc., Box 967, Indianapolis, IN 46206

*RYAN JR., J. T.,Chairman of Board, Mine Safety Appliances Company, 600 Penn. Center Blvd., Pittsburgh, PA 15235

SADLER, THOMAS B., R.R. 2, Benton, IL 62812

SAILLIEZ, GASTON, Warehouse, Truck Driver, V. R.-Wesson Div., Fansteel, Inc., 408 W. St. Louis St., West Frankfort, IL 62896

SALANSKI, CHARLES W., Executive Vice President, Leschen Wire Rope Company, Box 407, 609 S. Second St., St. Joseph, MO 64501

SANDERSON, RON, Rend Lake College, 422 W. 5th St., Benton, IL 62812

SANDUSKY, EARL E., Serv., Joy Manufacturing Co., Box 73, Benton, IL 62812

SARVER, CLARENCE, Pres., Sarco Mining Industry Service, Inc., RR 1,Box 121A, Litchfield, IL 62056

SASSER, LEWIS E. (PETE), Pres.,Sasser Electric Co,Box 622,Wytheville,VA 24382

SAVANT, JIM, Shift Maintenance Foreman, Monterey Coal Co., 610 North St., Benld, IL 62009

SAVKO, ROBERT R., Asst. Mine Mgr., Inland Steel Coal Co., 3520 Marlin Dr., Louisville, KY 40297

SAWYER, THOMAS H., Dist. Mgr., Ohio Brass Co., 211 Westernaire Dr., Marion, IL 62959

SCHAEFER, RICH, Sales Engineer, Ulmer Equipment Co. (Dezurik), 1554 Fenpark, St. Louis, MO 63026

SCHAEFER, RONALD W., Mng. Engr., Continental Bank, 231 S. La Salle St., Chicago, IL 60693

SCHAFER, ELMER E., Sales Rep.,Fairmont Supply Co.,702 N. Washington,Du Quoin, IL 62832

SCHAFFER, JEFF, Turris Coal Co., Coal 21, Elkhart, IL 62634

SCHERZER, H. WALTER, V. Pres., Columbia Quarry Co., Box 128,Columbia,IL 62236

SCHETTLER, WILLIAM A., Box 466, Sesser, IL 62884

SCHIEN, JOHN, Schien Body & Equipment Co., North on University, Box 229, Carlinville, IL 62626

SCHLAGETER, FREDERICK, Klein Armature Works, Inc., Box 426,Centralia,IL 62801

SCHLEMBACH, JAMES, Engr.,Monterey Coal Co,524 S. Oak St.,Carlinville,IL 62626

SCHMALACKER, A. E., (Retired), Bethlehem Steel Corp., 9200 Clydesdale Dr., St. Louis, MO 63126

SCHMIDT, WILLIAM (BILL), Sales, Ajax Engineering Co., Box 409, Shawneetown, IL 62984

SCHNAKE, STEVE, Chief Mng. Engr.,Zeigler Coal Co.,2700 River Rd.,Des Plaines, IL 60018

+*SCHONTHAL,JOSEPH,Pres., J. Schonthal & Associates, Inc., 807,Highland Park, IL 60035

SCHONTHAL JR., JOSEPH, Sales, J. Schonthal & Associates, Inc., Box 807, Highland Park, IL 60035

SCHOONOVER, CRAIG, Engr., Freeman United Coal Mining Co., 134 S. 17th St., Canton, IL 61520

SCHRECKENGOST, E. D., Schreckengost & Associates, 443 Knollcrest Dr., Galesburg, IL 61401

SCHUBA, RICHARD S., Conn-Weld Industries, Inc., Box 1238, Princeton, WV 24740

*SCHUBERT, R. R., Vigor & Billings (in care of), Box 1239, Ashland, KY 41101

SCHULTE, RICH, Sales Engineer ,C. L. Smith Industrial Co,1311 S. 39th St., St. Louis, MO 63110

SCHULTZBANK, DEAN N.,Client Serv. Mgr,Baker Engineering, Inc,1 E. Wacker Dr., 27th Floor, Chicago, IL 60601

SCHUM, GLENN L., Shop Foreman, Freeman United Coal Mining Co,2 West Lake Dr., Litchfield, IL 62056

SCHUTTE, JAMES,Mohler Armature & Electric,Inc,2355 Eby Rd.,Boonville,IN 47601

SCHWAGMEYER, BILL, V. Pres., Freesen, Inc., 111 West Port Plz., Suite 600, St. Louis, MO 63141

SCHWARTZ, HERBERT, Sales Rep., Mohler Armature & Electric, Inc.,2355 Eby Rd., Boonville, IN 47601

SCHWARTZ, JEFFREY R, Bethlehem Wire Rope, 278 Kettering Circle, Gibsonia, PA 15044-9323

SCHWENTKER, JOHN, Sales, Evansville Electric & Mfg. Co., Box 4717, Evansville, IN 47711

SCOTT, GARY,Associated Engineers III Inc,1201 S. 6th St.,Springfield,IL 62703

SCOTT, JAMES J., Scott Mts., Inc., Lecoma Star Rt., Box 36, Rolla, MO 65401

SCOTT, ROD, Renewal Parts Sales Mgr., Jeffrey Mining Machinery Div., Dresser Ind., Box 1879, Columbus, OH 43216

SEAGREN, ERIC H., Midwest Reg. Sales Mgr., Mud Cat Division, NCRS, Inc., 11901 Olive Blvd., Suite 310, St. Louis, MO 63141

SENSKY, CARMAN, Sales, Sanford-Day Co., Box 1511, Knoxville, TN 37901

SHACKLEFORD, HENRY, Gen. Mgr. Accts., Freeman United Coal Mining Co., R.R. 1, Box 265, Girard, IL 62640

SHAFER JR, HAROLD, Pres., Falcon Alloy Co., P.O. Box 827, Greenville,KY 42345

SHANNON, GARY, Dir., Business Devel.,Bendy Engineering Co,4260 Shoreline Dr., Earth City, MO 63045

SHARP, DWIGHT D., Prep. Plant Superv., Peabody Coal Co., R.R. 1, Box 101, Rochester, IL 62563

SHARP, JOSEPH E., Asst. Sales Mgr., Peabody Coal Co., Mine #10, Box 527, Shawneetown, IL 62984

SHARPE, CHARLES, Sales, Mine Safety Appliances Co,RR 2,Box 651,Creal Springs, IL 62922

SHEFFER, JERRY W., Construction Superv., Peabody Coal Co., R.R.2, Coulerville, IL 62237

SHELLCROSSLEE, G. E., Mgr., Drilling, Freeman United Coal Mining Co.,Box 570, Canton, IL 61520

SHELLEDY, ROSS, Proj. Engr., Peabody Coal Co., 6 Bramble Pt. Ct., Belleville, IL 62223

SHEPHERD, HARLEY H., Land Agent, Sahara Coal Co., Inc., 29 W. Mabel St., Harrisburg, IL 62946

SHERMAN, SANDY JEAN,Civil Engrg. Tech.,Army Corps of Engrs,Rock Island Dist., 1010 39th St., Apt. 11, Bettendorf, IA 52722

SHIELDS JR., MARVIN, Engr., Tabor Machine Co., Box 3037, Bluewell Station, Bluefield, WV 24701

*SHIMKUS, ERVIN L.,Safety Mgr., Peabody Coal Co., 44 Greentrail Dr., Chatham, IL 62629

*SHIMKUS, TONY, Legal Dept.,Peabody Coal Co., 111 White Dr., Marissa,IL 62257

SHINN, WAYNE, Sales, Varel Mfg. Co., 1329 102nd Ave., W., Duluth, MN 55808

SHOCKLEY, ALVA M., Sales,Michael-Walters Industries,Inc,Box M,Valier,IL 62891

SHOCKLEY, RICHARD R.,Chief Engr.,Inland Steel Coal Co,Box 566,Sesser,IL 62884

SHOCKLEY, VIRGIL (RED), Sales & Serv., Cincinnati Mine Machine Co., Box 711, Benton, IL 62812

SHUMATE, RICHARD F., Pemco Corp., 658 Audubon Dr., Evansville, IN 47715

SHUMATE SR., MACK H., V. Pres., Zeigler Coal Co., 2700 River Rd.,Des Plaines, IL 60018

SIDNEY JR., GEORGE L., Sales Engr., Mc Lanahan Corp., 200 Wall St., Hollidaysburg, PA 16648

SIGMUND, DALE E, Pres., Sligo, Inc., Box 171, 140 E. Prairie Ave., St. Louis, MO 63166

SILER, P. RON, V. Pres., Engrg. & Planning, MAPCO Coals, Inc., 2365 Harrodsburg Rd., Suite B250, Lexington, KY 40504

SILEVEN, G. DENNIS, Instructor, Wabash Valley College, R.R. 1,West Frankfort, IL 62896

SILVERMAN, MARC S., Mgr.-Explor. & Geology, Peabody Development Co., 301 N. Memorial Dr., St. Louis, MO 63102

SIMMONS, JOE, Asst. Office Mgr., Sahara Coal Co., Inc.,Box 330, Harrisburg, IL 62946

+SIMON, JACK A., (Retired), IL State Geological Survey, 615 E. Peabody Dr., Champaign, IL 61820

SIMONELLI, JOHN, Michael-Walters Industries, Inc., P.O. Box 176, Providence, KY 42450

SIMONELLI, JOHN, Distillate Distributor, Michael-Walters Industries, Inc., Box 34066, Louisville, KY 40232

SINGH, MADAN M., Pres., Engineers International, Inc., 98 E. Naperville Rd., Westmont, IL 60559-1595

SINHA, A. K., Assoc. Prof., Southern IL University, College of Engineering & Technology, Carbondale, IL 62901

SINK, BARRY F., Proj. Engr., Old Ben Coal Co,501 Mitchell St.,Benton,IL 62812

SINNOTT, WILLIAM T., Purchasing Head, Monterey Coal Co., Box 469, Carlinville, IL 62626

SISSON, LEROY, Gen. Mine Mgr., Inland Steel Coal Co., Mine #2, R.R. 4, Mt. Carmel, IL 62863

SIUDYLA, CONRAD, Illinois Power Co., 500 S. 27th St., Decatur, IL 62525

SKELTON, HOMER, Dowell Div., Dow Chemicals Co., Box 31, Mt. Carmel, IL 62863

SKELTON, LOWELL, Sales, Fabick Machinery Co., Box 166, Marion, IL 62959

SLACK, CLAYTON F., V. Pres., CLUES Corp., Box 999, Carbondale, IL 62901

SLOAN, WALTER E., Cincinnati Mine Machinery Co., 2980 Spring Grove Ave., Cincinnati, OH 45225

SLYGH, PHILIP L., Sales Engr., Ajax Engineering Corp., Box 409, Shawneetown, IL 62984

SMALL, JAMES L., Sales Mgr., Hendrick Screen Co., Box 360, Owensboro,KY 42302

SMAY, BYRON K., Account Mgr., Allis-Chalmers Corp., 10733 Sunset Office Dr., 259, St. Louis, MO 63127

SMITH, DANNY L., V. Pres., Sales, Central States Industries, Inc,24 Wren Pl., Beckley, WV 25801

SMITH, JAMES (JIM), Sales Engr., Cummins Mid-States Power, Inc., Box 348, Normal, IL 61761

SMITH, LARRY E., Sales, Kennametal, 207 S. Victor St., Christopher, IL 62822

SMITH, SONNY, S & S Distributors, Box 186, Farina, IL 62838

SMITH, WILLIAM A., P. E., Paul Weir Co., 20 N. Wacker Dr., Chicago, IL 60606

SMITH, WILLIAM C., Safety Superv., AMAX Coal Co., Inc., R.R. 2, Colchester, IL 62326

SMITH, WILLIAM C., Refuse Engr., Monterey Coal Co., Box 94, Albers, IL 62215

SMITH, WILLIAM E., Mgr.-Reclam. & Permits, Freeman United Coal Mining Co., Box 180, Du Quoin, IL 62832

SMITH, WILLIAM F., Controller, Midwest Energy Development, 617 E. Church St., Harrisburg, IL 62946

SMITH, WILLIAM H,Consulting Coal Geologist,William H. Smith&Assoc.,1319 Alms, Champaign, IL 61820

SMITH, WILLIAM S., (Retired), Peabody Coal Co., 1400 Waverly, Collinsville, IL 62234

SMYTH, WILLARD H., Prep. Plant Supt., Monterey Coal Co., Oak St., Okawville, IL 62271

SNEED, DWIGHT L., Carter Coal Corp., 15 Shawnee Rd., West Frankfort, IL 62896

SNEED, LINDELL A., Environ. Engr., Old Ben Coal Co., 500 N. Du Quoin St., Benton, IL 62812

SNYDER, DUKE, Dist. Mgr., Hydraulics, Inc., Box 191, Nashville, IL 62263

SNYDER, R. C., Midwestern Sales Manager, High Voltage Engrg. Division, Anderson Power Prod, 5901 N. Cicero Ave., Suite 505, Chicago, IL 60646

SORG JR, CHARLES E., Resident Engr., #2 Mine, Monterey Coal Co., Box 94, Albers, IL 62215

SORRELL, SHERWOOD W., Dir.-Engrg., IL Div., Peabody Coal Co., 201 Joseph Dr., Fairview Heights, IL 62208

SOWELL, JERRY, Sales, Dayco Co., 538 Mary St., Apt. 2, Collinsville, IL 62234

SPANI, EUGENE, Sales Rep., Towers Minetool, Inc.,Box 133,Christopher,IL 62822

SPEARS, BEN T., Safety Dir., MAPCO, 8115 Darmstadt Rd., Evansville, IN 47710

SPENCER, JIM, Sales Engr,General Electric Co,1115 East Rd.,St. Louis,MO 63110

SPIELER, W. J., Sales Acct. Mgr., Conoco, Inc.,11605 Studt St.,118,St. Louis, MO 63141-7015

SPIVEY,JOSEPH S.,Pres.,IL Coal Assocation,212 S. 2nd St.,Springfield,IL 62701

SPOKES, ERNEST M., University of MO, Rolla, School of Mines & Metallurgy, Rolla, MO 65401

SPOTTE, WALTER V., Pres.,Lincoln Equip. Co.,20 Museum Rd.,Washington,PA 15301

SPROULS, ERIC P., IN State University, Evansville, 8600 University Blvd., Evansville, IN 47712

SPROULS, MARK W.,Managing Editor, Coal Mining & Processing, 300 W. Adams St., Chicago, IL 60606

STACHURA, GEORGE A., Mng. Consultant, 620 Indian Hill Dr., Herrin, IL 62948

STANFIELD, JOSEPH E., Pres., Gen. Mgr., Watt Car and Wheel Co., Box 71, Barnesville, OH 43713

STEARNS, HOWARD, Coal Mng. Tech. Inst., Wabash Valley College, R.R. 1,Box 69, Pittsburg, IL 62974

STEELE, DEREK JOHN, Partner, Dames & Moore, 644 Linn St., Suite 501, Cincinnati, OH 45203

STEELE, TOMMY JOE, Safety Dir., White County Coal Co., Box 152,Carmi,IL 62821

STEELE, TROY T., Inst., Monterey Coal Co., P.O. Box 496, Carlinville,IL 62626

STEFFEN, JOHN R., Manager, National Accounts, El Dorado Chemical, Inc.,103 Edgewood Park, Marion, IL 62959

STEHN, JACK B., Gen. Mgr., Brad Ragan, Inc., Box 2728, Springfield, IL 62708

STERNER, ROBERT M., Mng. Engr., Kerr-Mc Gee Coal Corp., 6020 C, West Britton, Oklahoma City, OK 73132

STEWART, DONALD E., V. Pres., Purchasing, Freeman United Coal Mining Company, 300 W. Washington St., Chicago, IL 60606

STILLABOWER, GEORGE K., Sales Rep., Goodall Rubber Co., 5410 Danisher Rd., Countryside, IL 60525

STILLEY, RICHARD, Midwest Sales Mgr., Century Hulburt, Inc., Box 161, Marion, IL 62959

STITT, RICHARD A., Sales, W. S. Tyler Co., 406 Neal Ln., Union, OH 45322

STOKER, STEVEN, Area Mgr., Hewitt-Robins, 9920 Watson Rd., Suite 205, Crestwood, MO 63126

STONE, CHUCK, Serv. Mgr., Brad Ragan, Inc., Box 2728, Springfield, IL 62708

STORMS, ELLIS, Armco-Union Wire Rope Co,7000 Roberts St.,Kansas City,MO 64125

STOUT, BUFORD, Purchasing Agent, Old Ben Coal Co., 500 N. Du Quoin St., Benton, IL 62812

STRAIN, WILLARD, Pres., M.A.T. Industries,Inc,Box 250,West Frankfort,IL 62896

STRITZEL, DAVE, Dir.-Health & Safety, Zeigler Coal Co., Box 547, Coulterville, IL 62237

STROSINSKI, MICHAEL, Prep. Plant Maint. Foreman, Monterey Coal Co., #2 Mine, Box 381, Okawville, IL 62217

STRUBEL, A. J., Jennmar Corp., Box 70, Flora, IL 62839

STRZODKA, KLAUS, Prof., Dr., Bergakademie Freiberg, Agricolastrasse 1, 9200 Freiberg/Sa, German Democr. Republic,

SUBLETT, WILLIAM F., Sales Manager, Hemscheidt America Corporation Box 500, 252 Parkwest Dr., Pittsburgh, PA 15230

SUSMAN, IRVIN, Chairman of Board, Susman Wiping Materials Company, Inc., 420 E. De Soto Ave., St. Louis, MO 63147

SUTTON, WALTER, Sales, Bearings Service Co., 1607 S. Kentucky Ave., Evansville, IN 47713

SWALLOW, R. H., Turtle Creek Dr., 9B, Tequesta, FL 33458

SWICK, CARL, Sales Rep., Page Engineering Co., Clearing Post Office, Chicago, IL 60638

SWINGLE, DOROTHY, Buyer, AMAX Coal Co., Inc., Wabash Mine, Box 144, Keensburg, IL 62852

SWISHER, JAMES H., Director Coal Rsrch. Center, SIU, Coal Research Center, Carbondale, IL 62901

SYKES, JAMES T., Director, Sales & Mktg., Thyssen Mining Equipment Division, 202 E. Main St., Stanley Bldg., Suite 102, Marion, IL 62959

SZPYRKA, THOMAS E.,Geologist,Freeman United Coal Mining Co,328 Harvester Ln., Canton, IL 61520

TABOR, LINDY V., Pres., Tabor Machine Co., Box 3037, Bluewell Station, Bluefield, WV 24701

TABOR, JOSEPH C., R.R. 6, Springfield, IL 62707

TAIPALE, VICTOR K., Consultant, Victor K. Taipale Conveyor Belt & Systems, 2898 Bancroft Rd., Fairlawn, OH 44313

TALBOTT, JAYNE, Real Estate Agent, Nicor Minerals, Box 83, Naperville, IL 60566

TAPPENDORF, DAVID, Planning Engr., AMAX Coal Co., Inc., 547 Romblin Rd., Greenwood, IN 46142

TARLETON, GEO. J., Mgr. of Operations, Tri-State Maint. & Repair, Box 1388, Mt. Vernon, IL 62864

TARR, RONALD D., Owner, Coal Collectibles, R.R. 1, 17 Sunset Ln., Girard, IL 62640

TAUCHER, R. A., Special Projects, Consolidation Coal Co., Box 218, Pinckneyville, IL 62274

TAYLOR, ARNIE, Quarry Supply Products, Ltd., 6096 Conners Ln., Rockford, IL 61109

TAYLOR, DAVID L., Purchasing Mgr., Peabody Coal Co., 50 Jerome Ln., Fairview Heights, IL 62208

TAYLOR, MARK S., Minesafe Electronics, Box 281, Sturgis, KY 42459

TAYLOR III, LLOYD W., Commercial Testing & Engineering Co., Box 752, Henderson, KY 42420

TEAL, JAMES, Mine Supt., Sahara Coal Co., Inc., Box 330, Harrisburg, IL 62946

TEASDALE, DONALD R., Reg. Sales, Bethlehem Wire Rope, Bethlehem Steel Corp., Box 21687, St. Louis, MO 63139

TEISA, EMIL J., R.R. 1, Box 5, Coffeen, IL 62017

TETI, JOHN J., Consultant, Battery Transport & Engr, Box 756, Saltville, VA 24370

THELEN, RICH, Sales Rep., E.I.E. Co., Box 520, Lisle, IL 60532

THOMAS, DAVID H., Sales Mgr, J H Fletchers & Co., Box 2143, Huntington, WV 25722

THOMPSON, ALBERT C., Consolidation Coal Co., 35 Mocking Bird lane, Carterville, IL 62918

THOMPSON, CARL R., Maintenance Planner, Monterey Coal Co., R.R. 1, Box 199, Gillespie, IL 62033

THOMPSON, CULLEN R., Mgr., Coal Explor., Shell Mining Co., Box 2906, Houston, TX 77252

THOMPSON, DONALD E., Branch Mgr., Illinois Bearing Co., 3113 N. Main St., E. Peoria, IL 61611

THOMPSON, PHIL, Decatur Industrial Electric, Inc., 1500 N. 27th St., Decatur, IL 62525

THOMPSON, RAY M., Central Illinois Public Service Co., 607 E. Adams St., Springfield, IL 62701

THOMSON, MICHAEL L., Mktg. Rep., Celtite, Inc., 906 E. Illinois, Marion, IL 62959

TIERNON, CARLOS H., Chairman of Board, Deister Concentrator Company, Inc., 2200 E. Devon, Des Plaines, IL 60018

TILLSON JR., CHARLES B., Consultant, 718 E. Flag Way, Poinciana, FL 32758

TIONA, JAMES A, Foreman, Monterey Coal Co., Box 37, Sawyerville, IL 62085

TODD II, WILLIAM T., Exec. V. Pres., Fairmont Supply Co., Box 501, Mill Craft Centre, Washington, PA 15301

TOMIC, RANDALL J., Proj. Engr., Old Ben Coal Co., 500 N. Du Quoin St., Benton, IL 62812

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TOWLES, ARTHUR L,Michael E Walsh & Assoc.,2340 River Rd.,Des Plaines,IL 60018

TRASK, C BRIAN,Assoc Geologist,IL State Geological Survey,615 E. Peabody Dr., Champaign, IL 61820

TRAVELSTEAD, CHARLES, Operations Support Head, Carter Mining Company, 1013 S. Pioneer, Gillette, WY 82716

TREWORGY, JANIS D., IL State Geological Survey, 615 E. Peabody Dr., Champaign, IL 61820

TROUT, DARREL R., Plant Mgr,Ajax Engineering Co.,Box 409,Shawneetown,IL 62948

TROUT, TIM, Capitol Group, 1900 S. 8th St., Springfield, IL 62703

TRUAX JR., CHESTER N.,American Mining Congress,1920 North St.,N.W.,Suite 300, Washington, DC 20036

TUCKER, DEMPSEY, Chief Electrician, Peabody Coal Co., 600 E. Oak, Mascoutah, IL 62258

TURBEVILLE, ROBERT M., Gen. Mgr., Liquid/Solids Sepr, Heyl & Patterson, Inc., Box 36, 250 Park West Dr., Pittsburgh, PA 15230

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URBANCIC, JOHN J., Dir., Purchasing, Freeman United Coal Mining Co., 300 W. Washington St., Chicago, IL 60606

URBONAS, PETER P., Safety Inspector, Monterey Coal Co., 712 W. Mulberry, Carlinville, IL 62626

URTON, WILLIAM G., Gen. Mgr., Mid-West Mining Co., 22 Peachtree Pl., Harrisburg, IL 62946

UTLEY, JAMIE, Sales, Star Mine Service, 3113 Jamison, Mt. Vernon, IL 62864

VALETT, GENE L., Staff Geologist, Morrison-Knudsen Co., Inc., 2 M-K Plaza, Box 7808, Boise, ID 83729

VAN DEMAN, JOSEPH A., Sales Rep., FMC Corp., M.H.E. Div., 4 Spencer Valley Ct., St. Peters, MO 63376

VANDERGRIFF, GARY D., Exec. V. Pres., C & M Services, Inc.,Box 2086, Fairview Heights, IL 62208

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VARGO, ROBERT L, Gen. Sales Mgr., National Mine Service Co, 600 N. Bell Ave., Bldg. 2, Suite 110, Carnegie, PA 15106

VASS, GEORGE S., Managing Dir., Pattin Mfg. Co., Box 659, Marietta, OH 45750

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WALKER, DALE E., Freeman United Coal Mining Co., Box 570, Canton, IL 61520

*WALKER, HAROLD L., 2110 Belmore Ct., Champaign, IL 61820

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WEAVER, DAVID, Asst. to Supt., Freeman United Coal Mining Co., 708 N. 12th, Mt. Vernon, IL 62864

WEAVER, DAVID L., Mine Mgr., Freeman United Coal Mining Co., Box 153, Waggoner, IL 62572

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*WEIR, CHARLES R., 9534 Normandy Ave., Morton Grove, IL 60053

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WHITFIELD, THOMAS G., Geologist, U.S. Steel Corp., 315 Church St., Indiana, PA 15701-2126

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WIFORD, LARRY E., Branch Mgr., Mine Supply Co., Box 754, Mt. Vernon, IL 62864

WIGNALL, TOMMY K., Engr., Lovilia Coal Co., R.R. 1, Box 90A,Junction,IL 62954

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WILEY, G. B., Consultant, Sahara Coal Co., Inc., Box 330,Harrisburg, IL 62946

WILHELM, MARK, Branch Mgr,Bruening Bearings, Inc,437 N. 9th St.,E. St. Louis, IL 62201

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WILL, W. E., V. Pres., Oper. Serv., S. Div, Peabody Coal Co,1915 Barrett Ct., Box 1981, Henderson, KY 42420

WILLIAMS, BILLIE E., Supt., Lovilia Coal Co.,R.R. 1,Box 90A,Junction,IL 62954

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WILLIAMS, EMMET T. (TIM), Dist. Mgr., Reed, Inc., 6475 Joliet Rd., La Grange, IL 60525

WILLIAMS, JESS, Freeman United Coal Mining Co., Box 1587,Mt. Vernon,IL 62864

WILLIAMS, LOREN A., Coastal States Energy Co., 9 Greenway Plz., Suite 1482, Houston, TX 77046

WILLIAMS, MICHAEL G., Sales Rep., Smith-Gruner, 2628-A N. Cullen Ave., Evansville, IN 47715-2170

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WILLIS,EUGENE C,Plant Mgr,Joy Manufacturing Co., 4 Fountain Pl., Mt. Vernon, IL 62864

WILLMORE, WAYNE,Proj. Engr,Mech,Old Ben Coal Co.,RR 4,Box 120,West Frankfort, IL 62896

WILLS, BENJAMIN E., 1509 S. State St., Springfield, IL 62704

WILSON, JIMMY L., Mine Engr., Kerr-Mc Gee Coal Corp., Galatia Mine, Box 727, Harrisburg, IL 62946

WILSON, JOHN R., Contracting Engr., Roberts & Schaefer Co., 120 S. Riverside Plaza, Chicago, IL 60606

WILSON, LARRY, Gen. Supt., Old Ben Coal Co,727 Old Orchard Dr,Benton,IL 62812

WILSON, LEE, Instructor, Mng. Tech., Rend Lake College, R.R. 1, Ina, IL 62846

WILSON, ROBERT J., V. Pres., Anixter Bros., Inc,4711 Golf Rd.,Skokie,IL 60076

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WINN, C. H., (Retired), 3606 Stanton Ave., Springfield, IL 62703

WITT SR., RON, Gen. Mgr., Anixter Cable Service Co., Box 427, West Frankfort, IL 62896

WOJTOWICZ, DAVID, Sales Rep., Hydraulics, Inc., 709 S. Washington St., Nashville, IL 62263

WOOD, T. C., V. Pres., Gen. Mgr., Midco Sales & Service,Box 28729, St. Louis, MO 63146

WOODDELL II, KENNETH L., Pres.,Wooddell Logging,Inc,Box 1095,Mattoon,IL 61938

WOODROW, CHARLIE, Sales, W. M. Hales Co., Box 368, West Frankfort, IL 62896

WOODS, DAVE, Ajax Engineering Co., Box 409, Shawneetown, IL 62984

WOODS, GEORGE, Instructor, Wabash Valley College, 1001 E. Clark St., Marion, IL 62959

WOODS, M. C. (CHRIS), (Retired), Pennzoil Co., 1819 Paula Ln.,Marion,IL 62959

WOOLBRIGHT, CHARLES L., Sales Engr., Joy Manufacturing Co., 222 Breese, Centralia, IL 62801

WOOTON, DANNY G., Supt., White County Coal Corp., Box 152, Carmi, IL 62821

WORCESTER, RUSS, Sales, Ludlow Steel Corp., 2530 75th N., Lebanon, IN 46052

WORSEY, PAUL N., University of MO, Rolla, 101A Mining Bldg., Rolla, MO 65401

WRIGHT, CLARENCE E., Proj. Engr., Monterey Coal Co., Box 94, Albers, IL 62215

WRIGHT, RON P., Sales Mgr., Georgia Duck and Cordage Mill, 21 Laredo Dr., Scottdale, GA 30079

WYATT, WAYNE R., TSM Central Shop Supt., Peabody Coal Co., R.R. 2, Box 85, Marissa, IL 62257

YANCIK, JAMES R. ; Prep. Engr. ; Freeman United Coal Mining Co. ; Box 100, West Frankfort, IL 62896

YATES, LARRY, Purchasing Agent, Peabody Coal Co., 301 N. Memorial Dr., St. Louis, MO 63102

YOCUM, HARRY, Dir., Environ. Engrg., AMAX Coal Co., Inc., Box 967, Indianapolis, IN 46206

YOCUM, KEVIN L., Director, Land & Environ. Affairs, Coastal States Energy Co., 9 Greenway Plz., Houston, TX 77046

YODER, FRED L., Sverdrup Corp., 801 N. 11th St., St. Louis, MO 63101

YOUNG, BOB, V. Pres., Webb Oil Co., E. Main St., Carmi, IL 62821

YOUNG, CHARLES W., Superv., Tennessee Valley Authority, 307 Krystal Bldg., Chattanooga, TN 37401

YOUNG, WILLIAM ALONZO, Gen. Supt., Old Ben Coal Co., 501 E. St. Louis St., West Frankfort, IL 62896

YOUNKERS, FORREST, Supt., Peabody Coal Co., Eagle Mine #2, Box 527, Shawneetown, IL 62984

ZAPPA JR., LEO J, Legal Advisor,IL Dept. of Mines & Minerals, 227 S. 7th St., Springfield, IL 62701

ZMUDZINSKI, GERALD L., Sr. Environ. Engr., Inland Steel Coal Co., Box 566, Sesser, IL 62884

ZWAHLEN, BEVERLY S., Proj. Engr,Monterey Coal Co,Box 496,Carlinville,IL 62626

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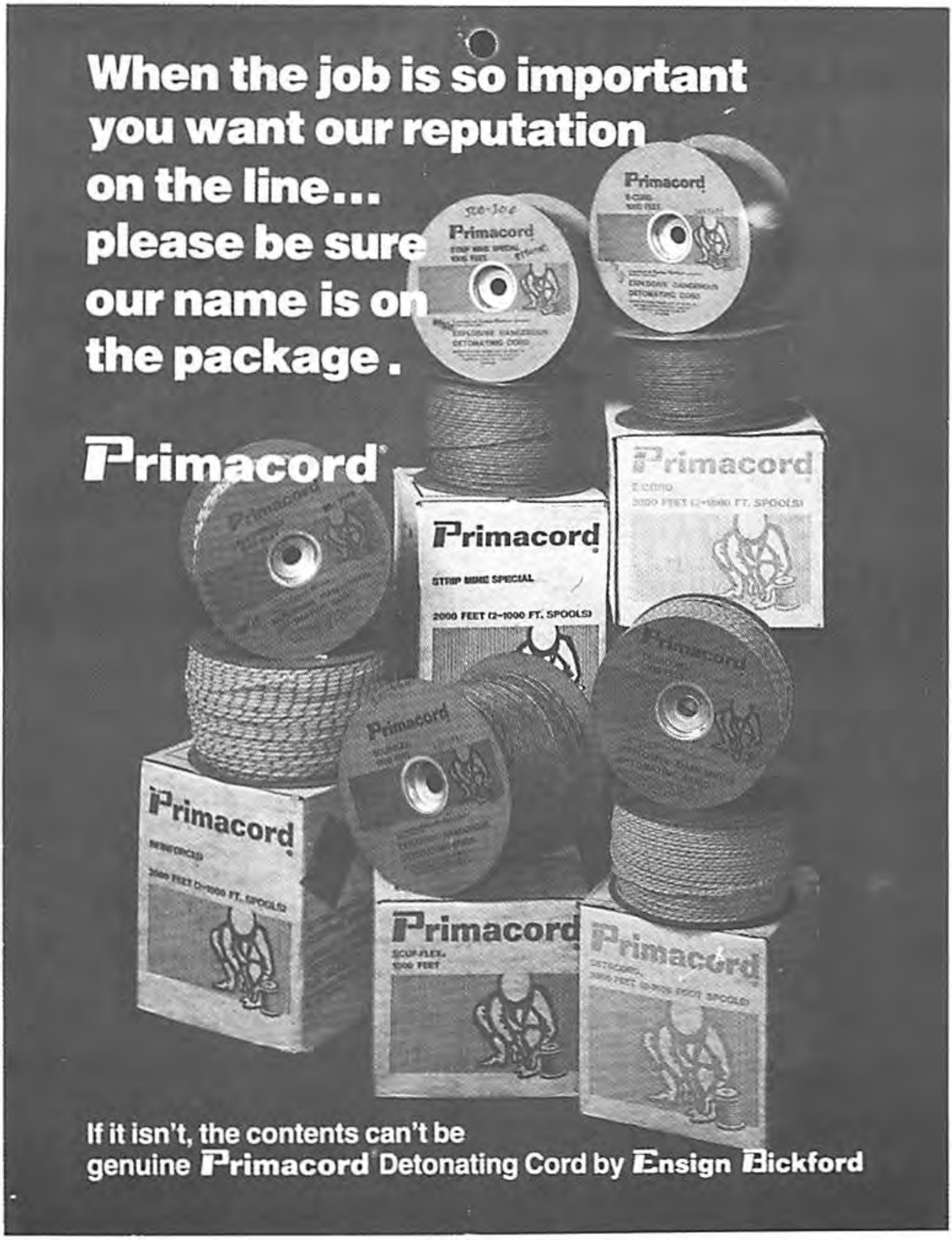
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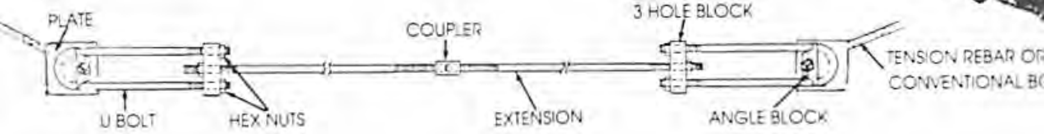

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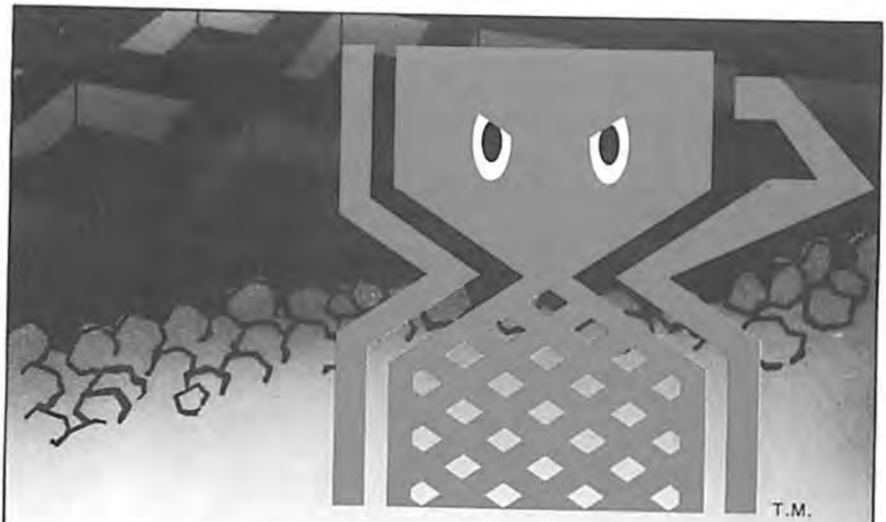
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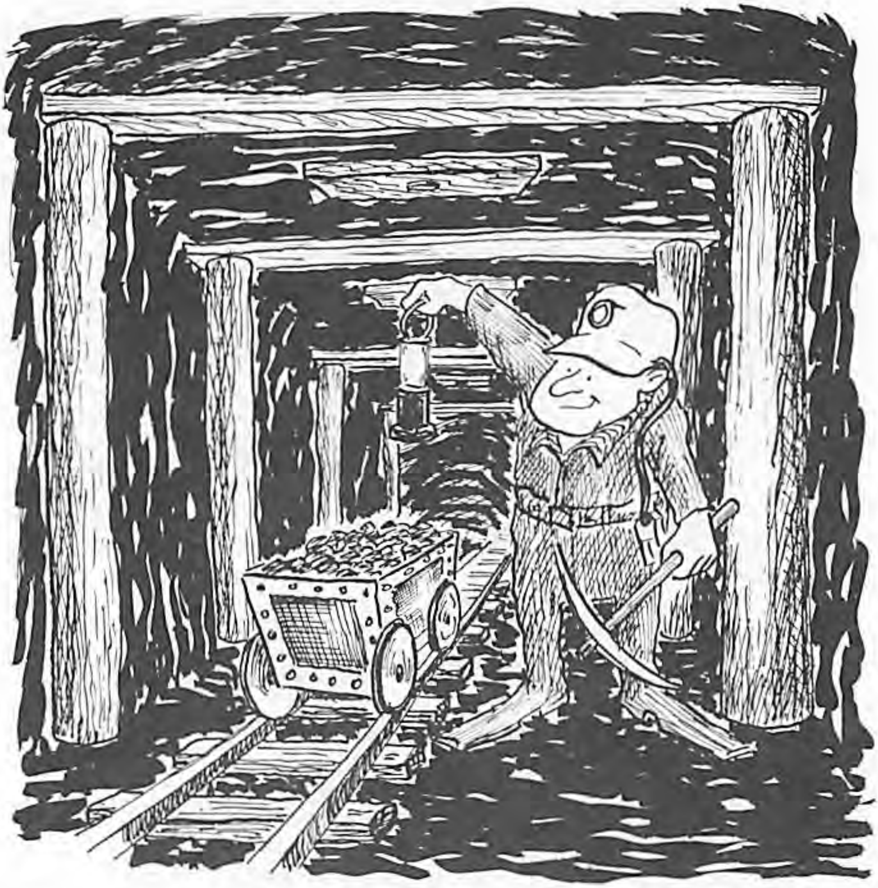

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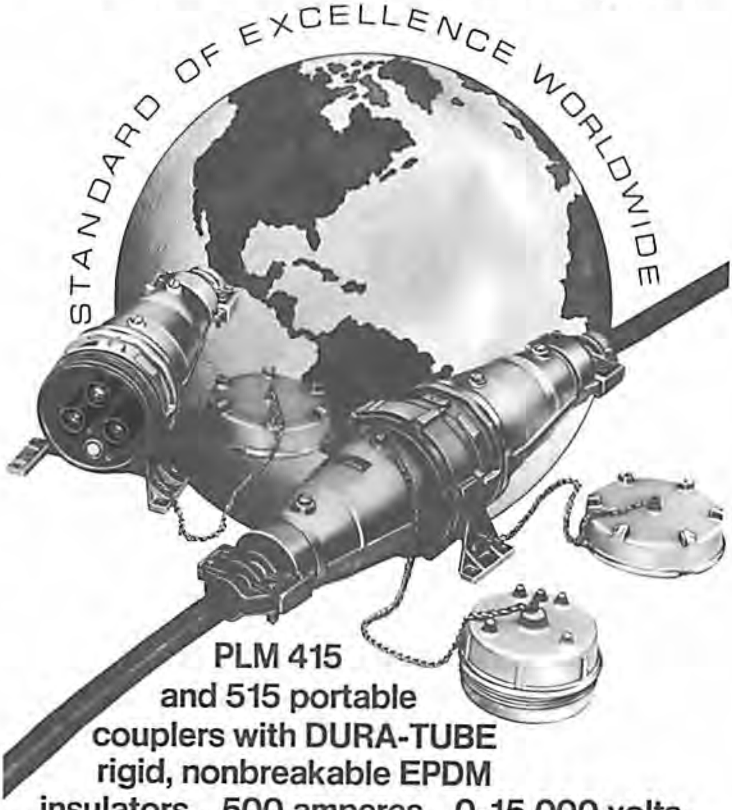
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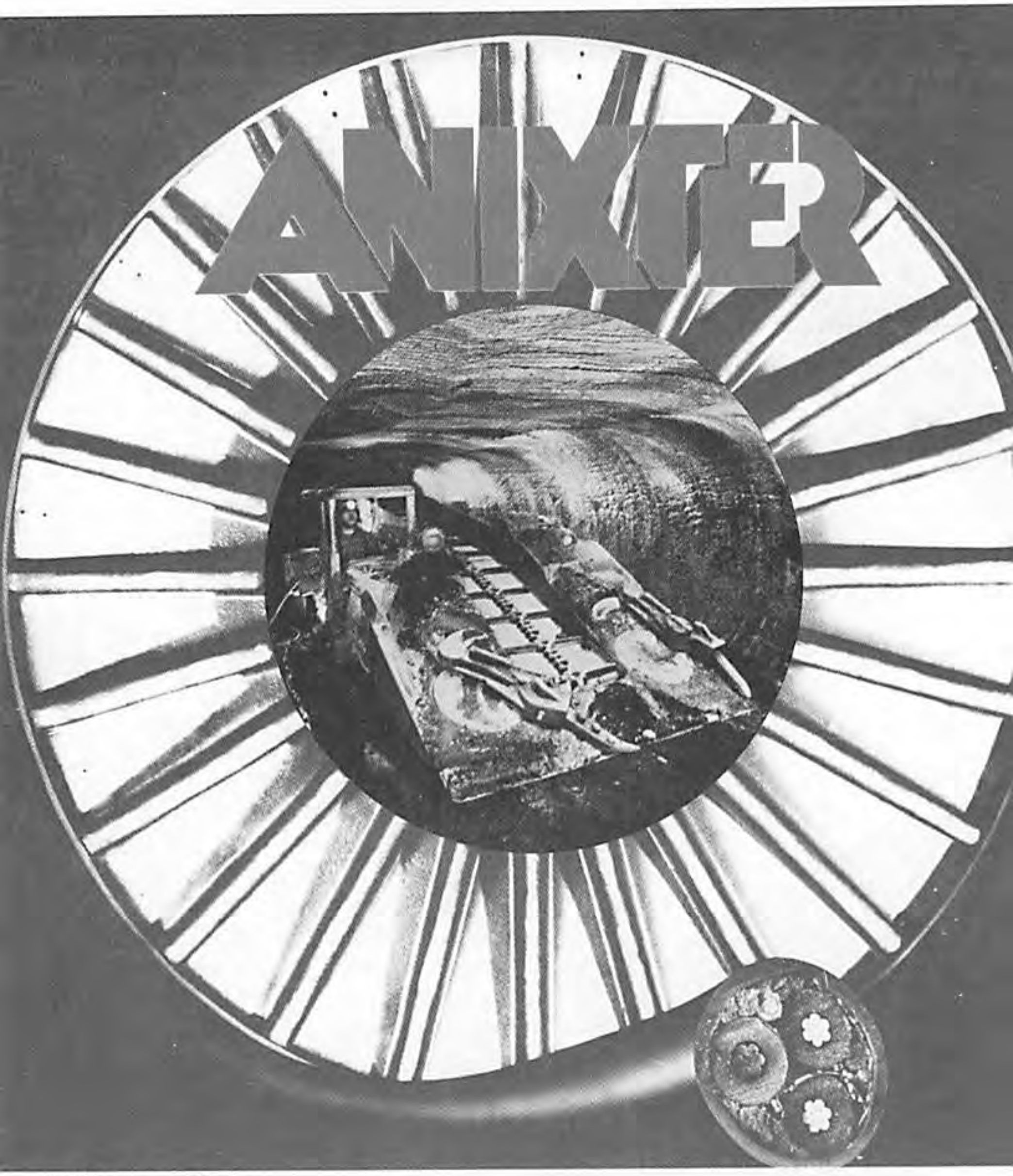
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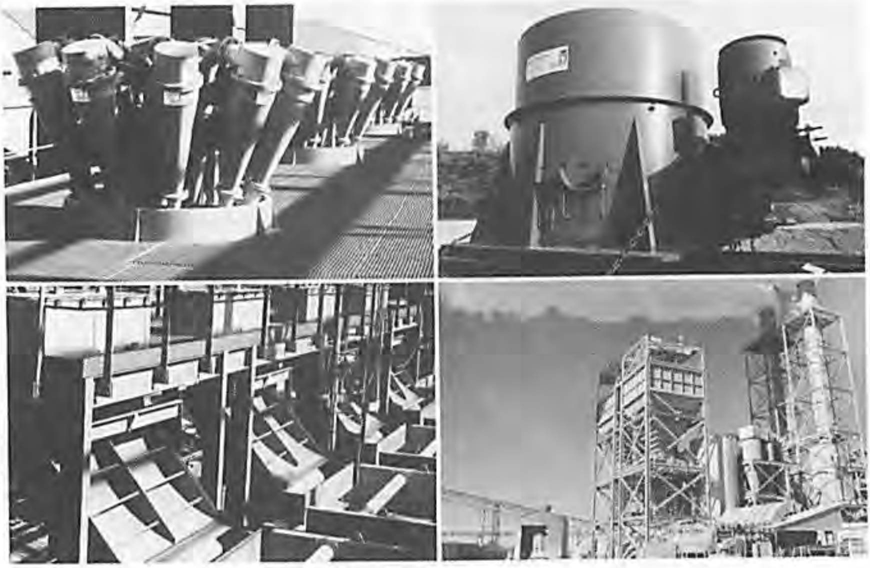

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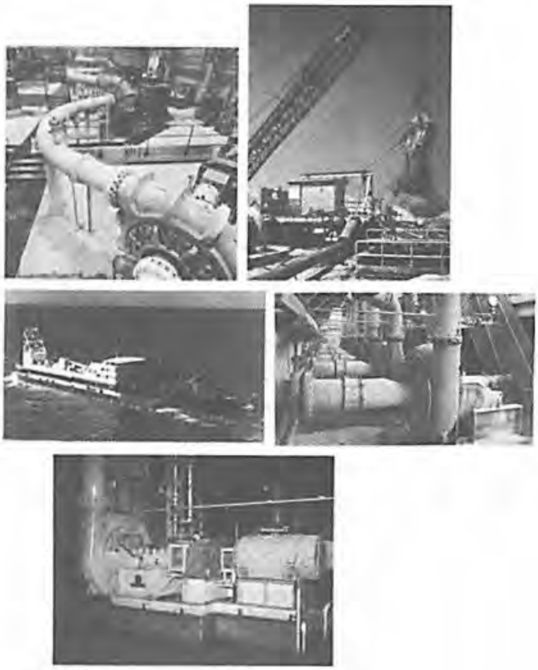

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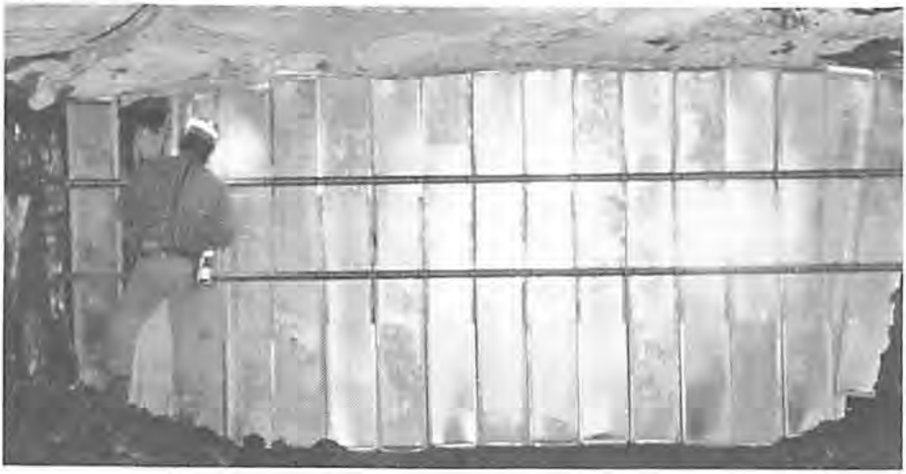


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HISTORY OF COAL MINING


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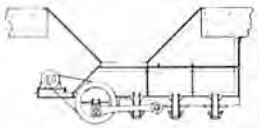
FAST 2000-8000 tph LOAD-OUT



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Field proven as a dependable and economical unit for feeding various materials in controlled quantities, and for unloading bins, hoppers, storage silos and storage piles.

Kanawha Feeders are custom tailored to the application in width, length, height and capacity. Available in widths of 2 to 8 feet and lengths of 5 to 20 feet. Single feeder installations unload at 50 to 2,000 TPH. Multiple feeders will handle loading rate up to 8,000 TPH.

SPECIAL FEATURES:

- All antifriction — including drive arms and drive shaft bearings.
- Floating feed plate rollers require no lubrication.
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- Driven sprocket ring assembly — bolted on flywheel and easily maintained.
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The Kanawha Rapid Load System has been the standard of the industry since the advent of unit train loading. Both the standard 4'x4' and the large 5'x5' system provide the same fast, dependable loading capability.

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Seven Kanawha Reciprocating Feeders under one silo is a proven, low cost system for the most efficient silo unloading . . . an arrangement that has become an industry standard.

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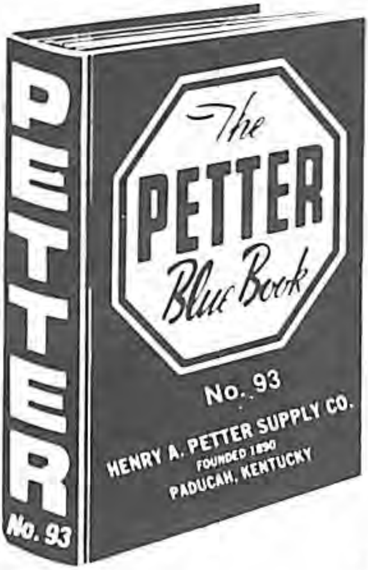
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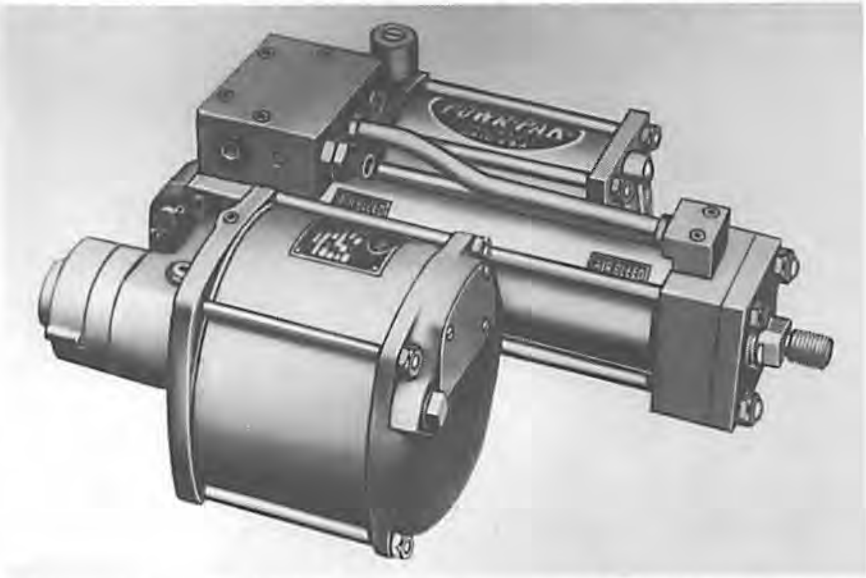
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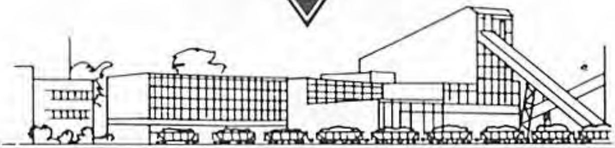

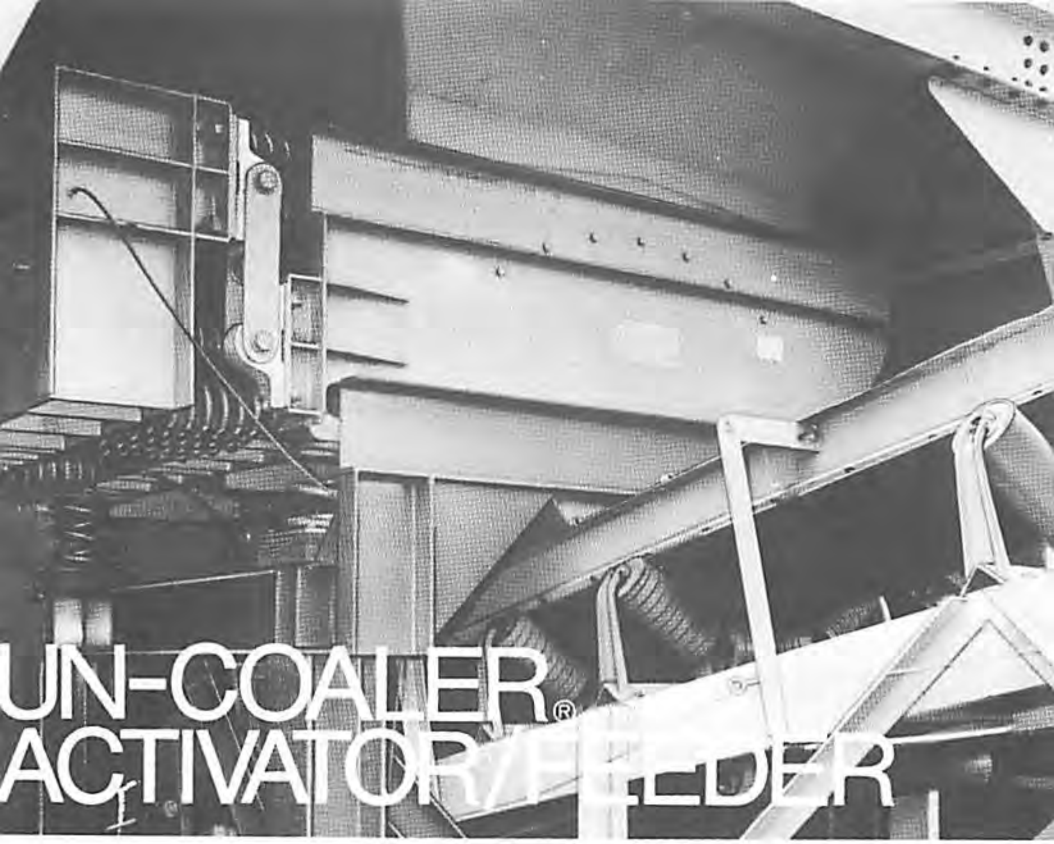

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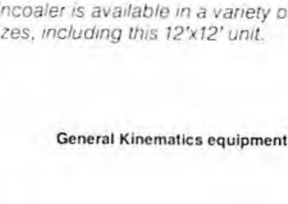
Like our Para-Mount II feeder, The Uncoaler is powered by a rugged, natural frequency vibratory drive system. Exciter force automatically compensates for change in material head load, and material discharge is fully adjustable to maintain optimum, uniform feed rates.

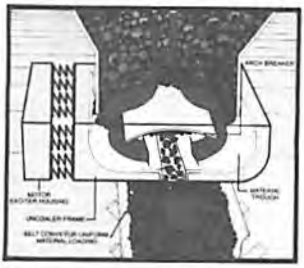


Uncoaler is available in a variety of izes, including this 12'x12' unit.

Stands on its own

Uncoaler needs no special suspension or roof construction. Entire unit stands on its own, directly above conveyor. Its few moving parts are readily serviced from the tunnel.

Get full information from your Man in Motion, the General Kinematics representative nearest you. Or contact us directly.



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The above picture features two types: The square unit is our Scoop Service Unit. This unit consists of two oil tanks with capacities of 235 gal. and 170 gal. and a service station type grease pump, all operated by hydraulics taken from the scoop hydraulic system. The grease pump works on either 38 lb. or 120 lb. container.

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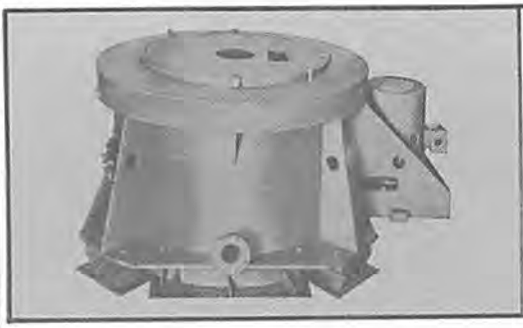

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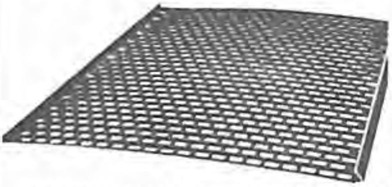

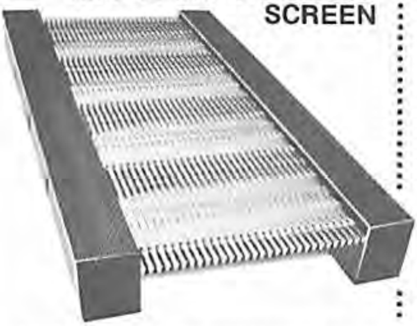

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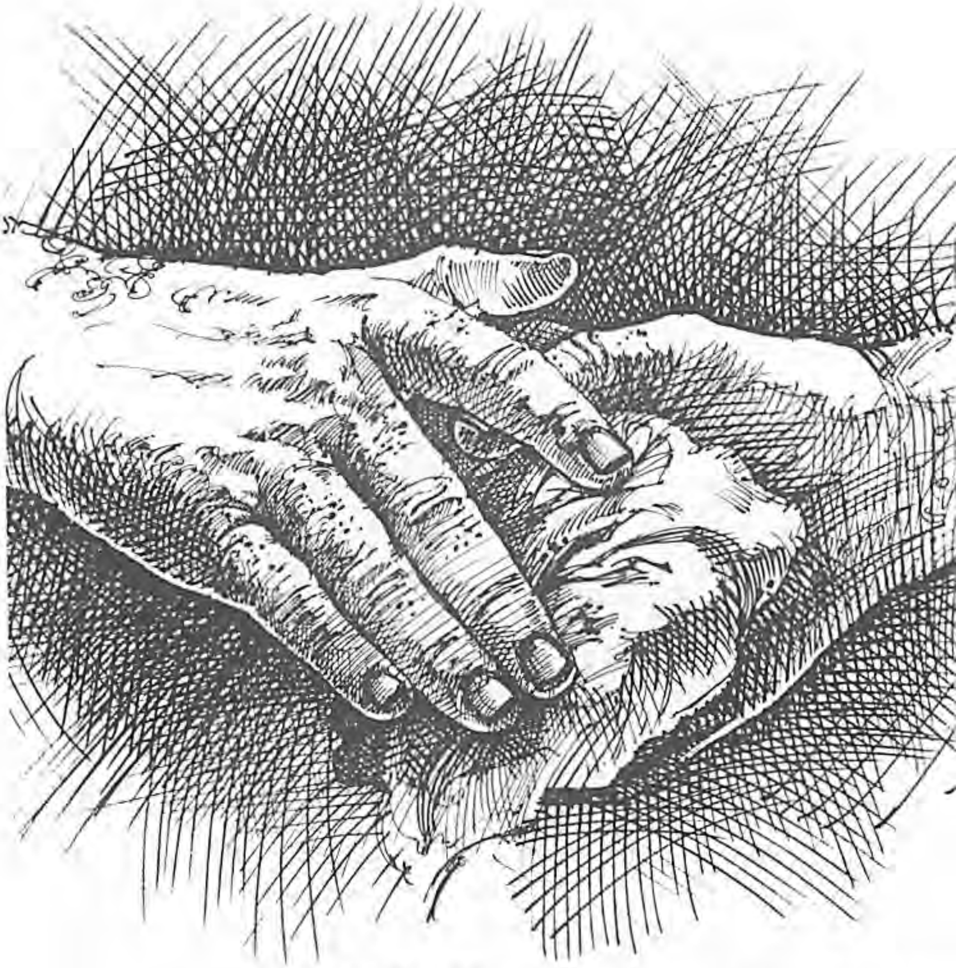

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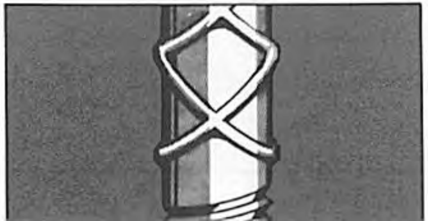

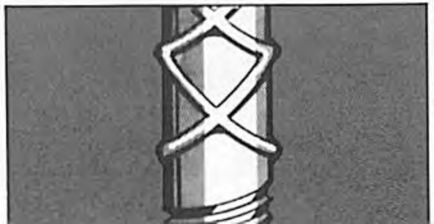

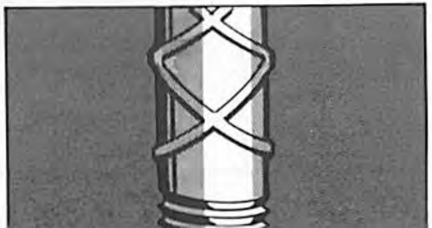

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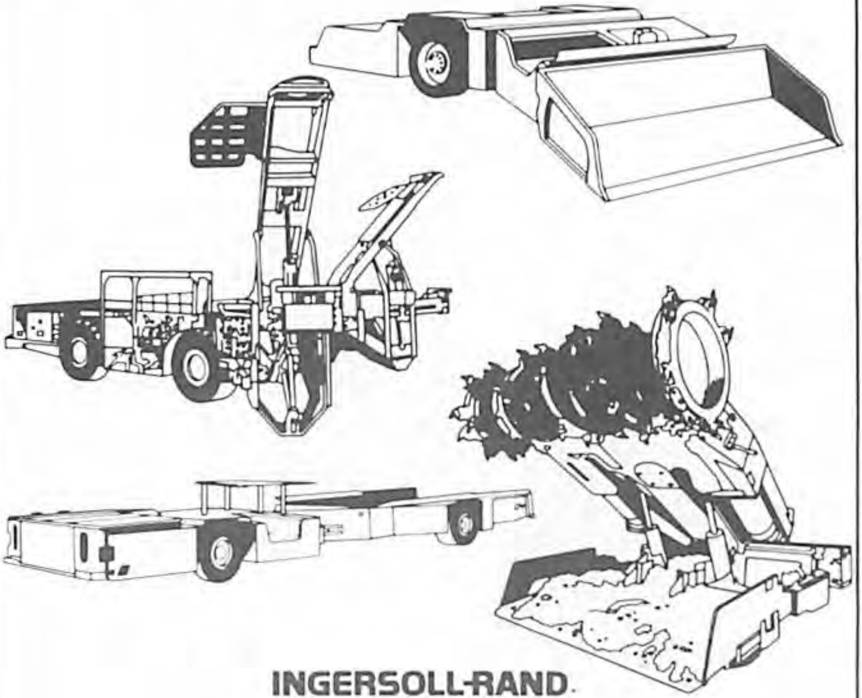

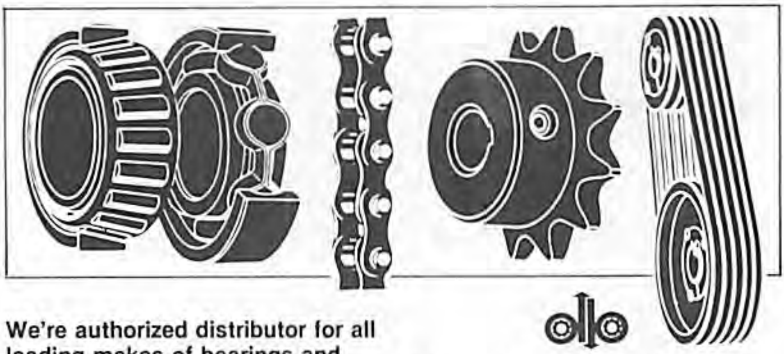

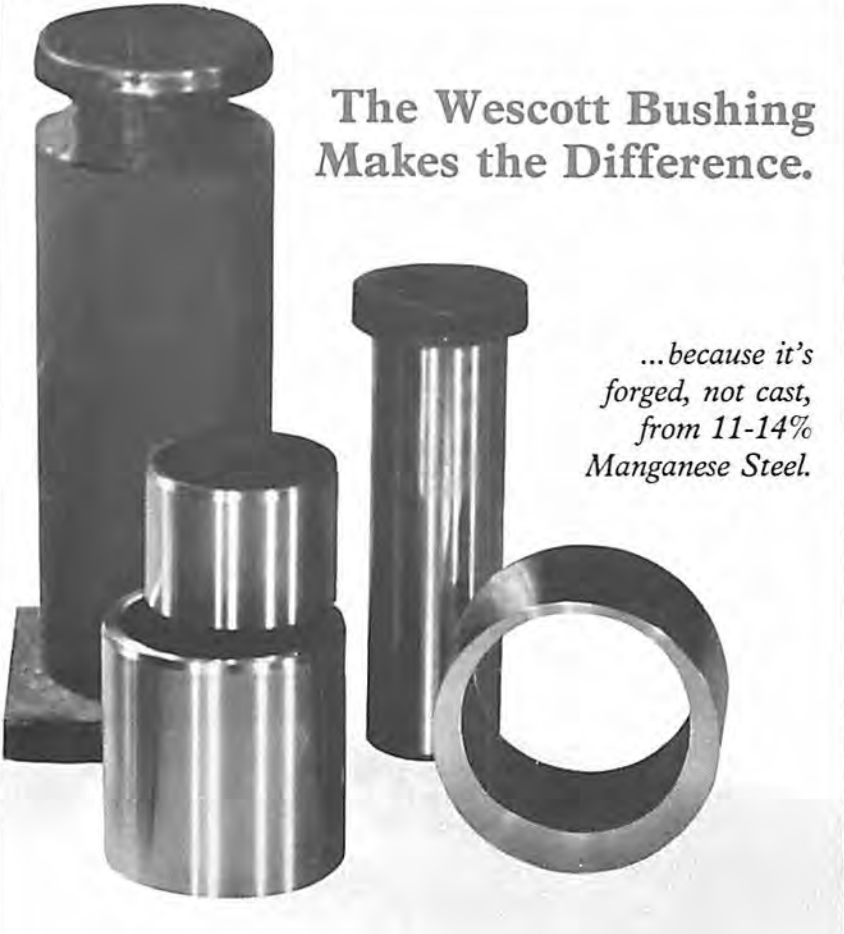

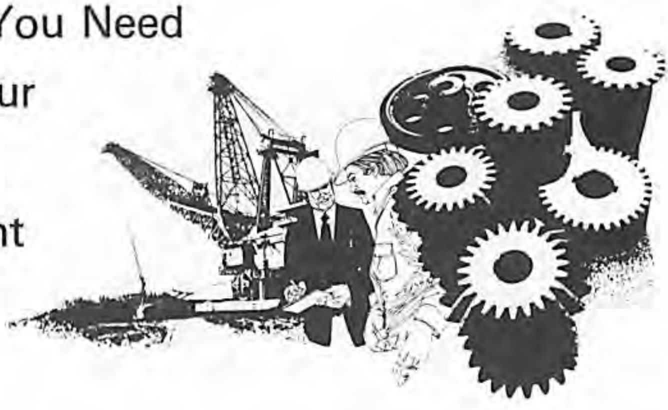

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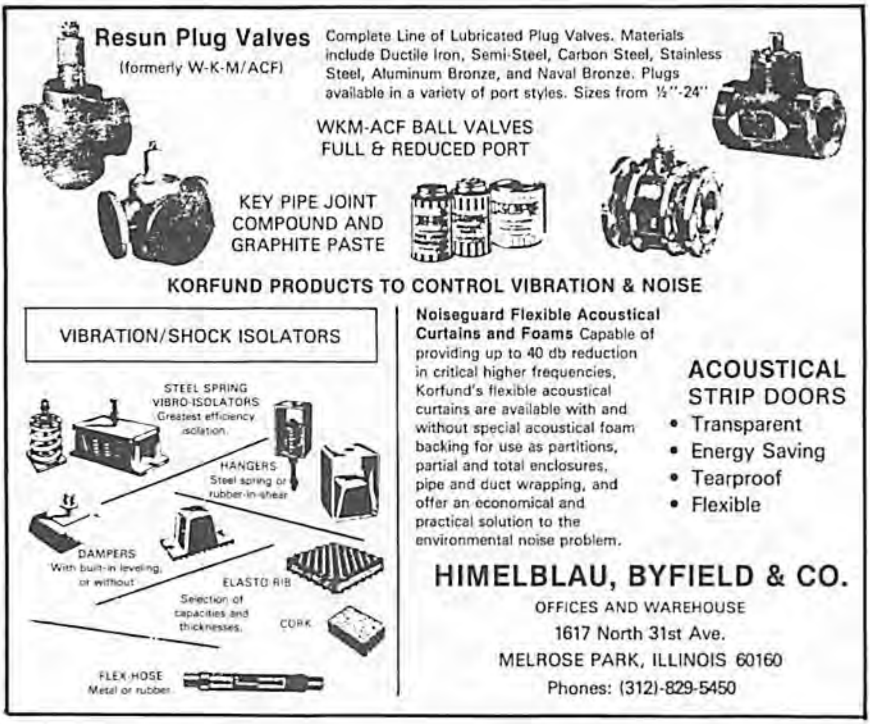

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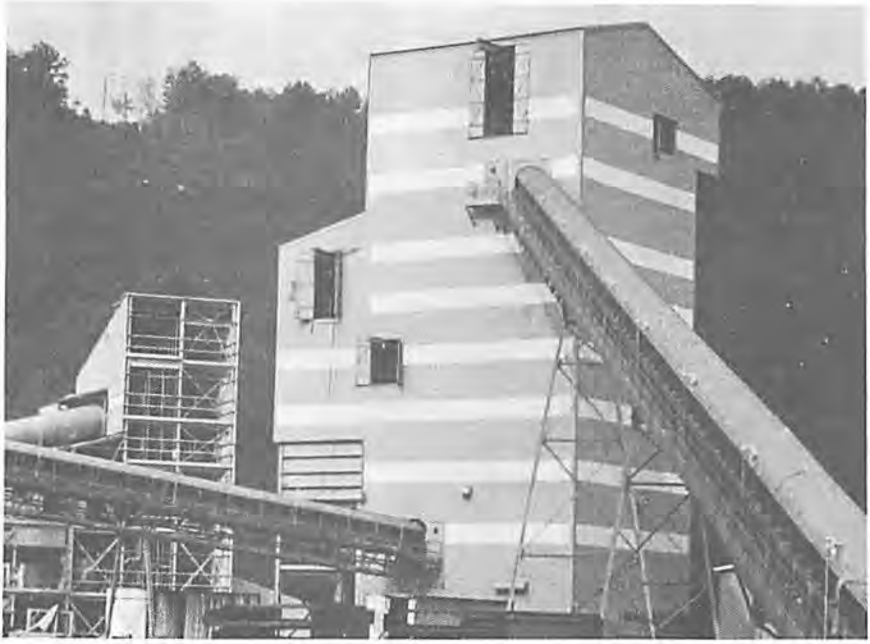

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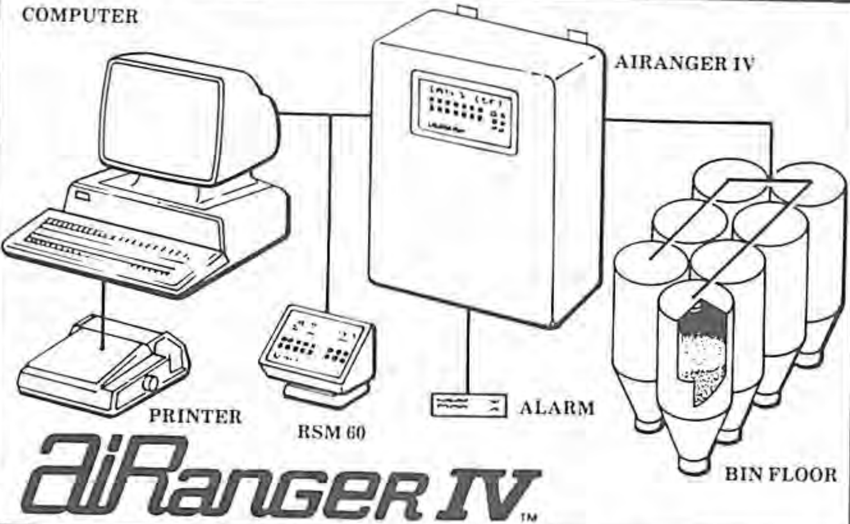
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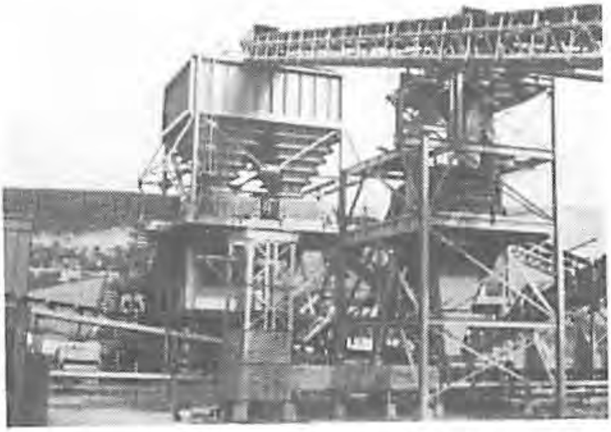

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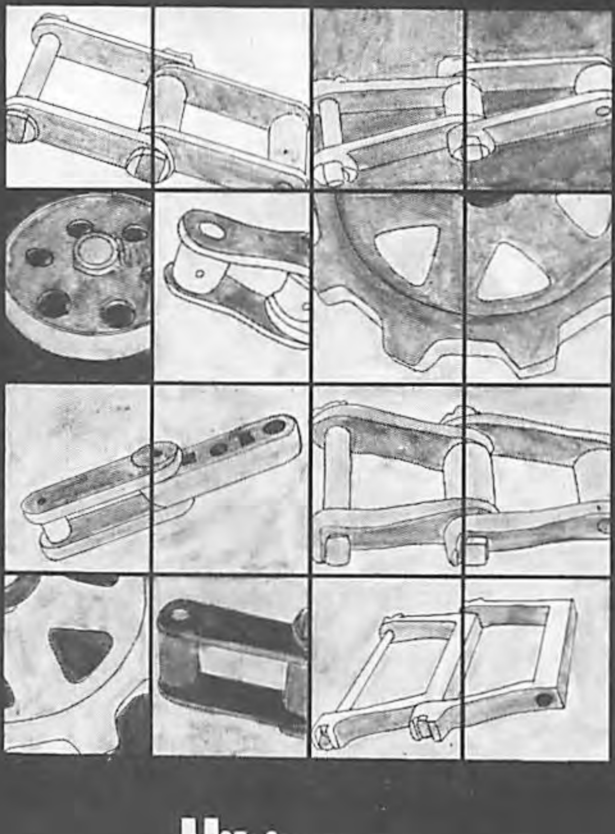

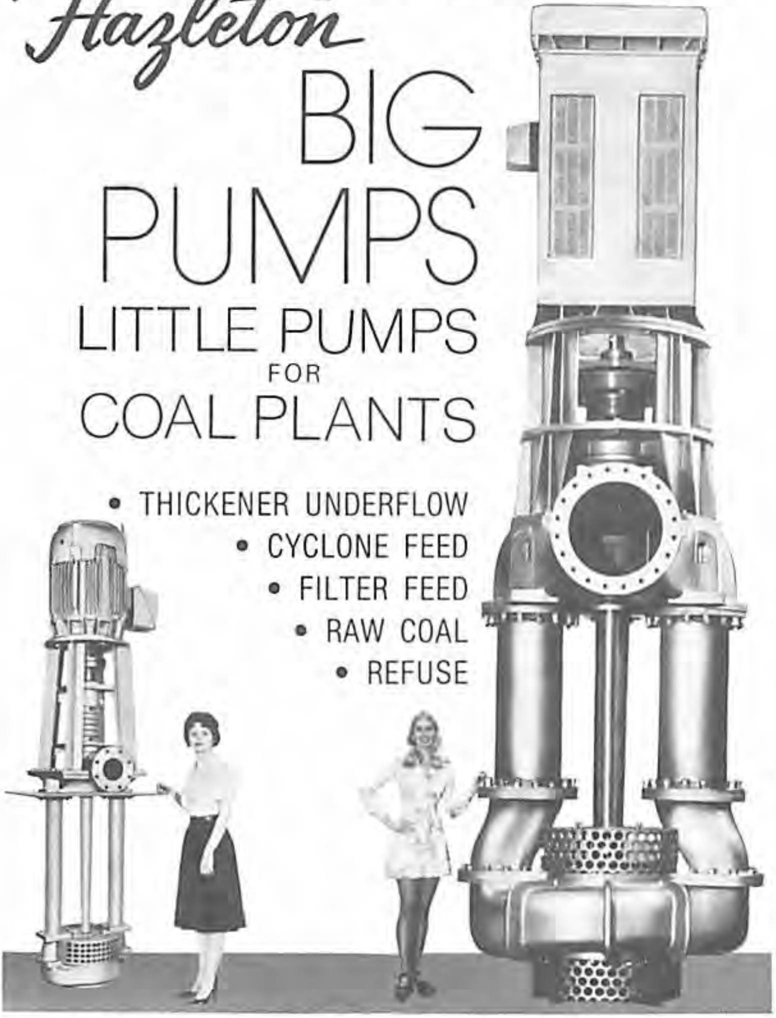

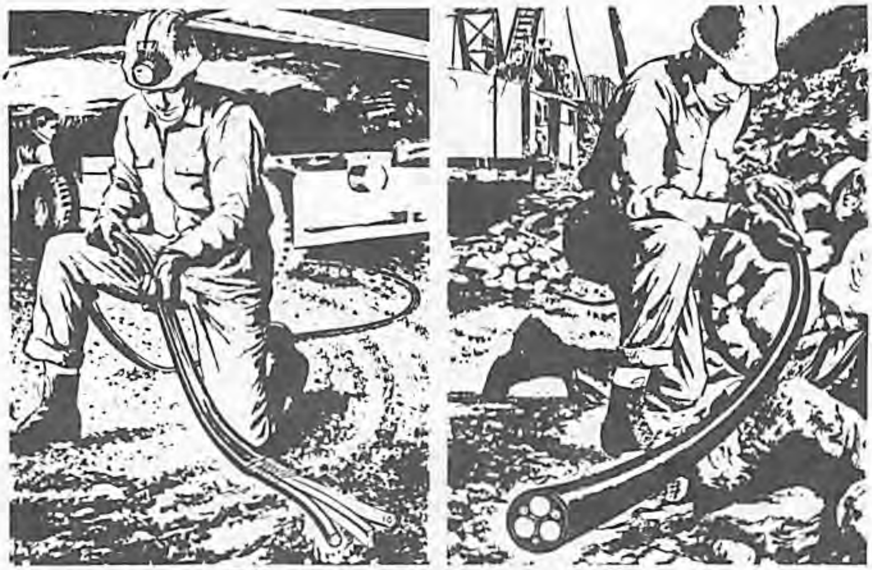

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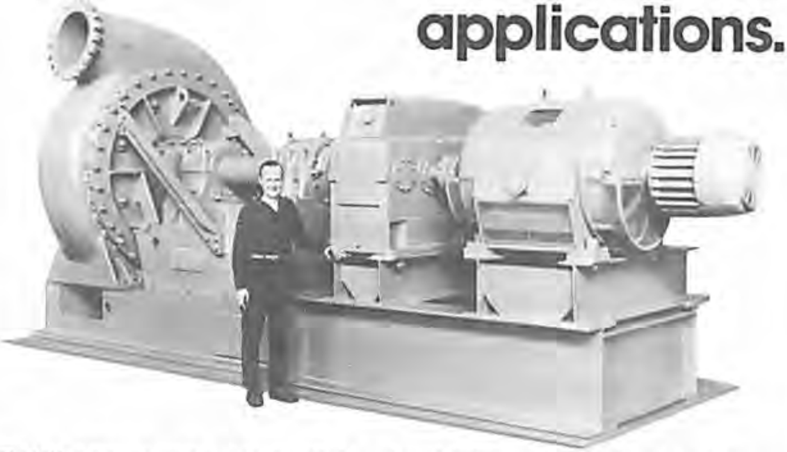


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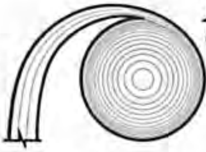

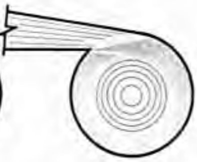

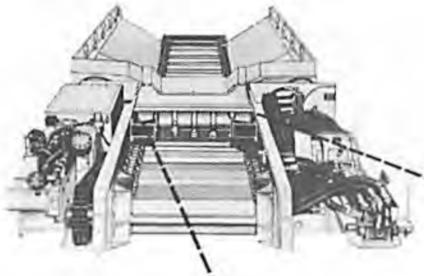

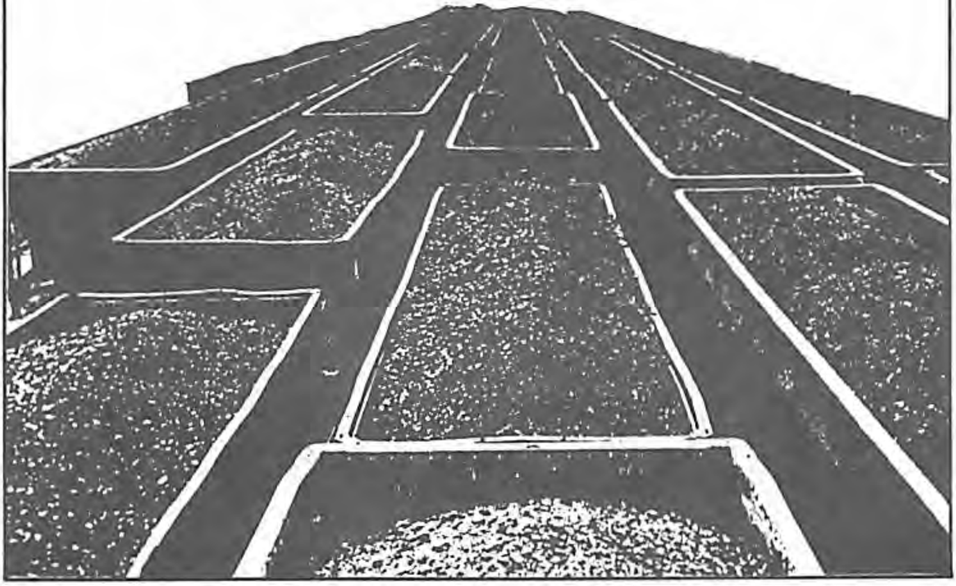

Go all the way with Sanford-Day Line of Products.

With over three-quarters of a century of experience in the manufacturing of mining equipment, the Sanford-Day haulage team is delivering its efficiency at the source, to mines all over America. Whether you need to transport men, equipment, coal, ore, refuse—Sanford-Day will move them fast and safely.

Every piece of equipment we build is reinforced for extra strength, longer lasting life, and has more safety features—to ensure your mining crews safety. The sturdiness and durability of our equipment means added efficiency, higher productivity, and operating economy, while reducing downtime.

Like our 8-wheel 6-Brake Brakeman Car, the only completely certified car of its kind—guarding against runaway trips at slope mines due to rope breakage or hoist failure.

Or our Rubber/Rail Car with a capacity of up to 16 tons on rail, and the car can be operated by one individual, who can lift and lock each wheel all in one motion.

Our 8-wheel Ballast Car has an 8-10 ton capacity. The car has 3 doors and they operate manually, with the ballast levelled in both directions. Also featured are automatic couplers and twin 4-wheel trucks.

Or the 4-wheel Ballast Car having a capacity of 9 to 15 tons, depending on the height of the car and featuring 4 doors that level the ballast in either direction.

Along with our Longwall Roof Support Transport Car, Hoist Retarders, and all other related mining equipment—all are designed with Sanford-Day practicality to stay on the job.

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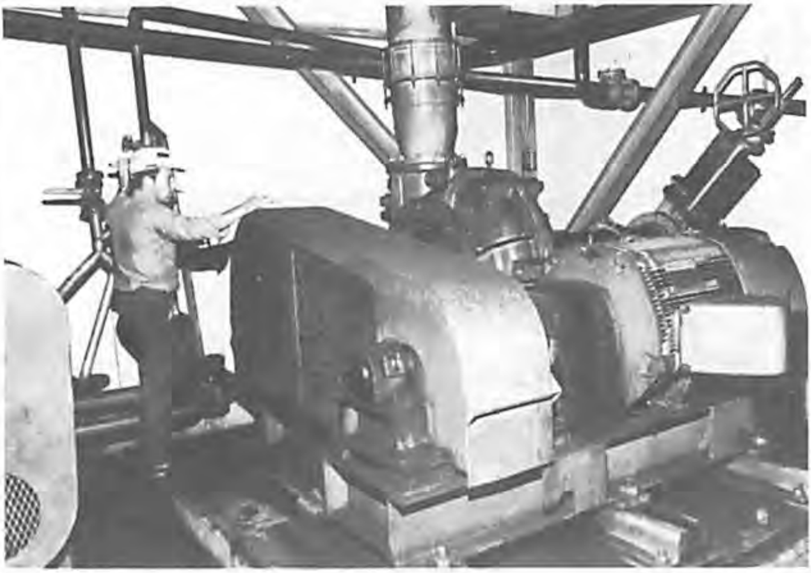

Trial Pump Offer Another Good Reason to Choose WARMAN

Mr. Ron Westfall, Preparation Plant Manager of Nemo Coal near Moberly, MO decided to test our pump in his application.

A 12/10 STAH ni-hard pump fitted with the no flush centrifugal seal was installed in July, 1983, replacing a ni-hard side suction slurry pump. The duty: Raw Coal Feed.

After one year of 24 hour a day, 6 day a week operation, we interviewed Mr. Westfall. The following were his comments to key criteria for pump selection:

Performance—"The Warman pump has reduced pump maintenance costs on that service by 90%. Previously, we had to rebuild the side suction pump every 2–3 months."

Service—"Excellent service day or night, and parts delivery has always been quick and reliable. Sometimes I've had to call my Warman rep at 4:30 a.m. to discuss problems. He's always been helpful and reliable."

Cost—"The premium on the initial cost has been more than justified in the first year of operation. I especially liked the Warman trial installation program — it conveyed the confidence that Warman has in their product."

Summary—"Warman is a step above. They are professional, helpful, and do a good job. Increased production, less downtime, and reliability. The men like the pump because it requires little attention. When we build another plant, we'll have Warman pumps in it. There's no doubt about it. Warman is the Cadillac of the industry. They make quality, heavy-duty pumps and give good service after the sale. I feel that I got my money's worth. What else can you ask for?"

For more information on the Warman Test Installation Program, **call the Sales Department at (608) 221-2261** and check out the benefits Warman pumps have to offer.

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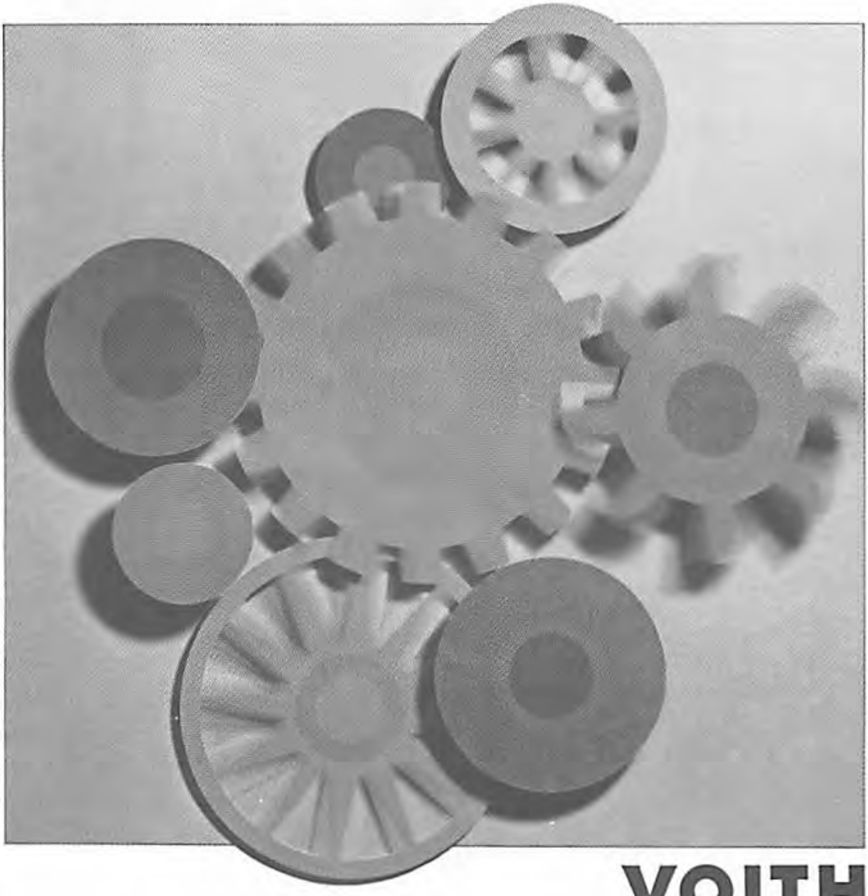


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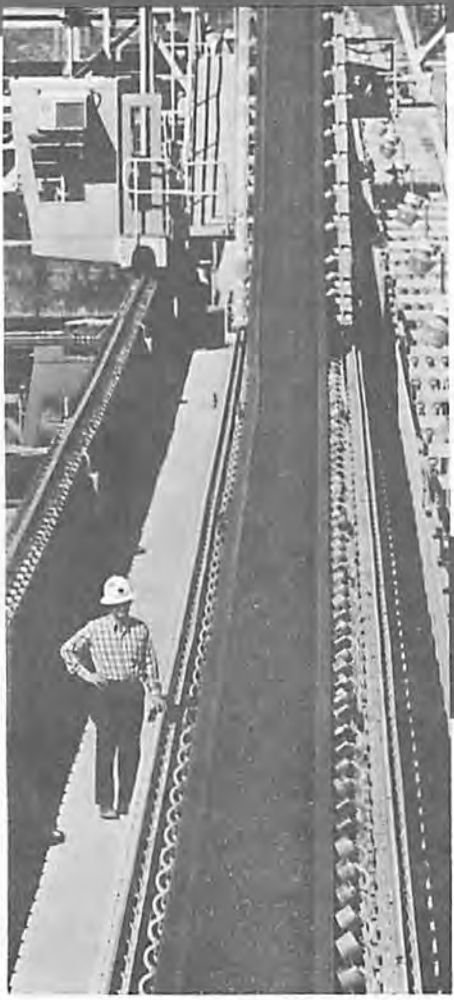

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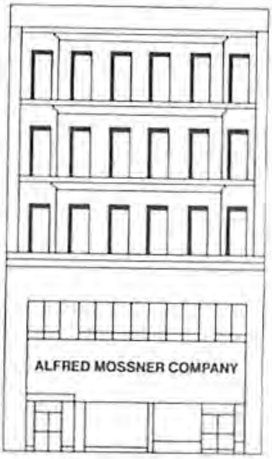

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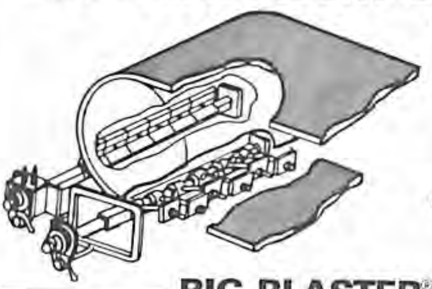
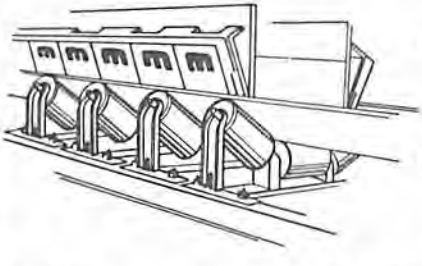
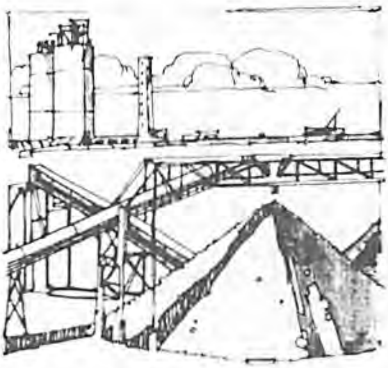
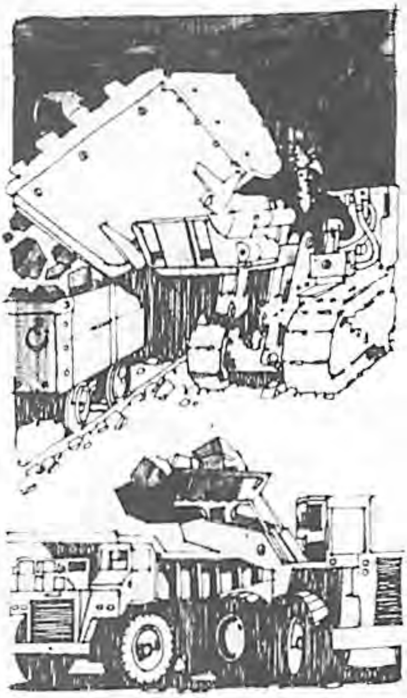








ESCO'S WEARCAP KWIK-TIP SYSTEM MAKES ADAPTERS LAST LONGER AND REDUCES REPLACEMENT DOWNTIME.

Now there's a dependable "insurance policy" available to protect your substantial investment in tooth adapters for dragline buckets or shovel dippers.

The Wearcap Kwik-Tip® system offers protection that gives virtually unlimited wear life to adapters.

A replaceable wear surface protects adapters.

The key to ESCO's Kwik-Tip system is the wearcap assembly. The summetrical top-and-bottom wearcaps protect the adapters from the pounding and abrasion that causes excessive wear.

Kwik-Tip Wearcaps save time and money.

Welding on wear plates or hardfacing adapters is an expensive, difficult job. It costs many hours of downtime and takes strength from the adapter steel.

But ESCO's Kwik-Tip system features mechanically replaceable wearcaps. They save hours of downtime and require no special tools for replacement.

Quick, in-field replacement for improved availability

Replace wear surfaces quickly and easily.

Top-and-bottom wearcaps slide on to protect the adapter and are locked into position by grooves. Then the Kwik-Tip point attaches quickly with two pins firmly secured by retainer rings.

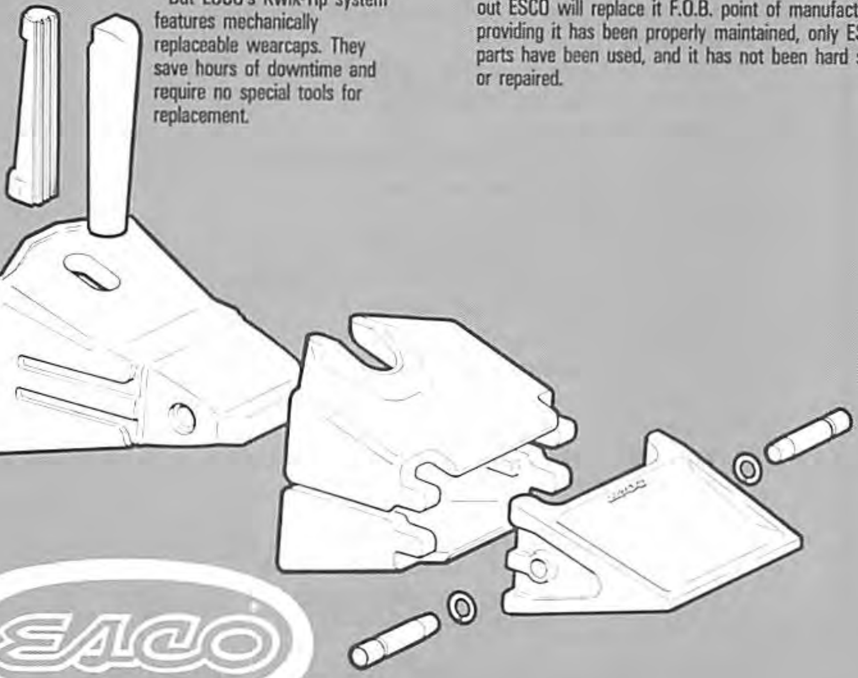
The assembly produces a positive lock. And you get additional metal where it counts – of the wear surface.

ESCO metallurgy assures dependable service.

The components of the Wearcap Kwik-Tip system are cast in tough ESCO alloys to resist shock and abrasion.

A warranty that says it all.

If a Wearcap Kwik-Tip system breaks before wearing out ESCO will replace it F.O.B. point of manufacture, providing it has been properly maintained, only ESCO parts have been used, and it has not been hard surfaced or repaired.



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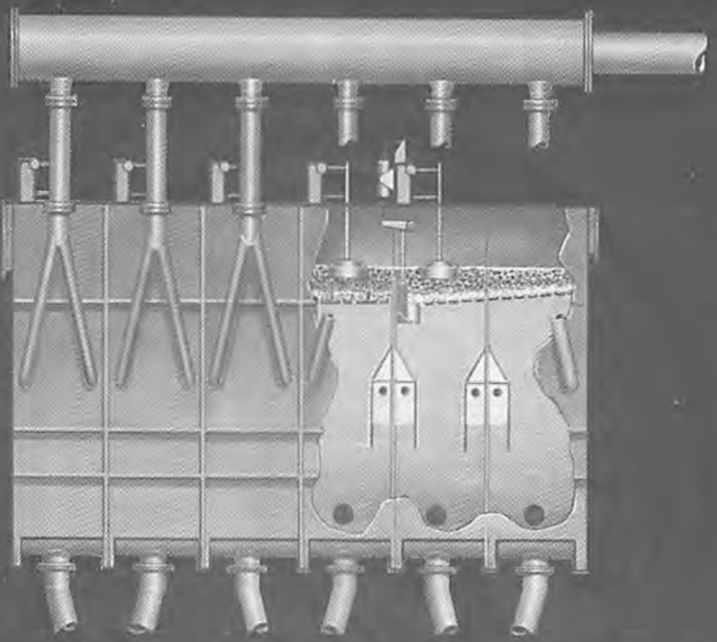


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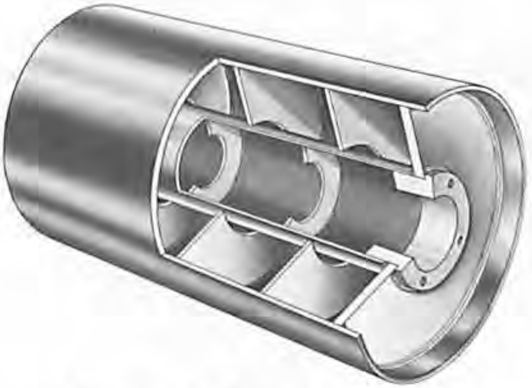

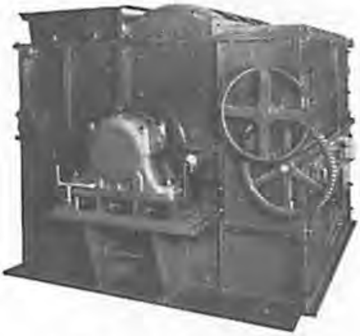

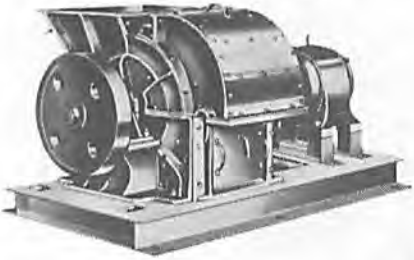

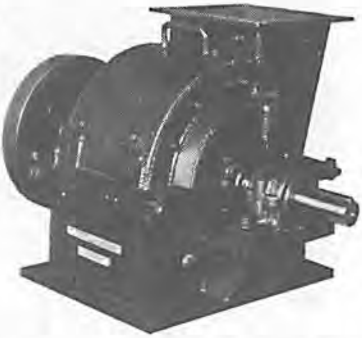

How the MSA® Machine-Mounted Model VII "outthinks" methane gas.

In years past, MSA has continuously improved its methane monitoring devices to keep pace with new requirements and new technology. Now… the MSA Model VII Methane Monitoring System.

The Model VII System is designed for installation on continuous mining machines to monitor the atmosphere at the face of a coal seam. Its rugged detector assembly readily mounts on the front end of the miner, enabling the system to sniff out methane gas. And automatically alerts the mine operator to any signal fault, line problem, or sensor imbalance. A two percent methane level will also shut down the miner.

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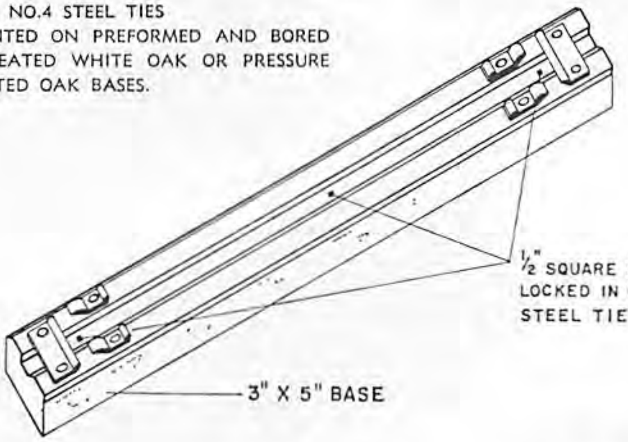

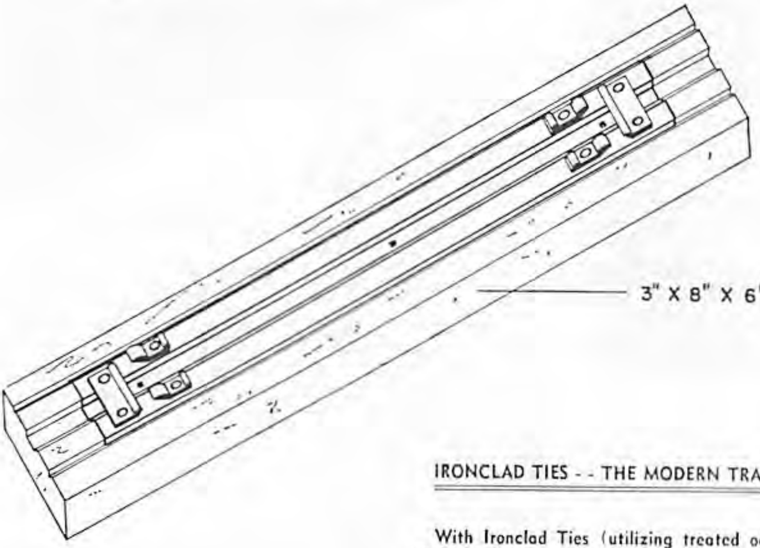

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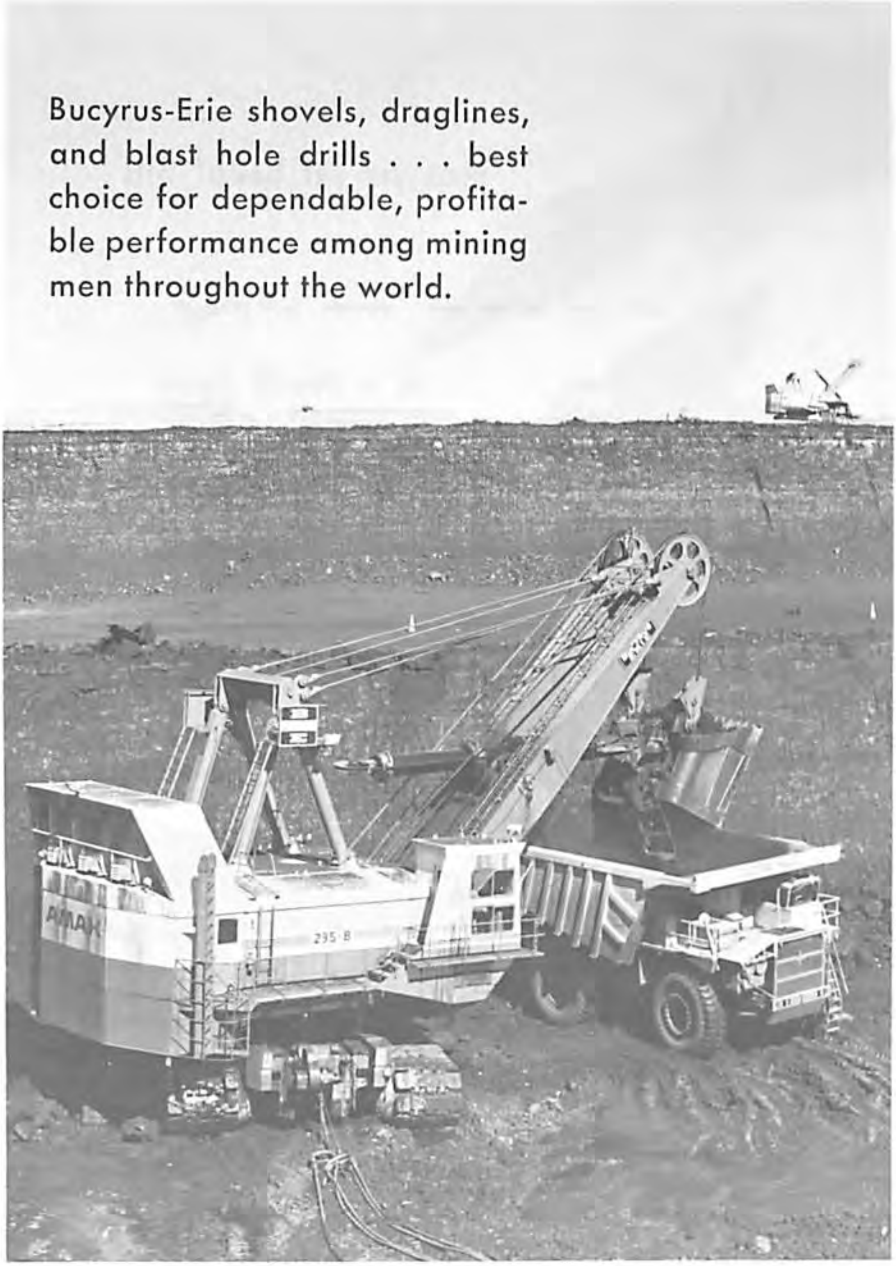
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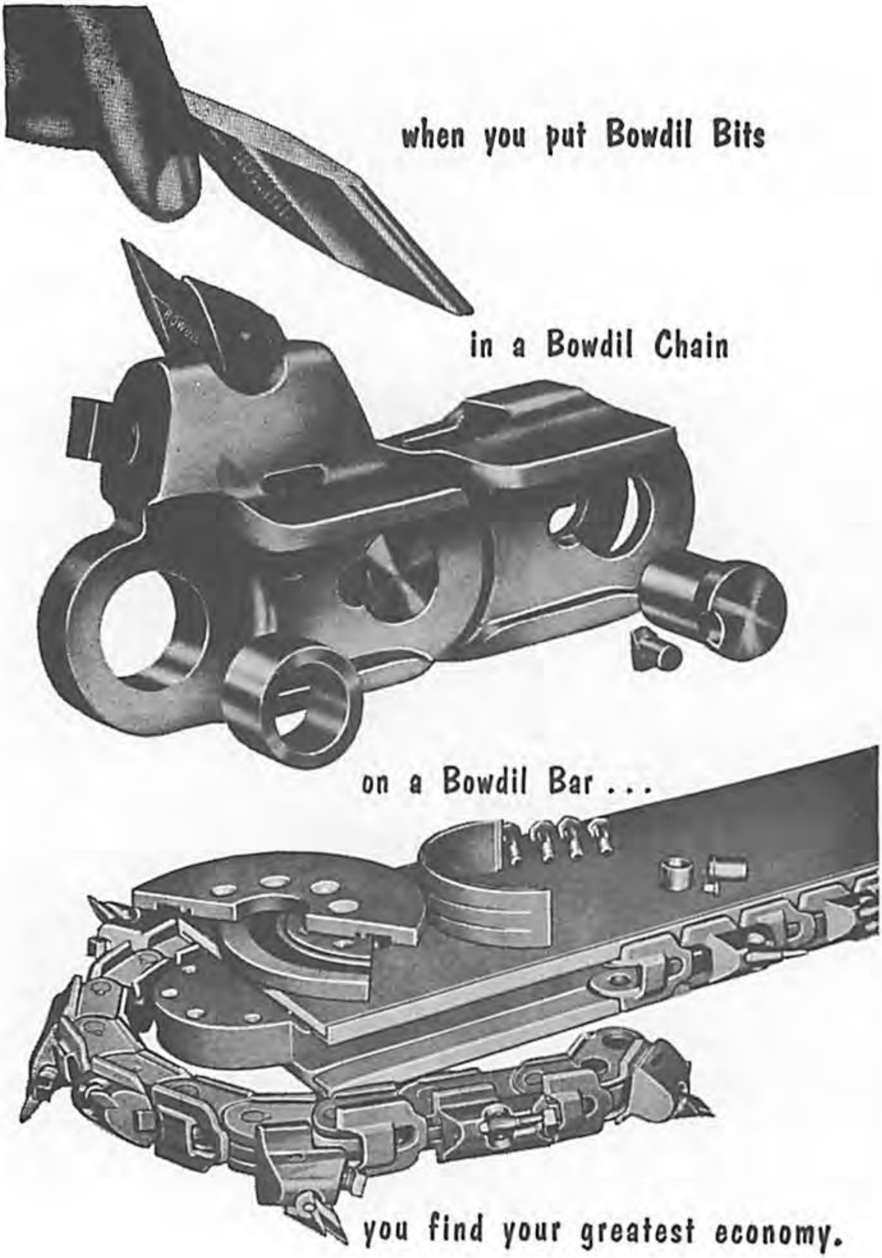
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Just to make sure, we went down ourselves to check. Four and a half miles from the portal to the face, in a long-established coal mine in Southeastern Ohio, near the West Virginia border. Opened in the late 40s, this model Appalachian mine has been worked continuously ever since.

We inspected a roof bolter, a continuous mining machine and a shuttle car, powered by Armaclad round and flat mining cables. A mine official and safety officer accompanied Laribee's Sales VP Paul Hronich (in and around the mines for more years than he cares to admit) and Sales Service Manager Bob Ogden (first time down).

Multiple flash photo of a face lobby showing the complex network of power cables necessary, with Laribee's Bob Ogden and a shuttle car in the rear.

Everything we saw below and heard from the miners helped confirm our view that Armaclad is as good a cable as any ever built, and far better than most. We invested millions in the first U.S. salt-cured mining cable production facility for just that reason ... unsurpassed cable quality, at a price the mining industry can afford, even in these tough times.

Power cables make a 230° turn around a pillar. Cable at bottom (being replaced) shows the terrific stresses a mine cable must undergo, and still perform reliably.

Mine officials and Laribee Sales VP Paul Hronich (far right) rest a moment during inspection tour.

We're so encouraged, we're now offering a full line of Armaclad Mine Power Feeder Cable in 5, 8 and 15KV constructions, in addition to our standard portable mining cables. It's all salt-cured, and stocked locally for instant service and delivery.

Laribee is responsive to your needs, because we're down there with you, digging out the coal.

For more information on Laribee's quality mining cables and the name of your local distributor, call Sales Service Manager Bob Ogden toll free.

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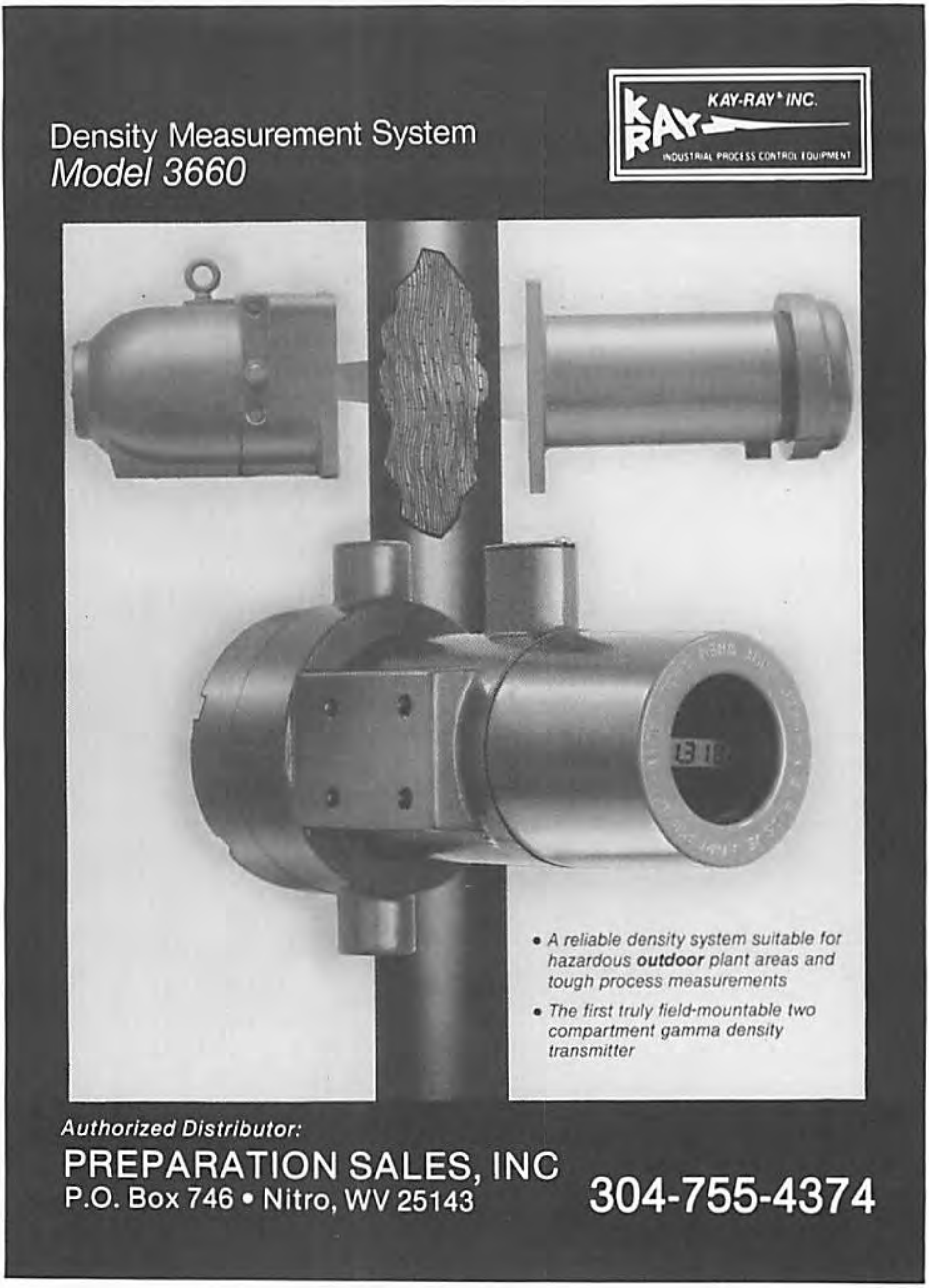

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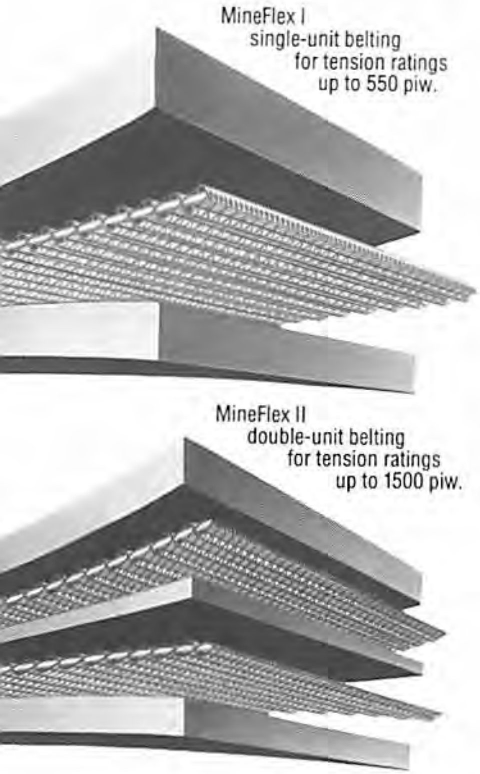
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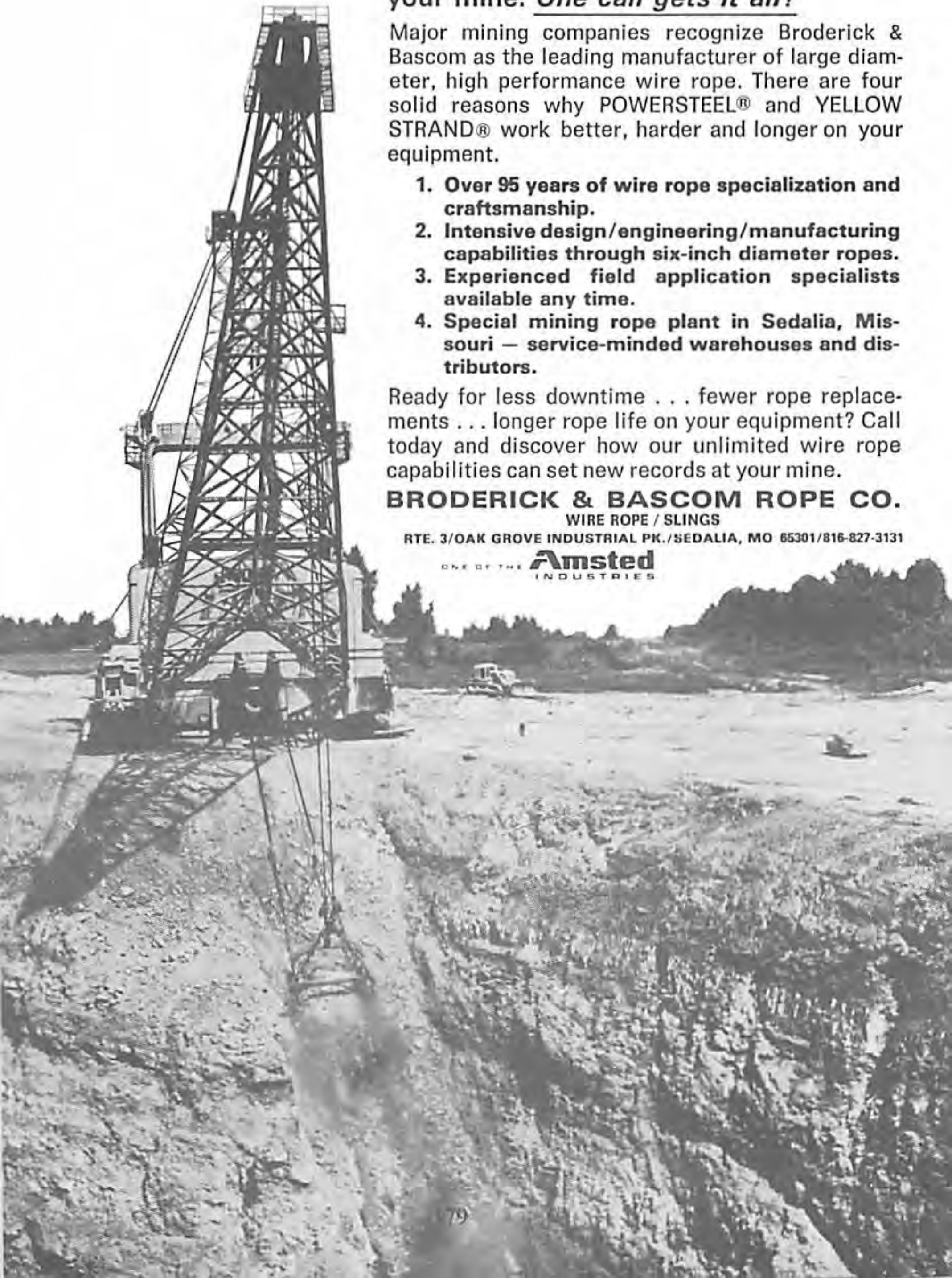

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