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TECHNICAL REPORT
December 1, 1992 through February 28, 1993

Project Title: **DEVELOPMENT OF AN ON-LINE IMAGE ANALYSIS FOR
ASSESSMENT OF PYRITE LIBERATION**

DE-FC22-92PC92521

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ABSTRACT

The degree of pyrite liberation is a key to determine whether a batch of ground coal obtained through a grinding process is acceptable. Currently, the liberation analysis is conducted manually through a microscope with a commercial image analysis software. This procedure is very labor intensive and time consuming. As a result, an automation procedure based on the principles of image processing is proposed to perform the analysis of pyrite/minerals liberation of coal. To make the automated image analysis system possible, a data base of the light reflectance characteristics of different coal constituents must be established. Characterization of coal images through the analysis of their histogram was conducted. In general, it was found that the distinction of coal particles or particle groups may be accomplished by determining the gray levels of zero pixel or by taking average gray level of each particle. In particular, when the gray level averaging is applied, the spread of gray levels of a given maceral becomes smaller. In other words, the spread in gray level among different maceral group becomes larger. This has led to a distinct boundary between different material group of coal. Two computer programs based on these findings are being developed. The implementation of these criteria will cover most of the coal samples that are previously analyzed. Consideration of special cases will require additional data analysis of histogram. Aside from image analysis, instrumentation for a laboratory scale on-line has been setup. An X-Y table was installed with a computer interface. A computer program was also developed to manipulate the motion of the X-Y table. A long distance imaging system was also put together. The integration of the X-Y table and the long distance imaging system will serve as the stage for image acquisition.

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MASTER

EXECUTIVE SUMMARY

To obtain the ultraclean fuel, coal must be pulverized into particles of ultrafine sizes. As a result, the characterization of ground coal, in particular, the assessment of pyrite liberation, becomes extremely difficult. The degree of pyrite liberation is the most important parameter of deciding whether a batch of ground coal is acceptable for fuel consumption.

Currently, the liberation analysis is conducted manually through a microscope with commercial image analysis software. This procedure, sometimes, causes discrepancies from one operator to the other in the interpret of microscopic images. On the other hand, the amount of coal can be inspected in each experiment is limited by the particle sizes of the ultrafine coal and the magnification factor of the microscope. Therefore, a large number of samples must be analyzed in order to assess the degree of pyrite liberation. This makes the present method of liberation analysis of coal a very labor intensive and very time consuming process. As a result, an automation procedure based on the principles of image processing is proposed to perform the analysis of pyrite/minerals liberation of coal.

Basically, different materials reflect light in different manners and, therefore, they can be identified based on their image of light reflectance characteristics (i.e. shade of gray). Furthermore, liberated and non-liberated pyrite particles are surrounded by media of different shades of gray. With these two pieces of information, the degree of pyrite liberation can be analyzed through a microcomputer. The proposed automated image analysis program will take the images of ground coal and conduct a series of analysis without any operator intervention. However, to make the automated image analysis system possible, an extensive data base documenting the light reflectance characteristics of different coal constituents (pyrites, vitrinite, inertinite, etc.) and a rule-based decision computer algorithm must be established. This will include the consideration of the effect of the actual operating parameters such as inclined incident of light, uneven focal planes of the sample. It is believed that this proposed automation process for image analysis is feasible in the laboratory operation involving polished pellet and can be considered as an integral part of the coal cleaning processes.

Analysis of coal images as well as the setup of new instrumentation have been carried out. This has included:

1. Study and compile the image characteristics of coal particles through the analysis of histograms.

2. Develop criteria suitable for particle grouping and pyrite liberation analysis.
3. Implement the data obtained in 1 and 2 into computer programs.
4. Setup and calibrate an X-Y table systems as well as a long distance imaging system.

The analysis of histograms has resulted in the development of criteria for characterizing coal image. First of all, it was found that the distinction of coal constituents (vitrinite, inertinite, and pyrite) are possible through the search for gray levels of zero pixel or through a gray level averaging technique. It appears that these two methods can be used to analyze most of the coal images obtained thus far. Two computer programs are being developed to test the proposed image analysis criteria.

OBJECTIVES

The objectives of this project are summarized in the following:

1. Improves the current coal characterization technology, in particularly, the assessment of pyrite liberation. This will include the detailed documentation of the light characteristics of different coal particles under a microscope.
2. Develop an image analysis procedure that provides a faster and more accurate pyrite liberation analysis than the existing manual process.
3. Provides a realistic assessment of making coal characterization procedure as a part of the coal cleaning and preparation processes.

INTRODUCTION AND BACKGROUND

The objectives of this research project is to develop an automation process for the determination of pyrite/minerals liberation as well as particle size distribution of ultrafine coal obtained during and/or after coal cleaning. To accomplish this, an image analysis computer program with an expert knowledge base for identifying different constituents (liberated and non-liberated) in coal must be developed. In addition, the evaluation process that allows an on-line evaluation of pyrite/minerals liberation will be developed. It is believed that the results of this research program can greatly reduce the intensive time and effort in the quality evaluation of coal during the liberation and separation processes.

Needs for the Evaluation of Ultrafine Coal:

The coal industries, today, are facing with a very stringent requirement on the emission and/or release of sulfuric compound to the living environment set forth by EPA. As a result, the need for producing ultra-clean coal effectively (Yen and Hippo 1990) has greatly increased. It has been reported by McCartnet (1969) and Jao (1991) that for the Illinois #6 coal the mean particle size of pyrite is less than 10 micron. Therefore, coal must be ground to ultrafine sizes in order to liberate the microscopically dispersed pyrite particles and to obtain the clean coal that meets the EPA requirements. The development of the procedure for effectively producing ultrafine coal is a difficult task and has been pursued by many researchers. On the other hand, to evaluate the degree of success of each of the newly developed coal pulverization procedures, a method for examining the ultrafine coal is needed. The traditional method (ASTM, 1973) for evaluation of coal fines is a two step approach. First of all, ground coal is subjected to centrifuge in heavy media for the separation of fraction with different specific gravities. Secondly, each fraction of a given specific gravity is then subjected to TGA for element analysis or SEM for the microscopic observation. However, these steps are quite time consuming and labor intensive. For example, the drying process after the centrifuge usually takes a few hours while the SEM inspection requires a tedious sample preparation. Clearly, the liberation analysis procedures recommended by ASTM is not suitable for the high volume ultrafine coal production which requires a quick analysis of coal particles. In our view, an effective characterization procedure for analyzing pyrite/mineral liberation should require a minimal specimen preparation. The actual measurement of ground coal particles should be conducted by taking the advantage of high speed data processing of computer. This is to ensure that a large number of samples can be accounted for whereby the liberation assessment will be statistically meaningful

and will be accomplished in a very short time. Ultimately, a high magnification device (such as optical microscope) is needed to examine the ultrafine coal particles. To develop into an on-line quality assurance mechanism, the sample preparation, sample inspection, and liberation analysis must be integrated into an automated mechanism. It is believed that the recent development of image analysis technique and long distance microscope may make such an integrated system possible.

Optical Microscopic Image Analysis:

Image analysis (Dawson 1987, Gonzales et al 1987) is a relatively new technique that is being applied to scientific and engineering research. Basically, image analysis is used to determine the optical characteristics (e.g. intensity of light reflectance) of objects. This is then followed by a logical assessment of the measured data and a comprehensive numerical calculation.

When an object is presented under a microscope several of its characteristics such as shades of gray, physical dimensions (length, width, area), shape, boundaries, texture are noticeable. Most of these characteristics, in general, are distinct among different objects. In the image analysis, an image is divided by a set of horizontal and vertical grids (or pixels). Within each grid area, optical characteristics are electronically recorded and analyzed through a computer system. Also, using a proper calibration procedure, the actual area represent by a group of grids can be calculated. Such an analysis procedure is referred to as the optical microscopic image analysis. In an image analysis system, a microscope is to provide a proper image for observation, a video camera along with a data acquisition mechanism (generally, a computer board) are to record the various optical characteristics of different objects, and finally a computer software is used to analyze data in order to distinguish different materials, and particle sizes.

Recently, the utilization of optical microscope with the Automated Image Analysis (AIA) has resolved some problems involving the visual interpretation of the objects at microscopic levels. For example, AIA has been applied successfully by Yen et al (1991) to determine the fiber angle orientation and fiber volume ratio of composite materials, and by Huggins et al (1982), Straszheim and Markuszewski (1985 and 1986) to analyze the particle size distribution of ultrafine coal, to identify different minerals and macerals in coal and to assess the pyrite liberation after coal grinding. This is primarily based on the principle that, in general, different materials have different light reflectance. Such characteristics appear as different shades of gray (or colors) under the video camera

observation and can be distinguished and analyzed through computer programs.

Current Application of AIA to Liberation Studies:

At present, for pyrite liberation analysis (Yen and Hippo 1990, Blankenship 1991, Jao 1991), a pellet is prepared by mounting samples of ground coal in epoxy resin. This pellet is subjected to several steps of polishing. The polished pellet was then brought to an optical microscope for examination and analysis using a commercial image analysis software. This software can only perform a limited number non-sequential routines in image enhancement and image analysis such as picture sharpening, area counting. In other word, a sequential logical analysis of pyrites with different surroundings (i.e. liberated and non-liberated) is beyond the capability of this computer program. Therefore, an interaction between operator and the computer program is necessary make a single measurement.

After the image of the desired area of the sample is adjusted for better human interpretation, a threshold gray level value is set for the pyrite particles. The operator records the area of the pyrite particles, their total number on the examined frame and the total area. Then, based on visual inspection, the person has to decide whether or not the pyrite particle is free and label it accordingly. This process is repeated until at least a total of about 200 pyrite particles are analyzed (Florek, 1991). Obviously, this procedure was laborious and time consuming. Even visual inspection is a rather daunting task and the operator is always doubtful as to whether or not the pyrite particle is free. In addition to these problems, due to the extreme brightness of the pyrite particles, the pixels in their neighborhood acquire a glow that makes it all the more difficult to establish the properties of the surroundings. Therefore, the results varied, depending on the decision made by different operators.

The most challenging task in making image analysis into an automated process is image segmentation, wherein, the classification of image regions into different objects. This is primarily because of the complexity of the image and the contrast variations in the particular video camera setting and in the light source of the object. For this purpose, numerous images of a sample must be analyze to determine their distribution of shades of gray (i.e. histograms), pixel values along a line, etc. These information will then be used to established an expert knowledge database regarding the relative gray levels of different macerals in coal. This will be followed by a decision making through a rule base artificial intelligent (Batchelor 1974, Pavlidis 1977) to detect the liberation of each individual particle. Base on the discussion above, it

is believed that the assessment of pyrite liberation proposed here is achievable.

Envisioned Process:

It is believed that the automated image analysis system proposed here can be used as a part of the coal cleaning process. The automated image analysis system can be used at the down stream of the liberation process and/or the separation process. Based on this concept, there will be a mechanism to collect coal samples from the cleaning process, a conveying system to transport coal samples into the inspection station, a process of sample preparation, and finally the facilities for the characterization of the liberation status.

TECHNICAL PROCEDURES

The overall goals of this project are (1) to develop a rule base automated image analysis system for assessment of pyrite liberation at the laboratory scale and (2) to upgrade the image analysis system into a bench scale package. These two phases will be conducted simultaneously. In the laboratory scale, the specimens to be analyzed will be under some what ideal conditions. However, the image analysis computer algorithm to be developed in this stage is essentially the foundation for any rule base coal characterization procedure. In addition, the completion of the first goal will represent a drastically improvement of the current technology in the liberation assessment. In the bench scale, we will attempt to emulate the automated image analysis into a part of the overall coal cleaning process. Under this constraint, live (non-pelletized) coal particles are to be inspected. In other words, the 3-dimensional features of an image which are not encountered in the observation of the flat surface of pellet will need to be thoroughly studied and analyzed. The mechanism to extract coal samples from the down stream of the liberation and/or process will be designed and the procedures as well as the facility for the on-line analysis of non-pelletized samples will be recommended. The specific tasks to be conducted in this proposed study are summarized as follows:

Task 1: Sample Preparation

Ultrafine coal (Illinois #6 coal) samples that have different degree of liberation will be used in this study. These samples were prepared through a previous CRSC/DOE project and are available at the Civil Engineering and Mechanics Department, Southern Illinois University. Both pelletized and particulate coal samples are needed. To prepare the pellet sample, ultrafine coal particles will be mixed with epoxy resin and cast into a plastic cylinder. Upon cured, the circular surfaces of the pellet will be subjected to several step of polishing until they are mirror like. To prepare the non-pelletized sample, ultrafine coal particles will be spread on a thin glass plate. A light brushing will be applied to minimized the overlapping of coal particles. Finally, a second glass plate will be used to clamp the coal particles in place.

Task 2: Determine the Image Characteristics of Pyrite and Coal Macerals

In this task, the expert knowledge base regarding the image characteristics of each coal constituents such as pyrite, vitrinite are to be developed. Normally, the light reflectance of each material in coal will have a band width of shades of gray. However, the gray levels of a material can shift under different light sources. Therefore, it is

necessary to determine the gray levels of each material in coal as well as to determine its relative difference in gray levels with other macerals/minerals. Sometimes, in a random sample, the gray level data may not be sufficient to differentiate one material from the other. In this case, particle characteristics such as shape factor (length to width ratio), particle size, surface texture will then be useful in assisting decision making. Therefore, in this task, we will attempt to measure as many image features as possible for pyrite, minerals, macerals in coal. The image analysis will be primarily conducted using a commercial image analysis software. In the meantime, we will develop an image analysis computer program of the similar capacity.

Task 3: Development of a Rule Base Liberation Criterion

So far, there is no commercial software which can do liberation analysis. Therefore, in this study, a computer program will be developed to perform pyrite liberation assessment. It is known that a liberated pyrite particle will be surrounded by the epoxy matrix of the pellet rather than the coal. As a result, base on the analysis of the gray level of the material surrounding to a pyrite particle. The status of liberation may be determined. On the other hand, the liberation status can also be determined based on the difference in gray between a particle and its surrounding. Ultimately, the variation of gray levels of an image containing the liberated and non-liberated particles can be modeled by Fourier series. Based on this mathematical model, the characteristics of the functional changes for liberated particle can be established. In this proposed study, the liberation criteria based on the gray levels of the surrounding to the pyrite particles will be developed into a computer program. This program will take an image (in terms of a computer file) and perform the liberation analysis. Interactive computer graphics will be developed and used to show the image with the results of the liberation analysis. The computer program developed in Task 2 will be combined with the computer program developed in this Task to form an integrated interactive image analysis software.

Task 4: Characterization of 3-Dimensional Image of Coal Particles

Image analysis of ultrafine coal particles prepared with glass plates will be conducted. This is to establish a preliminary database of the 3-dimensional image features of coal particles. To observe the non-pelletized particles, a microscope that can focus objects of different depths is needed. Thus a long distance microscope with a zoom lens to adjust for different field of depth is needed. In this task, we attempt to determine the effect of particle shadow on the gray level of a given materials. We will also

attempt to develop an method for calculating the area or volume of each particle.

Task 5: Verification Study

It is believed that the image analysis program to be developed here is capable of performing fast and accurate liberation analysis. To verify this, pyrite liberation data and the kinematics of ultrafine coal particles that obtained from the elaborated analysis through human operators will be used to compare with the results obtain from the image analysis program developed based Tasks 2 and 3. Extensive liberation data as well as particle size distribution of ground coal that established by Yen and Hippo (1990a) will be used as a reference.

Task 6: Design of an On-line System

In our view, the automated image analysis at its ultimate application should be built in a as a part of the coal cleaning process. The automated image analysis system can be used at the down stream of the liberation process and/or the separation process. As a result, the mechanism to extract coal fines from the cleaning process will be designed. During the conveying process into the observation stage, the coal sample will needed to be prepared. The use of glass plates recommended in Task 1 is thought to be one of the many possible options for specimen preparation that can be completed in short time. Most likely, it is necessary to characterize coal particle with 3-dimensional features, a measuring device such as a long distance optical microscope that can bring different fields of depth on to a focal plane is needed. In the observation stage, lighting facilities as well as the automated image analysis system are the essential elements. A flow chart of this on-line system will be developed. In this flow chart, the specification and design of all the key facilities will be provided.

RESULTS AND DISCUSSIONS

During the last three months, the research efforts has been concentrated on (1) setup the imaging system with long distance microscope and the X-Y table for the automated stage system, (2) extensive study on the histogram and gray levels (of particles) of several coal samples, and (3) development of the decision making criteria for liberation analysis.

Analysis of Histogram and particle gray level data

In analyzing a typical gray level image, one usually determines the pixel distribution of different gray levels (this is referred to as the histogram). during the inspection of ground coal particles, it is possible that the use of histogram may provide the information leading to the pyrite liberation analysis. This is because that different materials in coal appear to have distinct gray levels when a coal image is viewed through the computer monitor. Figures 1 and 2 give the typical coal images (viewed by a computer monitor) with their corresponding histograms. In general, the distinction in gray levels may be interpolated as (a) a gray level with zero pixel in a histogram represents the division between two types of maceral, or (b) the difference in gray level between macerals is greater than that of within the same maceral. In other words, there should be a distinct boundary between pyrites to inertinite and inertinite to vitrinite. Clearly, the images with different composition of particles will result in histograms of distinct characteristics. This suggests that analysis of coal images must be conducted on an individual frame basis.

Theoretically, there should be only four gray levels (or ranges of gray level) with zero pixel in an image. This will naturally divide the ground coal into voids/boundaries (in black), epoxy background, vitrinite, inertinite, and pyrite. However, the data extract from the histogram of several coal images have shown many gray levels with zero pixel. This will definitely bring confusing in the determination of boundaries between different macerals. On the other hand, since pyrite is the brightest among all the particles in an image, development of an computer algorithm searching for the upper gray scales of zero pixel may be worthy.

To further study the optical characteristics of ground coal, an gray level averaging technique was introduced. In general, in a particle there exists a distribution of (perhaps, continuous) gray levels. One can identify a particle much easier by using its average gray level. In addition, it was found that using the gray level averaging technique particles of the same kind (e.g. vitrinite, inertinite, pyrite) tend to group closer in their gray

Figure 1 Typical gray scale coal image (at 400x) and its corresponding histogram.

Figure 2 Typical gray scale coal image (at 400x) and its corresponding histogram.

values. In other words, the relative distance in gray level between vitrinite to inertinite and inertinite to pyrite becomes larger. Figure 3 shows the typical distribution of average gray level of different particles in a coal image. Based on the data shown in Figure 3, the distinction among pyrite, inertinite, and vitrinite using the average gray value approach is possible. More importantly, it was found that, for most of the images studied, the gray level spreads between vitrinite to inertinite (ΔG_1) and inertinite to pyrite (ΔG_2) tend to be the two largest values among the difference in gray level between two particles with adjacent light reflectance. In this regard, the particles that define the two largest differences in gray level are those which define the lowest gray level for pyrites, the highest and the lowest gray levels for inertinite, and the highest gray level for vitrinite. Furthermore, it was found that ΔG_1 usually greater than ΔG_2 .

Several special cases that do not fit the descriptions given in the previous paragraph have also been identified. For example, it is likely to have an image without the presence of pyrites and/or vitrinite. Also, it is possible that the particles involved in obtaining the first two largest gray level difference (i.e. ΔG_1 and ΔG_2) are not the particles define the boundaries between vitrinite to inertinite and inertinite to pyrite. To resolve these cases, it is necessary to investigate the spread in gray level of each individual maceral and mineral, the shape factor and size of each particle, the location where ΔG_1 and ΔG_2 were calculated, etc.

Implementation of Image Analysis Data into Computer Programs

Based on the flow chart established during first quarter of this project, two computer programs are being developed simultaneously. Both of these programs are designed to perform pyrite liberation analysis except they are based on different approaches. In particular, to differentiate different materials (pyrite, inertinite, etc.), one program is based on the zero-pixel gray level approach while the other program is based on the gray level average technique. Eventually, these two approaches will be merged into a master computer program. The brief descriptions of the two program are given as follows;

A: Zero-pixel gray level approach:

An image processing technique for pyrite pixel grouping was applied to the coal images and positive results were obtained. The pyrite particle identification process is called region growing. With this process, the coal image is scanned, and upon encountering a pyrite pixel, the region of pixels that are neighbors to the original pixel are tagged assigning them a different gray level and are included into

Figure 3 Distribution of coal particles based on the gray level averaging technique.

the growing group. The process for checking and tagging pyrite pixels will continue until all the boundary pixels of the current particle has been identified. Upon completing the group, the image scan is then resumed for the next pyrite pixel. The region growing technique employs an eight neighbor processing mask. Therefore, if there is only one pixel gap between pyrite pixels, the two pixels will be considered in different groups. Also, with the eight neighbor method, all attached pixels in any direction will be counted and included in the group. It should be realized that in this method a minimum threshold gray level must be given in order to isolate the pyrite particles.

The next step of this program is to identify free and non-free pyrite particles. This will require to check the pixels that are adjacent to the boundary of each pyrite particle. The status of liberation of a pyrite particle will be judged upon the gray level of its surrounding. Again, this will require the input of the gray level characteristics of other macerals and the epoxy (the pellet material).

B: Gray level averaging approach:

After careful examination and interpretation of the histogram of many coal images, we found that several gray-level patterns can be used to perform the liberation analysis of coal. By building meaningful and explicit descriptions of physical objects from the image, particles might be matched by its gray-level. Since pyrite has a very pronounced reflections to the viewer in the coal image, the "bright spots" due to the lighting are far more conspicuous than the matrix, therefore, we should have no difficulty recognize and classify the pyrites in the coal image taken.

Histogram segmentation through gray level averaging is an efficient computational techniques for detecting and segmenting the coal image by thresholding its gray levels so as to divide the particles such as vitrinite, inertinite, pyrites, matrix and holes into five subgroups. As discussed previously, the gray-level variance within these subgroups are small in comparison to the overall image gray-level variance among different macerals.

The basic idea of this method of histogram segmentation is as follows: Initially, we divide the gray-level into five intervals based on the gray-level characteristics distribution between particles. For each intervals, we computed the local minimum or the trough and record the thresholds at the histogram troughs (t_1, t_2, t_3, t_4 and t_5). These threshold values are then used to partition the particles into five separated gray-level ranges. This is done by reassigned those pixels whose intensity that are between the

threshold value t_{i-1} and t_i at the histogram trough are deemed to lie in one region, and those above and below are deemed to lie in the other regions. The particles, vitrinite, inertinite, pyrites, matrix and holes are then successfully recognized. The pyrite liberation analysis in this program will follow the same procedures as that used in the zero-pixel gray level approach.

It should be pointed out that special subroutines will have to be developed to analyze the coal image that does not have all the particle groups presented. This is also true for those images with an unclear division among particles of different material groups.

Development of Components for an On-line System

Two components of the envisioned on-line system have been together during this quarter. An X-Y table consists of two stepping motors with platform and a computer interface system have been received. The table has a stepping capability of 0.0025" with a resolution of 0.0001". A C-language based computer program was developed to manipulate the motion of the X-Y table. It should be pointed out that this system control program can be integrated as a part of the image analysis program. In the envisioned process, this table will bring coal samples under a long distance video imaging system through the manipulation algorithm to be developed and embedded in the C-language program. A z-axis motion has to be introduced to provide an automated focusing mechanism.

A long distance imaging system was also integrated during this quarter. This system consists of a long distance microscope (up to 660x), a color CCD video camera, a color frame grabber, and a 486 computer. The light source of the long distance imaging system is provide through a fiber optic ring light attached with the long distance microscope. The minimum working distance of the long distance microscope is 10 mm. It is necessary to calibrate the long distance imaging system so that an optimal working distance for observing coal pellet is obtained.

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PROJECT MANAGEMENT REPORT
December 1 through February 28, 1993

**Project Title: DEVELOPMENT OF AN ON-LINE IMAGE ANALYSIS FOR
ASSESSMENT OF PYRITE LIBERATION**

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Projected and Estimated Expenditures by Quarter

Quarter*	Types of Cost	Direct Labor	Materials and Supplies	Travel	Major Equipment	Other Direct Costs	Indirect Costs	Total
Sept. 1, 1992	Projected	6,618	475	0	8,500	750	1,934	18,277
to Nov. 30, 1992	Estimated Actual	4,052	124	0	6,025	0	912	11,113
Sept. 1, 1992	Projected	13,236	950	600	8,500	1,500	2,789	27,575
to Feb. 28, 1993	Estimated Actual	9,600	847	0	6,125	315	1,900	18,787
Sept. 1, 1992	Projected	19,855	1,425	600	8,500	2,250	3,643	36,273
to May 31, 1993	Estimated Actual							
Sept. 1, 1992	Projected	50,890	1,900	600	8,500	2,400	6,429	70,719
to Aug. 31, 1993	Estimated Actual							

*Cumulative by quarter.

COSTS BY QUARTER

Development of an On-Line Image Analysis for Assessment
of Pyrite Liberation

O = Projected Expenditures -----

Δ = Estimated Actual Expenditures _____

Total Illinois Clean Coal Institute Award \$70,719

SCHEDULE OF PROJECT MILESTONES

Milestones:

- A. Sample preparation
- B. Determine the image characteristics of pyrite and coal macerals
- C. Develop a rule-base liberation criterion
- D. Characterize a 3-dimensional image of coal particles
- E. Verification study
- F. Design an on-line system
- G. Reporting

END

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