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**THE CHARACTERISTICS OF AMERICAN COALS IN RELATION TO
THEIR CONVERSION INTO CLEAN ENERGY FUELS**

Final Report

By
W. Spackman

June 1982
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Pennsylvania State University
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**THE
CHARACTERISTICS OF AMERICAN COALS
IN RELATION TO
THEIR CONVERSION INTO CLEAN ENERGY FUELS**

Final Report

by

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ABSTRACT

Work performed under DOE Contract No. DE-AC01-76ET10615 represents a portion of the total effort at The Pennsylvania State University aimed at characterizing the Nation's coals and developing the ability to predict coal performance from a knowledge of coal characteristics.

Eighty one agencies representative of the agencies concerned with coal characterization were surveyed to determine the extent to which the Nation's coal resources were adequately characterized for future exploitation. The principal finding of this survey was that "the Nation's coals are inadequately characterized for their efficient and effective use, this being particularly true in relation to coal conversion technology and maintaining environmental quality."

To further characterize the Nation's coals, the Penn State Coal Sample Bank and Data Base were expanded to include a total of 1150 coal samples. This was, in part, accomplished with Contract funds. A Penn State Coal Sample Bank facility was constructed and outfitted with the aid of contract and University funds. The Sample Bank includes full-seam channel samples as well as samples of lithotypes, seam benches, and sub-seam sections. To the extent feasible and appropriate "basic compositional data" were generated for each sample and these data were validated and computerized. These data include:

1. proximate analysis
2. ultimate analysis
3. sulfur forms analysis
4. calorific value determination
5. maceral analysis
6. vitrinite reflectance analysis
7. ash fusion analysis
8. free-swelling index determination
9. Gray-King coke type determination
10. Hardgrove grindability determination
11. Vicker's microhardness determination
12. major and minor element analysis
13. trace element analysis
14. mineral species analysis.

During the contract period more than 5000 samples were prepared and distributed from the Sample Bank to Penn State researchers, analytical laboratories and the coal community for a broad spectrum of research purposes. Similarly more than 4000 computer print-outs of data were distributed from the Penn State Coal Data Base.

In conjunction with coal characterization, automated analytical systems were developed and proven for the production of:

- 1) reflectance profiles for use in coal quality control;

- 2) maceral group analyses for coal evaluation in beneficiation studies and for use in screening coals for carbonization and liquefaction;
- 3) vitrinite reflectance means for coal rank assessments, and
- 4) data on pyrite size consist as a means of evaluating coal cleaning potential.

In addition a system of "rational analysis" was developed as a means of advancing our ability to quantitatively determine the concentrations of the minerals forming a part of any coal feedstock.

Studies of the pyrolysis behavior of coal in an entrained flow isothermal reactor have resulted in a number of significant conclusions concerning the devolatilization of low rank coals during combustion. In order to permit study of coal/gas reactions at high pressures and temperatures a pressurized, entrained flow isothermal furnace was designed and constructed. The unit has been designed for use with hydrogen but is capable of being used with any variety of inert and reactive gases as may be appropriate in the study of pyrolysis and gasification reactions. A separate, explosion proof building was constructed by the University to house the facility. Shakedown testing of the reactor has been completed and it is ready for operation in a research mode.

A theoretical and experimental study of the pyrolysis of coal has been completed. The data indicate that, to a large extent, pyrolysis occurs in the shrinking core mode where actual pyrolysis temperatures are considerably lower than reactor temperature.

The reactivity of chars, produced from all ranks of American coals, has been studied with regard to reactivity to air, CO_2 , H_2 and steam. It has been shown that char reactivity is significantly enhanced by increasing the rate of heating of the coal to its maximum temperature. A review of the major factors influencing char structure and reactivity is presented along with a discussion of the significance of these factors in coal gasification processes.

Another area of the Contract research has concerned the catalytic effect of minerals and various cations on the gasification processes. These effects were examined using natural mineral contents, augmented mineral concentrations and variable additions of selected cations. The results show both inhibiting and accelerating effects depending upon the minerals and cations involved and the reaction environments in which they are operating.

Combustion of chars and low volatile fuels along with the combustion of coal-oil-water-air emulsions and other subjects of research which formed a part of the contract work and are reported on here and in the various publications stemming from the work. A computer model was devised to explain the otherwise anomalous experimental values of ignition distance for the low-reactivity, low volatile fuels. The

feasibility of utilizing coal/oil and coal/oil/water mixtures was demonstrated in a 1.25 million Btu/hr hot-wall furnace of 40 ft³ combustion volume.

Finally the use of small angle, x-ray scattering techniques was applied in the characterization of the micropore structure of heat treated coals and found to be a useful tool.

The products of this research can be found in 23 DOE Technical Research Reports and 49 papers published in the scientific literature. As another mechanism of technology transfer the results also have been conveyed to the coal research community via more than 70 papers presented at a variety of scientific meetings. References to all of the above are contained in this Report.

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EXECUTIVE SUMMARY
OF
SALIENT RESULTS

A representative cross section of agencies knowledgeable with regard to coal characterization was surveyed to determine the extent to which the Nation's coals were adequately characterized. The conclusions drawn from this survey were:

1. the Nation's coals are inadequately characterized for their efficient and effective use , this being particularly true in relation to coal conversion technology and maintaining environmental quality;
2. the number of agencies conducting coal characterization programs is too small to meet the Nation's needs within the time frame required;
3. the scope of coal characterization programs should be expanded to develop a broader spectrum of basic compositional and performance data.

This Report summarizes the results obtained during a four-year segment (1976-1980) of the on-going effort at The Pennsylvania State University to further our understanding of the characteristics of the Nation's coal resources. Associated with this goal of expanding our knowledge of coal characteristics is the objective of understanding the significance of coal characteristics in the conversion of coal to clean energy fuels. The overall objective of the Program is to achieve the capability of predicting, from a knowledge of coal composition, the behavior of a coal in pre-conversion processing and in coal gasification, liquefaction and combustion processes.

The bulk of the research achievements have been disseminated in the form of 23 Technical Research Reports and 49 papers published in the scientific and technical literature. References to these are contained herein. Technology transfer was further implemented by the design, development and presentation of 20 short courses based upon the research findings. In addition, more than 70 papers were presented at scientific meetings as another means of communicating the products of the investigations. During the four years of the Contract, the graduate training programs of more than 50 students were supported, 39 advanced degrees were awarded based, at least in part, on Contract work and 40 trained scientists and technicians were placed in the Nation's energy community.

The Penn State Coal Sample Bank was expanded to include more than 1100 samples. The samples represent more than 250 coal seams and have been derived from 25 states. The samples have been used extensively by researchers in the coal community. More than 3900 samples were prepared and distributed for analytical and experimental work as a part of the Contract work and in excess of 1300 samples were distributed to other agencies. Of the latter, 50% were distributed to University laboratories, 40% to industrial organizations and 10% were sent to governmental facilities.

All coal samples collected were subjected to a characterization program which resulted in a body of information referred to as "basic compositional data". All such data were computerized and stored in an IBM 360/370 system and on a PDP-8A mini-computer. The IBM system was designed for use in exploring inter-relationships between compositional characteristics, physical properties and coal performance. The mini-computer software was designed and used as a inter-active computer system to respond to both internal and external requests for coal data. This Penn State Coal Data Base is capable of accepting 370 pieces of information on any individual sample and an additional 225 values can be calculated from the raw data, bringing the total number of informational repositories to 595 for any given sample. During the four year Contract period, in excess of 4,000 printouts were supplied to agencies within the coal community.

Because the plastic properties displayed by bituminous coals are of significance in their utilization and because these properties can deteriorate in storage, a study of the effect of "weathering" and oxidation on the plastic properties was undertaken. The results of these studies revealed plastic measurements to be useful quality control tools in evaluating the coals stored in a sample bank. In addition, investigation of the effects of losses in plastic properties on the behavior of coal in coal liquefaction showed that the degree of oxidation necessary to significantly change the plastic properties of coal does not affect the degree of conversion during liquefaction. Also revealed was the fact that initially the oxidation appears to be a surface phenomenon, in that further crushing of the coal can restore some of the fluid properties.

An automated system for characterizing the maceral composition of a coal was designed and developed. This provides a "fingerprint" of coal composition which is useful in quality control. Such systems are now in use in the steel industry in conjunction with monitoring the composition of feedstocks for metallurgical coke production. Research conducted in automated reflectance microscopy under this Contract has demonstrated the following:

1. a high precision, automated microscope photometer can be constructed from commercially available system components;
2. reflectograms of the organic components in coal are highly reproducible and sensitive to minor compositional variations;
3. programs can be developed to quantify coal reflectograms, and, vitrinite reflectance data generated in this manner agree well with visually derived results;
4. data generated from such automated systems can be applied to wide-ranging problems where petrographic analyses are required.

An automated system for characterizing the pyrite in coals was designed and constructed. This provides information on pyrite size consist, as well as on total pyrite content. Such information will find use in evaluating a coal's potential for sulfur reduction and in devising effective and efficient methods of pyrite removal.

An entrained flow, isothermal furnace for use in the study of coal/gas reactions at high pressures (up to 100 atmospheres) was designed and constructed. Coal particles are delivered from a feed bin at a uniform and continuous

rate to a water-cooled nozzle and fall vertically through an isothermal reaction tube. The coal particles are subjected to rapid heating ($\sim 10^4$ °C/min). Design of the internal flow characteristics results in an effective inverted-flow profile which assures that the particles remain in the center of the gas stream instead of striking the reactor walls. The unit was designed primarily for use with hydrogen; however, it can be operated with inert and other reactive gasses (eg. O_2 , CO_2 , H_2O).

Two major steps occur in coal gasification: (i) devolatilization of the coal as it is heated to and held at reaction temperature and (ii) reaction of the resultant char with O_2 , CO_2 , H_2 and/or steam. To understand the over-all coal gasification process, it is important to understand the mechanism of coal devolatilization. In our attempt to do this, a dilute phase, entrained flow isothermal reactor was built, in which coal could be heated rapidly to a desired temperature in N_2 , held for a desired period of time at this temperature, and then the solid product quenched rapidly to room temperature. Major conclusions of these studies are as follows:

- 1) weight losses for fixed residence times up to 0.4 sec are independent of particle sizes between 41 and 201 μm diameter but increase with temperature over the range studied, that is, 700 to 1000°C.
- 2) the maximum yield of volatiles is particle size independent and essentially temperature independent;
- 3) the maximum yield of volatiles considerably exceeds that measured by the standard ASTM test; this is attributed to the essential absence of secondary hydrocarbon cracking reactions on char surfaces due to operating a dilute phase;
- 4) pyrolysis is multi-stage with the first stage essentially completed within 0.4 sec at 950°C and accounting for about 75% of the total volatile matter release;
- 5) release of volatiles in the first stage obeys a first order reaction; the apparent-activation energy for this release is low - that is about 45 kJ/mole;
- 6) rapid devolatilization of lignites is accompanied by rapid increases in the surface area and pore volume of the solid;
- 7) chars produced following rapid heating, have larger pore volumes than those produced using slow rates of heating (that is 5-10°C/min). This probably explains why chars produced by rapid heating of lignites have higher reactivities during their subsequent gasification than chars produced by slow heating.

The reactivity of chars, produced from all ranks of American coals, to air, CO_2 , H_2 and steam has been studied by following their weight loss as a function of time. It has been shown that char reactivity is enhanced by increasing the rate of heating of coal to maximum temperature and holding the level of maximum temperature and soak time at maximum temperature to a minimum. It has also been shown that there are major differences in the reactivity of coal chars and that these differences are strongly influenced by the rank of the starting coal. The major differences are attributed to

three factors:

1. concentration of active sites;
2. accessibility of the reactant gas to the active sites, and,
3. presence of inorganic catalysts.

Reactivity of chars produced from lignites and sub-bituminous coals is at a maximum because they exhibit optimum properties. In these coals, surface areas and active sites are at their maximum levels and during charring extensive porosity is developed with large volumes of feeder pores. Diffusion of reactant gases is rapid through the feeder pore system and active site utilization is high. These low rank coals typically contain large concentrations of well dispersed cations associated with carboxyl groups. Upon charring, well dispersed metals and metal oxides are present on the carbon surfaces and are available to catalyze the gas reactions.

The above applies when gasification takes place in the presence of an oxidizing gas such as air, CO_2 or steam. When hydrogen is involved, American coal chars show much less variation in reactivity as a function of the rank of the original coal.

Shapes of burn-off versus time (t) plots for various coal chars studied by reaction in air, CO_2 , H_2 , and steam were found to be quite similar in shape (Mahajan *et al.*, 1978). The plots can be normalized into a single characteristic curve using a dimensionless time scale such that $t/t_{0.5}$ (that is, τ) equals one at a fractional burn-off (BO) of 0.5. For each gasification medium, BO versus τ data for different chars up to a maximum BO of 0.7 can be correlated by a cubic equation of the form, $\text{BO} = a(\tau) + b(\tau)^2 + c(\tau)^3$. Computer correlation of the data showed that even though $t_{0.5}$ varied widely, depending upon the coal char reacted and gasification medium used, best values for the coefficients a , b and c in the above equation gave a very high correlation for all the results. This unification of the coal char-gasification reactions makes evident that, in the chemical control regime, there is a universal burn-off plot for most chars for the four important gasifying media.

The study of the catalytic effects of minerals and cations on the gasification reactions revealed the following:

1. minerals have little effect on the char-air reaction;
2. none of the minerals studied showed a catalytic activity in conjunction with the char- CO_2 reaction, but, pyrite and gypsum inhibited this reaction;
3. in hydrogasification, siderite and pyrite are very active catalysts;
4. calcite and clay minerals tend to inhibit the hydrogasification reaction;
5. at a level of approximately 0.3 moles of cation/g of coal, the relative ordering of various cations as to their catalytic activity depends upon the particular gasification reaction being considered - for the char-air reaction:

$$\text{Na} > \text{K} > \text{Ca} > \text{Raw} > \text{Fe} > \text{Mg} > \text{Dem},$$

where "Raw" and "Dem" signify chars produced from raw and demineralized lignite, respectively - for the char- CO_2 reaction:

Na > K > Ca > Raw > Fe > Dem > Mg,

and for the char-steam reaction:

K > Ca > Na > Fe > Raw > Mg > Dem;

6. catalysis of lignite char gasification in H_2 shows a radically different story - iron is the most active catalyst, followed closely by sodium - calcium and potassium are poor catalysts for the hydrogasification reaction, as is magnesium and in direct contrast to the behavior of calcium for the char-steam reaction, increasing amounts of calcium lead to an increasing extent of retardation of the char- H_2 reaction.

Studies of the effects of the pre-oxidation of bituminous coals on the reactivity of subsequently produced chars has shown that reactivities in the gasification reactions can be increased by factors of more than 30 times.

The feasibility of burning coal/oil/water mixtures was demonstrated using a hot wall furnace with a combustion volume of 40 cubic feet. The tests showed flame stability and turndown to be very good and carbon monoxide emission levels were substantially independent of water content. NO_x measurements showed a monotonic rise with increasing coal content but the levels at all times were well below allowed limits for large boilers.

I. GENERAL DESCRIPTION OF THE PROGRAM AND ITS OBJECTIVES

The research program at The Pennsylvania State University which is focused on understanding the significance of coal characteristics in the conversion of coal to clean energy fuels had its inception in the late 1960's under the auspices of the Office of Coal Research of the U.S. Department of Interior. Initially, the effort focused on the characteristics of American coals and their relationships to coal mining, preparation, liquefaction and gasification (Figure 1). Phase II (Figure 2) involved deletion of mining as a matter of concern and introduced studies related to establishing correlations between compositional characteristics, coal properties, and combustion behavior. Additional emphasis was placed on mineral matter and its significance in processing and utilization and the National Science Foundation and the Electric Power Research Institute participated in the support of the research. Phase III of the program maintained the same focus and during this period the Energy Research and Development Administration of the Department of the Interior and subsequently, the Department of Energy, assumed sponsorship for the liquefaction component of the program and the central element of the program was funded under DOE Contract EX-C-01-2030 (Figure 3). This latter contract has covered a four-year segment of the total program and it is this element that is treated in this Final Report.

The primary objective of the overall program is to achieve the capability of predicting, from a knowledge of coal composition, the behavior of a coal in pre-conversion processing and in coal gasification, liquefaction and combustion processes. The goal is to attain the same high level of predictive accuracy that is now found in the area of coal carbonization, where Penn State's collaborative work with the steel industry proved to be highly successful.

It is reasonable to ask if this goal is in fact attainable, recognizing the heterogeneity of coal seams. Clearly, it is not if one concerns oneself simply with the rank of the coal seam and its aggregate chemistry. The goal may very well be attainable, however, if as in the case of coal carbonization, we concern ourselves with the reacting entities and the properties of the important coal lithotypes.

Expressed in its simplest terms, the program consists of two principal components (Figure 4). The first involves the generation of sufficient quantitative data on the compositional characteristics and physical properties of the Nation's coals to permit the proper selection of coals for testing and to provide a statistically valid data base for inspecting interrelationships between compositional characteristics, properties, and behavior. The second component is the actual development of the "predictive technology" required for the effective and efficient use of coal in the several aspects of utilization with which the program is concerned. The latter includes coal beneficiation, gasification, liquefaction and combustion. Figure 5 attempts to depict the steps required to attain the desired predictive technology and indicates some of the areas in which such a predictive technology will find application.

THE PSU/DOE RESEARCH PROGRAM
Program History I

THE OCR PROGRAM

Figure 1

THE PSU/DOE RESEARCH PROGRAM
Program History II

Figure 2

THE PSU/DOE RESEARCH PROGRAM
Program History III

Figure 3

**THE PSU/DOE RESEARCH PROGRAM:
BASIC COMPONENTS**

Figure 4

Figure 5

In order to make progress toward this overall goal, an integrated, inter-disciplinary program was devised consisting of a number of interrelated "facets". These program facets and their interrelationships are identified in Figure 6. A brief description of the facet functions and interrelationships follows.

Facet I is entitled "Characterization of the Nation's Coal Reserves." Included in this facet is a function to provide the entire program with the coal samples required for the investigations. The program requires a sampling effort that would ensure the availability of the full spectrum of all of the volumetrically important lithotypes comprising the Nation's major coal reserves, with representation from the major regions which are capable of supporting conversion plants.

Also included in Facet I is the determination of basic compositional data on all coal samples. This is the main core of the effort to establish a knowledge of the causal interrelationships between important compositional characteristics and the coal properties significant in beneficiation and conversion processes. The data developed here are used to develop hypotheses for evaluation, and the information is used to select lithotypes or seams for testing in gasification or other reactors or for experimental use in developing beneficiation procedures.

A third component of Facet I involves the operation and maintenance of the Penn State Coal Sample Bank, in order to provide fully-characterized coal samples to the program's facet investigators, and to meet the requests of other DOE contractors and other agencies.

The generation of basic compositional, special analytical, seam fractionation, and behavioral data on coals and lithotypes has led to the development of a computerized coal data base which is maintained as an in-house research tool, primarily for the selection of individual samples and suites of samples for experimentation, and for the investigation of composition-property-behavior interrelationships. This constitutes the Penn State Coal Data Base.

Facet II emphasizes the kind of fractionation studies which permit the development of conventional washability data but which also define more adequately the preparation-beneficiation characteristics of coal seams. Innovative methods of fine and ultra-fine coal cleaning were sought. Another aspect of this research focused upon the techniques for managing the composition of conversion plant feedstocks.

Facet IV is concerned with the significance of coal characteristics in gasification processes. A major sub-facet involved the development and operation of suitable reactors and reactivity tests. Reaction, in this context, means reaction of the coal material in pyrolysis and agglomeration, as well as to oxygen, carbon dioxide, steam and hydrogen. A further objective is to attempt to develop a working model of coal constitution that would explain current experimental results, and be able to predict new ones with reasonable accuracy.

A second major component of Facet IV has as its objectives the development of additional approaches for characterizing the structure of coals and chars; the development of relationships between char structure and reactivity; the understanding of the role of impurities in catalyzing char gasification; the development of an ability to vary the structure of coal chars by varying conditions under which coals are thermally converted to chars, and the use of differential scanning calorimetry as a tool to further understand the phenomenon of coal conversion to chars.

Facet V is concerned with coal combustion research. One component of this is an investigation of the combustion of low volatile fuels. The objective of this work is to determine the requirements for use of char (primarily) in pulverized coal burners, the char being derived from gasification or liquefaction of coal.

A second component of the combustion research is a study of the combustion characteristics of coal-oil-water-air emulsions. The aim is to develop the coal-oil mixtures using normal grind coal to provide the required base for immediate use of coal additions in supplementing oil supplies. In the long run, it will also provide the basis for extension to dense dispersions of ultra-fine coal.

II. CONTRACT PRODUCTS

The products of DOE Contract DR-Ac01-76ET10615 have been published as a series of 23 Technical Research Reports and 49 papers published in the scientific and technical literature. A list of the Technical Research Reports is contained in Table 1 with an identification of the Contract "tasks" and "deliverables" to which each Report is related.

Table 1
Technical Reports Prepared for the
Department of Energy

<u>Task</u>	<u>Report Number</u>	<u>Report Title and Authors</u>	<u>Deliverable</u>
5	FE-0390-1	Problems and Solutions in the Use of Coal Analyses - P.H. Given, R.F. Yarzab	D4, D5, D6, D7
23, 35	FE-2030-TR2	The Characteristics of Chars Produced by Pyrolysis Following Rapid Heating of Pulverized coal - N. ya Nsakala, P.L. Wlaker, Jr., R.H. Essenhigh	D28, D30, D43
26, 27, 28	FE-2030-TR-3	Effects of Heat Treatment Conditions on Reactivity of Chars in Air - J.T. Ashu, P.L. Walker, Jr.	D33, D35, D36, D38
30	FE-2030-TR-4	The Effect of Cation Exchange on the Subsequent Reactivity of Lignite Chars to Steam - E.J. Hippo, P.L. Walker, Jr.	D44

Table 1 (cont.)

<u>Task</u>	<u>Report Number</u>	<u>Report Title and Authors</u>	<u>Deliverables</u>
1, 16	FE-2030-TR5	Survey of Selected Agencies Conducted to Determine the Extent to Which the Nation's Coal are Adequately Characterized - J.M. Hower, A. Davis, C.P. Dolsen, W. Spackman	D1, D12
30	FE-2030-TR6	The Effects of Impregnation of Coal with Potassium and Sodium Salts - H. Marsh, P.L. Walker, Jr.	D44
5, 27	FE-2030-TR7	Porosity of Coals and Coal Products - O.P. Mahajan, P.L. Walker, Jr.	D35, D39
26, 28, 30	FE-2030-TR8	Reactivity of Heat-Treated Chars - O.P. Mahajan, P.L. Walker, Jr.	D33, D40, D44
5, 17	FE-2030-TR9	Study of the Interrelationships Among Chemical and Petrographic Variables of United States Coals - C. Waddell, A. Davis, W. Spackman, J.C. Griffiths	D4, D5, D6, D7, D13, D14, D15
7	FE-2030-TR10	The Measurement of Reflectance of Coal Macerals - Its Automation and Significance - A. Davis	D10
5, 17	FE-2030-TR11	A Review of Some Physical Methods of Coal Characterization, Their Application in Constitution Analysis and Relevance to Industrial Utilization - A. Davis	D16, D17, D18 D 19, D20
31	FE-2030-TR12	Thermochemistry and Kinetics of Oxygen Interaction with Microporous Chars - I.M.K. Ismail and P.L. Walker, Jr.	D45, D46
28	FE-2030-TR13	Unification of Coal Char Gasification Reactions, O.P. Mahajan, R. Yarzab, P.L. Walker, Jr.	D40
28	FE-2030-TR14	Reactivity of Heat-Treated Coals in Steam - A. Linares-Solano, O.P. Mahajan and P.L. Walker, Jr.	D40
25	FE-2030-TR15	Specifications and Design of a Pressurized Laminar-Flow Isothermal Reactor for Studies of Coal Reactivity H.E. Shull, R.E. Essenhigh	D31
7	FE-2030-TR16	An Automated Microscopical Method for the Characterization of Pyrite in Coal K.W. Kuehn, A. Davis	D8
23, 24	FE-2030-TR17	Kinetics of Lignite Pyrolysis in Fixed Bed and Entrained Flow Reactors A.W. Scaroni and P.L. Walker, Jr.	D28, D30

Table 1 (cont.)

<u>Task</u>	<u>Report Number</u>	<u>Report Title and Authors</u>	<u>Deliverable</u>
7	FE-2030-TR18	Evaluation of an Automated Reflectance Microscope System for Coal Characterization - D.L. Liscinsky, F.J. Vastola	D10
24	FE-2030-TR19	A Numerical and Experimental Investigation of Rapid Coal Pyrolysis - J. Freihaut, F.J. Vastola	D30
27	FE-2030-TR20	The Effects of Preoxidation of the Swelling and Softening of Bituminous Coals, D.J. Maloney, R.G. Jenkins, P.L. Walker, Jr.	D39
30	FE-2030-TR21	Inorganic Constituents in American Lignites - M.E. Morgan, R.G. Jenkins, P.L. Walker, Jr.	D44
27	FE-2030-TR22	Characterization of Porous Nature of Heat-Treated Coals by Small Angle X-ray Scattering - J.R. Wang, R.G. Jenkins and P.L. Walker, Jr.	D35
7	FE-2030-TR23	The Development and Evaluation of an Automated Reflectance Microscope System for the Petrographic Characterization of Bituminous Coals - D.S. Hoover and A. Davis	D10

Papers published in the scientific and technical literature are listed in Appendix I. Each paper is identified with the Contract task from which the principal results were derived. As a further means of effecting technology transfer, 20 Short Courses were designed, developed and presented. These include:

1. Davis, A.
Short Course in COAL PETROLOGY
July 19-23, 1976, Caracas, Venezuela
2. Davis A.
COAL CHEMISTRY WORKSHIP
August, 1976, Stanford Research Institute, Palo Alto, California
3. Davis, A. and W. Spackman
Short Course in THE THEORY AND PRACTICE OF COAL PETROLOGY
September 26-28, 1977, State College, Pennsylvania
June 5-7, 1978
June 11-13, 1979
4. Essenhigh, R.H.
MODERN DEVELOPMENTS IN COMBUSTION TECHNOLOGY SEMINAR.
July 29, 1977

5. Given, P.H., P.L. Walker, Jr., W. Spackman, A. Davis, R.H. Essenhigh
Short Course on COAL CHARACTERISTICS AND COAL CONVERSION PROCESSES
June 7-11, 1976, State College, Pennsylvania
6. Given, P.H., P.L. Walker, Jr., W. Spackman, A. Davis, R.H. Essenhigh
Short Course on COAL CHARACTERISTICS AND COAL UTILIZATION
October 24-28, 1977, State College, Pennsylvania
October 22-26, 1979
7. Jenkins, R.G.
MODERN DEVELOPMENTS IN COMBUSTION TECHNOLOGY
July, 1979, State College, Pa.
8. Lovell, H.L. and A. Davis
Short Course on COAL CHARACTERISTICS IN COAL PREPARATION
October 11-13, 1976, State College, Pennsylvania
9. Lovell, H.L. and A. Davis
Short Course in the FUNDAMENTALS OF COAL PREPARATION
May 11-13, 1977, State College, Pennsylvania
10. Lovell, H.L.
Short Course on ELEMENTS OF COAL PREPARATION
November 16-18, 1977, State College, Pennsylvania
May 8-10, 1978
May 13-15, 1979
11. Lovell, H.L.
ADVANCED SHORT COURSE IN COAL PREPARATION
December 2-5, 1975 State College, Pennsylvania
October 24-27, 1977
12. Spackman, W. and A. Davis
COAL GEOLOGY AND COAL PETROGRAPHY
June 20-22, 1979, Houston, Texas
13. Spackman, W.
COAL GEOLOGY AND COAL PETROGRAPHY AND THEIR APPLICATION IN COAL EXPLORATION, Houston, Texas
September 25, 1979
14. Spackman, W. and A. Davis
APPLICATION OF COAL PETROGRAPHY TECHNIQUES IN THE STEEL INDUSTRY
February 26- March 2, 1979, Chicago, Illinois

More than 70 papers which included Contract research results were presented at a variety of scientific meetings. These are listed in Appendix II. As with the published papers, each is identified with the appropriate Contract task in the Appendix listing.

In view of the above, this present Final Report simply presents a summary of the salient features and results of the Contract work. The reader is referred to the DOE Technical Reports listed earlier and to the published literature for the detailed findings.

III. RESULTS OF A SURVEY TO DETERMINE THE EXTENT TO WHICH THE NATION'S COALS ARE ADEQUATELY CHARACTERIZED

Before proceeding further with Penn State's program aimed at characterizing the Nation's coal resources, it was decided to conduct a survey to determine the extent to which the Nation's coals already had been adequately characterized (see Hower, J.M., A. Davis, C.P. Dolsen and W. Spackman, DOE Technical Report FE-2030-TR5). A suitable questionnaire was devised and sent to 81 agencies in the coal community, selected to form a representative cross-section of the organizations concerned with coal characterization. A list of the agencies is presented in Table 2. Fifty-nine of the 81 questionnaires were completed and returned.

Table 2
Coal Community Agencies Receiving
Questionnaires

A. State Geological Surveys

1. Alabama	13. Montana
2. Alaska	14. New Mexico
3. Arizona	15. North Dakota
4. Arkansas	16. Ohio
5. Colorado	17. Oklahoma
6. Illinois	18. Pennsylvania
7. Indiana	19. Tennessee
8. Iowa	20. Texas
9. Kansas	21. Utah
10. Kentucky	22. Virginia
11. Maryland	23. Washington
12. Missouri	24. West Virginia
	25. Wyoming

B. Federal Agencies

1. U.S. Bureau of Mines
2. U.S. Geological Survey
3. Bartlesville Energy Research Center
4. Grand Forks Energy Research Center
5. Laramie Energy Research Center
6. Morgantown Energy Research Center
7. Pittsburgh Energy Research Center
8. Argonne National Laboratory
9. Brookhaven National Laboratory

Table 2 (cont.)

B. Federal Agencies (cont.)

10. Lawrence Livermore Laboratory
11. Lawrence Berkeley Laboratory
12. Los Alamos National Laboratory
13. Oak Ridge National Laboratory
14. Sandia National Laboratories
15. Pacific Northwest National Laboratory

C. DOE University Contractors

1. Brigham Young University
2. Lehigh University
3. Montana State University
4. State University of New York
5. Purdue University
6. University of Arizona
7. University of Illinois
8. University of Montana
9. University of North Dakota
10. University of Tennessee
11. University of Utah
12. Virginia Polytechnic Institute
13. West Virginia University
14. Western Michigan University
15. South Dakota School of Mines and Technology
16. University of Kentucky

D. Other Agencies

1. Coal Industry:
 - a. Amax Coal Company
 - b. Arch Minerals Corporation
 - c. Bituminous Coal Research, Inc.
 - d. Consolidation Coal Company
 - e. Eastern Associated Coal Corporation
 - f. Island Creek Coal Company
 - g. Peabody Coal Company
 - h. Pittsburg & Midway Coal Mining Company
 - i. The Pittston Company
 - j. Westmoreland Coal Company
2. Steel Industry:
 - a. Bethlehem Steel Corporation
 - b. U.S. Steel Corporation
3. Oil Industry:
 - a. Exxon Research and Engineering Company
 - b. Gulf Research and Development Corporation
 - c. Mobil Oil Research and Development Corporation
 - d. Shell Mining Ventures, Inc.

Table 2 (cont.)

4. Research Corporations:
 - a. Batelle, Columbus
 - b. Hydrocarbon Research, Inc.
 - c. Institute of Gas Technology
 - d. Stanford Research Institute
5. Other:
 - a. Dow Chemical Company
 - b. Fluor Engineers and Constructors, Inc.
 - c. FMC Corporation
 - d. Johns Manville Corporation
 - e. Rockwell International

Table 3 provides information on the percentage return from each of the agency classes. The overall return of 73% of the questionnaires is above normal for this type of survey. Also, the distribution of returns within classes appears to provide a properly balanced, well-informed, and experienced set of respondents, which, in turn, gives credibility to any conclusions that may be drawn from the study.

Table 3

Percentage of Questionnaires Returned
in Each Agency Class

<u>Agency Class</u>	<u>Number of Questionnaires Sent</u>	<u>Number of Questionnaires Received</u>	<u>Percentage</u>
1. State Geological Surveys	25	24	96%
2. Federal Agencies	15	13	87%
3. DOE University Contractors	16	11*	69%
4. Other Agencies			
a. Coal Industry	10	4	40%
b. Steel Industry	2	2	100%
c. Oil Industry	4	1	25%
d. Research Corporations	4	2	50%
e. Other	5	2	40%
5. Totals	81	59	73%

* Includes U.S.B.M., U.S.G.S. and 4 ERC Laboratories.

The detailed results of the survey can be found in DOE Technical Report FE-2030-TR5, which is the publication cited above. Analysis of the responses to the questionnaire revealed the following facts:

1. In the opinion of the respondents, 50-80% of the Nation's remaining coal reserves are inadequately characterized.
2. Less than one-half of the agencies perform a "minimal coal analysis"* on coal samples on a routine basis.
3. Only 12 agencies have more than 100 "minimal coal analyses" on open file.
4. None of the responding organizations routinely conduct the package of analyses designated "Basic Compositional and Performance Analyses".**.
5. Less than 1/4 of the responding agencies have significant quantities of ash fusion analyses and major element (in ash) data (Si, Al, Ti, Fe, Mg, Ca, Na, K, P).
6. Less than 1/8 of the responding agencies have significant quantities of data on trace element contents and free swelling properties.
7. Less than 1/2 of the responding agencies have significant quantities of data on the coal characteristics established through any of the following analyses:
 - a. maceral analysis
 - b. vitrinite reflectance analysis
 - c. Hardgrove grindability analysis
 - d. washability analysis
 - e. microhardness analysis
 - f. Gray-King coke type analysis
 - g. mineral species analysis.
8. In total, five coal samples have been fully characterized by performing all of the analyses required to develop what was designated "Basic Compositional and Performance Data".
9. The responses to questions on the types of analyses necessary to relate coal characteristics to behavior in industrial processes led to the conclusion that the "Basic Compositional and Performance Data" constitute a package that is generally adequate but that consideration should be given to adding the Gieseler Plastometer Test and Fischer Assay.

* "Minimal coal analysis" consists of a proximate analysis plus an ultimate analysis.

** "Basic Composition and Performance Analyses" include proximate analysis, ultimate analysis, calorific value determination, sulfur forms analysis, maceral analysis, vitrinite reflectance analysis, ash fusion analysis, free-swelling index, Gray-King coke type, microhardness determination, Hardgrove grindability determination, mineral species analysis, major and minor element analysis, trace element analysis and washability analysis.

From the above and from the contents of the aforementioned DOE Report, it is concluded that:

1. the Nation's coals are inadequately characterized for their efficient and effective use, this being particularly true in relation to coal conversion technology and maintaining environmental quality;
2. the number of agencies conducting coal characterization programs is too small to meet the Nation's needs within the time frame required;
3. the scope of coal characterization programs should be expanded to develop a broader spectrum of basic compositional and performance data.

IV. COAL SAMPLING OPERATIONS

A. Rationale for the Sampling Procedures

Coal seams are heterogeneous rock bodies consisting of various mixtures of macerals and minerals. Moreover, it is commonplace to find that a seam is a stratified rock body consisting of superposed layers of differing mixtures, each distinctive mixture representing a different "coal type" or "lithotype". Each of these lithotypes, at a given level of rank, may be presumed to possess a distinctive set of physical and chemical properties that will influence their behavior in both beneficiation and utilization. The same can be said for the more fundamental constituents, i.e. the macerals and minerals, and, because the lithotypes, the macerals and the minerals comprise the reacting entities in any given preparation or utilization process, knowledge of their characteristics is essential to predicting coal behavior. On the other hand, for purposes of the actual utilization of a coal seam at a given site, knowledge of the seam's "rank" and its "bulk chemistry" is often sufficient to guide processing and quality control. Such information will have limited value, however, in predicting the behavior of the other seams at other sites. A high volatile B bituminous coal from Indiana neednot react to beneficiation in the same manner as a high volatile B bituminous coal from Utah, even though their "chemistries" may be very similar. In contrast, a coal lithotype of a specific kind, at a given level of rank, can be expected to behave consistently, whether it derived from Alabama or Pennsylvania.

Recognizing the above, the coal sampling program included the procurement of two kinds of samples at each sampling site. A full-seam channel sample was obtained by hand-mining the coal from the seam in such a manner as to include the proper proportions of each of the seam's constituent layers. This, to some degree, simulates the "as-mined coal" at that site recognizing, of course, that in normal mining operations it is common for roof and floor rock to be included in the mined product. The second type of sample obtained at each site was a representative channel through the distinctive lithotypes that composed the seam at the sampling point. These two sample types are diagrammatically depicted in Figure 7.

Figure 7. DIAGRAMMATIC REPRESENTATION OF SAMPLING OPERATION

B. The Master Sampling Plan

Twenty-five states were identified as possessing coal seams containing large exploitable reserves. A master sampling plan was devised and this is outlined in Appendix III. For planning purposes, the 25 states were aggregated into 7 sectors, each sector representing a geographic area that that could conveniently be travelled during the course of a given sampling mission. Most samples were obtained by Penn State personnel trained in coal sampling operations. The typical sampling operation at a given sampling site involved extraction of:

1. a large full-seam channel sample of 500 to 1,000 pounds,
2. two small full-seam channel samples located approximately 1,000 feet from the site of the large channel, to determine local lateral variability,
3. a variable number (often 3) of lithotype samples (if lithotypes were not readily recognizable in the field, "sub-seam samples" were taken of the "benches" composing the seams and if the seam was not naturally "benched" by mineral-rich partings, three sub-seam samples were taken by arbitrarily dividing the seam into an upper, middle and lower sub-section).

All samples were collected at active mines from a fresh face and, after collection, were returned to the Penn State laboratories where they were split into representative sub-samples and sealed for preservation as soon as feasible.

C. Participation of Other Agencies in the Sampling Program

Sub-contracts were arranged with four other universities to permit them to participate in the sampling program. Following Penn State prescribed procedures, personnel from the University of Utah, West Virginia University, Southern Illinois University and Texas A&M University engaged in a number of sampling missions. A standardized "Coal Sample Data Sheet" was used by all sampling personnel to insure procurement of complete information on the sample and its source. A copy of this document is included in Appendix III.

In addition to the efforts of these universities, the United States Geological Survey and Shell Mining Ventures Company provided core samples from areas of interest in which no mines were currently operating. Table 4 lists the number of sites and the number of samples associated with the sample collection efforts of agencies other than Penn State.

D. Summary of Sampling Efforts

As the result of the above-described sampling operations, a total of 844 coal samples were added to the Penn State Sample Bank. These are listed as PSOC numbers 357 - 1200 inclusive in Appendix IV, identifying: 1) the sample type, 2) the name of the seam sampled, 3) the county and state in which the sampling site is located. Table 5 lists the number of seams sampled in each state and the total number of samples for that state.

Table 4
Sampling Operations Performed by Other Agencies

<u>Agency</u>	<u>Number of Sampling Sites</u>	<u>Number of Samples</u>
University of Utah	20	120
West Virginia University	22	127
Southern Illinois University	21	106
Texas A&M University	31	136
Shell Mining Ventures	5	25
U.S. Geological Survey	7	82
Missouri Department of Natural Resources	3	4

Table 5
Coal Samples by State

<u>Source of Samples</u>	<u>Number of Seams Sampled</u>	<u>Total Number of Samples</u>
Arkansas	4	20
Colorado	8	41
Illinois	5	31
Indiana	5	34
Iowa	5	22
Kentucky	10	45
Louisiana	7	7
Maryland	1	6
Missouri	3	4
Montana	3	29
New Mexico	12	49
Ohio	6	31
Oklahoma	9	35
Pennsylvania	27	96
Texas	27	107
Utah	7	49
West Virginia	17	121
Wyoming	31	117
	<u>187</u>	<u>844</u>

V. COAL CHARACTERIZATION

A. Basic Compositional Data

All coal samples collected were subjected to a characterization program which resulted in a body of information referred to as "basic compositional data". These data include the information obtained as the result of performing the following analyses or tests:

1. proximate analysis
2. ultimate analysis
3. sulfur forms analysis
4. calorific value determination
5. maceral analysis
6. vitrinite reflectance analysis
7. ash fusion analysis
8. free-swelling index determination
9. Gray-King coke type determination
10. Hardgrove grindability determination
11. Vicker's microhardness determination
12. major and minor element analysis
13. trace element analysis.
14. mineral species analysis.

Where appropriate and to the extent permitted by funding, all of the above tests and analyses were performed on the coal sample (lignites and anthracites would display no agglomerating properties so no free-swelling index determinations and no Gray-King coke type determinations would be made in the case of samples of such coals). In addition, a number of "special analytical procedures" were used in the case of selected coal samples. These included:

1. equilibrium moisture determination
2. surface area determination
3. density determination
4. porosity determination
5. Gieseler plastometer analysis
6. reactivity analysis
7. washability analysis

Where required, the experimentally determined values were converted to such calculated values as "as-received", "dry", "dry, ash-free", "dry, mineral-matter-free" (using the Paar formula to determine mineral matter), "dry, mineral-matter-free (Parr-Given)", which utilizes a P.H. Given modification of the Paar formula to determine mineral matter and, "dry, mineral-matter-free (direct)" which is based on the analytically determined quantity of mineral matter.

For the most part, the analytical procedures employed followed standard methods as prescribed by the American Society for Testing Materials. In the case of the "inorganic components" of the coals, the procedures outlined in Figure 8 were followed. These analyses provided the data on:

Figure 8. ANALYTICAL SCHEME FOR PSOC COALS AT THE PENN STATE MINERAL CONSTITUTION LABORATORIES

- 1) the major elements in the coal ash,
- 2) the minor elements in the coal ash,
- 3) the trace elements in the coal and ash, and,
- 4) the mineral species in the coal.

Because there is no commonly employed method for quantifying the mineral species in coal, the methods developed and employed at Penn State are described in Section VD of this Report.

All data on coal characteristics described above were computerized and stored for use by the program's "facet investigators" in the experimental phases of the program. A portion of the product of the characterization program is included in this report as Appendix XIII. This Appendix includes representative data on all full-seam seam samples collected under the contract.

The analytical values obtained in the characterization program were periodically checked by submitting replicate samples to two or more commercial test laboratories. Typical results are shown in Tables 6, 7 and 8.

In the case of the values shown in Tables 6, 7, and 8, the samples analyzed by Laboratories 1, 2 and 3 were representative subsamples of splits of the original PSOC head sample taken at a time subsequent to obtaining the initial split used to generate the data for the PSU Data Base. This is reflected by the typically higher moisture values in the PSU Data Base and variation in the other values provide some indication of the extent to which different splits of each PSOC sample may vary in their composition. It is evident that the Data Base values should be used only as a general guide to sample selection and any new experimental work performed on other sample splits should be fortified with a new set of analyses performed on the actual sample being used.

B. Gieseler Plastometer Studies

It is well known that the plastic properties exhibited by bituminous coals when heated in an inert atmosphere can be significantly diminished if the coal becomes oxidized or "weathered" during storage. This can have a serious impact on the coking capacity of a coal and it was thought that there might be similar deleterious effects in connection with the behavior of coal in a process like liquefaction. Also, it was felt that it would be useful to know more about the rate at which oxidation occurred as a guide in the handling of coal samples during sampling operations and in connection with proper management of the PSU Coal Sample Bank. In view of the above, a study of the effect of oxidation on a coal's plastic properties was undertaken using a Gieseler Plastometer as a monitoring device. The results of these studies can be found in DOE Reports Identified as FE-2030-13, FE-2030-14 and FE-2030-15. A brief description of the investigation follows.

The Gieseler Plastometer is the most commonly used method of measuring and characterizing the thermoplastic properties of coal. In a Gieseler Plastometer analysis, the degree of resistance offered to the rotation of a stirring rod in the middle of a mass of powdered coal is measured. The powdered coal is compacted, with the stirring rod in place, into a cylindrical

Table 6
Comparison of Proximate Analysis Values

<u>Sample Number</u>	<u>Data Source</u>	<u>% Moisture</u>	<u>% Volatile Matter</u>	<u>% Fixed Carbon</u>	<u>% Ash</u>
13	PSU Data Base	2.04	33.13	63.60	1.23
	Laboratory 1	2.10	33.10	63.45	1.35
	Laboratory 2	1.47	35.46	61.94	1.13
	Laboratory 3	2.45	31.80	64.14	1.61
22	PSU Data Base	17.69	31.66	42.30	8.35
	Laboratory 1	10.67	31.60	45.76	11.97
	Laboratory 2	7.62	35.54	45.30	11.54
	Laboratory 3	10.54	30.55	47.84	11.07
122	PSU Data Base	1.03	42.74	44.11	12.12
	Laboratory 1	1.34	38.59	46.46	13.61
	Laboratory 2	0.84	43.31	41.76	14.09
	Laboratory 3	1.58	39.11	45.68	13.63
156	PSU Data Base	16.66	33.80	42.76	6.78
	Laboratory 1	11.31	33.99	46.54	8.16
	Laboratory 2	10.04	39.38	42.43	8.15
	Laboratory 3	12.17	32.89	46.72	8.22
189	PSU Data Base	11.94	30.56	46.60	10.94
	Laboratory 1	8.79	36.87	44.93	9.41
	Laboratory 2	6.17	40.48	43.18	10.17
	Laboratory 3	9.20	35.01	45.73	10.06
341	PSU Data Base	3.51	37.46	47.95	11.09
	Laboratory 1	1.93	37.24	48.56	12.27
	Laboratory 2	1.18	39.69	47.70	11.43
	Laboratory 3	2.33	35.54	49.76	12.37
383	PSU Data Base	1.66	9.88	66.75	21.70
	Laboratory 1	1.16	9.81	69.20	19.83
	Laboratory 2	0.35	10.73	70.73	18.19
	Laboratory 3	1.23	9.19	70.18	19.40
399	PSU Data Base	3.99	42.30	45.96	7.75
	Laboratory 1	3.17	42.63	46.63	7.57
	Laboratory 2	1.88	46.15	43.98	7.99
	Laboratory 3	3.61	39.97	48.06	8.36
533	PSU Data Base	13.99	50.51	30.99	4.52
	Laboratory 1	13.07	38.04	44.32	4.57
	Laboratory 2	10.93	40.38	44.04	4.65
	Laboratory 3	13.58	34.65	46.91	4.86
614	PSU Data Base	2.30	36.08	49.27	12.35
	Laboratory 1	1.67	37.12	49.30	11.91
	Laboratory 2	0.66	39.69	47.25	12.40
	Laboratory 3	2.00	34.84	50.62	12.54
623	PSU Data Base	34.87	29.05	25.27	10.81
	Laboratory 1	33.12	28.14	28.03	10.71
	Laboratory 2	27.91	37.30	23.42	11.37
	Laboratory 3	33.60	25.91	29.71	10.78

Table 7

Comparison of Ultimate Analysis Values

<u>Sample Number</u>	<u>Data Source</u>	<u>% Ash</u>	<u>% Carbon</u>	<u>% Hydrogen</u>	<u>% Nitrogen</u>	<u>% Sulfur</u>	<u>% Oxygen</u>
13	PSU Data Base	1.26	83.97	5.29	1.33	0.35	7.80
	Laboratory 1	1.38	83.49	5.29	1.31	0.47	8.05
	Laboratory 2	1.15	82.42	5.38	1.56	0.48	9.01
	Laboratory 3	1.65	83.77	5.18	1.58	0.44	7.37
22	PSU Data Base	10.14	70.78	5.22	1.39	2.59	9.88
	Laboratory 1	13.40	65.62	4.55	1.05	2.54	12.80
	Laboratory 2	12.49	67.36	5.04	1.18	2.43	11.50
	Laboratory 3	12.37	67.56	4.60	1.20	2.25	12.02
122	PSU Data Base	12.25	72.77	5.85	1.20	0.92	7.01
	Laboratory 1	13.79	72.04	5.29	1.01	0.84	6.95
	Laboratory 2	14.21	71.03	5.39	1.16	0.80	7.41
	Laboratory 3	13.85	72.48	5.42	1.34	0.81	6.10
156	PSU Data Base	8.14	70.25	4.90	0.07	1.32	15.32
	Laboratory 1	9.20	67.89	4.51	1.06	1.20	16.11
	Laboratory 2	9.06	68.80	5.61	1.15	1.09	14.29
	Laboratory 3	9.36	68.64	4.85	1.29	1.29	14.58
189	PSU Data Base	12.38	66.55	4.96	0.91	4.84	10.33
	Laboratory 1	10.32	66.73	4.76	1.11	4.61	12.42
	Laboratory 2	10.84	66.29	5.37	1.11	4.74	11.65
	Laboratory 3	11.08	67.10	4.67	1.20	4.32	11.63
341	PSU Data Base	11.49	73.69	5.16	1.24	4.52	3.86
	Laboratory 1	12.51	71.08	5.28	1.11	4.41	5.37
	Laboratory 2	11.57	70.49	5.36	1.20	4.40	6.94
	Laboratory 3	12.67	70.57	5.01	1.15	4.33	6.28
383	PSU Data Base	22.07	69.68	3.16	0.81	0.73	3.54
	Laboratory 1	20.06	71.89	3.21	0.73	0.85	3.20
	Laboratory 2	18.25	73.31	3.43	1.19	0.89	2.93
	Laboratory 3	19.64	71.99	3.22	0.87	0.92	3.36
399	PSU Data Base	8.07	74.29	5.42	1.57	3.90	6.57
	Laboratory 1	7.82	74.56	5.28	1.28	3.95	6.82
	Laboratory 2	8.14	75.10	5.81	1.61	3.94	5.40
	Laboratory 3	8.67	75.05	5.20	1.57	3.86	5.66
533	PSU Data Base	5.25	71.52	4.97	0.85	0.53	16.87
	Laboratory 1	5.26	71.12	5.43	1.01	0.56	16.61
	Laboratory 2	5.22	75.12	6.15	1.25	0.65	11.61
	Laboratory 3	5.62	72.39	4.79	1.08	0.73	15.39
614	PSU Data Base	12.64	72.11	4.92	1.09	4.52	4.62
	Laboratory 1	12.11	72.31	5.20	1.04	4.23	4.90
	Laboratory 2	12.48	71.38	5.44	1.13	4.54	5.03
	Laboratory 3	12.80	72.01	5.03	1.26	4.43	4.48
623	PSU Data Base	16.60	60.90	4.49	1.07	1.13	15.78
	Laboratory 1	16.01	61.24	4.59	1.08	1.16	15.87
	Laboratory 2	15.77	55.23	5.09	1.00	1.14	21.77
	Laboratory 3	16.23	62.67	4.44	1.16	1.22	14.28

Note: Laboratory 1 values total less than 100 because chlorine values are omitted - all were less than 0.30%; the same is true for the PSU Data Base values.

Table 8
Comparison of Sulfur Values

<u>Sample Number</u>	<u>Data Source</u>	<u>Pyritic Sulfur</u>	<u>Sulfate Sulfur</u>	<u>Organic Sulfur</u>	<u>Total Sulfur</u>
13	PSU Data Base	0.04	0.00	0.31	0.35
	Laboratory 1	0.03	0.01	0.43	0.47
	Laboratory 2	0.01	0.01	0.46	0.48
	Laboratory 8	0.09	0.01	0.34	0.44
22	PSU Data Base	0.89	0.07	1.63	2.59
	Laboratory 1	0.16	0.61	1.77	2.54
	Laboratory 2	0.24	0.74	1.45	2.43
	Laboratory 3	0.31	0.64	1.30	2.25
122	PSU Data Base	0.22	0.01	0.69	0.92
	Laboratory 1	0.46	0.06	0.32	0.84
	Laboratory 2	0.08	0.05	0.67	0.80
	Laboratory 3	0.21	0.01	0.59	0.81
156	PSU Data Base	0.56	0.05	0.71	1.32
	Laboratory 1	0.29	0.10	0.81	1.20
	Laboratory 2	0.22	0.15	0.72	1.09
	Laboratory 3	0.52	0.03	0.74	1.29
189	PSU Data Base	2.57	0.15	2.12	4.84
	Laboratory 1	1.19	1.06	2.36	4.61
	Laboratory 2	1.56	1.56	1.80	4.92
	Laboratory 3	1.43	1.29	1.60	4.32
341	PSU Data Base	3.21	0.06	1.25	4.52
	Laboratory 1	2.28	0.41	1.72	4.41
	Laboratory 2	2.80	0.46	1.18	4.40
	Laboratory 3	2.35	0.34	1.64	4.33
3.83	PSU Data Base	0.26	0.00	0.47	0.73
	Laboratory 1	0.16	0.01	0.68	0.85
	Laboratory 2	0.18	0.07	0.64	0.89
	Laboratory 3	0.28	0.02	0.62	0.92
399	PSU Data Base	1.89	0.07	1.94	3.90
	Laboratory 1	1.57	0.17	2.21	3.95
	Laboratory 2	1.73	0.20	2.01	3.94
	Laboratory 3	1.45	0.01	2.40	3.86
533	PSU Data Base	0.13	0.00	0.40	0.53
	Laboratory 1	0.13	0.01	0.42	0.56
	Laboratory 2	0.15	0.02	0.48	0.65
	Laboratory 3	0.25	0.03	0.45	0.73
614	PSU Data Base	3.33	0.00	1.19	4.52
	Laboratory 1	2.95	0.00	1.28	4.23
	Laboratory 2	3.91	0.02	0.61	4.54
	Laboratory 3	2.46	0.04	1.93	4.43
623	PSU Data Base	0.19	0.10	0.84	1.13
	Laboratory 1	0.03	0.01	1.12	1.16
	Laboratory 2	0.29	0.08	0.77	1.14
	Laboratory 3	0.41	0.04	0.77	1.22

crucible, 21 mm in internal diameter and 35 mm in depth. The axis of the stirring rod is subjected to a constant torque using a constant speed motor coupled through a hysteresis brake. The torque applied is relatively weak, amounting to 100 g-cm.

The stirring shaft is fitted with a dial drum which is slotted with 100 dial divisions. Any rotation of the stirring rod is detected and measured by an electronic beam as it rotates past a reference point. The constant speed motor operates at 300 rpm, therefore the maximum measurable rotation is 30,000 dial divisions per minute (ddpm).

In a typical Gieseler Plastometer, the crucible containing 5 grams of powdered coal and stirring rod is placed inside a furnace containing a solder bath, the temperature of which is regulated. The stirring rod is coupled directly to the hysteresis brake and constant speed motor. The temperature of the sample is rapidly brought up to 330°C and then increased at a rate of 3.0°C/min. The rate of rotation of the stirrer is measured as a function of temperature. At lower temperatures, the stirrer remains stationary due to the resistance offered by the compacted coal within the crucible. As the temperature increases, certain coals become plastic and the stirring rod begins to rotate. The rate of rotation increases rapidly with temperature, passing through a maximum and then decreasing until it returns to zero when the coal resolidifies into a semi-coke. An example of a typical Gieseler plastometric curve can be seen in Figure 9.

In reporting Gieseler Plastometer data there are five parameters noted in standard practice: softening temperature, resolidification temperature, temperature range of softening, temperature of maximum plasticity and a measure of the relative degree of plasticity (ddpm).

The thermoplastic properties of coals as measured by the Gieseler Plastometer is a very sensitive index of oxidation. It has long been noted, for example, that reductions in Gieseler fluidity occurs long before the free-swelling index is reduced. The rate changes of fluidity with progressive oxidation has not been studied in detail.

Accordingly, a study of the effects of progressive oxidation on the thermoplastic properties of coal was performed. A detailed description of these experiments was given in DOE Reports FE-2030 13 and 14. It was found that maximum plasticity number (ddpm) decreased rapidly with initial oxidation and more slowly with additional oxidation. In addition, crushing of the oxidized coals was found to restore some of their thermoplastic behavior.

It is reasonable to assume that initial oxidation occurs on the outer surface of the coal particles. This oxidation of an outer layer can reduce the plastic properties of the coal. The "leveling off" of values after several weeks of oxidation may mark the completion of an "optimum" amount of oxidation around the coal particles. Recrushing of the coal breaks open the oxidized particles enabling the unoxidized fluid coal to plasticize the coal mass during heating, thereby restoring some of the thermoplastic behavior exhibited by the coal.

Figure 9. TYPICAL GIESELER PLASTOMETRIC CURVE

The thermoplastic behavior of coals results from the rupturing of cross-linkages and the formation of an isotropic fluid pitch when the free radicals have been stabilized by transferrable hydrogen contained within the coal. In liquefaction, hydrogen from a donor-solvent attaches to free radicals to stabilize the fluid system during an analogous pitch-like phase. Accordingly, the plastic characteristics of coal and its formation mechanism may be of great relevance in relation to liquefaction processes. In view of this, a study of the effects of oxidation on thermoplastic properties and liquefaction behavior of coals was undertaken.

A detailed description of the experiments comparing thermoplastic behavior and liquefaction conversion of coal was given in DOE Report FE-2030-15. In these experiments, coals were air oxidized until their thermoplastic properties were drastically reduced. Oxidized and unoxidized samples of these coals were then slurried with tetralin and heated rapidly to 400°C in tubing bombs. The liquefaction conversion was considered as material converted to ethyl acetate soluble material.

The results of this study show that the degree of oxidation necessary to significantly change the plastic properties of coal does not affect the degree of conversion during liquefaction.

These results, at first, appear to conflict with those presented by Neavel (1976). He found that oxidation is deleterious to liquefaction yields. This effect, however, did not become distinct until oxygen uptake, measured by neutron activation analyses, resulted in a 2% or greater weight increase of the coal.

It is proposed that initial oxidation has a strong influence on the transferable hydrogen contained within the coal. Low degrees of oxidation could convert alicyclic hydrogen to less reactive or non-transferable forms. The formation of non-transferable hydrogen would drastically affect the thermoplastic behavior of the coal. The liquefaction conversion of the same coal, however, would not be affected because the source of hydrogen would be from the donor-solvent, tetralin. With more severe oxidation, increased cross linking within the coal molecule probably occurs, thereby reducing the ability of the coal to form free radicals. This, in turn, prohibits the donor hydrogen access to the coal.

Regardless of the mechanism of oxidation, initial oxidation is deleterious to the thermoplastic properties of coal, while more severe oxidation is needed to reduce the liquefaction conversion of the coal.

C. Automation of Analytical Procedures

1) Introduction

One product of work under DOE Contract EX-76-C-01-2030 has been the development of an automated microscope system to characterize the petrographic composition of coals. All versions of this instrument which have been built during the course of this program consist of a reflected light microscope equipped with a scanning stage which moves the prepared coal sample under the microscope

objective either continuously or in steps. Output from the photometer is reported and processed by computer. The instrument, referred to in our reports and publications as Rapid Scan, has been used in separate research efforts to characterize the rank and petrographic composition of coal, and to measure the total amount and size distribution of pyrite in coals. These two research efforts are summarized separately below and the details of the investigations can be found in DOE Reports FE-2030-TR16 and FE-2030-TR23.

Since the initiation of this research program, many other institutions within the federal and state government, industry and the universities have begun similar efforts. Clearly, one of the objectives of the program, to demonstrate the feasibility and practicality of automated microscopy to the coal research community, has been accomplished.

At a symposium on the automated microscopy of coals held in conjunction with the International Carboniferous Congress in May 1979, it was apparent that the problems and potential of such systems had been anticipated in the development of the Rapid Scan. The reports prepared as a result of this program should save many years of effort on behalf of those research institutions which are now actively developing systems.

2) The Development and Testing of an Automated Reflectance Microscope (Rapid Scan) for the Characterization of the Organic Components in Bituminous Coals

Introduction: As the technology for the utilization of U.S. coal resources becomes more complex (i.e. coal liquefaction), the need for effective coal characterization increases greatly. The petrographic character of the organic components in coal has been shown to affect: the carbonization properties, the liquefaction properties and, to a lesser extent, the gasification and combustion properties of any given coal. Petrographic characterization is limited: 1) by the time necessary to complete the analysis (2-3 professional or technical man hours per sample) and 2) by the level of training and experience of the operator. Consequently, a rapid, objective analysis system would be desirable. The successful development and testing of one such system has been reported in DOE Report FE-2030-TR23 and in the published literature. The following is a summary of the salient results.

Hardware Development: Automated reflectance microscopy was chosen as the method which had the best opportunity for successful automation of petrographic characterization. Three generations of equipment were developed and tested during this program. The Version I system (see Figure 10) was limited by:

1. the capabilities of the PDP-9 computer,
2. the programs of signal digitization, and
3. poor photometer precision.

The Version II system incorporated a new reflectance photometer and an improved computer system (see Figure 11). The precision of this system was found to be limited by the signal integration time available using the

Figure 10. THE HARDWARE CONFIGURATION OF THE RAPID SCAN VERSION I SYSTEM

Figure 11. THE HARDWARE CONFIGURATION OF THE RAPID SCAN VERSION II SYSTEM

continuous moving FEMCO stage drive. As designed, the precision of reflectance determination was $\pm 0.04\%$ reflectance.

The Version III system incorporated a digital stepping stage to improve the signal integration time (see Figure 12). With this equipment, the precision of the reflectance measurement was improved to $\pm 0.02\%$ reflectance, with essentially no sample smear. This equipment configuration was adopted for all analyses where precision reflectance measurement was critical.

Procedural Developments: An experiment was designed to test the number of sample points necessary for the optimal sampling of a briquetted pellet. These results indicated that 50,000 data points, or a scan length of 125 mm, were necessary to minimize variations in reflectogram shape. Reflectograms were tested for reproducibility by using the Kolmogorov-Smirnov test statistic. These experiments indicated that replicate reflectograms from the same sample or subsamples of the same head sample, were reproducible. They also showed that reflectograms from similar coals were significantly different.

The effects controlling reflectogram shape and resolution were investigated in a systematic manner. Six primary controlling factors were identified as follows:

1. Instrumental Error
2. Sample Preparation
3. Analytical Technique
4. Concentration of Constituents
5. Reflectance Overlap of Constituents
6. Grain Size of Constituents

The first three factors are dependent factors over which the operator has some control. The final three are independent factors, related to the complex nature of coal. Factors 5 and 6 were shown to be the controlling influences on reflectogram shape. Figure 13 shows the reflectance range and overlap of various organic components at different levels of rank. It indicates that reflectance, as a single criterion, will never enable the differentiation of semifusinite and micrinite. It also indicates significant overlaps between semifusinite and vitrinite hindering the resolution of these macerals in automated reflectance microscopy.

Despite these problems of reflectance overlap, the effect of maceral grain size was shown to be of even greater importance. The relationship of size and shape of different macerals was shown to be directly related to the proportional number of interface reflectance readings on interfaces and boundaries. Strict control of sample preparation limited the problems of readings on interfaces between coal particles and epoxy, however, fine-grained macerals remained difficult to resolve.

Quantitative Data Interpretation: A computer program employing curve stripping and empirical, residuals analysis was developed to generate quantitative petrographic data from reflectograms. An example of the two-page printout from this program is shown in Figures 14 and 15. In order to test if the Rapid Scan could generate petrographic data comparable to manually derived data, a suite of coals varying in rank and petrographic composition were analyzed by both techniques. The comparative results shown in Figures 16 and 17 indicate that vitrinite reflectance data derived from Rapid Scan are very similar to visually derived results. Rapid Scan derived maceral

Figure 12. THE HARDWARE CONFIGURATION OF THE RAPID SCAN VERSION III SYSTEM

Figure 13. THE OVERLAP IN REFLECTANCE DISTRIBUTIONS OF DIFFERENT MACERALS FOR COALS OF VARIOUS RANK

****PENN STATE COAL RESEARCH SECTION****
RAPID SCAN PETROGRAPHIC ANALYSIS

PAGE-1

SAMPLE DESIGNATION PSOC-276

DATE 11/ 9/1978

**** ANALYSIS CONDITIONS ****

FULL SCALE REFLECTANCE----- 2.00%
STANDARDS USED----- 1.006%, 0.533%
STAGE DRIVE SPEED (U/SEC.)-- 200.
NUMBER OF DATA POINTS----- 50000.
SPOTSIZE AREA IN MICRONS--- 4.
TIME FOR ANALYSIS (MIN)---- 8.33
COMMENTS----- PITTSBURGH SEAM

**** SUMMARY ANALYSIS DATA ****

VITRINITE REFLECTANCE PARAMETERS

MARR VALUE----- 0.64%
STANDARD DEVIATION----- 0.046%
VIT. DISTRIBUTION POPULATION--- 22875.

CALCULATED VITRINITE MEAN-MAX.--- 0.68%

VITRINOID TYPE TABLE

V4	V5	V6	V7	V8	V9	V10	V11
---	---	---	---	---	---	---	---
0.0	0.9	67.5	31.6	0.0	0.0	0.0	0.0
V12	V13	V14	V15	V16	V17	V18	V19
---	---	---	---	---	---	---	---
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Figure 14. AN EXAMPLE OF PAGE ONE OF THE PRINTOUT FROM PETAN

****PENN STATE COAL RESEARCH SECTION****
RAPID SCAN PETROGRAPHIC ANALYSIS

PAGE-2

SAMPLE DESIGNATION PSOC-276

DATE 11/ 9/1978

TRANSFORMED REFLECTOGRAM PARAMETERS

THE FOLLOWING PETROGRAPHIC DATA ARE VOLUME PERCENT

VITRINITE PERCENTAGE----- 77.1

LIPTINITE PERCENTAGE----- 4.6

INERTINITE PERCENTAGE----- 18.1

TOTAL REACTIVES----- 81.8

TOTAL INERTS----- 18.1

TOTAL REACTIVES-(MMC)----- 76.0

TOTAL INERTS-(MMC)----- 23.9

UNTRANSFORMED REFLECTOGRAM PARAMETERS

"INERT COEFFICIENT"----- 0.142

"INERT COEFFICIENT"-(MMC)---- 0.163

Figure 15. AN EXAMPLE OF PAGE TWO OF THE PRINTOUT FROM PETAN

Regression Equation $\bar{R}_{\max(\text{vis})} = \bar{R}_{\max(\text{cal})} * 1.00$

Standard Deviation about the Regression Line = 0.02

* indicate individual data points

Numbers indicate number of superimposed data points

Figure 16. A COMPARISON OF MEAN MAXIMUM VITRINITE REFLECTANCE (VISUAL) TO MEAN MAXIMUM VITRINITE REFLECTANCE (RAPID SCAN)

Regression Equation $TRM_{vis} = TRM_{auto} * 1.0$

Standard Deviation about the Regression Line = 5.2

* indicate individual data points

Numbers indicate number of superimposed data points

Figure 17. A COMPARISON OF TOTAL REACTIVE MACERALS (VISUAL) TO TOTAL REACTIVE MACERALS (RAPID SCAN)

compositions show more scatter. The reasons for the discrepancies are several, however, the fundamental difference in the bases of the analytical methods is probably the most important. During a visual analysis, an operator uses three criteria (reflectance, morphology and texture) to categorize macerals, whereas the machine employs only one, reflectance. Whether the observed differences are of importance can only be determined by the application of the results.

Application of Rapid Scan Data: Petrographic data derived from reflectograms were used in three practical applications. The first involved the prediction of ASTM coke tumbler stability using the United States Steel System. Twenty coals, for which 500 pound carbonization test data were available, were analyzed both visually and by Rapid Scan. Predicted ASTM stability results for both sets of data were compared to the determined values. Results showed that the Rapid Scan predictions were only marginally different from the visually based predictions.

The second application involved monitoring petrographic compositional change as a result of physical coal beneficiation techniques. In this experiment, Rapid Scan data were used to show that, for one coal (PSOC-134), significant petrographic variation occurred due to density separation, whereas for a second coal (PSOC-102) little variation was evident in the same processing scheme.

The third application was in the characterization of coal blends. It was shown that the Rapid Scan is an excellent instrument for detecting blends of different rank coals. Variations in blend composition of as little as 5% were readily recognizable in the reflectogram. A computer program was developed to enable the quantification of blend reflectograms using simulated results and curve comparison techniques.

Summary and Conclusions: Research conducted on automated reflectance microscopy under this contract has demonstrated the following:

1. A high-precision, automated, reflectance microscope photometer can be constructed from commercially available system components.
2. Reflectograms of the organic components in coal are highly reproducible and sensitive to minor compositional variation.
3. Programs can be developed to quantify coal reflectograms, and vitrinite reflectance data generated in this manner agree well with visually-derived results.
4. Data generated from automated system can be applied to wide-ranging problems requiring petrographic analysis.

Future research will most likely be concerned with refinement of data interpretation techniques and application of data. Automated reflectance microscopy is now at a stage where it can begin to see more widespread industrial utilization.

3) The Characterization of Pyrite in Coal by Automated Reflectance Microscopy (Rapid Scan)

Introduction: Application of the Rapid Scan system for automated reflectance microscopy to the analysis of pyrite in coal has required extensive research and development in three principal areas: 1) system hardware, 2) system software, and 3) sampling and analysis. The present system configuration allows for a rapid and accurate assessment of both the amount and size distribution of pyrite in a coal. These analyses were applied to a hypothetical fine-coal beneficiation process, where the best locations for gravity separations were determined from Rapid Scan data. A detailed account of all aspects of this project has already been submitted in the form of a technical report (DOE Report FE-2030-TR16) to the United States Department of Energy.

Rapid Scan Hardware and Software Evolution: The original Rapid Scan system (Version I) was controlled by a Digital Equipment Corporation PDP-9 computer with 4000 bytes of core memory. The limited memory and inaccurate analog-to-digital converter in this computer placed serious limitations on the usefulness of the system. The photomultiplier power supply in this early version represented another problem area, as it contributed an unacceptable variation to the reflectance readings. Consequently, interpretations based upon the resulting data were not reliable.

Subsequent improvements in system hardware were accompanied by the development of a more sophisticated software for Rapid Scan control. This new version (Version II) of the system is shown in Plate 1 and a schematic of the complete system including the computer and peripheral devices appears in Figure 11. The optical equipment employed is a Leitz Orthoplan MPV-2 microscope photometer. The photomultiplier output, in voltage form, enters a specially built filter-amplifier-inverter unit. The output from this device is fed to a Digital Equipment Corporation PDP-8A minicomputer with 32,000, 12-bit words of random access memory. Several peripheral devices provide flexibility in data output format. The LA-36 Decwriter and VT-52 video terminal are the main interactive units. A high quality hard-copy may be obtained from a Xerox 1700 printer and graphics are provided by a Houston Instruments DP-1 incremental plotter.

In the automated pyrite analysis, the microscope stage is powered by a Femco AMEDA stage drive. The stage is moved continuously (as opposed to discrete steps) and its horizontal and vertical movements are controlled automatically. The drive unit is connected to the microscope on the coaxial operating knobs of the mechanical stage.

Sampling and Analysis: The automated pyrite analysis is based upon the ability of the system to distinguish between epoxy binder, coal, and pyrite solely on the basis of their reflectance levels. As the polished coal specimen moves beneath the microscope objective, the photomultiplier monitors reflectance differences from the sample surface. These are stored in digital form in computer memory as a reflectance histogram or 'reflectogram'. An example of a reflectogram appears in Figure 14. The reflectance values on

RAPID SCAN HARDWARE FOR AUTOMATED PYRITE ANALYSIS

PLATE I

the abscissa range from 0 to 8% (in oil immersion) and 8% serves as the boundary between pyrite and all other coal components. Invariably, pyrite grains reflect more than 8% of incident light so that all of its readings are stored in the last array element (labelled 'D' in Figure 18).

The epoxy binder used in the routine preparation of polished coal briquettes normally comprises 20 to 30% of the sample volume and reflects less than 0.1% of incident light. The first reflectance peak (A) in Figure 18 represents the contribution of the binder. This sample was specially prepared and contained more than 50% epoxy by volume in order to emphasize its effect. The epoxy contribution must be removed from the reflectogram and this is accomplished by subtracting the best-fit Gaussian curve from the area. The remainder consists of the organic coal components and minerals other than pyrite (B). The prominent Gaussian distribution (C) appearing in the figure is the contribution of vitrinite, the principal organic coal component. Using these relationships, the volumetric contribution of pyrite is easily calculated. For the reflectogram in Figure 18, the number of readings on pyrite (D) divided by the number of readings in the coal range (B) yields the percentage of pyrite by volume.

The other part of the automated pyrite analysis is a measure of size based on the lineal scanning technique. Software control of sampling allows data points to be placed adjacent to one another forming a line across the specimen surface. When a pyrite grain is intersected, an unbroken intercept length can be measured as shown in Figure 19. These intercept lengths are also stored in the form of a histogram, which is later analyzed statistically for measures of size, and size sorting for the pyrite particles in the sample (Kuehn and Davis, 1979). A histogram of pyrite chord lengths is illustrated in Figure 20. The intercept lengths have a potential range of 2 μm (the limit of resolution for the system) to about 850 μm , which is the diameter of the opening in a 20-mesh sieve used for sample preparation. These distributions always have a high positive skew (mean greater than the mode) owing to the fact that most measurements occur in the smallest size classes near the resolving limit of the system.

Application of the Rapid Scan Automated Pyrite Analysis to Coal Beneficiation: Both the size and volume analyses for pyrite were applied in a laboratory experiment to study the effects of comminution on the pyrite content of a coal. Conceivably, size splits that contain significantly different amounts or sizes of pyrite would indicate the ideal locations for gravity separation in the fine-coal cleaning circuit of a preparation plant.

A sample of PSOC-634, the Upper Freeport seam, was crushed to pass an 8 mesh sieve. Subsamples were taken from the 8x0 mesh range and analyzed by the Rapid Scan for their volume percent pyrite (1.82%) and mean pyrite intercept length (16.2 μm). Next, the bulk of the coal was separated into its natural size distribution using a series of 21 closely-sized sieves. Each individual fraction was subjected to Rapid Scan analysis and results compared to those obtained for the composite sample. All data are summarized in Table 9.

Figure 18. THE REFLECTANCE DISTRIBUTION FOR PSOC-634, THE UPPER FREEPORT SEAM,
AT 8% FULL-SCALE REFLECTANCE

Consecutive Readings for Chord Length Measurement

Figure 19. THE CORRECT SPATIAL RELATIONSHIP BETWEEN CONSECUTIVE PHOTOMULTIPLIER READINGS FOR INTERCEPT MEASUREMENT

CHORD SIZE(UM)	CUM %	FREQUENCY						
		5 V	10 V	15 V	20 V	25 V	30 V	35 V
2	11.02	*****						
4	20.47	*****						
6	30.71	*****						
8	39.37	*****						
10	45.67	*****						
12	50.39	*****						
14	54.33	*****						
16	58.27	*****						
18	62.99	*****						
20	63.78	*						
24	66.14	***						
26	66.93	*						
28	70.08	****						
30	73.23	****						
32	75.59	***						
34	78.74	****						
36	80.31	**						
38	81.89	**						
42	83.46	**						
48	85.04	**						
50	85.83	*						
52	86.61	*						
54	88.19	**						
56	88.98	*						
64	89.76	*						
72	90.55	*						
76	92.13	**						
82	92.91	*						
84	93.70	*						
98	94.49	*						
104	95.28	*						
110	96.06	*						
122	97.64	**						
132	98.43	*						
134	99.21	*						
204	100.00	*						

Figure 20. A HISTOGRAM OF PYRITE CHORD LENGTHS

Table 9
Automated Analysis of Specially Sized Sample Suite
for PSOC-634

<u>SIZE FRACTION</u>	<u>SCREEN OPENING</u>	<u>$\bar{x}$ PYRITE INTERCEPT</u>	<u>% PYRITE</u>	<u>D - VALUE</u>
8 x 0	2.36 mm	16.2 μ m	1.82	--
8 x 10	2.36 mm	13.6 μ m	1.42	.076*
10 x 12	2.00 mm	18.3 μ m	3.83	.086**
12 x 14	1.70 mm	11.7 μ m	1.51	.148***
14 x 16	1.40 mm	15.8 μ m	2.03	.105***
16 x 18	1.18 mm	14.7 μ m	1.24	.055
18 x 20	1.00 mm	15.4 μ m	1.65	.046
20 x 25	850 μ m	17.2 μ m	1.29	.051
25 x 30	710 μ m	14.0 μ m	1.46	.087*
30 x 35	600 μ m	16.5 μ m	1.65	.075*
35 x 40	500 μ m	13.4 μ m	1.71	.103***
40 x 45	425 μ m	13.8 μ m	.90	.072*
45 x 50	355 μ m	17.1 μ m	1.50	.112**
50 x 60	300 μ m	12.3 μ m	.92	.154***
60 x 70	250 μ m	12.0 μ m	1.01	.046
70 x 80	212 μ m	11.5 μ m	.82	.040
80 x 100	180 μ m	11.8 μ m	.79	.020
100 x 120	150 μ m	13.0 μ m	1.06	.060
120 x 170	125 μ m	11.3 μ m	1.19	.068*
170 x 200	90 μ m	9.0 μ m	1.16	.096***
200 x 270	75 μ m	7.0 μ m	1.28	.117***
270	53 μ m	5.5 μ m	.65	.142***

* - SIGNIFICANT AT 5% LEVEL OF PROBABILITY
 ** - SIGNIFICANT AT 1% LEVEL OF PROBABILITY
 *** - SIGNIFICANT AT .1% LEVEL OF PROBABILITY

Two fractions (10-12 mesh and 14-16 mesh) contain significantly higher proportions of pyrite than the whole-coal sample and the other size fractions. Also, three prominent episodes of pyrite size change occur. These were determined by testing D-values (from a non-parametric statistical test) for significance. The asterisks indicate a significant difference in size at a specified level of probability. Changes in the intercept size distributions indicate that the relationship of the pyrite particles to the surrounding coal has changed, and presumably, more pyrite has been liberated. Based on these data, gravity separations for this coal should be performed on the 8x16 and 25x60 mesh ranges. The final episode of pyrite size change (170x-270 mesh range) occurs in a size range so small that gravity separations are ineffective. It is significant, however, that there are no anomalously high concentrations of pyrite in these small fractions.

Summary: The Rapid Scan is a minicomputer-based system for automated reflectance microscopy. It is capable of collecting, storing and analyzing data concerning the amount and size distribution of pyrite contained in a coal. These analyses have been applied to a laboratory simulation of a fine-coal cleaning circuit where the best locations for gravity separations were determined solely from interpretations of Rapid Scan data.

The Rapid Scan system has gone through several stages of hardware and software evolution and is now ready for application to many problems in direct coal utilization and conversion.

D. Mineralogical Analysis of Coal Samples

The mineralogical analysis of PSOC coals occurs in four major steps. The first consists of the low temperature ashing of the as-received coal. The resultant low temperature ash (LTA) is then subjected to qualitative X-ray diffraction and infrared spectrometric scans to determine the presence or absence of various mineral phases. The third step involves the direct quantitative measurement of the phases quartz, pyrite and calcite by X-ray diffraction and kaolinite and gypsum (as anhydrite) by infrared spectrometry. In the fourth step, various chemical data are used in conjunction with the direct mineralogical analyses in estimating the amounts of the remaining phases detected in the qualitative scans (e.g. illite, montmorillonite, mixed-layer clays, melanterite, etc).

Discussions on the low temperature ashing of coals may be found in Gluskoter (1965) and O'Gorman (1971). At the Mineral Constitution Laboratories, the as-received coal is ground to -80 mesh (less than 177 microns) and heated at 105°C for at least 15 minutes (more if the coal is a high moisture coal) prior to placement in the low temperature asher. Enough coal is processed so that the final weight of the LTA will be about 500 mg. The ashing occurs in a partial vacuum of approximately 5 torr or less with an oxygen flow rate of approximately 100cc/min. The radio-frequency power is set so that each of the two chambers in the asher receives about 50 watts. The samples are stirred three times during each working day and are ready when the coal has lost 10 mg or less in weight during the course of a day or night (generally 4-5 days). The completed LTA is then ground (mortar and pestle) and sieved to -200 mesh (less than 74 microns) prior to any further analysis.

The qualitative X-ray scan is obtained by grinding 30-40 mg of the -200 mesh LTA under absolute alcohol in a mortar and pestle for 3-5 minutes, dispersing the slurry onto a glass slide with an eyedropper, drying the slide (at room temperature), and running the specimen on a diffractometer from $40-3^{\circ} 2\theta$ (Cu radiation). An infrared scan is prepared by grinding another 20-30 mg of the -200 mesh LTA under alcohol in a mortar and pestle for approximately 5 minutes, drying, and then mixing 1 mg of the powder with 200 mg of dried (105°C) spec-pure KBr in a mortar and pestle. The mix is then pressed into a relatively clear pellet which is scanned from $4000-200\text{ cm}^{-1}$.

The quantitative X-ray analysis of the LTA begins with the mixing of the appropriate amount of CaF_2 (fluorite) with LTA so that the CaF_2 constitutes 13% by weight of the total. If possible, at least 400 mg of LTA should be used to minimize any sampling problems and to reduce the effects of any sample loss or contamination during the sample preparation. CaF_2 was selected over Al_2O_3 as an internal standard as it tends to produce greater peaks with a given amount of sample, thereby requiring less dilution of the LTA. Calibration curves obtained using CaF_2 and Al_2O_3 are about the same in terms of precision. While a minor pyrite peak ($28.5^{\circ} 2\theta$) is located close to the CaF_2 peak used for calibration ($28.3^{\circ} 2\theta$), no significant interference occurs for pyrite contents $<40\%$ in the LTA.

The mix of CaF_2 and LTA is placed in a small steel ball mill ($\sim 2\text{ ml}$ capacity), which is taped shut and run for 12-14 minutes on a Spex mixer-mill. The sample is then scraped out of the ball mill and ground in a mortar and pestle under alcohol for 2-3 minutes, air dried, and scanned on an X-ray diffractometer from $38^{\circ}-24^{\circ} 2\theta$ using a dry cavity mount of plastic or glass set onto a rotating sample holder (Rao and Gluskoter, 1973). Quartz, pyrite and calcite are determined by taking the ratios of the 26.6° and/or 36.6° peaks (for quartz), the 33.1° and/or 37.0° peaks (for pyrite) and the 29.4° peak (for calcite) with the 28.3° peak of CaF_2 . These ratios are then translated into absolute percentages by reading off a series of calibration curves obtained from a series of standards. Two peaks were used, where possible, for quartz and pyrite to provide checks against errors in reading and extinction effects. Ideally, the % quartz and pyrite obtained using both sets of peaks should be the same.

Quantitative infrared analysis of the LTA for kaolinite is carried out using the qualitative IR scan. The baseline method (O'Gorman, 1971) is used in evaluating the 910 cm^{-1} peak of kaolinite and the % kaolinite is obtained via a calibration curve drawn from a series of standards. If the qualitative X-ray and/or IR scan indicates that there is gypsum, bassanite or anhydrite in the sample, the IR pellet is reground, heated to 500°C overnight, repressed and another pattern is run. The baseline method is then used in evaluating the 670 cm^{-1} peak of anhydrite, the percent anhydrite obtained from a calibration curve drawn from a series of standards, and the result recalculated as percent gypsum in the original LTA. The latter is done as most, if not all, of the bassanite and anhydrite is the result of dehydration of initial gypsum during the LTA process.

The relative precision of infrared and X-ray quantitative analyses is about $\pm 10-20\%$.

After mineralogical and chemical analyses have been obtained, the % "total other clays" (i.e. montmorillonite + illite + mixed layer clays) is obtained by determining how much clay can be formed with the % Al_2O_3 and % SiO_2 remaining after quartz and kaolinite have been accounted for. The direct determination of clays such as "montmorillonite", "illite" and "mixed-layer clays" on a routine basis is rendered infeasible by the fact that such names are general rather than specific terms such as "quartz" or "calcite", or even "kaolinite". Thus, the term "montmorillonite" is generally used to represent that group of clays which include montmorillonite proper, beidillite, nontronite, saponite, hectorite, and saconite. While these various "montmorillonites" or "smectites" show similar gross physical and chemical properties (e.g. swelling, cation exchange), the crystallographic differences due to composition and the variance in the degrees of crystallinity are such as to prevent any simple forms of quantitative analyses. While some limited success has been achieved by Rao and Gluskoter (1973) using an empirical X-ray diffraction method on Illinois coals, such a method does not appear amenable to coals obtained from a wider area of sampling as is the case in this study.

Since the mineralogical analyses have been performed on low temperature ash while the chemical analyses have been obtained from the high temperature ash (750°C), a conversion factor consisting of the ratio of the HTA to the LTA must be used to make the HTA and LTA data compatible with each other. To calculate the SiO_2 and Al_2O_3 remaining on an LTA basis after the kaolinite and quartz contributions have been subtracted out, the following equations are used:

$$\begin{aligned} \text{Al}_2\text{O}_3 \text{ remaining in LTA} &= \left[\left(\frac{\% \text{ HTA}}{\% \text{ LTA}} \right) \times \left(\frac{\% \text{ Al}_2\text{O}_3}{\text{in HTA}} \right) \right] - \left[\frac{\% \text{ kaolinite in LTA}}{\text{in LTA}} \times .395 \right] \\ \text{SiO}_2 \text{ remaining in LTA} &= \left[\left(\frac{\% \text{ HTA}}{\% \text{ LTA}} \right) \times \left(\frac{\% \text{ SiO}_2}{\text{in HTA}} \right) \right] - \left[\left(\frac{\% \text{ kaolinite in LTA}}{\text{in LTA}} \times .465 \right) \right. \\ &\quad \left. + \left(\frac{\% \text{ quartz in LTA}}{\text{in LTA}} \right) \right] \end{aligned}$$

If one assumes that "other clays" will tend to be approximately 25% Al_2O_3 and 50% SiO_2 figures which appear to be generally reasonable in view of the data from Deer, Howie and Zussman, 1971, then the amount of "other clays" will be approximately 4 times the remaining % Al_2O_3 and 2 times the % SiO_2 . In cases where the two numbers do not agree, the means of the two is used. Disagreement between the amount of clays estimated from the remaining Al_2O_3 and SiO_2 may indicate a number of problems:

1) The clays involved may not be composed of 25% Al_2O_3 and/or 50% SiO_2 and the procedure has therefore underestimated or overestimated the significance of the Al_2O_3 and/or SiO_2 remaining. The 50% estimate for SiO_2 in clays

is probably more accurate an estimate than is the 25% estimate for Al_2O_3 .

2) There are other Al_2O_3 or SiO_2 bearing phases in the LTA besides clays and quartz such as feldspars, micas, gibbsite, etc.

3) An error lies in the determination of either quartz, kaolinite, % Al_2O_3 or % SiO_2 . An error of 5 percent in the quartz determination for example, will mean a corresponding 10 percent error in the amount of clay estimated.

As it is highly probable that one or more of the problems mentioned in the preceding paragraph will apply in the estimation of the clay content of any particular LTA, it can be concluded that such estimates are, at best, semi-quantitative procedures.

The % S content of the LTA as determined by a Leco Sulfur Analyzer allows a check on the % pyrite + % gypsum. The directly determined % S should not be less than the total S contribution from pyrite and gypsum, however, it is possible that the % S as determined via the sulfur analyzer may be greater than that accounted for by the pyrite and gypsum determinations even if such determinations are accurate. This may be due to the presence of residual organic sulfur in the LTA's (especially a problem in the low rank coals) and the presence of other sulfur-bearing phases such as melanterite, szomolnokite, etc. For most coals, where another sulfur-bearing phase is detected in the qualitative scans, the amount of this phase may be estimated via the difference between the Leco S and the S from pyrite and gypsum since the organic sulfur is generally negligible.

Table 10 shows how various mineral species may contribute to the amounts of other chemical constituents present in the high temperature ash.

Table 10

Amount of Chemical Species Present in Various Mineral Phases
Occurring in Low Temperature Ashes of PSOC Coal Samples

<u>Chemical Species</u>	<u>Predominant Phase(s)</u>	<u>Minor Phases</u>
SiO_2	Quartz (100%) Kaolinite (45%) Illite, Montmorillonite (~50%)	Chlorite (~25%)
Al_2O_3	Kaolinite (39%) Illite, Montmorillonite (~25%)	Corundum (100%) Gibbsite (65%)
CaO	Calcite (56%) Gypsum (33%) Bassanite (39%) Anhydrite (41%)	Montmorillonite (2-3%)
Fe_2O_3	Pyrite (67%)	Iron Sulfates (50-90%) Clays (0-5%, as high as 30%)
K_2O	Illite (5-10%)	Mixed-layer clays
TiO_2	Rutile (100%)	Clays (0-2%)
MgO	Dolomite (22%)	Clays (0-5%, as high as 30%)
P_2O_5	Apatite	
Na_2O	Montmorillonite (0-1%) Illites (0-1%, as high as 5%)	

While, ideally, the results from the mineralogical analyses should total 100%, the totals will, invariably, be below 100. This is due to a number of factors:

1) presence of minor and trace phases not seen in the X-ray or I.R. patterns. Generally, if a phase is present in amounts less than 5%, difficulty will be encountered in determining it from the background. It is also possible that the major peaks of minor and trace phases will be hidden by the peaks of more predominant phases.

2) presence of organic and/or amorphous matter in the low temperature ash;

3) varying degrees of non-crystallinity in the mineral phases, leading to lesser signal responses for a given amount of phase;

4) presence of extinction effects leading to lesser signal responses for a given amount of phase;

5) underestimation of clay matter and/or negative errors in other phase determinations.

VI. THE PENN STATE COAL SAMPLE BANK

A. Management and Operation of the Sample Bank

The Penn State Coal Sample Bank contains over 1150 well-documented coal samples that were collected either by Penn State sampling crews or by crews from other agencies following Penn State prescribed procedures. Although initially developed simply to serve the requirements of Penn State coal researchers in conjunction with research supported by the federal Office of Coal Research (hence the sample designation of PSOC-), it has developed into an important reservoir of samples for the Nation's coal community and is now being used by agencies in other countries.

Funding for the management and operation of the Sample Bank is derived from a number of sources. The six principal sources of support are identified in Figure 21, as are the principal classes of costs. Capital facility costs include the funds required to design, engineer and construct the Sample Bank Facility which was developed with funds derived from University sources and the federal Energy Research and Development Administration. The exterior and interior of the facility are shown in Plates II and III. Plate III also shows another mode of sample storage involving other university facilities.

In addition to the financial aspects of Sample Bank management, a number of other "management" aspects are involved in maintaining and developing the Bank. The unit operations associated with the procurement of coal samples is depicted in Figure 22. This facet of the operation requires appreciation of the fact that sampling in active mines impacts on mine productivity. For this reason, sampling crews arrive at the mine site fully equipped and ready to take the samples expeditiously with minimum involvement of mine personnel.

Figure 21. FINANCIAL MANAGEMENT OF THE PENN STATE SAMPLE BANK

PLATE II

Plate II Exterior and Interior of Penn State

Sample Bank Facility

PLATE III

Plate III Sample Bank Operations

Handling of coal samples in Penn State Sample Bank Facilit (upper left). Riffing of coal sample to produce representative sub-samples (upper right). Sealed storage of 1 pound units of minus 20 mesh coal samples in facilities in Deike Building at The Pennsylvania State University.

Figure 22. MANAGEMENT OF SAMPLE PROCUREMENT

As soon as feasible after collection, the samples are delivered to the University for processing. In the case of the full-seam channel samples, 4 classes of sub-samples are produced. One set is prepared for the various analyses and distributed to the several analytical laboratories for characterization. The remaining coal is stored in three modes:

- 1) one pound lots are stored in nitrogen in #2 sealed cans as minus 20 mesh coal;
- 2) thirty-five pound lots are stored in nitrogen in sealed polyethylene pails as minus 1/4" coal;
- 3) the remainder of the sample is stored as 200 pound lots in plastic bags, sealed in fiber drums, in an "as-mined" condition.

These procedures are shown in the flow sheet presented as Figure 23.

Daily operation of the Sample Bank is by no means routine. This is true because the majority of persons requesting samples need assistance in determining which samples best fit their needs. Because of this, the staff required for operation includes professional, technical and secretarial personnel. Figure 24 identifies the personnel currently associated with Sample Bank operations and their functions. As implied above, the procedures required to effectively respond to requests for samples are quite varied. Figure 25 indicates that only about one-fourth of the requests are clearly defined and capable of being passed directly to technicians for retrieval, packaging and shipping. In Figure 25 an attempt is made to depict the various interactions and pathways that requests commonly involve in the course of compliance.

B. Contents of the Sample Bank

The great majority of samples in the Penn State Sample Bank are "raw" coals, by which is meant that they have not been subjected to any cleaning or beneficiation procedure. "Cleaned" coal samples are labeled as "preparation plant products". Eight types of samples are contained in the Bank. The principal types are:

- 1) large volume, full-seam channel samples (200-1000 pounds);
- 2) small volume, full seam channel samples (50-75 pounds representing 4"x4"x seam thickness);
- 3) channel samples of specific coal lithotypes (30-75 pounds);
- 4) channel samples of benches or sub-seam unit thicknesses (50-100 pounds);
- 5) core samples (normally 3" diameter).

Small numbers of the following sample types also are contained in the Bank:

- 1) preparation plant samples;
- 2) run-of-mine samples;
- 3) grab samples.

The distribution of coal samples by Coal Province is as follows:

1) Eastern Province	434
2) Interior Province	226
3) Great Plains Province	127
4) Rocky Mountain Province	224
5) Gulf Coast Province	122
6) Pacific Coast Province	13
7) Alaskan province	0

Figure 23. MANAGEMENT OF SAMPLE HANDLING AND STORAGE

Figure 24. MANAGEMENT OF SAMPLE BANK OPERATIONS: Personnel Required

Figure 25. MANAGEMENT OF SAMPLE BANK OPERATIONS: Interactions and Pathways Involved in Sample Request Compliance

The distribution of coal samples by state is as follows:

1) Alabama	6
2) Arkansas	22
3) Arizona	2
4) Colorado	57
5) Illinois	53
6) Indiana	47
7) Iowa	26
8) Kansas	1
9) Kentucky	73
10) Louisiana	7
11) Maryland	6
12) Missouri	9
13) Montana	36
14) New Mexico	58
15) North Dakota	8
16) Ohio	53
17) Oklahoma	40
18) Pennsylvania	174
19) Tennessee	2
20) Texas	111
21) Utah	63
22) Virginia	9
23) Washington	13
24) West Virginia	142
25) Wyoming	128

A complete listing of the coal samples contained in the Penn State Coal Sample Bank may be found in Appendix IV.

C. Sample Service to PSU Principal Investigators and Other Agencies

During the four year period 8/26/75 through 8/26/79 in excess of 2600 samples were prepared and transmitted to four analytical laboratories for the development of basic compositional data. In excess of 1300 were prepared and transmitted to PSU Principal Investigators for their particular studies. As a service to other agencies in the coal community in excess of 1300 samples were prepared and transmitted to a broad range of organizations in industry, government and universities. Exhibit A is a copy of the "Sample Request Form". In addition to the use of this, letter and verbal requests are accepted and acted on. Appendix V presents a representative list of the agencies that received samples during the four year contract period. The list identifies the agency and indicates the number and size of the samples supplied.

PENN STATE COAL SAMPLE BANK

REQUEST FORM

William Spackman, Director
Coal Research Section
517 Deike Building
The Pennsylvania State University
University Park, Pennsylvania 16802

THIS IS A REQUEST FOR:

☐ A complete list of coal samples contained in the PSU/DOE Coal Sample Bank.

☐ Coal samples as specified below:

a. See attached letter for description of samples requested. ☐

-- OR --

b. Total number of samples requested. _____

c. Quantity required for each. _____

Desired quantity _____

Minimum acceptable quantity _____

d. Identity of each sample by PSOC number.

PSOC _____ PSOC _____ PSOC _____ PSOC _____ PSOC _____

PSOC _____ PSOC _____ PSOC _____ PSOC _____ PSOC _____

PSOC _____ PSOC _____ PSOC _____ PSOC _____ PSOC _____

e. Equivalent substitutes for the above samples will be acceptable if the one specifically requested is unavailable.

Yes ☐

No ☐

f. Supply coal characteristics data on above samples. ☐

g. One sentence description of proposed sample use.

ADDRESS TO WHICH SAMPLES ARE TO BE SENT:

I understand that Penn State would like to be kept informed of any research results generated through the use of the samples.

Signature

VII. THE PENN STATE COAL DATA BASE

A. Description of the Data Base

The Penn State Coal Data Base is a computerized compilation of a broad spectrum of analytical and performance data on well documented coal samples, replicates of which are contained in the Penn State Sample Bank. Many of the classes of data included in the Data Base have been described in the section of this report entitled "Coal Characterization". The Data Base is capable of accepting a total of 370 pieces of information on any individual sample and an additional 225 values can be calculated from the raw data values bringing the total number of informational repositories to 595 for any given sample. Table 11 classifies and lists the 370 informational and raw data repositories available in the Data Base.

The Data Base is contained in the IBM 360/370 Computer at the University Computational Center for complex statistical analysis and manipulation of the data. It is also stored in a PDP-8A Minicomputer in the Coal Research Laboratories in Deike Building. The PDP-8A System serves to provide simple search and retrieval capabilities and provides researchers with an interactive computer facility. A 10 page data printout in a convenient 8 1/2" x 11" format can be produced for any coal sample. An example of this printout is displayed in Appendix VI.

The minicomputer (PDP-8A) system is the day-by-day service unit employed to respond to most requests for coal data. It is programmed to provide most of the procedures required to generate the information involved in the bulk of the cases. These capabilities are described in Table 12.

Table 12
PDP-8A Capabilities

1. Print-out of standard data formats with letter quality on 8 1/2" x 11" sheets (any or all of the 10 pages for any coal sample)
2. Search Data Base on any raw data parameter.
3. Sort raw data generated by a search.
4. Display searched and sorted raw data together with any associated calculated values.
5. Print searched and sorted raw data together with any associated calculated values.

Table 11
Informational and Raw Data Repositories
in the Penn State Coal Data Base

1) SAMPLE AND SAMPLING INFORMATION.

TABLE ENTRY-TABLE INDEXED-LOCATION-NAME

1	0	6	PSOC NUMBER-----
2	1	7	COLLECTOR-----
3	0	8	COLLECTORS NUMBER-----
4	0	9	COLLECTION DATE-----
5	2	10	SAMPLE TYPE-----
6	3	11	SAMPLE QUALIFIER-----
7	4	12	HARDNESS-----
8	5	13	SIZE-----
9	6	14	SPECIFIC GRAVITY-----
10	0	15	SAMPLE RESERVE-----
11	32	16	SAMPLE INFORMATION-----
12	7	17	REPORTED RANK-----
13	8	18	SEAM NAME-----
14	9	19	ALTERNATE SEAM NAME-----
15	0	20	SEAM THICKNESS-----
16	0	21	THICKNESS SAMPLED-----
17	0	22	CORE RECOVERY-----
18	0	23	CORE DIAMETER-----
-1			

2) GEOGRAPHIC INFORMATION.

TABLE ENTRY-TABLE INDEXED-LOCATION-NAME

1	10	24	COUNTRY-----
2	11	25	STATE-----
3	29	26	NEAREST TOWN-----
4	30	27	COUNTY-----
5	31	28	TOWNSHIP-----
6	0	29	ZIP CODE-----
7	33	30	QUADRANGLE-----
8	0	31	LATITUDE-----
9	0	32	LONGITUDE-----
10	12	33	COAL PROVINCE-----
11	13	34	COAL REGION-----
12	14	35	COAL FIELDS-----
-1			

3) GEOLOGIC INFORMATION.

TABLE ENTRY-TABLE INDEXED-LOCATION-NAME

1	15	36	GEOLOGIC SYSTEM (AGE)-----
2	16	37	GEOLOGIC SERIES-----
3	17	38	LEVEL IN SYSTEM-----
4	18	39	LEVEL IN SERIES-----
5	19	40	GROUP-----
6	20	41	FORMATION-----
7	21	42	OVERBURDEN LITHOLOGY-----
8	21	43	FLOOR LITHOLOGY-----
-1			

4) SEAM STRATA INFORMATION.

TABLE ENTRY-TABLE INDEXED-LOCATION-NAME

1	0	44	STRATUM I THICKNESS-----
2	22	45	STRATUM I LITHOTYPE-----
3	0	46	STRATUM II THICKNESS-----
4	22	47	STRATUM II LITHOTYPE-----
5	0	48	STRATUM III THICKNESS-----
6	22	49	STRATUM III LITHOTYPE-----
7	0	50	STRATUM IV THICKNESS-----
8	22	51	STRATUM IV LITHOTYPE-----
9	0	52	STRATUM V THICKNESS-----
10	22	53	STRATUM V LITHOTYPE-----
11	0	54	STRATUM VI THICKNESS-----
12	22	55	STRATUM VI LITHOTYPE-----
13	0	56	STRATUM VII THICKNESS-----
14	22	57	STRATUM VII LITHOTYPE-----
15	0	58	STRATUM VIII THICKNESS-----
16	22	59	STRATUM VIII LITHOTYPE-----
17	0	60	STRATUM IX THICKNESS-----
18	22	61	STRATUM IX LITHOTYPE-----
19	0	62	STRATUM X THICKNESS-----
20	22	63	STRATUM X LITHOTYPE-----

-1

5) MINE INFORMATION.

TABLE ENTRY-TABLE INDEXED-LOCATION-NAME

1	23	64	MINE NAME-----
2	24	65	MINING METHOD-----
3	0	66	MINE RESERVES-----
4	0	67	MINE PRODUCTION-----
5	0	68	MINE LIFE EXPECTANCY-----
6	0	69	OVERBURDEN THICKNESS (FEET)-----
7	0	70	OVERBURDEN THICKNESS (INCHES)-----

-1

6) OTHER CHEMICAL DATA.

TABLE ENTRY-TABLE INDEXED-LOCATION-NAME

1	0	71	% CARBON DIOXIDE CONTENT (DRY)-----
2	0	72	SULFUR AS SULFATE IN ASH (DRY)-----
3	0	73	OXYGEN AS COOH (MILLIEQUIVALENTS/GRAM OF DRY COAL)---
4	0	74	OXYGEN AS OH (% OF DRY COAL)-----
5	25	75	INFRA-RED ANALYSIS AVAILABILITY-----

-1

7) PROXIMATE ANALYSIS.

TABLE ENTRY-TABLE INDEXED-LOCATION-NAME

1	0	76	EQUILIBRIUM MOISTURE-----
2	0	77	MOISTURE - AS RECEIVED-----
3	0	78	ASH CONTENT (DRY)-----
4	0	79	VOLATILE MATTER CONTENT (DRY)-----
5	0	80	FIXED CARBON CONTENT (DRY)-----
6	0	81	CALORIFIC VALUE (DRY)-----

-1

8) ULTIMATE ANALYSIS.

TABLE ENTRY-TABLE INDEXED-LOCATION-NAME

1	0	82	CARBON CONTENT (DRY)-----
2	0	83	HYDROGEN CONTENT (DRY)-----
3	0	84	NITROGEN CONTENT (DRY)-----
4	0	85	CHLORINE CONTENT (DRY)-----
5	0	86	OXYGEN CONTENT (DRY)-----

-1

9) ANALYSIS FOR SULFUR AND SULFUR FORMS.

TABLE ENTRY-TABLE INDEXED-LOCATION-NAME

1	0	87	PYRITIC SULFUR (DRY)-----
2	0	88	SULFATE SULFUR (DRY)-----
3	0	89	ORGANIC SULFUR (DRY)-----
4	0	90	TOTAL SULFUR (DRY)-----

-1

10) ASH FUSION ANALYSIS.

TABLE ENTRY-TABLE INDEXED-LOCATION-NAME

1	0	91	INITIAL DEFORMATION TEMPERATURE (RED.)-----
2	0	92	SOFTENING TEMPERATURE (RED.)-----
3	0	93	HEMISPHERE TEMPERATURE (RED.)-----
4	0	94	FLUID TEMPERATURE (RED.)-----
5	0	95	INITIAL DEFORMATION (OXID.)-----
6	0	96	SOFTENING TEMPERATURE (OXID.)-----
7	0	97	HEMISPHERE TEMPERATURE (OXID.)-----
8	0	98	FLUID TEMPERATURE (OXID.)-----

-1

11) GEISELER PLASTICITY DATA.

TABLE ENTRY-TABLE INDEXED-LOCATION-NAME

1	0	99	MAXIMUM FLUIDITY-----
2	0	100	MAXIMUM FLUIDITY TEMPERATURE-----
3	0	101	INITIAL SOFTENING TEMPERATURE-----
4	0	102	SOLIDIFICATION TEMPERATURE-----
5	0	103	FLUID TEMPERATURE RANGE-----
6	27	104	PLASTOMETER TYPE-----

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12) PHYSICAL PROPERTIES.

TABLE ENTRY-TABLE INDEXED-LOCATION-NAME

1	0	105	FREE SWELLING INDEX-----
2	34	106	GRAY KING COKE TYPE-----
3	0	107	HARDGROVE GRINDABILITY-----
4	0	108	VICKERS MICROHARDNESS-----
5	0	109	SURFACE AREA - NITROGEN-----
6	0	110	SURFACE AREA - CO2-----
7	0	111	HELIUM DENSITY-----
8	0	112	MERCURY DENSITY-----
9	0	113	WATER DENSITY-----
10	0	114	SPECIFIC GRAVITY-----
11	0	115	MICROPORE VOLUME-----
12	0	116	MACROPORE VOLUME-----
13	0	117	TOTAL PORE VOLUME-----
14	0	118	PORE SIZE DISTRIBUTION-----

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13) PETROGRAPHIC ANALYSIS - LOW RANK COALS.

TABLE ENTRY-TABLE INDEXED-LOCATION-NAME

1	0	119	TEXTINITE-----
2	0	120	ULMINITE-----
3	0	121	ATTRINITE-----
4	0	122	DENSINITE-----
5	0	123	GELINITE-----
6	0	124	CORPOHUMINITE-----
7	0	125	SPORINITE-----
8	0	126	CUTINITE-----
9	0	127	RESINITE-----
10	0	128	EXUDATINITE-----
11	0	129	FLUORINITE-----
12	0	130	BITUMINITE-----
13	0	131	ALGINITE-----
14	0	132	LIPTODETRINITE-----
15	0	133	FUSINITE-----
16	0	134	SEMIFUSINITE-----
17	0	135	MACRINITE-----
18	0	136	MICRINITE-----
19	0	137	SCLEROTINITE-----
20	0	138	INERTODETRINITE-----
-1			

14) PETROGRAPHIC ANALYSIS - HIGH RANK COALS.

TABLE ENTRY-TABLE INDEXED-LOCATION-NAME

1	0	139	VITRINITE-----
2	0	140	PSEUDOVITRINITE-----
3	0	141	FUSINITE-----
4	0	142	SEMIFUSINITE-----
5	0	143	MACRINITE-----
6	0	144	MICRINITE-----
7	0	145	SCLEROTINITE-----
8	0	146	SPORINITE-----
9	0	147	CUTINITE-----
10	0	148	RESINITE-----
11	0	149	EXUDATINITE-----
12	0	150	FLUORINITE-----
13	0	151	BITUMINITE-----
14	0	152	ALGINITE-----
15	0	153	LIPTODETRINITE-----
-1			

15) REFLECTANCE ANALYSIS.

TABLE ENTRY-TABLE INDEXED-LOCATION-NAME

1	0	154	TYPE OF REFLECTANCE ANALYSIS-----
2	0	155	VITRINITE: HIGH RO VALUE-----
3	0	156	LOW RO VALUE-----
4	0	157	MEAN-MAX RO VALUE-----
5	0	158	STANDARD DEVIATION-----
6	0	159	PSEUDOVITRINITE: HIGH RO VALUE-----
7	0	160	LO RO VALUE-----
8	0	161	MEAN-MAX RO VALUE-----
9	0	162	STANDARD DEVIATION-----
10	0	163	ULMINITE: HIGH RO VALUE-----
11	0	164	LOW RO VALUE-----
12	0	165	MEAN-MAX RO VALUE-----
13	0	166	STANDARD DEVIATION-----

14	0	167	VITRINOIDS: HIGH RO VALUE-----
15	0	168	LOW RO VALUE-----
16	0	169	MEAN-MAX RO VALUE-----
17	0	170	STANDARD DEVIATION-----

16) REFLECTANCE HALF-STEPS.

TABLE ENTRY-TABLE INDEXED-LOCATION-NAME

1	0	171	STEP 1-----
2	0	172	STEP 2-----
3	0	173	STEP 3-----
4	0	174	STEP 4-----
5	0	175	STEP 5-----
6	0	176	STEP 6-----
7	0	177	STEP 7-----
8	0	178	STEP 8-----
9	0	179	STEP 9-----
10	0	180	STEP 10-----
11	0	181	STEP 11-----
12	0	182	STEP 12-----
13	0	183	STEP 13-----
14	0	184	STEP 14-----
15	0	185	STEP 15-----
16	0	186	STEP 16-----
17	0	187	STEP 17-----
18	0	188	STEP 18-----
19	0	189	STEP 19-----
20	0	190	STEP 20-----
21	0	191	STEP 21-----
22	0	192	STEP 22-----
23	0	193	STEP 23-----
24	0	194	STEP 24-----
25	0	195	STEP 25-----
26	0	196	STEP 26-----
27	0	197	STEP 27-----
28	0	198	STEP 28-----
29	0	199	STEP 29-----
30	0	200	STEP 30-----
31	0	201	STEP 31-----
32	0	202	STEP 32-----
33	0	203	STEP 33-----
34	0	204	STEP 34-----
35	0	205	STEP 35-----
36	0	206	STEP 36-----
37	0	207	STEP 37-----
38	0	208	STEP 38-----
39	0	209	STEP 39-----
40	0	210	STEP 40-----
41	0	211	STEP 41-----
42	0	212	STEP 42-----
43	0	213	STEP 43-----
44	0	214	STEP 44-----
45	0	215	STEP 45-----
46	0	216	STEP 46-----
47	0	217	STEP 47-----

48	0	218	STEP 48	-----
49	0	219	STEP 49	-----
50	0	220	STEP 50	-----
51	0	221	STEP 51	-----
52	0	222	STEP 52	-----
53	0	223	STEP 53	-----
54	0	224	STEP 54	-----
55	0	225	STEP 55	-----
56	0	226	STEP 56	-----
57	0	227	STEP 57	-----
58	0	228	STEP 58	-----
59	0	229	STEP 59	-----

17) MINERALOGICAL ANALYSIS (OGORMAN)

TABLE ENTRY-TABLE INDEXED-LOCATION-NAME

1	26	230	KAOLINITE	-----
2	26	231	ILLITE	-----
3	26	232	MUSCOVITE	-----
4	26	233	CHLORITE	-----
5	26	234	MONTMORILLONITE	-----
6	26	235	MIXED CLAYS	-----
7	26	236	CALCITE	-----
8	26	237	ARAGONITE	-----
9	26	238	DOLOMITE	-----
10	26	239	ANKERITE	-----
11	26	240	SIDERITE	-----
12	26	241	QUARTZ	-----
13	26	242	GYP SUM	-----
14	26	243	PYRITE	-----
15	26	244	JAROSITE	-----
16	26	245	HEMATITE	-----
17	26	246	RUTILE	-----
18	26	247	THENARDITE	-----
19	26	248	PLAGIOCLASE	-----

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18) MINERALOGICAL ANALYSIS (MCL).

TABLE ENTRY-TABLE INDEXED-LOCATION-NAME

1	0	249	QUARTZ	-----
2	0	250	PYRITE	-----
3	0	251	CALCITE	-----
4	0	252	GYP SUM	-----
5	0	253	KAOLINITE	-----
6	0	254	MONTMORILLONITE + ILLITE + MIXED LAYER CLAY	-----
7	0	255	MONTMORILLONITE + ILLITE	-----
8	0	256	MONTMORILLONITE + MIXED LAYER CLAYS	-----
9	0	257	ILLITE + MIXED LAYER CLAYS	-----
10	0	258	MONTMORILLONITE	-----
11	0	259	ILLITE	-----
12	0	260	MIXED LAYER CLAYS	-----
13	0	261	FELDSPAR	-----
14	0	262	MINOR FE SULFATES	-----

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19) MAJOR AND MINOR ELEMENT ANALYSIS.

TABLE ENTRY-TABLE INDEXED-LOCATION-NAME

1	0	263	SIO2	CONTENT-----
2	0	264	AL2O3	CONTENT-----
3	0	265	TIO2	CONTENT-----
4	0	266	FE2O3	CONTENT-----
5	0	267	MGO	CONTENT-----
6	0	268	CAO	CONTENT-----
7	0	269	NA2O	CONTENT-----
8	0	270	K2O	CONTENT-----
9	0	271	P2O5	CONTENT-----
10	0	272	SO3	CONTENT-----

20) ASH ANALYSIS.

TABLE ENTRY-TABLE INDEXED-LOCATION-NAME

1	0	273	ASH	CONTENT (LOW TEMPERATURE - MCL)-----
2	0	274	ASH	CONTENT (LOW TEMPERATURE - OGL)-----
3	0	275	ASH	CONTENT (LOW TEMPERATURE - O'GORMAN)-----
4	0	276	ASH	CONTENT (HIGH TEMPERATURE MCL)-----
5	0	277	%	MM - DIRECT-----
6	0	278	TEMPERATURE	OF ASH ANALYSIS (DEG. C.)-----
7	0	279	MOISTURE	CONTENT OF COAL SAMPLE-----

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21) TRACE ELEMENT ANALYSIS.

TABLE ENTRY-TABLE INDEXED-LOCATION-NAME

1	0	280	AG	CONTENT-----
2	0	281	B	CONTENT-----
3	0	282	BA	CONTENT-----
4	0	283	BE	CONTENT-----
5	0	284	BI	CONTENT-----
6	0	285	CE	CONTENT-----
7	0	286	CO	CONTENT-----
8	0	287	CR	CONTENT-----
9	0	288	CU	CONTENT-----
10	0	289	GA	CONTENT-----
11	0	290	GE	CONTENT-----
12	0	291	LA	CONTENT-----
13	0	292	LI	CONTENT-----
14	0	293	MN	CONTENT-----
15	0	294	MO	CONTENT-----
16	0	295	NI	CONTENT-----
17	0	296	NB	CONTENT-----
18	0	297	PB	CONTENT-----
19	0	298	RB	CONTENT-----
20	0	299	SC	CONTENT-----
21	0	300	SN	CONTENT-----
22	0	301	SR	CONTENT-----
23	0	302	TH	CONTENT-----
24	0	303	U	CONTENT-----
25	0	304	V	CONTENT-----
26	0	305	Y	CONTENT-----
27	0	306	YB	CONTENT-----
28	0	307	ZN	CONTENT-----
29	0	308	ZR	CONTENT-----

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22) VOLATILE TRACE ELEMENTS.

TABLE ENTRY-TABLE INDEXED-LOCATION-NAME

1	0	309	AS	CONTENT-----
2	0	310	BR	CONTENT-----
3	0	311	CD	CONTENT-----
4	0	312	CL	CONTENT-----
5	0	313	F	CONTENT-----
6	0	314	HG	CONTENT-----
7	0	315	SB	CONTENT-----
8	0	316	SE	CONTENT-----

23) PREPARATION DATA.

TABLE ENTRY-TABLE INDEXED-LOCATION-NAME

1	0	317	1.35	FLOAT: YIELD-----
2	0	318		: ASH-----
3	0	319		: SULFUR-----
4	0	320		: VITRINITE-----
5	0	321		: LIPTINITE-----
6	0	322		: INERTINITE-----
7	0	323	1.35 X 1.45:	YIELD-----
8	0	324		: ASH-----
9	0	325		: SULFUR-----
10	0	326		: VITRINITE-----
11	0	327		: LIPTINITE-----
12	0	328		: INERTINITE-----
13	0	329	1.45 X 1.55:	YIELD-----
14	0	330		: ASH-----
15	0	331		: SULFUR-----
16	0	332		: VITRINITE-----
17	0	333		: LIPTINITE-----
18	0	334		: INERTINITE-----
19	0	335	1.55 X 1.65:	YIELD-----
20	0	336		: ASH-----
21	0	337		: SULFUR-----
22	0	338		: VITRINITE-----
23	0	339		: LIPTINITE-----
24	0	340		: INERTINITE-----
25	0	341	1.65 SINK:	YIELD-----
26	0	342		: ASH-----
27	0	343		: SULFUR-----
28	0	344		: VITRINITE-----
29	0	345		: LIPTINITE-----
30	0	346		: INERTINITE-----

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24) GASIFICATION DATA.

TABLE ENTRY-TABLE INDEXED-LOCATION-NAME

1	0	347	CHAR	REACTIVITY (AIR)-----
2	0	348	TEMPERATURE	(AIR DEG. C)-----
3	0	349	PRESSURE	(AIR ATM.)-----
4	0	350	CHAR	REACTIVITY (CO2)-----
5	0	351	TEMPERATURE	(CO2 DEG. C)-----
6	0	352	PRESSURE	(CO2 ATM.)-----
7	0	353	CHAR	REACTIVITY (H2)-----
8	0	354	TEMPERATURE	(H2 DEG. C)-----
9	0	355	PRESSURE	(H2 ATM.)-----

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25) CARBONIZATION DATA.

TABLE ENTRY-TABLE INDEXED-LOCATION-NAME

1	0 356	MEASURED STABILITY	-----
2	0 357	MEASURED MICUM 40	-----

26) ANALYSIS LOG.

TABLE ENTRY-TABLE INDEXED-LOCATION-NAME

1	28 358	AS RECEIVED MOISTURE:	AGENCY-----
2	0 359		: DATE-----
3	28 360	EQUILIBRIUM MOISTURE:	AGENCY-----
4	0 361		: DATE-----
5	28 362	PROXIMATE ANALYSIS:	AGENCY-----
6	0 363		: DATE-----
7	28 364	ULTIMATE ANALYSIS:	AGENCY-----
8	0 365		: DATE-----
9	28 366	SULFUR FORMS:	AGENCY-----
10	0 367		: DATE-----
11	28 368	FREE SWELLING INDEX:	AGENCY-----
12	0 369		: DATE-----
13	28 370	GEISELER PLASTICITY:	AGENCY-----
14	0 371		: DATE-----
15	28 372	DIRECT MINERAL MATTER:	AGENCY-----
16	0 373		: DATE-----
17	28 374	GRAY KING COKE TYPE:	AGENCY-----
18	0 375		: DATE-----

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The IBM 360/370 system is regarded as the research tool to be used in exploring relationships between coal characteristics, coal properties and coal performance in utilization. It contains the various statistical packages required to perform regression analyses, cluster analyses and a bevy of other statistical analyses and tests which are useful in generating information that can lead to understanding causal relationships. In addition it has the ability to search on all calculated as well as raw data. Some capabilities and products are described in Table 13.

B. Management and Operation of the Data Base

As shown in Figure 26, data and other sample related information enters the Data Base via the PDP-8A microcomputer. The system serves not only as the "input" medium but also as the data validation and correction instrument. A master print-out file containing 10 pages for each coal sample is produced and these pages are reproduced by copies to respond to simple data requests that require only the standard formats. Data are transferred to the IBM 360/370 from the minicomputer after checking and validation.

The standard Data Request Form is presented on the two following pages as Exhibit B. During the four year period of the contract in excess of 4000 print-outs were supplied to agencies within the coal community. Appendix VII provides a representative list of agencies that received data print-outs during the Contract period.

Table 13
IBM 360/370 Capabilities

1. Printout of Standard Data Formats (in 1, 3, or 5 large page versions).
2. Search Data Base on any raw data parameter or calculated value.
3. Sort raw data or calculated values generated by a search.
4. Print searched and sorted raw data and/or calculated values.
5. Perform complex statistical manipulations of any and all data.

Figure 26. MANAGEMENT AND OPERATION OF THE PSU COAL DATA BASE

PENN STATE COAL DATA BASE

REQUEST FORM

William Spackman, Director
Coal Research Section
517 Deike Building
The Pennsylvania State University
University Park, Pennsylvania 16802

THIS IS A REQUEST FOR:

☐ A complete list of the analytical data categories contained in the PSU Coal Data Base.

☐ An example of the Standard Data Printout of analytical data for an individual coal sample.

☐ Analytical data as specified below:

a. See attached letter for description of data requested. ☐

-- OR --

b. Standard Data Printouts for the following samples in the PSU/DOE Coal Sample Bank:

PSOC_____	PSOC_____	PSOC_____	PSOC_____	PSOC_____
PSOC_____	PSOC_____	PSOC_____	PSOC_____	PSOC_____
PSOC_____	PSOC_____	PSOC_____	PSOC_____	PSOC_____

c. Standard Data Printouts for coal seams and/or geographic areas listed below:

Seams

States

_____	_____
_____	_____
_____	_____
_____	_____
_____	_____

d. Special Data Printouts for coal samples conforming to the following specifications:

1) Specific analytical data requested: (e.g. sulfur content, Btu value, etc.)

a) _____
b) _____
c) _____

2) Upper and lower cut-off limits for above data

a) _____
b) _____
c) _____

3) Supply above data for the following coal seams and/or geographic areas:

Seams

States

_____	_____
_____	_____
_____	_____
_____	_____
_____	_____

Purpose for which data are required: Research ☐
 Educational ☐
 Commercial ☐

ADDRESS TO WHICH DATA ARE TO BE SENT:

Signature

VIII. GASIFICATION AND COMBUSTION RESEARCH

A. Pyrolysis Behavior of Coal in an Entrained Flow Isothermal Reactor

Two major steps occur in coal gasification: (i) devolatilization of the coal as it is heated to and held at reaction temperature and (ii) reaction of the resultant char with O_2 , CO_2 , H_2 , and/or steam. To understand the over-all coal gasification process, it is important to understand the mechanism of coal devolatilization. In our attempt to do this, a dilute phase, entrained flow isothermal reactor was built in which coal could be heated rapidly to a desired temperature in N_2 , held for a desired period of time at this temperature, and then the solid product quenched rapidly to room temperature.

The experimental equipment for carrying out rapid devolatilization of pulverized coal particles (Figure 27) accomplishes these major functions: (i) feeds closely size-graded coal particles into the reaction zone of known length at a known rate; (ii) raises the temperature of the particles as rapidly as possible to the predetermined gas temperature, and then allows them to decompose isothermally at that temperature for a specified time; (iii) subsequently quenches the reactions; and finally (iv) separates the solid (the char) from gaseous products. The various components of the equipment shown in Figure 27 are capable of accomplishing these functions. Under our experimental conditions the heating rate is about 10^4 °C/sec, and the cooling rate is about 3×10^4 °C/sec. A constant feed rate of coal between 0.5-1.0 g/min is used.

Studies in this program, concentrated on devolatilization of lignite. They have been covered in special DOE Reports FE-2030-TR2 and FE-2030-TR17 and a series of publications (Nsakala et al., 1977; Nsakala et al., 1978; and Scaroni et al., in press). Major conclusions of these studies are as follows:

(i) Weight losses for fixed residence times up to 0.4 sec are independent of particle sizes between 41 and 201 μm diameter but increase with temperature over the range studied, that is, 700 to 1000°C.

(ii) The maximum yield of volatiles is particle size independent and essentially temperature independent.

(iii) The maximum yield of volatiles considerably exceeds that measured by the standard ASTM test; this is attributed to the essential absence of secondary hydrocarbon cracking reactions on char surfaces due to operating a dilute phase.

(iv) Pyrolysis is multi-stage with the first stage essentially completed within 0.4 sec at 950°C and accounting for about 75% of the total volatile matter release.

Figure 27. ENTRAINED FLOW ISOTHERMAL REACTOR WITH AUXILIARY EQUIPMENT

(v) Release of volatiles in the first stage obeys a first order reaction; the apparent-activation energy for this release is low -- that is about 45 kJ/mole.

(vi) Rapid devolatilization of lignites is accompanied by rapid increases in the surface area and pore volume of the solid.

(vii) Chars produced following rapid heating, have larger pore volumes than those produced using slow rates of heating (that is 5-10°C/min). This probably explains why chars produced by rapid heating of lignites have higher reactivities during their subsequent gasification than chars produced by slow heating (Ashu et al., 1978).

B. Design and Operation of a Pressurized Entrained Flow Isothermal Furnace

The entrained flow, isothermal furnace (described in detail in DOE Report FE-2030-TR15) was designed so that coal/gas reactions could be studied at high pressures (up to 100 atm) and temperatures (up to 1200°C). It was constructed by Autoclave Engineers Inc., Erie, Pa. Essentially, it consists of an internally heated steel reaction pressure vessel. Coal particles are delivered from a feed-bin at a uniform, continuous rate to a water-cooled nozzle and fall vertically through an isothermal reaction tube. Thus, coal particles are subjected to rapid heating ($\sim 10^4$ °C/min). Design of the internal flow characteristics results in an effective inverted flow profile which assures that the particles remain at the center of the gas stream instead of striking the reactor walls. A water-cooled collector probe, inserted from the bottom of the reaction vessel, rapidly quenches the particulate stream. Solid and gaseous constituents are then separated and collected for subsequent analysis.

The unit was primarily designed for use with hydrogen; however, it can be operated with inert and other reactive gases (eg. O₂, CO₂, H₂O). Because of the anticipated use of hydrogen, the system incorporates many safety devices so that in the event of operational problems it can be shut-down automatically.

Associated with the reaction vessel are a number of separate components including a hydrogen compressor, an argon supply rack, a reactant gas supply rack and a temperature control console.

The coal feeder assembly consists of a feed bin, screw feeder and a semi-venturi injector. Powdered coal is held in the bin (~ 500 cm³ capacity) and is delivered to the reactor by use of a magnetically driven rotating feed tube (1-5 gm/min). Primary hydrogen (or other reacting gas) and coal enter the reaction vessel through a water cooled feed nozzle. Preheated secondary hydrogen is mixed with the primary stream prior to entry into the reaction zone. Argon is used to balance pressure between the furnace and the reaction zone.

Temperature in the reaction zone (1 1/16 in diameter) is controlled to within 10°C of the set value (1200°C maximum). Pressure is controlled up to 100 atm. Residence time of the coal within the reaction zone is adjusted by varying the distance between the feed nozzle and the top of the water-cooled collection probe. This distance can be varied from 4 in to 20 in. The actual residence times will be dependent on such parameters as gas flow rate, coal particle size and temperature. Maximum residence time is of the order of 600 millisec. After passing through the reaction zone solid materials are collected in a separate vessel. Gases and vapors are then vented or collected for analysis.

Because of safety considerations, the reactor is housed in a newly constructed addition to the University's High-Pressure Gas Facility. Construction costs were borne by the University. The reaction vessel has been assembled in a test cell designed to withstand blast forces while venting accidental blasts into an earthen embankment.

C. Coal Pyrolysis

A theoretical and experimental study of the pyrolysis of coal under conditions of rapid heating has been made. One of the major problems faced when one tries to analyze the experimental data obtained from the pyrolysis of coal is the assignment of pyrolysis temperature. This problem is especially acute under conditions of rapid heating.

If the pyrolysis time of a coal particle injected into a high temperature gas and radiation environment is of the same order as the thermal response time of the coal particle, coupled chemical and physical parameters will be significant in determining the temperature of pyrolysis.

When the pyrolysis time is long with respect to the thermal response time, the pyrolysis will proceed in a volumetric mode in which there is an insignificant intraparticle temperature gradient resulting in uniform pyrolysis throughout the particle at temperatures equivalent to the external environment. Conversely if the pyrolysis time is short with respect to the thermal response time large intraparticle temperature gradients can develop resulting in a shrinking core mode of pyrolysis where the actual temperature of pyrolysis can be much lower than the external temperature.

In order to determine the effect of coupled thermal-transfer and chemical reaction on the pyrolysis temperature a mathematical model was developed. The model enabled a study of the influence of the physical variables of thermal conductivity and heat capacity as well as the chemical variables of heat of reaction, activation energy and preexponential factor, upon observable pyrolysis response. The study was made over a range of particle sizes and reaction temperatures.

The question arises as to what extent will an endothermic reaction occurring within a particle affect the temperature-time history of the particle. Figure 28 shows the temperature-time history of a particle,

Figure 28. TEMPERATURE RESPONSE OF PARTICLE CENTER (500 μ m PARTICLE)

with 40% volatile matter, injected into a 1250°K thermal environment. It can be seen that if an endothermic process is assumed to take place during the heating, the actual heating of the particle will be considerably retarded and the majority of the pyrolysis will occur at a temperature much lower than the reactor temperature. Figure 29 shows the influence of particle size on intraparticle temperature gradient. It can be seen that moving from a particle size of 25 μm to 500 μm changes the pyrolysis mode from volumetric to shrinking core. Figures 30 and 31 show the predicted observable response, rate of pyrolysis vs time, of the model with a variation of particle size and reactor temperature respectively.

If one were to use the observable response of the model to calculate the activation energy of the reaction, presupposing isothermal conditions, erroneous results could be expected. From a procedural point of view, determining the chemical activation energy for a solid-state decomposition reaction involves choosing a point of reaction, determining the observed rate at that point for various temperatures, normalizing the rate with respect to sample size, and taking the natural logarithm of the rate. The Arrhenius activation energy is then extracted as the slope of the line joining the natural logarithms versus the reciprocals of the absolute temperature.

Table 14 lists the apparent activation energies obtained for various particle sizes using 50% reaction as the basis point.

It can be seen that considerable error can arise when isothermal conditions are assumed for the pyrolysis of larger sized particles where the shrinking core mode of pyrolysis is occurring. In order to evaluate the mathematical coal pyrolysis model an experimental reactor was constructed which would enable the injection of sized samples of coal into a preheated flow reactor. In order to monitor the rate of pyrolysis, the concentration of tar down stream from

Table 14
Apparent Activation Energy
True Activation Energy of 25 Kcal/mole

<u>Particle Size,</u> <u>microns</u>	<u>Reactor Temperature</u> <u>Range, °C</u>	<u>Apparent Activation</u> <u>Energy, Kcal/mole</u>
25	700-1000	25
100	700-1000	20
500	700-1000	14

Figure 29. EFFECT OF PARTICLE SIZE UPON INTERNAL TEMPERATURE PROFILES AT 50% REACTION COMPLETION

Figure 30. PARTICLE-SIZE EFFECTS UPON DIFFERENTIAL MASS RELEASE AS A FUNCTION OF TIME WITHIN AN ISOTHERMAL ENVIRONMENT

Figure 31. REACTOR TEMPERATURE EFFECTS UPON DIFFERENTIAL MASS RELEASE AS A FUNCTION OF TIME

the reaction zone was measured. The concentration of tar in the flowing gas stream was taken as an index of the reaction rate. Figure 32 shows a series of differential tar release curves for a range of particle sizes. This plot of the experimental data can be compared to Figure 30, a plot of the theoretical model. The great similarity between these plots indicates that a large extent of the pyrolysis occurs in the shrinking core mode where actual pyrolysis temperatures are considerably lower than reactor temperature. Analysis of the experimental curves indicates that even for the smallest particle size an appreciable amount of pyrolysis occurs under non-isothermal conditions. A more extensive write-up of the theoretical and experimental aspects of this investigation is available in special report FE-2030-TR19.

D. Factors Affecting the Reactivity of American Coal Chars

The reactivity of chars, produced from all ranks of American coals, to air, CO_2 , H_2 , and steam has been studied by following their weight loss as a function of time. Studies have been covered in DOE Technical Reports FE-2030-TR3, FE-2030-TR4, FE-2030-TR8, FE-2030-TR13, and FE-2030-TR14 and a series of publications (Ashu et al., 1978; Tomita et al., 1977; Mahajan et al., 1980).

It is shown that char reactivity is enhanced by increasing the rate of heating of coal to maximum temperature (Ashu et al., 1978) and holding the level of maximum temperature and soak time at maximum temperature to a minimum (FE-2030-TR3). Char reactivity is reduced if carbon is deposited within the pores of the char as a result of the cracking of hydrocarbons (Kamishita et al., 1977). Thus, it is desirable that volatiles leave the coal particles promptly upon their production, thereby minimizing the time available for secondary cracking reactions to occur.

It is shown (Figure 33) that there are major differences in reactivity of coal chars, which depend on the rank of the starting coal. Figure 33 summarizes results for chars produced by heating coals in N_2 at a low heating rate to 1000°C and then reacting them in 1 atm of air at 500°C and 1 atm of CO_2 at 900°C . The major differences in reactivity are attributed to three factors: (i) concentration of active sites where gasification reactions can occur, (ii) accessibility of the reactant gas to the active sites through large feeder pores, and (iii) presence of inorganic catalysts.

Reactivity of chars produced from low rank lignites and sub-bituminous coals is at a maximum because they exhibit optimum properties. That is, the surface areas of the chars and, hence, active areas, are at a maximum as seen in Figure 34. Because these coals are high in volatile matter, when they are converted to chars large amounts of porosity and, hence, large volumes of feeder pores are generated. Diffusion of reactant gas through the feeder pores is rapid; and, hence, active site utilization for gasification is high. Mostly, these low rank coals contain large concentrations of well-dispersed cations associated with carboxyl groups (see DOE Technical Report

Figure 32. DIFFERENTIAL TAR RELEASE CURVES AT A REACTOR TEMPERATURE OF 600°C (Numbers in parentheses indicate time of observable tar release.)

Figure 33. REACTIVITY OF AMERICAN COAL CHARS PREPARED AT 1000°C TO AIR AT 500°C AND CO₂ AT 900°C

Figure 34. CORRELATION BETWEEN THE CO₂ SURFACE AREAS OF CHARs AND THE CARBON CONTENT OF THE PARENT COALS

FE-2030-TR21). Upon conversion of these coals to chars, well dispersed metal and metal oxide catalysts are present on the surface. By contrast, chars produced from the higher rank coals are essentially devoid of well dispersed catalyst particles; they only contain large particles of mineral matter which are not particularly active catalysts for gasification, as will be determined later.

It is to be emphasized that the major differences in char reactivities just discussed is when gasification takes place in the presence of an oxidizing gas, that is air, CO_2 , and steam. By contrast, reactivities of American coal chars in H_2 show much less variation with coal ranks, primarily since inorganic constituents show different catalytic activities in H_2 from those shown in an oxygen-containing gas from two main standpoints. First, cations in high concentrations in low rank coal (calcium and magnesium), are not good catalysts for hydrogasification (Walker *et al.*, 1979). Second, higher rank coals frequently contain significant concentrations of pyrite, which upon conversion to iron in the presence of H_2 become a very active hydrogasification catalyst (Tomita *et al.*, 1977). By contrast, in the presence of an oxidizing atmosphere, pyrite is converted to iron oxide, which is essentially inactive as a catalyst for coal char gasification.

Shapes of burn-off versus time (t) plots for various coal chars studied by reaction in air, CO_2 , H_2 , and steam were found to be quite similar in shape (Mahajan *et al.*, 1978). The plots can be normalized into a single characteristic curve using a dimensionless time scale such that $t/t_{0.5}$ (that is, τ) equals one at a fractional burn-off (BO) of 0.5. For each gasification medium, BO versus τ data for different chars up to a maximum BO of 0.7 can be correlated by a cubic equation of the form, $\text{BO} = a(\tau) + b(\tau)^2 + c(\tau)^3$. Computer correlation of the data showed that even though $t_{0.5}$ varied widely, depending upon the coal char reacted and gasification medium used, best values for the coefficients a , b , and c in the above equation gave a very high correlation for all the results.

Figure 35 presents results for reaction of a lignite char (PSOC-91) with different partial pressures of air in 1 atm of O_2 - N_2 mixtures. As first discussed, the shape of the plot is similar for most chars in all gasification media and at different pressures of reacting gas. The shape is a result of surface area development during char gasification. In the early stages of gasification, open micropores are enlarged in size and closed pores are opened. This results in an increase in both the total number of micropores and their average size -- or an increase in surface area in micropores. Thus, reactivity increases. As burn-off proceeds, further pore enlargement results finally in the breakthrough of pore walls and a consequent decrease in the number of micropores and surface area in these pores. Reactivity decreases monotonically with further increases in char burn-off.

The importance of surface area in micropores, or active surface area, as one of the major factors in determining rates of char

Figure 35. NORMALIZED PLOT FOR REACTION OF PSOC-91 CHAR AT 405°C IN DIFFERENT PRESSURES OF O_2

gasification was shown in some very recent studies (Mahajan et al., 1980). The char of lowest reactivity shown in Figure 33 was produced from a low volatile bituminous coal of 89.6% carbon. Upon heating, this coal becomes fluid and loses most of its microporosity; consequently its char has a low reactivity. It has been shown that if this coal is preoxidized in air at low temperatures (120-250°C) to weight gains between 0.45 and 3.0% of oxygen there is a continuing increase in subsequent reactivity of the char produced to air with increase in oxygen added. At a maximum oxygen addition of 3.0%, by weight original coal, char reactivity was increased some thirty times. Thus preoxidation of caking coals not only improves the ease of handling of the coals in gasifiers but also increases their reactivity.

Because of the potential importance of coal preoxidation to gasification, an in-depth study was performed on measuring the effect of preoxidation on the swelling properties of caking coals when heated. Results were reported in detail in special report FE-2030-TR20. In summary, temperatures of initial softening, swelling, and resolidification are strongly affected by deliberate preoxidation of bituminous coal in air at temperatures up to 250°C. Results for an HVA bituminous coal preoxidized to different levels at 125°C are summarized in Figure 36. Expansion was measured using a thermomechanical analyzer (TMA). It is seen that preoxidation to a weight gain of about 1.5% essentially completely removes swelling of this coal. As previously discussed, concurrent with the removal of swelling, a large increase in subsequently reactivity would be found.

E. Catalytic Effect of Minerals on Gasification

To study the catalytic activity of the major minerals found in coal for char gasification, 5 wt% of 200 x 325 mesh size minerals were added to a high purity Saran char of 200 x 325 mesh particle size. Table 15 summarizes the results for reactions in air at 550°C, CO₂ at 960°C, and H₂ at 940°C. Minerals have little effect on the rate of the char-air reaction. None of the minerals show a catalytic activity for the char-CO₂ reaction; however, some minerals, pyrite and gypsum in particular, inhibit this reaction. It is thought that this inhibition could be related to the transfer of sulfur to carbon active sites via the production of COS. In the hydrogasification reaction, it is seen that siderite and pyrite are very active catalysts. In both cases, iron is produced, which is known to be particularly active for the dissociation of molecular hydrogen to atomic hydrogen, which in turn reacts rapidly with chars. Interestingly, a number of other minerals, calcite being the prime example, strongly inhibits the hydrogasification reaction; the clays are also inhibitors. Thus calcium is found to inhibit char gasification in H₂ whether it is present as a mineral or as an exchangeable cation, as will be seen.

Figure 36. TMA OXIDATION DATA FOR PSOC-1099 (HVA COAL)
(Modified for Clarity - Dilatometer Operating Conditions: 50 C/min Heating Rate,
1g Dilatometer Load, 200 x 230 Mesh Coal)

Table 15
Reactivity Results

<u>Mineral</u>	<u>Reactivity, mg hr⁻¹ mg⁻¹</u>		
	<u>Air</u>	<u>CO₂</u>	<u>H₂</u>
None	1.1	1.9	2.3
Siderite	1.0	1.8	5.6
Pyrite	1.1	1.3	3.9
Dolomite	1.0	2.0	2.0
Illite	1.0	1.8	1.4
Quartz	-	2.0	2.1
Gypsum	1.0	1.5	1.6
Rutile	1.1	2.0	1.6
Kaolinite	1.2	1.6	1.2
Calcite	1.0	1.7	0.6

F. Catalytic Effect of Exchangeable Cations on Gasification

As just discussed, one of the major reasons that low rank coals lead to the production of highly reactive chars is that they contain significant concentrations of exchangeable cations. A study was, therefore, conducted to measure the concentration of carboxyl groups on major lignite deposits from Texas, N. Dakota, and Montana and the fraction of the groups with which cations are associated (DOE Technical Report FE-2030-TR21 and Morgan *et al.*, 1980). Carboxyl group concentration was measured by first putting all groups in the acid form by treatment with HCl and HF and then reacting with barium acetate. Concentrations varied between 2.11 mequivalents per g coal for Texas lignite to 3.13 meq/g for N. Dakota lignite. The percentage of the total oxygen in the coals associated with these groups ranged from 37% for the Texas lignite to 46% for the N. Dakota lignite. Major cations associated with the carboxyl groups were determined by exchanging them with ammonium acetate and measuring cation concentrations in solution using emission spectrometry. Calcium was the main cation found, ranging in concentration between 12.9 mg/g for the Texas lignite to 21.2 mg/g for the Montana lignite. Other cations of importance detected were magnesium, sodium, potassium, barium and strontium. Total cation concentrations ranged between 17.0 mg/g for the Texas lignite and 30.1 mg/g for the Montana lignite.

Confirmation of the importance of cations to the reactivity of a Texas lignite char in air, CO₂, H₂, and steam was made in an in depth study (DOE Technical Report FE-2030-TR4 and Walker et al., 1979; Hippo et al., 1979). Carboxyl groups in the lignite were first put in the acid form by exposure to HCl. Selected concentrations of cations were then added by exposure of the coal to metal acetate solutions. By increasing the concentration of calcium acetate solution from 0.04 to 2.0 molar, variable amounts of calcium were added up to about 12.5 wt% in the 800°C char subsequently prepared. Char reactivity in steam increased linearly with increasing amounts of calcium added. Reactivity of the char with maximum calcium loading exceeded that of the char produced from the raw Texas lignite by over ten fold.

At a level of approximately 0.3 mmoles of cation/g of coal, the relative ordering of various cations as to their catalytic activity depends upon the particular gasification reaction being considered (Walker et al., 1979). For the char-air reaction:

where Raw and Dem signify chars produced from raw and demineralized lignite, respectively. For the char-CO₂ reaction:

For the char-steam reaction:

For all three of the oxygen-transfer reactions, potassium, calcium, and sodium are the most active catalysts. Iron is less active because it becomes oxidized and in its oxidized state is not a good catalyst. Magnesium is a poor catalyst for all the reactions, which, in a way, is unfortunate because it exists in reasonably high concentrations in all American lignites.

Catalysis of lignite char gasification in H₂ shows a radically different story. Iron is the most active catalyst, followed closely by sodium. Calcium and potassium are poor catalysts for the hydro-gasification reaction, as is magnesium. In direct contrast to the behavior of calcium for the char-steam reaction, increasing amounts of calcium lead to an increasing extent of retardation of the char-H₂ reaction.

G. Use of Differential Scanning Calorimetry (DSC) in Evaluating Coals for Conversion

For the gasification of coal chars with oxygen containing gases, the first step is the transfer of oxygen from the gas phase species to the char surface, that is

In each case, this first step is followed by the gasification step

To further our understanding of coal char gasification it is, therefore, desirable to study the rate of the oxygen transfer step. This was done for the char- O_2 reaction using DSC to measure the heat of interaction of O_2 with active sites at $100^\circ C$. At this temperature, the gasification step proceeds at a negligible rate. At $100^\circ C$, essentially all of the heat of reaction (Q) occurs in the first 15 min; thus Q_{15} was measured. As seen in Figure 37, a linear relationship exists between Q_{15} and the time for a fractional burn-off in air at $405^\circ C$ of 0.5. For this plot, coals varied in rank from PSOC-91 (Montana lignite) to PSOC-67 (Utah HVB bituminous). The only sample falling considerably off the plot was PSOC-140, a Texas lignite. Thus for most chars the rate determining step appears to be the initial dissociation of molecular oxygen and chemisorption of atomic oxygen onto active carbon sites. This is an important conclusion since it means that if we are to increase the rate of coal char gasification, catalysts which are particularly active for the oxygen transfer step should be sought.

H. Combustion of Chars and Low Volatile Fuels

Several coal chars, anthracites, and a bituminous coal were burned in a special one-dimensional furnace (Cogoli *et al.*, 1977) (a plane flame furnace) in order to determine their combustion characteristics. Most of the experimental work was performed on three different coal chars; two of which were produced from an Exxon gasification process (parent coals -- Wyodak and Illinois No. 6). The third char was obtained from the FMC COED process, also an Illinois No. 6 coal. Less detailed studies were carried out on a USBM Entrained Carbonizer char, a regular grind Pennsylvania anthracite, an ultra-fine grind anthracite coal and a Pittsburgh seam bituminous coal. The principal combustion characteristics were determined by location of the flame front below a stabilizing water-cooled tube bank and wall temperature profiles. Effects of particle size, fuel/air ratio, cloud velocity and influence of a hot or cold boundary at the furnace bottom were investigated.

The fuels were found to split into two main groups; those of high reactivity with flame/ fronts 4 or 5 cm below the tube bank and those of low reactivity with flame/ fronts 40 to 50 cm below the tube bank. The high reactivity group included the bituminous coal and the two Exxon chars, supporting the contention that reactivity is not conferred by volatile matter *per se*. The low reactivity group included the FMC and USBM chars and the ultra-fine grind anthracite. Runs with the standard grind anthracite would not stabilize. For the chars, it is

Figure 37. VARIATION OF Q_{15} WITH TIME REQUIRED TO GASIFY 50% OF CHARS IN AIR

obvious that reactivity is dominated by the original gasification process conditions and not the parent coal. This observation is not surprising because of the widely differing process conditions utilized to make the chars. Studies of the pore structures and surface areas of the chars indicated that high reactivity was primarily a function of internal surface. Ignition times of the high reactivity group were in good agreement with simple radiation theory. However, the theory does not account properly for the large differences between ignition times for the high and low reactivity fuels.

A computer model (Cogoli and Essenhigh, 1977) was devised to explain the otherwise anomalous experimental values of ignition distance for the low reactivity, low volatile fuels. The dominant element of the model was the radiation flux modified by inclusion of a reactivity parameter. This model did account for ignition distances up to 50 cm with flame lengths and temperatures reasonably comparable to those found experimentally when the reactivity parameter lay between defined values. Overall, the results indicated that ignition distances are appreciably sensitive to fuel reactivity although ignition temperatures (defined as the 1% combustion point) are not.

I. Combustion of Coal-Oil Emulsions

Studies were made on combustion characteristics of coal/oil and coal/oil/water mixtures (Masuda, 1979; Kokkinos, 1980). However, these studies were terminated by DOE during the period of the contract. The following are brief descriptions of these studies. Further details can be outlined from aforementioned references.

Mixtures of coal dispersed in No. 6 and No. 2 fuel oils (up to 16 wt%) were fired at 1.25 million Btu/hr in a hot-wall furnace of 40 ft³ combustion volume (Masuda, 1979). A commercial air-atomizing swirl burner was utilized. The furnace had 17 water-cooled tubes in its floor to simulate the load of an industrial continuous thermal-processing furnace. These tubes were also used to measure heat flux profiles and thermal efficiencies. The efficiency initially increased with added coal percentage, but reached a maximum, at about 10 wt% coal, and then declined. Reflecting this pattern, the variation of exhaust gas temperature was a mirror image of the efficiency. This phenomenon is characteristic of a hot-walled furnace and would not appear in a boiler. Measurements of NO_x showed a monotonic rise with increasing coal addition, but the levels at all times were below EPA-allowed limits for large boilers. The results showed a steady drop in the fuel-nitrogen conversion, from 45% at the lowest coal concentration examined to 15% at the highest. Other studies included an examination of the unsteady-state behavior on heat-up with determination of the characteristic response time for the furnace (2.9 hours).

In another study (Kokkinos, 1980) mixtures of fuel oil, water with and without the addition of pulverized coal were fired in the same furnace just described. The burners used were a split jet-can

(perforated wall) type of combustor with air supplied such that it produced a double vortex mixing pattern and a commercial air atomizing swirl burner.

Dispersions of fuel oil, water and air were found to reduce flame emissivity and to remove carbon build-up on the burner. Excess air at the smoke point was unchanged; however, smoke level at a given excess air and soot concentration (at a given smoke level) were generally reduced by water addition. On account of reduced emissivity, thermal efficiency also dropped by about 5% at efficiencies in the range of 20-25%.

Flame emissivity was restored to its original value or better by the addition of pulverized coal or by permitting operation with medium to heavy smoke levels. This resulted in increasing thermal efficiency reaching a peak at 7-10 wt% coal addition, then declining again. Additional results indicated that flame stability and turndown were very good and that carbon monoxide emission levels were substantially independent of water content. Carbon monoxide did not appear until smoke was at the 10-15% obscuration level.

J. Characterization of the Porous Nature of Heat Treated Coals by Small Angle X-ray Scattering

A study (DOE Technical Report FE-2030-TR22) has been conducted into the applicability of Small Angle X-ray Scattering (SAXS) techniques in the characterization of the micropore structure of heat treated coals. These procedures offer the advantage that they do not involve the penetration of fluids (as is the case in gas adsorption and mercury porosimetry). Thus, they are not limited by molecular sieving effects and, therefore, yield information on the entire pore structure.

Diffuse SAXS is brought about by the presence of heterogeneities in solid matrices. For porous carbonaceous solids (such as chars) heterogeneities stem from the presence of pores within the carbonaceous matrix. Interpretation of diffuse SAXS profiles can yield a wide range of characteristic structural parameters and size distributions. Four primary parameters, related to averaged structural dimensions, can be evaluated directly from intensity profiles. They are: i) R_g -radius of gyration of a scattering center (of a pore), ii) ℓ_m -range of inhomogeneity, iii) a -correlation distance and iv) ℓ_c -length of coherence. Three secondary parameters can be determined from ℓ_m or a if the volume fraction of the pores is known. These parameters are: d_{voids} - an average dimension of segments in the pores, ii) d_{solid} - an average distance between pore walls within the carbonaceous matrix and iii) S_p - the specific surface area. In general, for relatively dense systems (such as coal chars) these secondary parameters are unambiguous, whereas the primary parameters, R_g and ℓ_c , can be difficult to interpret in direct physical terms.

Recent developments in the SAXS field have made it possible to estimate pore size distributions without prior knowledge of its form

(Vonk, 1975; 1976). By these methods it is possible to determine number, surface and volume-diameter distributions. It is also possible to back calculate the four primary parameters from the distributions in order to check internal consistency.

In these studies SAXS profiles were collected on a range of microporous carbons (Wang *et al.*, 1979) and a series of three demineralized coal chars (DOE Technical Report FE-2030-TR22). All data were acquired by use of a Kratky SAXS camera with $\text{CuK}\alpha$ radiation. Data manipulations were provided by use of a modified form of the Vonk program (*op. cit.*).

Results obtained for the microporous carbon (a Saran carbon) showed that as heat treatment temperature increased from 1100°C to 1300°C the structure of the carbons underwent little change. Further heating to 1500°C brought about much more marked changes; average pore size and distance between pore walls increased with a corresponding decrease in surface area. Volume distributions confirmed the observation that the porosity of the 1100°C and 1300°C samples were very similar and that heating to 1500°C brought about an increase in pore size. Comparisons of surface areas determined by SAXS methods and those from CO_2 adsorption showed significant differences. Values obtained by SAXS showed comparatively little difference with heat treatment in this range. However, CO_2 surface areas were similar for 1100°C and 1300°C samples, but the value obtained for the 1500°C sample was much smaller. These data indicate that there are pore apertures in the 1500°C sample which are small enough to partially inhibit the penetration of the absorbate gas (CO_2).

Application of these SAXS techniques to coal chars was applied to chars prepared from samples of demineralized semianthracite (PSOC-379), subbituminous coal (PSOC-420) and a lignite (PSOC-625). As an example of these results, data are presented for the Texas lignite (PSOC-420). From an examination of the average parameters (Table 16), it can be seen that on heating from 1000°C to 1300°C relatively little change in pore structure has occurred. However, it is evident that the average size of pore has increased somewhat (e.g., d_{voids} , R_g and ℓ_c), whereas the average distance between pore walls has remained essentially constant.

Table 16
SAXS Parameters for Heat Treated PSOC-623 (Texas Lignite)

<u>Parameter</u>	<u>Heat Treatment Temperature $^\circ\text{C}$</u>	
	<u>1000</u>	<u>1300</u>
R_g (A)	7.5	11.2
ℓ_m (A)	7.8	8.2
ℓ_c (A)	9.9	10.7
d_{voids} (A)	11.8	12.9
d_{solid} (A)	23.1	22.6
S_p m^2gm^{-1}	888	891
S_p (CO_2 ads) m^2gm^{-1}	680	17

It is suggested that these observations may be indicative of a loss of supermicropores. Perhaps the most important results are that the surface areas (S_p) as determined by SAXS are substantial ($\sim 890 \text{ m}^2\text{gm}^{-1}$) and are unchanged by heat treatment in this range. On the other hand, surface areas measured by CO_2 adsorption (at 25°C) are very much different; for the 1000°C char, the value is large ($680 \text{ m}^2\text{gm}^{-1}$) but smaller than the SAXS value, indicating that CO_2 cannot penetrate the 'total' pore system. On further heating to 1300°C the CO_2 area is dramatically reduced and is very much different to the SAXS value ($17 \text{ m}^2\text{gm}^{-1}$ versus $890 \text{ m}^2\text{gm}^{-1}$). These results show that whereas total internal area has not changed from 1000°C to 1300°C , it has become markedly closed to adsorption of CO_2 molecules. Similar results were noted for the chars of the other two coals.

Volume pore size distributions for chars from PSOC-420 show that the pore structures of the 1000°C and 1300°C materials are quite similar. Carbonization in this temperature range results in a small loss of supermicropores and a modest increase in larger (30A-40A diameter) pores.

In conclusion, it is suggested that SAXS methods do provide a marked increase in our knowledge of the porous nature of heat treated coals. They can be used to define and characterize a wide range of parameters which are to varying degrees affected by heat treatment.

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APPENDIX I
Identification
of
Publications
with
Contract Tasks

Identification
of
Publications
with
Contract Tasks

Task 5

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Tasks 5 and 17

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Tasks 5 and 27

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APPENDIX II
Identification
of
Papers Presented at Scientific Meetings
with
Contract Tasks

Identification
of
Papers Presented at Scientific Meetings
with
Contract Tasks

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Tasks 5 and 7

Davis, A., The Origin, Mode of Occurrence and Importance of Pyrite in Coal, Seminar at Department of Materials Sciences, 1976.

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Davis, A. and Spackman, W., Development, Use and Significance of the PSU/DOE Coal Data Base, DOE 5th Annual Fossil Energy Conference on University Coal Research, August 1978.

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Waddell, C., Davis, A., Spackman, W. and Griffiths, J.C., Study of Interrelationships Among Chemical and Petrographic Parameters of United States Coals, Annual Meeting, Geological Society of America, Seattle, November 1977.

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- Walker, P.L., Jr., Scientific Base of Coal Gasification, Coal Characteristics and Coal Utilization Short Course, The Pennsylvania State University, October 1979.

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Task 30

Walker, P.L., Jr., Catalysis of Lignite Char Gasification by Various Exchanged Cations--Dependence of Reactivity on Reactive Atmosphere, American Chemical Society Meeting, Washington, D.C., September 1979.

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Koval, A., Slupek, S., Kokkinos, A., Shaler, A., Miskovsky, N. and Essenhigh, R.H., Smoke Point and Heat Transfer Characteristics of Oil/Water Air Emulsions without and with Coal Addition in a Hot Wall Furnace, Central States Section, The Combustion Institute, Columbus, Ohio, April 1976.

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Essenhigh, R.H., Workshop on Advanced Energy Conservation held in Virginia, March 25-26, 1976.

Essenhigh, R.H., Energy Use, Efficiency and Conservation in Industry, Symposium on Environment and Energy Conservation, Denver, Colorado, Nov. 3-6, 1975.

Essenhigh, R.H., Energy Efficiency and Conservation in Industry, Dept. of Commerce, Washington, D.C., November 12, 1975.

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Essenhigh, R.H., Future Fuels Supplies for Industry: Bases for Choice, 1977 ASHRAE, Chicago, February 17, 1977.

Shull, H.E., Energy Research at the University Level, Autoclave Engineers, Ind., September 20, 1976.

APPENDIX III

Master Sampling Plan

MASTER SAMPLING PLAN

**Prepared by
William Spackman
at
THE PENNSYLVANIA STATE UNIVERSITY**

**Prepared for
UNITED STATES
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
Under Contract No. EX-76-C-01-2030**

MASTER SAMPLING PLAN **ERDA CONTRACT EX-76-C-01-2030**

SECTOR I		SECTOR II		SECTOR III		Schedule
WVU Mission 1: Objectives 20 Sites 120 Samples (West Virginia)				SIU Mission 1: Objectives 20 Sites 120 Samples (Ill., Ind., Ia., Ky.)		
PSU Mission 3: Objectives 10 Sites 20 Samples				MONR Mission 1: Objectives 1 Site 4 Samples		
SECTOR IV		SECTOR V		SECTOR VI		Schedule
Tex. A & M Mission 1: Objectives 6 Sites 36 Samples (Oklahoma)		Utah Mission 1: Objectives 20 Sites 120 Samples (Utah, Colo., Wyo., Mont.)		Tex. A & M Mission 2: Objectives 14 Sites 84 Samples (Tex., N. Mex., Ark.)		
PSU Mission 4: Objectives 5 Sites 10 Samples (Oklahoma)				PSU Mission 5: Objectives 4 Sites 16 Samples (Texas)		
SECTOR IX						
Gulf Coast Province			Powder River Basin			
Shell Mission 1: Objectives 2 Seam Cores 11 Samples (Ala., Tex.)			U.S.G.S. Mission 1: Objectives 15 Seam Cores 45 Samples (Wyo.)			
Tex. A & M Mission 3: Objectives 20 Seam Cores 80 Samples (Tex., Ark.)			Mobil Mission 1: Objectives 1 Seam Core 5 Samples (Wyo.)			

MASTER SAMPLING PLAN
ERDA CONTRACT EX-76-C-01-2030

SECTOR I	SECTOR II	SECTOR III	Schedule
PSU Mission 6: Objectives 15 Sites 90 Samples (Ohio)	PSU Mission 7: Objectives 15 Sites 90 Samples	SIU Mission 2: Objectives 10 Sites 60 Samples (Ill., Ind., Ky., Mo.)	1
WVU Mission 2: Objectives 10 Sites 60 Samples (Ky., W.Va)		PSU Mission 8: Objectives 12 Exploratory Sites 12 Samples (Ill., Ky.)	9
SECTOR IV	SECTOR V	SECTOR VI	
PSU Mission 9: Objectives 5 Sites 30 Samples	PSU Mission 10: Objectives 10 Sites 60 Samples (Colo., Wyo.)	Tex. A & M Mission 4: Objectives 5 Sites 30 Samples (Tex., Okla.)	7
	PSU Mission 11: Objectives 8 Sites 48 Samples (Colo., Wyo., Mont.)		7
SECTOR VII	SECTOR VIII	SECTOR IX	
UAL Mission 1: Objectives 5 Sites 20 Samples (Alaska)	PSU Mission 12: Objectives 2 Sites 9 Samples (Mont., Utah)	U.S.G.S. Mission 2: Objectives 10 Seam Cores 30 Samples (Wyo., Mont.)	1
Mobil Mission 2: Objective 1 Site 4 Samples	Mobil Mission 3: Objectives 1 Seam Core 25 Samples (Wyo.)	Tex. A & M Mission 5: Objectives 10 Seam Cores 40 Samples (Tex., La.)	9
			7
			8

MASTER SAMPLING PLAN
ERDA CONTRACT EX-76-C-01-2030

SECTOR I	SECTOR II	SECTOR III	Schedule
PSU Mission 13: Objectives 10 Sites 60 Samples		PSU Mission 14: Objective 10 Sites 60 Samples	1 9 7 8
		MONR Mission 2: Objectives 5 Sites 20 Samples	
SECTOR IV	SECTOR V	SECTOR VI	
PSU Mission 15: Objectives 8 Sites 32 Samples (S.Dak., N.Dak.)	PSU Mission 16: Objectives 10 Sites 60 Samples		
SECTOR VII	SECTOR VIII	SECTOR IX	
	PSU Mission 17: Objectives 1 Site 4 Samples (Wash.)	U.S.G.S. Mission 3: Objectives 10 Seam Cores 30 Samples (Wyo., Mont.)	1 9 7 9
		Tex. A & M Mission 6: Objectives 10 Seam Cores 40 Samples (Tex.)	

THE PENNSYLVANIA STATE UNIVERSITY
COAL RESEARCH SECTION
COAL SAMPLE DATA SHEET

IMPORTANT: sample information in italicized data categories must always be provided. Other data should be reported when available.

PSU NUMBER _____ SUB-CONTRACTOR'S NUMBER _____

SEAM DATA:

SEAM NAME _____ ALTERNATIVE NAME _____

RESERVES _____ AREA OF RESERVES _____

(in mine, county or state)

CATEGORY OF RESERVES _____ SOURCE _____

REPORTED RANK AT SITE _____ SEAM AGE _____

GROUP _____

FORMATION _____

SEAM THICKNESS AT SAMPLE POINT _____ AVERAGE THICKNESS

IN MINE _____

THICKNESS OF OVERBURDEN AT SAMPLE POINT _____

SEAM ROOF _____ SEAM FLOOR _____

MINE DATA:

MINE NAME _____ LIFE EXPECTANCY _____

ANNUAL PRODUCTION _____ MINING METHOD _____

(deep, strip, auger, etc.)

LOCATION:

COUNTRY _____ STATE _____ COUNTY _____

TOWNSHIP _____ NEAREST CITY OR TOWN _____

COAL PROVINCE _____ REGION _____ FIELD _____

QUADRANGLE: NAME _____ SIZE _____

TOWNSHIP _____ RANGE _____ SECTION _____

MAP REFERENCE: LATITUDE DEGREES _____ MINUTES _____ SECONDS _____

LONGITUDE DEGREES _____ MINUTES _____ SECONDS _____

POSITION OF SAMPLE IN MINE _____

SAMPLE:

TYPE _____ SAMPLING DATE _____

SAMPLING AGENCY _____ APPROXIMATE WEIGHT _____

CLEAT MEASUREMENTS: _____ DIP _____ STRIKE _____

1. _____	1. _____
2. _____	2. _____
3. _____	3. _____

PSU NUMBER _____

SUB-CONTRACTOR'S NUMBER _____

MINE COMPANY:

PARENT COMPANY NAME AND ADDRESS:

WORKING COMPANY NAME AND ADDRESS:

COMPANY CONTACT (name, address, position, phone):

PHONE _____

MINE CONTACT (name, address, position, phone):

PHONE _____

*DIAGRAM AND DESCRIPTION OF SEAM PROFILE**

*Diagram of Seam Section showing thickness and position in inches of all major seam units including mineral partings.

APPENDIX IV

Samples Contained
in the
Penn State Sample Bank

Coal Research Section
The Pennsylvania State University

PSU-DOE SAMPLE BANK

<u>SAMPLE NO.</u>	<u>SEAM AND LOCATION</u>
PSOC-1	Elkhorn #3 Seam, Deane, Kentucky
PSOC-2	Elkhorn #3 Seam, Deane, Kentucky
PSOC-3	Elkhorn #3 Seam, Deane, Kentucky
PSOC-4	Elkhorn #3 Seam, Deane, Kentucky
PSOC-5	Elkhorn #3 Seam, Deane, Kentucky
PSOC-6	Elkhorn #3 Seam, Deane, Kentucky
PSOC-11	C Seam, Benham, Kentucky
PSOC-12	C Seam, Benham, Kentucky
PSOC-13	C Seam, Benham, Kentucky
PSOC-21	Illinois #6 Seam, Victoria, Illinois
PSOC-22	Illinois #6 Seam, Victoria, Illinois
PSOC-23	#2 Colchester Seam, Vermont, Illinois
PSOC-24	#2 Colchester Seam, Vermont, Illinois
PSOC-25	Illinois #6 Seam, Carrier Mills, Ill.
PSOC-26	Illinois #6 Seam, Carrier Mills, Ill.
PSOC-51	#80 Seam, Hanna, Wyoming
PSOC-52	#11 Seam, Quealy, Wyoming
PSOC-53	Alton, Utah
PSOC-54	Blue Seam, Window Rock, Arizona
PSOC-55	#8 Seam, Fruitland, New Mexico
PSOC-56	#2 Seam, Cow Springs, Arizona
PSOC-57	#3 Seam, Durango, Colorado
PSOC-58	Hart Seam, Craig, Colorado
PSOC-59	Wadge Seam, Hayden, Colorado
PSOC-60	Wadge Seam, Steam Boat Springs, Colorado
PSOC-61	School Seam, Glen Rock, Wyoming
PSOC-62	Lennox Seam, Oak Creek, Colorado
PSOC-63	Colstrip, Montana
PSOC-64	Monarch Seam, Sheridan, Wyoming
PSOC-65	Deitz Seam, Decker, Montana
PSOC-67	Lower Sunnyside Seam, Horse Canyon, Utah
PSOC-68	Lower Sunnyside Seam, Horse Canyon, Utah
PSOC-70	#3 Big Seam, Roslyn, Washington
PSOC-71	Black Diamond, Washington
PSOC-72	Tono #2 Seam, Thurston, Washington
PSOC-73	Queen Seam, Carbonado, Washington
PSOC-74	Beulah, North Dakota
PSOC-75	Lower Lignite Seam, Savage, Montana
PSOC-76	Zap Seam, Zap, North Dakota
PSOC-80	Buck Mountain Seam, Zerbe, Pennsylvania
PSOC-81	Buck Mountain Seam, Zerbe, Pennsylvania
PSOC-82	Buck Mountain Seam, Zerbe, Pennsylvania

SAMPLE NO.	SEAM AND LOCATION
PSOC-83	8½ Seam, Shamokin, Pennsylvania
PSOC-84	#8 Seam, Shamokin, Pennsylvania
PSOC-85	#8 Leader, Shamokin, Pennsylvania
PSOC-86	Zap Seam, Zap, North Dakota
PSOC-87	Zap Seam, Zap, North Dakota
PSOC-88	Zap Seam, Zap, North Dakota
PSOC-89	Harmon Seam, Gascoyne, North Dakota
PSOC-90	Lower Lignite Seam, Savage, Montana
PSOC-91	Lower Lignite Seam, Savage, Montana
PSOC-92	Lower Lignite Seam, Savage, Montana
PSOC-93	Lower Lignite Seam, Savage, Montana
PSOC-95	Queen or #4 Seam, Carbonado, Washington
PSOC-96	Queen or #4 Seam, Carbonado, Washington
PSOC-97	#80 Seam, Hanna, Wyoming
PSOC-98	#80 Seam, Hanna, Wyoming
PSOC-99	School Seam, Glenrock, Wyoming
PSOC-100	Wyodak-Roland Seam, Gillette, Wyoming
PSOC-101	Roland Seam, Gillette, Wyoming
PSOC-102	Pittsburgh Seam, Thomas, Pennsylvania
PSOC-103	Pittsburgh Seam, Thomas, Pennsylvania
PSOC-104	Pittsburgh Seam, Thomas, Pennsylvania
PSOC-105	Indiana #1 Block, Coal City, Indiana
PSOC-106	Indiana #1 Block, Coal City, Indiana
PSOC-107	Brazil Block, Ashboro, Indiana
PSOC-108	Pittsburgh Seam, Marianna, Pennsylvania
PSOC-109	Pittsburgh Seam, Marianna, Pennsylvania
PSOC-110	Pittsburgh Seam, Marianna, Pennsylvania
PSOC-111	Pittsburgh Seam, Marianna, Pennsylvania
PSOC-113	Lower Kittanning Seam, Tire Hill, Penna.
PSOC-114	Lower Kittanning Seam, Tire Hill, Penna.
PSOC-115	Lower Kittanning Seam, Tire Hill, Penna.
PSOC-116	Lower Freeport Seam, Ehrenfeld, Penna.
PSOC-119	Tioga Seam, Tioga, West Virginia
PSOC-120	Tioga Seam, Tioga, West Virginia
PSOC-121	Tioga Seam, Tioga, West Virginia
PSOC-123	#5 Block, Bickmore, West Virginia
PSOC-124	#5 Block, Bickmore, West Virginia
PSOC-125	Upper Freeport Seam, Hastings, Penna.
PSOC-126	Lower Kittanning Seam, Ebensburg, Penna.
PSOC-127	Lower Kittanning Seam, Ebensburg, Penna.
PSOC-128	Lower Kittanning Seam, Ebensburg, Penna.
PSOC-129	Lower Kittanning Seam, Ebensburg, Penna.
PSOC-130	Pocahontas #3 Seam, Gary, West Virginia

<u>SAMPLE NO.</u>	<u>SEAM AND LOCATION</u>
PSOC-132	Pocahontas #3 Seam, Gary, West Virginia
PSOC-133	Pocahontas #3 Seam, Gary, West Virginia
PSOC-134	Pratt Seam, Hueytown, Alabama
PSOC-135	Pratt Seam, Hueytown, Alabama
PSOC-136	Pratt Seam, Hueytown, Alabama
PSOC-137	Pratt Seam, Hueytown, Alabama
PSOC-138	Lignite, Darco, Texas
PSOC-139	Lignite, Darco, Texas
PSOC-140	Lignite, Darco, Texas
PSOC-141	Lignite, Darco, Texas
PSOC-142	Hartshorne Seam, Heavener, Oklahoma
PSOC-143	Hartshorne Seam, Heavener, Oklahoma
PSOC-144	Hartshorne Seam, Heavener, Oklahoma
PSOC-145	Hartshorne Seam, Heavener, Oklahoma
PSOC-146	Hartshorne Rider, Heavener, Oklahoma
PSOC-147	Lower Spadra (Hartshorne), Clarksville, Ark.
PSOC-148	Upper Spadra Seam, Clarksville, Ark.
PSOC-149	Lehigh, Oklahoma
PSOC-150	Yankee Seam, Yankee, New Mexico
PSOC-151	Lower Split of Blue Seam, Gallup, New Mexico
PSOC-152	Upper Split of Blue Seam, Gallup, New Mexico
PSOC-153	New Harmony, Utah
PSOC-154	Cannel (?) North Fork Virgin River, Utah
PSOC-155	Cannel (?) North Fork Virgin River, Utah
PSOC-156	Unnamed Seam, Alton, Utah
PSOC-157	Colorado B Seam, Redstone, Colorado
PSOC-158	Floresta, Colorado
PSOC-159	Crested Butte, Colorado
PSOC-160	Crested Butte, Colorado
PSOC-161	Crested Butte, Colorado
PSOC-162	Upper Rich Hill Seam, Rich Hill, Missouri
PSOC-163	Baxter Seam, Fort Scott, Kansas
PSOC-164	Big Tebo Seam, Calhoun, Missouri
PSOC-165	Kentucky #9 Seam, Paradise, Kentucky
PSOC-166	Kentucky #11 Seam, Paradise, Kentucky
PSOC-167	Pittsburgh Seam, Clarksburg, West Virginia
PSOC-168	Pittsburgh Seam, Clarksburg, West Virginia
PSOC-169	Preparation Product, Marion County, W. Va.
PSOC-170	Preparation Product, Marion County, W. Va.
PSOC-171	Preparation Product, Marion County, W. Va.
PSOC-172	Triadelphia, West Virginia
PSOC-173	Pittsburgh Seam, Farmington, West Virginia
PSOC-174	Pittsburgh Seam, Farmington, West Virginia
PSOC-175	Preparation Product, Holden, West Virginia

SAMPLE NO.	SEAM AND LOCATION
PSOC-176	Preparation Product, Osage, West Virginia
PSOC-177	Anthracite, Pennsylvania
PSOC-178	Anthracite, Pennsylvania
PSOC-179	Anthracite, Pennsylvania
PSOC-180	Anthracite, Pennsylvania
PSOC-181	Upper Block Seam, Patricksburg, Indiana
PSOC-182	Upper Block, Cardonia, Indiana
PSOC-183	Upper Block, Brazil, Indiana
PSOC-184	Upper and Lower Block, Carbon, Indiana
PSOC-185	Indiana #6 Seam, Sullivan, Indiana
PSOC-186	Indiana #7 Seam, Sullivan, Indiana
PSOC-187	Illinois #6 Seam, Waltonville, Illinois
PSOC-188	Illinois #7 Seam, Banner, Illinois
PSOC-189	Illinois #1 Seam, New Windsor, Illinois
PSOC-190	Illinois #6 Seam, Victoria, Illinois
PSOC-191	Illinois #2 Seam, Braceville, Illinois
PSOC-192	Illinois #2 and #4, Braceville, Illinois
PSOC-193	Oak Hill, Ohio
PSOC-194	Ohio #5 Seam, Logan, Ohio (L. Kittanning)
PSOC-195	Ohio #5 Seam, Logan, Ohio (L. Kittanning)
PSOC-196	Ohio #6 Seam, Logan, Ohio (L. Kittanning)
PSOC-197	Ohio #6 Seam, Logan, Ohio (L. Kittanning)
PSOC-198	Ohio #4 A, Creola, Ohio (L. Clarion)
PSOC-199	Ohio #3 Seam, Hamden, Ohio (Mercer)
PSOC-200	Ohio #6 Seam, Hamden, Ohio
PSOC-201	Ohio #4A, Jackson County, Ohio
PSOC-202	Ohio #1 Seam (Sharon), Jackson, Ohio
PSOC-203	Ohio #7 Seam (Up. Freeport), Wellston, Ohio
PSOC-204	Ohio #4A, Oak Hill, Ohio
PSOC-205	Ohio #5, Firebrick, Kentucky
PSOC-206	Ohio #1 (?), S. Webster, Ohio
PSOC-207	Ohio #5 (L. Kittanning), Hanging Rock, Ohio
PSOC-208	#7 Seam (U. Freeport), Ashland, Kentucky
PSOC-209	#7 Seam, Cannonsburg, Kentucky
PSOC-210	Pomeroy #8 A (Redstone), Kyger, Ohio
PSOC-211	Ohio #8 (Pittsburgh), Gallipolis, Ohio
PSOC-212	Ohio #2 (Quakertown), Coal Township, Ohio
PSOC-213	Kentucky #9 Seam, Owensboro, Kentucky
PSOC-215	Kentucky #9 Seam, Sturgis, Kentucky
PSOC-216	Kentucky #14 Seam, Madisonville, Kentucky
PSOC-217	Kentucky #9 Seam, Madisonville, Kentucky
PSOC-218	Kentucky #4 Seam, St. Charles, Kentucky

SAMPLE NO.	SEAM AND LOCATION
PSOC-219	Kentucky #4 Seam, St. Charles, Kentucky
PSOC-220	Kentucky #11 Seam, St. Charles, Kentucky
PSOC-221	Mining City Seam, Morgantown, Kentucky
PSOC-222	Dunbar Seam, Morgantown, Kentucky
PSOC-223	Kentucky #6 Seam, Morgantown, Kentucky
PSOC-224	Beestone-Durain - From England, supplied by Dr. Given
PSOC-225	Shallow Seam Durain - from England, supplied by Dr. Given
PSOC-226	Silkstone-Durain - From England, supplied by Dr. Given
PSOC-227	Beestone Clarain - From England, Supplied by Dr. Given
PSOC-228	Shallow Seam Clarain - From England, supplied by Dr. Given
PSOC-229	Silkstone Clarain - From England, supplied by Dr. Given
PSOC-230	Rosebud Seam, Colstrip, Montana
PSOC-231	Laramie #3 Seam, Erie, Colorado
PSOC-232	C Seam, Craig, Colorado
PSOC-233	Wadge Seam, Energy, Colorado
PSOC-234	Wadge Seam, Oak Creek, Colorado
PSOC-235	B Seam - B2 Bed, Somerset, Colorado
PSOC-236	Basin B Seam, Redstone, Colorado
PSOC-237	Rock Canyon Seam, Price, Utah
PSOC-238	King Mine A-Seam, Hiawatha, Utah
PSOC-239	King Mine B-Seam, Hiawatha, Utah
PSOC-240	Big 'D' Seam, Centralia, Washington
PSOC-241	Monarch Seam, Sheridan, Wyoming
PSOC-242	Deitz Seam, Sheridan, Wyoming
PSOC-243	Iowa Bottom Seam, Melrose, Iowa
PSOC-244	L. Cherokee, Chillicothe, Iowa
PSOC-245	Lignite, Gascoyne, North Dakota
PSOC-246	Lignite Coteau Seam, Stanton, North Dakota
PSOC-247	Lignite, Larson, North Dakota
PSOC-248	Adaville #1 Seam, Frontier, Wyoming
PSOC-249	Rock Canyon Seam, Wellington, Utah
PSOC-250	York Seam, Raton, New Mexico
PSOC-251	Mineral Seam, Hallowell, Kansas
PSOC-252	Ill. #5 Seam, Shawneetown, Illinois
PSOC-253	"A" Seam, Bigler, Pennsylvania
PSOC-254	"B" Seam Top Bench, Clearfield County, Penna.
PSOC-255	"B" Seam Bottom Bench, Clearfield County, Penna.

<u>SAMPLE NO.</u>	<u>SEAM AND LOCATION</u>
PSOC-256	"D" Seam Lower Freeport, Ansonville, Pennsylvania
PSOC-257	"E" Seam Upper Freeport, Ansonville, Pennsylvania
PSOC-258	"C" Seam, Clearfield County, Pennsylvania
PSOC-259	Mt. Carmel Mine #2, Keewaydin, Pennsylvania
PSOC-260	"C" Seam Mid-Kittanning, Keewaydin, Penna.
PSOC-261	Ill. #6 - From Big Ridge Mine
PSOC-262	Illinois #6 Delta Mine, Williamson County, Illinois
PSOC-263	Herrin #6 Coal Elm Mine, Peoria, Illinois
PSOC-264	#2 Coal Sunspot, Fulton County, Illinois
PSOC-265	Jawbone or Shannon Seam, Coeburn, Virginia
PSOC-266	Upper Banner Seam, Nora, Virginia
PSOC-267	Clintwood Seam, Wise, Virginia
PSOC-268	Lyons Seam, Duncan Gap, Wise County, Virginia
PSOC-269	Imboden Seam, Big Stone Gap, Virginia
PSOC-270	American Seam, Quinton, Alabama
PSOC-271	Mary Lee Seam, Goodsprings, Alabama
PSOC-272	Ky. #9 Seam, Drakesboro, Kentucky
PSOC-273	Ky. #11 Seam, Drakesboro, Kentucky
PSOC-274	Sewell Seam, Leivasy, West Virginia
PSOC-275	Lower Freeport or Ohio #6A, Cadiz, Ohio
PSOC-276	Ohio #8, Cadiz, Ohio
PSOC-277	Ohio #9, Cadiz, Ohio
PSOC-278	Meigs Creek #9, Cumberland, Ohio
PSOC-279	Ind. #3, Jasonville, Indiana
PSOC-280	Ind. #6, Dugger, Indiana
PSOC-281	Ind. #7, Dugger, Indiana
PSOC-282	Preparation Product Ill. #6, Waltonville, Illinois
PSOC-283	Top Dekoven, Stonefort, Illinois
PSOC-284	Lower Dekoven, Stonefort, Illinois
PSOC-285	Davis, Stonefort, Illinois
PSOC-286	Tebo, Montrose, Illinois
PSOC-287	Bee Veer, Macon, Missouri
PSOC-288	Preparation Product Ill. #6, Victoria, Illinois
PSOC-289	Preparation Product Ill. #4, So. Wilmington, Illinois
PSOC-290	Ill. #4, So. Wilmington, Illinois
PSOC-291	Shallow - England
PSOC-292	Beeston - England
PSOC-293	Pittsburgh Seam, Thomas, Pennsylvania
PSOC-294	Lithotype Pittsburgh, Thomas, Pennsylvania
PSOC-295	Lithotype Pittsburgh, Thomas, Pennsylvania
PSOC-296	L. Kittanning #5, North Lima, Ohio
PSOC-297	L. Kittanning #5, North Lima, Ohio

SAMPLE NO.	SEAM AND LOCATION
PSOC-298	Shallow Seam, Cannock Area, England
PSOC-299	Sewanee Seam, Dunlap, Tennessee
PSOC-300	Peewee Seam, Caryville, Tennessee
PSOC-301	Splashdam Seam, Haysi, Virginia
PSOC-302	Lower Banner Seam, Carrie, Virginia
PSOC-303	Callide Seam, Queensland, Australia
PSOC-304	Big Seam, Queensland, Australia
PSOC-305	Ohio #11, Smithfield, Ohio
PSOC-306	Ohio #12, Yorksville, Ohio
PSOC-307	Ohio #12A, Yorksville, Ohio
PSOC-308	Ohio #5, Hamden, Ohio
PSOC-309	#8 Seam, Fruitland, New Mexico
PSOC-310	#7 Seam, Fruitland, New Mexico
PSOC-311	#6 Seam, Fruitland, New Mexico
PSOC-312	Red Seam, Kayenta, Arizona
PSOC-313	Hiiawatha Seam, Wattis, Utah
PSOC-314	Blind Canyon Seam, Huntington, Utah
PSOC-315	Wadge Seam, Oak Creek, Colorado
PSOC-316	Fish Creek Seam, Steamboat Springs, Colorado
PSOC-317	Lower Freeport Seam (B), Stoystown, Pennsylvania
PSOC-318	Upper Freeport Seam, Stoystown, Pennsylvania
PSOC-319	("C") Seam, Stoystown, Pennsylvania
PSOC-320	Pittsburgh Seam, Berlin, Pennsylvania
PSOC-321	Lithotype of Pittsburgh Seam, Berlin, Pennsylvania
PSOC-322	Restone Seam, Meyersdale, Pennsylvania
PSOC-323	"A" or Brookville Seam, Ginter, Pennsylvania
PSOC-324	"C" Seam, Bigler, Pennsylvania
PSOC-325	Middle Kittanning, Kittanning, Pennsylvania
PSOC-326	Upper Kittanning, Kittanning, Pennsylvania
PSOC-327	Lithotype of Upper Kittanning, Kittanning, Pennsylvania
PSOC-328	Upper Freeport, Shippingport, Pennsylvania
PSOC-329	Brookville Seam, Edinburg, Pennsylvania
PSOC-330	Middle Kittanning, Edinburg, Pennsylvania
PSOC-331	Brookville Seam, Sharon, Pennsylvania
PSOC-332	Lower Kittanning, Sharon, Pennsylvania
PSOC-333	Marion Co., Iowa
PSOC-334	Mahaska Co., Iowa
PSOC-335	#15 Seam, Winterpock, Virginia
PSOC-336	Upper Freeport Seam, Clearfield, Pennsylvania
PSOC-337	Lower Kittanning Seam, Brookville, Pennsylvania
PSOC-338	Lithotype of Lower Kittanning Seam, Brookville, Pennsylvania
PSOC-339	Lithotype of Lower Kittanning Seam, Brookville, Pennsylvania

SAMPLE NO.	SEAM AND LOCATION
PSOC-340	Lithotype of Lower Kittanning Seam, Brookville, Pennsylvania
PSOC-341	Clarion Seam, Corsica, Pennsylvania
PSOC-342	Lithotype of Clarion Seam, Corsica, Pennsylvania
PSOC-343	Lithotype of Clarion Seam, Corsica, Pennsylvania
PSOC-344	Lithotype of Clarion Seam, Corsica, Pennsylvania
PSOC-345	Lower Kittanning Seam, Corsica, Pennsylvania
PSOC-346	Lithotype of Lower Kittanning Seam, Corsica, Pennsylvania
PSOC-347	Lithotype of Lower Kittanning Seam, Corsica, Pennsylvania
PSOC-348	Lithotype of Lower Kittanning Seam, Corsica, Pennsylvania
PSOC-349	Lower Clarion Seam, Bruin, Pennsylvania
PSOC-350	Lithotype of Lower Clarion Seam, Bruin, Pennsylvania
PSOC-351	Lithotype of Lower Clarion Seam, Bruin, Pennsylvania
PSOC-352	Lithotype of Lower Clarion Seam, Bruin, Pennsylvania
PSOC-353	Upper Clarion Seam, Bruin, Pennsylvania
PSOC-354	Lower Kittanning Seam, Bruin, Pennsylvania
PSOC-355	Lower Kittanning Seam, Darlington, Pennsylvania
PSOC-356	Illinois #6, Pinckneyville, Illinois
PSOC-357	Lower Elkhorn Seam, Mouthcard, Pike County, Kentucky
PSOC-358	Lithotype of Lower Elkhorn Seam, Mouthcard, Pike Co., Kentucky
PSOC-359	Lithotype of Lower Elkhorn Seam, Mouthcard, Pike Co., Kentucky
PSOC-360	Lithotype of Lower Elkhorn Seam, Mouthcard, Pike Co., Kentucky
PSOC-361	Small Channel of Lower Elkhorn Seam, Mouthcard, Kentucky
PSOC-362	Small Channel of Lower Elkhorn Seam, Mouthcard, Kentucky
PSOC-363	Hazard #5A Seam, Hazard, Perry County, Kentucky
PSOC-364	Lithotype of Hazard #5A Seam, Hazard, Perry County, Kentucky
PSOC-365	Lithotype of Hazard #5A Seam, Hazard, Perry County, Kentucky
PSOC-366	Lithotype of Hazard #5A Seam, Hazard, Perry County, Kentucky
PSOC-367	Hazard #7 Seam, Hazard, Perry County, Kentucky
PSOC-368	Lithotype of Hazard #7 Seam, Hazard, Perry County, Kentucky
PSOC-369	Lithotype of Hazard #7 Seam, Hazard, Perry County, Kentucky
PSOC-370	Lithotype of Hazard #7 Seam, Hazard, Perry County, Kentucky
PSOC-371	Imboden Seam, Ovenfork, Letcher County, Kentucky
PSOC-372	Lithotype of Imboden Seam, Ovenfork, Letcher County, Kentucky
PSOC-373	Lithotype of Imboden Seam, Ovenfork, Letcher County, Kentucky
PSOC-374	Lithotype of Imboden Seam, Ovenfork, Letcher County, Kentucky
PSOC-375	#9 Seam, Harlan, Harlan County, Kentucky
PSOC-376	Lithotype of #9 Seam, Harlan, Harlan County, Kentucky
PSOC-377	Lithotype of #9 Seam, Harlan, Harlan County, Kentucky
PSOC-378	Lithotype of #9 Seam, Harlan, Harlan County, Kentucky

SAMPLE NO.	SEAM AND LOCATION
PSOC-379	P&M B Seam, Mildred, Pennsylvania
PSOC-380	Lithotype of B Seam, Mildred, Pennsylvania
PSOC-381	Lithotype of B Seam, Mildred, Pennsylvania
PSOC-382	Lithotype of B Seam, Mildred, Pennsylvania
PSOC-383	P&M A Seam, Mildred, Sullivan County, Pennsylvania
PSOC-384	P&M Anderson Pit (B) Coal, Mildred, Sullivan County, Pennsylvania
PSOC-385	Core Sample 35 1/2", SCH-49-2, Webb County, Texas
PSOC-386	Core Sample 0-12", SCH-49-2, Webb County, Texas
PSOC-387	Core Sample 12-23", SCH-49-2, Webb County, Texas
PSOC-388	Core Sample 23-25 1/2", SCH-49-2, Webb County, Texas
PSOC-389	Core Sample, 20 1/2" Lower Coal, SCH-49-2, Webb County, Texas
PSOC-390	Core Sample, top half, Lower Coal, SCH-49-2, Webb County, Texas
PSOC-391	Core Sample, bottom half, Lower Coal, SCH-49-2, Webb County, Texas
PSOC-392	Core Sample 89.4-91.45', SCH-45A-1, Webb County, Texas
PSOC-393	Core Sample 15 1/2-21 1/2" from top, SCH-45A-1, Webb County, Texas
PSOC-394	Core Sample 157.4-159.9', SCH-45A-1, Webb County, Texas
PSOC-395	Core Sample Top 11", SCH-45-A-1, Webb County, Texas
PSOC-396	Core Sample, Middle 11 - 22", SCH-45A-1, Webb County, Texas
PSOC-397	Core Sample, Bottom 22-33", SCH-45A-1, Webb County, Texas
PSOC-398	Core Sample, 222.6-225.6', SCH-15-1, Webb County, Texas
PSOC-399	Fort Scott Seam, Craig County, Oklahoma
PSOC-400	Fort Scott Seam, Craig County, Oklahoma
PSOC-401	Large Channel of Mineral Seam, Craig County, Oklahoma
PSOC-402	Small Channel of Mineral Seam, Craig County, Oklahoma
PSOC-403	Large Channel of Stigler #9 Seam, Haskell County, Oklahoma
PSOC-404	Large Channel of Lower Hartshorne Seam, LeFlore County, Oklahoma
PSOC-405	Subsection of Lower Hartshorne Seam, LeFlore County, Oklahoma
PSOC-406	Subsection of Lower Hartshorne Seam, LeFlore County, Oklahoma
PSOC-407	Subsection of Lower Hartshorne Seam, LeFlore County, Oklahoma
PSOC-408	Large Channel of Upper Hartshorne Seam, LeFlore County, Oklahoma
PSOC-409	Subsection of Upper Hartshorne Seam, LeFlore County, Oklahoma
PSOC-410	Subsection of Upper Hartshorne Seam, LeFlore County, Oklahoma
PSOC-411	Subsection of Upper Hartshorne Seam, LeFlore County, Oklahoma
PSOC-412	Large Channel of Lignite Seam, Harrison County, Texas
PSOC-413	Subsection of Lignite Seam, Harrison County, Texas
PSOC-414	Subsection of Lignite Seam, Harrison County, Texas
PSOC-415	Subsection of Lignite Seam, Harrison County, Texas
PSOC-416	Large Channel of Lignite Seam, Titus County, Texas
PSOC-417	Subsection of Lignite Seam, Titus County, Texas
PSOC-418	Subsection of Lignite Seam, Titus County, Texas
PSOC-419	Subsection of Lignite Seam, Titus County, Texas
PSOC-420	Large Channel of Wildcat Seam, Milam County, Texas
PSOC-421	Subsection of Wildcat Seam, Milam County, Texas
PSOC-422	Subsection of Wildcat Seam, Milam County, Texas
PSOC-423	Subsection of Wildcat Seam, Milam County, Texas
PSOC-424	Small Channel of Wildcat Seam, Milam County, Texas

SAMPLE NO.	SEAM AND LOCATION
PSOC-425	Large Channel of Lignite Seam, Freestone County, Texas
PSOC-426	Subsection of Lignite Seam, Freestone County, Texas
PSOC-427	Subsection of Lignite Seam, Freestone County, Texas
PSOC-428	Subsection of Lignite Seam, Freestone County, Texas
PSOC-429	Large Channel of Upper Hiawatha Seam, Sevier County, Utah
PSOC-430	Right Small Channel of Upper Hiawatha Seam, Sevier County, Utah
PSOC-431	Left Small Channel of Upper Hiawatha Seam, Sevier County, Utah
PSOC-432	Upper Bench of Upper Hiawatha Seam, Sevier County, Utah
PSOC-433	Middle Bench of Upper Hiawatha Seam, Sevier County, Utah
PSOC-434	Lower Bench of Upper Hiawatha Seam, Sevier County, Utah
PSOC-435	Large Channel of "B" Seam, Carbon County, Utah
PSOC-436	Left Small Channel of "B" Seam, Carbon County, Utah
PSOC-437	Right Small Channel of "B" Seam, Carbon County, Utah
PSOC-438	Upper Specific Lithotype of "B" Seam, Carbon County, Utah
PSOC-439	Mid. Specific Lithotype of "B" Seam, Carbon County, Utah
PSOC-440	Bottom Specific Lithotype of "B" Seam, Carbon County, Utah
PSOC-441	Large Channel of "E" Seam, Gunnison County, Colorado
PSOC-442	Left Small Channel of "E" Seam, Gunnison County, Colorado
PSOC-443	Right Small Channel of "E" Seam, Gunnison County, Colorado
PSOC-444	Top Bench of "E" Seam, Gunnison County, Colorado
PSOC-445	Middle Bench of "E" Seam, Gunnison County, Colorado
PSOC-446	Bottom Bench of "E" Seam, Gunnison County, Colorado
PSOC-447	Large Channel of Upper "B" Seam, Pitkin County, Colorado
PSOC-448	Right Small Channel of Upper "B" Seam, Pitkin County, Colorado
PSOC-449	Left Small Channel of Upper "B" Seam, Pitkin County, Colorado
PSOC-450	Top Bench of Upper "B" Seam, Pitkin County, Colorado
PSOC-451	Middle Bench of Upper "B" Seam, Pitkin County, Colorado
PSOC-452	Bottom Bench of Upper "B" Seam, Pitkin County, Colorado
PSOC-453	Large Channel of Blind Canyon, Emery County, Utah
PSOC-454	Left Small Channel of Blind Canyon, Emery County, Utah
PSOC-455	Right Small Channel of Blind Canyon, Emery County, Utah
PSOC-456	Top Specific Lithotype of Blind Canyon, Emery County, Utah
PSOC-457	Mid. Specific Lithotype of Blind Canyon, Emery County, Utah
PSOC-458	Bottom Specific Lithotype of Blind Canyon, Emery County, Utah
PSOC-459	Large Channel of Lower Sunnyside Seam, Emery County, Utah
PSOC-460	Right Small Channel of Lower Sunnyside Seam, Emery County, Utah
PSOC-461	Left Small Channel of Lower Sunnyside Seam, Emery County, Utah
PSOC-462	Top Bench of Lower Sunnyside Seam, Emery County, Utah
PSOC-463	Middle Bench of Lower Sunnyside Seam, Emery County, Utah
PSOC-464	Bottom Bench of Lower Sunnyside Seam, Emery County, Utah
PSOC-465	Large Channel of Upper Deadman, Sweetwater County, Wyoming
PSOC-466	Right Small Channel of Upper & Lower Deadman, Sweetwater, Wyoming
PSOC-467	Left Small Channel of Upper & Lower Deadman, Sweetwater County, Wyoming
PSOC-468	Top Bench of Upper & Lower Deadman, Sweetwater County, Wyoming
PSOC-469	Middle Bench of Upper & Lower Deadman, Sweetwater County, Wyoming
PSOC-470	Bottom Bench of Upper & Lower Deadman, Sweetwater County, Wyoming
PSOC-471	Large Channel of #2 Seam, Lincoln County, Wyoming

SAMPLE
NO.

SEAM AND LOCATION

SAMPLE NO.	SEAM AND LOCATION
PSOC-472	Left Small Channel of #2, Lincoln County, Wyoming
PSOC-473	Right Small Channel of #2, Lincoln County, Wyoming
PSOC-474	Top Bench of #2, Lincoln County, Wyoming
PSOC-475	Middle Bench of #2, Lincoln County, Wyoming
PSOC-476	Bottom Bench of #2, Lincoln County, Wyoming
PSOC-477	Large Channel of Hanna #5, Carbon County, Wyoming
PSOC-478	Right Small Channel of Hanna #5, Carbon County, Wyoming
PSOC-479	Left Small Channel of Hanna #5, Carbon County, Wyoming
PSOC-480	Top Spec. Lithotype of Hanna #5, Carbon County, Wyoming
PSOC-481	Middle Spec. Lithotype of Hanna #5, Carbon County, Wyoming
PSOC-482	Bottom Spec. Lithotype of Hanna #5, Carbon County, Wyoming
PSOC-483	Large Channel of Bed #53, Carbon County, Wyoming
PSOC-484	Right Small Channel of Bed #53, Carbon County, Wyoming
PSOC-485	Left Small Channel of Bed #53, Carbon County, Wyoming
PSOC-486	Top Bench of Bed #53, Carbon County, Wyoming
PSOC-487	Middle Bench of Bed #53, Carbon County, Wyoming
PSOC-488	Bottom Bench of Bed #53, Carbon County, Wyoming
PSOC-489	Large Channel of Bed #80, Carbon County, Wyoming
PSOC-490	Right Small Channel of Bed #80, Carbon County, Wyoming
PSOC-491	Left Small Channel of Bed #80, Carbon County, Wyoming
PSOC-492	Top Spec. Lithotype of Bed #80, Carbon County, Wyoming
PSOC-493	Middle Spec. Lithotype of Bed #80, Carbon County, Wyoming
PSOC-494	Bottom Spec. Lithotype of Bed #80, Carbon County, Wyoming
PSOC-495	Large Channel of Hiawatha Seam, Emery County, Utah
PSOC-496	Left Small Channel of Hiawatha Seam, Emery County, Utah
PSOC-497	Right Small Channel of Hiawatha Seam, Emery County, Utah
PSOC-498	Top Spec. Lithotype of Hiawatha Seam, Emery County, Utah
PSOC-499	Middle Spec. Lithotype of Hiawatha Seam, Emery County, Utah
PSOC-500	Bottom Spec. Lithotype of Hiawatha Seam, Emery County, Utah
PSOC-501	Large Channel of Upper Sunnyside, Carbon County, Utah
PSOC-502	Left Small Channel of Upper Sunnyside, Carbon County, Utah
PSOC-503	Right Small Channel of Upper Sunnyside, Carbon County, Utah
PSOC-504	Top Bench of Upper Sunnyside, Carbon County, Utah
PSOC-505	Middle Bench of Upper Sunnyside, Carbon County, Utah
PSOC-506	Bottom Bench of Upper Sunnyside, Carbon County, Utah
PSOC-507	Large Channel of #24 Seam, Carbon County, Wyoming
PSOC-508	Left Small Channel of #24 Seam, Carbon County, Wyoming
PSOC-509	Right Small Channel of #24 Seam, Carbon County, Wyoming
PSOC-510	Top Bench of #24 Seam, Carbon County, Wyoming
PSOC-511	Middle Bench of #24 Seam, Carbon County, Wyoming
PSOC-512	Bottom Bench of #24 Seam, Carbon County, Wyoming
PSOC-513	Large Channel of Hanna #2, Carbon County, Wyoming
PSOC-514	Left Small Channel of Hanna #2, Carbon County, Wyoming
PSOC-515	Right Small Channel of Hanna #2 Seam, Carbon County, Wyoming
PSOC-516	Top Specific Lithotype of Hanna #2 Seam, Carbon County, Wyoming
PSOC-517	Middle Specific Lithotype of Hanna #2 Seam, Carbon County, Wyoming

SAMPLE
NO.

SEAM AND LOCATION

PSOC-518	Bottom Spec. Lithotype of Hanna #2, Carbon County, Wyoming
PSOC-519	Large Channel of Rock Springs #7 Seam, Sweetwater County, Wyoming
PSOC-520	Right Sm. Channel of Rock Springs #7, Sweetwater County, Wyoming
PSOC-521	Left Small Channel of Rock Springs #7, Sweetwater County, Wyoming
PSOC-522	Top Bench of Rock Springs #7, Sweetwater County, Wyoming
PSOC-523	Middle Bench of Rock Springs #7, Sweetwater County, Wyoming
PSOC-524	Bottom Bench of Rock Springs #7, Sweetwater County, Wyoming
PSOC-525	Large Channel of Deitz #3 Seam, Sheridan County, Wyoming
PSOC-526	Right Small Channel of Deitz #3, Sheridan County, Wyoming
PSOC-527	Left Small Channel, Dietz #3, Sheridan County, Wyoming
PSOC-528	Top Bench of Dietz #3, Sheridan County, Wyoming
PSOC-529	Middle Bench of Dietz #3, Sheridan County, Wyoming
PSOC-530	Bottom Bench of Dietz #3, Sheridan County, Wyoming
PSOC-531	Large Channel of Dietz Seam, Big Horn County, Montana
PSOC-532	Right Small Channel of Dietz Seam, Big Horn County, Montana
PSOC-533	Left Small Channel of Dietz Seam, Big Horn County, Montana
PSOC-534	Top Bench of Dietz Seam, Big Horn County, Montana
PSOC-535	Middle Bench of Dietz Seam, Big Horn County, Montana
PSOC-536	Bottom Bench of Dietz Seam, Big Horn County, Montana
PSOC-537	Large Channel of Wadge Seam, Routt County, Colorado
PSOC-538	Right Small Channel of Wadge Seam, Routt County, Colorado
PSOC-539	Left Small Channel of Wadge Seam, Routt County, Colorado
PSOC-540	Top Bench of Wadge Seam, Routt County, Colorado
PSOC-541	Middle Bench of Wadge Seam, Routt County, Colorado
PSOC-542	Bottom Bench of Wadge Seam, Routt County, Colorado
PSOC-543	Large Channel of Wolf Creek Seam, Routt County, Colorado
PSOC-544	Right Small Channel of Wolf Creek Seam, Routt County, Colorado
PSOC-545	Left Small Channel of Wolf Creek Seam, Routt County, Colorado
PSOC-546	Top Spec. Lithotype of Wolf Creek Seam, Routt County, Colorado
PSOC-547	Middle Spec. Lithotype of Wolf Creek Seam, Routt County, Colorado
PSOC-548	Bottom Spec. Lithotype of Wolf Creek Seam, Routt County, Colorado
PSOC-549	Large Channel of seam, Mahaska County, Iowa
PSOC-550	Channel of Seam, Mahaska County, Iowa
PSOC-551	Lithotype of seam, Mahaska County, Iowa
PSOC-552	Lithotype of seam, Mahaska County, Iowa
PSOC-553	Lithotype of seam, Mahaska County, Iowa
PSOC-554	Large Channel of #1 Seam, Lucas County, Iowa
PSOC-555	Lithotype of #1 Seam, Lucas County, Iowa
PSOC-556	Lithotype of #1 Seam, Lucas County, Iowa
PSOC-557	Lithotype of #1 Seam, Lucas County, Iowa
PSOC-558	Lithotype of Cooks Coal Bed, Campbell County, Wyoming
PSOC-559	Lithotype of Cooks Coal Bed, Campbell County, Wyoming
PSOC-560	Lithotype of Cooks Coal Bed, Campbell County, Wyoming
PSOC-561	Lithotype of 2nd seam(lower Cook), Campbell County, Wyoming
PSOC-562	Lithotype of 2nd seam(Lower Cooke), Campbell County, Wyoming

SAMPLE
NO.

SEAM AND LOCATION

SAMPLE NO.	SEAM AND LOCATION
PSOC-563	Lithotype of 2nd seam(Lower Cook), Campbell County, Wyoming
PSOC-564	Lithotype of 2nd seam(Lower Cook), Campbell County, Wyoming
PSOC-565	Lithotype of 2nd seam(Lower Cook), Campbell County, Wyoming
PSOC-566	Lithotype of 2nd seam(lower Cook), Campbell County, Wyoming
PSOC-567	Lithotype of 2nd seam(Lower Cook), Campbell County, Wyoming
PSOC-568	Lithotype of 2nd seam(Lower Cook), Campbell County, Wyoming
PSOC-569	Lithotype of 2nd seam(Lower Cook), Campbell County, Wyoming
PSOC-570	Lithotype of 2nd seam(Lower Cook), Campbell County, Wyoming
PSOC-571	Lithotype of 3rd seam(Wall Coal Bed), Campbell County, Wyoming
PSOC-572	Lithotype of 3rd seam, Campbell County, Wyoming
PSOC-573	Lithotype of 3rd seam, Campbell County, Wyoming
PSOC-574	Whole seam of unknown seam, Maverick County, Texas
PSOC-575	Lithotype of unknown seam, Maverick County, Texas
PSOC-576	Lithotype of unknown seam, Maverick County, Texas
PSOC-577	Lithotype of unknown seam, Maverick County, Texas
PSOC-578	lithotypo of unknown seam, Maverick County, Texas
PSOC-579	Lithotype of unknown seam, Maverick County, Texas
PSOC-580	Large channel of Illinois #5 seam, Randolph County, Illinois
PSOC-581	Lithotype of Illinois #5 seam, Randolph County, Illinois
PSOC-582	Lithotype of Illinois #5 Seam, Randolph County, Illinois
PSOC-583	Lithotype of Illinois #5 seam, Randolph County, Illinois
PSOC-584	Lithotype of Illinois #5 Seam, Randolph County, Illinois
PSOC-585	Large Channel of Indiana #V Seam, Gibson County, Indiana
PSOC-586	Lithotype of Indiana #V Seam, Gibson County, Indiana
PSOC-587	Lithotype of Indiana #V Seam, Gibson County, Indiana
PSOC-588	Lithotype of Indiana #V Seam, Gibson County, Indiana
PSOC-589	Lithotype of Indiana #V Seam, Gibson County, Indiana
PSOC-590	Channel of Indiana #V Seam, Gibson County, Indiana
PSOC-591	Channel of Illinois #5 Seam, Fulton County, Illinois
PSOC-592	Lithotype of Illinois #5 Seam, Fulton County, Illinois
PSOC-593	Lithotype of Illinois #5 Seam, Fulton County, Illinois
PSOC-594	Lithotype of Illinois #5 Seam, Fulton County, Illinois
PSOC-595	Large Channel of Indiana #VII Seam, Warrick County, Indiana
PSOC-596	Lithotype of Indiana #VII Seam, Warrick County, Indiana
PSOC-597	Lithotype of Indiana #VII Seam, Warrick County, Indiana
PSOC-598	Lithotype of Indiana #VII Seam, Warrick County, Indiana
PSOC-599	Channel of Indiana #VI Seam, Warrick County, Indiana
PSOC-600	Channel of Kentucky #12, Muhlenberg County, Kentucky
PSOC-601	Lithotype of Kentucky #12 Seam, Muhlenberg County, Kentucky
PSOC-602	Lithotype of Kentucky #12 Seam, Muhlenberg County, Kentucky
PSOC-603	Lithotype of Kentucky #12 Seam, Muhlenberg County, Kentucky
PSOC-604	Lithotype of Kentucky #12 Seam, Muhlenberg County, Kentucky
PSOC-605	Large Channel of Opdyke Seam, Jefferson County, Illinois
PSOC-606	Lithotype of Opdyke Seam, Jefferson County, Illinois
PSOC-607	Lithotype of Opdyke Seam, Jefferson County, Illinois
PSOC-608	Small Whole seam of Opdyke Seam, Jeffereson County, Illinois

SAMPLE
NO.

SEAM AND LOCATION

PSOC-609	Core Composite of Unknown seam, Maverick County, Texas
PSOC-610	Lithotype of unknown seam, Maverick County, Texas
PSOC-611	Lithotype of unknown seam, Maverick County, Texas
PSOC-612	Lithotype of unknown seam, Maverick County, Texas
PSOC-613	Lithotype of unknown seam, Maverick County, Texas
PSOC-614	Channel of Clarion, Clarion County, Pennsylvania
PSOC-615	Large Channel of Kelly Seam, Bedford County, Pennsylvania
PSOC-616	Subsection of Kelly Seam, Bedford County, Pennsylvania
PSOC-617	Subsection of Kelly Seam, Bedford County, Pennsylvania
PSOC-618	Subsection of Kelly seam, Bedford County, Pennsylvania
PSOC-619	Channel of Barnett Seam, Bedford County, Pennsylvania
PSOC-620	Channel of Twin Seam, Bedford County, Pennsylvania
PSOC-621	Subsection of Twin Seam, Bedford County, Pennsylvania
PSOC-622	Subsection of Twin Seam, Bedford County, Pennsylvania
PSOC-623	Whole seam Channel of Lignite Seam, Harrison County, Texas
PSOC-624	Subsection of Lignite Seam, Harrison County, Texas
PSOC-625	Subsection of Lignite seam, Harrison County, Texas
PSOC-626	Subsection of Lignite seam, Harrison County, Texas
PSOC-627	Channel sample, #2 Seam, Northumberland County, Pennsylvania
PSOC-628	Lithotype, #2 Seam, Northumberland County, Pennsylvania
PSOC-629	Lithotype, #2 Seam, Northumberland County, Pennsylvania
PSOC-630	Lithotype, #2 Seam, Northumberland County, Pennsylvania
PSOC-631	#4 Seam, Channel, Lycoming County, Pennsylvania
PSOC-632	#1 Seam, Channel, Lycoming County, Pennsylvania
PSOC-633	#1 Rider, Small Channel, Lycoming County, Pennsylvania
PSOC-634	E Seam, Channel, Tioga County, Pennsylvania
PSOC-635	Bloss Seam, Channel, Tioga County, Pennsylvania
PSOC-636	Wildcat Seam, Small channel, Milam County, Texas
PSOC-637	Wildcat Seam, Subsection, Milam County, Texas
PSOC-638	Wildcat Seam, Subsection, Milam County, Texas
PSOC-639	Wildcat Seam, Subsection, Milam County, Texas
PSOC-640	Kentucky #6, Channel, Hopkins County, Kentucky
PSOC-641	Kentucky #6, Subsection, Hopkins County, Kentucky
PSOC-642	Kentucky #6, Lithotype, Hopkins County, Kentucky
PSOC-643	Kentucky #6, Lithotype, Hopkins County, Kentucky
PSOC-644	Philpott Seam, Large channel, Franklin County, Arkansas
PSOC-645	Philpott Seam, Lithotype, Franklin County, Arkansas
PSOC-646	Philpott Seam, Lithotype, Franklin County, Arkansas
PSOC-647	Philpott Seam, Lithotype, Franklin County, Arkansas
PSOC-648	Philpott Seam, Small Channel, Franklin County, Arkansas
PSOC-649	Philpott Seam, Small Channel, Franklin County, Arkansas
PSOC-650	Paris Seam, Large channel, Logan County, Arkansas
PSOC-651	Paris Seam, Subsection, Logan County, Arkansas
PSOC-652	Paris Seam, Subsection, Logan County, Arkansas
PSOC-653	Paris Seam, Subsection, Logan County, Arkansas
PSOC-654	Paris Seam, Small Channel, Loga County, Arkansas

SAMPLE
NO.

SEAM AND LOCATION

SAMPLE NO.	SEAM AND LOCATION
PSOC-655	Paris Seam, Small Channel, Logan County, Arkansas
PSOC-656	Unknown Seam (#1 ?), Small channel, Lucas County, Iowa
PSOC-657	Unknown Seam (Lower Ford ?), Small channel, Mahaska County, Iowa
PSOC-658	Lower Seam, Large channel, Mahaska County, Iowa
PSOC-659	Lower Seam, Lithotype, Mahaska County, Iowa
PSOC-660	Lower Seam, Lithotype, Mahaska County, Iowa
PSOC-661	Lower Seam, Lithotype, Mahaska County, Iowa
PSOC-662	Lower Seam, Small channel, Mahaska County, Iowa
PSOC-663	Lower Seam, Small Channel, Mahaska County, Iowa
PSOC-664	Upper Seam, Large Channel, Mahaska County, Iowa
PSOC-665	Upper Seam, Lithotype, Mahaska County, Iowa
PSOC-666	Upper Seam, Lithotype, Mahaska County, Iowa
PSOC-667	Upper Seam, Lithotype, Mahaska County, Iowa
PSOC-668	Upper Seam, Small channel Mahaska County, Iowa
PSOC-669	#5 (Harrisburg) Seam, Small channel, Fulton County, Illinois
PSOC-670	#6 Seam, Large channel, Pike County, Indiana
PSOC-671	#6 Seam, Small channel, Pike County, Indiana
PSOC-672	#6 Seam, Lithotype, Pike County, Indiana
PSOC-673	#6 Seam, Lithotype, Pike County, Indiana
PSOC-674	#6 Seam, Lithotype, Pike County, Indiana
PSOC-675	#6 Seam, Small Channel, Pike County, Indiana
PSOC-676	Lower VI (L. Millersburg), Large channel, Warrick County, Indiana
PSOC-677	Lower VI (L. Millersburg), Lithotype, Warrick County, Indiana
PSOC-678	Lower VI (L. Millersburg), Subsection, Warrick County, Indiana
PSOC-679	Lower VI (L. Millersburg), Subsection, Warrick County, Indiana
PSOC-680	Lower VI (L. Millersburg), Small channel, Warrick County, Indiana
PSOC-681	Upper VI, Small channel, Warrick County, Indiana
PSOC-682	Indiana #VI, Large Channel, Warrick County, Indiana
PSOC-683	Indiana #VI, Small channel, Warrick County, Indiana
PSOC-684	Indiana #VI, Lithotype,, Warrick County, Indiana
PSOC-685	Indiana #VI, Lithotype, Warrick County, Indiana
PSOC-686	Indiana #VI, Lithotype, Warrick County, Indiana
PSOC-687	Indiana #VI, Small channel, Warrick County, Indiana
PSOC-688	Elk Lick Seam, Large channel, Grant County, West Virginia
PSOC-689	Elk Lick Seam, Small channel, Grant County, West Virginia
PSOC-690	Elk Lick Seam, Small channel, Grant County, West Virginia
PSOC-691	Elk Lick Seam, Lithotype, Grant County, West Virginia
PSOC-692	Elk Lick Seam, Subsection, Grant County, West Virginia
PSOC-693	Elk Lick Seam, Subsection, Grant County, West Virginia
PSOC-694	Gilbert Seam, Large channel, Randolph County, West Virginia
PSOC-695	Gilbert Seam, Small channel, Randolph County, West Virginia
PSOC-696	Gilbert Seam, Small channel, Randolph County, West Virginia
PSOC-697	Waynesburg Seam, Large channel, Monongalia County, West Virginia
PSOC-698	Waynesburg Seam, Small Channel, Monongalia County, West Virginia
PSOC-699	Waynesburg Seam, Small channel, Monongalia County, West Virginia
PSOC-700	Waynesburg Seam, Lithotype, Monongalia County, West Virginia
PSOC-701	Waynesburg Seam, Lithotype, Monongalia County, West Virginia
PSOC-702	Pittsburgh Seam, Large channel, Braxton County, West Virginia
PSOC-703	Pittsburgh Seam, Small Channel, Braxton County, West Virginia

SAMPLE NO.	SEAM AND LOCATION
PSOC-704	Pittsburgh Seam, Small channel, Braxton County, West Virginia
PSOC-705	Pittsburgh Seam, Lithotype, Braxton County, West Virginia
PSOC-706	Pittsburgh Seam, Lithotype, Braxton County, West Virginia
PSOC-707	Pittsburgh Seam, Lithotype, Braxton County, West Virginia
PSOC-708	Redstone Seam, Large channel, Barbour County, West Virginia
PSOC-709	Redstone Seam, Small channel, Barbour County, West Virginia
PSOC-710	Redstone Seam, Small channel, Barbour County, West Virginia
PSOC-711	Redstone Seam, Lithotype, Barbour County, West Virginia
PSOC-712	Redstone Seam, Lithotype, Barbour County, West Virginia
PSOC-713	Redstone Seam, Lithotype, Barbour County, West Virginia
PSOC-714	Redstone Seam, Large Channel, Lewis County, West Virginia
PSOC-715	Redstone Seam, Small channel, Lewis County, West Virginia
PSOC-716	Redstone Seam, Small channel, Lewis County, West Virginia
PSOC-717	Redstone Seam, Lithotype, Lewis County, West Virginia
PSOC-718	Redstone Seam, Lithotype, Lewis County, West Virginia
PSOC-719	Redstone Seam, Lithotype, Lewis County, West Virginia
PSOC-720	Upper Kittanning, Large channel, Preston County, West Virginia
PSOC-721	Upper Kittanning, Small channel, Preston County, West Virginia
PSOC-722	Upper Kittanning, Small channel, Preston County, West Virginia
PSOC-723	Upper Kittanning, Lithotype, Preston County, West Virginia
PSOC-724	Upper Kittanning, Lithotype, Preston County, West Virginia
PSOC-725	Upper Kittanning, Lithotype, Preston County, West Virginia
PSOC-726	Sewell B Seam (U. Sewell), Large channel, Randolph co., West Va.
PSOC-727	Sewell B Seam (U. Sewell), Small channel, Randolph co., West Va.
PSOC-728	Sewell B Seam (U. Sewell), Small channel, Randolph co., West Va.
PSOC-729	Sewell B Seam (U. Sewell), Subsection, Randolph co., West Virginia
PSOC-730	Sewell B Seam (U. Sewell), Subsection, Randolph co., West Virginia
PSOC-731	Sewell B Seam (U. Sewell), Subsection, Randolph co., West Virginia
PSOC-732	Upper Kittanning, Large channel, Webster County, West Virginia
PSOC-733	Upper Kittanning, Small channel, Webster County, West Virginia
PSOC-734	Upper Kittanning, Small channel, Webster County, West Virginia
PSOC-735	Upper Kittanning, Lithotype, Webster County, West Virginia
PSOC-736	Upper Kittanning, Lithotype, Webster County, West Virginia
PSOC-737	Upper Kittanning, Lithotype, Webster County, West Virginia
PSOC-738	Upper Kittanning, Lithotype, Webster County, West Virginia
PSOC-739	#12 Seam, Small channel, Muhlenberg County, Kentucky
PSOC-740	#12 Seam, Large channel, Muhlenberg County, Kentucky
PSOC-741	#12 Seam, Lithotype, Muhlenberg County, Kentucky
PSOC-742	#12 Seam, Lithotype, Muhlenberg County, Kentucky
PSOC-743	#12 Seam, Lithotype, Muhlenberg County, Kentucky
PSOC-744	#12 Seam, Small channel, Muhlenberg County, Kentucky
PSOC-745	#12 Seam, Small channel, Muhlenberg County, Kentucky
PSOC-746	#6 Seam, Small channel, Hopkins County, Kentucky
PSOC-747	Waynesburg Seam, Lithotype, Monongalia County, West Virginia
PSOC-748	4A (?) Seam, Large channel, Mahoning County, Ohio
PSOC-749	4A Seam, Bench, Mahoning County, Ohio
PSOC-750	4A Seam, Bench, Mahoning County, Ohio
PSOC-751	Ohio #6 Seam, Large channel, Tuscarawas County, Ohio
PSOC-752	Ohio #6 Seam, Lithotype, Tuscarawas County, Ohio

SAMPLE NO.	SEAM AND LOCATION
PSOC-753	Ohio #6 Seam, Lithotype, Tuscarawas County, Ohio
PSOC-754	Ohio #6 Seam, Lithotype, Tuscarawas County, Ohio
PSOC-755	Ohio #5 Seam, Small channel, Tuscarawas County, Ohio
PSOC-756	Ohio #4 Seam, Large Channel, Wayne County, Ohio
PSOC-757	Ohio #4 Seam, Bench, Wayne County, Ohio
PSOC-758	Ohio #4 Seam, Bench, Wayne County, Ohio
PSOC-759	Ohio #4 Seam, Bench, Wayne County, Ohio
PSOC-760	Ohio #5 Seam, Large channel, Coshocton County, Ohio
PSOC-761	Ohio #5 Seam, Subsection, Coshocton County, Ohio
PSOC-762	Ohio #5 Seam, Subsection, Coshocton County, Ohio
PSOC-763	Ohio #6 Seam, Large Channel, Tuscarawas County, Ohio
PSOC-764	Ohio #6 Seam, Bench, Tuscarawas County, Ohio
PSOC-765	Ohio #6 Seam, Bench, Tuscarawas County, Ohio
PSOC-766	Ohio #6 Seam, Bench, Tuscarawas County, Ohio
PSOC-767	Unknown Seam, Small channel, Craig County, Oklahoma
PSOC-768	Mineral Seam, Small channel, Craig County, Oklahoma
PSOC-769	Lower Philpot Seam, Large channel, Franklin County, Arkansas
PSOC-770	Ohio #6 Seam, Large channel, Hocking County, Ohio
PSOC-771	Ohio #6 Seam, Bench, Hocking County, Ohio
PSOC-772	Ohio #6 Seam, Bench, Hocking County, Ohio
PSOC-773	Ohio #6 Seam, Bench, Hocking County, Ohio
PSOC-774	Ohio #5 Seam, Large channel, Hocking County, Ohio
PSOC-775	Ohio #5 Seam, Lithotype, Hocking County, Ohio
PSOC-776	Ohio #5 Seam, Lithotype, Hocking County, Ohio
PSOC-777	Ohio #1 Seam, Large Channel, Belmont County, Ohio
PSOC-778	Ohio #1 Seam, Subsection, Belmont County, Ohio
PSOC-779	Ohio #1 Seam, Subsection, Belmont County, Ohio
PSOC-780	Ohio #1 Seam, Subsection, Belmont County, Ohio
PSOC-781	Ohio #11 Seam, Small channel, Belmont County, Ohio
PSOC-782	Lower Philpot Seam, Lithotype, Franklin County, Arkansas
PSOC-783	Lower Philpot Seam, Lithotype, Franklin County, Arkansas
PSOC-784	Lower Philpot Seam, Lithotype, Franklin County, Arkansas
PSOC-785	Lower Seam, Small Channel, Freestone County, Texas
PSOC-786	Lower Seam, Lithotype, Freestone County, Texas
PSOC-787	Lower Seam, Lithotype, Freestone County, Texas
PSOC-788	Lower Seam, Lithotype, Freestone County, Texas
PSOC-789	"A" Pit, Small channel, Titus County, Texas
PSOC-790	"A" Pit, Lithotype, Titus County, Texas
PSOC-791	"A" Pit, Lithotype, Titus County, Texas
PSOC-792	"A" Pit, Lithotype, Titus County, Texas
PSOC-793	"A" Pit, Lithotype, Titus County, Texas
PSOC-794	Croweburg Seam, Large Channel, Okmulgee County, Oklahoma
PSOC-795	Croweburg Seam, Lithotype, Okmulgee County, Oklahoma
PSOC-796	Croweburg Seam, Lithotype, Okmulgee County, Oklahoma
PSOC-797	Croweburg Seam, Lithotype, Okmulgee County, Oklahoma
PSOC-798	Stigler Seam, Channel sample, Muskogee County, Oklahoma
PSOC-799	Stigler Seam, Lithotype, Muskogee County, Oklahoma
PSOC-800	Stigler Seam, Lithotype, Muskogee County, Oklahoma
PSOC-801	Stigler Seam, Lithotype, Muskogee County, Oklahoma

SAMPLE
NO.

SEAM AND LOCATION

SAMPLE NO.	SEAM AND LOCATION
PSOC-802	Croweburg Seam, Large channel, Rogers-Wagner Counties, Okla.
PSOC-803	Croweburg Seam, Bench, Rogers-Wagoner Counties, Oklahoma
PSOC-804	Croweburg Seam, Bench, Rogers-Wagoner Counties, Oklahoma
PSOC-805	Croweburg Seam, Bench, Rogers-Wagoner Counties, Oklahoma
PSOC-806	Croweburg Seam, Large channel, Wagoner County, Oklahoma
PSOC-807	Croweburg Seam, Lithotype, Wagoner County, Oklahoma
PSOC-808	Croweburg Seam, Lithotype, Wagoner County, Oklahoma
PSOC-809	Croweburg Seam, Lithotype, Wagoner County, Oklahoma
PSOC-810	Lower Kittanning (#5 Block), Large channel, Barbour co., W. Va.
PSOC-811	Lower Kittanning, Small channel, Barbour County, West Virginia
PSOC-812	Lower Kittanning, Small channel, Barbour County, West Virginia
PSOC-813	Lower Kittanning, Lithotype, Barbour County, West Virginia
PSOC-814	Lower Kittanning, Lithotype, Barbour County, West Virginia
PSOC-815	Lower Kittanning, Lithotype, Barbour County, West Virginia
PSOC-816	Pittsburgh Seam, Large channel, Harrison County, West Virginia
PSOC-817	Pittsburgh Seam, Small channel, Harrison County, West Virginia
PSOC-818	Pittsburgh Seam, Small channel, Harrison County, West Virginia
PSOC-819	Pittsburgh Seam, Lithotype, Harrison County, West Virginia
PSOC-820	Pittsburgh Seam, Subsection, Harrison County, West Virginia
PSOC-821	Pittsburgh Seam, Subsection, Harrison County, West Virginia
PSOC-822	Sewell Seam, Large channel, Nicholas County, West Virginia
PSOC-823	Sewell Seam, Small channel, Nicholas County, West Virginia
PSOC-824	Sewell Seam, Small channel, Nicholas County, West Virginia
PSOC-825	Sewell Seam, Subsection, Nicholas County, West Virginia
PSOC-826	Sewell Seam, Subsection, Nicholas County, West Virginia
PSOC-827	Sewell Seam, Subsection, Nicholas County, West Virginia
PSOC-828	Brazil Block, Large channel, Parke County, Indiana
PSOC-829	Brazil Block, Small channel, Parke County, Indiana
PSOC-830	Brazil Block, Lithotype, Parke County, Indiana
PSOC-831	Brazil Block, Lithotype, Parke County, Indiana
PSOC-832	Brazil Block, Lithotype, Parke County, Indiana
PSOC-833	Fort Union Bed (Pust), Large channel, Richland County, Montana
PSOC-834	Fort Union Bed (Pust), Subsection, Richland County, Montana
PSOC-835	Fort Union Bed (Pust), Subsection, Richland County, Montana
PSOC-836	Fort Union Bed (Pust), Subsection, Richland County, Montana
PSOC-837	Fort Union Bed (Pust), Large channel, Richland County, Montana
PSOC-838	Fort Union Bed (Pust), Subsection, Richland County, Montana
PSOC-839	Fort Union Bed (Pust), Subsection, Richland County, Montana
PSOC-840	Fort Union Bed (Pust), Subsection, Richland County, Montana
PSOC-841	Fort Union Bed (Pust), Subsection, Richland County, Montana
PSOC-842	Hanna #5 Seam, Large channel, Carbon County, Wyoming
PSOC-843	Hanna #5 Seam, Lithotype, Carbon County, Wyoming
PSOC-844	Hanna #5 Seam, Lithotype, Carbon County, Wyoming
PSOC-845	Hanna #5 Seam, Lithotype, Carbon County, Wyoming
PSOC-846	Brooks Seam, Large channel, Carbon County, Wyoming
PSOC-847	Brooks Seam, Lithotype, Carbon County, Wyoming
PSOC-848	Brooks Seam, Lithotype, Carbon County, Wyoming
PSOC-849	Brooks Seam, Lithotype, Carbon County, Wyoming
PSOC-850	"D" Seam, Large channel, Delta County, Colorado
PSOC-851	"D" Seam, Lithotype, Delta County, Colorado

SAMPLE
NO.

SEAM AND LOCATION

SAMPLE NO.	SEAM AND LOCATION
PSOC-852	D Seam, Lithotype, Delta County, Colorado
PSOC-853	D Seam, Lithotype, Delta County, Colorado
PSOC-854	Juanita C Seam, Large channel, Gunnison County, Colorado
PSOC-855	Juanita C, Subsection, Gunnison County, Colorado
PSOC-856	Juanita C, Subsection, Gunnison County, Colorado
PSOC-857	Juanita C, Subsection, Gunnison County, Colorado
PSOC-858	Dakota Seam, Large channel, Montrose County, Colorado
PSOC-859	Dakota Seam, Lithotype, Montrose County, Colorado
PSOC-860	Dakota Seam, Lithotype, Montrose County, Colorado
PSOC-861	Dakota Seam, Lithotype, Montrose County, Colorado
PSOC-862	G Seam, Large channel, Fremont County, Colorado
PSOC-863	G Seam, Lithotype, Fremont County, Colorado
PSOC-864	G Seam, Lithotype, Fremont County, Colorado
PSOC-865	G Seam, Lithotype, Fremont County, Colorado
PSOC-866	G Seam, Lithotype, Fremont County, Colorado
PSOC-867	Primrose Seam, Large channel, Schuylkill County, Pennsylvania
PSOC-868	Primrose Seam, Lithotype, Schuylkill County, Pennsylvania
PSOC-869	Primrose Seam, Lithotype, Schuylkill County, Pennsylvania
PSOC-870	Primrose Seam, Subsection, Schuylkill County, Pennsylvania
PSOC-871	Wharton Seam, Small channel, Luzerne County, Pennsylvania
PSOC-872	Buck Mt. Seam, Run-of-mine, Luzerne County, Pennsylvania
PSOC-873	Parlor Seam, Small channel, Luzerne County, Pennsylvania
PSOC-874	Ross Seam, Small channel, Luzerne County, Pennsylvania
PSOC-875	Seymour Seam, Channel, Lycoming County, Pennsylvania
PSOC-876	Seymour Seam, Lithotype, Lycoming County, Pennsylvania
PSOC-877	Seymour Seam, Lithotype, Lycoming County, Pennsylvania
PSOC-878	Seymour Seam, Lithotype, Lycoming County, Pennsylvania
PSOC-879	One-Foot Seam, Channel, Lycoming County, Pennsylvania
PSOC-880	Bear Creek Seam, Channel, Lycoming County, Pennsylvania
PSOC-881	Bear Creek Seam, Lithotype, Lycoming County, Pennsylvania
PSOC-882	Bear Creek Seam, Lithotype, Lycoming County, Pennsylvania
PSOC-883	Drywood Seam (Kniveton), Small channel, Barton co., Missouri
PSOC-884	Rowe Seam, Small channel, Barton County, Missouri
PSOC-885	Mulberry Seam, Small channel, Bates County, Missouri
PSOC-886	Mulberry Seam, Small channel, Bates County, Missouri
PSOC-887	Stockton-Lewiston Seam, Large channel, Logan County, West Virginia
PSOC-888	Stockton-Lewiston Seam, Small channel, Logan County, West Virginia
PSOC-890	Stockton-Lewiston Seam, Lithotype, Logan County, West Virginia
PSOC-891	Stockton-Lewiston Seam, Lithotype, Logan County, West Virginia
PSOC-892	Stockton-Lewiston Seam, Lithotype, Logan County, West Virginia
PSOC-893	Stockton-Lewiston Seam, Lithotype, Logan County, West Virginia
PSOC-894	Stockton-Lewiston Seam, Lithotype, Logan County, West Virginia
PSOC-895	Cedar Grove Seam, Large channel, Mingo County, West Virginia
PSOC-896	Cedar Grove Seam, Small channel, Mingo County, West Virginia
PSOC-897	Cedar Grove Seam, Small channel, Mingo County, West Virginia
PSOC-898	Cedar Grove Seam, Subsection, Mingo County, West Virginia
PSOC-899	Cedar Grove Seam, Subsection, Mingo County, West Virginia
PSOC-900	Cedar Grove Seam, Subsection, Mingo County, West Virginia

SAMPLE NO.	SEAM AND LOCATION
PSOC-901	Upper Kittanning Seam, Large channel, Monongalia County, W. Va.
PSOC-902	Upper Kittanning Seam, Small channel, Monongalia County, W. Va.
PSOC-903	Upper Kittanning Seam, Small channel, Monongalia County, W. Va.
PSOC-904	Upper Kittanning Seam, Subsection, Monongalia County, W. Va.
PSOC-905	Upper Kittanning Seam, Subsection, Monongalia County, W. Va.
PSOC-906	Upper Kittanning Seam, Subsection, Monongalia County, W. Va.
PSOC-907	Lower Kittanning Seam, Large channel, Clay County, West Virginia
PSOC-908	Lower Kittanning Seam, Small channel, Clay County, West Virginia
PSOC-909	Lower Kittanning Seam, Small channel, Clay County, West Virginia
PSOC-910	Lower Kittanning Seam, Bench, Clay County, West Virginia
PSOC-911	Lower Kittanning Seam, Bench, Clay County, West Virginia
PSOC-912	Lower Kittanning Seam, Bench, Clay County, West Virginia
PSOC-913	Opdyke Seam, Small channel, Jefferson County, Illinois
PSOC-914	Croweburg Seam, Small channel, Okmulgee County, Oklahoma
PSOC-915	#6 Seam, Channel, San Juan County, New Mexico
PSOC-916	#6 Seam, Lithotype, San Juan County, New Mexico
PSOC-917	#6 Seam, Lithotype, San Juan County, New Mexico
PSOC-918	#6 Seam, Lithotype, San Juan County, New Mexico
PSOC-919	#6 Seam, Lithotype, San Juan County, New Mexico
PSOC-920	#6 Seam, Small channel, San Juan County, New Mexico
PSOC-921	#6 Seam, Small channel, San Juan County, New Mexico
PSOC-922	#8 Seam, Large channel, San Juan County, New Mexico
PSOC-923	#8 Seam, Bench, San Juan County, New Mexico
PSOC-924	#8 Seam, Bench, San Juan County, New Mexico
PSOC-925	#8 Seam, Bench, San Juan County, New Mexico
PSOC-926	#8 Seam, Bench, San Juan County, New Mexico
PSOC-927	#8 Seam, Bench, San Juan County, New Mexico
PSOC-928	#8 Seam, Small channel, San Juan County, New Mexico
PSOC-929	#8 Seam, Small channel, San Juan County, New Mexico
PSOC-930	Green Seam, Large channel, McKinley County, New Mexico
PSOC-931	Green Seam, Lithotype, McKinley County, New Mexico
PSOC-932	Green Seam, Lithotype, McKinley County, New Mexico
PSOC-933	Green Seam, Lithotype, McKinley County, New Mexico
PSOC-934	Green Seam, Lithotype, McKinley County, New Mexico
PSOC-935	Green Seam, Small channel, McKinley County, New Mexico
PSOC-936	Lower Blue Seam, Large channel, McKinley County, New Mexico
PSOC-937	Lower Blue Seam, Bench, McKinley County, New Mexico
PSOC-938	Lower Blue Seam, Bench, McKinley County, New Mexico
PSOC-939	Lower Blue Seam, Bench, McKinley County, New Mexico
PSOC-940	York Canyon Seam, Large channel, Colfax County, New Mexico
PSOC-941	York Canyon Seam, Bench, Colfax County, New Mexico
PSOC-942	York Canyon Seam, Subsection, Colfax County, New Mexico
PSOC-943	York Canyon Seam, Subsection, Colfax County, New Mexico
PSOC-944	York Canyon Seam, Colfax County, New Mexico, Large channel
PSOC-945	York Canyon Seam, subsection, Colfax County, New Mexico
PSOC-946	York Canyon Seam, Subsection, Colfax County, New Mexico
PSOC-947	York Canyon Seam, Subsection, Colfax County, New Mexico
PSOC-948	York Canyon Seam, Small channel, Colfax County, New Mexico
PSOC-949	York Canyon Seam, Small channel, Colfax County, New Mexico

SAMPLE
NO.

SEAM AND LOCATION

SAMPLE NO.	SEAM AND LOCATION
PSOC-950	Opdyke Seam, Small channel, Jefferson County, Illinois
PSOC-951	Illinois #5 Seam, Small channel, Randolph County, Illinois
PSOC-952	Core Sample, Whole Seam, DeSoto County, Louisiana
PSOC-953	Core Sample, Whole Seam, DeSoto County, Louisiana
PSOC-954	Core Sample, Whole Seam, DeSoto County, Louisiana
PSOC-955	Core Sample, Whole Seam, Red River County, Louisiana
PSOC-956	Core Sample, Whole Seam, Red River County, Louisiana
PSOC-957	Core Sample, Whole Seam, Bienville County, Louisiana
PSOC-958	Core Sample, Whole Seam, Red River County, Louisiana
PSOC-959	Core Sample, Whole Seam, Columbia County, Arkansas
PSOC-960	Core Sample, Whole Seam, Columbia County, Arkansas
PSOC-961	Core Sample, Whole Seam, Columbia County, Arkansas
PSOC-962	Core Sample, Whole Seam, Columbia County, Arkansas
PSOC-963	Upper Hartshorne Seam, Small channel, LeFlore County, Oklahoma
PSOC-964	Lower Hartshorne Seam, Small channel, LeFlore County, Oklahoma
PSOC-965	Stigler Seam, Small channel, Haskell County, Oklahoma
PSOC-966	Unnamed Seam, Core, Campbell County, Wyoming
PSOC-967	Pawnee Seam, Core subsection, Campbell County, Wyoming
PSOC-968	Pawnee Seam, Core subsection, Campbell County, Wyoming
PSOC-969	Pawnee Seam, Core subsection, Campbell County, Wyoming
PSOC-970	Pawnee Seam, Core subsection, Campbell County, Wyoming
PSOC-971	Cache Seam, Core subsection, Campbell County, Wyoming
PSOC-972	Cache Seam, Core subsection, Campbell County, Wyoming
PSOC-973	Cache Seam, Core subsection, Campbell County, Wyoming
PSOC-974	Anderson Seam, Core subsection, Campbell County, Wyoming
PSOC-975	Anderson Seam, Core subsection, Campbell County, Wyoming
PSOC-976	Anderson Seam, Core subsection, Campbell County, Wyoming
PSOC-977	Anderson Seam, Core subsection, Campbell County, Wyoming
PSOC-978	Anderson Seam, Core bench, Campbell County, Wyoming
PSOC-979	Unknown (Gentry?), Large channel, Pope County, Illinois
PSOC-980	Unknown, (Gentry?), Lithotype, Pope County, Illinois
PSOC-981	Unknown, (Gentry?), lithotype, Pope County, Illinois
PSOC-982	Unknown, (Gentry?), lithotype, Pope County, Illinois
PSOC-983	Unknown (Gentry?), Small channel, Pope County, Illinois
PSOC-984	Unknown (Gentry?), Small channel, Pope County, Illinois
PSOC-985	Beckley Seam, Large channel, Greenbrier County, West Virginia
PSOC-986	Beckley Seam, Small channel, Greenbrier County, West Virginia
PSOC-987	Beckley Seam, Small channel, Greenbrier County, West Virginia
PSOC-988	Beckley Seam, Bench, Greenbrier County, West Virginia
PSOC-989	Beckley Seam, Bench, Greenbrier County, West Virginia
PSOC-990	Beckley Seam, Bench, Greenbrier County, West Virginia
PSOC-991	Fire Creek, Large channel, Greenbrier County, West Virginia
PSOC-992	Fire Creek, Small channel, Greenbrier County, West Virginia
PSOC-993	Fire Creek, Small channel, Greenbrier County, West Virginia
PSOC-994	Fire Creek, Lithotype, Greenbrier County, West Virginia
PSOC-995	Fire Creek, Bench, Greenbrier County, West Virginia
PSOC-996	Fire Creek, Bench, Greenbrier County, West Virginia
PSOC-997	Pittsburgh Seam, Large channel, Marion County, West Virginia
PSOC-998	Pittsburgh Seam, Small channel, Marion County, West Virginia
PSOC-999	Pittsburgh Seam, Small channel, Marion County, West Virginia
PSOC-1000	Pittsburgh Seam, Bench, Marion County, West Virginia
PSOC-1001	Pittsburgh Seam, Subsection, Marion County, West Virginia

SAMPLE NO.	SEAM AND LOCATION
PSOC-1002	Pittsburgh Seam, Subsection, Marion County, West Virginia
PSOC-1003	Canyon "A" Seam, Core subsection, Campbell County, Wyoming
PSOC-1004	Canyon "A" Seam, Core subsection, Campbell County, Wyoming
PSOC-1005	Canyon "A" Seam, Core subsection, Campbell County, Wyoming
PSOC-1006	Canyon "B" Seam, Core subsection, Campbell County, Wyoming
PSOC-1007	Canyon "B" Seam, Core subsection, Campbell County, Wyoming
PSOC-1008	Lower Canyon "B" Seam, Core subsection, Campbell County, Wyoming
PSOC-1009	Lower Canyon "B" Seam, Core subsection, Campbell County, Wyoming
PSOC-1010	Lower Kittanning Seam, Small channel, Fayette County, Pennsylvania
PSOC-1011	Lower Kittanning Seam, Small channel, Jefferson County, Pennsylvania
PSOC-1012	Lower Kittanning Seam, Small channel, Jefferson County, Pennsylvania
PSOC-1013	Lower Kittanning, Small channel, Jefferson County, Pennsylvania
PSOC-1014	Lower Kittanning Seam, Small channel, Somerset County, Pennsylvania
PSOC-1015	Lower Kittanning Seam, Small channel, Somerset County, Pennsylvania
PSOC-1016	Lower Kittanning Seam, Small channel, Somerset County, Pennsylvania
PSOC-1017	Lower Kittanning Seam, Small channel, Armstrong County, Pennsylvania
PSOC-1018	Lower Kittanning Seam, Small channel, Armstrong County, Pennsylvania
PSOC-1019	Lower Kittanning Seam, Small channel, Armstrong County, Pennsylvania
PSOC-1020	Lower Kittanning Seam, Small channel, Lawrence County, Pennsylvania
PSOC-1021	Lower Kittanning Seam, Small channel, Lawrence County, Pennsylvania
PSOC-1022	Lower Kittanning Seam, Small channel, Lawrence County, Pennsylvania
PSOC-1023	Lower Freeport Seam, Small channel, Jefferson County, Pennsylvania
PSOC-1024	Lower Kittanning Seam, Small channel, Centre County, Pennsylvania
PSOC-1025	Lower Kittanning Seam, Small channel, Centre County, Pennsylvania
PSOC-1026	Lower Kittanning Seam, Small channel, Clearfield County, Pennsylvania
PSOC-1027	Mercer Seam, Small channel, Clearfield County, Pennsylvania
PSOC-1028	Clarion Seam, Small channel, Clearfield County, Pennsylvania
PSOC-1029	Clarion Seam, Small channel, Clearfield County, Pennsylvania
PSOC-1030	Kelly Seam, Small channel, Bedford County, Pennsylvania
PSOC-1031	Kelly Seam, Small channel, Bedford County, Pennsylvania
PSOC-1032	Twin Seam, Small channel, Bedford County, Pennsylvania
PSOC-1033	Fulton Seam, Small channel, Bedford County, Pennsylvania
PSOC-1034	Lower Freeport Seam, Small channel, Jefferson County, Pennsylvania
PSOC-1035	Lower Freeport Seam, Small channel, Jefferson County, Pennsylvania
PSOC-1036	Unnamed Seam, Small channel, Panola County, Texas
PSOC-1037	Unnamed Seam, Lithotype, Panola County, Texas
PSOC-1038	Unnamed Seam, Lithotype, Panola County, Texas
PSOC-1039	Unnamed Seam, Lithotype, Panola County, Texas
PSOC-1040	Unnamed Seam, Core Lithotype, Robertson County, Texas
PSOC-1041	Unnamed Seam, Core Lithotype, Robertson County, Texas
PSOC-1042	Unnamed Seam, Core Lithotype, Grimes County, Texas
PSOC-1043	Unnamed Seam, Core Lithotype, Grimes County, Texas
PSOC-1044	Unnamed Seam, Core Lithotype, Grimes County, Texas
PSOC-1045	Unnamed Seam, Core Lithotype, Grimes County, Texas
PSOC-1046	Unnamed Seam, Core Lithotype, Grimes County, Texas
PSOC-1047	Unnamed Seam, Core Lithotype, Grimes County, Texas
PSOC-1048	Unnamed Seam, Core Lithotype, Grimes County, Texas

SAMPLE
NO.

SEAM AND LOCATION

PSOC-1049	Unnamed Seam, Core Lithotype, Grimes County, Texas
PSOC-1050	Unnamed Seam, Core Lithotype, Grimes County, Texas
PSOC-1051	Upper Seam, Core Lithotype, Wood County, Texas
PSOC-1052	Upper Seam, Core Lithotype, Wood County, Texas
PSOC-1053	Upper Seam, Core Lithotype, Wood County, Texas
PSOC-1054	Upper Seam, Core Lithotype, Wood County, Texas
PSOC-1055	Unnamed Seam, Core Lithotype, Wood County, Texas
PSOC-1056	Unnamed Seam, Core Lithotype, Wood County, Texas
PSOC-1057	Unnamed Seam, Core Lithotype, Freestone County, Texas
PSOC-1058	Unnamed Seam, Core Lithotype, Freestone County, Texas
PSOC-1059	Unnamed Seam, Core Lithotype, Freestone County, Texas
PSOC-1060	Unnamed Seam, Core Lithotype, Freestone County, Texas
PSOC-1061	Unnamed Seam, Core Lithotype, Freestone County, Texas
PSOC-1062	Unnamed Seam, Core Lithotype, Freestone County, Texas
PSOC-1063	Unnamed Seam, Core Lithotype, Freestone County, Texas
PSOC-1064	Unnamed Seam, Core Lithotype, Freestone County, Texas
PSOC-1065	Unnamed Seam, Core Lithotype, Freestone County, Texas
PSOC-1066	Unnamed Seam, Core Lithotype, Freestone County, Texas
PSOC-1067	Unnamed Seam, Core Lithotype, Freestone County, Texas
PSOC-1068	Unnamed Seam, Core, Freestone County, Texas
PSOC-1069	Unnamed Seam, Core, Freestone County, Texas
PSOC-1070	Unnamed Seam, Core, Freestone County, Texas
PSOC-1071	Unnamed Seam, Core Lithotype, Van Zandt County, Texas
PSOC-1072	Unnamed Seam, Core Lithotype, Van Zandt County, Texas
PSOC-1073	Unnamed Seam, Core Lithotype, Van Zandt County, Texas
PSOC-1074	Unnamed Seam, Core Lithotype, Brazos County, Texas
PSOC-1075	Unnamed Seam, Core Lithotype, Brazos County, Texas
PSOC-1076	Unnamed Seam, Core Lithotype, Freestone County, Texas
PSOC-1077	Unnamed Seam, Core Lithotype, Freestone County, Texas
PSOC-1078	Unnamed Seam, Core Lithotype, Freestone County, Texas
PSOC-1079	Unnamed Seam, Core Lithotype, Brazos County, Texas
PSOC-1080	Unnamed Seam, Core Lithotype, Brazos County, Texas
PSOC-1081	Unnamed Seam, Core, Freestone County, Texas
PSOC-1082	Kentucky #11 Seam, Prep. Plant Raw Coal, Ohio County, Kentucky
PSOC-1083	Kentucky #11 Seam, Prep. Plant Cleaned Coal, Ohio County, Kentucky
PSOC-1084	Sawyer Seam, Core Subsection, Powder River County, Montana
PSOC-1085	Sawyer Seam, Core Subsection, Powder River County, Montana
PSOC-1086	Sawyer Seam, Core Subsection, Powder River County, Montana
PSOC-1087	Sawyer Seam, Core Subsection, Powder River County, Montana
PSOC-1088	Sawyer Seam, Core Subsection, Powder River County, Montana
PSOC-1089	Sawyer Seam, Core Subsection, Powder River County, Montana
PSOC-1090	Sawyer Seam, Core Subsection, Powder River County, Montana
PSOC-1091	Sawyer Seam, Core Subsection, Powder River County, Montana
PSOC-1092	Sawyer Seam, Core Subsection, Powder River County, Montana
PSOC-1093	Sawyer Seam, Core Subsection, Powder River County, Montana
PSOC-1094	Sawyer Seam, Core Subsection, Powder River County, Montana
PSOC-1095	Sawyer Seam, Core Subsection, Powder River County, Montana
PSOC-1096	Sawyer Seam, Core Subsection, Powder River County, Montana
PSOC-1097	Sawyer Seam, Core Subsection, Powder River County, Montana
PSOC-1098	Illinois #6, Small Channel, Saline County, Illinois

SAMPLE
NO.

SEAM AND LOCATION

SAMPLE NO.	SEAM AND LOCATION
PSOC-1099	Pittsburgh Seam, Channel Sample, Washington County, Pennsylvania
PSOC-1100	Pittsburgh Seam, Lithotype, Washington County, Pennsylvania
PSOC-1101	Pittsburgh Seam, Lithotype, Washington County, Pennsylvania
PSOC-1102	Pittsburgh Seam, Lithotype, Washington County, Pennsylvania
PSOC-1103	Elkhorn #3 Seam, Channel Sample, Letcher County, Kentucky
PSOC-1104	Elkhorn #3 Seam, Lithotype, Letcher County, Kentucky
PSOC-1105	Elkhorn #3 Seam, Lithotype, Letcher County, Kentucky
PSOC-1106	Elkhorn #3 Seam, Lithotype, Letcher County, Kentucky
PSOC-1107	King Cannel Seam, Channel, Kane County, Utah
PSOC-1108	King Cannel Seam, Lithotype, Kane County, Utah
PSOC-1109	King Cannel Seam, Lithotype, Kane County, Utah
PSOC-1110	King Cannel Seam, Lithotype, Kane County, Utah
PSOC-1111	King Cannel Seam, Lithotype, Kane County, Utah
PSOC-1112	Blind Canyon Seam, Channel, Emery County, Utah
PSOC-1113	Blind Canyon Seam, Lithotype, Emery County, Utah
PSOC-1114	Blind Canyon Seam, Lithotype, Emery County, Utah
PSOC-1115	Blind Canyon Seam, Lithotype, Emery County, Utah
PSOC-1116	Upper Sunnyside Seam, Channel, Carbon County, Utah
PSOC-1117	Upper Sunnyside Seam, Subsection, Carbon County, Utah
PSOC-1118	Upper Sunnyside Seam, Lithotype, Carbon County, Utah
PSOC-1119	Upper Sunnyside Seam, Subsection, Carbon County, Utah
PSOC-1120	Brush Creek Seam, Large channel, Garrett County, Maryland
PSOC-1121	Brush Creek Seam, Small channel, Garrett County, Maryland
PSOC-1122	Brush Creek Seam, Small Channel, Garrett County, Maryland
PSOC-1123	Brush Creek Seam, Lithotype, Garrett County, Maryland
PSOC-1124	Brush Creek Seam, Subsection, Garrett County, Maryland
PSOC-1125	Brush Creek Seam, Subsection, Garrett County, Maryland
PSOC-1126	Middle Kittanning Seam, Large channel, Upshur County, West Virginia
PSOC-1127	Middle Kittanning Seam, Small Channel, Upshur County, West Virginia
PSOC-1128	Middle Kittanning Seam, Small Channel, Upshur County, West Virginia
PSOC-1129	Middle Kittanning Seam, Lithotype, Upshur County, West Virginia
PSOC-1130	Middle Kittanning Seam, Lithotype, Upshur County, West Virginia
PSOC-1131	Middle Kittanning Seam, Lithotype, Upshur County, West Virginia
PSOC-1132	Pocahontas #3 Seam, Run-of-Mine, Wyoming County, West Virginia
PSOC-1133	Lower Kittanning Seam, Channel, Cambria County, Pennsylvania
PSOC-1134	Lower Kittanning Seam, Lithotype, Cambria County, Pennsylvania
PSOC-1135	Lower Kittanning Seam, Bench Sample, Cambria County, Pennsylvania
PSOC-1136	Lower Kittanning Seam, Bench, Cambria County, Pennsylvania
PSOC-1137	Lower Kittanning Seam Upper Split, Channel Sample, Clearfield County, Pa.
PSOC-1138	Lower Kittanning Seam, Channel Sample, Clearfield County, Pennsylvania
PSOC-1139	Lower Kittanning Seam Upper Split, Channel Sample, Clearfield County, Pa.
PSOC-1140	Green Seam, Lithotype, McKinley County, New Mexico
PSOC-1141	Lower Kittanning Seam, Channel, Jefferson County, Pennsylvania
PSOC-1142	Lower Kittanning Seam, Small Channel, Jefferson County, Pennsylvania
PSOC-1143	Lower Kittanning Seam, Small Channel, Armstrong County, Pennsylvania
PSOC-1144	Lower Kittanning Seam, Small Channel, Clearfield County, Pennsylvania
PSOC-1145	Lower Kittanning Seam, Small Channel, Clearfield County, Pennsylvania
PSOC-1146	Lower Kittanning Seam, Small Channel, Jefferson County, Pennsylvania

SAMPLE
NO.

SEAM AND LOCATION

SAMPLE NO.	SEAM AND LOCATION
PSOC-1147	Anderson Seam, Core lithotype, Campbell County, Wyoming
PSOC-1148	Anderson Seam, Core subsection, Campbell County, Wyoming
PSOC-1149	Anderson Seam, Core subsection, Campbell County, Wyoming
PSOC-1150	Anderson Seam, Core subsection, Campbell County, Wyoming
PSOC-1151	Canyon Seam, Upper Split, Core, Campbell County, Wyoming
PSOC-1152	Canyon Seam, Lower Split, Core subsection, Campbell County, Wyoming
PSOC-1153	Canyon Seam, Lower Split, Core subsection, Campbell County, Wyoming
PSOC-1154	Canyon B Seam, Core subsection, Campbell County, Wyoming
PSOC-1155	Canyon B Seam, Core subsection, Campbell County, Wyoming
PSOC-1156	Canyon B Seam, Core subsection, Campbell County, Wyoming
PSOC-1157	Top Cook Seam, Core, Campbell County, Wyoming
PSOC-1158	Second Cook Seam, Core, Campbell County, Wyoming
PSOC-1159	Third Cook Seam, Core, Campbell County, Wyoming
PSOC-1160	Fourth Cook Seam, Core, Campbell County, Wyoming
PSOC-1161	Fifth Cook Seam, Core, Campbell County, Wyoming
PSOC-1162	Unnamed Seam, Core subsection, Campbell County, Wyoming
PSOC-1163	Unnamed Seam, Core subsection, Campbell County, Wyoming
PSOC-1164	Wall Seam, Core subsection, Campbell County, Wyoming
PSOC-1165	Wall Seam, Core subsection, Campbell County, Wyoming
PSOC-1166	Lower Kittanning Seam, Channel, Venango County, Pennsylvania
PSOC-1167	Lower Kittanning Seam, Channel, Lawrence County, Pennsylvania
PSOC-1168	Lower Kittanning Seam, Channel, Lawrence County, Pennsylvania
PSOC-1169	Lower Kittanning Seam, Channel, Clarion County, Pennsylvania
PSOC-1170	Lower Kittanning Seam, Channel, Clarion County, Pennsylvania
PSOC-1171	Lower Kittanning Seam, Channel, Butler County, Pennsylvania
PSOC-1172	Unnamed Seam, Core, San Juan County, New Mexico
PSOC-1173	Unnamed Seam, Core, San Juan County, New Mexico
PSOC-1174	Unnamed Seam, Core subsection, San Juan County, New Mexico
PSOC-1175	Unnamed Seam, Core subsection, San Juan County, New Mexico
PSOC-1176	Unnamed Seam, Core subsection, San Juan County, New Mexico
PSOC-1177	Unnamed Seam, Core Subsection, San Juan County, New Mexico
PSOC-1178	Unnamed Seam, Core, San Juan County, New Mexico
PSOC-1179	Unnamed Seam, Core, San Juan County, New Mexico
PSOC-1180	Unnamed Seam, Core, San Juan County, New Mexico
PSOC-1181	Unnamed Seam, Core subsection, San Juan County, New Mexico
PSOC-1182	Unnamed Seam, Core subsection, San Juan County, New Mexico
PSOC-1183	Unnamed Seam, Core, San Juan County, New Mexico
PSOC-1184	Unnamed Seam, Core, San Juan County, New Mexico
PSOC-1185	Illinois #5 Seam, Channel, Perry County, Illinois
PSOC-1186	Illinois #5 Seam, Subsection, Perry County, Illinois
PSOC-1187	Illinois #5 Seam, Subsection, Perry County, Illinois
PSOC-1188	Illinois #6 Seam, Channel, Perry County, Illinois
PSOC-1189	Illinois #6 Seam, Subsection, Perry County, Illinois
PSOC-1190	Illinois #6 Seam, Subsection, Perry County, Illinois
PSOC-1191	Illinois #6 Seam, Subsection, Perry County, Illinois
PSOC-1192	Lower Kittanning Seam, Channel, Clearfield County, Pennsylvania
PSOC-1193	Lower Kittanning Seam, Channel, Indiana County, Pennsylvania
PSOC-1194	Lower Kittanning Seam, Channel, Cambria County, Pennsylvania

SAMPLE
NO.

SEAM AND LOCATION

PSOC-1195	Lower Kittanning Seam, Channel, Cambria County, Pennsylvania
PSOC-1196	Lower Kittanning Seam, Channel, Centre County, Pennsylvania
PSOC-1197	Lower Kittanning Seam, Channel, Somerset County, Pennsylvania
PSOC-1198	Lower Kittanning Seam, Channel, Indiana County, Pennsylvania
PSOC-1199	Unnamed Seam, Core, Grimes County, Texas
PSOC-1200	Unnamed Seam, Core, Grimes County, Texas

APPENDIX V

Samples Supplied to Other
Agencies

SERVICE TO THE COAL COMMUNITY

PENN STATE SAMPLE BANK

Recipient	Sample	
	Number	Pounds
Aerojet Liquid Rocket Company Sacramento, California	1	100
Aerospace Corporation Los Angeles, California	1 14	100 1
Adelphi University Garden City, New York	6 1	100 35
Air Products and Chemicals Allentown, Pennsylvania	4 2	35 1
Alabama, University of University, Alabama	1	1
Argonne National Laboratory Argonne, Illinois	14 1 12	1 5 Special Grinding
Atlantic Research Corporation Alexandria, Virginia	1 3	16 100
Atlantic Richfield Company Harvey, Illinois	17	10
Auburn University Auburn, Alabama	9 11	1 3
Boston College Chestnut Hill, Massachusetts	1	15
Brigham Young University Provo, Utah	1	1
Brookhaven National Laboratory Upton, New York	5	35
Calgon Corporation Pittsburgh, Pennsylvania	3	2
California Institute of Technology Jet Propulsion Laboratory Pasadena California	7 19 1 11 2 2	1 5 10 15 20 35
California Institute of Technology Chemical Engineering Pasadena, California	2 1	1 25

Recipient	Sample	
	Number	Pounds
California State University Los Angeles, California	11 6	2 1
California, University of Berkeley, California	12 2	35 2
California, University of Los Alamos, New Mexico	11	1
Chevron Oil Field Research Company La Habra, California	7	1
Cities Service Research and Development Cranbury, New Jersey	1 1 3	20 400 1
City College of New York Department of Chemical Engineering New York, New York	4 5	1 500 gram
Cleveland State University Cleveland, Ohio	3	5
Colorado School of Mines Golden, Colorado	19	1
Columbia University Chemical Engineering New York, New York	7 2 1	30 1 5
Consultant St. George, Utah	8	1
Department of Energy Pittsburgh, Pennsylvania	29 3	1 Washability
Dow Chemical, USA Plaquemine, Indiana	5	1
Eastern Illinois University Charleston, Illinois	2	1
Electric Power Institute Palo Alto, California	3	60
Energy and Minerals Research Company Exton, Pennsylvania	3	5
Emory University Atlanta, Georgia	1	1
Fairleigh Dickinson University Teaneck, New Jersey	4	1

Recipient	Sample Number	Pounds
Florida Atlantic University Boca Raton, Florida	34 11	200 grams 60 grams
General Electric Company Schenectady, New York	8 1	1 5
General Electric Valley Forge Space Center Philadelphia, Pennsylvania	7	5
General Electric Space Technology Center King of Prussia, Pennsylvania	6 4 1 2 4 6 1 3 3	with sulfur specifications 1 5 10 15 25 30 35 150
Gulf Research and Development Pittsburgh, Pennsylvania	33	1
Horizons Research, Inc. Cleveland, Ohio	4 2	1 2
Howard University Washington, D.C.	6	2
Institute of Gas Technology Chicago, Illinois	3 2 1	100 35 1
Iowa State University Ames, Iowa	50	1
Kansas State University Manhattan, Kansas	2	100
Kentucky, University of Institute for Mining and Minerals Research Lexington, Kentucky	17	2
Kentucky, University of Department of Chemical Engineering Lexington, Kentucky	5	2 gram demineralized
Lebanon Valley College Annville, Pennsylvania	2	1
Marathon Oil Company Littleton, Colorado	1	1

Recipient	Sample	
	Number	Pounds
Marquette University Department of Chemistry Milwaukee, Wisconsin	108	1
Michigan Technological University Houghton, Michigan	4	1
Michigan, University Of Ann Arbor, Michigan	3 2	1 50
Mississippi, University of University, Mississippi	15	150 grams
Missouri, University of Columbia, Missouri	33	1
Missouri, University of Rolla, Missouri	15	1
Mobil Research and Development Corp. Princeton, New Jersey	5	1
Mobil Research and Development Corp. Dallas, Texas	12	1
Naval Research Laboratory Washington, D.C.	13	1
New Hampshire, University of Durham, New Hampshire	1	3
Northern Natural Gas Research Center Omaha, Nebraska	3	1
North Dakota State University Fargo, North Dakota	100	2
Oak Ridge National Laboratory Oak Ridge, Tennessee	4 2 2	3 1 5
Ohio University Athens, Ohio	36	1
Pennsylvania State University Department of Mining Engineering	24	2
Pennsylvania, University of Philadelphia, Pennsylvania	9	10
Phillips Petroleum Company Bartlesville, Oklahoma	6	100

Recipient	Sample Number	Pounds
Princeton University Princeton, New Jersey	5	1
Purdue University West Lafayette, Indiana	7	1
Robertson Research, Inc. Houston, Texas	10	1
Rockwell International Corporation Conoga Park, California	2	35
Sandia Laboratories Livermore, California	8	25
Shell Oil Company Houston, Texas	4 5	1 2
South Florida, University of Tampa, Florida	4 2	5 3
Southern California, University of Department of Chemical Engineering Los Angeles, California	3 3 15	5 2 100 grams
Southwest Research Institute San Antonio, Texas	22	1
Standard Oil (Indiana) Naperville, Indiana	12	1
Standard Oil Company (Ohio) Cleveland, Ohio	3	1
Stanford Research Institute Menlo Park, California	6	5
Superior Oil Company Houston, Texas	8	1
Tennessee, University of Knoxville, Tennessee	4	1
Texas A&M University College Station, Texas	1	1 (High organic sulfur)
Texas A&M University Department of Chemistry College Station, Texas	7	1

Recipient	Sample	
	Number	Pounds
Toledo, University of Toledo , Ohio	10	5
TRW Redondo Beach, California	14	5
Tufts University Medford, Massachusetts	8	1
United Technologies East Hartford, Connecticut	19	1
Utah, University of Salt Lake City, Utah	1 1	1 100
Versar, Inc. Springfield, Virginia	4	1
Virginia Polytechnic Institute Blacksburg, Virginia	1	1
Wayne State University Detroit Michigan	8	1
West Virginia University Department of Chemical Engineering Morgantown, West Virginia	16	1
West Virginia University Department of Geology Morgantown, West Virginia	25	2
Worcester Polytechnic Institute Worcester, Massachusetts	7 10	5 1

APPENDIX VI
Typical
Penn State Coal Data Base
Printout
for a
Single Coal Sample

THE PENNSYLVANIA STATE UNIVERSITY

COAL RESEARCH SECTION

C O A L D A T A B A S E

(SELECTED PRINTOUTS)

THESE DATA ARE NOT FOR PUBLICATION
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OF THE
PENNSYLVANIA STATE UNIVERSITY

** PENN STATE COAL DATA BASE **

** PSOC-2 **
** PAGE 1 **

* *
* SAMPLE HISTORY *
* *

PENN STATE NUMBER

PSOC-2

COLLECTED BY
COLLECTION DATE
COLLECTOR'S NUMBER

PENNSYLVANIA STATE UNIVERSITY
4/20/67
2

REPORTED RANK

HIGH VOLATILE A BITUMINOUS (HVAB)

SAMPLE TYPE
OTHER SAMPLE INFORMATION
SAMPLE RESERVE

CHANNEL LITHOTYPE
DURAIN

SEAM NAME
ALTERNATE SEAM NAME

UPPER ELKHORN #3

TOTAL SEAM THICKNESS
THICKNESS OF SEAM SAMPLED
PORTION RECOVERED IN CORE
DIAMETER OF CORE

4 FT. 1 IN.
0 FT. 8 IN.

* *
* SAMPLE LOCATION *
* *

COUNTRY
STATE
COUNTY
TOWNSHIP
NEAREST TOWN

U.S.A.
KENTUCKY
LETCHER
DEANE

COAL PROVINCE
COAL REGION
COAL FIELD

EASTERN
APPALACHIAN

MAP REFERENCE: LATITUDE 37D 14M 20S
LONGITUDE 82D 46M 20S
QUADRANGLE MAYKING (7.5')

** PENN STATE COAL DATA BASE **

** PSOC-2 **
** PAGE 2 **

SEAM NAME UPPER ELKHORN #3
APPARENT RANK HIGH VOLATILE A BITUMINOUS (HVAB)

COUNTRY U.S.A.
STATE KENTUCKY

* *
* GEOLOGIC INFORMATION *
* *

SYSTEM (AGE)
SERIES
GROUP
FORMATION

PENNSYLVANIAN

BREATHITT

OVERBURDEN LITHOLOGY
FLOOR LITHOLOGY

* *
* SEAM STRATA INFORMATION *
* *

THICKNESS LITHOTYPE

* *
* MINE INFORMATION *
* *

MINE NAME
MINING METHOD
MINE RESERVES
MINE PRODUCTION
MINE LIFE EXPECTANCY
OVERBURDEN THICKNESS

HENDRIX #22
UNDERGROUND

731 THOUSAND TONS/YEAR

** PENN STATE COAL DATA BASE **

 ** PS0C-2 **
 ** PAGE 3 **

SEAM NAME UPPER ELKHORN #3

COUNTRY U.S.A.

APPARENT RANK HIGH VOLATILE A BITUMINOUS (HVAB)

STATE KENTUCKY

* *

* CHEMICAL DATA 1 *

* *

PROXIMATE ANALYSIS	AS REC'D	DRY	DAF	DMMF (PARR)	DMMF (PARR-G)	DMMF (DJR MM)
--------------------	----------	-----	-----	----------------	------------------	------------------

% MOISTURE	2.08					
% ASH	3.82	3.90				
% VOLATILE MATTER	35.40	36.15	37.62	37.29	37.31	
% FIXED CARBON	58.70	59.95	62.38	62.71	62.69	

CALORIFIC VALUE	DRY	AS REC'D MOIST.	EQUIL. MOIST.
(GROSS BTU/LB)			

MM-FREE, DIRECT		
MM-CONTAINING	14554	14251
MM-FREE (PARR)	15215	14884
MM-FREE (MOD.P)	15232	14868
BEST MM FREE		14868
NET CV, DMMF BTU/LB	14712	
ASH-FREE	15145	

MOTT-SPOONER DIFFERENCE =

ASSOCIATED ANALYSES	DRY	MMF
---------------------	-----	-----

% EQUILIBRIUM MOISTURE		
% TOTAL SULFUR	0.61	

* *

* RANK CALCULATIONS *

* *

APPARENT RANK (AS REC'D MOIST)	HIGH VOLATILE A BITUMINOUS (HVAB)
ASIM RANK (EQUIL. MOIST.)	
REFLECTANCE RANK CATEGORY	HIGH VOLATILE A BITUMINOUS (HVAB)
INTERNATIONAL RANK	
AS REC'D MOIST.	
EQUIL. MOIST.	
REPORTED RANK	HIGH VOLATILE A BITUMINOUS (HVAB)

** PENN STATE COAL DATA BASE **

 ** PSOC-2 **
 ** PAGE 4 **

SEAM NAME UPPER ELKHORN #3

COUNTRY U.S.A.

APPARENT RANK HIGH VOLATILE A BITUMINOUS (HVAB)

STATE KENTUCKY

 *
 * CHEMICAL DATA 2 *
 *

ULTIMATE ANALYSIS	AS REC'D	DRY	DAF	DMMF (PARR)
				(4.55 %MM)
% ASH	3.82	3.90		
% CARBON	80.02	81.72	85.04	85.61
% HYDROGEN	5.25*	5.36	5.58	5.62
% NITROGEN	1.36	1.39	1.45	1.46
% SULFUR	0.60	0.61	0.63	
% CHLORINE	0.08	0.08	0.09	0.09
% OXYGEN (DIFF)	6.79*	6.93	7.22	7.23

SULFUR FORMS	% PYRITIC	% SULFATIC	% ORGANIC	% TOTAL
DRY	0.02	0.00	0.59	0.61
DAF	0.02	0.00	0.61	0.63
OPTICAL				

ELEMENTAL ANALYSIS	DRY	DMMF (MOD. P)	DMMF (DIR.)
		(4.46%MM)	(%MM)
% CARBON	81.68	85.49	
% HYDROGEN	5.31	5.56	
% NITROGEN	1.39	1.46	
% ORGANIC SULFUR	0.59	0.62	
% OXYGEN (DIFF)	6.57	6.79	
% CHLORINE	0.08	0.09	
% MINERAL MATTER	4.49		
(INCLUDES 0.04 % FES2)			

ATOM RATIOS (DMMF)	PARR	MOD. PAR	DIRECT
ATOMJC H/C	0.788	0.781	
ATOMJC O/C	0.063	0.062	

MSC. CHEMICAL DATA	DRY	OF DMMF COAL	OF DMMF OXYGEN
% O AS COOH			
% O AS OH			
% S AS SO4, IN ASH	0.03		
% CARBONATE AS CO2	0.14		
% CHLORINE	0.17		

INFRA-RED ANALYSIS

(*)-EXCLUDES MOISTURE

* PENN STATE COAL DATA BASE *

 ** PSOC-2 **
 ** PAGE 5 **

SEAM NAME UPPER ELKHORN #3
 APPARENT RANK HIGH VOLATILE A BITUMINOUS (HVAB)

COUNTRY U.S.A.
 STATE KENTUCKY

 *
 * CHEMICAL DATA 3 *
 *

% MOISTURE IN COAL = 1.90 AT 750 DEGREES C
 % HIGH TEMPERATURE ASH = 5.20

TRACE ELEMENT ANALYSIS	PPM HTA	PPM TOTAL COAL	MAJOR ELEMENT ANALYSIS	OXIDE % OF HTA DRY COAL	ELEMENT % OF TOTAL
AG	< 1	0	SiO2	64.40	1.57
B			AL2O3	24.30	0.67
BA	1000	52	TiO2	4.19	0.13
BE	13	1	Fe2O3	3.12	0.11
BJ	< 20	1	MGO	0.37	0.01
CE	160	8	CaO	1.64	0.06
CO	< 20	1	Na2O	0.58	0.02
CR	270	14	K2O	0.04	0.00
CU	350	18	P2O5	0.11	0.00
GA	22	1	SO3	1.60	0.03
GE	< 25	1			
LA	190	10			
LJ					
MN	93	5			
MO			VOLATILES	PPM TOTAL COAL	
NJ	58	3			
NE	< 20	1	AS		
PB	140	7	BR		
RB	10	1	CD		
SC	44	2	CL		
SN	1400	73	F		
SR	1750	91	HG		
TH			SB		
U	18	1	SE		
V	210	11			
Y	160	8			
YU	17	1			
ZN	32	2			
ZR	680	35			

** PENN STATE COAL DATA BASE **

 ** PSOC-2 **
 ** PAGE 6 **

SEAM NAME UPPER ELKHORN #3 COUNTRY U.S.A.
 APPARENT RANK HIGH VOLATILE A BITUMINOUS (HVAB) STATE KENTUCKY

 *
 * MINERALOGICAL DATA *
 *

TOTAL MINERAL MATTER

% MM-PARR	4.55
% MM-MODIFIED PARR	4.46
% MM-KMC	4.49
% MM-DIRECT	
% MM-BEST AVAILABLE	4.49
VOL % MM-PARR	2.25

MINERAL COMPOSITION

% LOW TEMPERATURE ASH (MCL) =

% LOW TEMPERATURE ASH (O'GORMAN) = 4.51
 (ALL DATA DETERMINED ON 65X100
 MESH SIZE FRACTION)

<u>% OF LTA</u>		<u>% OF LTA</u>
QUARTZ	KAOLINITE	40 - 50
PYRITE	ILLITE	< 1
CALCITE	MUSCOVITE	NOT DETECTED
GYPSUM	CHLORITE	NOT DETECTED
KAOLINITE	MONTMORILLONITE	NOT DETECTED
MONT + ILL + MLC	MIXED CLAYS	1 - 10
MONT + ILL	CALCITE	NOT DETECTED
MONT + MLC	ARAGONITE	NOT DETECTED
ILLITE + MLC	DOLOMITE	NOT DETECTED
MONTMORILLONITE	ANKERITE	NOT DETECTED
ILLITE	SIDERITE	NOT DETECTED
MIXED LAYER CLAYS	QUARTZ	30 - 40
FELDSPAR	GYPSUM	1 - 10
MINOR FE SULFATES	PYRITE	1 - 10
	JAROSITE	NOT DETECTED
	HEMATITE	NOT DETECTED
	ROUTLE	1 - 10
	THENARDITE	NOT DETECTED
	PLAGIOCLASE	NOT DETECTED

** PENN STATE COAL DATA BASE **

 ** PSOC-2 **
 ** PAGE 7 **

SEAM NAME UPPER ELKHORN #3
 APPARENT RANK HIGH VOLATILE A BITUMINOUS (HVAB)

COUNTRY U.S.A.
 STATE KENTUCKY

 *
 * PETROGRAPHIC DATA *
 *

MACERAL COMPOSITION

	DRY VOLUME %	DMF VOLUME %	DRY WEIGHT %
VITRINITE (CALC.)	31.4	32.1	30.4
INERTINITE	31.0	31.7	32.9
LIPITINITE	35.4	36.2	32.2
MINERAL MATTER	2.2		4.5
VITRINOIDS			
VITRINITE	28.9	29.6	28.0
PSEUDOVITRINITE	2.4	2.5	2.4
FUSINITE	6.8	7.0	7.7
SEMI-FUSINITE	8.1	8.3	8.5
MACRINITE	7.5	7.7	7.9
MICRINITE	8.5	8.7	8.9
SCLEROTINITE	0.0	0.0	0.0
SPORINITE	32.8	33.6	29.9
CUTINITE	1.4	1.4	1.2
EXINITE (ANAL)			
RESINITE	1.2	1.2	1.1
EXUDATINITE	0.0	0.0	0.0
FLUORINITE	0.0	0.0	0.0
BITUMINITE	0.0	0.0	0.0
ALGINITE	0.0	0.0	0.0
LIPITODETRINITE	0.0	0.0	0.0
MINERAL MATTER (ANAL)			
INERTINITE			
LIPITINITE			

REFLECTANCE DATA (% IN OIL)	HIGH	LOW	RANGE	MEAN MAX	STAND. DEV.
VITRINITE	0.00	0.80		0.89	
PSEUDOVITRINITE	1.13	0.92	0.21	0.97	
VITRINOIDS			0.00		

** PENN STATE COAL DATA BASE **

 ** PSOC-2 **
 ** PAGE 8 **

SEAM NAME UPPER ELKHORN #3
 APPARENT RANK HIGH VOLATILE A BITUMINOUS (HVAB)

COUNTRY U.S.A.
 STATE KENTUCKY

 *
 * PETROGRAPHIC DATA *
 * CONTINUED *
 *

% VITRINOID REFLECTANCE	HALF-TYPE	VOLUME PERCENT	% VITRINOID REFLECTANCE	V-TYPE	VOLUME PERCENT
0.80-0.84	VHT 0.825	24.35			
0.85-0.89	VHT 0.875	24.35	0.80-0.89	V8	48.70
0.90-0.94	VHT 0.925	25.40			
0.95-0.99	VHT 0.975	25.40	0.90-0.99	V9	50.80
1.10-1.14	VHT 1.125	0.25			
1.15-1.19	VHT 1.175	0.25	1.10-1.19	V11	0.50

** PENN STATE COAL DATA BASE **

** PSOC-2 **
** PAGE 9 **

SEAM NAME UPPER ELKHORN #3
APPARENT RANK HJGH VOLATILE A BITUMINOUS (HVAB)

COUNTRY U.S.A.
STATE KENTUCKY

* *
* PHYSICAL PROPERTIES *
* *

HARDGROVE GRINDABILITY	42.1
VICKER'S MICROHARDNESS	38.2
FREE SWELLING INDEX	4.5
GRAY KING COAL TYPE	

SURFACE AREA
(DETERMINED WITH NITROGEN)
SURFACE AREA
(DETERMINED WITH CARBON)
DIOXIDE

DENSITY
(DETERMINED WITH HELIUM)
DENSITY
(DETERMINED WITH MERCURY)
DENSITY (DETERMINED WITH WATER)

SPECIFIC GRAVITY

MICROPORE VOLUME
MACROPORE VOLUME
TOTAL PORE VOLUME
PORE SIZE DISTRIBUTION

GIESELER PLASTICITY DATA

MAXIMUM FLUIDITY	235
MAXIMUM FLUIDITY TEMPERATURE	435
INITIAL SOFTENING TEMPERATURE	412
SOLIDIFICATION TEMPERATURE	459
FLUID TEMPERATURE RANGE	47
PLASTOMETER TYPE	BETHLEHEM

ASH FUSION ANALYSIS (DEGREES F)	REDUCING	OXIDIZING
---------------------------------	----------	-----------

INITIAL DEFORMATION TEMPERATURE
SOFTENING TEMPERATURE
HEMISPHERE TEMPERATURE
FLUID TEMPERATURE

** PENN STATE COAL DATA BASE **

 ** PSOC-2 **
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SEAM NAME UPPER ELKHORN #3
 APPARENT RANK HIGH VOLATILE A BITUMINOUS (HVAB)

COUNTRY U.S.A.
 STATE KENTUCKY

 * *
 * ANALYSIS LOG *
 * *

ANALYSIS	DATA	PERFORMED BY
A.R. MOIST	5/30/67	COMMERCIAL TESTING & ENGINEERING
EQUIL. MOIST.		
PROXIMATE	5/30/67	COMMERCIAL TESTING & ENGINEERING
ULTIMATE	5/30/67	COMMERCIAL TESTING & ENGINEERING
SULFUR FORMS	5/30/67	COMMERCIAL TESTING & ENGINEERING
FSJ	12/17/67	COAL PETROGRAPHY LABORATORIES - PSU
PLASTOMETER		
DIRECT MM		
GRAY-KJNG		

 * *
 * PERFORMANCE DATA *
 * *

PREPARATION DATA	YIELD	ASH	SULFUR	VOLATILE (HUMIDITY)	LIPTINITE	INERTINITE
------------------	-------	-----	--------	---------------------	-----------	------------

1.35 FLOAT
 1.35 X 1.45
 1.45 X 1.55
 1.55 X 1.65
 1.65 X SINK

GASIFICATION DATA (MAX REACTIVITY OF 1000 DEGREES C, 40 X 100 MESH COAL CHARS)
 TEMPERATURE (DEGREES C) PRESSURE (ATM) REACTIVITY

AJR
 2
 H

CARBONIZATION DATA

TOTAL REACTIVE MACERAL MATERIAL (USS)
 TOTAL REACTIVE MACERAL MATERIAL (BETH)
 TOTAL INERT MATERIAL
 EFFECTIVE INERT MATERIAL
 BALANCE INDEX
 STRENGTH INDEX
 PREDICTED STABILITY
 PREDICTED MJCUM 40
 MEASURED STABILITY
 MEASURED MJCUM 40

APPENDIX VII
Data Printouts Supplied
to
Other Agencies

SERVICE TO THE COAL COMMUNITY

PENN STATE COAL DATA BASE

<u>Recipient</u>	<u>Number of Printouts or Listing Supplied</u>
Aerojet Liquid Rocket Company Sacramento, California	1
Aerospace Corporation Los Angeles, California	16
Adelphi University Garden City, L.I., New York	7
Air Products and Chemicals Allentown, Pennsylvania	17
Amoco Production Company Denver, Colorado	53
Anker Mining Pittsburgh, Pennsylvania	1
ARCO Coal Company Denver, Colorado	6
Argonne National Laboratory Argonne, Illinois	12
Ashland Oil, Inc. Ashland, Kentucky	26
Atlantic Research Corporation Alexandria, Virginia	3
Atlantic Richfield Company Harvey, Illinois	176 Listing decreasing total sulfur Listing increasing organic sulfur Listing - washability studies
Atlantic Richfield Company Los Angeles, California	12
Auburn University Auburn, Alabama	16
Azcon Corporation New York, New York	200
Bethlehem Steel Corporation Bethlehem, Pennsylvania	17

<u>Recipient</u>	<u>Number of Printouts or Listing Supplied</u>
Boston College Chestnut Hill, Massachusetts	1
Brookhaven National Laboratory Upton, New York	7
Calgon Corporation Pittsburgh, Pennsylvania	12
California Institute of Technology Jet Propulsion Laboratory Pasadena, California	47 Listing - all coals in order of decreasing sulfur content
California Institute of Technology Chemical Engineering Pasadena, California	8 Listing - by Province and Rank
California State University Los Angeles, California	17
California, University of Berkeley, California	15
California, University of Los Alamos, New Mexico	17 Listing - all coals in descending order of organic sulfur
Case Western Reserve Cleveland, Ohio	45
Chevron Oil Field Research Co. La Habra, California	6
Cities Service Research and Development Cranbury, New Jersey	9
Cities Service Company Tulsa, Oklahoma	Listing - all coals - elemental analyses, maceral analyses, vitrinite reflectance, volatile matter content
City College Department of Chemical Engineering New York, New York	5
Cleveland State University Cleveland, Ohio	3
COGAS Development Company Princeton, New Jersey	19

<u>Recipient</u>	<u>Number of Printouts or Listing Supplied</u>
Colorado Plateau Geological Services, Inc. Farmington, New Mexico	11
Colorado Geological Survey Denver, Colorado	38
Colorado School of Mines Golden, Colorado	60
Columbia Gas Company Columbus, Ohio	46
Columbia University Chemical Engineering New York, New York	6
Combustion Engineering, Inc. Windsor, Connecticut	4
Commonwealth of Pennsylvania Science Advisor to the Governor	102
Consultant Murrysville, Pennsylvania	5
Consulting Geologist Farmington, New Mexico	13
Consultant St. George, Utah	8
Continental Oil Company Morgantown, West Virginia	Listing- Proximate analyses of all
CSIRO Clayton, Victoria, Australia	48
Department of Energy Pittsburgh, Pennsylvania	34 Listing - coals in order of decreasing sulfur content; decreasing rank
Dravo Corporation Pittsburgh, Pennsylvania	3
Eastern Illinois University Charleston, Illinois	2
Electric Power Research Institute Palo Alto, California	Listing - coals in decreasing order of pyritic sulfur content; decreasing order of organic sulfur content and single page printout for each sample in the above lists

<u>Recipient</u>	<u>Number of Printouts or Listing Supplied</u>
Energy and Minerals Research Company Exton, Pennsylvania	3
Energy Research Laboratory Ottawa, Ontario	3
ERDA-FE Washington, D.C.	4 (Pa. coals) 14 (HVA Bituminous) Listing - Mary Lee Seam and lignites of Choctaw County, Alabama Listing - all coals - decreasing carbon content, oxygen, F.S.I. and Gray King. List of ash contents.
Farleigh Dickinson University Teaneck, New Jersey	4
Florida Atlantic University Boca Raton, Florida	40
Frontier Technical Associates, Inc. Buffalo, New York	6
General Electric Company Schenectady, New York	9
General Electric Valley Forge Space Center Philadelphia, Pennsylvania	7
General Electric Space Technology Center King of Prussia, Pennsylvania	13
Gilbert Associates Rading, Pennsylvania	5
Green Well Development Company, Ltd. Hong Kong	1
Gulf Research and Development Pittsburgh, Pennsylvania	37
Horizons Research, Inc. Cleveland, Ohio	6
Howard University Washington, D.C.	6
Inland Steel Company East Chicago, Indiana	547 (Selected printouts listing vitrinite, inert, ash and sulfur contents.)

<u>Recipient</u>	<u>Number of Printouts or Listing Supplied</u>
Institute of Gas Technology Chicago, Illinois	203
Iowa State University Ames, Iowa	50
Kansas State University Manhattan, Kansas	2
Kentucky Center for Energy Research Lexington, Kentucky	23
Kentucky, University of Institute for Mining and Minerals Research Lexington, Kentucky	67
	Listing by Rank and Province
Kentucky, University of Department of Chemical Engineering Lexington, Kentucky	5
Kutztown State College Kutztown, Pennsylvania	2
Lawrence Livermore Laboratories Livermore, California	11
Lebanon Valley College Annville, Pennsylvania	2
Marathon Oil Company Littleton, Colorado	1
Marquette University Department of Chemistry Milwaukee, Wisconsin	108
Massachusetts Institute of Technology Cambridge, Massachusetts	119
	Magnetic tape of above
Michigan Technological University Houghton, Michigan	4
	Listing by rank
Michigan, University of Ann Arbor, Michigan	3
Midwest Research Institute Kansas City, Missouri	32

<u>Recipient</u>	<u>Number of Printouts or Listing Supplied</u>
Mississippi, University of Department of Chemistry University, Mississippi	15
Missouri, University of Columbia, Missouri	36
	Listing by Rank
Missouri, University of Rolla, Missouri	15
Mobil Research and Development Corporation Paulsboro, New Jersey	17
Mobil Research and Development Corporation Dallas, Texas	100
Naval Research Laboratory Washington, D.C.	13
	Listing by Rank
New Hampshire, University of Durham, New Hampshire	1
North Carolina State University Raleigh, North Carolina	2
Northern Natural Gas Research Center Omaha, Nebraska	3
North Dakota State University Fargo, North Dakota	100
Oak Ridge National Laboratory Oak Ridge, Tennessee	11
Ohio University Athens, Ohio	36
Pennsylvania Department of Transportation Harrisburg, Pennsylvania	4
Pennsylvania, University of Department of Chemical and Biochemical Engineering Philadelphia, Pennsylvania	7
Phillips Petroleum Company Bartlesville, Oklahoma	6
Princeton University Princeton, New Jersey	15

<u>Recipient</u>	<u>Number of Printouts or Listing Supplied</u>
Purdue University West Fayette, Indiana	14
Radian Corporation Austin, Texas	56
Research Cattrell Bound Brook, New Jersey	199
Reaearch Triangle Institute Research Triangle Park, North Carolina	35
Robertson Research (U.S.) Inc. Houston, Texas	10
Rockwell International Corporation Conoga Park, California	2
Sandia Laboratories Albuquerque, New Mexico	8 Listing by State and seam with chlorine contents
Sandia Laboratory Livermore, California	150
Shell Oil Company Houston, Texas	15
Southern California, University of Department of Chemical Engineering Los Angeles, California	18
Southern Illinois University Carbondale, Illinois	217
South Florida, University of Tampa, Florida	4
South Dakota School of Mines and Technology Rapid City, South Dakota	6
Southwest Research Institute San Antonio, Texas	22 Listing by rank
Standard Oil of Indiana Naperville, Illinois	24
Standard Oil of Ohio Cleveland, Ohio	13
Stanford Research Institute Menlo Park, California	3

<u>Recipient</u>	<u>Number of Printouts or Listing Supplied</u>
STELCO Hamilton, Ontario	7
Superior Oil Company Houston, Texas	8
Systems Consultants Washington, D.C.	157
Tennessee, University of Chattanooga, Tennessee	2
Tennessee, University of Knoxville, Tennessee	5
Texas A&M University Department of Petroleum Engineering College Station, Texas	23 All printouts from Southwest
Texas A&M University Center for Energy and Mineral Resources College Station, Texas	1
Texas A&M University Department of Chemistry College Station, Texas	5
Texas A&M University Department of Chemical Engineering College Station, Texas	4
Texas Eastern Corporation Houston, Texas	57
Texas, University of Bureau of Exonomic Geology Austin, Texas	13
Toledo, University of Toledo, Ohio	10
TRW Redondo Beach, California	17 Listing by volatile matter
Tufts University Medford, Massachusetts	8
Union Carbide Tonawanda, New York	26

<u>Recipient</u>	<u>Number of Printouts or Listing Supplied</u>
United Technologies East Hartford, Connecticut	19
U.S. Bureau of Mines Pittsburgh, Pennsylvania	18
USGS Reston, Virginia	Magnetic tape of data on 180 coals
USGS Salt Lake City, Utah	2
Utah, University of Salt Lake City, Utah	2
Versar, Inc. Springfield, Virginia	4
Virginia Polytechnic Institute Blacksburg, Virginia	1
Wayne State University Detroit, Michigan	2
West Virginia University Department of Chemical Engineering Morgantown, West Virginia	33
West Virginia University Department of Geology Morgantown, West Virginia	25
West Virginia University College of Mineral and Energy Resources Morgantown, West Virginia	8
Worcester Polytechnic Institute Department of Chemical Engineering Worcester, Massachusetts	22
Wyoming, University of Laramie, Wyoming	70