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Nuclear Assay of Coal
Volume 8: Continuous Nuclear Assay of Coal (CONAC)

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Research Project 983-1

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ABSTRACT

Using californium-252 as a source of exciting neutrons, prompt gamma photons emitted by elemental nuclei in the coal have been measured using several detectors, including sodium-iodide and germanium-lithium. Several coal types, including bituminous, subbituminous lignite and anthracite were crushed to various top sizes and analyzed carefully by traditional ASTM wet chemistry techniques at two or three different laboratories. The elements (sulfur, hydrogen, carbon, aluminum, silicon, iron, calcium, sodium, nitrogen, and chlorine) were determined by prompt neutron activations and the quantities compared with those of the wet chemical analyses. Since satisfactory correlation has been obtained at bench-scale level using 100-200 kG samples, an apparatus has been designed to analyse a coal stream of up to 50 ton/hour, at an electric power generating station.

EPRI PERSPECTIVE

PROJECT DESCRIPTION

This volume is one of several reports describing the development of a continuous on-line nuclear analyzer of coal (CONAC). The CONAC project (RP983) has four phases, and this report describes portions of the results of investigations conducted during Phases 1 and 2. The schedule of activity for all four phases is shown under Appendixes 1 and 2.

Project researchers examine stationary and moving samples of coal by means of a small source of neutrons that excite gamma emissions from the coal nuclei. The gamma emissions are captured by solid-state detectors, and the resulting spectrum is analyzed by a minicomputer. The elemental composition by weight is displayed, along with derived quantities such as Btu per pound. The most favorable of several possible mechanical configurations of neutron source, detector, and coal is determined.

The project requires the coordinated efforts of teams with expertise not only in gamma spectroscopy but also in coal and coal handling. Hence, project results represent the combined efforts of the two contractors, Science Applications, Inc. and Kennedy Van Saun Corp. (a subsidiary of McNally-Pittsburg Mfg. Corp.).

PROJECT OBJECTIVES

The project objective is the phased development of a continuous nuclear analyzer of coal, which with appropriate coal-handling systems will enable a utility to do the following:

- Control coal quality at the mine
- Provide surveillance for coal at delivery sites
- Provide process control at coal preparation and conversion plants

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- Provide for total heat management at utility power stations
- Predict and avoid slagging or fouling episodes in utility boilers
- Comply more effectively with sulphur dioxide and particulate regulations
- Provide the means to schedule and optimize power system load flows

Hence CONAC readouts will be available in several forms:

- Percentage of sulfur by weight
- Percentage of moisture by weight
- Btu per pound of coal
- Percentage by weight of ash and principal elements

PROJECT RESULTS

The results presented in this report and its companions may be summarized as follows: (All reports for EPRI RP983 are listed in the next section, entitled "Companion Volumes.")

- Using californium-252 as a source of existing neutrons, prompt gamma photons emitted by elemental nuclei in the coal have been measured using several detectors, including sodium-iodide and germanium-lithium. Several coal types, including bituminous, subbituminous, lignite, and anthracite, were crushed to various top sizes and analyzed carefully by traditional ASTM wet chemistry techniques at two or three laboratories. The elements sulfur, hydrogen, carbon, aluminum, silicon, iron, calcium, sodium, nitrogen, and chlorine were determined by prompt neutron activations, and the quantities were compared with those estimated by means of wet chemistry analyses.
- For a coal sample thickness of $\simeq$ 30 cm, the measured gamma signal is almost independent of density variations within the sample and of the bulk density itself. The favored mechanical configuration is to have the coal on a belt and the source and detector situated below the belt and above the coal, respectively.
- Hydrogen is easily and most accurately determined by measuring the leakage of epithermal neutrons from a slab of coal approximately 30 cm thick. For coal that is 6% hydrogen by weight and has an average bulk density of 0.7 g/cm^{s}, the average relative error is less than 1.5%. This accuracy is largely independent of coal type, composition, and bulk density. However, hydrogen bonded in water or in an organic molecule cannot be distinguished by nuclear techniques. The water content must be determined separately.

- Of three electromagnetic techniques--microwave attenuation, capacitance, and nuclear magnetic resonance--surveyed and available for determining moisture in a granular solid, the first two are considered to be applicable to coal and are promising for an experimental program.

- As part of a total CONAC system, it is necessary to determine the time rate of mass flow of coal. Existing technologies have been surveyed and compared. Conventional weighing transducers of the mechanical, electromechanical, and gamma-ray attenuation types, with tachogenerators for speed, are adequate.

- A number of possible techniques for presenting a proper sample of coal to the nuclear source and detector have been evaluated, including flow and nonflow methods. A modified flat belt feeder system is recommended. The success of such a coal presentation technique implies proper entry to the feed hopper, proper shape of the withdrawal opening from the feed hopper, and a slow belt speed to minimize demixing.

- An apparatus (CONAC) designed to interrogate a coal flow of up to 50 ton/hour incorporating a moisture meter as well as the prompt neutron activation technology has been designed for demonstration at an electric power generating station in 1980.

- A simpler version of the 50 ton/hour apparatus (Rapid Sulfur Meter) is already under commercial construction for installation at the Monroe Power Plant at Detroit Edison for coal blending control.

- Another version of the device for rapid (60 sec) sulfur analysis of coal in trucks entering Kingston Power Plant is under development between TVA and Science Applications Inc./Kennedy Van Saun Corp.

Owen J. Tassicker, Project Manager
Fossil Fuel and Advanced Systems Division

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COMPANION VOLUMES

All reports in print or being planned to describe the work in progress under the related projects RP983 and RP1048-7 are described below:

Volume 1 — Coal Composition by Prompt Neutron Activation Analysis--Basic Experiments (available December 1978)

Volume 2 — Coal Composition by Prompt Neutron Activation Analysis--Theoretical Modeling (available January 1979)

Volume 3 — Determination of Total Hydrogen Content of Coal by Nuclear Techniques (available December 1978)

Volume 4 — Moisture Determination in Coal: Survey of Electromagnetic Techniques (available December 1978)

Volume 5 — Coal BTU Measurement Study: Monitoring of Moisture in Coal (available September 1979)

Volume 6 — Mass Flow Devices for Coal Handling (available December 1978)

Volume 7 — Coal Rheology and Its Impact on Nuclear Assay (available December 1978)

Volume 8 — Continuous Nuclear Assay of Coal: Progress Review and Industry Applications (anticipated March 1979)

Volume 9 — Prototype Design of Continuous Coal Assay System--Laboratory Performance (anticipated December 1979)

Volume 10 — Operation of a Continuous Coal Assay System--Laboratory Performance (anticipated December 1979)

Volume 11 — Operation of a Continuous Coal Assay System--Field Performance (anticipated June 1980)

1.0 BACKGROUND

O. J. Tassicker
Electric Power Research Institute

The electric utility industry has long recognized the need for a rapid continuous analyzer of coal composition and quality. EPRI initiated an investigation more than three years ago, following requests by utilities to see if better and more rapid analyses of coal quality could be obtained by using today's advanced instrumentation techniques. Applications include continuous coal measurements for monitoring mining, power plants, coal preparation, Btu input, and specific boiler operation for slagging control by adjusting the amount of excess air required.

At this progress review meeting interested utility representatives were invited to meet with the principal EPRI investigators, discuss utility requirements, and indicate how the application of CONAC could help utility performance and economics. The following report summarizes the results of the meeting.

The initial EPRI program was designed to carry the program from its inception in 1976 (Figure 1.1) through the first two phases in 1978 (Figure 1.2). During this period the principal parameters which were to be analyzed were identified.

Of the techniques considered, the real-time potential and the nondestructive assay (NDA) of coal using nuclear techniques were particularly attractive (Figure 1.3) and appeared to overshadow the disadvantages.

Specific areas of investigation for nondestructive assay of coal were identified:

- Sulfur determination
- Moisture determination
- Ash analysis
- Elemental ash analysis
- Btu content

EPRI invited five qualified organizations to present their approach to developing instrumentation for nuclear assay of coal. Following review of proposal submissions, the team of Science Applications, Inc., McNally-Pittsburgh and its subsidiary, Kennedy Van Saun Corporation, was selected on the basis of their prominent national stature and their willingness to share in the costs of development.

PROVISIONAL DEVELOPMENT PROGRAM FOR NUCLEAR ASSAY OF COAL

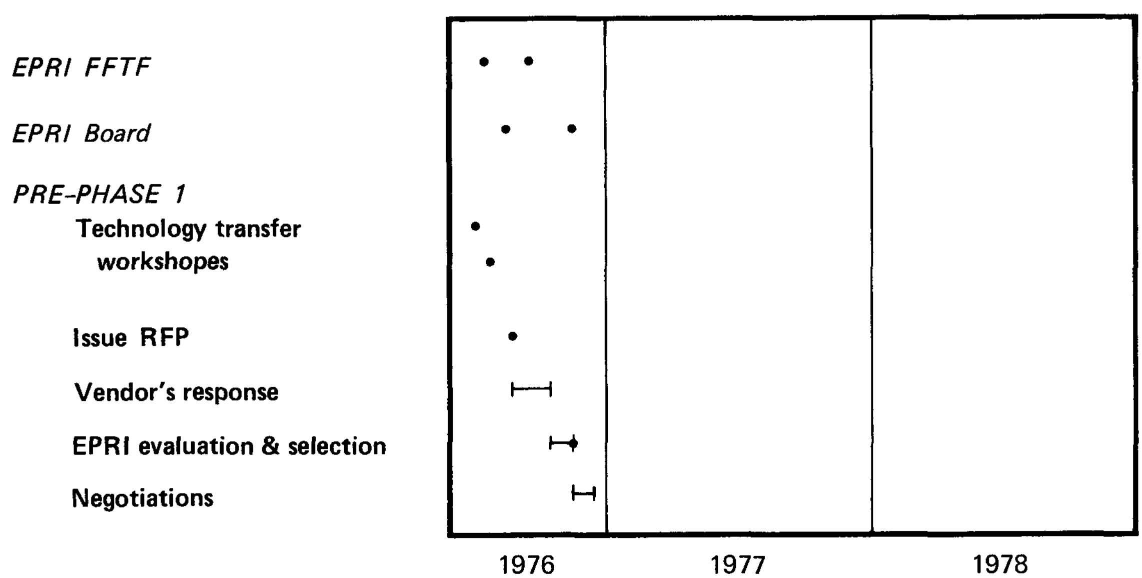


Figure 1-1.

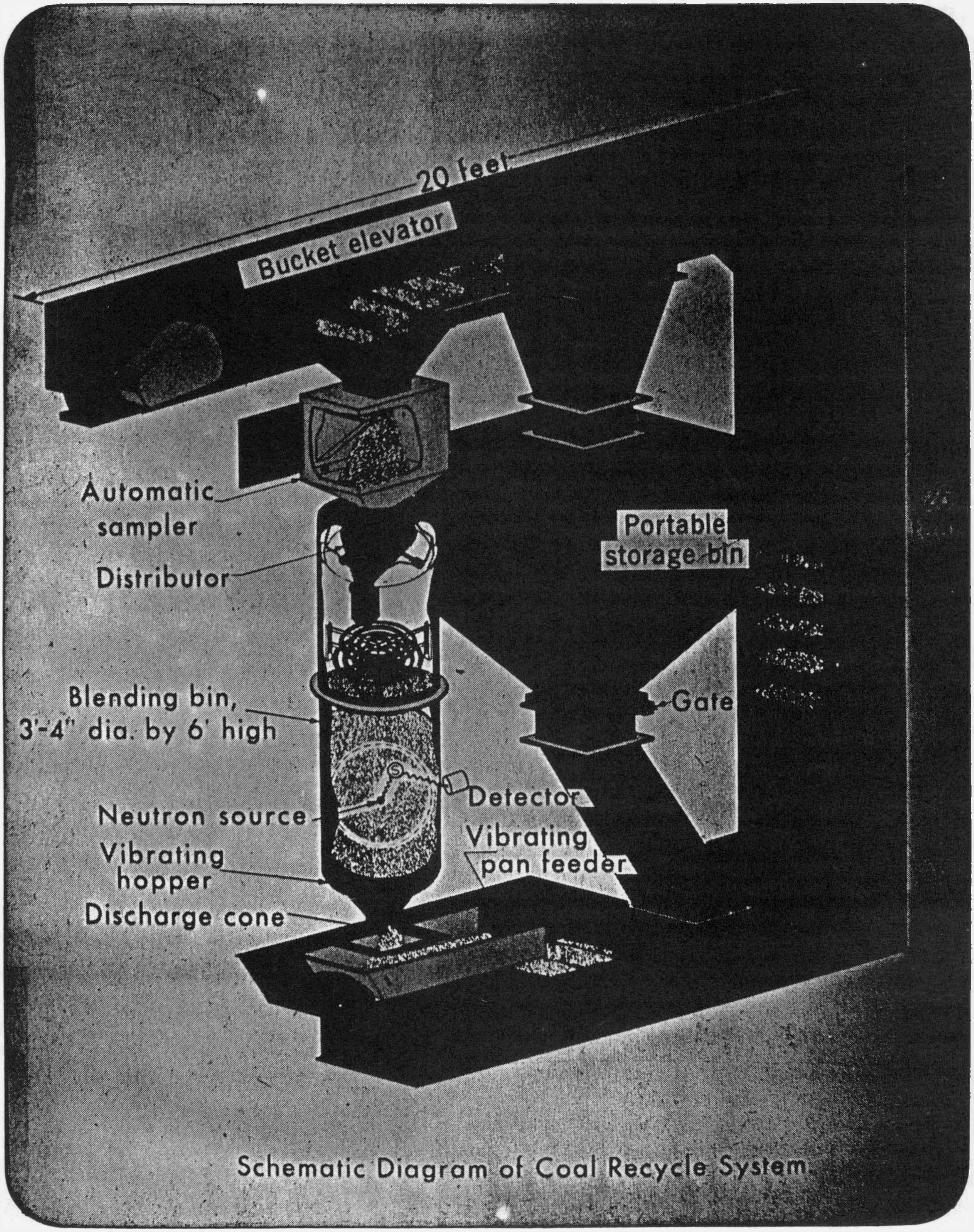


Figure 1-2. DOE Morgantown, West Virginia, Approach Vertical Bed Scan

NONDESTRUCTIVE ASSAY (NDA) OF COAL BY NUCLEAR TECHNIQUES

ADVANTAGES

- Non destructive
- Practically nonobtrusive
- Apply to large samples thus reducing sampling errors
- Very amenable for on-line real time application
- Rapid — results are obtained virtually instantaneously
- Can now be made to withstand harsh industrial environment

Figure 1-3.

As an initial task, the pioneering work of a Government R&D program was reviewed, particularly that of the Morgantown, West Virginia, Energy Center approach which used a neutron source located in a vertically moving coal bed. The movement of coal particles relative to each other, however, presented potential difficulties for maintaining uniform density (Figure 1.4). To overcome this situation a static coal deposit on a moving belt was felt to be more desirable, and this latter approach has been followed by the EPRI investigators.

Phases I and II of the CONAC program through 1978 have now been completed. The program for Phase III has been started (Figure 1.5). Phase IV, the construction of a prototype with utility participation, is in the planned state. Examples of where CONAC may be located in a utility system are illustrated in Figure 1.6.

During Phase IV, EPRI will require a utility site location and a utility partner for the practical application of CONAC. A utility partner that has a strong motivation and an immediate application for CONAC analyses is desired.

As EPRI does not have the financial resources to support all prototype developments coming from research investigations, it will need cooperative utility involvement. Utilities will be contacted to determine their interest in participating in a prototype application.

PROPOSED SCHEDULE FOR THE CONAC PROGRAM

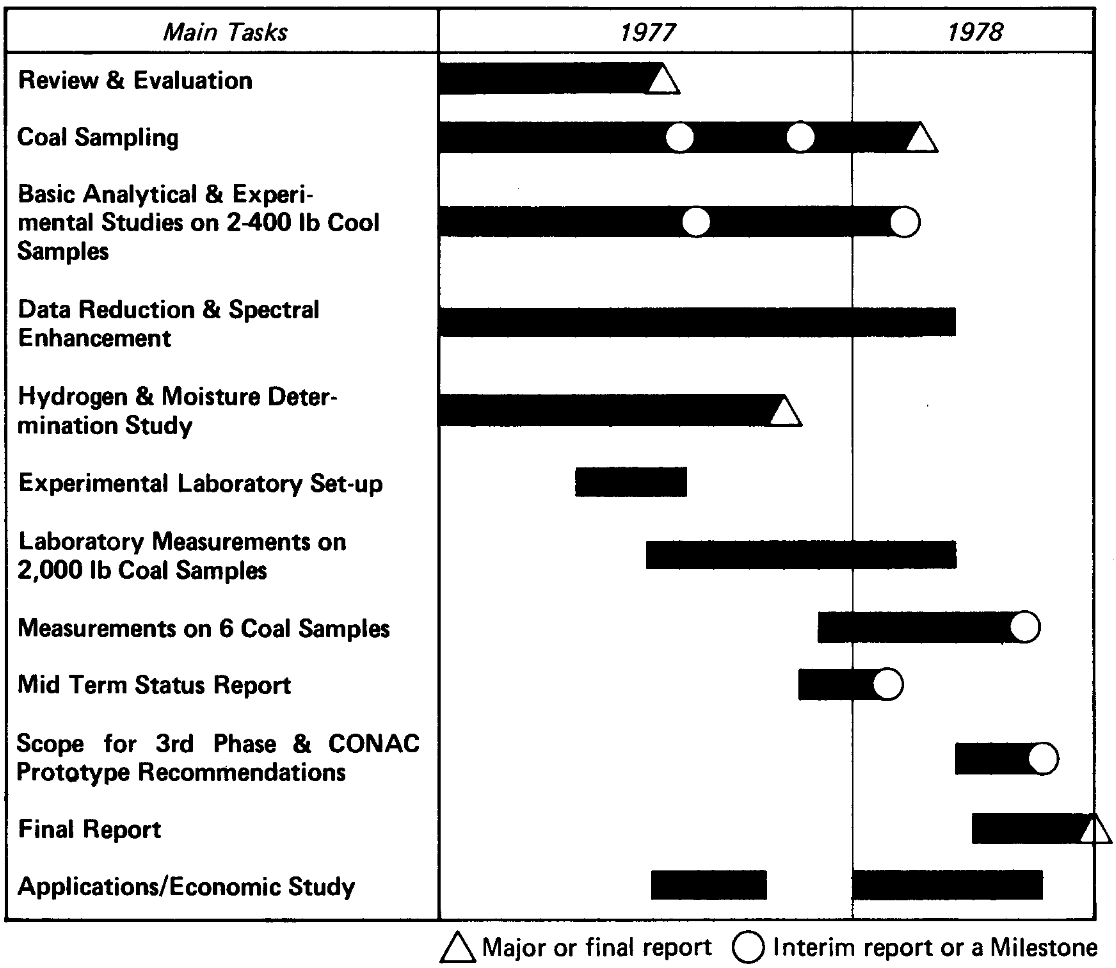


Figure 1-4.

PROPOSED SCHEDULE FOR THE CONAC PROGRAM

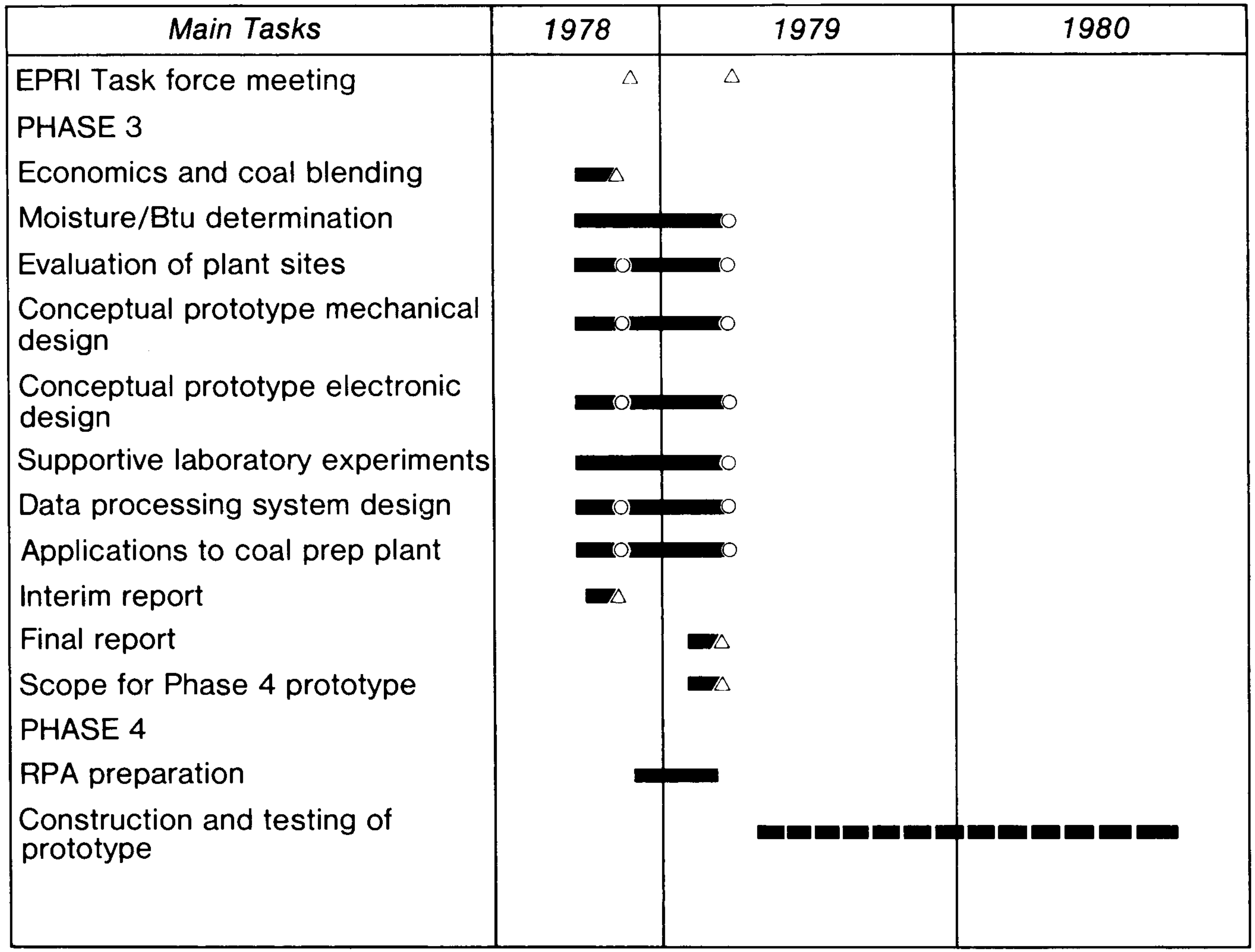


Figure 1-5.

SCHEMATIC OF COAL-FIRED ELECTRIC ENERGY SYSTEM

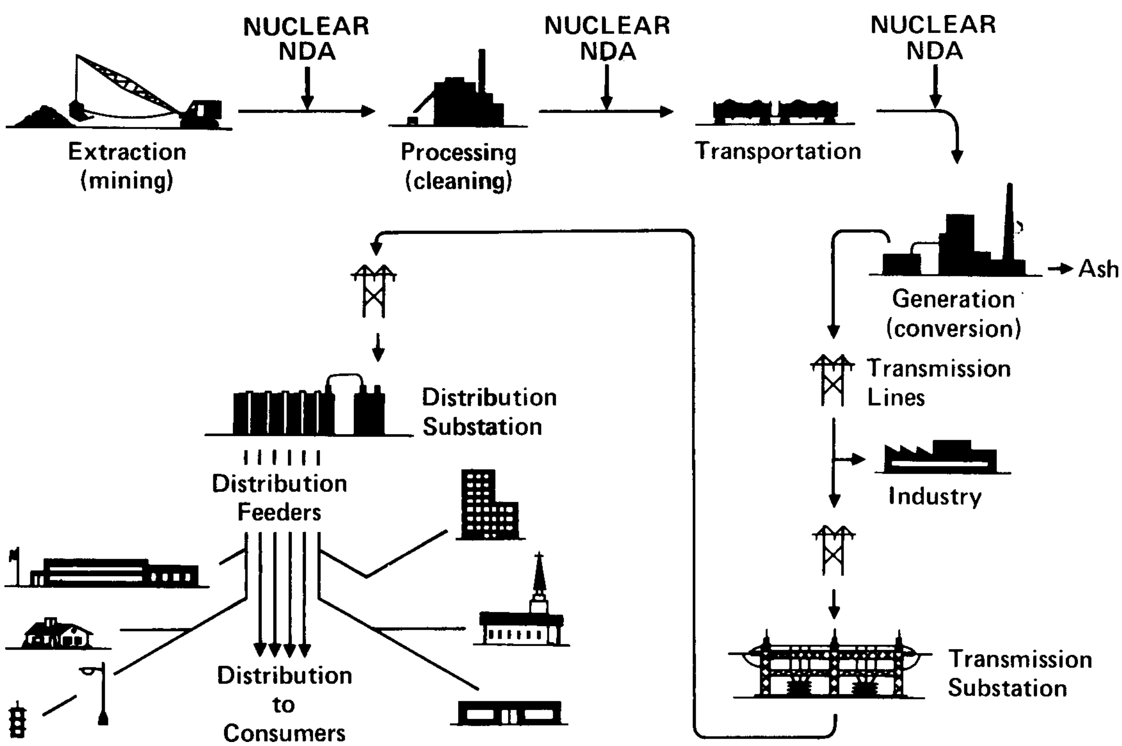


Figure 1-6.

2.0 RECENT TECHNICAL PROGRESS WITH CONAC

Tsahi Gozani
Science Applications, Inc.

and

Peter Luckie
Kennedy Van Saun Corporation

Introduction

Identification of the elemental composition of materials utilizing neutron activation techniques has been carried out since the early 1950's. Recent advances in technology have made it realistic to utilize this technique to continuously analyze coal feed to a power plant. These advances consist of the development of high-intensity neutron sources of small size, relatively large radiation detectors with high energy resolution capabilities, and better computers and software.

The following goals were established for the development of the CONAC system.

- Optimize coal handling and conveyance equipment
- Develop instrumentation and equipment that can measure the composition of actual coal from various sources in the United States
- Design the components so that they can operate satisfactorily in a typical power plant environment
- Design the system so that it can be integrated into an existing facility

SAI believes the goals have been met and now the CONAC system is ready to be tailored for a specific power plant. To do this, the following information is needed.

- Plant-specific data
- Specific CONAC data output required by the plant
- Cost of installing the system into the plant

After a power plant is selected, the next step would be to prepare a detailed design of the system, install the system, and operate the system as a field demonstration unit. Data provided by the system could allow optimization of coal utilization, control of coal blending, emission control and correlations with boiler corrosion, combustion data, and slag formation.

Elemental Composition of Coal

To determine the elemental composition of coal it is necessary to expose the coal to a source of neutrons and detect the prompt gamma rays given off as a result of neutron capture. If only the sulfur content of coal is desired, a high-sensitivity low-resolution detector, such as a sodium iodide (NaI) crystal, can be used. This crystal is physically large and can obtain a large number of counts in a short period of time, but it does not have a high energy resolution and thus cannot identify all of the impurities in coal.

A conceptual design of a "Sulfur Meter" installation is shown in Figure 2.1.

If it is necessary to detect all of the elements in coal, a low-sensitivity high-resolution detector, such as a germanium lithium (GeLi) or hyper-pure germanium crystal, can be used. These are the detectors used in CONAC (Figure 2.2).

The types of coal that have been analyzed in the CONAC program are tabulated below.

COAL SOURCE	SULFUR CONTENT	TOP SIZES
New Mexico Subbituminous	Low	3", 1¼" 3/4", ¼"
Montana Subbituminous	Low	1¼"
Eastern Ohio Bituminous	High	1¼"
Eastern Kentucky Bituminous	Low	1¼"
Blend 1	Medium	1¼"
Blend 2	Medium	1¼"
Pittsburgh #8 Bituminous	High	¼"
Wyoming Subbituminous	Low	¼"
Illinois Bituminous	High	1¼"
Lower Freeport Bituminous	Low	3/4"
Homer-City Bituminous	Medium	1¼"

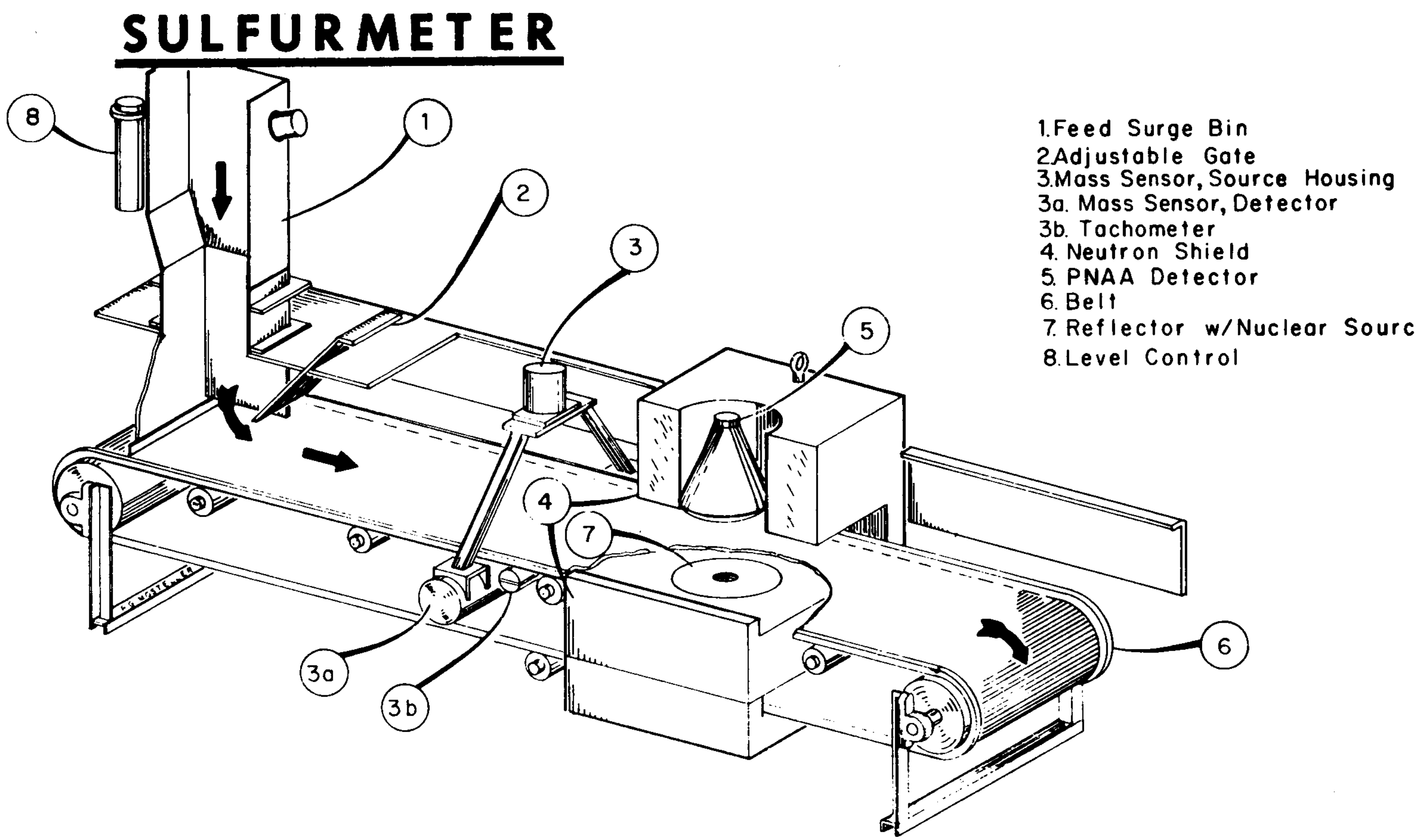

SULFURMETER
1.Feed Surge Bin
2.Adjustable Gate
3.Mass Sensor, Source Housing
3a. Mass Sensor, Detector
3b. Tachometer
4. Neutron Shield
5. PNAA Detector
6. Belt
7. Reflector w/Nuclear Source
8.Level Control
1
2
3
3a
3b
4
5
6
7
8

Figure 2-1.

CONAC

1. Feed surge bin
2. Adjustable gate
3. Mass sensor, source housing
3a. Gamma detector
3b. Tachometer
4. Dewar
5. Neutron shield
6. Detector
7. Belt
8. Reflector w/nuclear source
9. Microwave moisture meter

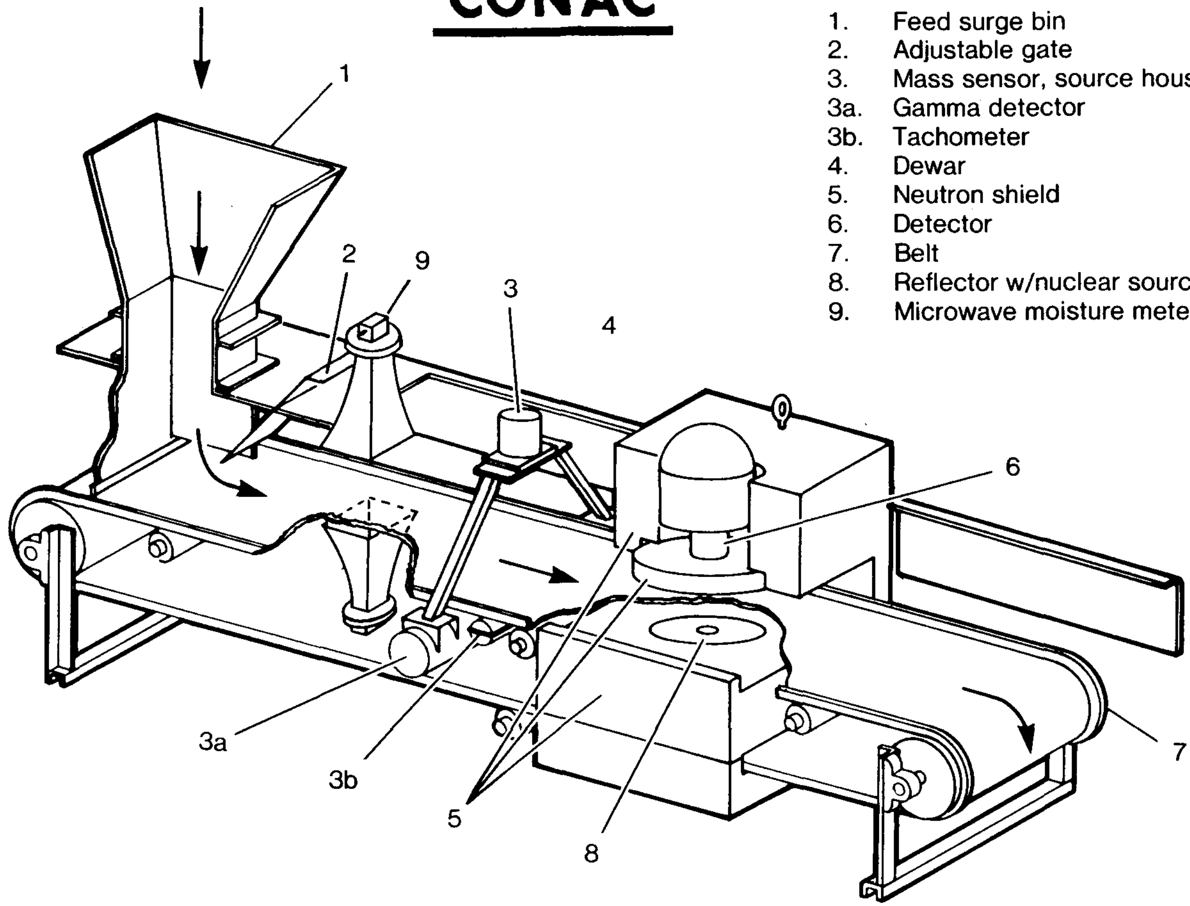


Figure 2-2.

Generally, the results from the CONAC system are much more accurate than the results obtained from ASTM analytical methods. Table 2.1 shows the error spread for the four elements (H, S, C, and Cl) obtained in seven different coal samples by CONAC and ASTM methods, respectively. In addition to these elements, the concentration of N, Si, Fe, Al, Ti, Ca, and Na have also been measured. The CONAC results have been normalized to Pittsburgh coal. Pittsburgh coal was selected as a standard because analyses by three independent laboratories were in good agreement with each other. Analysis of the other coals by independent laboratories using ASTM methods resulted in widely varying results.

The sulfur meter can give results with an accuracy similar to the CONAC system but will not identify as many elements as CONAC. The sulfur content for various coals (sample size of about 250 pounds) as determined by a sulfur meter is shown in Figure 2.3. Figure 2.4 shows a comparison of the sulfur meter measurements with ASTM measurements. The linear response over the entire range of sulfur concentration and the lack of bias (as evidenced by the linear regression going through zero) are quite remarkable.

We would recommend additional efforts be made to develop Prompt Neutron Activation Analysis (PNAA) standards for several types of coal; thus, the CONAC analysis need not be normalized to ASTM results.

Effect of Coal Top Size (and Size Distribution)

Originally it was thought that coal subjected to CONAC analysis would have to be crushed to a small size to give consistent results. However, two CONAC analyses of New Mexico coal in 3-inch top size and 1/4-inch top size gave very similar results, as shown in Table 2.2. The results for C, Si, and Al were about the same. H, N, S, and Fe showed slightly more variance. The results of the ASTM analysis on the two sizes showed significant differences, however. These differences were probably due to sampling errors even though the sampling was done with care.

In general, these results provide convincing evidence that the PNAA method gives more accurate results than ASTM analysis. In a field installation it is possible that the PNAA errors might be up to a factor of three higher than shown in Table 2.2 but this would still be better than ASTM results, considering the sampling errors in the latter.

Moisture Content

Hydrogen exists as two forms in coal -- as moisture, and as hydrocarbons. The PNAA method can determine the total hydrogen content but not its molecular form. To do this, independent instrumentation will be incorporated into CONAC. Three instrumentation systems that can make this

Table 2.1. Concentration of Some Elements in Various Types of Coal as Determined by CONAC and Conventional ASTM Techniques

Coal Type	*Analysis ("As Received" Basis)*							
	Hydrogen		*Sulfur*		*Carbon*		*Chlorine*	
	PNAA†	*ASTM**	*PNAA*†	*ASTM**	*PNAA*†	*ASTM**	*PNAA*†	ASTM*
E. Ohio (1¼)	5.11 ± 0.02	5.02 ± 0.11	2.91 ± 0.02	2.91 ± 0.13	68.65 ± 0.9	68.7 ± 1.3	0.1280 ± 0.0020	0.086
DEK	6.44 ± 0.02	5.23 ± 0.99	0.38 ± 0.01	0.39 ± 0.07	56.36 ± 0.7	60.5 ± 5.2	0.0038 ± 0.0006	0.018
E.KEN.	5.62 ± 0.02	4.93 ± 0.19	0.90 ± 0.01	0.82 ± 0.04	69.11 ± 0.9	67.8 ± 0.1	0.0390 ± 0.0010	0.037
B1	5.74 ± 0.02	5.52 ± 0.64	1.25 ± 0.01	1.28 ± 0.17	68.77 ± 0.8	67.8 ± 4.4	0.0510 ± 0.0010	0.042 ± 0.018
B2	6.03 ± 0.02	5.63 ± 0.98	1.34 ± 0.01	1.21 ± 0.09	65.16 ± 0.8	64.9 ± 4.4	0.0500 ± 0.0010	0.086 ± 0.034
NM (¼)	4.78 ± 0.02	4.70 ± 0.53	0.93 ± 0.01	0.94 ± 0.03	51.50 ± 0.7	55.8 ± 4.0	0.0660 ± 0.0010	0.082
PITTS.**	5.13 ± 0.02	5.13 ± 0.07	2.91 ± 0.02	2.91 ± 0.03	71.40 ± 0.9	71.4 ± 0.7	0.1440 ± 0.0010	0.144 ± 0.023

†PNAA uncertainties in analysis; PNAA = Prompt Neutron Activation Analysis.

*ASTM uncertainties based on deviations between 2 or 3 laboratory results. With Chlorine where no uncertainties are quoted, only one laboratory submitted results.

**PNAA results for Pittsburgh-8 coal normalized to ASTM results.

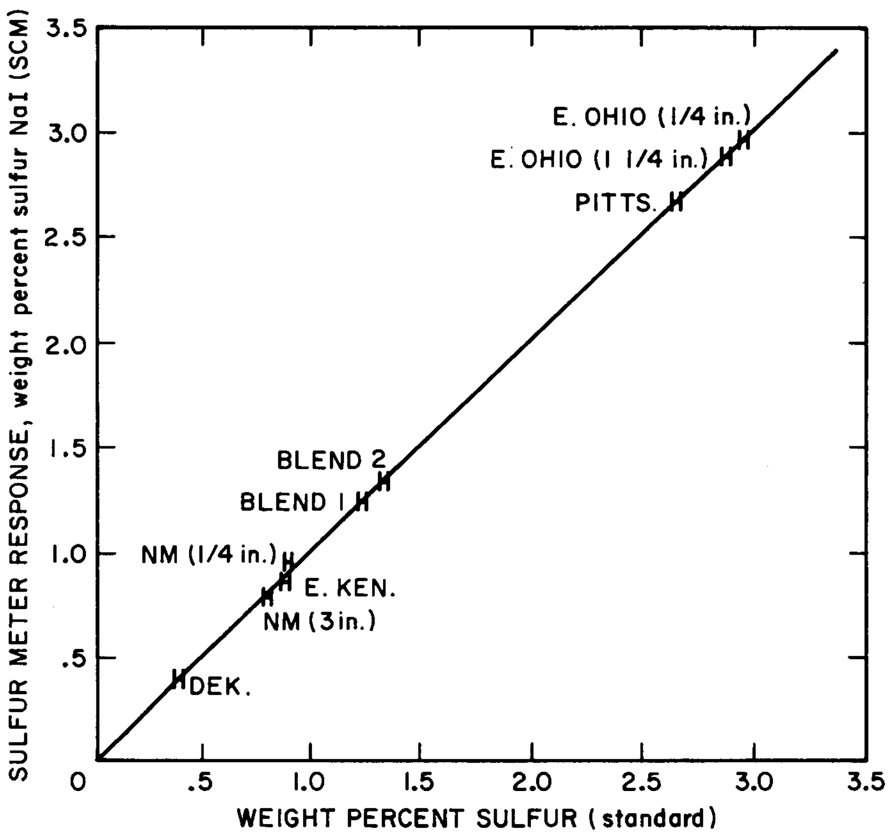
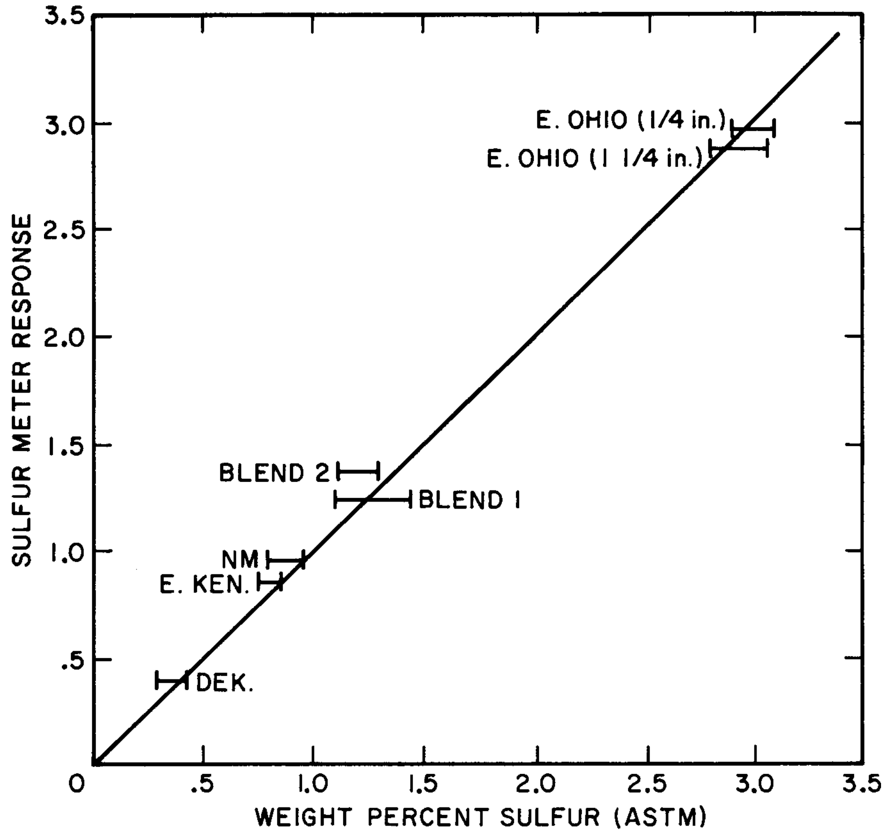

SULFUR METER RESPONSE, weight percent sulfur NaI (SCM)
WEIGHT PERCENT SULFUR (standard)
0
.5
1.0
1.5
2.0
2.5
3.0
3.5
E. OHIO (1/4 in.)
E. OHIO (1 1/4 in.)
PITTS.
BLEND 2
BLEND 1
NM (1/4 in.)
E. KEN.
NM (3in.)
DEK.

Figure 2-3.



SULFUR METER RESPONSE
WEIGHT PERCENT SULFUR (ASTM)
0
.5
1.0
1.5
2.0
2.5
3.0
3.5
E. OHIO (1/4 in.)
E. OHIO (1 1/4 in.)
BLEND 2
BLEND 1
NM
E. KEN.
DEK.

Figure 2-4.

Table 2.2. Comparison Between CONAC-PNAA and ASTM Analyses for NM Subbituminous Coal With 2 Different Top Sizes

	Weight Percent (on "as recieved" basis)			
	PNAA		*ASTM*	
Element	*NM (3")*	*NM (¼")*	*NM (3")*	*NM (¼")*
C	53.960 ± 0.700	51.920 ± 0.700	59.200 ± 1.800	55.800 ± 4.000
H	5.290 ± 0.020	5.080 ± 0.020	4.930 ± 0.800	4.700 ± 0.500
N	0.930 ± 0.060	0.890 ± 0.060	1.200 ± 0.060	1.070 ± 0.070
S	0.880 ± 0.010	0.980 ± 0.010	0.710 ± 0.010	0.840 ± 0.030
Cl	0.065 ± 0.001	0.068 ± 0.001	0.063	0.082
Si	5.070 ± 0.030	5.060 ± 0.030	3.210 ± 0.030	5.720 ± 0.250
Al	3.030 ± 0.050	3.040 ± 0.050	1.780 ± 0.130	3.020 ± 0.280
Fe	0.710 ± 0.010	0.790 ± 0.010	0.520 ± 0.040	0.780 ± 0.010
Ti	0.095 ± 0.002	0.099 ± 0.002	0.074 ± 0.002	0.121 ± 0.010

measurement have been analyzed. They are capacitance, microwave attenuation, and nuclear magnetic resonance techniques. One of the electromagnetic techniques will be incorporated in CONAC.

Btu Determination

To determine the heat value of coal, it will be necessary to determine the moisture content using one of the methods mentioned above. The accuracy of the heat value or Btu determination will depend upon the moisture content of the coal and the uncertainty in the moisture determination. Figure 2.5 shows this dependence. As can be seen, in the range of moisture content of 10% to 25% the accuracy requirement for moisture determination is modest. A 5% relative accuracy will result in a Btu determination to better than 2%.

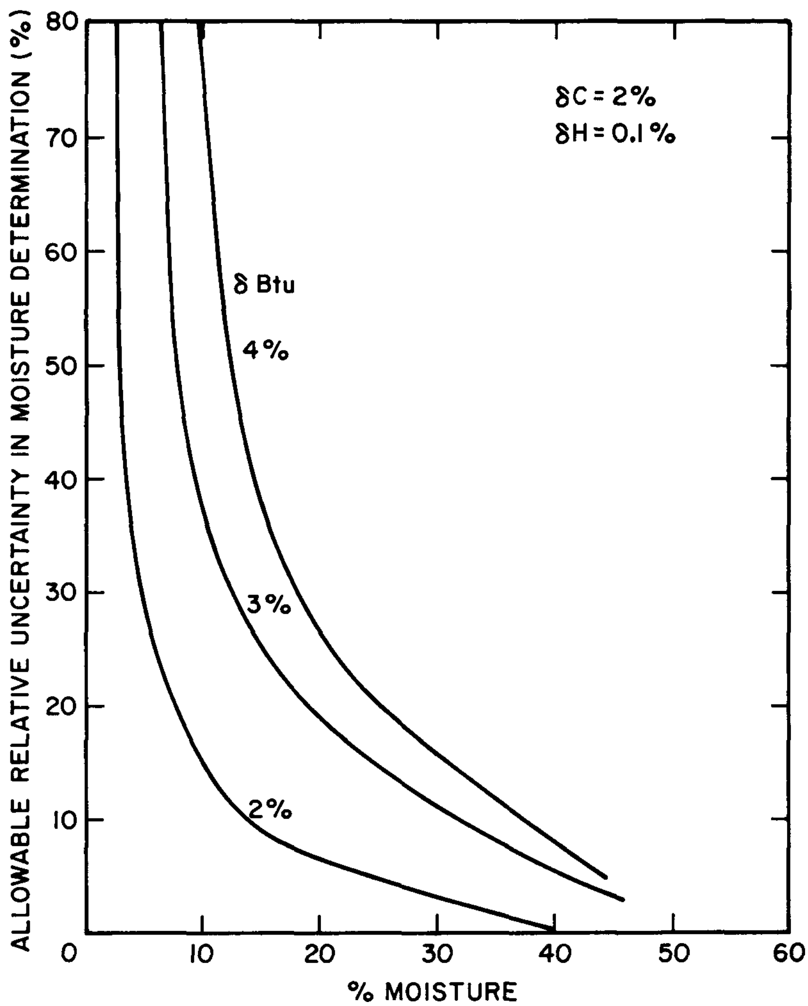
Integration of CONAC with Typical Power Plants

Of great concern at the beginning of this program was the method of presenting the coal to the neutron source/detector for accurate analysis of the coal constituents. Measurement of coal quality both in a bin and on a belt was considered. It was concluded that the bin concept was undesirable because it would be difficult to detect voids that could occur and, thus, affect the results. Also, if coal particles were moving with respect to each other, segregation could occur. The belt method (combined with a mass sensor for mass flow rate measurements, if desired), as shown in Figure 2.2, was selected as the best delivery method.

To minimize the effect of materials in the structural supports and to provide a proper nonstagnating, moving coal profile, it was concluded that a two-to-one width-to-height ratio of the coal stream would be optimum. Thus, structural materials are relatively far from the detector and do not contribute significantly to the gamma rays detected by the GeLi or NaI detectors.

The only unique material of construction required is the coal conveyor belt. If conventional belt materials are used, the sulfur in the belt interferes with the sulfur content in the coal measurements. A satisfactory belt material has been identified. Its cost is approximately ten times more than conventional belt material. Thus, it appears that CONAC should not be directly inserted into an existing coal handling system. Rather, it should be integrated into a coal handling system by diverting coal to a separate short belt made of special belt material.

CONAC could be designed to handle 1%, 10%, or 100% of the coal flow. However, if it is necessary to measure a large fraction of the coal,



ALLOWABLE RELATIVE UNCERTAINTY IN MOISTURE DETERMINATION (%)
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
% MOISTURE
δC = 2%
δH = 0.1%
δ Btu
4%
3%
2%

Figure 2-5.

multiple neutron sources and detectors would be required across the belt since one source/detector only interrogates a strip of coal approximately 2-ft wide. The speed of the belt for the prototype is being designed to vary so as to present between 1 and 10 tons of coal per hour for analysis.

The moisture detector, not shown in Figures 2.1 or 2.2, can be located anywhere along the belt.

Figure 2.6 shows one arrangement for integrating CONAC into a coal-fired power plant. Diversion of the coal is accomplished by cutting the stream of coal to the power plant and sending a stream of coal to the analysis section located in a sample house. After sampling, the coal can be routed back into the main coal stream.

Summary

The composition of coal samples from various locations in the United States and with widely varying composition has been measured. It has been demonstrated that all important coal constituents can be measured in a continuous manner. Reliable results have been obtained for sulfur, hydrogen, carbon, nitrogen chlorine, and typical metals which are slag formers.

Design studies have shown that a CONAC system can be located almost anywhere in a power plant coal handling system. Belts appear to be the optimum method of delivering coal to the analytical instrumentation, but the system could be adapted to a bin presentation system, if required.

Coal up to 3-inch top size can be analyzed so it will not be necessary to incorporate coal crushing equipment in a CONAC system.

The CONAC components lend themselves to field use. In an actual installation the sophisticated instrumentation and output would not be seen by the plant operator. Instead, the operator would be provided only with basic data, such as weight-percent of significant constituents. Possibly, these data could be further processed, and the operator would be given directions for proper blending of coal and operation of the plant.

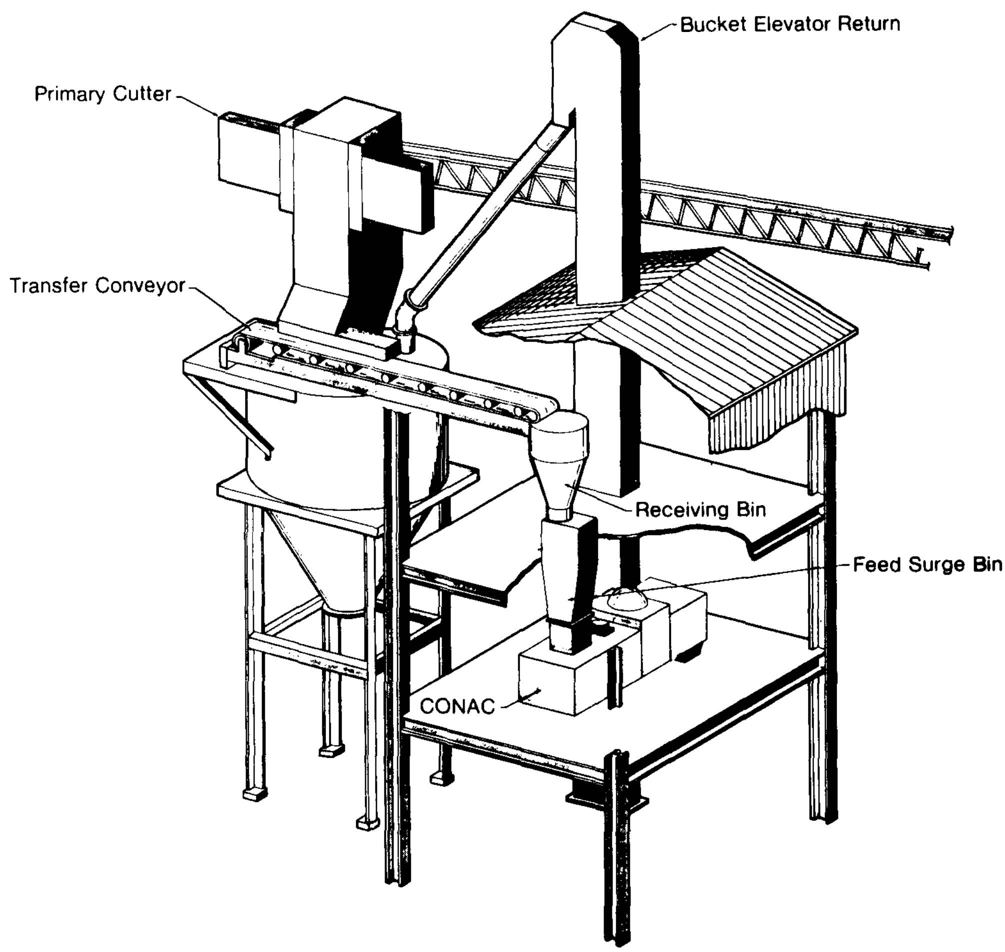


Figure 2-6. CONAC Integrated Into a Typical Power Plant

3.0 APPLICATION OF A SULFUR/BTU METER TO THE MONROE POWER PLANT'S COAL BLENDING FACILITY

R. J. Buckler
Detroit Edison Company

Background

The Detroit Edison Company has worked for several years to devise the most economical strategy to comply with the State of Michigan's sulfur dioxide emission regulation for its Monroe Power Plant. The method that was finally selected to satisfy the sulfur dioxide emission requirement comprises the blending of high and low sulfur coals. The following describes the projected economic advantages of utilizing an on-line sulfur meter for the coal blending facilities.

The Monroe Power Plant is a four-unit super-critical complex rated at 3,000 megawatts, consuming approximately 6.5 million tons per year of West Virginia and Ohio coals. The coal, most of which is under long-term contract, is delivered primarily by 17,000-ton unit train service utilizing private railcars and locomotives. In addition, vessel delivery capability has been uprated to a demonstrated level of 300,000 tons per month.

Construction began in 1977 on the coal blending facilities, which will be located within the existing unit train loop. The blending system will have two to three active coal piles (depending upon the number of coal types), discharging onto an underfeed reclaim belt by rotary plow feeders. The result is a layered coal blending.

Sulfur Dioxide Limitations

The sulfur dioxide emission limitation agreement with the State of Michigan can be summarized as follows:

January 1, 1980, through December 31, 1984

- 3.68 pounds of SO_2/million Btu of heat input
- Equivalent to 2.3% sulfur at 12,000 Btu/pound
- Calculated on an integrated calendar-day basis

January 1, 1985, and Thereafter

- 1.60 pounds of SO_2/million Btu of heat input
- Equivalent of 1.0% sulfur at 12,000 Btu/pound
- Calculated on an integrated 24-hour basis

Coal Blend Determinations

As stated previously, most of the high sulfur coal is obtained under existing long-term contracts. The cost of that coal is significantly less than that projected for the new low sulfur coals that will be required as blending coals to ensure compliance with the regulations. The primary goals in the coal blend determination were, therefore, to maximize the quantity of existing high sulfur coal and minimize the quantity of new low sulfur coal while resulting in no sulfur dioxide violations.

Analyses of typical coals to be blended are shown in Figures 3.1 through 3.4 and are summarized in Table 3.1.

Table 3.1

	Sulfur Content (%)		Btu per Pound	
Coal Type	Mean	Range	Mean	Range
High Sulfur Eastern	2.6	2.0-4.0	12,600	11,800-13,200
Low Sulfur Eastern	0.7	0.5-1.1	12,000	11,200-12,800

Noting the range indicated for the coals above, it is easy to see why it was determined early on that mean sulfur values could not be used to determine a coal blend that would comply with a 24-hour regulation. A more sophisticated procedure was therefore required to determine the blend of high and low sulfur coals. A methodology was developed for the coal blend determination using a Monte Carlo technique to simulate blending, operation of the boilers, and sulfur dioxide stack emissions. The resultant Monte Carlo computer code specifically accounted for:

- Physical design of the coal blending facility and the power plant, from the individual coal piles, to blending, and through combustion to the stack gas exit
- Compliance constraints by year
- Coal variability
- Load duration
- Sulfur meter, sulfur/Btu meter where applicable

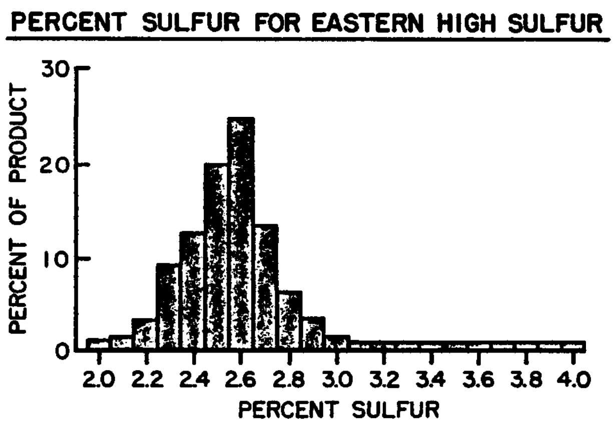


Figure 3-1.

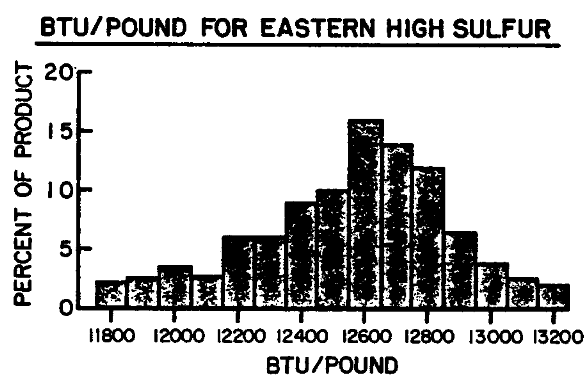


Figure 3-2.

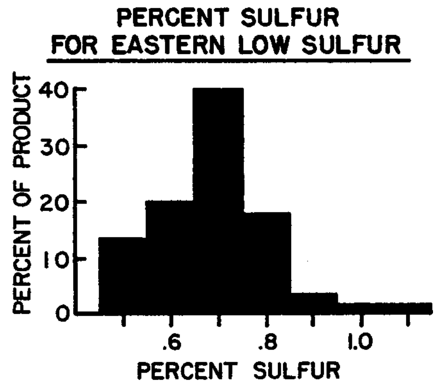


Figure 3-3.

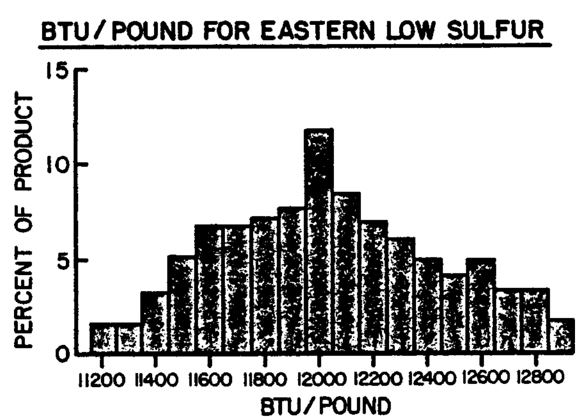


Figure 3-4.

In addition, the application of this technique involved several major assumptions; they are:

- As-delivered coal data were used as the basic input. As-fired data on an individual coal basis were not available.
- Train loads of coal retain their identity after being stacked out on the coal pile.
- The SO_2 monitor is not used as a control device.
- The power plant is represented as one unit.
- Four percent of the sulfur is retained in the ash.
- Sulfur meter tolerance is ± .04% sulfur.
- Btu meter tolerance is ± 175.0 Btu/lb.
- Averaging period for sulfur meter is 1/2 hour.

A simplified schematic diagram showing the simulation of the coal blending system without a sulfur meter is shown as Figure 3.5. The alternative logic required for the simulation including a sulfur meter is shown on Figure 3.6.

Figures 3.7 through 3.12 show the results of a selected output from the Monte Carlo simulation. These figures represent a 1980 through 1984 compliance scenario where there would be a sulfur meter and the desired goal would be to maximize the existing contract high sulfur coal and minimize the new low sulfur coal.

Figure 3.7 indicates that for this scenario, the daily sulfur content will average between 2.30% and 2.34%, with a maximum value of 2.38%. This would appear to be in violation; however, as Figure 3.8 shows, due to the heat content of the coals involved, the daily average pounds of SO_2 per MBtu never exceed the limitation of 3.68. As stated previously, the averaging period for the sulfur meter was assumed to be 1/2 hour. For the following discussion, each 1/2-hour averaging period during the coal loading of the power plant will be defined as a load increment. On Figure 3.6, the schematic diagram of the sulfur meter simulation logic, it was shown that the blend ratio of high and low sulfur coal will be changed at the end of each load increment. Based on a loading rate of 1,500 tons per hour, this would amount to approximately 25 to 30 blend ratio changes per day. Figures 3.9 through 3.12 are concerned with the property changes on a load-increment basis. As can be seen from Figure 3.9, the sulfur content can range from a low value of 1.2% to a high value of 3.4%; however, only about 10% of all

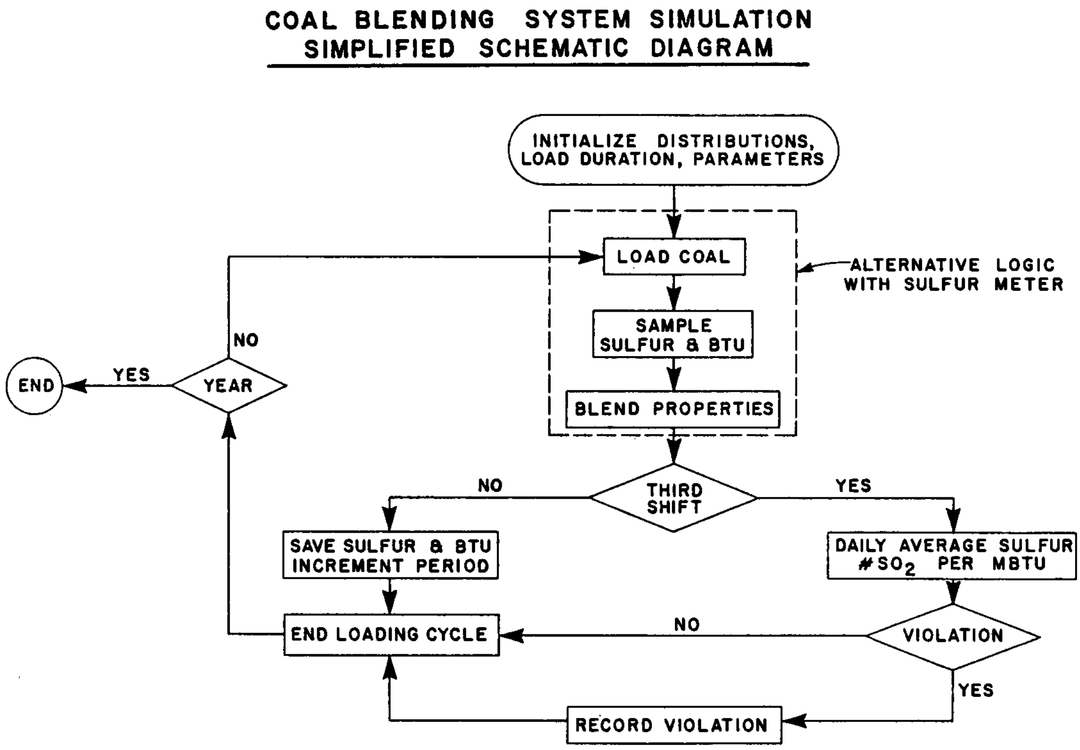

COAL BLENDING SYSTEM SIMULATION
SIMPLIFIED SCHEMATIC DIAGRAM
INITIALIZE DISTRIBUTIONS, LOAD DURATION, PARAMETERS
LOAD COAL
ALTERNATIVE LOGIC WITH SULFUR METER
SAMPLE SULFUR & BTU
BLEND PROPERTIES
NO
END
YES
YEAR
NO
THIRD SHIFT
YES
SAVE SULFUR & BTU INCREMENT PERIOD
DAILY AVERAGE SULFUR #SO2 PER MBTU
END LOADING CYCLE
NO
VIOLATION
YES
RECORD VIOLATION

Figure 3-5.

COAL BLENDING SYSTEM SIMULATION
SULFUR METER SCHEMATIC DIAGRAM

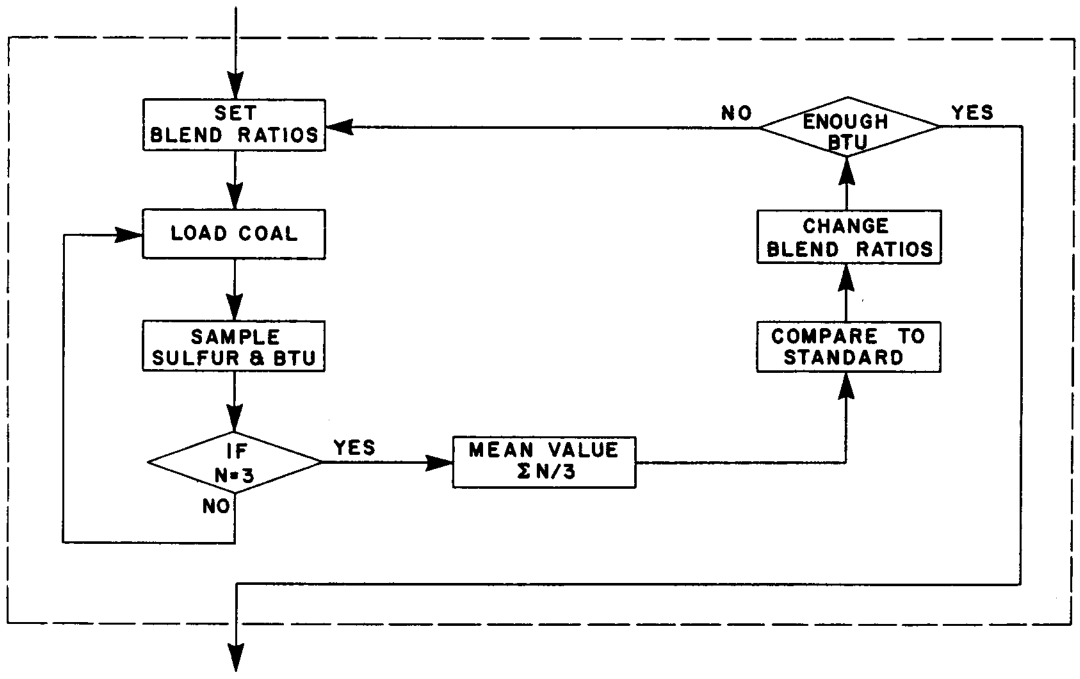
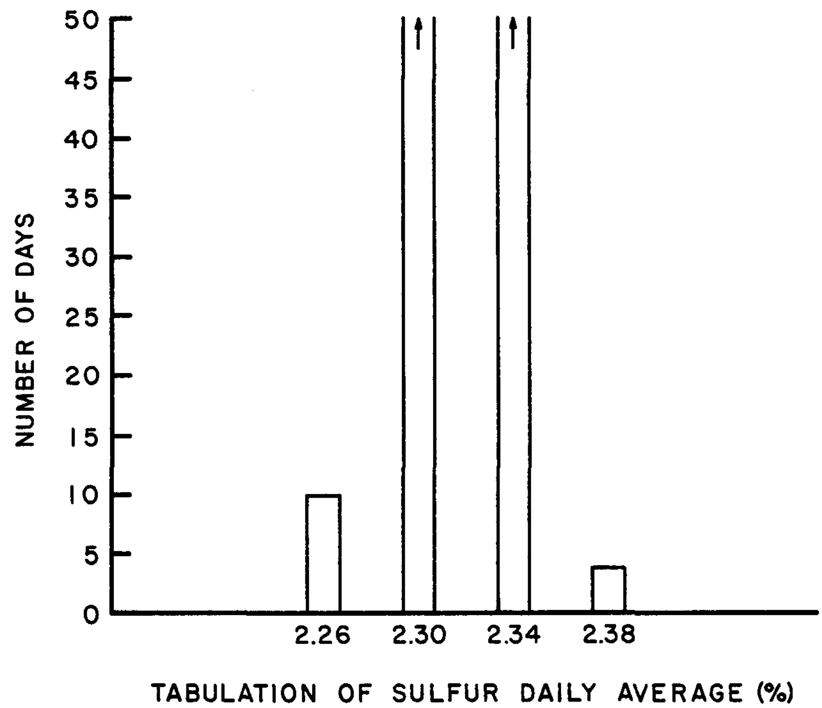
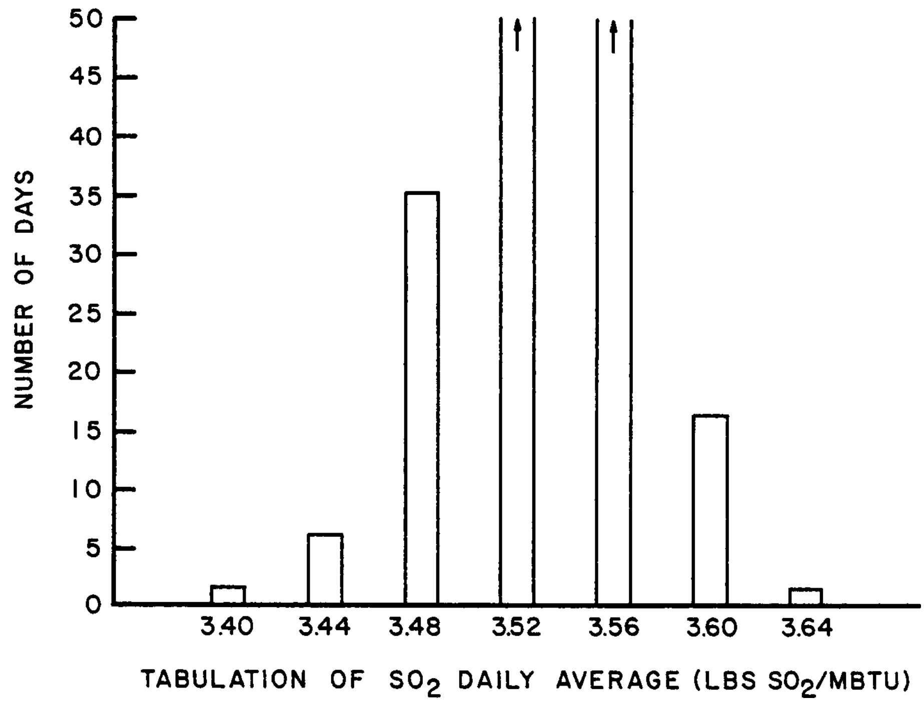


Figure 3-6.



50
45
40
35
30
25
20
15
10
5
0
NUMBER OF DAYS
2.26
2.30
2.34
2.38
TABULATION OF SULFUR DAILY AVERAGE (%)

Figure 3-7.



50
45
40
35
30
25
20
15
10
5
0
NUMBER OF DAYS
3.40
3.44
3.48
3.52
3.56
3.60
3.64
TABULATION OF SO_2 DAILY AVERAGE (LBS SO_2/MBTU)

Figure 3-8.

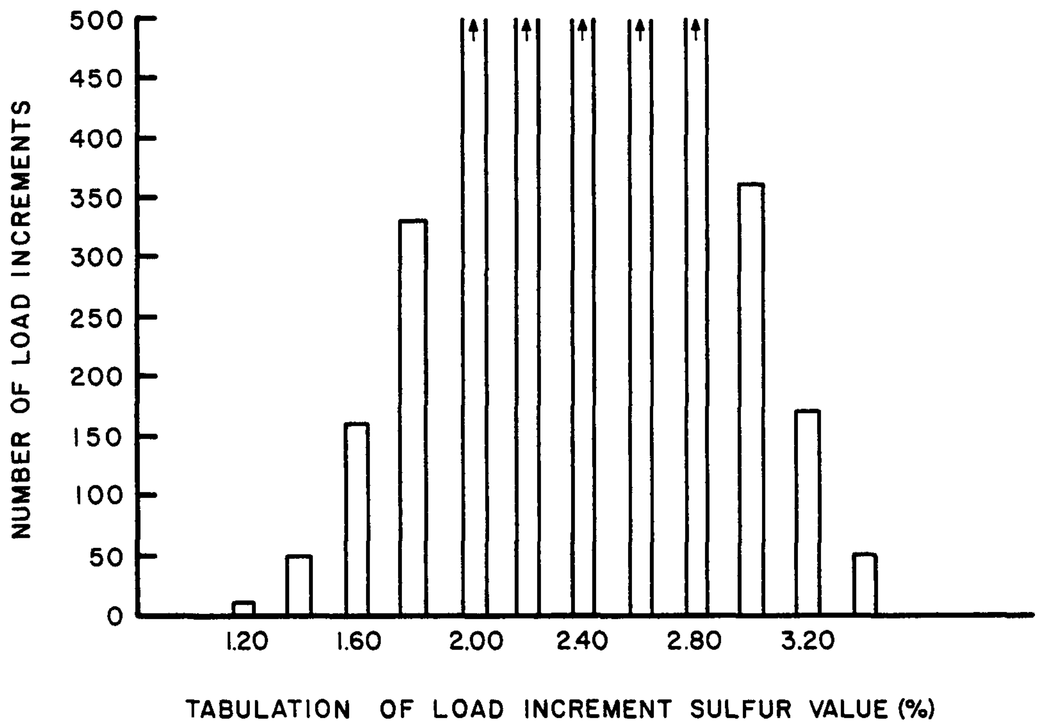

NUMBER OF LOAD INCREMENTS
500
450
400
350
300
250
200
150
100
50
0
1.20
1.60
2.00
2.40
2.80
3.20
TABULATION OF LOAD INCREMENT SULFUR VALUE (%)

Figure 3-9.

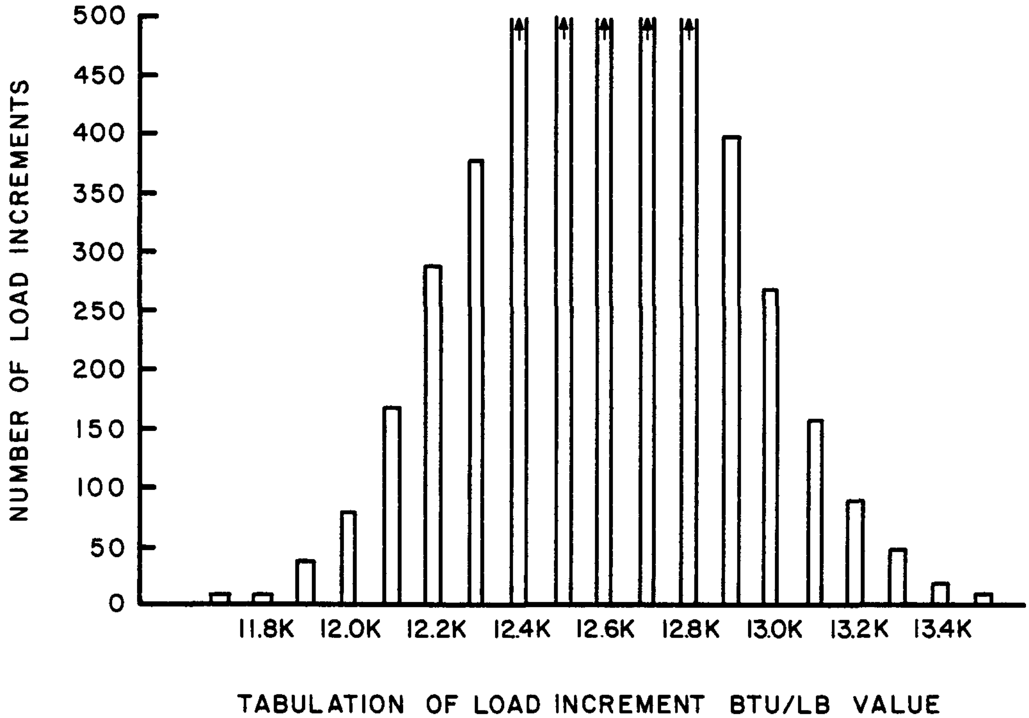
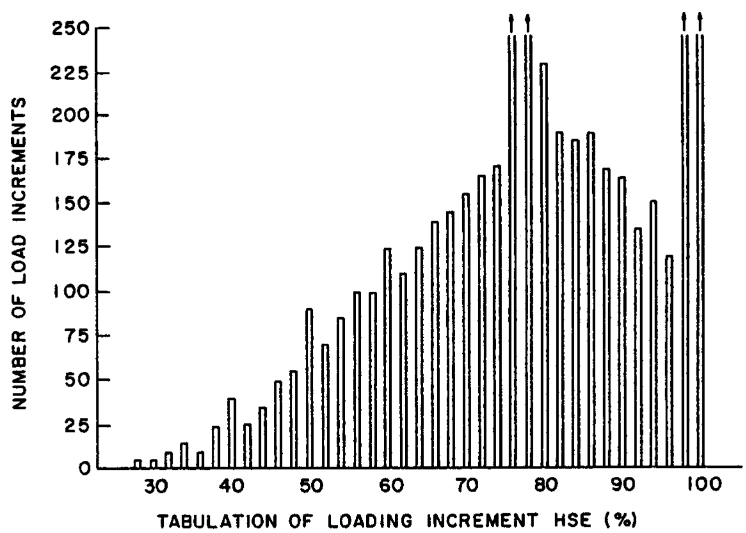
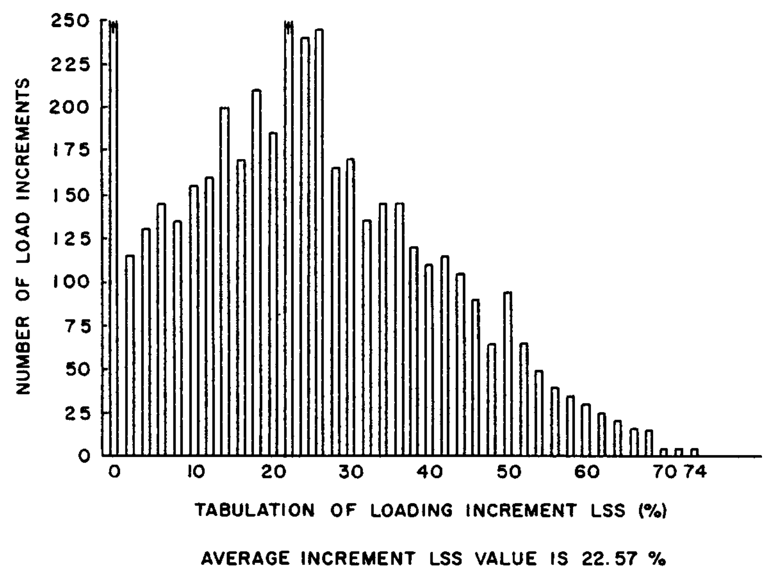

500
450
400
350
300
250
200
150
100
50
0
NUMBER OF LOAD INCREMENTS
11.8K 12.0K 12.2K 12.4K 12.6K 12.8K 13.0K 13.2K 13.4K
TABULATION OF LOAD INCREMENT BTU/LB VALUE

Figure 3-10.



AVERAGE INCREMENT HSE VALUE IS 77.42 %

Figure 3-11.



250
225
200
175
150
125
100
75
50
25
0
NUMBER OF LOAD INCREMENTS
0
10
20
30
40
50
60
70 74
TABULATION OF LOADING INCREMENT LSS (%)
AVERAGE INCREMENT LSS VALUE IS 22.57 %

Figure 3-12.

possible load increments are outside of a 2.0% to 2.8% range. Likewise, the heat content of the blend, as indicated in Figure 3.10, also has a wide range of from 11,200 Btu/lb to 13,500 Btu/lb. However, again noting that a majority of the values are within a very narrow band, in this case, no more than 15% of the values are outside of a range of 12,400 Btu/lb to 12,800 Btu/lb. The primary result garnered from the Monte Carlo simulation is the weight percentage of high and low sulfur coals required in the blend. As detailed in Figure 3.11, the amount of high sulfur coal averages approximately 77.5% and ranges from 30% to 100%, with the percentage of high sulfur being at least 60% for 95% of the time and at least 70% for 85% of the time. Conversely, the low sulfur coal averages approximately 22.5%, as detailed on Figure 3.12.

The above techniques were used to determine the blend percentages for a non-sulfur-meter scenario, a sulfur-meter scenario, and a sulfur/Btu-meter scenario. The projected blends shown below are reflective of the direct computer output and include no correction for possible simulation error. In any case, the percentage difference between individual cases would remain as shown:

Meter Type	Percent High Sulfur Eastern	Percent Low Sulfur Eastern
None	66.0	34.0
Sulfur	77.5	22.5
Sulfur/Btu	78.0	22.0

The significance of a workable sulfur meter is evident. To stay in compliance without the use of a continuous on-line meter, it is estimated that a blend containing 34% low sulfur coal will be required. However, with a sulfur meter, the low sulfur coal could be reduced to 22.5% and to 22% with a combined sulfur and Btu meter.

Economic Analysis

It is not the policy of the Detroit Edison Company to make known existing contract fuel prices; in that regard only projected new contract prices have been used in the economic investigations presented here. However, the wide disparity between projected prices of high and low sulfur coal will result in giving an approximate, though minimum, reflection of the potential economic savings. For the presentation the Monte Carlo simulation, outlined in Figure 3.13, was developed to determine the potential

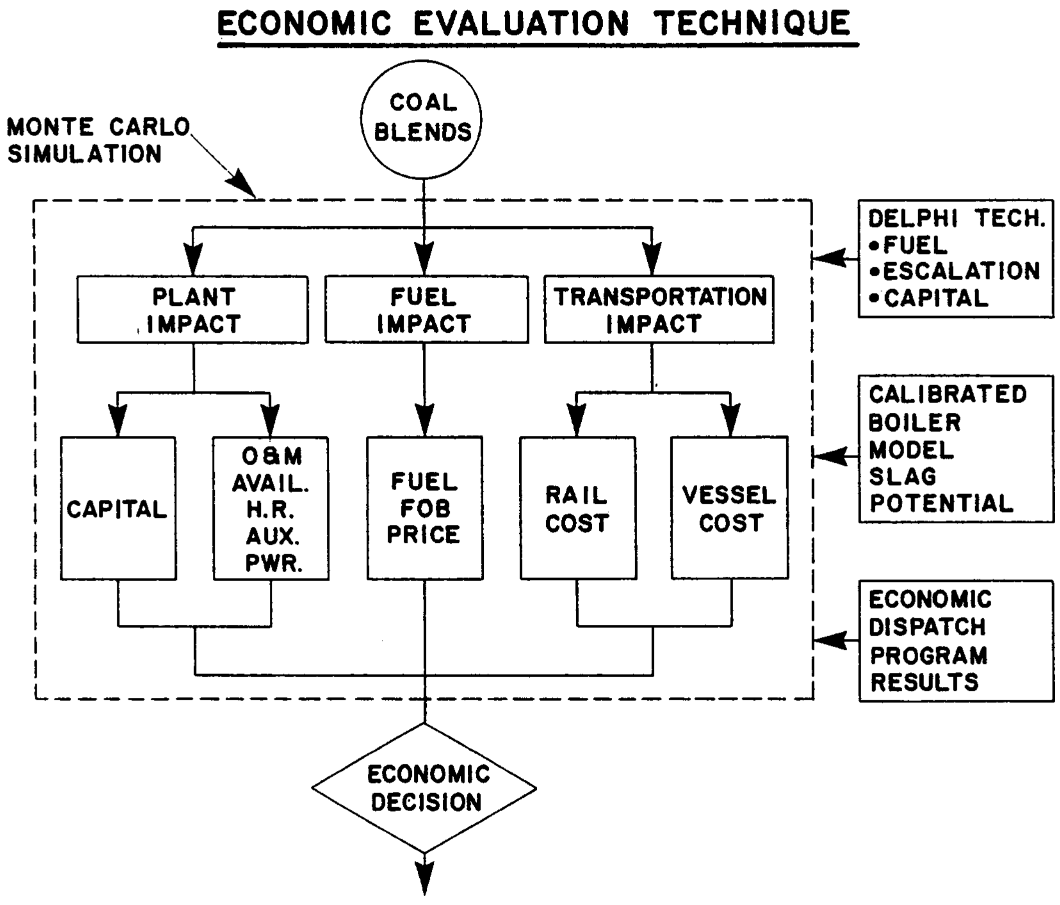

ECONOMIC EVALUATION TECHNIQUE
COAL BLENDS
MONTE CARLO SIMULATION
PLANT IMPACT
FUEL IMPACT
TRANSPORTATION IMPACT
DELPHI TECH.
•FUEL
•ESCALATION
•CAPITAL
CAPITAL
O&M AVAIL. H.R. AUX. PWR.
FUEL FOB PRICE
RAIL COST
VESSEL COST
CALIBRATED BOILER MODEL SLAG POTENTIAL
ECONOMIC DISPATCH PROGRAM RESULTS
ECONOMIC DECISION

Figure 3-13.

economic savings. The basic inputs into that simulation were the coal prices and escalation rates shown in Table 3.2. It is essential to note that the new low sulfur coal at a mean value of $1.83 per million Btu is estimated to be $0.58 per million Btu more expensive than the high sulfur at $1.25 per million Btu. The availability of a sulfur meter to use the maximum amount of lower cost high sulfur coal is estimated to result in a levelized annual savings of between 9 and 18 million dollars for the 1980 through 1984 period (Figure 3.14). The savings are increased an additional 1.4 million dollars annually by including a Btu meter.

In conclusion, the real-time analysis of sulfur and Btu could have a significant economic advantage by permitting Detroit Edison to remain in compliance with sulfur limitations by the cost-effective blending of high and low sulfur coals.

Table 3.2

ECONOMIC ANALYSIS ASSUMPTIONS

Projected Composite Contract Coal Prices (cents/MBtu, mid-year 1978)

Coal Type	Mean	Range
High Sulfur Eastern	125.0	110.0-145.0
Low Sulfur Eastern	183.0	160.0-200.0

Projected Escalation Rates

Type	Period	Mean	Range
High Sulfur Eastern	1978-1979	9.5	8.5-10.5
	1980-1984	8.0	7.0- 9.0
Low Sulfur Eastern	1978-1979	10.5	9.5-11.5
	1980-1984	8.5	7.5- 9.5
Rail	1978-1979	9.5	8.5-10.5
	1980-1984	9.0	8.0-10.0
Vessel	1978-1979	8.5	7.5- 9.5
	1980-1984	8.0	7.0- 9.0

For their study we have assumed no differences in the plant parameters. Economic advantages are due solely to fuel.

PROJECTED ECONOMIC SAVINGS FOR SULFUR-SULFUR/BTU METER
5 YEAR LEVELIZED ANNUAL COST SUMMARY

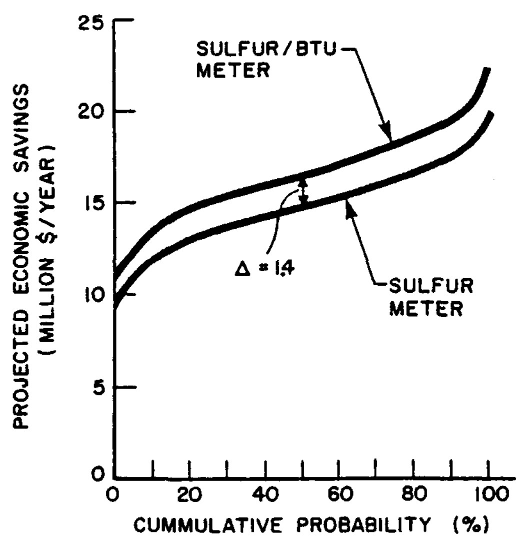


Figure 3-14.

4.0 APPLICATION OF A SULFUR/BTU/ASH METER TO THE KINGSTON STEAM PLANT

C. M. Huang
Tennessee Valley Authority

TVA has considered a continuous coal analyzer as it may be used in connection with a proposed consent agreement involving environmental regulations, compliance schedules, and methods of achieving compliance for sulfur dioxide and particulate emissions.

TVA has chosen to use three methods of control to meet sulfur dioxide emissions:

- Flue gas desulfurization
- Low sulfur coal
- Coal washing

The use of low sulfur coal was chosen as a compliance strategy for the Kingston Plant. To be most effective, it will be necessary to use some method for continuous monitoring of coal quality. The plant has a capacity of 1,600 MW and uses 4.3 million tons of coal per year.

The coal handling facilities include a truck unloading facility that handles 40 to 50 trucks per hour, two rotary car dumpers that handle 40 cars per hour, and 124-ton-capacity receiving hoppers. The remaining plant includes crushers, conveyors to bunkers and reclaiming from storage, all having capacities of 2,000 tons per hour. The storage capacity is 1,350,000 tons (90-day supply).

An estimated 1-1/2 minutes are available to analyze each truck. A grab sample is taken from each truck and an ASTM analysis is made of a six-truck composite sample. The results are not available for several days and a real-time analysis of the coal quality cannot be made. Historical analyses are unable to control the feed to the plant.

While it may be desirable to monitor the coal quality at the mine or at a preparation stage, the most important control point is at the delivery to the power plant. Therefore, TVA is concentrating initial efforts on developing an instantaneous sulfur meter to monitor the coal as it is delivered. This will permit TVA to accept or reject delivery of coal according to the sulfur content and thus become more capable of being in compliance.

Instrument capability to monitor ash and Btu content is desirable at some later time. This requirement is not of major importance now, although the variability in sulfur content is critical at Kingston. Recently installed precipitators at the Kingston plant are extremely efficient and the particle emissions are well below the regulatory requirements. Thus, some variability in ash content can be tolerated.

TVA has two reasons for using a sulfur meter at Kingston.

- To analyze the coal delivered by rail and road. Specifically, to analyze each of 400 to 600 trucks per 14-hour day, which represents 60% to 70% of the coal supply at present. A successful instantaneous analyzer for this application could be adapted easily for use on barge, railcars, or conveyors.

- To demonstrate a compliance standard of 2.8 lb SO_2/MBtu by July 1, 1979. A fine of $35,000 is liable for each violation per 24 hours. Until that time, the standard is 4.2 lb SO_2/MBtu, with a $20,000 fine on a weekly basis.

TVA has a strong desire to comply with these regulations to adequately protect the environment and to avoid payment of heavy penalties. Thus, there is a strong incentive for developing a reliable system for continuous monitoring of the coal quality.

In response to a question, TVA is planning to use continuous monitoring of the stacks to demonstrate compliance and instruments are in order. Currently, calculations based on weekly bunker sample analyses are used to estimate the SO_2 emissions.

5.0 COMBUSTION CONTROL BY CONAC AT MONTOUR

R. Bielecki
Pennsylvania Power & Light Company

The PP&L Montour plant consists of two 750-MW units using western Pennsylvania bituminous coal. About 80% of the coal is delivered from a captive dedicated mine (Greenwich) and 20% is vendor-supplied coal of varying quality.

The coal handling and processing flow diagrams were made (Figure 5.1) to provide a framework for discussing the potential application and location of the continuous coal analyzer. We could foresee the application of a coal analyzer to assist in control of plant operations. This is presently not feasible because the coal is burned within 62 hours of sampling, whereas the analysis is not available until much later. Thus the coal is burnt long before any corrective action based on complete analyses is possible.

Run-of-mine coals have the options of being washed for ash and sulfur control and dried for moisture control before transfer to the blending, storage, and loadout area. Vendor coal is also delivered by truck to this point.

An early warning coal sample is collected before the coal is loaded into a unit train for the 150-mile trip to the Montour plant rotary car dump. Elapsed time from the mine to the car dump is about 51 hours. The early warning coal sample is analyzed by an independent laboratory, and the results are distributed to the mine, the plant, and the fuels division.

A commercial coal sample is taken at the car dump and is analyzed at the PP&L laboratory. The results of this analysis are available after a period of about one week, whereas the coal will be burnt within 4 to 11 hours.

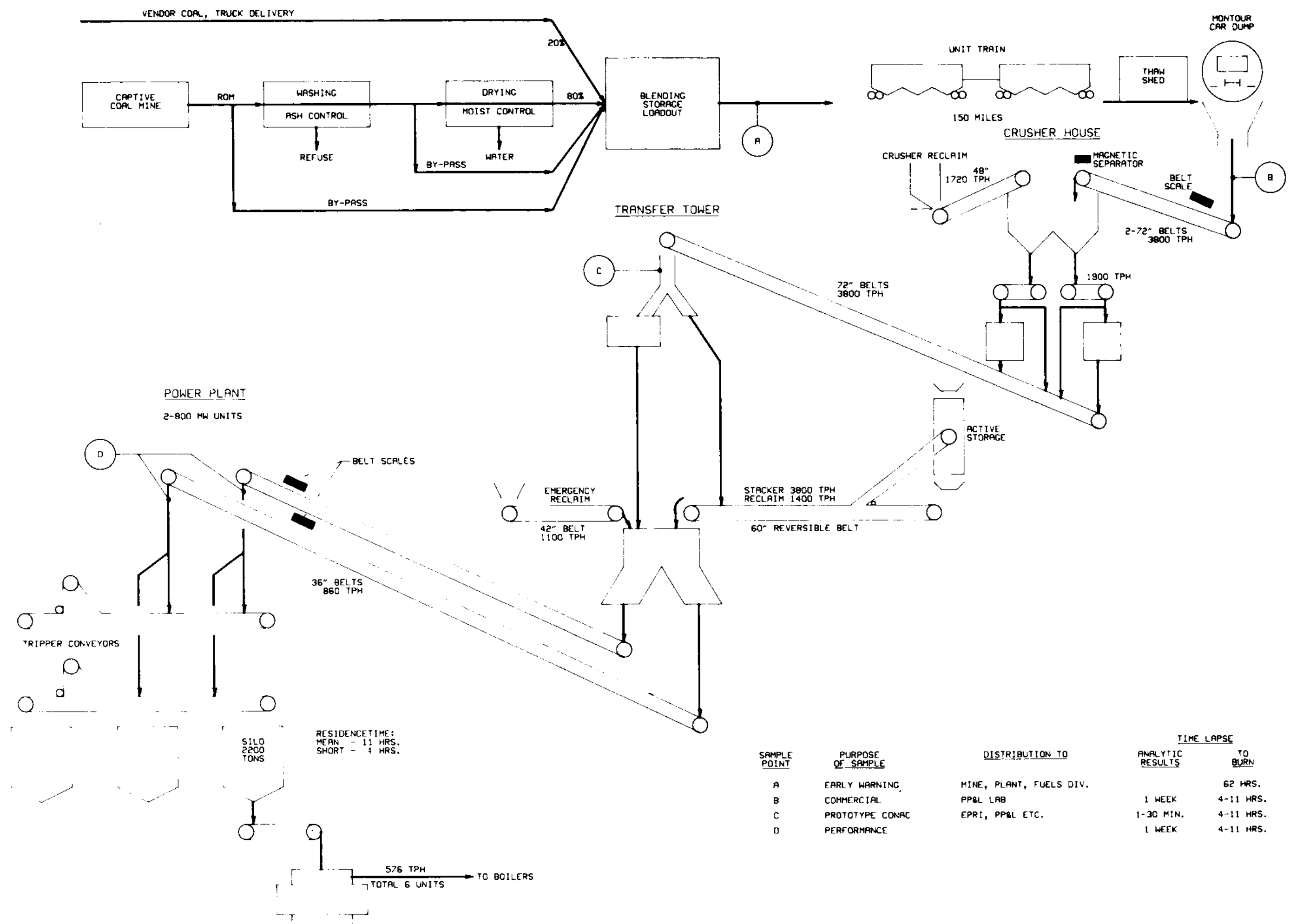
The coal is crushed and conveyed to the transfer tower, where the proposed CONAC prototype sampling point might be located. From this point the coal is either passed directly to the power plant silo feed conveyors or to the stacker/reclaimer for the active coal storage pile.

A performance sample is taken from the silo feed conveyor.

Alternative locations for the CONAC analyzer might be at the car dump or silos. Retrofitting at the transfer tower was considered to be more convenient for potential experimental purposes, however.

The potential applications and benefits of using the continuous coal analyzer are listed in Table 5.1.

COAL QUALITY CONTROL AND USE OF CONAC AT MONTOUR SE STATION



SAMPLE POINT	PURPOSE OF SAMPLE	DISTRIBUTION TO	TIME LAPSE: ANALYTIC RESULTS	TIME LAPSE: TO BURN
A	EARLY WARNING	MINE, PLANT, FUELS DIV.		62 HRS.
B	COMMERCIAL	PP&L LAB	1 WEEK	4-11 HRS.
C	PROTOTYPE CONAC	EPRI, PP&L ETC.	1-30 MIN.	4-11 HRS.
D	PERFORMANCE		1 WEEK	4-11 HRS.

Figure 5-1.

Table 5.1

POTENTIAL APPLICATION OF CONAC

Location	Use	Benefit	Evaluation
Mine	Feedback control for wash/dry process	Optimization of ash, sulfur %; fewer environmental problems at plant, reduction of energy cost to treat coal	None
Plant	Immediate:		
	1) Adjustment of excess air based on predictive analysis	a) Reduction of slag-related outages	Assume one outage/3 yr/unit ~$920,000/outage
		b) Performance improvement oxygen trim from 5% to 4%	~ $840,000/plant/2-yr period $440,000/yr/plant
	2) Environmental early warning		
	a) sulfur	a) Change of coal mix being put to silo	Reduced violation potential
	b) ash	b) Preparation of gas conditioning system for opacity control	Reduced violation potential
	Long Term:		
	Dynamic performance analysis via process computer	Ability to diagnose equipment problems quickly	None
	Elimination of manual ASTM sampling	Savings in labor	4 persons/plant at $20,000/yr $80,000/yr

A CONAC located at the mine could be useful for feedback control for coal washing and drying. One could then optimize ash as well as sulfur content. Fewer environmental problems would occur and there would be a reduction of energy cost to treat coal. Located at the plant, an immediate application of CONAC would be the ability to adjust excess air based on a predictive analysis of the coal ash. This information could also serve to reduce slag-related outages. It is currently estimated that approximately one outage occurs per unit every three years at an estimated cost of $920,000. For Montour, slag-related outages did cost $1.8 million over a 3-year period.

If excess oxygen can be reduced from 5% to 4% based on a predictive knowledge of the slagging characteristics of the ash, savings at the plant are estimated at approximately $440,000 per year.

Knowledge of the ash content in the coal could enable plant operators to prepare the gas conditioning system in advance so that opacity regulations are complied with and potential violations are reduced or avoided.

On a long-term basis, the availability of CONAC could enable one to use the plant process computer to compute true, real-time heat rates and to diagnose equipment problems more quickly. Further, one might anticipate the elimination of the manual ASTM sampling and analysis. The estimated reduction in labor costs for four persons at $20,000 each would be about $80,000 per year.

6.0 APPLICATION OF A REAL-TIME BTU METER FOR OPTIMAL LOAD DISPATCH

R. Thomas

Southwestern Public Service Company

Southwestern Public Service Company (SPS) feels that the development of a device or instrument to continuously analyze coal would be a significant contribution to the industry. Heat input measurement on a timely basis to a coal-fired boiler is not possible today. Coal analysis is a relatively slow and "after-the-fact" process. As a result, rapid decisions to make operational changes to influence plant performance cannot be made. In gas-fired power plants BTU and gas flow determinations are relatively easy, and the changes in plant operation can be evaluated in a matter of minutes. SPS sees several areas where a rapid evaluation of heat rate can provide significant improvements in power system performance.

First, in day-to-day operation of a generating unit the ability to evaluate equipment "faults" immediately is important. For example, a knowledge of condenser performance (its effect on heat rate) may dictate that cleaning may be necessary. The dollar value of restored cold water temperature can be used to justify the shut-down or partial shut-down for cleaning. Other component evaluations can be made on feedwater heaters, cooling towers, the operation of circulating water pumps as well as boiler operationsl deficiencies. The degree of plant cycle parameter measurements as well as boiler input BTU are very important to the evaluations.

Second, in complying with todays regulatory orders, the improvement of heat rate is extremely important. In the State of Texas, the rate structure provides for a fuel cost adjustment on the basis of a fixed heat rate (BTU/KWH delivered to the customer). The elements of this heat rate determination include the boiler and turbine performance and the losses in the transmission and distribution systems of the utility. Since improvements in heat rate below the fixed point increase profits, and poor performance above the fixed point provide a penalty, the instantaneous knowledge of unit heat rate is imperative. This again makes the ability to quickly analyze the coal stream going to the furnace an important function. It is predictable that audits by regulatory bodies will cause detailed investigations into a utilities heat rate improvement efforts. In addition, performance assurance programs make it mandatory to know the heat rate on all units in service.

Third, the accurate determination of the heat rate of all units in the system is necessary to economically coordinate and optimize the system fuel input. At SPS all the plants were gas-fired until 1976. At that time, we began operation of our first coal-fired unit. The bulk power supply system (all plants, transmission lines and interconnections) is operated and monitored by computer control from the System Operating

Center in Amarillo. All plant outputs are determined on a continuous basis to supply the instantaneous demand in the optimum manner. Economic loading considerations must include fuel cost, fuel availability, contract constraints and short and long term contract requirements. The basis on which coordination equations are based begin with a knowledge of each unit's heat rate at all loads. Scheduling equations also include optimization of losses. It is important to optimize losses as they affect the overall (plant to customer) heat rate.

To keep the heat rate curves that are used to administer the economic loading program current, periodic performance tests are conducted. Any changes in performance will be taken into account by altering the equations used in the loading programs. The objectives of our economic loading program include a goal to reconstruct unit heat rates on a real-time rather than historical basis. We feel that a continuous BTU meter on our coal units would enable us to move toward that goal with our coal-fired units.

SPS and the University of Texas are jointly conducting research on a gas-fired plant to determine the true nature of heat rate curves. To date, the testing indicates that the representation of heat rate as a function of load may be a three dimensional function. As this research continues and as the utility industry moves more toward coal, detailed tests will eventually need to be conducted on coal units. To make the results more accurate and anlysis more determinable, instantaneous coal analysis will be a necessity This is another way to apply the BTU meter such as CONAC.

7.0 TECHNICAL SUMMARY

Tsahi Gozani
Science Applications, Inc.

The status of the CONAC project was reviewed. The present status can be summarized by the following points:

- Advanced feasibility measurements using coal samples from across the United States have been completed.
- The results demonstrated clearly that all important coal constituents can be measured in a continuous real-time fashion.
- Reliable and accurate results for S, H, C, N, and Cl, as well as for mineral matter constituents (some of which are slag formers) -- Si, Fe, Al, Ca, Ti, Na, have been obtained for a wide variety of coals.
- On-line techniques to determine coal-moisture content in real time have been advanced.
- The problem of coal handling and presentation within the CONAC has been carefully analyzed and incorporated into the conceptual design.
- System concepts that are applicable to wide (most elemental constituents) or narrow (sulfur alone) applications have been developed.
- CONAC systems are adaptable to almost any part of the power station coal conveyance system.

The number of CONAC systems required for a power plant depends on their locations. To minimize the number of systems, one should locate the CONAC in strategic locations upstream from the boiler. This will provide reasonable analysis time of coal quality and provide central information for plant operators. If located at each coal pulverizer, for example, many installations may be required.

The information provided by CONAC, e.g., percentage weight of various elements in coal, is given virtually instantaneously. However, in order to improve precision, data accumulation over a period of a few minutes to few hours may be required, depending on the specific element of interest. Thus two parallel outputs can be provided: the instantaneous one, which allows a trend determination, and the more accurate one, which is updated every time the desired accumulation time has been reached.

From the preceding presentations, it appears that the application of CONAC to the control of coal blending by measurement of sulfur content is very clear-cut and is quite attractive economically.

Rapid analysis of the mineral (ash) content in coal can be useful in improving boiler operation by reducing the chances for slagging. CONAC measurement for the alkali elements, i.e., sodium and potassium, requires more time than for sulfur because the signal from the former is weaker. An analysis time of about an hour is anticipated. Note however that trend data are generated and are available during the hour measurement time. This time period is available by monitoring coal input to the storage silos. The information obtained (e.g., percentage weight of S, Na, or K) is retained for future operation of the boiler with the coal from the silos.

The ability to quickly analyze and accept or reject coal being delivered by trucks on the basis of quality suggests that a go/no-go analyzer would be useful. This should be achievable, but one would be giving up accuracy for speed. This should be possible within useful limits.

A Btu meter on coal for dispatch control will require measuring the total hydrogen content of the coal, the hydrogen in moisture as well as the carbon content. Carbon is a difficult element to analyze rapidly because of interferences from other elements, and this measurement is a more challenging task for CONAC. However, very accurate carbon measurements are routinely made now with our laboratory-type CONAC. The order of difficulty in analyzing elements in coal, starting with the easiest and ending with the most difficult, is as follows: hydrogen, sulfur, nitrogen, iron, chlorine, carbon, and silicon and the rest of the ash constituents.

The CONAC is ready now for implementation and demonstration. It can be readily integrated into the specific coal conveyance systems and be responsive to the specific needs of the interested utilities.

8.0 PRELIMINARY ECONOMIC ASSESSMENT

Owen J. Tassicker
Electric Power Research Institute

It is important at a very early stage to assess the potential economic benefit that might result from the successful application of CONAC. However, it is difficult to determine the ultimate cost of a CONAC installation even before the first prototype has been built. The discussions we have heard today are helpful in identifying some of the economic uses that may accrue from the CONAC development.

The technical goals for the laboratory development of CONAC under Phases I and II have been broadly achieved. Additional studies under Phase III and eventually Phase IV are needed for final development. However, based on the status of development at this early state, it appears that significant economic benefits result from continuous sulfur and ash analysis of large coal flow rates.

Instrument Cost

Initial estimates by the developer for a CONAC installation depend, in part, upon its ultimate sophistication, software, and offsite requirements. The estimates range between $200,000 and $500,000 for the commercial system. An additional $400,000 for an 8- to 12-month field demonstration and detailed analysis of the prototype will be required. While these figures are tentative, they do consider the major components that will be required.

Coal Blending Benefits

Bob Buckler has analyzed the potential economic benefit to Detroit Edison of sulfur monitoring to control coal blending. Detroit Edison must meet a fuel compliance limit of 2.3% sulfur in coal (24-hour basis), which is not to be exceeded between 1980 and 1984. In 1985 and beyond, a limit of 1% sulfur in coal must be met.

If a sulfur measurement technique is not available, the 1980 through 1984 compliance requirement would be met by using a mixture of 66% high sulfur and 34% low sulfur coal. There is an incremental $0.58/million Btu premium cost for the low sulfur coal.

If a sulfur meter is available, Detroit Edison projects that a more precise blending of an average of 77.5% high sulfur and 22.5% low sulfur coal could be used. The same degree of compliance could still be achieved, but with a corresponding savings in the premium cost for the low sulfur coal.

With the additional availability of a Btu meter, the percentage of high sulfur coal that could be used could be further increased to average 78.0% high sulfur coal and 22% low sulfur coal. The relatively minor reduction in low sulfur coal consumption, from 22.5% to 22.0%, is due to the similar Btu content in the high sulfur and low sulfur coals.

On the basis of this comparison, Detroit Edison projects that, with a sulfur meter, an annual savings in coal costs of between $9 million and $18 million could be made during the 1980 through 1984 period.

A Btu meter would save Detroit Edison an additional $2 million annually for a total annual savings in fuel costs of $11 million to $20 million. These savings may be increased for a greater difference in the Btu content between the high and low sulfur coal.

Excess Air Control Benefit

The use of a CONAC type analyzer at Pennsylvania Power & Light's Montour Station could result in several areas of savings. The adjustment of excess air based on predictive analysis of the ash composition is estimated to save $440,000 per year per plant, based on reducing excess oxygen on the average from 5% to 4%. For Montour, this savings could be $880,000 per year.

Plant Outages

By controlling ash content at Montour, slag-related outages can also be reduced. Slag-related outages are estimated to cost approximately $920,000 each, with a frequency of one occurrence per plant every two years. An estimate has not been made of the savings that could occur if slag-related outages were reduced, but presumably the savings would not be insignificant.

Labor Savings Benefit

At Montour, conversion from manual ASTM sampling to CONAC automated sampling may result in labor savings currently estimated at $80,000 per year. These savings will be offset, in part, by personnel required for the CONAC instrumentation.

Compliance Coal Benefit

The situation at the Kingston TVA plant is somewhat different. Here two projected savings are foreseen. In one instance, by ensuring that the coal received is in compliance, TVA protects itself from potential $35,000 per day fines for emitting excessive sulfur dioxide which might occur without means of analyzing sulfur content of truck delivered coal. A second savings is anticipated to occur from using a go/no-go sulfur meter that could reject unacceptable truck loads of coal at the plant gate.

Load Dispatch Control Benefit

Experience at Southwestern Public Service Company has demonstrated that load dispatch control based on fuel heat release rates is practical and has been practiced for a number of years with natural gas. Southwestern Public Service Company would like to do the same with coal. Southwestern Public Service Company, like many utilities, has a fuel adjustment clause by which fuel costs can be recovered. The software controls for load dispatch based on heat rate input have already been demonstrated, but information concerning coal-fired heat rates is needed in sufficient time to control load dispatch. This type of information--load dispatch based on heat release rate--is applicable to all multi-plant systems and can be applied to grid networks as well. Such economic analysis may have to be made on a utility by utility basis. Savings can be significant.

In summary, six CONAC instrumentation applications have been identified by utility users. Substantial cost savings are indicated. Additional cost savings should also occur as the CONAC technology is made available and more applications are identified.

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Appendix A

Report Schedule

APPENDIX A REPORT SCHEDULE

Companion volumes in print or planned are as follows:

Volume 1	Coal Composition by Prompt Neutron Activation Analysis - Basic Experiments (Available December 1978)
Volume 2	Coal Composition by Prompt Neutron Activation Analysis - Theoretical Modelling (Available January 1979)
Volume 3	Determination of Total Hydrogen Content in Coal by Nuclear Techniques (Available December 1978)
Volume 4	Moisture Determination in Coal - Survey of Electromagnetic Techniques (Available December 1978)
Volume 5	Moisture Determination in Coal by Microwave and Capacitance Techniques (Anticipated June 1979)
Volume 6	Mass Flow Devices for Coal Handling (Available December 1978)
Volume 7	Coal Rheology and its Impact on Nuclear Assay (Available December 1978)
Volume 8	Progress Review and some Industry Applications (Available January 1979)
Volume 9	Prototype Conceptual Design of Continuous Assay System in a Coal-Fired Power Plant (Anticipated April 1979)
Volume 10	Operation of a Continuous Coal Assay System - Laboratory Performance (Anticipated December 1979)
Volume 11	Operation of a Continuous Coal Assay System - Field Performance (Anticipated June 1980)

Appendix B

Abstracts

COAL COMPOSITION
BY
PROMPT NEUTRON ACTIVATION ANALYSIS
BASIC EXPERIMENTS

Research Project 983

Final Report - Volume 1

ABSTRACT

Prompt neutron activation analysis (PNAA) measurements for on-line real-time determination of coal composition are reported to study the effect of various operational parameters for optimal system design. Spectral data were obtained to provide information about the following parameters: coal thickness, coal bulk density, source-to-detector distance, conveyor belt versus bin geometry, neutron source shielding, detector shielding, coal composition, and detector type and resolution.

Measurements were made using high-sulfur Pittsburgh #8 and low-sulfur Wyoming bituminous coals.

Using a high resolution Ge(Li) spectroscopy system, more than 100 gamma ray peaks were identified from 14 elements, including those elements important to coal analysis--hydrogen, carbon, silicon, aluminum, sulfur, iron, nitrogen, sodium, potassium, titanium, and chlorine. A fast-running, relatively simple code was designed specifically to analyze coal PNAA spectra. Values of the weight-percentages for 12 elements in the Pittsburgh and Wyoming coal were obtained from the analyzed Ge(Li) data. There was generally good agreement with previously made ASTM-laboratory composition analysis, although some questions still remain about lack of agreement for hydrogen and aluminum and some of the minor constituents.

Measurements were also made with larger, more efficient NaI detectors. These spectra were enhanced and unfolded with the SAI MAZE code, to investigate the potential of specialized applications where assay of only a few of the more important coal elements is required.

COAL COMPOSITION
BY
PROMPT NEUTRON ACTIVATION ANALYSIS
THEORETICAL MODELING

Research Project 983

Final Report - Volume 2

ABSTRACT

Coupled neutron-gamma transport calculations were carried out to study the effect of various parameters on the measured capture gamma signal and to guide the design and assess the performance of the experimental program. Simplified one-dimensional models were used in the calculations. These models are shown, however, to yield useful and practical results by bounding the measured responses. The "clean" experiments described separately (Volume 1) were used to verify the theoretical findings and to determine the range of parameters used in the calculations. Important conclusions were obtained from this theoretical modeling.

The interaction between the experimental and theoretical programs has been shown to provide a better insight into the complex physical phenomena controlling the performance of the prompt neutron activation analysis (PNAA) method. In addition, the theoretical calculations enable us to study the relative magnitude of the various effects and hence to improve the overall capability of the PNAA system.

DETERMINATION OF TOTAL HYDROGEN CONTENT IN
COAL BY NUCLEAR TECHNIQUES

Research Project 983

Final Report - Volume 3

ABSTRACT

The hydrogen content of coal is of primary concern to both designers and operators of coal-based utility plants. This report reviews possible nuclear techniques for determining the total hydrogen content of coal, given the wide variations in composition and density found in practical measurement. This study was based on theoretical neutron transport calculations and laboratory experiments. This study has shown that hydrogen is most accurately determined by measuring the leakage of epithermal neutrons from a slab sample 30 cm thick. Using this method, hydrogen density was measured with an average absolute error of 6.2×10^{-4} g/cm^3. For example, for 6 percent weight hydrogen and an average bulk density of 0.7 g/cm^3, the average relative error is less than 1.5 percent. This result was achieved with no prior knowledge regarding the type, composition, and bulk density of the sample. Higher accuracy is achievable if the variations in coal type are bounded. Although this study was directed towards coal measurement, its main conclusions can in principle be applied to other solid materials of variable bulk density and elemental composition.

MOISTURE DETERMINATION IN COAL -
SURVEY OF ELECTROMAGNETIC TECHNIQUES

Research Project 983

Final Report - Volume 4

ABSTRACT

This survey consists of two basic parts. The first consists of a survey of various non-nuclear moisture determination techniques. Three techniques are identified as promising for eventual on-line application with coal; these are the capacitance, microwave attenuation, and nuclear magnetic resonance (NMR) techniques. The second part is devoted to an in-depth analysis of these three techniques and the current extent to which they have been applied to coal. With a given coal type, accuracies of ± 1% absolute in moisture content are achievable with all three techniques. The accuracy of the two electromagnetic techniques has been demonstrated in the laboratory and on-line in coal burning plants, whereas only small samples have been analyzed with NMR. The current shortcoming of the simple electromagnetic techniques is the sensitivity of calibrations to physical parameters and coal type. NMR is currently limited by small sample sizes and non-rugged design. These findings are summarized and a list of manufacturers of moisture analyzers is given in the Appendix.

MOISTURE DETERMINATION IN COAL
By MICROWAVE AND CAPACITANCE TECHNIQUES

Research Project 983
Final Report-Volume 5

ABSTRACT

Two electromagnetic techniques, capacitance response and microwave absorption, have been investigated for on-line moisture monitoring of coal. The response of instruments based on these techniques was measured using a representative range of U. S. coal types and moisture levels. Uncertainties in moisture determination of less than 5 percent were obtained with both techniques. However, a microwave interrogation is judged best for on-line application because it is both accurate and nonobtrusive. In on-line applications, this level of accuracy in moisture determination, combined with reasonable accuracies in determination, combined with reasonable accuracies in determination of the elemental content, will allow the Btu value of the coal to be deduced to accuracies of 2 percent or better.

MASS FLOW DEVICES FOR COAL HANDLING

Research Project 983

Final Report - Volume 6

ABSTRACT

The mass of coal entering the boiler per unit time is an essential parameter for determining the total rate of heat input. The mass flow rate of coal on a conveyor belt is generally determined as a product of the instantaneous mass of material on a short section of the belt and the belt velocity. Belt loading could be measured by conventional transducers incorporating mechanical or electromechanical weighers or by gamma-ray attenuation guage. This report reviews the state of the art in mass flow devices for coal handling. The various methods are compared and commented upon. Special design problems are discussed relative to incorporating a mass flow measuring device in a Continuous On-Line Nuclear Analysis of Coal (CONAC) system.

COAL RHEOLOGY AND ITS IMPACT ON
NUCLEAR ASSAY

Research Project 983

Final Report - Volume 7

ABSTRACT

A number of possible techniques for introducing coal to a continuous on-line nuclear analysis of coal (CONAC) system have been evaluated, including flow methods and nonflow methods. A modified flat-belt feeder system was recommended. The success of such a coal-presentation technique would rely on proper entry to the feed hopper, shape of the withdrawal opening from the feed hopper, and a slow belt speed to minimize demixing.