Energy &
Environmental
Research
Center

UNIVERSITY OF NORTH DAKOTA

15 North 23rd Street — P.O. Box 9018 / Grand Forks, ND 58202-9018 / Phone: (701) 777-5000 Fax: 777-5181

September 30, 1993

Ms. Karlene Fine
Secretary to the Industrial Comission of North Dakota
600 East Boulevard Avenue
Bismarck, ND 58505

Dear Karlene:

Subject: EERC Proposal No. 94–6223

The University of North Dakota Energy and Environmental Research Center (EERC) is pleased to submit the enclosed proposal in response to the North Dakota Industrial Commission solicitation entitled "Mitigation of Air Toxics from Lignite Generation Facilities." Subject to negotiation of a mutually agreeable contract between the EERC and the ND Industrial Commission, EERC is committed to participate in the proposed project.

EERC has actively begun soliciting sponsors for the matching share of this project: proposals have been submitted to eight potential sponsors requesting that each provide $20,000 in matching funds. Assuming project funding comes together as envisioned by EERC, $80,000 in Industrial Commission funds will be matched with $120,000 (six sponsors required) in commercial matching funds and this entire $200,000 will be matched with $200,000 in EPA funding available to EERC through EERC's Cooperative Agreement with EPA entitled "National Center for Excellence on Air Toxic Metals." EERC has discussed EPA participation in the project with EPA and has received a favorable response from them. While this is not a formal commitment from EPA, the EERC fully expects they will participate if the Industrial Commission and commercial matching are available.

Thank you for the opportunity to submit this proposal. If you have any questions, please call me at (701) 777-5215. Technical questions can be addressed to Thomas Erickson at (701) 777-5153.

Sincerely,

John G. Hendrikson

John G. Hendrikson
Assistant to the Director

Approved by:

Ronald E. Pyna

for Dr. Kenneth J. Dawes, Director
Office of Res. and Prog. Development

JGH/hcl

Enclosures

c/enc: Steven Benson
Tom Erickson

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MITIGATION OF AIR TOXICS FROM LIGNITE GENERATION FACILITIES

EERC Proposal No. 94-6223

Submitted to:

Karlene Fine

Industrial Comission of North Dakota
600 East Boulevard Avenue
Bismarck, North Dakota 58505

Submitted by:

Steven A. Benson
Thomas A. Erickson

Energy & Environmental Research Center
University of North Dakota
P.O. Box 9018
Grand Forks, ND 58202-9018

Thomas A. Erickson
Thomas A. Erickson, Principal Investigator

Ronald E. Pynn
for Dr. Kenneth J. Dawes, Director
Office of Res. and Prog. Development

September 1993

Amount Requested: $80,000.00

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MITIGATION OF AIR TOXICS FROM LIGNITE GENERATION FACILITIES

1.0 ABSTRACT

This proposal is written in response to the request for proposal (RFP) entitled "Mitigation of Air Toxics from Lignite Generation Facilities." Concerns over emissions of trace metals considered to be air toxics are increasing throughout the world. The work proposed in this project is designed to evaluate these concerns for lignite coal and to determine the potential application of technologies to control these emissions. The objective of this project is twofold: 1) to determine the trace element concentrations of eleven lignite coals and 2) to propose and test the most promising trace element mitigation methods.

The concentrations of eleven trace elements will be determined for eleven lignite coals as identified by the North Dakota Lignite Research Council (NDLRC). For each of the coals, the total amount of trace species that could potentially be emitted during combustion will be calculated and compared to the major source limits defined by the EPA. The continued work will concentrate on those elements that have the potential to exceed the EPA limits. Based on the potential for air toxic emissions, a series of control technologies will be investigated.

The air toxic-control technologies to be investigated include precombustion, combustion, and postcombustion sorbent injection, along with gas-conditioning agents. In addition, because the alkali and alkaline earth components (sodium, magnesium, calcium) in these coals may adsorb many of the trace metal, the ash constituents need to be considered as possible sorbents. The potential for these technologies to provide mitigation of trace metal emissions will be reviewed, and the most promising techniques will be tested. Bench- and pilot-scale testing of the sorbents and conditioning agents will be performed to accumulate

data on their effectiveness. The bench-scale testing will be used to screen the sorbents, and the pilot-scale testing will be used to determine the effectiveness of the sorbents in conjunction with conventional fine-particulate-control systems. The degree of control/capture of trace species will be compared and contrasted for all of the sorbents tested.

The results from this study will provide trace element data for selected coals as well as the potential of sorbents to serve as mitigation technologies for trace metal emissions. It is expected that one or several sorbents will be proposed as potential full-scale emission control technologies.

The duration of this project will be approximately 8 months at a total project cost of $400,000. The NDLRC will be responsible for $80,000 of the funding, with $120,000 coming from private industry and $200,000 from the U.S. Environmental Protection Agency (EPA) through the National Center for Excellence on Air Toxic Metals at the Energy & Environmental Research Center (EERC). Each industry participant will contribute $20,000 to the project. A search for industrial participants is underway. The following industrial affiliations are being contacted for participation; Basin Electric, BNI Coal, Limited, Electric Power Research Institute, Montana–Dakota Utilities, Knife River Coal Company, North American Coal Corporation, Minnkota Power Cooperative, Incorporated, Otter Tail Power Company, Wisconsin Power and Light Company, Cooperative Power Association, Minnesota Power, Minnesota Power. It is expected that six of these companies will participate in the project.

2.0 PROJECT SUMMARY

Concerns over emissions of trace metals, considered air toxics, from coal-fired power plants are increasing. The Amendments to the Clean Air Act of 1990 listed 189 substances as potentially hazardous air pollutants. Further, the Amendments established a schedule under which the EPA is required to establish maximum achievable control technology (MACT) standards for existing major sources of hazardous pollutants. A major source is any source which emits more than 10 tons per year of any one listed pollutant, or 25 tons per year or more of any combination of listed pollutants. Coal combustion is thought to be an important source for eleven metals on the list of 189 substances (antimony, arsenic, beryllium, cadmium, chromium, cobalt, lead, manganese, mercury, nickel, and selenium).

Emission reduction strategies for trace elements in both conventional and advanced combustion systems face the concurrent problems of 1) collection and removal of trace concentrations on a large scale, 2) the costs associated with the removal, and 3) eventual disposal of the trace species once collected. The current collection strategies are focusing on the use of sorbents as the removal method. The use of sorbents is an existing technology with many applications, and handling, injection, and recovery methods are already available. The primary concern is the selection of the best, most cost-effective sorbent or sorbents for a specific purpose. The sorbents to be examined are either conventional ones where a large volume of cheap disposable material with modest sorption capacity is used, or innovative ones that use a small volume of more expensive material with high sorption capacity, from which the trace metals are recovered and the sorbent material reused.

The objective of this project is to determine the applicability of using sorbents to control the emissions of trace elements during the combustion of lignite coals. Eleven coals, as chosen by the commission, will be analyzed using state-of-the-art methods, including atomic absorption (AA) and inductively coupled argon plasma spectroscopy (ICAP), to determine the concentrations of antimony, arsenic, beryllium, cadmium, chromium, cobalt, lead, manganese, mercury, nickel, and selenium. Along with the trace element analysis, the standard bulk-chemistry analyses will be performed. After reviewing the literature for the best methods to mitigate emission of the trace elements during combustion, three precombustion sorbents, one postcombustion sorbent, and one gas-conditioning agent will be selected for testing. Both conventional and innovative sorbents will be considered.

The three precombustion sorbents selected will be tested in a bench-scale, laminar-flow, drop-tube furnace (DTF) to determine their effectiveness in capturing the trace species. Both particulate and gas samples will be obtained during the tests to determine their trace element contents. After completion of the DTF testing, one of the three precombustion sorbents will be selected for further testing. The selected precombustion sorbent, the postcombustion sorbent, and the gas-conditioning agent will each be separately tested in a pilot-scale, 550,000-Btu/hr particulate test combustor (PTC) equipped with an electrostatic precipitator (ESP) and baghouse. The mitigation tests will be conducted with three of the eleven previously analyzed coals. Particulate and gas samples will be collected and analyzed using currently accepted EPA methods. The results from the PTC testing will be compiled to determine the reduction in trace element emissions as result of the three mitigation technologies tested. The ashes from the tests will be tested for their leachability, which may impact their potential disposal.

The testing conducted in this project will be directed towards the eventual full-scale application of these technologies. All testing will be done to best simulate the conditions in full-scale combustion systems.

3.0 PROJECT DESCRIPTION

3.1 Objectives

The overall objective of this project is to determine the usefulness of sorbents in controlling the emission of trace elements during the combustion of lignite coals. The sorbents include precombustion-, combustion-, and postcombustion-injection materials along with possible gas-conditioning agents. The specific objectives of the project are as follows:

- To determine the concentrations of eleven trace elements in eleven lignite coals
- To investigate the current state-of-the-art sorbents for trace element emission-control technology
- To test the most promising control sorbents
- To evaluate the effectiveness of the tested sorbents

3.2 Work Plan

To best meet the objectives, this project is broken into five tasks: Task 1 – Review of Trace Element-Removal Methods, Task 2 – Trace Element Characterization, Task 3 – Identification of Control Technologies, Task 4 – Combustion Testing, and Task 5 – Reporting. Each of these tasks is discussed in more detail below.

3.2.1 Task 1 – Review of Trace Element-Removal Methods

The current literature reporting research on the use of sorbents to capture air toxics metals will be reviewed, with particular attention to the characteristics and combustion behavior of North Dakota lignites. Much of the literature is already available at the EERC, and additional papers and reports will be obtained at the start of the project. The review will concentrate on the use of sorbents during and after combustion, along with potential gas-conditioning agents.

3.2.2 Task 2 – Trace Element Determination

The eleven coals which are to be selected by the North Dakota Lignite Research Council will be analyzed for major, minor, and trace species. The trace element quantities in the coals (antimony, arsenic, beryllium, cadmium, chromium, cobalt, lead, manganese, mercury, nickel, and selenium) will be determined using atomic adsorption (AA) and inductively coupled argon plasma spectroscopy (ICAP). The AA and ICAP techniques are two of the most sensitive techniques for determining trace elements. Each of these techniques has multiple variations which can be utilized to improve the detection limits for some of the elements. The major and minor species will be measured by x-ray fluorescence (XRF) and computer-controlled scanning electron microscopy (CCSEM). XRF measures the bulk composition of the major and minor species (sodium, magnesium, aluminum, silicon, phosphorus, sulfur, potassium, calcium, iron, and titanium) while CCSEM provides a more detailed analysis of the major and minor species by determining the size and composition distribution of the individual minerals in the coal. The association of inorganic components and the size and composition of minerals are very important to consider when a sorbent is selected because of the interactions that may occur between the coal inorganics (or ash-forming constituents) and the sorbents. The lignitic coals contain high levels of alkali and alkaline earth elements that have the potential to adsorb trace elements, especially elements such as arsenic and selenium that can form calcium arsenates and calcium selenates, respectively.

After the major, minor, and trace analyses are completed, three of the eleven coals will be selected for combustion testing. The three coals selected for testing will undergo proximate–ultimate, particle-size distribution, heat-content, and moisture analyses. In addition, chemical fractionation will be conducted to determine the association of major, minor, and trace elements. A duplicate analysis of the trace elements will also be run to ensure the ability to mass balance the combustion data.

3.2.3 Task 3 – Identification of Control Technologies

From the literature review and the coal analyses, the best sorbent-control technologies will be identified. The literature will aid in the decision by presenting previous work done by other researchers. The coal analysis will be used to evaluate the potential for the eleven trace elements to impact the current EPA guidelines. Three precombustion sorbents, one postcombustion sorbent, and one gas-conditioning agent will be selected for further testing. Section 5.1.5 of this proposal discusses the sorbents that could be used.

3.2.4 Task 4 – Combustion Testing

The control-technology tests will be carried out in two phases. Phase I will test the three selected precombustion sorbents. Phase II will test the best precombustion sorbent as determined in Phase I, the postcombustion sorbent, and the gas-conditioning agent. Mass balancing will be performed on all tests to determine the total recovery of the trace metals.

Phase I testing will be carried out in a laminar-flow, down-fired, drop-tube furnace (DTF). The drop-tube furnace, described in Section 3.4.1, is capable of running very closely controlled combustion conditions. The three sorbents chosen for testing will each be blended with the coal at a ratio determined from the literature and mass balances based on the EPA emission limits. The coal and sorbent will then be combusted in the DTF and the resultant particulate and gas samples collected as shown in the test matrix in Table 1. The particulate and gas stream will be collected using a water-cooled quench probe and the EPA's Sampling Method 29. The particulates will be aerodynamically separated into three sizes and the vapors will be collected in a series of impingers. The samples from the DTF will be analyzed using AA and ICAP for the trace elements along with XRF for the major and minor species. The results from the DTF combustion testing will be used to determine the best of the three sorbents. The best sorbent will be chosen by its ability to absorb the vapor-phase trace air toxics.

TABLE 1

Drop-Tube Furnace Test Matrix for Precombustion Sorbents

Sorbent	Residence Time, sec	Particulate Sample	Gas Sample
No Sorbent	2.5	Cyclones	Impingers
Sorbent 1	1.5	Cyclones	Impingers
	2.5	Cyclones	Impingers
Sorbent 2	1.5	Cyclones	Impingers
	2.5	Cyclones	Impingers
Sorbent 3	1.5	Cyclones	Impingers
	2.5	Cyclones	Impingers

The best precombustion sorbent along with the previously selected postcombustion sorbent and gas-conditioning agent will be tested in the pilot-scale particulate test combustor (PTC). The PTC unit is described in Section 3.4.1. Each of the three coals selected in Task 2 will undergo a maximum of four separate tests: baseline, precombustion sorbent, postcombustion sorbent, and gas-conditioning agent as shown in the test matrix in Table 2. The baseline test will consist of combusting the coal without any sorbents to determine the levels of emissions out of the system. The presorbent test will use the sorbent selected during the DTF testing to control the emissions of the air toxics. The postcombustion sorbent test will involve injection of a sorbent after the combustor and before the particulate removal device. The final test, gas-conditioning agent evaluation, will inject a gas after the combustion zone in an effort to force the vapor species into a solid form. The sorbent and gas-conditioning agent feed rates will be based on surface area of the materials and on reported literature rates of interactions. Each of these four tests will involve sampling of the gas and particulate stream at either two or three locations, before and after the particulate collection system (in the case of two sampling locations) or these two zones and at the exit of the combustion furnace (in the case of three sampling locations). The samples will be collected and analyzed similarly to the samples from Phase I. In addition to the gas and particulate samples, a sample of the collection-device ash will be retrieved for analysis and leaching studies. Both a toxicity characteristics leaching procedure (TCLP) and a synthetic groundwater leaching procedure (SGLP) will be used to determine the potential for trace elements to be leached from the ash material.

TABLE 2

Particulate Test Combustor Test Matrix for Sorbents

Coal	Sorbent	Sample Location	Particulate Sample	Gas Sample
Coal 1	None	Baghouse Inlet	Multicyclone	Impingers
		Baghouse Outlet	Multicyclone	Impingers
		Furnace Outlet	Filter	Impingers
	Precombustion	Baghouse Inlet	Multicyclone	Impingers
		Baghouse Outlet	Multicyclone	Impingers
		Furnace Exit	Filter	Impingers
	Postcombustion	Baghouse Inlet	Multicyclone	Impingers
		Baghouse Outlet	Filter	Impingers
	Gas Condition	Baghouse Inlet	Multicyclone	Impingers
		Baghouse Outlet	Filter	Impingers
Coal 2	None	Baghouse Inlet	Multicyclone	Impingers
		Baghouse Outlet	Multicyclone	Impingers
		Furnace Exit	Filter	Impingers
	Precombustion	Baghouse Inlet	Multicyclone	Impingers
		Baghouse Outlet	Multicyclone	Impingers
		Furnace Exit	Filter	Impingers
	Postcombustion	Baghouse Inlet	Multicyclone	Impingers
		Baghouse Outlet	Filter	Impingers
Coal 3	None	Baghouse Inlet	Multicyclone	Impingers
		Baghouse Outlet	Multicyclone	Impingers
		Furnace Exit	Filter	Impingers
	Postcombustion	Baghouse Inlet	Multicyclone	Impingers
		Baghouse Outlet	Filter	Impingers
	Gas Condition	Baghouse Inlet	Multicyclone	Impingers
		Baghouse Outlet	Filter	Impingers

Results from the PTC testing will be compiled to determine the effectiveness of the control technologies tested. The removal efficiency will be calculated for each element as a function of the control technology used and the coal composition. A mass balance will be calculated for the trace elements on each of the runs to ensure the efficiencies of the tests. The relationships between the forms of the trace species in the coal, sorbent type, injection mode, and collection will be determined.

3.2.5 Task 5 – Reporting

This task will consist of a kickoff meeting, two progress reports, and a final report and meeting. The kickoff meeting may be held in conjunction with the meeting for the EPA National Center for Excellence on Air Toxic Metals at the EERC if the timing of the projects coincides. Progress-report meetings will be held at critical decision points in the project, such as after the coal analysis section and before the additive/sorbent section, to allow for sponsor input and direction. The progress reports will also be a short summary, 3–5 pages, of theprogress in the project to date. These reports will serve to keep the project participants informed of the project's performance. The final report will contain the results of all the testing conducted as well as a discussion and summary. A final meeting will be held with the participants as well to discuss the project.

3.3 Deliverables

The deliverables for this project are:

1. Trace element data on eleven coals for eleven elements as specified.
2. Report of the state-of-the-art trace element sorbent technologies.
3. Combustion trace metal emission data for three coals using no sorbents.
4. Air toxic metal capture efficiencies for three precombustion sorbents.
5. Combustion-emissions data on three coals using two sorbents and a gas-conditioning agent.

3.4 Description of EERC Facilities

The energy and environmental research of today typically requires the expertise of a total-systems team that can focus on technical details, while retaining a broad perspective. More than 150 professional full-time scientists, engineers, and technicians are available at the EERC to address current problems and assess future needs. The multidisciplined engineering and scientific research staff is equipped with state-of-the-art analytical and engineering facilities. The main EERC facilities, with over 120,000 square feet of laboratory, pilot plant, and office space, are located on the southeast corner of the University of North Dakota campus. High-severity processes can be developed from conceptual ideas through proof-of-concept demonstrations in the flexible, EERC reactor systems. Laboratory- and pilot-scale combustors and gasifiers with capacities of up to 4.0 million Btu/hr, as well as diesel and gas turbine simulators, are available for evaluating new fuels and assessing new emission-control technologies. Analytical techniques and instrumentation are available for the characterization of solid, liquid, and gaseous materials. Thus the EERC can provide a total-systems assessment of a wide variety of energy, environmental, and mineral-resource research topics.

3.4.1 Combustion Testing Facilities

The EERC possesses the laboratory-, bench-, and pilot-scale reactors needed for this project. The following details the reactor facilities to be used.

3.4.1.1 Drop-Tube Furnace

The atmospheric drop-tube furnace (DTF) is a laboratory-scale, entrained-flow, tube furnace with the ability to combust coal and to produce ash under closely controlled conditions. Combustion parameters such as initial hot-zone temperature, residence time, and gas cooling rate can be closely controlled and monitored.

The furnace system, as shown in Figure 1, is housed in a three-floor laboratory specifically designed for clean and efficient operation of the system. The furnaces are mounted on furnace bars extending through all three levels and can be moved to accommodate specific applications. The adjoining control room provides a clean, climate-controlled environment for the electronic equipment associated with the drop-tube system.

The furnace assembly consists of a series of vertically oriented tube furnaces illustrated in Figure 2. These furnaces possess a total of four independently controlled, electrically heated zones, with the lower three zones capable of reaching temperatures of 1500°C. Each of these furnaces can be used separately or in conjunction with the other furnaces. This allows for maximum flexibility and precise control over combustion conditions.

Coal, primary air, and secondary air are introduced into the furnace system by means of a preheat injector. This system injects ambient-temperature primary air and coal into the furnace from a water-cooled probe assembly at the center of the tube. Secondary air is typically heated to 1000°C and introduced into the furnace through a mullite flow straightener. Thus the material to be combusted is introduced into the top of the furnace, along with preheated secondary air, and travels down the length of the furnace in a laminar-flow regime. Various sampling probes or collection devices can be used with the drop-tube furnace to collect ash samples.

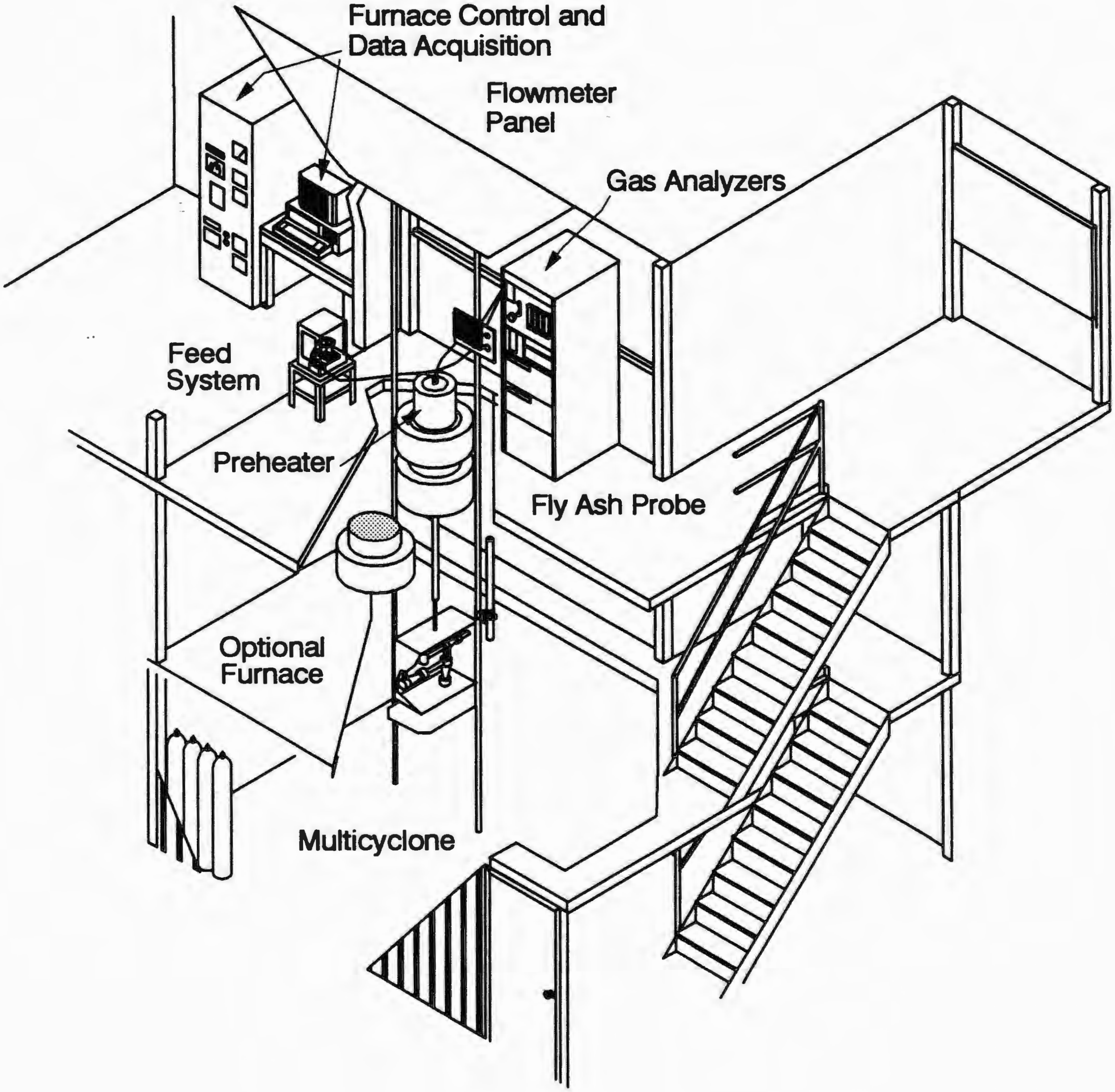

Figure 1. Schematic of drop-tube furnace.

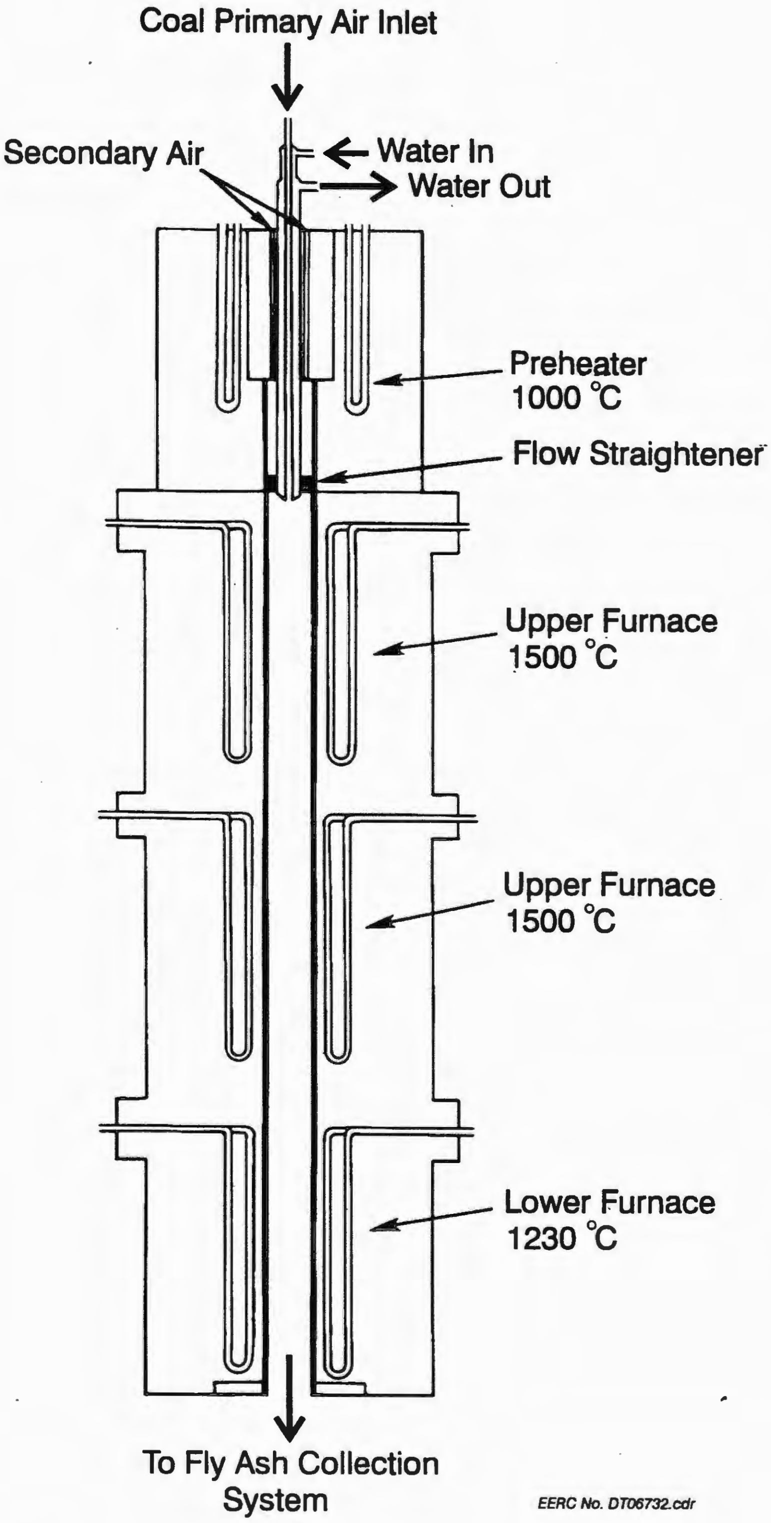

Figure 2. Schematic of furnace assembly.

Downstream of the sampling probe and collection filter, the combustion gas is cooled and passed through a filter before entering a diaphragm pump. The pump is designed so no air can leak into the sampling gas. The gas leaving the positive-pressure side of the pump is passed through a flowmeter that measures the volume of gas being pulled through the probe. After the flowmeter, part of the gas is directed through carbon monoxide, carbon dioxide, and oxygen analyzers. The concentrations of these gases can be read directly from the digital readouts of the analyzers. The analog output signals from the analyzers are routed both to a chart recorder and to an analog-to-digital board on a personal computer (PC). The gas concentrations and the coal feed rates obtained from the coal feed system are logged by the PC for data interpretation. The configuration of this system is shown in Figure 3.

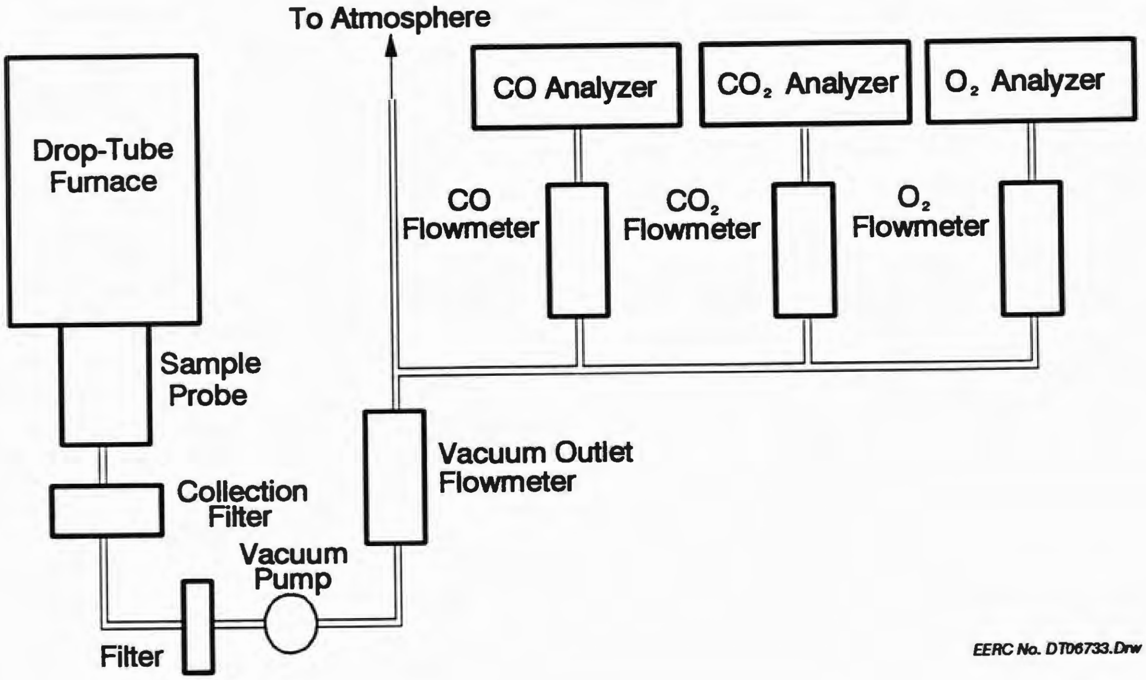

Figure 3. Gas-sampling schematic.

The coal feed system is designed to feed particles of various sizes in the pulverized-coal range at rates of 0.05 to 0.5 g/min and at primary-carrier gas rates of approximately 1 L/min. The basic apparatus shown in Figure 4 consists of a pressurized cylinder in which a container filled with coal is placed. A rotating brush and a stirrer attached to a variable-speed motor feed the coal from the container into a funnel where it is transported through the feed tubing into the furnace injector by the carrier gas. The coal feeder is mounted on a Mettler PM 2000 top-loading balance that is accurate to 0.01 gram. The balance is equipped with an RS232C interface, which allows recording and storing real-time coal feed rates on a PC.

A short-residence-time gas-quenching probe is used to collect ash samples at any residence time. The probe consists of a series of four concentric, water-cooled, steel tubes. The outer shell introduces the quench gas at the top of the probe. The combustion products pass through the innermost shell, and the remaining shells carry the cooling water. The probe is covered with a 2-in.-outside-diameter alumina insulating cylinder (Figure 5).

The probe is inserted in the bottom of the furnace at a set distance (calculated from the desired residence time) from the injector. The quench gas and the vacuum are turned on. The coal is fed through the preheat injector; the combustion products are quenched upon entering the probe; and the residue char or ash is collected on a filter attached to the probe's innermost shell.

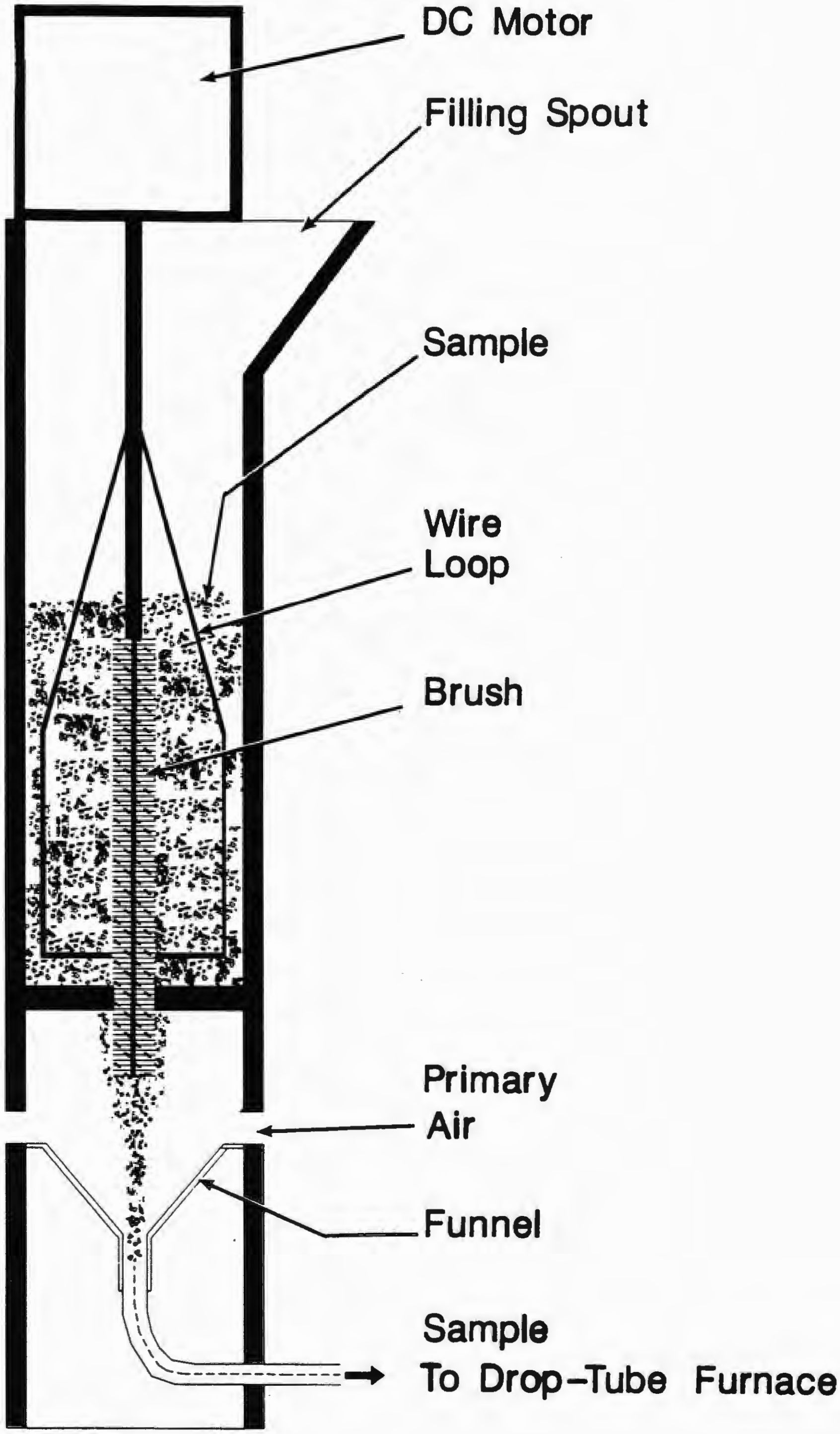

Figure 4. Coal feed system.

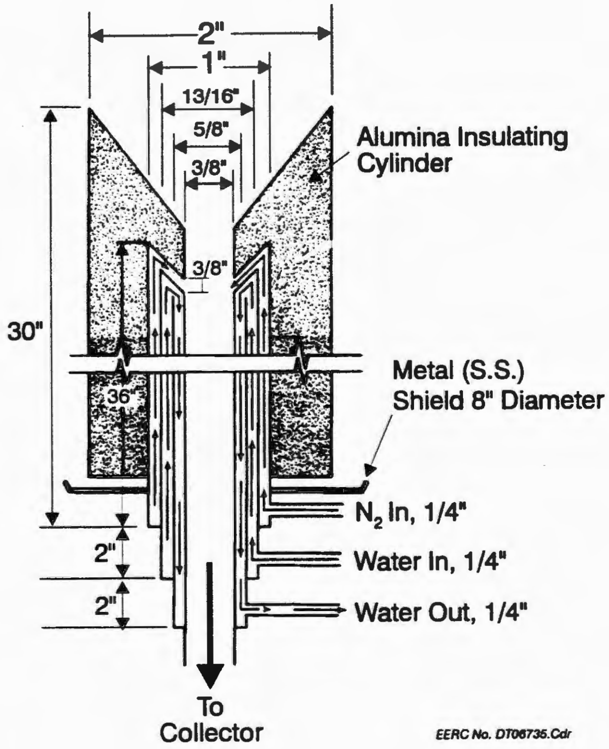

Figure 5. Schematic of short-residence-time gas-quenching probe.

A fly ash-quenching probe shown in Figure 6 can be attached to the bottom of the drop-tube furnace to cool the fly ash before collection. This system is reliable and versatile. Several collection devices can be added to the probe to collect the fly ash. The Environmental Protection Agency Southern Research Institute five-stage cyclone (EPAFSC) shown in Figure 7 is used routinely to collect fly ash. The operation of the EPAFSC is described in Section 3.4.1.3 in this proposal.

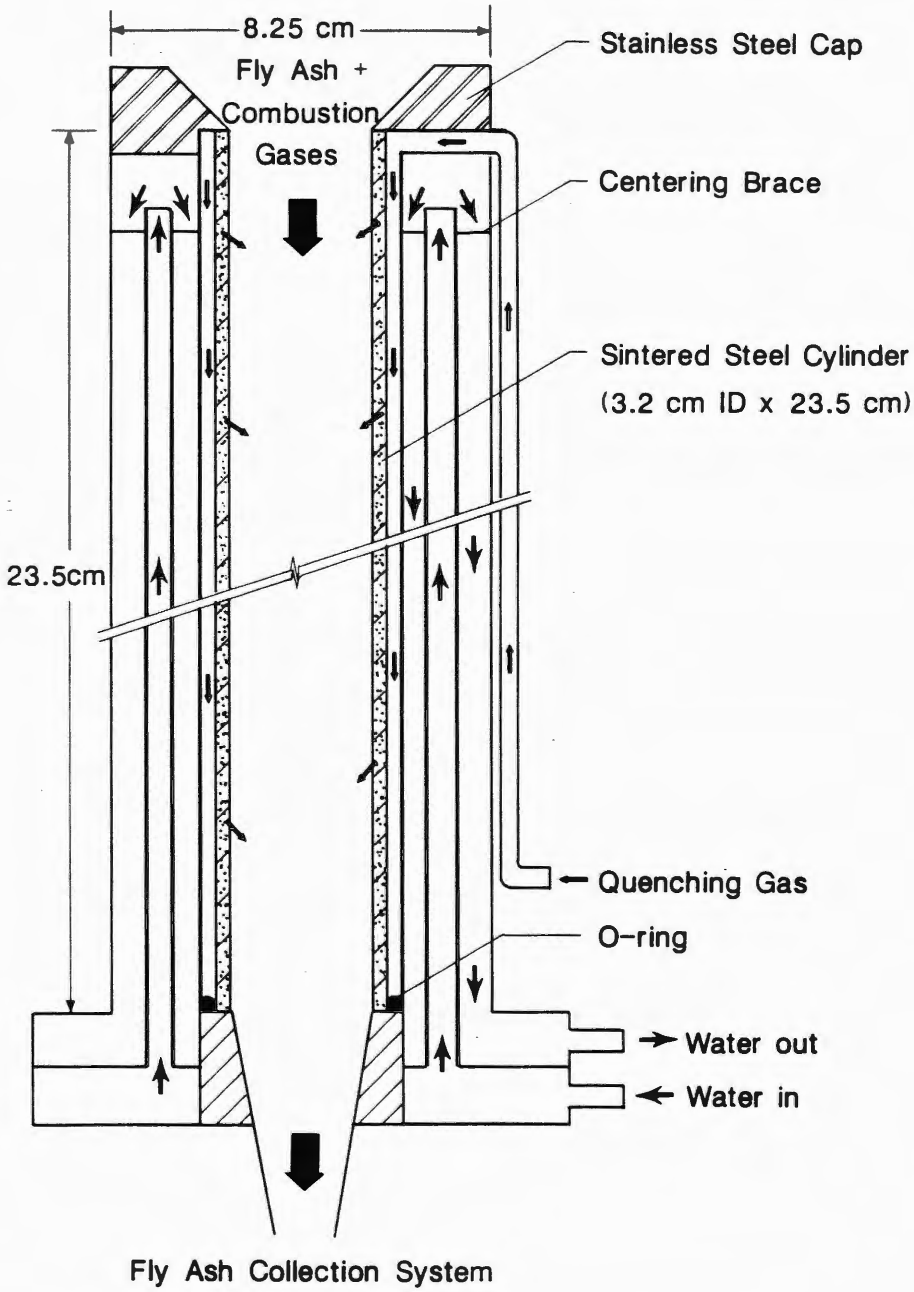

Figure 6. Schematic of fly ash-quenching probe.

3.4.1.2 Particulate Test Combustor

The pilot furnace, known as the particulate test combustor (PTC), is a 550,000-Btu/hr pulverized coal-fired unit designed to generate fly ash representative of that produced in a full-scale utility boiler. The combustor is vertically oriented to minimize wall deposits. A refractory lining helps to ensure adequate flame temperature for complete combustion and prevents rapid quenching of the coalescing or condensing fly ash. The mean residence time of a particle in the combustor is approximately three seconds, based on the superficial gas velocity. The coal nozzle of the PTC fires axially upward from the bottom of the combustor, and secondary air is introduced concentrically to the primary air with turbulent mixing. In addition, tertiary air is supplied above the base of the combustor. Coal is introduced to the primary air stream via a screw feeder and ejector. An electric air preheater is used for precise control of the combustion air temperature. Water-jacketed heat exchangers provide flue gas-temperature control to the baghouse or ESP. The PTC instrumentation permits system temperatures, pressures, flow rates, flue gas-constituent concentrations, and baghouse operating data to be monitored continuously and recorded on a data logger. Figure 8 illustrates the PTC schematically.

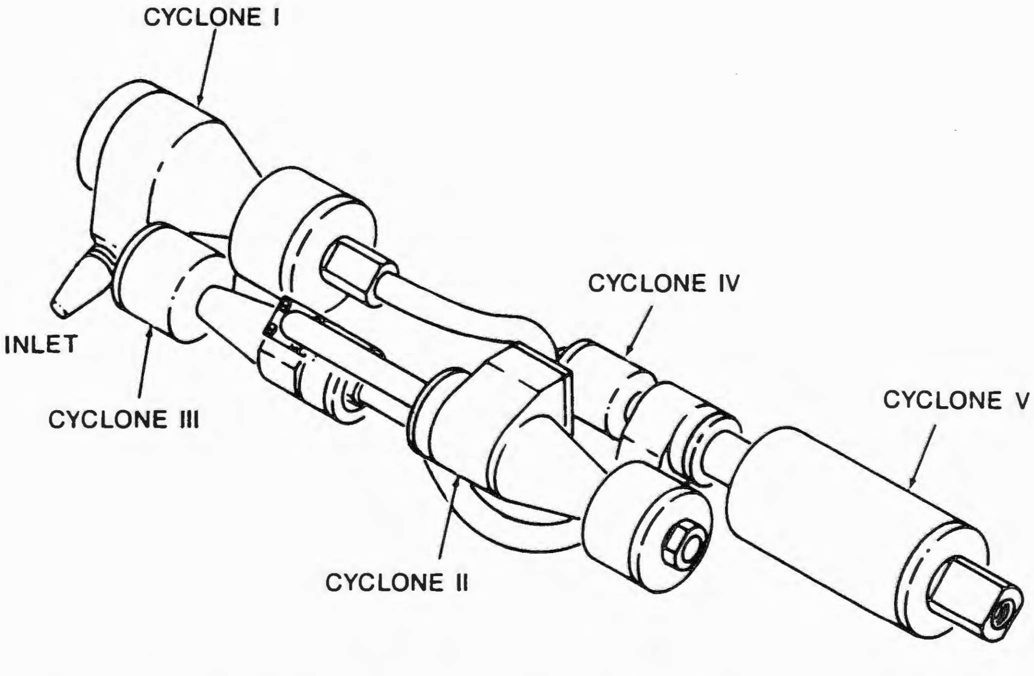

Figure 7. EPA Southern Research Institute five-stage cyclone (EPAFSC).

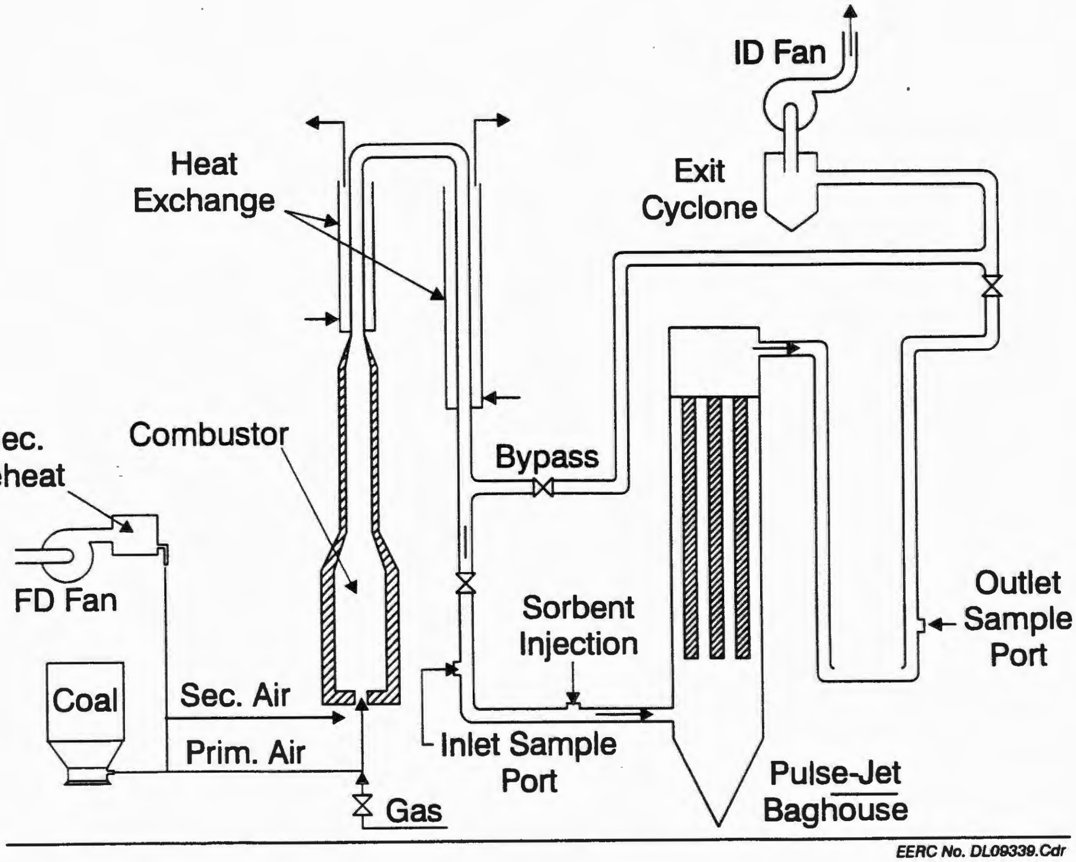

Figure 8. Combustion system used for tests showing the PTC and baghouse.

Flue gas samples can be taken at three system sample points: the furnace exit and the baghouse inlet and outlet. After passing through sample conditioners to remove the moisture, the flue gas is typically analyzed for O_2, CO_2, SO_2, NO_x, and CO. Except for CO_2 and CO, each constituent is normally determined simultaneously at both the furnace exit and outlet of the baghouse using two analyzers. The concentration values from all of the instruments are recorded continuously using circle charts. In addition, all data are manually recorded at set time intervals. NO_x is determined using two Thermo Electron Chemiluminescent NO_x analyzers. The O_2, CO, and CO_2 analyzers are made by Beckman, and the SO_2 analyzers are manufactured by DuPont. Each of these analyzers is regularly maintained and calibrated to provide accurate flue gas-concentration measurements.

The baghouse vessel is a 20-inch-ID chamber that is heat traced and insulated. Flue gas is introduced near the bottom of the baghouse. Since the combustor produces about 200 acfm of flue gas at 300°F, three 13-ft by 5-in. bags will provide an air-to-cloth (A/C) ratio of 4 ft/min. Each bag is cleaned separately with its own diaphragm pulse valve. The bags will be cleaned on timed intervals, rather than initiated by pressure drop, to quantify differences in pressure drop with different test conditions. Once bag cleaning is initiated, all three bags will be pulsed in rapid succession on-line. A new set of Ryton felted bags will be installed for each test. Baghouse specifications are given in Table 3.

3.4.1.3 Sampling and Particle-Sizing Equipment

The equipment used in the particulate sampling from the drop-tube furnace and particle test combustor includes an aerodynamic particle sizer, a condensation nucleus counter, multicyclones, cascade impactors, and an impinger train. Each of these is discussed in more detail below.

TABLE 3

Pulse-Jet Fabric Filter Specifications

Baghouse Temperature	200°, 300°, and 400°F
Air-To-Cloth Ratio	4 ft/min @ 300°F
Fabrics	Ryton needled felt with Ryton scrim, singed face of fabric in and plain side out, weight - 17.56 oz/yd^2, permeability - 39.4 cfm/ft^2 @ 0.5" WG, Mullen Burst - 496 psi
Bag Size	5 in. by 13 ft
Cages	Royal Wire Products Inc., 20 vertical wires; 6-in. ring spacing; 11-gauge galvanized wire
Bag-Cleaning Mode	On-line
Venturi	None
Pulse-Reservoir Pressure	40 psig
Pulse-Nozzle Diameter	0.5 in.
Pulse Volume Per Bag	0.3 scf

Near-real-time particulate measurements are conducted with an aerodynamic particle sizer (APS 33) manufactured by TSI, Inc. The primary advantages of this system are high resolution and short sampling time. In the APS, particle-laden air is passed through a thin-walled orifice, and because of their higher inertia, the particles lag behind the gas. The velocity lag is uniquely related to the aerodynamic diameter of the particles. Therefore, the aerodynamic diameter of a particle can be determined by measuring the particle velocity as it exits from the orifice. To measure the particle velocity, the APS employs a laser that is split into two beams. The light scattered by a particle passing through these beams is collected, and two signals are emitted, separated by the time taken for the particle to cross the distance between the two beams. From this time interval, which is measured electronically, the aerodynamic diameter is calculated. For most applications, the particle-size distribution for particles ranging in size from 0.5 to 30 μm can be obtained within 20 sec, giving near-real-time measurements. The particle-size distribution can be obtained on the basis of either a number or mass concentration. However, rather than looking at emissions of several particle sizes, fine-particle emissions can be combined by using a calculated value of respirable mass. The definition of respirable mass for the American Council of Governmental and Industrial Hygienists (ACGIH) is in Table 4. The ACGIH definition is extrapolated or interpolated to calculate the percentage of that particle size at the midpoint of each channel. The respirable mass from all of the channels is added to obtain the total respirable mass. This provides a convenient and effective method of plotting fine-particle emissions as a function of time.

TABLE 4

ACGIH Respirable Mass Definition

Aerodynamic Diameter, μm	Respirable Mass Fraction, %
2.0	90
2.5	75
3.5	50
5.0	25
10.0	0

To determine the concentration of submicron particles (0.01 to 1.0 μm), a condensation nucleus counter (CNC) is used. The CNC measures particle number concentration by using a light-scattering technique. Since the dry, submicron particles are too small to be easily detected by light scattering, the particles pass through an alcohol vapor which condenses on the particle, forming a droplet. Each droplet is large enough to scatter a detectable amount of light when it passes through a light beam. The droplet size is nearly independent of the size of the original particle over a wide range of particle sizes, so the light scattered is a function of concentration only, not of size distribution. This instrument is used independently as a continuous real-time monitor of the number of fine particles present in the flue gas. An impactor, prior to the gas stream entering the CNC, removes the particles larger than 1 μm, so the CNC measures the concentration of submicron particles only.

For both the APS 33 and CNC particle analyzers, a dilution system is employed. Dilution of the flue gas is necessary to prevent moisture condensation in the sensors and to reduce particle concentration, which, if too high, may exceed the maximum output of the CNC and may cause coincidence error in the APS. The APS pump draws the sample into the diluter volume. A second pump is used to draw off a portion of the flue gas to recycle it back as dilution gas after the flue gas has been cleaned and the moisture removed. Both the APS and CNC are operated simultaneously using this dilution system. The maximum dilution that can be obtained with this system is about 1:10; if higher dilutions are needed, the system is operated in conjunction with a model 3302 TSI diluter. With both systems operating, dilutions up to 1:1000 can be obtained. Typically, a differential-mobility particle sizer (DMPS) is also used in conjunction with the CNC to provide the submicron particle-size distribution. A DMPS sample requires approximately a 25-min period when the particulate emissions are fairly constant.

In addition to the CNC and APS, a modified EPA Method 5 is used to provide dust loadings at the inlet and outlet of the baghouse to determine the overall particulate-collection efficiency. Two outlet dust loadings were typically completed for each 8-hr test, and seven outlet dust loadings were typically completed for each 100-hr test. Each outlet dust loading is conducted over at least two complete cleaning cycles and, therefore, includes the spike in emissions just after pulsing the bags. Inlet multicyclone sampling provides another inlet dust loading measurement as well as a determination of the particle-size distribution for particles smaller than 10 μm.

The Environmental Protection Agency Southern Research Institute five-stage cyclone (EPAFSC) is used on a routine basis to collect fly ash. The EPAFSC is designed to make five equally spaced particle-size cuts (D_{50}) on a logarithmic scale within the range of 0.1–10 microns. The advantage of this system is its capability of collecting the relatively large sample amounts needed for subsequent chemical and morphological analyses. In addition to the EPAFSC, the University of Washington Mark 5 source test cascade impactor (STCI) is used during selected combustion tests. The STCI was developed as a means of measuring the size distribution of particles in stacks and ducts at air pollution emission sources. The Mark 5 impactor produces size cuts of fly ash particles by inertial separation. These data are used for comparison with the EPAFSC data to provide more detailed information concerning the effects of combustion conditions on the size distribution of the fly ashes.

A set of glass impingers is used for collection of the gas-phase species. A total of six impingers are included in the sampling train. Impingers 1 and 2 are filled with 200 mL of an aqueous solution of 10% hydrogen peroxide (H_2O_2) and 5% HNO_3. Impinger 3 is empty to prevent any mixing of the two types of trapping solutions. Impingers 4 and 5 are filled with an aqueous solution of 4 wt% potassium permanganate ($KMnO_4$) solution and 10% sulfuric acid (H_2SO_4). Impinger 6 contains silica gel to ensure that the flue gas is thoroughly dried before it leaves the impinger train. After collection of the vapor-phase species, the impinger solutions are analyzed using AA and ICAP.

3.4.2 Analytical Equipment

The following describes in detail the analytical facilities involved in this project. The analytical aspects of this project are critical to its success. The EERC has all of the needed analytical facilities on-site.

The EERC analytical laboratories have been designed to support energy and environmental research. Many of our analytical capabilities are unique as they offer analytical services designed specifically to address engineering problems in the field of energy research. State-of-the-art analytical facilities, combined with an experienced team of researchers, provide a full range of advanced materials characterization and data interpretation. An ongoing commitment to technique development has produced several unique analytical procedures. These advanced capabilities have made the EERC an internationally recognized analytical research laboratory, especially in the areas of coal and coal by-products characterization. Numerous industrial and government sponsors are presently contacting the EERC for analytical support and engineering problem-solving capabilities. The staff is also familiar with many EPA, ASTM, and other standard methods for analysis. The following outlines the selected equipment and capabilities of the laboratory that will be available for the trace element emissions program:

- Scanning electron microscopy (SEM) for imaging and photography at magnifications of 10 to 80,000
- Automated digital electron microscope/microanalytical imaging system for simultaneous image analysis, compositional data accumulation and data manipulation
- Automated quantitative multipoint energy and wavelength dispersive x-ray analysis for trace element determinations for SEM/microprobe system
  - Ultrathin window energy dispersive x-ray detector provides the capability to quantify elements with atomic numbers greater than that of sodium
- X-ray fluorescence energy dispersive spectrometer (XRF) for qualitative and quantitative determination of major, minor, and trace elements in coal and coal-related materials
  - Kevex Delta XRF analyst system, superberyllium thin-window detector enhances light element performance with detection capabilities down to and including fluorine, and secondary-target excitation for background suppression in complex multielement samples
- Dionex 2120i dual-channel ion chromatograph with auto sampler and conductivity, UV/Vis, and electrochemical detectors for the quantitative analyses of anions and cations at the part per billion level
  - Also equipped with and ASRS-1 anion self-regeneration suppressor for increased baseline stabilization and lower detection limits
- Dionex capillary electrophoresis system with UV/Vis and fluorescence detection for use in conjunction with the ion chromatograph for the separation of anion and cations as well as rare earth element determination

- Leeman Labs PS1000 sequential inductively coupled argon plasma/Echelle spectrophotometer with integrated computer, autosampler and Hildebrand grid nebulizer for quantitative, multielement analysis
  - Purged optics allow for increased analytical capabilities by expanding the wavelength coverage to a range of 178–800 ηm.
- Atomic absorption spectrophotometers (flame and electrothermal atomization) with options for deuterium arc or Zeeman background correction which allow for quantitative, trace element analysis at the part per billion level for highly complex sample matrices such as coal and coal fly ash-mixed acid digestion.
- Varian 3300 and 3400 gas chromatograph (GC) with flame ionization detector, photoionization detector and Hall electrolytic conductivity detector.
- Perkin Elmer 200 UV/Vis (scanning) spectrophotometer used for methods development to select absorption maxima for selection of detection wavelengths in capillary electrophoresis and ion chromatography. Also used for routine measurement of trace species amenable to spectrophotometric detection
- CEM MDS-2100 microwave sample-preparation system with power output of 950 W and in-board pressure controller for safe and efficient acid-digestion applications such as coal and coal combustion by-products
- Cynosure SLL 250 tunable dye laser with second harmonic generation and fluorescence detector for the determination of mercury, selenium, and arsenic at the parts per trillion level
- Beckman 915A and Dohrman DC-80 total-organic-carbon analyzer
- Leeman Labs PS200 automated mercury analyzer based on cold vapor atomic absorption spectroscopy for the determination of mercury with parts per trillion sensitivity due to the addition of an atomic fluorescence detector

4.0 STANDARDS OF SUCCESS

This project is designed to demonstrate the ability to control the emissions of air toxics during combustion of lignite coals. The standards of success by which this project can be measured are:

- The ability to quantatively determine the concentrations of eleven trace elements, considered to be air toxics, in eleven lignite coals using the highest degree of quality control. These concentrations can be used by the combustion industry to determine the potential for a specific coal to exceed the emissions ratings proposed by future legislation.
- Effectively relay to the sponsors the current state-of-the-art applications of additives in controlling air toxics during combustion. This information will be secured through in-house data and national and international literature.
- The production of high-quality data on the emissions of air toxics from a pilot-scale facility located at the EERC. These results will better allow the lignite industry to determine which of the eleven elements studied are present in the emissions of the system.
- Produce quality results demonstrating the ability of precombustion additives, postcombustion additives and gas-conditioning agents to aid in the control of air toxics.
- Demonstrate that the air toxics released during the combustion of lignite coals can be controlled using precombustion additives, postcombustion additives and gas-conditioning agents.
- The organization of all research around the eventual concept of full-scale application.

5.0 BACKGROUND

5.1 Introduction

Trace element emissions pose a problem to existing and emerging electricity-generating technologies that utilize coal, since volatile trace elements have the potential to be released to the environment as a result of combusting or gasifying coal. Some of these trace metals are considered air toxics. The 1990 Clean Air Act Amendments (CAAA) have significantly revised the regulation of hazardous air pollutants, specifically identifying 189 hazardous air pollutants. The Environmental Protection Agency (EPA) has been directed to assemble a list of both major- and area-source categories that emit those pollutants. The major sources of hazardous air pollutants are those that emit more than 10 t/yr of any hazardous air pollutant or 25 t/yr of any combination of hazardous air pollutants. The major sources will have to meet air emission standards based on the maximum-achievable control technology (MACT). Area sources include all other sources of hazardous pollutants. The area sources will be required to comply with emission standards based on generally available control technology (GACT). Further study of fossil fuel-fired power plants has been required under the CAAA. To develop effective technologies to control trace element emissions within anticipated regulatory requirements, the type and quantity of trace elements emitted from coal-fired systems must be determined as a function of system design, operating conditions, and coal composition.

The fate of trace elements in a coal-fired system is closely tied to the associations of trace elements in the coal as well as to system conditions. During combustion or gasification, these inorganic elements are partitioned into inorganic gases, liquids, and other solids. The degree to which these trace elements are transformed into the various states depends upon: 1) the characteristics of the elements and how they are associated with minerals and coal particles, and 2) system conditions—such as reducing and oxidizing environments, gas-phase composition, pressure, and temperature—which influence the partitioning of the air toxics among various gas, liquid, and solid inorganic components as a function of location in the system. Detailed knowledge of the reactions and transformations of trace metals provides essential information as to the form of the inorganic species at any point in the combustion or gasification system that aids in identifying applications for controlling trace metalic emissions. This information is essential to enhance existing and developing trace metal control technologies.

5.1.1 Health Effects of Trace Elements

The concern over trace elements considered to be toxic is not limited to the absolute concentration of the element in the coal but also depends on the fate of the element during combustion. Some of the trace elements volatilize during combustion and subsequently condense on the surfaces of other entrained species or condense to form very small particles. However, some elements, such as mercury and selenium can remain in the vapor phase throughout the combustion and air-pollution-control devices and be released into the environment. The very small particles are then enriched in combustion systems, which have shown enrichment of volatile trace elements with decreasing particle size. These elements include arsenic, antimony, barium, gallium, selenium, vanadium (Markowski and Filby, 1985), zinc, mercury, nickel, cesium (McElroy et. al., 1982), cadmium, lead, and thallium (Radian Corporation, 1980). The actual reported enrichment ratios when comparing larger-particle concentrations to fine-particle concentrations may be as high as 100.

Table 5 is a summary of the trace element concentrations for a variety of U.S. coals, enrichment factors, and health effects. The factors that determine the level of health hazard include the concentration of the element in the coal, the extent that the element is enriched in the fine (respirable) particulate matter, and toxic or carcinogenic effect on humans.

TABLE 5

Concentrations, Enrichment Factors, Permissible Exposure Limits, and Toxicity of Selected Trace Elements (ppm, unless indicated otherwise)

					Toxicity			
	Range	Avg.	Enrichment Factor[a]	Perm. Exposure	LD_{50}	Acute[b]	Chronic[b]	Carc.[c]
Arsenic	0.5-100	(25)	310	--	20	3	3	K
Boron	5-224	(55)	200	--	--	--	2	--
Cadmium	0.1-65	(0.24)	1900	40	27	3	3	S
Lead	4-218	(9)	1500	50	150	3	3	S
Mercury	0.05-5	(2)	560	50	27	3	3	--
Molybdenum	0.1-30	(6)	13	5000	190	--	1	--
Selenium	0.45-232	(4)	3100	200	3	2-3	--	S
Chromium	4-90	(20)	8	500	180	3	3	K
Copper	5-61	(18)	100	100	50	2	1	--
Fluorine	25-220	(89)	--	0.1	--	3	3	--
Nickel	3-80	(20)	32	15	800	3	3	K
Vanadium	11-78	(33)	14	50	200	2	--	--
Zinc	5-5350	(329)	260	5000	2000	1	1	S

[a] Enrichment factor of the trace element in atmospheric aerosols with respect to the earth's crust.
[b] 1 = slight, 2 = moderate, 3 = high.
[c] K = known, S = suspected.

TABLE 6

Silicate and Oxide Minerals Found in Coals (Modified after Raask, 1985)

Species	Chemical Formula
	Silica and Silicates - Common Occurrence
Quartz	SiO_2
Kaolinite	$Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$
Muscovite	$K_2O \cdot 3Al_2O_3 \cdot 6SiO_2O$
Illite	As Muscovite with Mg, Ca and Fe
Montmorillonite	$(1\text{-}x)Al_2O_3 \cdot x(MgO, Na_2O) \cdot 4SiO_2 \cdot H_2O$
Chlorite	$Al_2O_3 \cdot 5(FeO, MgO)_3 \cdot 5SiO_2 \cdot 7.5H_2O$
Orthoclase	$K_2O \cdot Al_2O_3 \cdot 6SiO_2$
Plagioclase	$Na_2O \cdot Al_2O_3 \cdot 6SiO_2$-Albite $CaO \cdot Al_2O_3 \cdot 2SiO_2$-Anorthite
	Silicates-Rare
Augite	$Al_2O_3 \cdot Ca(Mg,Fe,Al,Ti) \cdot O.2SiO_3$
Biotite	$Al_2O_3 \cdot 6(MgO,FeO) \cdot 6SiO_2 \cdot 4H_2O$
Sanadine	$K_2O \cdot Al_2O_3 \cdot 6SiO_2$
Zeolite	$Na_2O \cdot Al_2O_3 \cdot 4SiO_2 \cdot 2H_2O$
Analcime	$CaO \cdot Al_2O_3 \cdot 7SiO_2 \cdot 6H_2O$
Zircon	$ZrO_2 \cdot SiO_2$
	Oxides and Hydrated Oxides
Rutile	TiO_2
Magnetite	Fe_3O_4
Hematite	Fe_2O_3
Limonite	$Fe_2O_3 \cdot H_2O$
Diaspore	$Al_2O_3 \cdot H_2O$
	Carbonates
Calcite	$CaCO_3$
Dolomite	$CaCO_3 \cdot MgCO_3$
Ankerite	$CaCO_3 \cdot FeCO_3$
Siderite	$FeCO_3$
	Sulfides
Pyrite	FeS_2
Marcasite	FeS_2
Chalcopyrite	CuFeS
Galena	PbS
Sphalerite	ZnS
	Sulfates
Barite	$BaSO_4$
Gypsum	$CaSO_4 \cdot 2H_2O$
Jarosite	$K_2SO_4 \cdot xFe_2(SO_4)_3$
	Phosphates
Apatite	$Ca_5F(PO_4)_3$
Monazite	$(Ce,La,Y,Th)PO_4$

5.1.2 Association and Distribution of Trace Elements in Coals

The inorganic constituents (including trace elements) in coals consist of a complex mixture of cations associated with oxygen-containing functional groups and clay minerals, coordinated inorganic elements, and discrete mineral grains, such as clays, sulfides, carbonates, oxides, and sulfates. The association and abundance of the inorganic constituents vary as a function of coal rank. For example, lower-ranked subbituminous and lignitic coals contain high levels of oxygen, as compared to higher-ranked bituminous coals. The carboxylic acid groups act as ion exchange sites for significant quantities of sodium, potassium, calcium, magnesium, strontium, and minor amounts of barium. The minerals that are associated with coals are summarized in Table 6.

The association of major, minor, and trace elements has been investigated by numerous investigators (including Karner et al., 1984, 1986; Benson and Holm 1985; Benson, 1984; Finkelman, 1980, 1993). The associations of the major, minor, and trace elements are summarized in Table 7. The association of a trace element in a coal is a function of its chemical and geochemical properties as summarized in Table 8 for Beulah–Zap lignite. For example, the ionic potential of elements provides a rough indication of the possible association of the element in the coal. The ionic potential of elements is defined as the ratio of Z/r, where Z is the ionic charge, and r is the ionic radius. The ionic potential of elements has a great effect on the association of the element in mineral-forming processes. Elements having low ionic potential ($Z/r \leq 3$), such as sodium, magnesium, and calcium, associate as hydrated cations. Insoluble hydrolysates have ionic potentials of $3 < z/r < 12$ and include, for example, the elements aluminum, silicon, and titanium. Relationships with other elements also provide an indication of the association of the trace element in coals.

TABLE 7

Principal Associations of Elements in Coals

Na	Organically bound, some Na montmorillonites, zeolites
Mg	Organically bound, carbonates
Al	Clay minerals, possible hydroxide or coordinated
Si	Clay minerals, quartz
P	Organically bound, phosphates associated with rare earth elements, in various phosphates, some may be organically associated
S	Sulfides, sulfates, organically bound,
Cl	Inorganic association, organically associated
K	Associated with illite and other K-bearing clay minerals, organically bound
Ca	Organically bound, carbonates
Sc	Unclear, inorganic clay minerals, clays, phosphates, or may have organic association
Ti	Rutile, associated with quartz and clay minerals, titanium oxides, organic associations, clays
V	Organic and inorganic association, in clays (illite)
Cr	Inorganic, clays
Mn	Organically bound, carbonate minerals, in siderite
Fe	Oxides, hydroxides, sulfides, sulfates
Co	Inorganic, sulfates, associated with sulfides such as pyrite and linnaeite
Ni	Unclear, inorganic, sulfides, may be with sulfides, organics, or clays
Cu	Chalcopyrite
Zn	Inorganic, sulfides, sphalerite
Ga	Clays, organic association, sulfides
Ge	Organic association, rarely in silicates, sphalerite
As	Inorganic, sulfides, solid solution in pyrite
Se	Inorganic, sulfides, organically associated, as PbSe in Appalachian coals
Br	Possible organic association
Rb	Organically bound, probably in illite
Sr	Organically bound
Y	Inorganic, possibly carbonates, rare earth phosphates
Zr	Zircon (mineral)
Nb	In oxides
Mo	Unclear, probably with sulfides, or organics
Ag	Inorganic, possibly sulfides
Cd	Inorganic, possibly sulfides, in sphalerite
Sn	Inorganic, tin oxides or sulfides
Te	Unclear
I	Organic association
Ba	Organic, sulfides, in barite, crandallites, and other Ba-bearing minerals
La	Inorganic, phosphates
Ta	In oxides
W	Unclear, may be organically associated
Re	Unclear, sulfides or organics
Pt	Probably native Pt alloys
Au	Native gold, gold tellurides
Hg	In solid solution with pyrite
Tl	In sulfides, probably epigenetic pyrite
Pb	Coprecipitated with Ba, Galena, PbSe
Bi	Accessory sulfide, perhaps bismuthinite
Ce	Inorganic, phosphates
Sm	Inorganic
Eu	Inorganic
Yb	Inorganic
Th	Inorganic, phosphates, in rare earth phosphates
U	Inorganic, organic association, zircon

TABLE 8

Qualitative Relationships Between Geochemical Properties and Elemental Distribution in the Beulah-Zap Seam (Beulah Mine) (Schobert et al., 1987)

	Orange Pit	Upper Seam	Lower Seam	Chemical Fractionation Behavior*	Affinity	Ionic Potential Z/r
Na	E	E	CE	IE	Organic	1.0
Mg	E	E	E	IE	NC	3.0
Al	T-MA	MA	B-MA	AS, RS	Inorganic	5.9
Si	T-MA	IR	E	RS	Inorganic	9.5
P	ND	IR	B-MA	ND	Inorganic	14.3
S	IR	IR	MA	RS, IE	Organic/Inorganic	17.1
Cl	E	E	E	ND	NC	
K	E	E	E	RS, AS	Inorganic	0.75
Ca	E	CE	E	IE, AS	NC	2.0
Sc	MA	MA	MA	RS, AS	NC	3.7
Ti	T-MA	IR	B-MA	RS	Inorganic	5.9
V	E	MA	B-MA	AS	NC	4.0
Cr	MA	MA	B-MA	S	Inorganic	4.8
Mn	E	T-MA	T-MA	AS, IE	NC	2.5/6.7
Fe	IR	IR	B-MA	RS, AS	Inorganic	2.7/4.7
Co	B-MA	ND	ND	AS, RS	Inorganic	2.8
Ni	IR	E	MA	RS	Inorganic	3.0
Cu	IR	E	B-MA	ND	Inorganic	1.0/2.8
Zn	IR	ND	ND	RS	Inorganic	0.88/2.7
Ge	ND	ND	ND	ND	ND	2.7/7.5
As	IR	IR	IR	RS	Inorganic	10.8
Se	CE	IR	B-MA	RS	Inorganic	14.3
Br	B-MA	MA	CE	ND	NC	
Rb	ND	ND	ND	ND	ND	0.68
Sr	E	ND	ND	IE	Organic	1.8
Y	MA	ND	ND	ND	ND	3.4
Zr	T-MA	ND	ND	RS	ND	5.1
Ru	E	E	B-MA	ND	Inorganic	6.0
Ag	IR	ND	ND	ND	ND	2.2
Cd	ND	E	E	RS	NC	0.87/2.1
Sb	IR	B-MA	B-MA	RS	Inorganic	4.0
Cs	T-MA	B-MA	B-MA	RS	Inorganic	0.6
Ba	E	T-MA	T-MA	IE, AS	NC	1.5
La	B-MA	IR	MA	AS, RS	Inorganic	2.6
Ce	B-MA	IR	B-MA	AS, RS	Inorganic	2.9
Sm	MA	MA	E	AS, RS	Inorganic	3.1
Eu	MA	MA	MA	AS, RS	Inorganic	3.2
Yb	MA	MA	MA	AS, RS	NC	
Th	T-MA	MA	B-MA	RS	Inorganic	3.9
U	T-MA	MA	B-MA	AS, RS	Inorganic	4.2

Patterns of Distribution in Coal Seam

E – Even distribution
MA – Enrichment at both margins
T-MA – Enrichment at top margin
B-MA – Enrichment at bottom margin
CE – Enrichment at the center of the seam
IR – Irregular
NC – No correlation

*Chemical Fractionation Behavior

IE – Ion-exchangeable
AS – Acid soluble
RS – Remains in the residue
ND – Not determined

5.1.3 Quantification of Trace Element Associations in Coals and Coal Combustion-Derived Materials

As described above, trace elements in the coal are found in several associations, including mineral and organic (salts of organic acids and coordination complexes). To determine the behavior and eventual fate of the trace elements in coal-utilization systems, these associations must be determined or estimated. During combustion, trace elements are transformed into gases, liquids, or solids in the following forms: elements, hydrides, hydroxides, sulfides, oxides (reduced forms), and silicates. The presence of potentially harmful elements in a process stream is not de facto evidence for eventual environmental impact. The complete characterization of each stream is essential for a true evaluation of potential impact. A determination of the quantity of an element by itself is relatively meaningless for predicting environmental effects. Therefore, the quantity and the form of the toxic trace elements must be elucidated in the coal and the combustion products.

Extensive research on the transformations of inorganic and mineral components in coal has been conducted at the EERC. Conventional ASTM techniques for analyzing coal and coal ash materials do not provide adequate detail regarding their complex chemical and mineralogical properties. Advanced analytical techniques are currently used to determine the association and forms of inorganic components in coals (Zygarlicke and Steadman, 1990) and coal ash-derived materials (Steadman et al., 1991) using scanning electron microscopy/microprobe techniques. When SEM is combined with wavelength dispersive analysis, some trace element associations can be determined directly (Finkelman, 1980; Galbreath and Brekke, 1993). In addition, chemical fractionation is used to determine the association of major, minor, and trace elements (Benson and Holm, 1985; Karner et al., 1986).

Computer-controlled scanning electron microscopy (CCSEM) is used to characterize unaltered coal samples and inorganic combustion products to determine major and minor minerals. The reason this technique is important is that many of the trace elements are associated with minerals in the coal, and information on the major components must be known to determine and to predict the fate of the trace species. In addition, manual SEM microprobe analysis using both energy-dispersive and wavelength-dispersive x-ray analysis of coal minerals (Finkelman, 1980; Galbreath and Brekke, 1993) is an effective means to detemine trace element–mineral associations.

Quantification of the association of major, minor, and trace elements in coals is currently performed using a technique called chemical fractionation (Benson and Holm, 1985). Chemical fractionation is used to selectively extract elements from the coal based on their solubilities, which reflect their association in the coal. Briefly, the technique involves extracting the coal with water to remove water-soluble elements such as sodium in sodium sulfate or those elements most likely associated with the groundwater in the coal. This is followed by extraction with 1 M ammonium acetate to remove elements such as sodium, calcium, and magnesium that may be bound as salts of organic acids. The residue of the ammonium acetate extraction is then extracted with 1 M HCl to remove acid-soluble species, such as iron and calcium that may be in the form of hydroxides, oxides, carbonates, and organic species. The components remaining in the residue after all three extractions are assumed to be associated with the insoluble mineral species such as clays, quartz, and pyrite.

Because there is no coal analysis technique that can automatically generate the concentrations of trace element contents in specific minerals, some association assumptions need to be made based on:

- Past trace element studies in the literature,
- Manual SEM microprobe analysis using a wavelength-dispersive spectrometer (WDS) on minerals in the test coals to note trace element associations, and
- Quantitation of trace elements in drop-tube furnace fly ash collected in an impactor collection device using a bulk detection analysis such as AA.

There have been some investigations performed to correlate trace elements with appropriate organic and inorganic portions of the coal. Common associations between trace elements and minerals are given in Table 7. Extensive work (Schobert et al., 1987; Karner et al., 1984, 1986) has been performed to determine inorganic and organic associations of trace elements in a low-rank coal, and the summary is listed in Table 8.

Trace elements can be measured in coal and coal ash-related materials by AA and ICAP spectroscopy, as appropriate. All samples must be put into solution for AA and ICAP analyses using sample-preparation techniques, such as pressure acid decomposition, microwave-enhanced acid digestion, and fusion fluxing. Specific analytical methods and sample-preparation techniques are appropriately selected for the elements of interest and the sample form. For a chemical characterization to be useful in predicting potential environmental hazards, elements that may be hazardous must be included. To best accomplish this, trace elements to be determined are selected on the basis of an initial screening procedure. Although no single analytical technique can perform at this level, several techniques, such as proton-induced x-ray emission (PIXE) or neutron activation analysis (NAA), are broad enough in scope to be useful. These techniques are used to screen for the elements sodium through uranium. PIXE is frequently used by the EERC for the screening analysis of coal conversion products.

The elements that appear to be at a sufficient level to pose an environmental problem will be further characterized using more sensitive techniques, such as graphite furnace atomization (GFA), atomic absorption spectroscopy inductively coupled argon plasma (ICAP), and ion chromatography (IC). The screening step prevents the determination of elements that are not present in amounts large enough to be of concern. In addition, potentially problematic elements found to be present in significant quantities by PIXE can be quantified. In addition to elements identified in the screening, a selection of elements known to accumulate as a result of coal conversion, as well as the RCRA elements (for regulatory purposes), will be included. These elements are arsenic, barium, boron, cadmium, chromium, lead, mercury, molybdenum, selenium, and silver. Potential environmental problems are rarely overlooked through the use of careful elemental screening. However, this analytical approach, (an initial, thorough screening) saves considerable time by focusing the analyses only on significant elements.

5.1.4 Trace Element Transformations during Combustion

The transformations of inorganic components, including trace metals, during combustion consist of a complex series of chemical and physical transformations that are dependent on the physical and chemical properties of the coal and combustion conditions. The behavior of the trace metals in the combustor depends on the initial partitioning of ash components during boiler operation. This partitioning influences the distribution of the ash species in slags, entrained ash, deposits, hopper ashes and vapors. Partitioning can be responsible for concentrating volatilized species in the smaller, entrained ash particles and on the surfaces of ash particles or in vapors leaving the system. Studies of the final ash product (fly ash) produced in combustion systems indicate a bimodal size distribution (Sarofim et al., 1977; Flagan and Friedlander, 1978; Damle et al., 1982; Benson et.al, 1993). The submicron-size particles form as a result of homogeneous condensation of flame-volatilized species. Flame-volatilized species may also condense heterogeneously on the surfaces of larger particles. The larger particles, sometimes referred to as residual ash, are largely derived from mineral grains. The composition and size distribution of the larger particles are a result of the transformations and interactions between discrete mineral grains in higher-rank coals. In lower-rank coals, the interaction of the organically associated elements with mineral grains occurs as well as mineral–mineral interactions. Processes such as vaporization/condensation, mineral coalescence, and partial coalescence; ash shedding and char fragmentation during char combustion; gasification; and mineral fragmentation all play an important role in the size and composition of the final fly ash.

The transformation mechanisms during combustion and gas cooling need to be more clearly elucidated. The trace element-transformation mechanisms are currently being incorporated into the framework of the major mineral- and inorganic-transformation mechanisms that have already attracted significant attention. The major inorganic component-transformation mechanisms have been determined (Benson et. al, 1993; Zygarlicke et. al. 1992; Wilemski et. al., 1992). Better understanding of these mechanisms has allowed for the development of computer codes to predict the particle-size composition distribution of the major inorganic constituents. A model is under development to predict the fate of seven trace elements during gasification (Erickson and Benson, 1993). These computer-based tools can be used as a guide for directing experimental work.

Trace metals have been classified (Ratafia-Brown, 1993; Clarck and Sloss, 1992) based on their volatility, as illustrated in Figure 9. Class I includes those elements that show no significant enrichment or depletion in the fly ash. Class II elements show increasing enrichment with decreasing particle size and a depletion in the bottom ash. Class III elements are vaporized and remain in the vapor phase. The Class III elements are the most volatile, and they include mercury, selenium, fluorine, and chlorine. The Class II elements are volatile but condensable, and they include barium, cromium, nickel, arsenic, cadmium, lead, antimony, thallium, and zinc. The Class I elements are not volatile and include scandium and thorium.

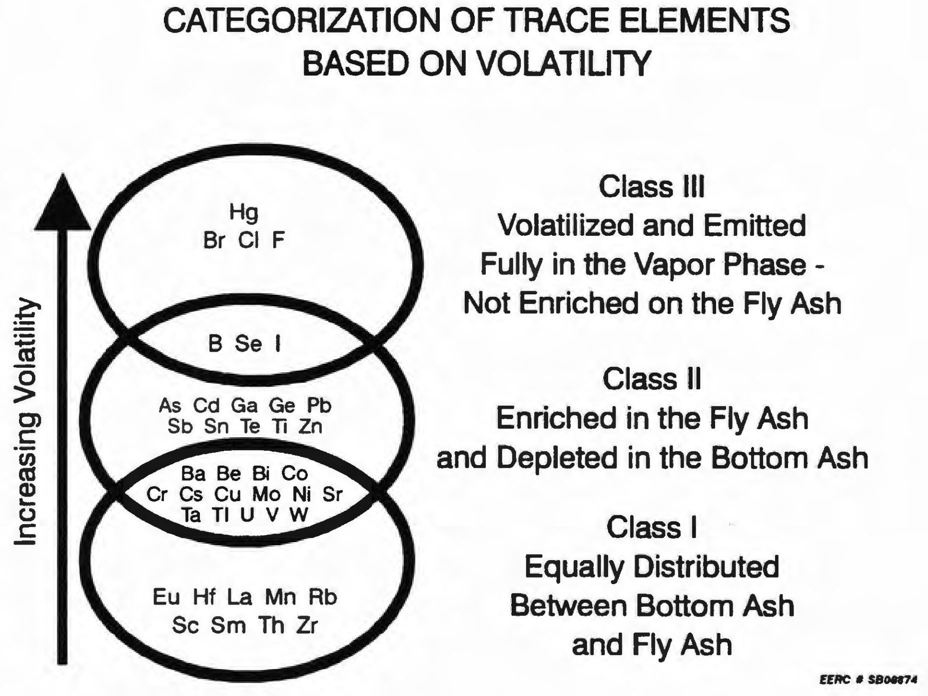

Figure 9. Classification of trace metals according to their volatility and partitioning in power plants.

The Class III elements, those that are the most volatile and can more easily escape the combustion and air-pollution-control equipment, require the highest priority relative to research needs. These elements include mercury and selenium. The next-highest priority of elements includes arsenic, cadmium, lead, antimony, and thallium.

5.1.5 Sorbents for Controlling Trace Metal Emissions

As discussed in the partitioning portion of this proposal, the trace metal components are transformed into inorganic gases, liquids, and solids upon combustion. Partitioning is influenced by the mode of occurrence of the trace elements in the coal and the combustion conditions. Of specific interest are the Class II and Class III trace metals because they vaporize upon combustion. Minimizing the vaporization of trace metals and capturing trace elements in the furnace of the coal-fired power plant is likely possible through proper coal selection, modification of combustion conditions, and the addition of sorbents. Control involves the collection of the very fine particulates as well as the vapor-phase species. The enhancement of current pollution-control technologies is the short-term solution. The efforts must be focused on the control of the vapor-phase species and the very fine particulates. The key elements of concern are mercury and selenium. These elements have the potential to escape from the system in the vapor phase.

An opportunity exists for the capture of vapor-phase trace metals through the use of in-furnace sorbents. The sorbents include a wide range of materials, many of which are naturally occurring materials, Table 9. The factors that influence the capture of sorbents include sorbent characteristics, metal speciation, and system condition. The capture mechanisms likely include chemisorption, physical absorption, and interaction with other species. The economics of in-furnace sorbent use also need to be considered. Finally, the issue of the effects of the added sorbent on disposal and recycling needs to be addressed.

Research has been performed on removing trace metals from high-temperature zones in the furnace (Uberoi and Shadman, 1990 and 1991; Scotto et. al., 1992). Tests have been conducted to remove cadmium and lead using a variety of sorbents, including bauxite, kaolinite, emathalite, and limestone. The tests indicate that bauxite and kaolinite can capture cadmium and lead. The most practical sorbent for the capture of lead, based on pilot-scale testing, is kaolinite. The capture is compromised by the presence of chlorine. Calcium-based sorbents (such as hydrated lime and limestone) injected into the post-flame region have shown significant reductions of antimony, arsenic, mercury, and selenium (Gullett and Raghunathan, 1993).

Other attention has been focused on chemically converting the vapor-phase elements, such as arsenic, selenium, and mercury, to a solid for control in an electrostatic precipitator or baghouse. Research indicated that volatile SeO_2 could be converted through the use of ammonia to elemental selenium and molecular oxygen for collection in a baghouse. The control of arsenic by conversion to a solid may also be possible but, as yet, has not been proven. Minimizing the emission of arsenic is likely to be more effective, since elemental arsenic is less volatile than selenium. The prospects for condensing vapor-state mercury on particulates for control in an electrostatic precipitator (ESP) or a baghouse are not very good. The high volatilities of elemental mercury and $HgCl_2$ and the lack of stability of solid mercury compounds make mercury control difficult.

TABLE 9

Possible Sorbents for the Control of Trace Metal Emissions

Sorbent/Sorbent	Chemistry	Injection Point*	Trace Metals
Kaolinite	$Al_2Si_2O_5(OH)_2$	Pre or Post	Pb, Cd
Emathalite	Clay and mixed silicates	Pre or Post	Pd, Cd
Bauxite	Aluminum rich	Pre or Post	Pb, Cd
Zeolites	Mixed layer aluminosilicate	Pre or Post	Pb, Cd
Limestone	$CaCO_3$	Post	Sb, As, Se, Hg
Hydrated Lime	CaOH	Post	Sb, As, Se, Hg
Activated Carbon	Carbon	Post—Low Temperature	Hg
Sulfur-Impregnated Carbon	Carbon & sulfur	Post—Low Temperature	Hg
Iodated Carbon	Carbon + Iodine	Post—Low Temperature	Hg

* Pre – blending sorbent with coal
Post – injection after combustion zone

The control of mercury emissions through injection of carbon-based materials has been demonstrated (Felsvang et.al., 1993). The pilot-scale testing investigated the control of mercury emission in a baghouse and an ESP. The full-scale work reported was focused on dry scrubbers. The removal of mercury inherent in dry flue gas desulfurization (FGD) in full-scale systems ranged from as low as 6% to as high as 96%. In an eastern U.S. installation, the mercury-removal efficiency was further enhanced by active carbon injection upstream of the spray dryer absorber, resulting in removal efficiencies of greater than 99%. Testing conducted with a western U.S. coal in a pilot plant spray dryer absorber (SDA) using a slipstream on a full-scale system indicated removal efficiencies of 50% to 60% for mercury. This was below what was expected. The key component missing from the western U.S. coal tested was chlorine. Chlorine content of the coal has a major impact on the removability of mercury. The chlorine reacts with Hg to produce $HgCl_2$. Tests were conducted by injecting Cl_2 and HCl along with activated carbon to increase Hg removal efficiencies. However, the high alkali and alkaline earth contents reacted preferentially with the Cl, not with the Hg. Tests were conducted with iodine activated carbon, and high removal efficiencies were obtained.

Hassett (1993) illustrated the need for a thorough understanding of the waste and its relationship with the environment to ensure disposal of the waste in an environmentally acceptable manner. Solid, coal residuals (fly ash, bottom ash, etc.) usually release chemical elements to the subsurface environment through a leaching process. There are numerous leaching procedures available for the laboratory evaluation of solid materials. The procedure must be selected wisely since leachability of components depend on soil pH and other conditions, and time limits required for leaching experiments can vary from hours to months for valid data. It has been demonstrated in a previous study (Hassett et al., 1987) that transformations in gasification and coal-combustion fly ash can have a profound effect on leachate chemistry. Laboratory experiments, currently carried out at the EERC, have demonstrated that the formation of hydrated secondary phases can influence the solubility of elements such as arsenic, boron, chromium, and selenium.

6.0 QUALIFICATIONS

6.1 Related Project Experience

The following are short summaries of projects at the EERC related to the work in this project:

- Particulate Control and Trace Element Emissions from Low-Rank Coals – Funding level: $995,000. The goals of the project were to 1) develop, evaluate, and apply methods for sampling and characterizing particulate matter; 2) develop methods to evaluate the collectibility of particulate matter; and 3) characterize and measure the organic and trace element emissions from pc-fired and atmospheric fluidized-bed combustion systems. Project duration was from 1983 to 1988, and funded by the U.S. Department of Energy.

- Distribution of Inorganics and Geochemistry – Funding level: $519,000. The goals of the project were to 1) develop methods to determine the abundance and distribution of inorganic constituents (major, minor, and trace) in coals and 2) examine a range of coals to determine the association of inorganic components with organic and mineral constituents in the coal. Chemical fractionation and SEM/microprobe methods to determine associations were developed. Project duration was from 1983 to 1986, and funded by the U.S. Department of Energy.
- Fixation of Trace Elements by Ettringite: A Screening Study – Total funding: $385,000. The goal of the project is to determine the effectiveness of ettringite to attenuate certain oxyanionic trace elements such as selenate and borate by incorporating them into a low-solubility mineral phase. Project duration was from 1989 to 1993. Joint funding was provided by the GRI and the U.S. Department of Energy.
- Combustion Inorganic Transformations – Total funding: $2,004,000. The goals of this project were 1) to perform experiments to determine the partitioning of inorganic components in combustion systems using a laboratory-scale entrained-flow reactor, 2) to collect size-fractionated ash using impactors and multicyclones, 3) to characterize the ash by size to determine the transformations (vaporization, condensation, fragmentation, and coalescence of inorganic components), and 4) to develop models to predict the size and composition evolution (partitioning) of the inorganic components as a function of coal composition and combustion conditions. Product duration was from 1986 to 1992, funded by the U.S. Department of Energy.
- Trace Element Emissions – Total funding: $949,000. This 24-month-long project, begun in July of 1992 and sponsored by the U.S. Department of Energy, is investigating the transformations and partitioning of trace metals in gasification

systems in an effort to provide the information needed to develop more effective control technologies.

- Trace Elements Transformations in Coal-Fired Power Systems Workshop – Total funding: $118,000. This project is jointly sponsored by the U.S. Department of Energy and EPRI. The goal of the workshop is to bring the top experts in the world together to identify the current state of knowledge and research needs in the area of trace element emissions from coal-fired power plants. The project will be completed in 1993.
- Enhanced Flue Gas Conditioning Study – Total funding: $271,000. The goal of the project was to test enhanced flue gas-conditioning methods to improve the performance of ESPs. Project duration from 1990 to 1991 and was jointly sponsored by the U.S. Department of Energy and Wahlco, Inc.
- Flue Gas Cleanup – Total funding: $824,000. The goal of this project was the development of a catalyst-coated fabric filter for NO_x and particulate control that would provide high removal efficiency of NO_x and particulate matter, acceptably long bag and catalyst life, and an economic savings over a conventional selective catalytic reduction system and baghouse. Project duration was from 1988 to 1992, and was funded by the U.S. Department of Energy/Pittsburgh Energy Technology Center.
- Pulse-Jet Baghouse Performance Improvement – Total funding: $524,000. The goal of this project was to evaluate the effectiveness of flue gas conditioning in reducing tube-sheet pressure drop and particulate emissions from a pulse-jet fabric filter. Project duration was from 1989 to 1992, and was jointly sponsored by the U.S. Department of Energy, EPRI, and the Canadian Electric Association.

- Determination of the Distribution of Rare Earth Elements in Coal and Coal Ash: A Screening Study – Total funding: $48,000. The goals of this project were to identify, through a literature search, sample-preparation and analytical techniques that could be applied to coal and coal by-products for the determination of rare earth elements or, alternatively, to develop a sensitive and precise analytical method and utilize this method to begin an extensive characterization effort on samples of these materials available through the Coal Ash Resources Research Consortium (CARRC). The ultimate goal was to determine if a relationship existed between ratios of rare earth elements in coal conversion residues and the location of the source coal. Project duration was from 1990 to 1992, and was funded by the U.S. Bureau of Mines.
- Geotechnical, Geochemical Characterization of Advanced Coal Process Waste Streams – Total funding: $285,000. The goal of the project was to characterize the disposal-related properties of a wide range of different waste materials produced from advanced coal-utilization processes. Project duration was from 1989 to 1991, and was funded by Universal Fuel Development Association, under contract to the U.S. Department of Energy/Morgantown Energy Technology Center.
- Duct Injection Technology Prototype Development – Total funding: $435,000. The goal of this project was to establish and verify the necessary engineering design and scaleup criteria for preparing a full-scale design basis for duct injection technology. Project duration was from 1989 to 1991, and was funded by United Engineers and Constructors under contract to the U.S. Department of Energy/Pittsburgh Energy Technology Center.

- Enhanced Air Toxics Control – Total funding: $978,000. The goal of this project is to determine the potential to control air toxic emissions in conventional particulate control devices with gas-conditioning agents. Since many of the toxic heavy metals are more concentrated in fine fly ash particles, a method of superior control of these air toxic emissions is simply to collect them in a particulate-control device. Parametric pilot tests will be conducted evaluating independent variables such as conditioning or capture agent, conditioning concentration, temperature, coal type, and particulate control method. Project duration is from 1992 to 1994, and is jointly sponsored by EPRI and the U.S. Department of Energy.
- Evaluation of Mercury in Lignite Coal and Energy Conversion Facility Emissions – Total funding: $34,000. Mercury is increasingly of concern to the energy-producing industry, but little is clearly understood about its occurrence in fuels and combustion products. This project was designed to clarify the extent of scientific knowledge about the mercury content of North Dakota lignites by reviewing published data and the procedures used to obtain them, and comparing them with recent, unpublished results. Data from older, published sources suggest that North Dakota lignites are higher in mercury content than most other coals, but recent data, acquired using currently accepted analytical methods, indicate that the lignites are lower in average mercury concentration, similar to that of Powder River Basin coals. Project was completed in February 1993, and was funded by the Lignite Energy Council and the U.S. Department of Energy.
- National Center for Excellence on Air Toxic Metals - Total funding: $1,600,000. This project was directly appropriated by the U.S-Congress to establish the EERC as a national center for expertise in the area of air toxic metals. Efforts in this project will concentrate on sampling and characterization of trace metals, emissions

of trace metals from coal-, gas-, oil-, and waste-fired facilities and the environmental impacts of air toxic metals. The current funding is in place for the first year, with equal funding expected for four additional years.

6.2 Qualifications of Key Personnel

Because of the multidisciplinary nature of the EERC, many of the team members have demonstrated capabilities in several of the research areas critical to this project. The project team has shown the creativity, innovation, and dedication needed to successfully combine engineering and science in a research program. These uniquely qualified individuals will ensure that the diverse project goals will work in concert to produce commercially applicable results. Appendix A contains the resumes of the key personnel involved in this paper.

7.0 VALUE TO NORTH DAKOTA

Due to the abundance of lignite coal in North Dakota, any advantage that lignite has over the use of other coals would create a positive effect on the economy of North Dakota. In addition, since North Dakota is a large user of lignite coals, any environmental advancement would benefit the general environment of North Dakota. The specific values to North Dakota are:

- The potential for a cleaner environment in the air, soil and groundwater. Using additives to remove the air toxics from the air while keeping them inert to groundwater leaching has huge environmental advantages.

- Trace elements distribution in the coals tested will enhance the knowledge base of the coals in North Dakota, increasing the ability to use these coals in blending programs to assure emission limits are not exceeded.
- The demonstration of air toxic control in lignites will benefit their use over coals that lack such data. The absence of this data results in the preferential use of nonlignite coal.
- The information generated will enhance the efficiency and environmental acceptability of existing and future lignite-utilization facilities.
- Information developed could lead to the creation of new products and technologies that are beneficial to the economy of North Dakota.
- This project will receive a large amount of attention because of its cutting-edge approach towards air toxics. This attention will be directed towards North Dakota's leadership role in the study of air toxic emissions during combustion.

8.0 MANAGEMENT

To best administer this project, a three-tier management system will be utilized (Figure 10). Because of the multidisciplinary nature of the EERC, many of the team members have demonstrated capabilities in several of the research areas critical to this project. The project team has shown the creativity, innovation, and dedication needed to successfully combine engineering and science in a research program. These uniquely qualified individuals will ensure that the diverse project goals will work in concert to produce commercially applicable results. The responsibilities of the key project team members are summarized as follows:

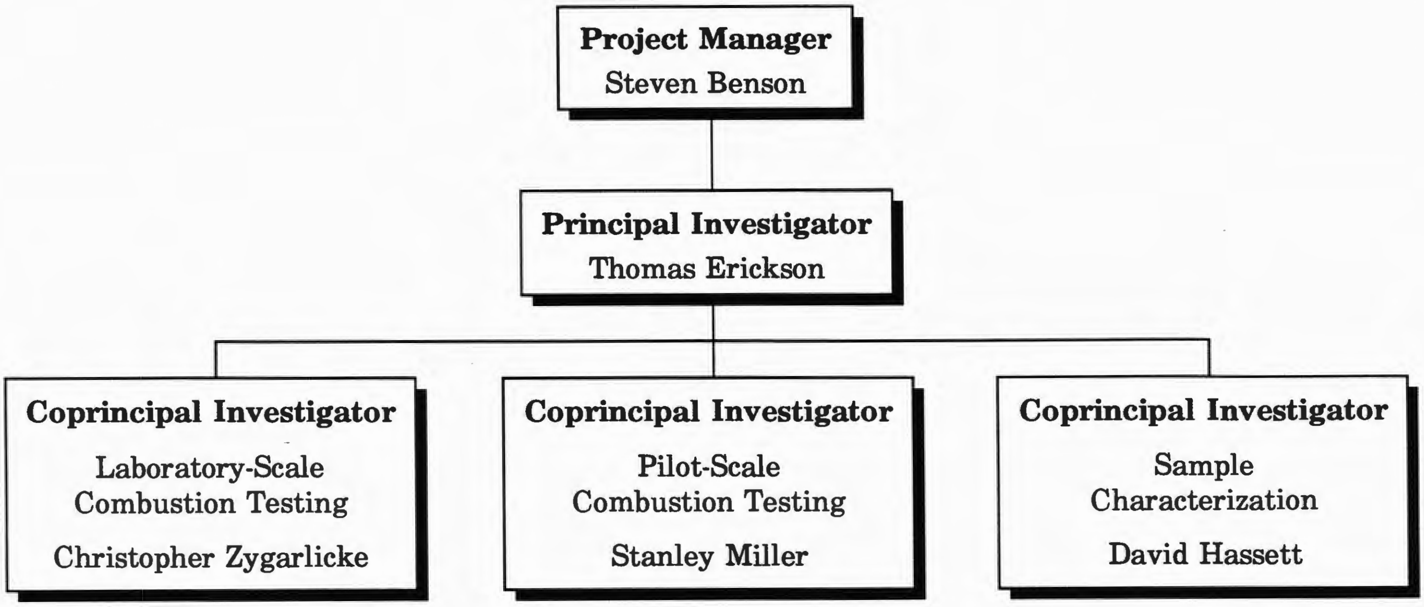

Figure 10. Management plan.

Steven Benson, Project Manager - Responsible for overall project management and control, integration, and coordination of tasks to achieve proper goals.

Thomas Erickson, Principal Investigator - Responsible for the day-to-day management of the project, coordination of the three research areas, and contributes to the interpretation of data.

Dave Hassett, Research Associate - Responsible for the trace element analysis of the coals and ash samples generated and particulates in the interpretation of data.

Stan Miller, Research Manager - Responsible for the production of samples in the pilot-scale equipment and particulates in the interpretation of data.

Chris Zygarlicke, Research Manager - Responsible for the production of samples in the laboratory-scale equipment and particulates in the interpretation of data.

9.0 TIMETABLE

The projected time line for this project is eight months. Figure 11 shows the time schedule broken down to the major areas in each task. The progress of this work will be reviewed throughout the project by both the North Dakota Lignite Research Council and the commercial sponsors through two progress reports submitted during the project. These reports will be submitted by April 15 and July 15, 1994.

10.0 BUDGET

The total budget for this project is $400,000. The cost per task is shown in the enclosed detailed budget. The cost for each of the proposed industrial participants is $20,000. The EERC is seeking six industrial sponsors will provide a total of $120,000. The North Dakota Industrial Commission who will provide $80,000, and the National Center for Excellence on Air Toxic Metals will provide $200,000 from its jointly sponsored research money. The $8,000 for equipment is for two computers at $4,000 each.

The budget presented is designed to provide the best results at the lowest possible cost. A reduction in funds would entail a decrease in the quantity of results. A decrease in the budget due to fewer industrial sponsors is possible but will decrease the total number of sorbents researched. In no way will the quality of the work be affected.

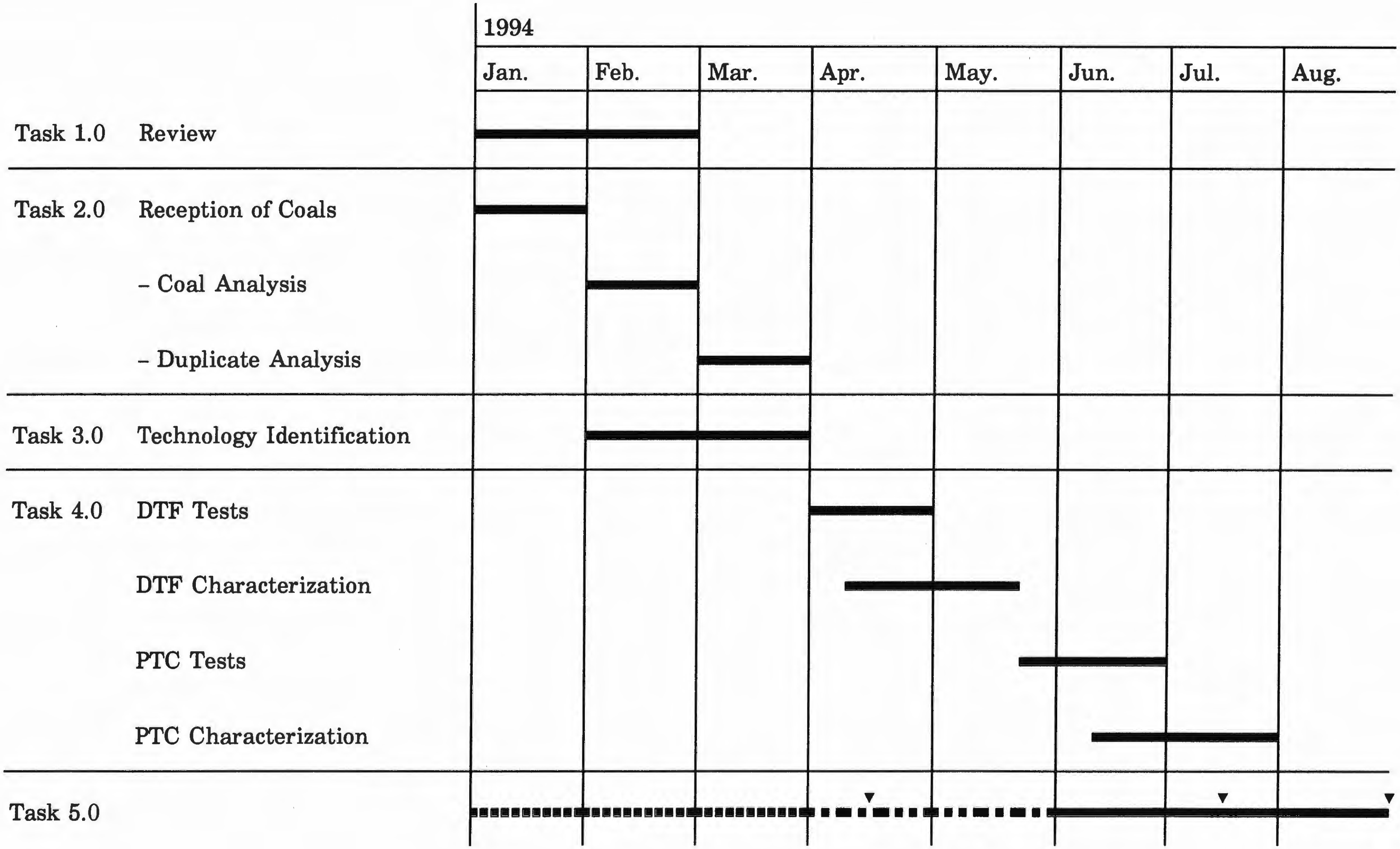

Figure 11. Project timeline.

11.0 MATCHING FUNDS

The matching funds for this project will come from two sources. The Environmental Protection Agency (EPA) Center for Excellence on Air Toxic Metals will cost share the project at approximately $200,000. An additional $120,000 is being sought from industry at a cost of $20,000 for each sponsor. None of the commercial companies have yet to commit, though many have shown great interest in the project. The industry affiliates contacted to date are: Basin Electric, BNI Coal, Limited, Electric Power Research Institute, Montana–Dakota Utilities, Knife River Coal Company, North American Coal Corporation, Minnkota Power Cooperative, Incorporated, Otter Tail Power Company, Wisconsin Power and Light Company, Cooperative Power Association, Minnesota Power, Minnesota Power. The receipt of six industrial sponsors into the project is believed to be feasible.

12.0 TAX LIABILITY

The EERC is an organized research center within the University of North Dakota. The University of North Dakota is an institution of higher education within the State of North Dakota and is not a taxable entity.

13.0 CONFIDENTIAL INFORMATION

There is no confidential information contained within this proposal.

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TRACE ELEMENT MITIGATION TECH.
JAN. 1, 1994-SEP. 31, 1994
29-Sep-93 EERC PROPOSAL #94-6223

			TASK 1		TASK 2		TASK 3		TASK 4		TASK 5							
					COAL				COMBUSTION						COMMERCIAL			
			REVIEW		CHARACTERIZATION		CONTROL		TESTING		REPORTING		EPA SHARE		SHARE		GRAND TOTAL	
LABOR	LABOR CATEGORY	HOURLY RATE	HOURS	$ COST	HOURS	$ COST	HOURS	$ COST	HOURS	$ COST	HOURS	$ COST	HOURS	$ COST	HOURS	$ COST	HOURS	$ COST
S. BENSON	PRINCIPAL SCIENTIST	$33.95	19	$645	19	$645	19	$645	148	$5,025	76	$2,580	148	$5,025	133	$4,515	281	$9,540
T. ERICKSON	RES. SCIENTIST III	$22.06	57	$1,257	95	$2,096	57	$1,257	333	$7,346	111	$2,449	280	$6,177	373	$8,228	653	$14,405
J. GROENEWOLD	PRINCIPAL SCIENTIST	$46.00	0	$0	0	$0	0	$0	0	$0	15	$690	8	$368	7	$322	15	$690
M. JONES	PRINCIPAL SCIENTIST	$41.35	0	$0	0	$0	0	$0	0	$0	72	$2,977	40	$1,654	32	$1,323	72	$2,977
S. MILLER	PRINCIPAL SCIENTIST	$29.44	38	$1,119	19	$559	19	$559	166	$4,887	70	$2,061	167	$4,916	145	$4,269	312	$9,185
R. SCHULZ	RES. TECHNICIAN III	$15.67	19	$298	9	$141	19	$298	266	$4,168	37	$580	185	$2,899	165	$2,586	350	$5,485
C. ZYGARLICKE	RES. SCIENTIST III	$23.80	38	$904	19	$452	19	$452	190	$4,522	37	$881	160	$3,808	143	$3,403	303	$7,211
-------------------------	RES. SCIENTIST I	$16.83	0	$0	0	$0	0	$0	190	$3,198	74	$1,245	140	$2,356	124	$2,087	264	$4,443
J. HENDRIKSON	FACILITY MANAGER	$32.69	0	$0	0	$0	0	$0	26	$850	0	$0	13	$425	13	$425	26	$850
D. HASSETT	RES. SCIENTIST III	$25.07	19	$476	19	$476	19	$476	109	$2,733	69	$1,730	127	$3,184	108	$2,707	235	$5,891
D. TOMAN	RES. SCIENTIST II	$19.96	0	$0	0	$0	0	$0	171	$3,413	36	$719	110	$2,196	97	$1,936	207	$4,132
E. O'LEARY	RES. TECHNICIAN II	$14.36	4	$57	4	$57	3	$43	42	$603	14	$201	35	$503	32	$458	67	$961
R. BEARD	RESEARCH ENGINEER	$23.44	0	$0	0	$0	0	$0	33	$774	14	$328	25	$586	22	$516	47	$1,102
B. BECKSTEAD	RESEARCH TECHNICIAN I	$8.12	7	$57	7	$57	6	$49	85	$690	29	$235	71	$577	63	$511	134	$1,088
-------------------------	PILOT PLANT III	$13.67	0	$0	0	$0	0	$0	855	$11,688	0	$0	420	$5,741	435	$5,947	855	$11,688
-------------------------	UNDERGRAD-RES.	$5.90	20	$118	19	$112	15	$89	247	$1,457	86	$507	206	$1,215	181	$1,068	387	$2,283
-------------------------	OFFICE SERVICES	$9.36	0	$0	0	$0	0	$0	0	$0	225	$2,106	125	$1,170	100	$936	225	$2,106
			221	$4,931	210	$4,595	176	$3,868	2861	$51,354	965	$19,289	2260	$42,800	2173	$41,237	4433	$84,037
SALARY ESC. - % ABOVE CURRENT BASE		1.5%		$74		$69		$58		$770		$289		$642		$618		$1,260
DIRECT LABOR				$5,005		$4,664		$3,926		$52,124		$19,578		$43,442		$41,855		$85,297
FRINGE BENEFITS - % OF DIRECT LABOR		46%		$2,302		$2,145		$1,806		$23,977		$9,006		$19,983		$19,253		$39,236
TOTAL LABOR				$7,307		$6,809		$5,732		$76,101		$28,584		$63,425		$61,108		$124,533
OTHER DIRECT COSTS																		
TRAVEL				$0		$0		$0		$0		$900		$450		$450		$900
SUPPLIES -																		
OPERATING SUPPLIES INCLUDING RAW MATERIALS				$2,400		$2,550		$2,505		$8,700		$6,016		$10,000		$12,171		$22,171
EQUIPMENT COSTING >$500				$0		$0		$0		$8,000		$0		$0		$8,000		$8,000
OTHER																		
COMMUNICATIONS - PHONES & POSTAGE				$0		$0		$0		$0		$3,100		$1,518		$1,582		$3,100
FEES																		
PROF. STAFF CLERICAL SUPPORT @$0.62/HR			194	$120	184	$114	155	$96	1674	$1,038	625	$388	1438	$892	1394	$864	2832	$1,756
GRAPHIC SERVICES @$24/HR			0	$0	0	$0	0	$0	0	$0	118	$2,832	60	$1,440	58	$1,392	118	$2,832
NATURAL MATERIALS ANALYTICAL RES. LAB.				$0		$9,470		$0		$12,395		$0		$9,000		$12,865		$21,865
COAL LAB ANALYSIS				$0		$586		$0		$0		$0		$300		$286		$586
FUELS RESEARCH LAB				$0		$0		$0		$6,821		$0		$2,950		$3,871		$6,821
ANALYTICAL RESEARCH LAB.				$0		$10,465		$0		$60,293		$0		$42,000		$28,758		$70,758
PARTICULATE ANALYSIS				$0		$0		$0		$5,791		$0		$4,450		$1,341		$5,791
PTC OPERATIONS & MAINT.				$0		$0		$0		$6,029		$0		$4,000		$2,029		$6,029
SHOP/OPERATIONS SUPPORT			0	$0	0	$0	0	$0	855	$855	0	$0	420	$420	435	$435	855	$855
TOTAL OTHER				$120		$20,635		$96		$93,222		$6,320		$66,970		$53,423		$120,393
TOTAL OTHER DIRECT COST				$2,520		$23,185		$2,601		$109,922		$13,236		$77,420		$74,044		$151,464
TOTAL DIRECT COST = LABOR BASED + OTHER DIRECT				$9,827		$29,994		$8,333		$186,023		$41,820		$140,845		$135,152		$275,997
INDIRECT COST - % OF MTDC													42%	$59,155	51%	$64,848	VAR	$124,003
TOTAL ESTIMATED COST														$200,000		$200,000		$400,000

BUDGET NOTES – ENERGY & ENVIRONMENTAL RESEARCH CENTER

The proposed work will be done on a cost-reimbursement basis. The distribution of costs between budget categories (labor, travel, supplies, equipment, subcontracts) is for planning purposes only. The principal investigator may, as dictated by the needs of the work, reallocate the budget among approved items or use the funds for other items directly related to the project, subject only to staying within the total dollars authorized for the overall program. Financial reporting will be at the total project level.

FRINGE BENEFITS

Fringe benefits are estimated based on historical data. The fringe benefits which will actually be charged consist of two components. The first component covers average vacation, holiday, and sick leave for the EERC. This component will be charged as a percentage of direct labor. The second component covers actual expenses for items such as health and life insurance, social security, UND retirement, unemployment insurance, and worker's compensation.

INDIRECT COST

The indirect cost rate included in this proposal is the rate which became effective July 1, 1989. Indirect cost is calculated on Modified Total Direct Costs (MTDC). MTDC is defined as Total Direct Costs less individual items of equipment in excess of $500 and subcontracts/subgrants in excess of the first $25,000 for each award.