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Advanced Emissions Control Development Program

Quarterly Technical Progress Report #7

for the period: April 1 to June 30, 1996

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Executive Summary

Babcock & Wilcox (B&W) is conducting a five-year project aimed at the development of practical, cost-effective strategies for reducing the emissions of hazardous air pollutants (commonly called air toxics) from coal-fired electric utility plants. The need for air toxic emissions controls may arise as the U. S. Environmental Protection Agency proceeds with implementation of Title III of the Clean Air Act Amendment (CAAA) of 1990. Data generated during the program will provide utilities with the technical and economic information necessary to reliably evaluate various air toxics emissions compliance options such as fuel switching, coal cleaning, and flue gas treatment. The development work is being carried out using B&W's new Clean Environment Development Facility (CEDF) wherein air toxics emissions control strategies can be developed under controlled conditions, and with proven predictability to commercial systems. Tests conducted in the CEDF provide high quality, repeatable, comparable data over a wide range of coal properties, operating conditions, and emissions control systems. Development work to date has concentrated on the capture of mercury, other trace metals, fine particulate, and the inorganic species hydrogen chloride and hydrogen fluoride.

Background

Promulgation of air toxics emissions regulations for electric utility plants could dramatically impact utilities burning coal, their industrial and residential customers, and the coal industry. Work during the project will supply the information needed by utilities to respond to potential air toxics regulations in a timely, cost-effective, environmentally-sound manner which supports the continued use of the Nation's abundant reserves of coal, such as those in the State of Ohio.

The Clean Air Act Amendment of 1990

Title III of the CAAA's established a list of 189 hazardous air pollutants and charged the EPA with the responsibility for regulating emissions of these substances into the atmosphere as required to protect public health and the environment. The first phase of compliance is to be based on available technology, and will require many industrial plants to install the "maximum achievable control technology" (MACT). Electric utility plants are exempt from this requirement, however, pending the outcome of several risk assessment and emissions characterization studies. The EPA is scheduled to propose its plan for regulating electric utilities under Title III in the near future.

The EPA has been working with the U. S. Department of Energy (DOE), the Electric Power Research Institute (EPRI), and the Utility Air Regulatory Group (UARG) to characterize air toxics emissions from existing power plants. Both DOE and EPRI have conducted major field testing programs toward this end. The results of these emissions characterization studies have been reviewed by the EPA in conjunction with the results of several on-going EPA risk assessment studies to determine the need for air toxics emissions regulations aimed at electric utilities. These field testing programs provide considerable insight into the quantities of air toxics being emitted by power plants. However, B&W believes that they are only a first step toward developing an understanding of the formation, partitioning, and capture of air toxics species, and how to effectively control their emissions.

While the EPA's ultimate approach is uncertain, at least some air toxics species issuing from utility stacks may be regulated -- especially some of the high-risk compounds such as arsenic, cadmium, chromium, and mercury, and/or compounds known to be emitted in relatively large quantities such as hydrogen chloride and hydrogen fluoride. Mercury, in particular, is the subject of intensive research due to its presence in the atmosphere, subsequent deposition in lakes, and potential human health and environmental impacts. B&W strongly believes that a proactive approach to the development of the technical and economic information utilities will need to assess air toxics control options is needed to keep pace with regulatory actions.

Overview of the Project

The objective of this project is to develop practical strategies and systems for the simultaneous control of SO_2, NO_x, particulate matter, and air toxics emissions from coal-fired boilers in such a way as to keep coal economically and environmentally competitive as a utility boiler fuel. Of particular interest is the control of air toxics emissions through the cost-effective use of conventional flue gas clean-up equipment such as electrostatic precipitators (ESP's), fabric filters (baghouses), and SO_2 removal systems such as wet scrubbers and various "clean coal technologies". This objective will be achieved through extensive development testing in B&W's state-of-the art, 10 MW_e equivalent, Clean Environment Development Facility (CEDF). The project has extended the capabilities of the CEDF to facilitate air toxics emissions control development work on "backend" flue gas cleanup equipment. Specifically, an ESP, a baghouse, and a wet scrubber for SO_2 (and air toxics) control were added -- all designed to yield air toxics emissions data under controlled conditions, and with proven predictability to commercial systems. A schematic of B&W's CEDF and the project test equipment is shown in Figure 1.

The specific objectives of the project are to:

Measure and understand production and partitioning of air toxics species in coal-fired power plant systems.

Optimize the air toxics removal performance of conventional flue gas cleanup systems.

Quantify the impacts of coal cleaning on air toxics emissions.

Identify and/or develop advanced air toxics emissions control concepts.

Develop and validate air toxics emissions measurement and monitoring techniques.

Establish an air toxics data library to facilitate studies of the impacts of coal selection, coal cleaning, and emissions control strategies on the emissions of coal-fired power plants.

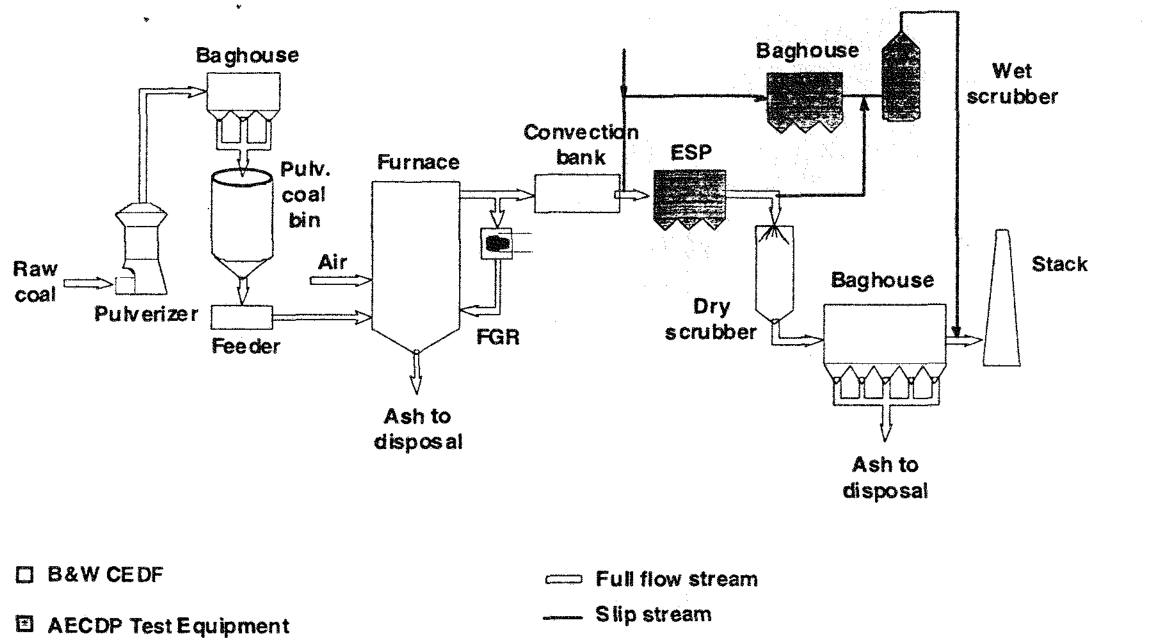

Figure 1 -- Clean Environment Development Facility

Description of Project Phases

The project is divided into three phases. Phase I (Facility Modification and Benchmarking) consisted of installation, shakedown, validation, and benchmarking of the test equipment (ESP, fabric filter, and wet SO_2 scrubber) added to B&W's CEDF. Baseline air toxics emissions and capture efficiency were established for each of the major flue gas cleanup devices: ESP, baghouse, and wet SO_2 scrubber. All tests were conducted with a high sulfur Ohio steam coal. The work in this phase culminated in the development of a data library, or database, for use by project participants.

Phase II (Optimization of Conventional Systems) testing will involve the development of air toxics control strategies based on conventional particulate and SO_2 control equipment. Development testing, engineering and evaluation will be done to optimize the performance of these devices for the capture of air toxic species. Phase II testing will also provide data on the impacts of coal properties and combustion conditions on air toxics emissions for several steam coals. The impacts of coal cleaning on air toxics emissions will be investigated through the testing of cleaned coals and their associated parent (uncleaned) coals. The development of new air toxics measurement techniques and monitoring instrumentation will also be investigated in this phase.

Phase III (Advanced Concepts and Comparison Coals) testing will be directed at the development of new air toxics emissions control strategies and devices, to further reduce the emissions of selected toxics. Testing will also be conducted to extend the air toxics data library to include a broader range of coal techniques begun in Phase II will continue in Phase III.

Summary of Phase I Results

Phase I -- Facility Modifications and Benchmarking -- work began on November 1, 1993, and ended on February 29, 1996. Phase I activities were primarily directed at providing a reliable, representative test facility for conducting air toxic emissions control development work later in the project. The AECDP equipment installed on the CEDF consisted of an ESP, pulse-jet baghouse, and wet scrubber. All verification and air toxic tests were conducted with an Ohio high sulfur, bituminous coal.

Fabric Filter

The fabric filter system comprises a pulse-jet baghouse and fly ash disposal system. The fabric filter is designed for a partial flow flue gas slipstream from the CEDF of approximately 0.6 MW_e equivalent.

Pulse-Jet Baghouse. Particulate from the flue gas stream is collected on the outside surface of porous filter bags in the baghouse. The pulse-jet baghouse is named for the manner in which the bags are cleaned. The filter cake is removed from the outer surface of the bag by a pulsed jet of compressed air supplied to its interior which causes a sudden bag expansion. The dust is effectively removed by inertial forces as the bag reaches maximum expansion. The baghouse was initially configured with commercial size, conventional fabric filter bags to simulate air toxics capture in commercial baghouses. The baghouse design permits operation over a wide range of air-to-cloth ratio (a measure of the amount gas passing through each square foot of fabric in the baghouse), particulate loading, cleaning cycle frequency and cleaning pressure. The baghouse temperature can be varied to evaluate the effect of operating temperature on air toxics and particulate collection. Particulate collection efficiency can also be affected by the type of fuel combusted, the resulting particulate characteristics, and the particle size distribution.

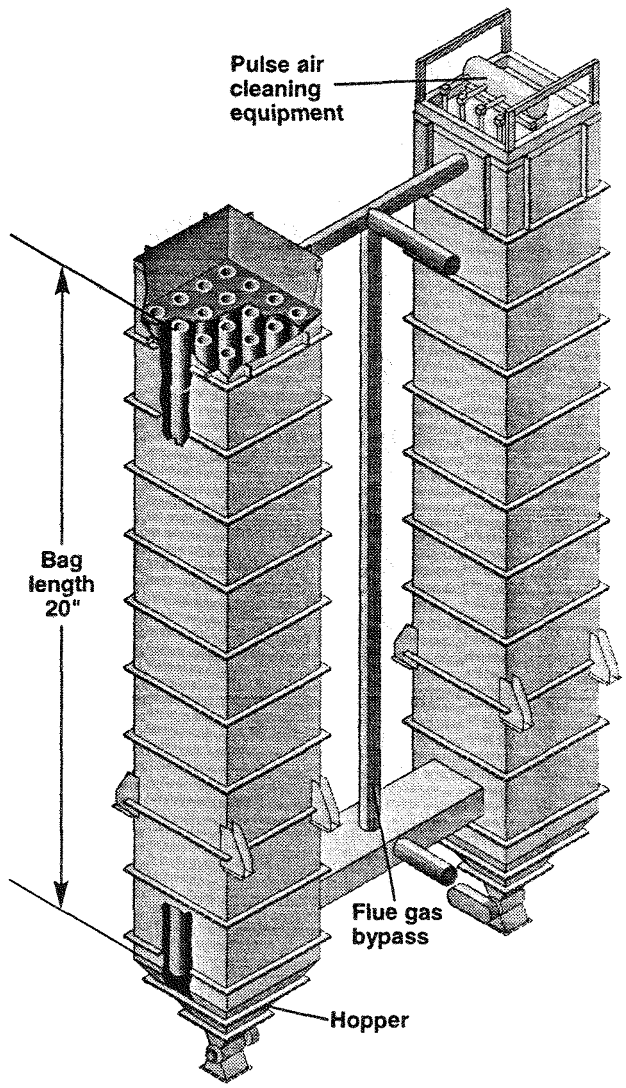

Figure 2 -- Pulse-Jet Baghouse

The baghouse is designed to process 6,000 lb/hr of flue gas with a particulate loading of

94 lb/hr. The baghouse will reduce particulate emissions to less than the New Source Performance Standard of 0.03 $lb/10^6$ Btu. The primary design characteristics for the baghouse are summarized below:

AECDP Baghouse Design Summary

Compartments	two; 33 ft high x 4 ft square
Bags/Compartment	16
Bag Dimensions	6¼" diameter x 20 ft long
Air-to-Cloth ratio	3.2 to 5.2 ft/sec
Cleaning Method	Pulse-jet; on-line or off-line

Fly Ash Disposal System. The fly ash collected on the fabric filter bags falls into the baghouse hoppers. From there it passes through a rotary valve into a vacuum ash handling system for transport to a disposal bin. The baghouse flyash is typically mixed with wet scrubber by-product for landfill disposal.

Wet Scrubber

The 0.6 MW_e equivalent wet scrubber subsystems include the absorber tower, reagent feed system, mist eliminator system, and slurry dewatering and disposal system. The absorber tower is designed to simulate a vertical section down through a commercial reactor to accurately reproduce SO_2 and air toxics removal mechanisms. Emphasis is placed on the duplication of gas/liquid interaction, minimization of wall impingement, and the proper simulation of operating parameters that affect particulate control in a wet scrubber. The wet scrubber is designed to treat the flue gas from the partial flow, pulse-jet baghouse or a flue gas slipstream from the full-flow electrostatic precipitator, and includes the equipment required to handle the associated reagent and waste streams.

Absorber. The absorber consists of the absorber tower and slurry recirculation tank. The particulate loading in the flue gas entering the absorber tower depends upon the operating efficiency of either the upstream ESP or pulse-jet baghouse, and is typically around 0.03 $lb/10^6$ Btu. The absorber tower operating conditions are influenced by the type of fuel. The design is based on B&W's commercial scrubbers and incorporates a perforated-plate tray to reduce flue gas flow maldistribution. The absorber tower comprises several interchangeable modules to vary the number of perforated trays and the tray height. The modular tower design permits testing with different spray and tray configurations to best simulate the operation of conventional wet scrubbers.

The wet scrubber is designed to process 5,062 lb/hr of flue gas with a SO_2 concentration of up to 6,000 ppm. The primary design characteristics for the wet scrubber system are summarized in the following table:

AECDP Wet Scrubber Design Summary

Design limestone stoichiometry	1.1 mole Ca/mole SO_2 absorbed
Nominal SO_2 removal	90%
Design L/G ratio	267 gpm/1000 acfm
Normal L/G ratio	120 gpm/1000 acfm
Tower velocity range	5.0 to 20 ft/sec

Absorber Recirculation Tank. The absorber recirculation tank is located below the absorber tower to facilitate the gravimetric flow of reaction products into the tank. The design of the recirculation tank facilitates the evaluation of the degree of forced oxidation on SO_2 removal and air toxics collection in the wet scrubber. The air sparger system provides clean, humidified air to obtain a wide range of oxidation levels. The absorber recirculation tank is equipped with an agitator to keep the solids from settling. The pH of the slurry stream from the recirculation tank to the spray nozzles is monitored with an in-line pH sensor. The continuous pH measurement is used to control the slurry feed rate from the fresh slurry storage tank to the recirculation tank.

Reagent Feed System. This system comprises a slurry storage/preparation tank, agitator, and pump and operates in a batch mode. The reagent (typically limestone) preparation system does not include a ball mill for grinding the limestone on site. Pulverized limestone is delivered to the facility. The reagent feed system is designed to handle a wide range of slurry feed rates and reagents to achieve specific levels of SO_2 control for the variety of coals.

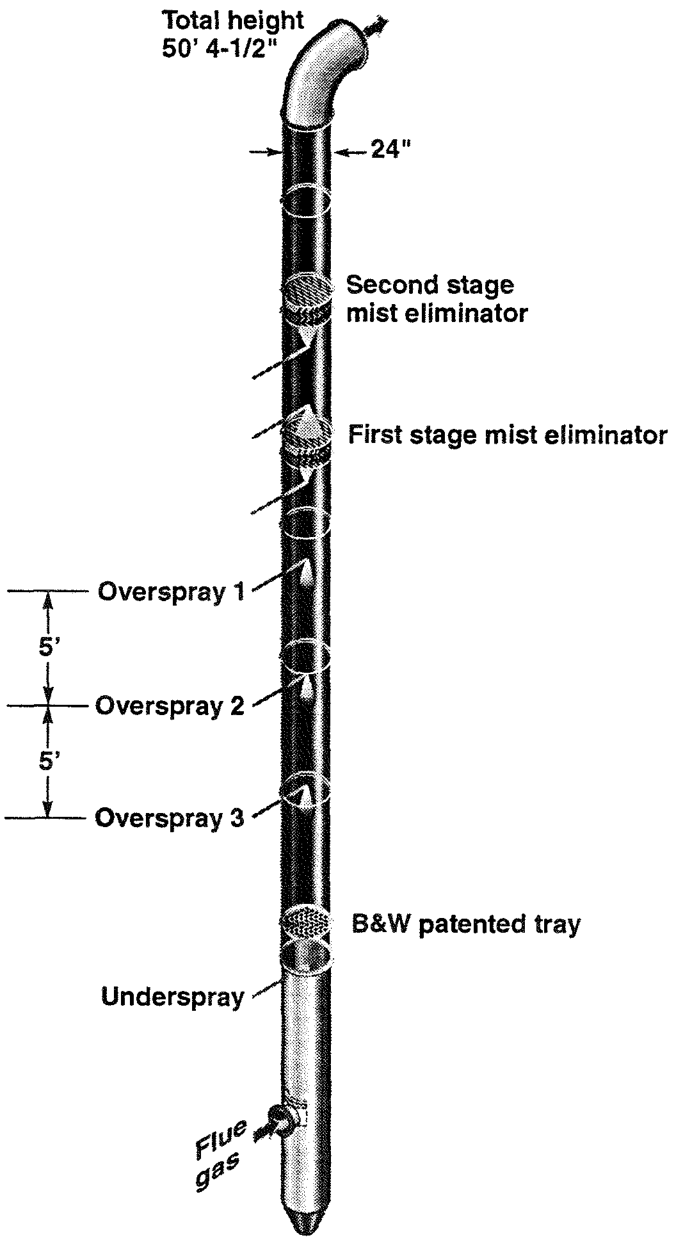

Figure 3 -- Wet Scrubber

Mist Eliminator System. Mist eliminators minimize carryover of slurry and liquid droplets generated in the absorber tower. To prevent buildup and plugging, the mist eliminators are periodically washed by way of water spray nozzles. The wet scrubber is designed to operate with vertical flow and/or horizontal flow mist eliminators. The system also includes a mist eliminator wash/recycle tank. To evaluate the impacts of mist eliminator efficiency on particulate collection efficiency and air toxics capture, sampling ports are located at the inlet and outlet of the mist eliminator sections. The modular tower design permits simple removal of the mist eliminator sections for testing purposes.

Slurry Dewatering and Disposal System. Slurry from the absorber recirculation tank is sent to the dewatering system for solids disposal and return of the clarified water. The waste slurry dewatering system consists of a hydroclone, several slurry settling tanks, a clarified recycle water storage tank, an agitator and a pump. The system is designed to be run on a batch basis. The reaction products from the slurry recirculation tank are sent to the hydroclone for primary dewatering. A density transmitter in the recirculation line is used to activate the pump to the hydroclone. The hydroclone overflow is returned to the slurry recirculation tank to duplicate the slurry chemistry in a commercial scrubber. Secondary dewatering occurs in settling bins prior to mixing with flyash or dry sorbent for landfill disposal. The clarified recycle water storage tank is equipped with a blowdown line to control the concentration of chlorides in the scrubber liquor. The blowdown on the clarified recycle water storage tank is adjustable to determine the effect of chloride level on SO_2 removal performance and the possible influence on air toxics capture.

Electrostatic Precipitator

The ESP operates on the full flue gas flow (100 million Btu/hr, 10 MW_e equivalent) from the CEDF. The ESP was supplied by B&W's commercial Environmental Equipment Division (EED). Design of the ESP follows conventional practice used commercially in power boiler emissions control. The ESP consists of discharge electrodes which impart an electric charge to ash particles in the flue gas as it passes through the ESP. The charged particles are attracted to charged collector plates and are removed from the gas stream. The plates are rapped periodically to remove the collected particles. The ash falls into hoppers below the plates and is removed from the ESP through rotary air locks.

The ESP design is sufficiently flexible to treat flue gas from a range of coals with variable ash and sulfur contents. The ESP is designed to process 102,893 lb/hr of flue gas with a particulate loading of 1883 lb/hr. The ESP is designed reduce particulate emissions to less than the New Source Performance Standard of 0.03 lb/10^6 Btu. The ESP includes wire discharge frames and rigid discharge electrodes. Both discharge systems are used in commercial ESPs. The primary design characteristics for the ESP are summarized in the following table:

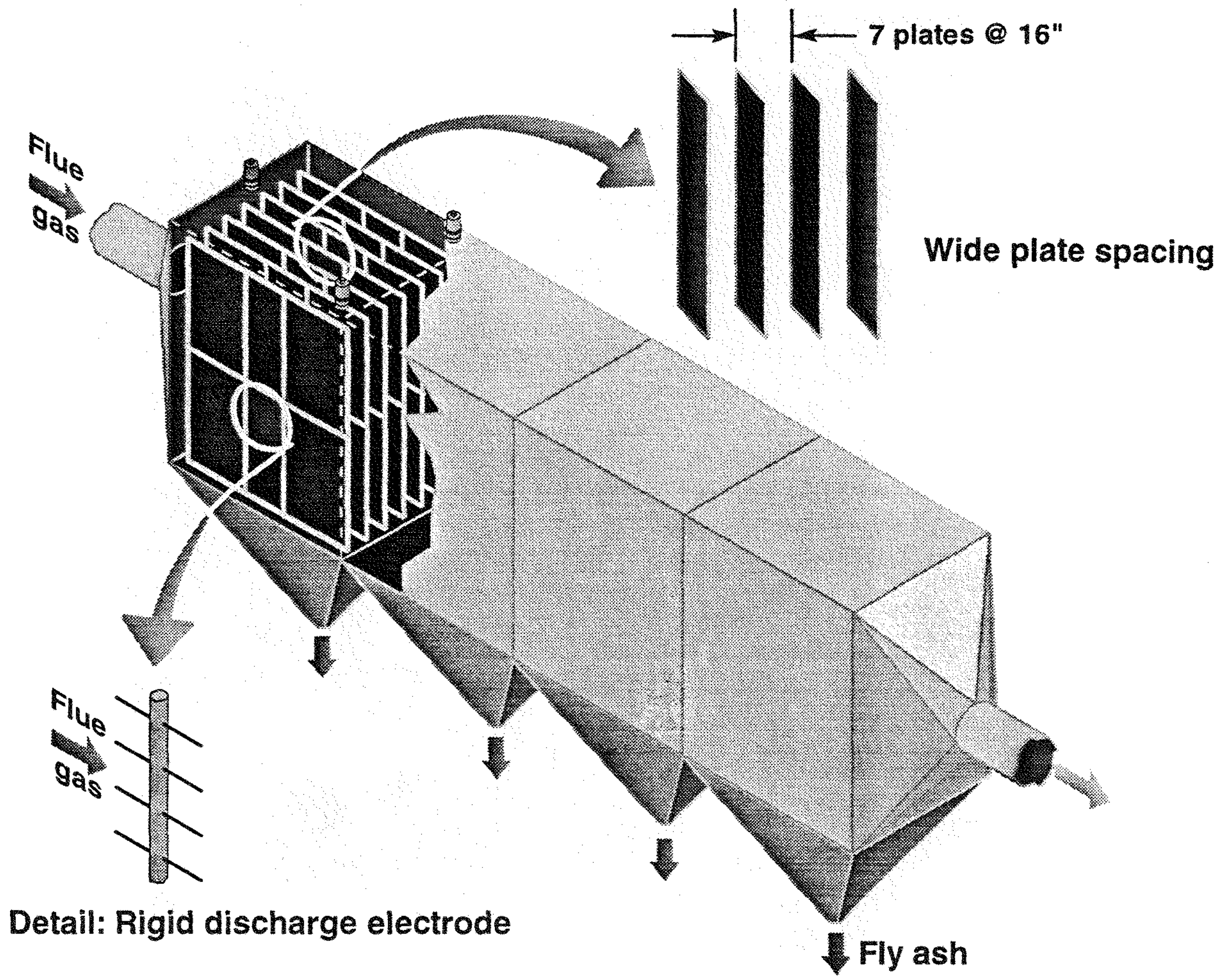

Figure 4 -- Electrostatic Precipitator

AECDP ESP Design Summary

Electric fields	four; 6m high x 4m deep
Specific collection area (SCA)	330-370 ft^2/1000 ACFM
Flue gas velocity	3.6 to 4.0 ft/sec
Migration velocity	7.5 to 9.8 cm/sec
Residence time	13 to 14 sec
Transformer rectifier sets	four; 75 kV, 125 mA

Verification Tests

In order to successfully apply the results of the program to utility systems, the relationship between the performance of the CEDF/AECDP test equipment and commercial units had to be established. The first step in the verification process was to verify that the flue gas treatment devices — boiler/convection pass simulator; ESP, baghouse, and wet SO_2 scrubber — operate in a manner representative of commercial units.

The 10 MW_e CEDF was carefully designed to yield combustion zone temperatures, flow patterns, and residence times representative of commercial boilers. Verification measurements confirmed that representative gas phase time-temperature profiles *and surface metal temperatures* are maintained throughout the CEDF convection pass. Baghouse and ESP performance was confirmed through a series of particulate and opacity measurements to determine the particulate removal efficiency. Two test series were then conducted to evaluate and compare the operation of the pilot wet scrubber with commercial units. The AECDP wet scrubber exhibited similar operating trends to a commercial unit: increased SO_2 removal with increased L/G ratio, improved SO_2 removal with increased tower velocity, and increased removal with increased spray zone height. Wet scrubber SO_2 removal performance was, as expected for a pilot unit, slightly lower than achieved by commercial systems (typically due to wall impingement).

Air Toxics Benchmarking

Air toxic benchmarking tests were then performed to quantify the air toxics removal performance of the back-end equipment, and to verify that the results are comparable to those available for commercial systems. Testing focused on those substances with the highest potential for regulation, currently assumed to be mercury, fine particulate, and the acid gases hydrogen chloride and hydrogen fluoride. Mercury speciation was also targeted because of the different mercury species present in utility stacks (elemental and oxidized mercury) and their widely differing environmental fate and toxicity. The testing methods selected to sample and quantify the air toxic emissions were similar to those used in the EPRI Field Chemical Emissions Monitoring Program (FCEM) and DOE field testing programs which facilitated subsequent comparison to the available field data.

The CEDF was maintained at steady, full-load conditions throughout the benchmarking tests. Key CEDF operating parameters (coal feed rate and boiler load) had standard deviations of approximately 1% over the testing period. The high sulfur Ohio test coal met the selection criteria: 1) it is mined in quantity, 2) it is fired by Ohio utilities, and it exhibits uniform trace element content. The test coal trace element content is within the OGS/USGS published ranges for Ohio coal, and therefore can be considered a "typical" Ohio bituminous coal from a trace element standpoint.

Measured air toxics emissions from the CEDF were compared to emissions predicted by the draft EPA emissions modification factors (EMFs) and the EPRI particulate phase metal correlations. Both correlations were developed from field emissions data taken after 1990. The measured uncontrolled CEDF emissions are in good agreement with values predicted by the use of draft EPA EMFs. The draft EMFs generally predict slightly higher boiler emissions than measured. However, the similarity between the predicted and measured emissions indicate that the HAPs generated by the CEDF are representative of commercial front-fired boilers firing bituminous coals.

The majority of the trace "particulate" metals exhibited field-documented behavior where the metals are removed at about the same level of efficiency as the particulate ash. In general, the particulate-phase metals (antimony, arsenic, beryllium, cadmium, chromium, cobalt, lead, manganese, and nickel) were primarily associated with the inlet particulate and this was reflected in the high metals removal efficiencies across the ESP and baghouse. The baghouse outlet particulate phase metal emissions were on the same order of magnitude as the emissions predicted by both the EPA EMFs and EPRI particulate correlations with the exception of cadmium. ESP outlet particulate phase metal emissions were generally less than the emissions predicted by the EPA EMFs and the EPRI correlations with the exception of cadmium. Wet scrubber trace element emissions were on the same order of magnitude as the predicted emissions with the exception of cadmium and chromium. The ESP and baghouse performance were comparable to the utility trace element emissions data from the DOE 8 Plant Study where particulate control limited trace element penetration to 5% or less with the exception of Cd, Hg, and Se.

As expected, the selenium, mercury, hydrogen chloride, and hydrogen fluoride emissions from the CEDF boiler were partially, if not completely, in the vapor phase. The uncontrolled hydrogen chloride and hydrogen fluoride emissions from the CEDF were consistent with the chlorine and fluorine content in the coal. However, the hydrogen chloride and hydrogen fluoride test removal efficiencies measured across the ESP and baghouse were inconsistent and inconclusive.

In all of the work to date on air toxics, the quantification of mercury species has received more attention than the other trace elements. The technical reasons for this include the varying fate and toxicity of the species, but also that their volatility makes them difficult collect in control devices and pass unaffected to the stack. EPA Method 29 has recently been approved by the EPA for the measurement of total mercury emissions from stationary sources. Originally devised for the measurement of total mercury emissions, many researchers have reported speciated results based on Method 29.

Total uncontrolled CEDF mercury emissions averaged 10.7 ± 2.7 lb/trillion Btu and correlated quite well to the predicted emissions of 12.6 ± 2.7 lb/trillion Btu based on the coal mercury content and the mercury EPA EMF for front-fired boilers. The percentage of total mercury measured on the particulate averaged 5%, confirming the expectation that mercury would be present mainly in the vapor state. The fraction of non-elemental or oxidized mercury averaged 71% of the total uncontrolled mercury emissions and 25% was detected as elemental mercury. The speciated mercury results as measured by EPA Method 29 are comparable to those reported in the literature for bituminous coal. Total mercury removal across the baghouse was negligible, whereas total mercury removal across the ESP was unexpectedly high.

PHASE II – OPTIMIZATION OF CONVENTIONAL SYSTEMS

Work performed During Reporting Period

The Phase II scope of work is being conducted under six major tasks. Phase II work began under Task 1, *Project Planning and Reporting*, on February 29, 1996. With the submission of the Phase II Management Plan, activity under Task 2, Task 4 ,Task 5 and Task 6 was initiated during the reporting period.

Task 1 -- Project Planning and Management

Work during the reporting period primarily consisted of planning and scheduling activities related to the preparation of the Phase II Management Plan (DOE) and the Phase II Milestone Plan (OCDO). Routine air toxics cognizance activities, begun during the last phase, continued. This work includes a literature survey, discussions with a variety of other air toxics investigators, and participation in various meetings, seminars and workshops. Members of the project team attended the Air & Waste Management Association's 89th Annual Meeting and Exhibition held June 24 - 28 in Nashville, TN.

Project plans for Phase II were discussed during the Project Participants Committee meeting held at DOE-PETC's offices on April 3, 1996. A general consensus was reached with the project participants with respect to the Phase II testing priorities and objectives to aid in the preparation of the Phase II Management Plan. The draft Phase II Management Plan (DOE) and the Phase II Milestone Plan (OCDO) were submitted May 31, 1996. Comments on the draft were received from the project participants.

Task 2 -- Capture of Air Toxics in Conventional Systems

Test planning and operations were completed for the initial test series, Conventional Systems Performance, in the reporting period. A detailed Test Plan was completed and submitted to the project sponsors for review and comment. The plan was subsequently approved by OCDO and the DOE. Major test preparations included the design and installation of a flue gas humidification system upstream of the full-flow ESP and the acquisition of an alternative baghouse fabric.

The primary emphasis of the Conventional Systems Performance test series was to characterize the trace metal and particulate emissions from the particulate control devices as a function of operating temperature, ESP electrical conditions and baghouse fabric. Flue gas cooling upstream of the ESP was achieved through humidification or the air-air heat exchanger (simulated convection bank). Testing emphasis was placed on mercury speciation and control. Mercury speciation measurements were conducted according to EPA Method 29 and the Ontario Hydro Method. Simultaneous Method 29 and Ontario Hydro measurements were conducted by B&W and ATS, Inc. (Monroeville, PA) to leverage operating time. Limited mercury speciation measurements were also obtained downstream of the wet and dry fluegas desulfurization systems. Ninety-eight percent (98%) of the planned fluegas samples were obtained within one hour of the original schedule. The CEDF and AECDP test equipment performed well over the entire test period (5 days) with one significant interruption due to a blackout at the electric utility's substation.

Task 3 -- Impacts of Coal Properties on Air Toxic Emissions

To aid coal selection, coal properties and commercial coal suppliers are under review. Ohio utilities are being surveyed as to Ohio coal usage, coal preparation and blending practices.

Task 4 -- Advanced Air Toxics Measurement Concepts

Other investigators were contacted regarding their experience applying several developmental on-line mercury analyzers at coal- and refuse-fired pilot-scale test facilities. Several vendors for on-line mercury analyzers (primarily developed for MWC's) were also contacted.

Task 5 -- Data Analysis and Reporting

Chemical analysis and data reduction work are in progress for the Conventional Systems Performance tests. Required status reports were prepared and issued.

Task 6 -- Technology Transfer

Work on the Newsletter continued.

Planned Work for Next Reporting Period

Task 1 -- Project Planning and Management

Comments on the draft Phase II Management Plan (DOE) and Phase II Milestone Plan (OCDO) will be incoporated and the final version will be issued. The project manager will attend the First Joint Power & Fuel Systems Contractors Conference held July 9 - 11 in Pittsburgh, PA.

Task 2 -- Capture of Air Toxics in Conventional Systems

Planning and preparation will begin for the second testing campaign.

Task 3 -- Impacts of Coal Properties on Air Toxics Emissions

Coal property and commercial suppliers review will continue. Ohio utility surveys will also continue.

Task 4 -- Advanced Measurement Concepts

Identification of potential on-line monitoring techniques will continue.

Task 5 -- Data Analysis and Reporting

Chemical analysis and data reduction work will continue for the Conventional Systems Performance tests conducted in June. The air toxics data library created in Phase I will be updated with the Conventional Systems Performance final test results when available. Required status reports will be issued.

Task 6 -- Technology Transfer

The Newsletter will be issued.

Phase II Milestones and Schedule

Progress to date is illustrated in Figure 5. Completed milestones are indicated in the figure.

Budget and Schedule Issues

Phase II activities began on February 29, 1996. A funding authorization was received from OCDO for the Phase II scope of work. Complete funding authorization for Phase II has not been received from the DOE. It is anticipated that the current authorized DOE funding will take us through August of this year.

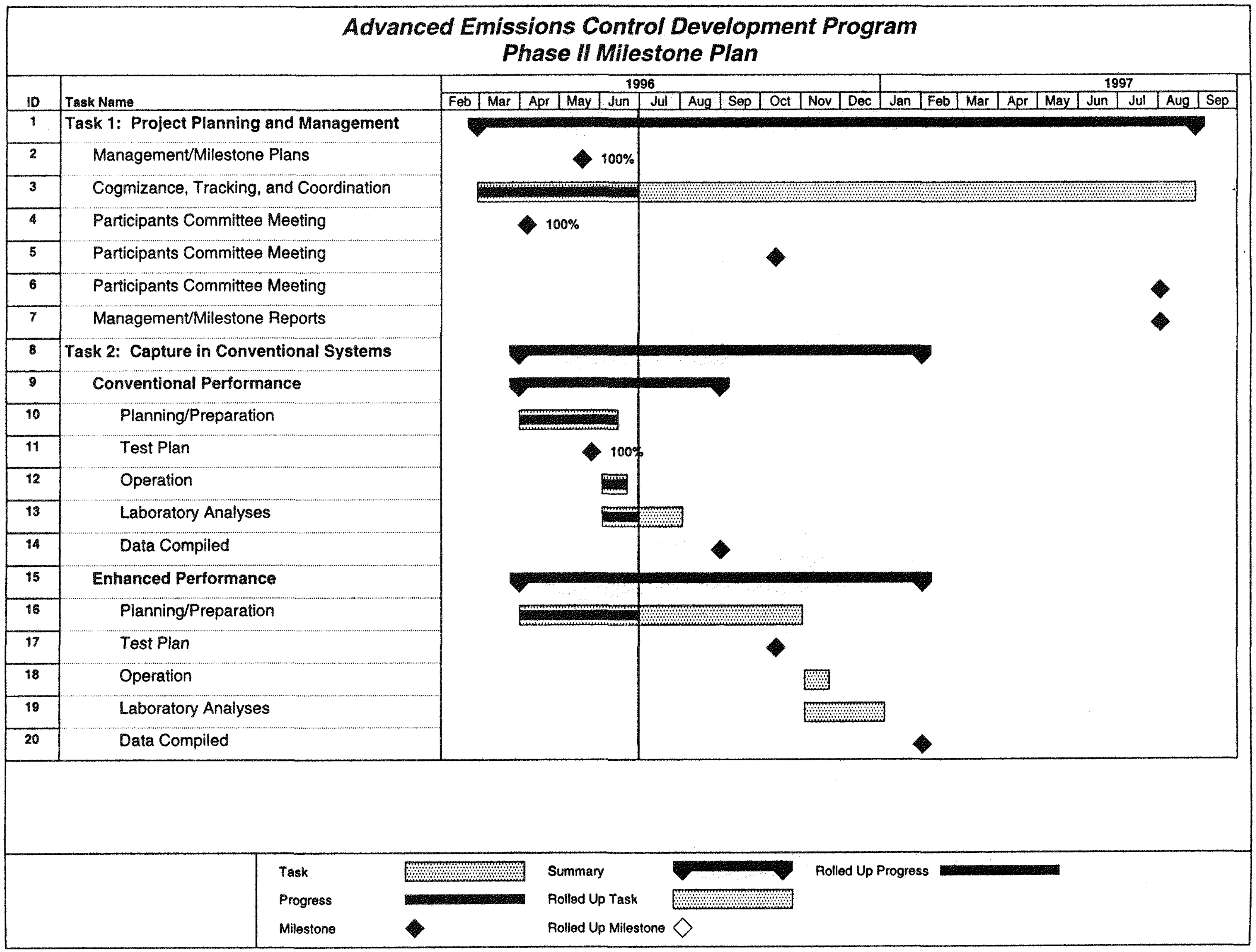

Figure 5 -- Phase II Milestone Plan

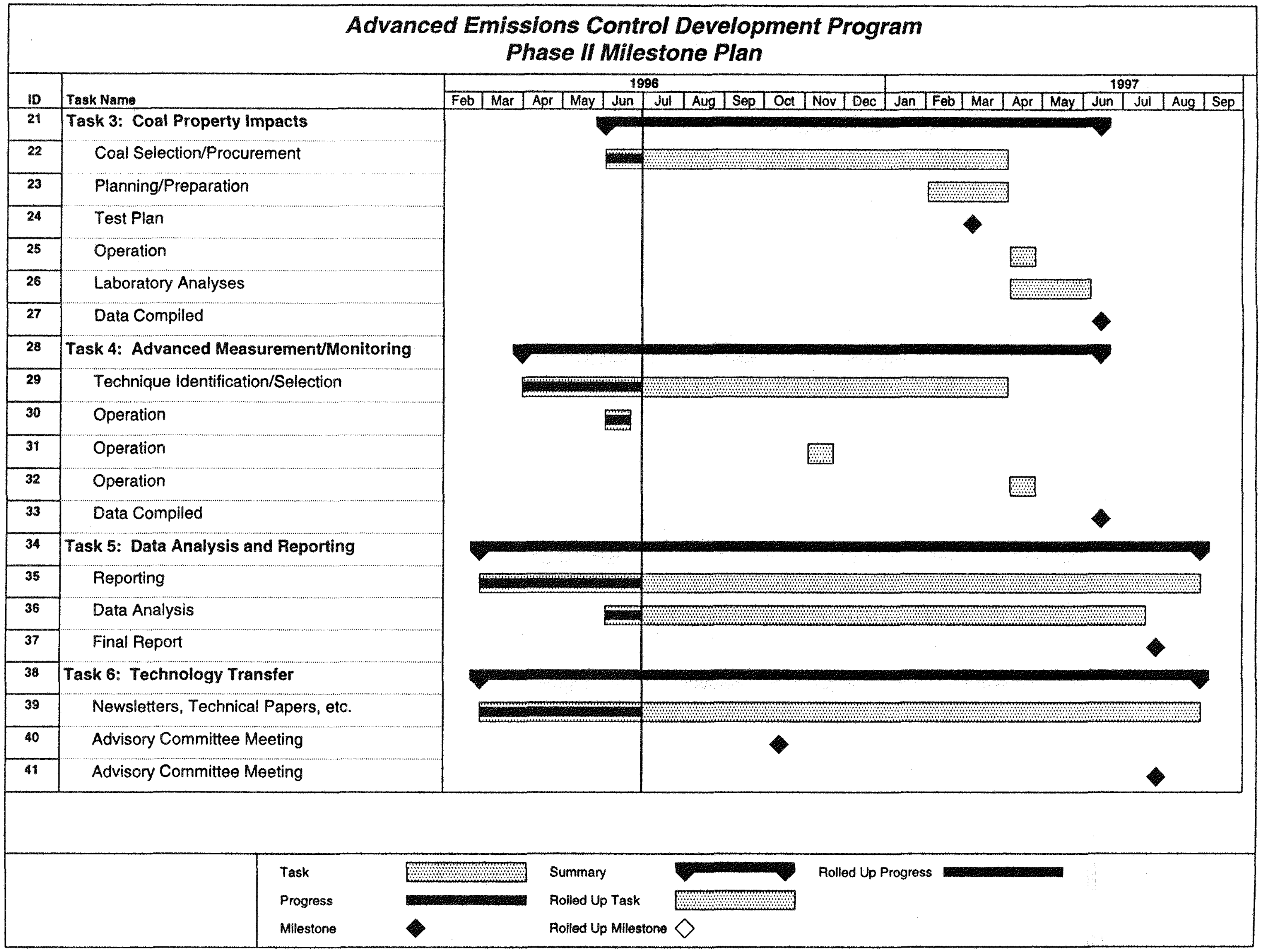

Figure 5 -- Phase II Milestone Plan (cont.)