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# COMPARISON OF HAZARDOUS AIR POLLUTANTS FROM ADVANCED AND CONVENTIONAL POWER SYSTEMS

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## ABSTRACT

The Clean Air Act Amendments (CAAA) of 1990 are expected to impact both conventional and advanced power systems. Pressurized fluidized-bed combustion (PFBC) and other coal combined-cycle processes combined with high-temperature cleanup devices are environmentally friendly and economically attractive. Though PFBCs are beneficial because they can decrease the emission of sulfur and NO<sub>x</sub> species, and advanced combined-cycle systems that incorporate high-temperature cleanup devices are beneficial because they can enhance efficiency, the impact of these technologies on the emission of trace metals and certain organic compounds needs to be assessed. This paper compares 1) the Tidd PFBC demonstration plant with conventional pulverized coal- and cyclone- fired systems and 2) the Tidd plant advanced particulate filter with the performance of conventional electrostatic precipitators and baghouses. We also attempt to extrapolate the comparison to other advanced systems. Except for mercury, the PFBC at Tidd released less trace metals into the flue gas stream than the adjacent conventional pulverized-coal combustor, using the same coal. Similar to conventional power systems, hazardous air pollution emissions from advanced systems appear to be lower than the trigger level of 1990 CAAA, which requires maximum achievable control technologies.

## INTRODUCTION

The Clean Air Act Amendments (CAAA) of 1990 identified 189 substances as hazardous air pollutants (HAPs). The U.S. Environmental Protection Agency (EPA) is regulating these trace emissions from various industries, including power systems used for the production of electricity. Electric utilities were singled out to provide required reporting to Congress on these emissions. A decision on whether regulation is needed and the extent of controls required to remove HAPs will be included in the mandated report due in November 1995. Under the CAAA, EPA will gain more authority for regulating emissions of these air toxics, will define those sources that require regulation, and will limit their emissions according to regulatory directives.

The Tidd PFBC Demonstration Plant located in Brilliant, Ohio, was the site of extensive HAP sampling and analysis funded by the U.S. Department of Energy 1994. The boiler at the Tidd plant is a bubbling-bed PFBC rated at 70 MWe; 55 MW is produced by a steam turbine generator, and 15 MW is produced by depressurizing the hot flue gas in a gas turbine. The Tidd plant contains an advanced particulate filtration (APF) system and a conventional electrostatic precipitator (ESP). Treated gas from one of seven primary cyclones is directed to a ceramic barrier APF and backup cyclone. The treated gas is then returned to the process upstream of the ESP. The APF system operates at approximately 1350°F (730°C), while the ESP operates at approximately 400°F (205°C). The ceramic candles are back-pulsed approximately every 30 minutes to remove particulate matter captured on the outside of the candles.

Under a separate initiative, nine full-scale combustion systems utilizing a variety of conventional gas cleanup technologies have been studied. These systems include both pulverized-coal and cyclone-fired boilers with ESPs, baghouses, and various scrubber systems. One of these, the Cardinal station, was chosen for comparison to the Tidd plant. The Cardinal station is an opposed-wall fired, dry-bottom boiler with a conventional ESP that operates at approximately 300°F (150°C). Both the Tidd plant and the Cardinal Station burn Pittsburgh No. 8 coal, which permits meaningful comparisons. Only the Tidd and Cardinal Station data sets are referred to by name within this report. The other sampling data sets are shown as averages grouped by their respective control technologies.

## **METHODS**

### Sample Collection, Characterization, and Manipulation

The sample collection and characterization techniques used at Tidd and at the conventional sampling sites can be found in the individual sampling reports [1–10]. In general, all sampling teams followed accepted EPA sampling and analysis techniques and most teams utilized American Society for Testing and Materials (ASTM) or American Society of Mechanical Engineers (ASME) data manipulation routines. Since significant differences in methodology among contractors was noted, the 95% confidence limit was calculated from raw data in the individual reports. The confidence limits include only the precision of the data and contain no information related to the bias of the measurements. Comments are offered to help qualify any potentially incorrect data.

### Modeling

We compared modeling results of trace element emissions generated by Lee [11] for the Tidd plant with actual measurements from the Tidd plant. Lee used a partitioning model to satisfy trace element phase equilibria and material balance constraints. This technique is based on a model originally described by Cobb et al. [12], which was developed for fixed-, fluid-, and entrained-bed gasifiers in integrated gasification combined cycle (IGCC) systems. The model was extended to combustion systems that remove sulfur with calcium-based sorbents, using the Tidd

plant as the initial application. The calculations cited by Lee were reported prior to the measurements at the Tidd plant.

## RESULTS

The following trace element comparisons are reported: 1) comparison of the Tidd APF and ESP with the Cardinal ESP, 2) summary of conventional and advanced power system collection efficiencies and emission factors, and 3) comparison of predicted and measured values for the Tidd APF system.

### Comparison of Tidd APF and ESP Units with Cardinal ESP

The comparative efficiencies in removing trace elements from flue gases using advanced and conventional control technologies for the Tidd and Cardinal systems are shown in Fig. 1. Both the APF and ESP units from the Tidd are shown on the graph. The APF system shows a higher collection efficiency than the Tidd ESP for all trace elements except arsenic, chromium, molybdenum, nickel, and selenium. However, as noted in the contractor's report [10], there is an apparent error in the nickel, chromium, and molybdenum values of the APF because of contamination from the sampling probe. This results in a lower-than-expected collection efficiency for chromium, nickel, and molybdenum in the Tidd APF system. The APF unit shows the same or higher collection efficiency as the Cardinal ESP except for antimony, chromium, cobalt, mercury, molybdenum, and nickel. In general, the Tidd APF system was effective (99.5%) in collecting the particulates and trace elements that passed through it. However, the higher operating temperatures of the APF unit permits some elements to remain as vapor, and these are not captured.

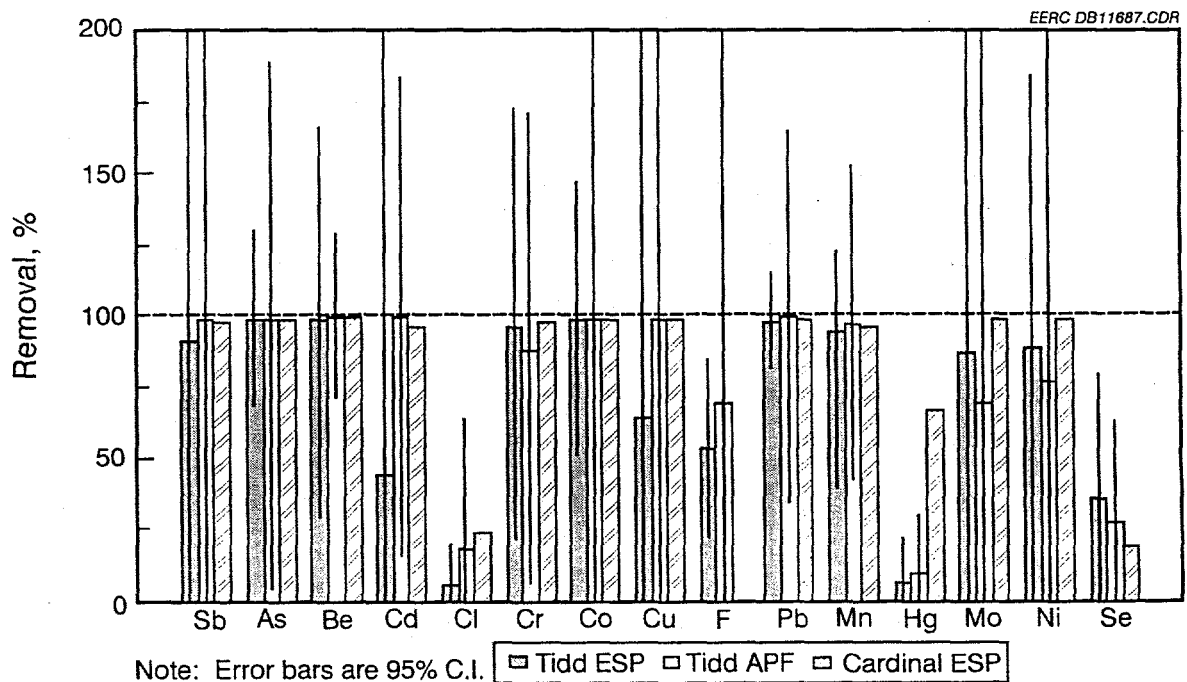


Fig. 1. Control efficiency of Tidd APF, Tidd ESP, and Cardinal ESP systems.

Figure 2 shows the amount of trace elements in the vapor state leaving the Tidd APF and ESP units. Most of the trace elements escaping through the APF are in the vapor state, while a significant amount escapes through the ESP as particulate. Overall, the APF system is a good collector of particulate matter, but the higher operational temperatures result in more vapor-phase species escaping the system.

### Conventional and Advanced Power System Collection Efficiencies and Emission Factors

Collection efficiencies and emission factors from the nine conventional plants were compared with emission factors for the Tidd APF and ESP units. The average collection efficiencies for mercury, selenium, and total particulate are shown in Fig. 3 for four ESPs, one baghouse, five FGDs/other, and the APF. Mercury and selenium are recognized as the two most difficult trace elements to capture because they are in the vapor state at the collection temperatures in conventional systems (300°–400°F) (150°–205°C). Since the cleanup devices in advanced systems operate at higher temperatures (1000°–1400°F) (540°–760°C), there would be no expected increase in capture, even with better particle entrapment. The general order of increasing capture of mercury and selenium for the four control technologies is ESP < APF < FGD/other < baghouse. Because of the extreme temperatures in the Tidd APF unit, the APF system does not collect as much of the mercury and selenium as the baghouse or FGD/other systems.

The total collection efficiency of the control technologies for all trace elements on the CAAA list is also shown in Fig. 3. The general order of capture for total CAAA

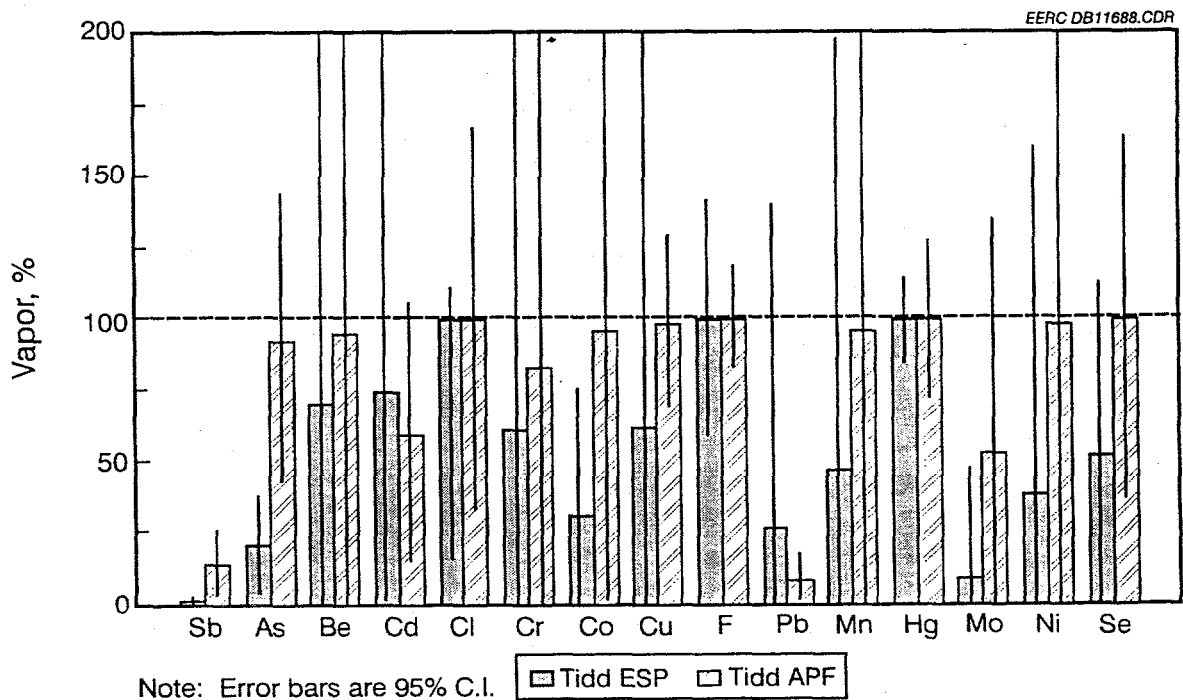


Fig. 2. Amount of trace elements present in the vapor state exiting with the flue gas in the Tidd APF and Tidd ESP.

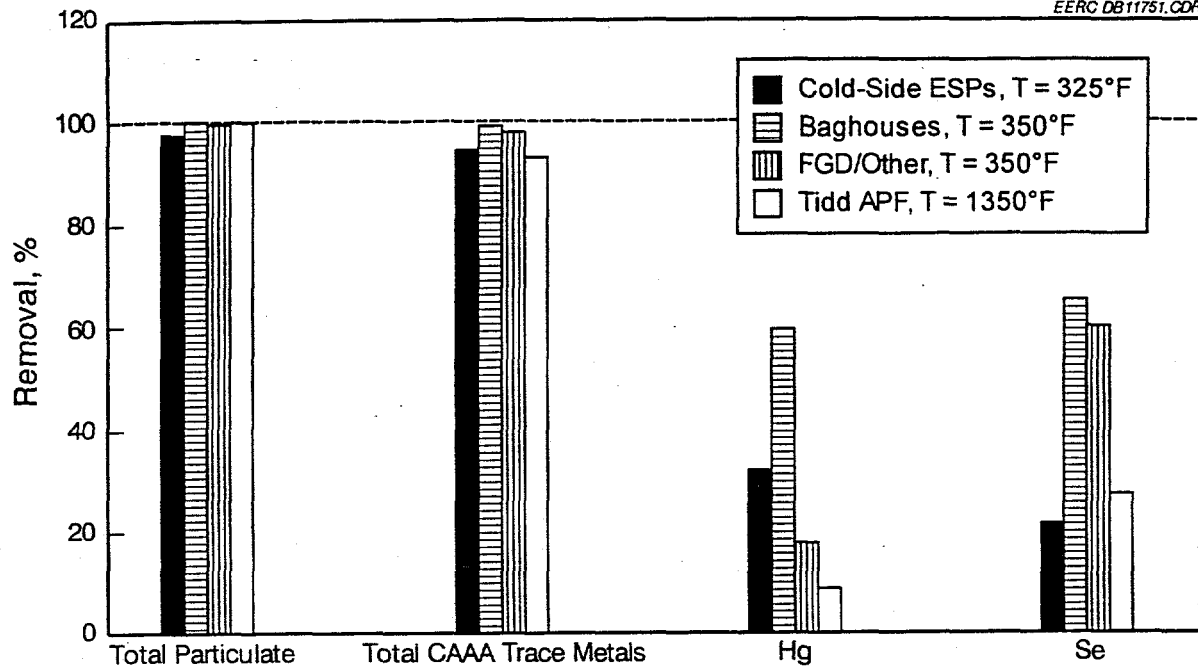


Fig. 3. Average control efficiencies for conventional and advance control technologies.

trace elements for the four control technologies is ESP < baghouse < FGD/other < APF. The APF unit controls total trace elements very well since most of these trace elements are present as particulate, even at the higher temperatures of the APF system.

Emission factors are summarized for the total CAAA trace elements, mercury, and selenium in Fig. 4. The results demonstrate that all plants have fairly low average emission factors for total CAAA trace elements. However, the amount of trace elements emitted into the atmosphere is largely a function of the amount initially present in the coal. Therefore, comparisons with different coals are difficult at best. The Tidd APF system, however, shows a higher mercury and selenium emission than most of the others. Though the total is small in comparison to other technologies, the political perception of mercury, in any amount, is important.

Two common features of advanced systems such as FBCs and IGCCs that influence trace metal emission are combustion/gasification and particulate filtration temperatures. The former temperature influences trace metal volatilization in the boiler/gasifier and also the portion that is removable with the bed ash. The filter temperature determines how much of the volatilized metals condense and become removable by the hot-gas cleanup subsystem. Combustion temperatures in FBC systems are advantageously low, around 1500°F (815°C), much lower than conventional pulverized-coal systems combustion temperatures; gasifiers operate closer to FBC temperatures. Also, filtration temperatures in the current IGCC designs are lower than those at Tidd. It appears that the Tidd data could serve as

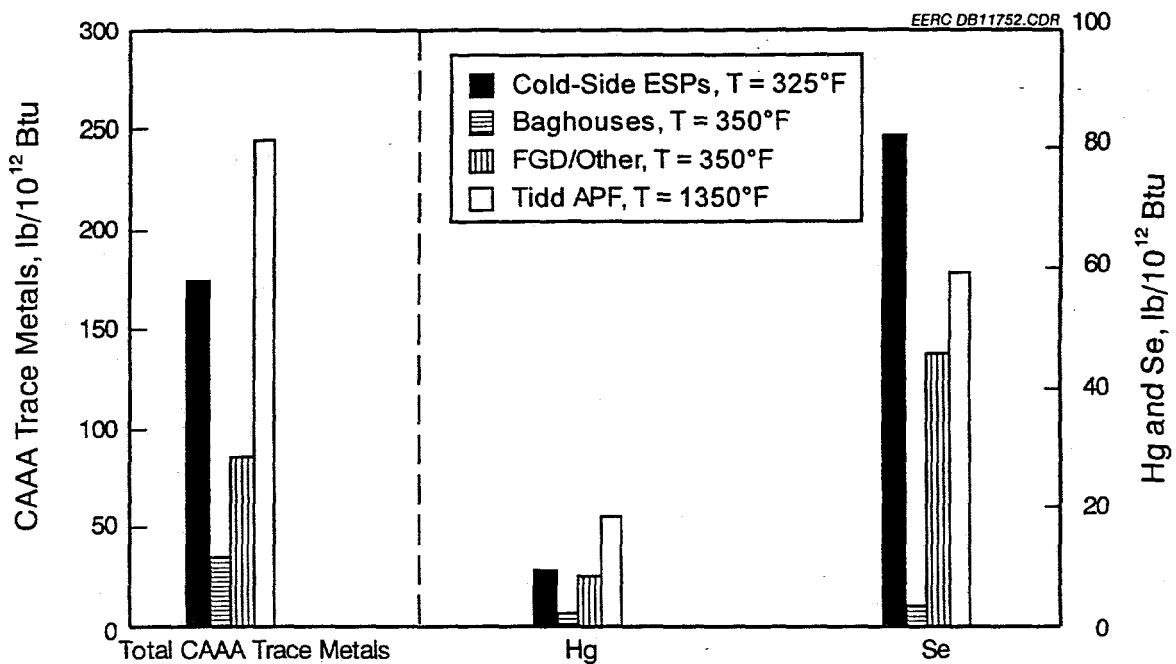


Fig. 4. Average emission factors for conventional and advanced control technologies.

a guide to estimate the expected emissions from IGCC systems until measurements from such installations become available.

#### Tidd APF Predicted versus Measured Values

Although full-scale measurements are the most reliable method of determining concentrations of trace elements throughout a given system, predictive methods provide a quicker and less expensive approach. Figure 5 compares the measured control efficiencies for the Tidd APF with those predicted by Lee [11]. The model successfully predicts control efficiency for highly refractive materials. However, the model is only marginally correct for vapor species, and shows poor agreement with elements that fluctuate between vapor and particulate states at the temperatures in the APF system. The cause of this inconsistency is probably 1) the limited number of phases considered during the phase equilibria calculations, and 2) the exclusion of the physical mechanisms of vapor capture in the model. Again, the nickel and chromium control efficiencies are believed to be low because of contamination during sampling.

#### Potential Regulation

The potential for regulation of HAP emissions in advanced power systems is currently being driven by the CAAA of 1990. The CAAA lists 189 compounds considered hazardous air pollutants that must be reduced 90% by the year 2000. The current form of the regulation would allow only 10 tons/year of any single HAP



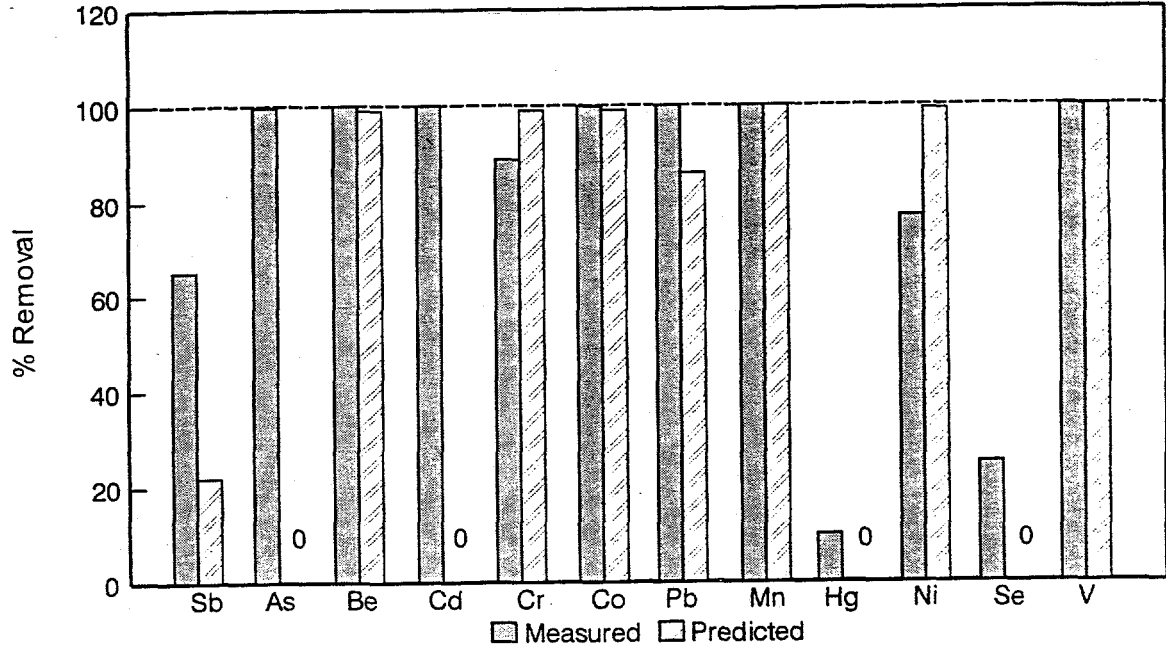


Fig. 5. Measured versus predicted values for collection efficiency and emission factors for Tidd APF.

and 25 tons/year of all HAPs combined. (To estimate the amount of a particular emission in tons/year for a 250-MW plant using 12,000 Btu/lb fuel and operating at 80% operational capacity, multiply the emission factor by 16 and multiply by a factor of 32 for a 500-MW plant.) If a major source exceeds these limits, the maximum achievable control technology will have to be added to the system to meet the regulation. It is assumed that advanced systems will be governed by the results from testing of conventional systems.

The emission of trace elements from advanced power systems or conventional systems is not expected to exceed standards or heavily contribute to the emission totals. Although the total CAAA trace elements emission is not expected to be significant, additional regulation of mercury is anticipated because of public concern and multimedia exposure. Since the APF emission of mercury is relatively high compared to baghouse and scrubbers, it may pose a regulatory problem.

## REFERENCES

1. Radian Corporation, A study of toxic emissions from a coal-fired power plant utilizing an ESP while demonstrating the ICCT CT-121 FGD Project, Final report, DOE Contract No. DE-AC22-93PC93252, June 16, 1994.
2. Energy and Environmental Research Corporation, Assessment of toxic emissions from a coal fired power plant utilizing an ESP, Final report, DOE Contract No. DE-AC22-93PC93252, December 15, 1994.

3. WESTON, Toxics assessment report, Minnesota Power Company, Boswell Energy Center – Unit 2, Final report, DOE Contract No. DE-AC22-93PC93255, July, 1994.
4. WESTON, Toxic assessment report, Illinois Power Company, Baldwin Power Station – Unit 2, Final report, DOE Contract No. DE-AC22-93PC93255, July, 1994.
5. Battelle, A study of toxic emissions from a coal-fired power plant utilizing an ESP/Wet FGD system, Final report, DOE Contract No. DE-AC22-93PC93251, July 1994.
6. Battelle, A study of toxic emissions from a coal-fired power plant – Niles Station Boiler No. 2, Final report, DOE Contract No. DE-AC22-93PC93251, June 1994.
7. Battelle, A study of toxic emissions from a coal-fired power plant utilizing the SNOX innovative clean coal technology demonstration, Final report, DOE Contract No. DE-AC22-93PC93251, July, 1994,
8. Southern Research Institute, Springerville Generating Station Unit No. 2, Final report, DOE Contract No. DE-AC22-93PC93254, June 21, 1994
9. Southern Research Institute, Bailly Station Units 7 and 8 and AFGD ICCT project, Final report, DOE Contract No. DE-AC22-93PC93254, August 11, 1994
10. Radian Corporation, A study of hazardous air pollutants at the Tidd PFBC demonstration plant, Draft report, DOE Contract No. 94-633-021-02, September 9, 1994.
11. George T. Lee, Personal communication.
12. J.T. Cobb, A.N. Mann, H.G. McIlvried, and W.E. Young, Determine allowable and actual contaminant emission rates, performance, and economics for three IGCC systems, Final report, DOE Contract No. DE-AC21-90MC27346, K&M Engineering and Consulting Corporation, June 1991.