**LIMESTONE SCRUBBING FOR 2000
FLUE GAS DESULFURIZATION SYSTEM**

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FINAL REPORT

October 16, 1998

**OHIO COAL DEVELOPMENT OFFICE
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**DEPARTMENT OF DEVELOPMENT
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ABSTRACT

As emission limits for sulfur dioxide from utility coal-fired boilers become lower due to increased regulation and environmental concern around the globe, power generating companies require increasingly cost-effective pollution control technology in order to maintain or reduce the cost of electricity to the end user. Limestone based wet flue gas desulfurization, or WFGD, is the preferred sulfur dioxide removal technology for utilities in the United States and worldwide. This is a result of its extensive reference list, lower risks, and lower evaluated overall costs.

For more than two decades ABB has supplied WFGD systems and currently has greater than 29,000 MWe of scrubbing capacity in operation. Given the industry's ever-present need for lower costs, ABB funds a continuous research and development program focused on technology advancements that will reduce both capital and operating costs for its customers. As a result of this effort, the LS-2 Concept WFGD System was developed through revolutionary design changes in every significant sub-process of conventional WFGD technology.

To demonstrate the cumulative effects of all the individual advancements of the LS-2 Concept and to prove the process's viability and cost-efficiency under representative U.S. power plant conditions, the Limestone Scrubbing for 2000 project was initiated. The project, cofunded by the Ohio Coal Development Office, the Electric Power Research Institute, Ohio Edison, and ABB, was executed over the period of October 1, 1993, to April 1, 1997, at the Ohio Edison Niles Generating Station in Niles, Ohio.

This report is the final submittal to the Ohio Coal Development Office to document the results of this demonstration project. The four-phase project execution, from the initial design and procurement through erection and extensive testing, proceeded as scheduled and on budget. The project resulted in a successful reference program that illustrates, in detail, the improved efficiencies and costs of the LS-2 advancements.

A commercial demonstration, such as this one, was necessary to successfully bring these technology advancements to the U.S. utility marketplace in a low risk and cost competitive manner. As a result, concepts demonstrated during the LS-2 project are now marketed as a viable, proven solutions to commercial desulfurization requirements in Ohio and the rest of the United States, and World. Power generation from higher-sulfur coal, as is found in Ohio, can be expected to remain cost efficient with the availability of low-cost desulfurization technologies such as that demonstrated at Niles.

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EXECUTIVE SUMMARY

The following Final Report was prepared for the Ohio Coal Development Office by ABB Environmental Systems, pursuant to OCDO Project Agreement CDO/D-932-1, for the purpose of documenting the results of the Limestone Scrubbing for 2000 Project. This project was conceived and executed jointly by the Ohio Coal Development Office, Ohio Edison, the Electric Power Research Institute, and ABB Environmental Systems. The duration of the project lasted from October 1, 1993 to April 1, 1997, and the host site was the Ohio Edison Niles Generating Station in Niles, Ohio.

The Limestone Scrubbing for 2000 demonstration, or LS-2, is the result of the continuous research and development efforts of ABB to further enhance and improve limestone based wet flue gas desulfurization (WFGD) technology for utility application. While WFGD is a mature technology, the LS-2 project has resulted in improvements of virtually every subsystem of the process. The cumulative effects of these process modifications were targeted to produce 30% lower capital costs and 20% lower operating costs.

The process demonstration at Niles achieves these significant cost reductions in several ways. Increasing flue gas velocities up to 18 ft/sec minimizes absorber diameter. Reaction tank volume is reduced by using very finely ground limestone reagent and unique recycling of unreacted reagent. Cost-effective sparing and general arrangement philosophies yield considerable reductions in equipment and space requirements. Other economies result from unique equipment applications and construction practices. Perhaps the major asset of the process is its generation of a very high quality gypsum product that is directly salable to the wallboard manufacturing industry. This avoids high waste disposal costs and eases permitting requirements. All of these advancements are achieved while maintaining impressive process performance such as 95% sulfur dioxide (SO₂) removal, lower reagent usage, and lower power consumption.

The combination of all of these process advancements had not previously been demonstrated in unison. A commercial scale demonstration was necessary to effectively bring these more cost-efficient concepts to the U.S. utility marketplace with an acceptably low risk profile. The project consisted of the construction and operation of a 130 MWe full scope proof-of concept test facility to be operated for two years with the specific objectives of:

- Demonstrating thoroughly the projected benefits of each advanced WFGD concept,
- Developing an extensive performance database to fully characterize all critical design criteria,
- Evaluate and quantify the full extent of process improvements possible with each of the individual concepts.

All major objectives for the project were accomplished and the predicted cost benefits and performance targets for the LS-2 Facility were met or exceeded. Significant mechanical design and erection experience was gathered that both confirm projected cost savings and will allow additional savings on future projects. All significant process design criteria such as SO₂ removal efficiency, system pressure drop, reagent consumption, gas reheat, reagent preparation, oxidation, and gypsum product quality were broadly examined and characterized. Throughout the operation of the LS-2 Facility, valuable performance insights regarding the interactions of individual process changes were gained that will allow additional enhancements in future advanced WFGD designs.

Based on data collected during the test program, the LS-2 plant's performance versus the design targets is summarized in Table 1.

Parameter	Goal	Test Results
Gypsum Purity	>95%	95-98%
Gypsum Moisture	<8%	6 – 8%
Gypsum Chloride	< 100 ppm	30-50 ppm
Sulfite Oxidation	>99.5%	>99.5%
Gypsum MMD	>30 um	>30 um
SO ₂ Removal	95%	85 – 98% ⁽¹⁾
Limestone Grind	99% < 44 um	85-99.5% < 44 um
Gas Velocity	>15 ft/sec	up to 18 ft/sec
Reheat	> 200 °F	>210 °F

⁽¹⁾ Depending on limestone grind size and pH.

Table 1: Typical LS-2 Performance Results

The LS-2 demonstration project proceeded according to the original schedule for individual phases and tasks and for the overall project. Some additional third party performance testing is still on going under the EPRI portion of the project and is expected to conclude in late 1998. Pursuant to the original vision of ABB and Ohio Edison, the Facility will be operated at least into the year 2000 as a valuable pollution control resource for the OE power generating system.

The impacts of this project are immediate and widespread. During construction, and certainly during operation, this plant served and still serves as a technology showcase to utility FGD customers from throughout the world. ABB has capitalized on this resource by presenting the plant on many occasions by on-site tours, customer presentations, and broad publication in the technical community. The demonstrated concepts have been well received to date as their advantages become known. The project's other sponsors have also benefited directly. Ohio Edison has gained a valuable flue gas desulfurization plant that will serve as a significant part of its Clean Air Act Amendment compliance strategy well into the future. The Ohio Coal Development

Office, and the state of Ohio, will benefit from the continued use of high-sulfur Ohio coal at the Niles Generation Station and potentially at other plants in Ohio and surrounding states.

The presence of a full-scale commercial plant designed and operating with LS-2 concepts can be expected to expedite the commercialization of the technology. Especially in the U.S., utility FGD customers demand proven technologies for application to essential generating capacity. Without the LS-2 demonstration, full acceptance in the utility market would most likely be delayed. LS-2 concepts are now being successfully presented for immediate consideration as cost-efficient high-performance pollution control solutions.

LS-2 technology improvements as applied to large scale, higher-sulfur boilers have been evaluated relative to other commercial WFGD technologies and found to improve cost and performance. One overriding goal of the LS-2 project, however, is not only to demonstrate lower cost WFGD but also a competitive alternative to fuel switching and SO₂ allowance purchasing. The project has achieved these objectives with projected levelized costs as low as \$150 per ton of SO₂ removed and \$11 per ton of coal burned. As SO₂ allowance credits and low-sulfur fuel continue to increase in price, these low costs will act to shift utility compliance evaluations in favor of advanced WFGD.

Substantial operating cost savings are gained by avoiding the high-volume solids waste streams common with conventional WFGD technology. The Niles plant produces a high-quality gypsum product that meets strict wallboard manufacturing specifications without intermediate treatment. Depending on transportation costs, the sale of gypsum can generate revenue from \$0 to \$5 per ton while avoiding possible landfill disposal costs of \$10 to \$15 per ton.

The Ohio coal consumption market can be expected to benefit from the commercialization of advanced utility WFGD processes that are lower cost, higher performing, and more environmentally friendly. This is supported as more coal-fired generating capacity will conceivably utilize advanced WFGD in place of fuel switching, derating, or allowance purchasing to meet SO₂ emission limits. Thus, these advanced processes should have a stabilizing effect to maintain current levels of Ohio coal use in a regulatory environment that would otherwise tend to depress its use.

Finally, in addition to the major accomplishment of streamlining advanced WFGD commercialization into the utility power generation marketplace, the Project has served to define some near-term steps for further process development. Process development will continue as the large quantity of performance data collected at Niles is condensed into specific design tools. Mechanical and structural feedback will likewise be compiled and translated into further design standardizations that should in turn reduce costs for future designs.

I. INTRODUCTION

A. PROBLEM STATEMENT

ABB Environmental Systems (ABBES) is a supplier of wet flue gas desulfurization technology to utilities worldwide has amassed an installed experience base of greater than 29,000 MWe. As a major supplier, ABBES strives to continually improve the WFGD product line by reducing capital and operating cost requirements. The utility power generating community has a legitimate need for lower cost FGD if it is to maintain or decrease power costs in the presence of increasingly stringent sulfur dioxide (SO₂) emissions restrictions.

Through years of research and testing either at full-scale WFGD systems or ABB's integrated pilot facility in Sweden, ABB has developed many individual process upgrades. However, the collective set of these enhancements had not been demonstrated. ABB considered a U.S. based demonstration project running on U.S. coals, with U.S. operators and facing normal daily cycling demands to be necessary. The key underlying reasons for this were:

- The electric utility industry (considering its critical place in the domestic economy infrastructure) must have absolute assurance of the performance of a technology. Extrapolation from similar operations on different fuels with different daily cycles in foreign countries is not sufficient to permit a utility to employ a technology except on a test basis or in a non-essential service.
- When legislation is passed requiring emissions control, time is not available to experiment with new technologies, see the results, and perform the evaluations needed to allow widespread application.

Considering the above, ABBES proposed a program, the LS-2 Project, to construct and operate a full-scale proof-of-concept test facility (the Facility) at Ohio Edison's Niles Generating Station. The plant would be 130 MWe capacity, a sufficient size to soundly demonstrate the fabrication, construction and operational savings. It was planned to operate the Facility for 2 to 3 years to confirm process and system operability and maintainability.

While the LS-2 project relied on the proven open spray tower absorber technology, it differs from conventional state-of-art spray tower absorbers in many important ways:

- Absorber and reaction tank are significantly smaller,
- Parasitic power consumption is substantially lower,
- Reagent preparation system is less costly both to construct and operate yet produces a finer quality limestone reagent, and

- Dewatering system is simpler.

Total Process Capital for the WFGD system demonstrated at Niles was targeted at levels 30% less than that required for a conventional state-of-art limestone FGDS. Further, operating cost about 20% lower than conventional systems when cleaning flue gas generated from moderate to high sulfur coals were targeted. With these improvements, the cost for scrubbing flue gas from Ohio coals should be very competitive relative to coal switching as a Clean Air Act Amendment (CAAA) Phase II compliance strategy.

B. PROJECT OBJECTIVES

In response to an industry need for lower cost flue gas desulfurization, ABB Environmental Systems proposed and executed a program to demonstrate advanced Wet FGD concepts on a full scale at the Ohio Edison Niles Generating Station. The objectives of this demonstration program were as follows:

- Demonstrate thoroughly the projected benefits of these advanced WFGD concepts,
- Develop an extensive database for predicting operation under a variety of conditions, and
- Evaluate and quantify the extent of process improvements and economic benefits possible.

The facility would have the following design features to achieve these objectives:

- Full scale componentry, such as nozzles, nozzle layout and headers, mist eliminators, reheat sections, reaction tank submergence, agitation and oxidation air dispersion characteristics, etc.;
- Modular construction to expedite erection with minimal impact on the host plant and minimal cost;
- High degree of subsystem supplier involvement during tests and evaluations, especially with the limestone pulverizing circuit, reheater, agitation and oxidation system, and liquid cyclone separation/fractionation system;
- Attractive site layout with enclosed facilities for security and local visual impact;
- A full scope training/briefing room for meetings and presentations on the LS-2 FGD Facility, program plans, and operating results;
- Commercial grade gypsum production to be sold to local wallboard manufacturers; and
- Fully automated control system with extensive data acquisition and recording functions.

c. PROJECT COSPONSORS

ABBES acted as project manager of the demonstration and was responsible for the project design, installation, and testing. ABBES was also responsible for the project's budget, test plan, and the preparation and submittal of the project deliverables, which include progress reports and this final report. Ohio Edison provided the host site, operation and maintenance, utilities, and technical assistance. Ohio Edison will also control the final disposition of the Facility after the original contract terms expire.

ABBES, the Ohio Coal Development Office, and the Ohio Edison Company jointly funded the project. The Electric Power Research Institute also cosponsored the project by providing the funding for a third party verification of the facility's performance. Contact points for each of these participants follow:

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The contribution levels for each cosponsor are listed below in Table 2:

	<u>Dollar Amount</u>	<u>Percentage</u>
Ohio Coal Development Office	\$ 6,811,591	21.6
ABB Environmental Systems	\$ 22,551,015	71.5
Ohio Edison	\$ 1,500,000	4.8
Electric Power Research Institute	\$ 670,000	2.1
TOTAL	\$ 31,532,606(*)	100

Table 2: Project Cosponsor Contributions

* - It should be noted that this total not only includes all project costs such as supply, erection, and commissioning but also all operating, testing, reporting, and managing costs for a three year period.

II. TECHNICAL DISCUSSION

D. PROCESS DESCRIPTION

The LS-2 project at the Niles Plant includes a number of innovative process improvements over conventional wet flue gas desulfurization technologies. The spray tower has the ability to run as high as 18 ft/sec, features a compact spray zone with ABB's patented nozzle arrangement, and a compact reaction tank. The reagent system is based on an ABB Raymond roller mill that features a completely dry grinding circuit. This limestone grinding system is less costly, both to construct and operate yet produces a significantly finer grind. The primary dewatering system features fully integrated high efficiency hydrocyclones followed by centrifuges for secondary and final dewatering. A 3-D overview of the FGD system installed at the Niles Plant is shown in Figure 1.

Figure 1: 3-D View of the LS-2 Installation at Niles, OH

The FGD system at the Niles Plant is cross-connected to both Unit 1 and Unit 2 boilers. Hence, the system is capable of taking flue gas from either or both boilers. Each boiler is rated at 108 MW_e net. The system is cross-connected in order to maximize flue gas availability and maintain a high FGD system capacity factor. Treated flue gas is discharged into the pre-existing Unit 1 carbon steel lined stack. To protect this lining, an ABB Air Preheater Ljungstrom type gas-to-gas heat exchanger (GGH) was incorporated, as also shown in Figure 1. The GGH features ABB's patented horizontal shaft orientation that greatly reduces the amount and cost of expensive cool-side ductwork. All cool-side duct work and plate surfaces are lined with various types of flake glass while all hot-side surfaces are unlined carbon steel.

1. Additive Preparation

The additive preparation system features an ABB Raymond roller mill, as shown in Figure 2. The mill system accepts a limestone feed stock less than 40 mm (1.6 in.). Untreated flue gas is used to dry and convey the limestone during mill operation. The flue gas leaving the milling system is returned to the absorber for processing. The limestone preparation and handling system is completely dry and includes a wetting system prior to injection into the reaction tank.

The grinding system includes a limestone loading area and a storage silo for raw feedstock. Ground limestone leaving the roller mill is collected in a cyclone followed by a baghouse and then transported pneumatically to a final storage silo. Based on demand, the ground limestone is fed to the absorber reaction tank to maintain pH. The limestone grind will typically be 99.5 percent less than 44 micron (325 mesh) although coarser and finer grinds have been tested.

2. Absorber System

The LS-2 absorber design has evolved from ABB's open spray tower technology and employs a high superficial gas velocity and fine grind limestone to achieve a significant reduction in absorber size and recycle tank volume. In addition, this absorber employs a new patented spray header design that allows a higher spray density to be used resulting in fewer spray levels and a corresponding reduction in absorber height and cost. The absorber system is designed to consistently provide a SO₂ removal efficiency of 95 percent or greater on flue gas from a 3.5 percent sulfur coal. Potential reductions for this type of absorber over a current 400 MWe state-of-the-art absorber are shown in Table 3.

Parameter	Reduction
Reduction in Absorber Diameter	15-25 %
Reduction in Overall Height	20-30 %
Reduction in Plate Area	25-35 %
Reduction in Plate Weight	35-45 %
Reduction in Liquid-to-Gas Ratio	20-40 %
Reduction in Power Consumption	10-20 %

Table 3: Potential Reductions with Advanced WFGD

Figure 2: ABB Raymond Roller Mill

3. Mist Elimination

The spray zone is followed by a proprietary two-section mist eliminator system including a vertical flow Bulk Entrainment Separator (BES) followed by a unique 2-pass by 2-stage horizontal flow chevron type Mist Eliminator (ME). The trailing edges of these ME vanes contain ABB's patented extensions that significantly improve droplet collection while maintaining pressure drop performance.

Traditionally, open spray tower systems operate at 8 to 12 ft/sec due to limitations of the vertical flow mist eliminator. Vertical flow mist eliminators start to experience flooding and significant carryover at higher velocities. Horizontal flow mist eliminator can handle velocities exceeding 20 ft/sec, which provides an opportunity for higher gas velocities to be used in the spray zone.

ABB has developed and patented a new BES that operates well with velocities at or below 22 ft/sec. A schematic illustration of the new mist elimination system is shown in Figure 3. The BES is inclined at an angle that provides the required drainage to operate at these high velocities.

An even gas distribution is critical to the performance of any mist eliminator design, in particular the performance of the second stage. The BES is designed to provide an even gas distribution ahead of the second stage mist eliminator by acting as a set of turning vanes as well as a bulk entrainment separator. Further, the inclined BES provides protection from buildup of deposits on the roof of the absorber vessel. Also, the design results in an inherently low pressure drop.

Figure 3: LS-2 BES and Mist Eliminator

4. Reaction Tank

The reaction tank is an integral part of the absorber and provides liquid residence time to complete a number of critical chemical reactions:

Limestone Dissolution:

Sulfite Oxidation:

Gypsum Precipitation:

The size of the reaction tank at Niles has been reduced by about 50 percent compared with conventional sizing criteria. ABB has determined that for liquid residence times above 3 minutes, the limiting reaction step is the limestone dissolution, not sulfite oxidation or gypsum precipitation. At liquid residence times above 3 minutes, the gypsum precipitation reaction is sufficiently fast not to affect the gypsum relative saturation. Also, the oxidation reaction is much faster than the dissolution rate and is not affected by a reduced reaction tank size.

With typical limestone grinds, a significant reduction in the reaction tank size will dramatically lower the liquid phase alkalinity and increase the solid phase alkalinity. In order to reduce the solid phase alkalinity, the operating pH must be lowered which would result in a reduction in SO₂ removal efficiency. In order to maintain the SO₂ removal efficiency, i.e. maintain the pH and the liquid phase alkalinity at reduced residence time, the only option is to increase the limestone surface area available for dissolution.

The system at Niles overcomes this traditional limitation in reaction tank size by using an ultra-fine limestone grind. The required limestone grind is achieved by using ABB Raymond's roller mills. The roller mill technology has been used in the limestone industry for more than half a century and is superior to wet balls from the standpoint of power consumption and cost. In addition, the grinding process is completely dry, eliminating the need for costly wet slurry handling systems including pumps, classification system, and storage tanks.

The grind size used is 99.5 percent less than 44 um (325 mesh), or 90 percent less than 25 um. This provides a clear advantage in the primary dewatering step

as fractionation can be readily accomplished due to the greater size difference between the gypsum and limestone.

5. Dewatering System

The dewatering system consists of hydrocyclones for primary dewatering and centrifuges for secondary dewatering. The hydrocyclones are tightly integrated with the absorber loop to utilize their separation capabilities.

The centrifuges are designed to dewater the gypsum byproduct down to a moisture content of 8 percent or less. Also, they are located directly above a gypsum storage bunker. Hence, the centrifuges discharge directly into the storage bunker eliminating the need for a costly solids handling system.

Wallboard grade gypsum is loaded directly from the gypsum bunker into trucks for transportation to the wallboard manufacturer.

6. Waste Slurry Processing

Waste slurry processing, also referred to as the Solids Separation System, treats the blowdown slurry from the process. This is necessary to control soluble chlorides in the scrubbing loop. When the hydrocyclones are in operation, a small portion of the overflow is sent to a blowdown tank for storage before treatment.

The system chosen to treat this waste stream is a precoat rotary vacuum filter followed by a polishing filter. The purpose of this treatment is to separate the liquid phase from the solid phase and produce a clear liquid discharge containing no suspended solids. Because Ohio Edison is discharging the liquid stream into an ash pond, no contamination by extraneous solids is permitted. Solids from the vacuum filter, approximately 90% gypsum with the remainder limestone and inerts, can be discharged for landfill disposal, but is normally sent to the centrifuge feed tank. Here they are blended and sold with the product gypsum. This option is viable depending on the amount of inerts in the limestone and the quantity of flyash entering the scrubber.

7. Gas-to-Gas Heat Exchanger Performance

The gas-to-gas heat exchanger (GGH) used to cool and reheat the flue gas entering and exiting the absorber is a horizontal shaft Ljungstrom unit. Flue gas entering the system is between 265° to 335° F, and flue gas exiting the system should be no lower than 196° F. Table 4 contains data for a typical operation condition.

	Deg. F
Unit 1&2 Flue Gas into GGH	290
Flue Gas entering Scrubber	186
Flue Gas leaving Scrubber	125
Flue Gas leaving GGH	219

Table 4: Typical System Temperatures

Cleaning of the GGH is accomplished by routine high-pressure air blowing and periodic high-pressure water washing, both on-line. Air blowing is performed three times per day, and water washing has been conducted on an as-needed basis dictated by GGH pressure drop.

E. PLANT SITE

The Niles Plant is located on a 130-acre site along the banks of the Mahoning River near Warren, Ohio. Electricity was first generated at the plant on December 19, 1953. At that time, the plant was capable of producing 250,000 kilowatts of electricity from two coal-fired generating units (shown in Figure 4). In 1972, a 30-kilowatt oil-fired combustion-turbine unit was installed to help meet peak demand periods.

The plant is equipped with cyclone-fired boilers. When operating at full load, the plant burns as much as 2,300 tons of coal per day. Nearly all of the plant's coal is mined in Ohio. The current plant and related facilities represent a capital investment of approximately \$115 million.

In 1981 each boiler was equipped with an electrostatic precipitator for the removal of flyash emissions as well as a common 393-foot concrete chimney. This equipment upgrade cost approximately \$32 million and replaced flyash controls that were about 60% efficient. In 1995 the LS-2 scrubber facility (Figure 5) was installed and cross-connected to both boiler trains. The LS-2 System routinely achieves greater than 95% removal of the sulfur dioxide entering the plant.

Figure 4: Ohio Edison Niles Generating Station

Figure 5: LS-2 WFGD System at Niles, Ohio

F. PROJECT APPROACH

1. Phase and Task Definition

In order to achieve the project's objectives, a phased project execution approach was planned and executed. Each phase had specifically identified tasks and timetables. These phases and tasks are described below:

The project was divided into four phases:

- Phase I: Design and Permitting
- Phase II: Procurement and Fabrication
- Phase III: Construction and Start-up
- Phase IV: Operation

Phase I was further divided in three tasks: Basic Engineering, Detailed Engineering, and Permitting. These tasks are described below:

Task 1: Basic Engineering

- Calculation of production and consumption figures.
- Process Flow Diagrams.
- Piping and Instrument Diagrams.
- Preliminary plot plan showing the general layout of the plant.
- Equipment and Machinery Details.
 - Equipment list.
 - Process specifications for all itemized equipment.
- Instrumentation.
 - Description of the general requirements for instrumentation.
 - Instrumentation data sheets listing all instruments, control and safety valves, and indicating main components in the loops as well as operating conditions, measuring ranges, special materials, etc.
 - Loop diagrams for complicated control loop and interlocks.
 - Typical hook-up drawings showing the alarm system, the safety interlock trip system, and the data acquisition system.
- Operating Manual.
- General description of process with regard to start-up, normal operation, planned shut-down, and emergency shut-down.

Task 2: Detailed Engineering

- General arrangement drawings.
- Equipment installation drawings.
- Duct work and piping drawings.

- Electrical equipment installation and connection drawings.
- Logic or elementary drawings for instrumentation and controls.
- Technical specification for procurement and installation of equipment and material.
- Steel work design and drawings.
- Technical specifications covering supply and installation of all civil/structure items.

Task 3: Permitting

- Interface with state agencies to finalize procedures.
- Detailed calculation of chemical composition and amount of any waste to be produced as a result of construction, installation, or operation.
- Description of equipment or apparatus covered by the application.
- Generation of record keeping and reporting procedures.

Phase II consisted primarily of two tasks: Procurement and Fabrication. These are described below:

Task 1: Procurement

- Prepare and release equipment requisitions.
- Receive vendor bids and select equipment.
- Procurement of all equipment and material.

Task 2: Fabrication

- Issue Release for Fabrications after approval of vendor drawings.
- Quality assurance inspections during fabrication and after delivery.
- Manage progress and final payments.
- Manage performance warranties and guarantees on vendor equipment.

Phase III consisted of four tasks: Scheduling, Site Development and Foundations, Construction, and Plant Start-up. These are further described below:

Task 1: Scheduling

- Development of construction schedule.
- Integration of construction schedule with engineering and procurement schedule.

Task 2: Site Development and Foundations

- Site excavation.

- Installation of foundations for construction

Task 3: Construction

- Establish site organization.
- Hire labor.
- Erect plant equipment.

Task 4: Plant Start-up

- Check installed equipment for correctness of installation and readiness for operation.
- Review contract documents, installation drawings and instruction manuals.
- Coordinate the commission of individual components and start-up of subsystems.
- Resolve subsystem and component performance problems.

Phase IV of the project, Operation, was comprised of three tasks: Process Tuning, Parametric Testing, and Data Assessment/Reporting. These are further described below:

Task 1: Process Tuning

- Nozzle and header adjustments.
- Pulverizer system adjustments.
- Oxidation air adjustments to achieve gypsum quality.
- Ljungstrom reheater adjustments (cleaning system, purge air, etc.).
- Gas path damper control adjustment.
- Mist eliminator wash system tuning.
- Hydrocyclone adjustments.
- Centrifuge cycle adjustments to achieve gypsum quality and throughput.
- Adjustments of blowdown solids separator.

Task 2: Parametric Testing

This task overlapped with Phase IV - Task 1 above. However, it extended beyond Task 1 in duration. The following subsystems were thoroughly tested to establish the range and impact of all significant influences:

Absorber System

Impacts on SO₂ removal and pressure drop from changes in L/G, pH, and spray zone velocity.

Gas-to-Gas Heat Exchanger

Impacts on heat transfer rate and pressure drop from gas velocity, cleaning cycle, and mist eliminator wash operation.

Pulverizer System

Impacts on particle size distribution from rate of limestone feed, turbine classifier speed, gas throughput, and gas temperature.

Oxidation Air System

Impacts on sulfite in liquid and calcium sulfite in solids from slurry level above air injection point, pH, solution chemistry, and air stoichiometric ratio (i.e., air injection rate).

Gypsum Dewatering System

Impacts on gypsum quality from centrifuge spin intensity, centrifuge wash rate, wash water quality, reaction tank pH, chloride content, and level of oxidation.

Task 3: EPRI Test Program

Following Task 2 testing to establish the impact of key design performance parameters, the Electric Power Research Institute coordinated a test program to further explore and verify the performance of LS-2 and to calibrate EPRI's FGDPRIISM performance model.

Task 4: Data Assessment and Reporting

The data gathered from parametric testing and tuning was assessed and, together with data from consumable rates and Ohio Edison's assessment of operating manpower, ABBES formulated an economic and overall design performance assessment of the LS-2 system as presented in this report.

2. Sequence and Timing

Phase I began on October 1, 1993, and lasted for ten months to July 31, 1994. During that time, ABBES and Ohio Edison worked closely to execute the three included tasks. ABBES took the lead in execution of Basic and Detailed Engineering, with input from Ohio Edison. Ohio Edison took the lead in executing the Permitting of the facility, with input from ABBES.

Phase II began on December 1, 1993, and lasted nine months to August 31, 1994. ABBES took the lead for both Procurement and Fabrication, with input from Ohio Edison on an as-needed basis.

LIMESTONE SCRUBBING FOR 2000 PROJECT SCHEDULE

Figure 6: LS-2 Project Schedule

**LIMESTONE SCRUBBING FOR 2000
PROJECT SCHEDULE (Cont.)**

PROJECT TASK	1997	1998
	J F M A M J J A S O N D	J F M A M J J A S O N D
PHASE I Task 1 - Basic Engineering Task 2 - Detailed Engineering Task 3 - Permitting		
PHASE II Task 1 - Procurement Task 2 - Fabrication		
Phase III Task 1- Scheduling Task 2 - Site Development Task 3 - Construction Task 4 - Plant Start-up		
Phase IV Task 1 - Process Tuning Task 2 - Parametric Testing Task 3 - EPRI Test Program Task 4 - Assessment / Reporting

**Figure 6: LS-2 Project Schedule
(Continued)**

Task 1 of Phase III, Scheduling, occurred in November, 1993. Site Preparation and Construction began on or about March 1, 1994, and lasted until all equipment was "turned over" and certified ready for operation in August of 1995. Plant commissioning and start-up took place in July and August of 1995.

Phase IV - Task 1, Process Tuning, began on August 15 and lasted through September 15, 1995. Parametric Testing started on September 15 and lasted through January 31, 1997. Task 3, the EPRI Test Program, then started and will last till late 1998. The final report (Task 4) was provided to OCDO in October of 1998. A Gant chart with the project's schedule is shown in Figure 6.

3. Management Approach

To successfully plan, schedule, and execute this project, an effective and efficient management process was organized and staffed. This management approach is outlined below:

Project Manager - The overall execution of the program was the responsibility of the ABBES Project Manager. He was responsible for coordination of all technical design, test evaluation, and reporting functions. Reporting to the ABBES Project Manager were experienced project engineers serving as appropriate coordinators for engineering and construction, technical evaluation, and operations.

The ABBES Project Manager worked closely with Ohio Edison's Project Manager to assure program activities were conducted within the schedule and operating requirements of the plant. Reporting also to the ABBES Project Manager was the QA/QC officer from ABBES. Utilizing the latest standards and methods, supplemented by their knowledge and judgement, they insured that the project performance and generated data would be obtained in a manner consistent with the statement of work.

The ABBES project management team was advised by a project management committee. Participating in this committee were appropriate representatives from ABBES, Ohio Edison, EPRI, and OCDO.

The primary point of communication between OCDO, co-sponsors, and ABBES was through the ABBES Project Manager. He provided the overall management necessary for successfully conducting the project. His responsibilities were:

- Provide general project direction and leadership.
- Communicate contract performance information to the OCDO Program Manager and recommend, when necessary, changes in contract direction and scope to improve performance.

- Conduct planning and scheduling activities to insure that project goals were met within the allocated time.
- Provide coordination for all subcontractors and consultants in the project.
- Monitor and inspect technical work for completeness and quality.
- Monitor project expenditures for compliance with an allocated budget.
- Participate in ad hoc committee and peer review briefings, meetings, symposia, etc.
- Work closely with OCDO to insure that OCDO and other sponsor's development program findings are adequately considered in the demonstration program decisions.
- Inform OCDO of project activities and results through preparation and submittal of specified reports.

Project Engineer - The Project Team organization included a Project Engineer who was responsible for all technical work, designation of work packages, engineering schedules, drawing submittals, field liaison and direction of all design work.

The Project Engineer oversees the work of the lead discipline engineers and directs their efforts on the project. The Project Engineer reports to the Project Manager.

Project Administrator - A Project Administrator was assigned to the Project Team and was responsible to the Project Manager for the overall control of all administrative functions of the project. This included conformance of contract documents, issuance of detailed instructions to all participating departments, release of contract requisitions for material procurement, procurement monitoring, expediting and issuance of invoicing instructions. The Project Administrator, in most cases, served as Assistant Project Manager.

Field Organization - For the construction phase of the project, the Construction Contractor used direct hire labor and subcontract labor where appropriate. A Site Organization was established prior to mobilization to effectively manage construction activities. The numbers and levels of personnel included in the Site Organization varied with the magnitude and complexity of the project as the work progressed.

The Site Organization had complete jobsite responsibility for construction of the project in accordance with the drawings, specifications, and codes.

Project Control - ABBES is dedicated to the project management process for execution of large, complex projects using the work-package technique in conjunction with CPM analysis to evaluate the project plan and performance. Recognizing that cost control and schedule control are inseparable, ABBES applied computer systems to relate budgets, actual expenditures, resources and activities in the project schedule.

The Project Manager conducted constant surveillance of the project's status and schedule. Early warnings of impending overruns and schedule slippages were mandatory for effective control. Discovery of any problem areas were immediately reported to the Project Manager including a description of the deviation and its possible impact together with optional or recommended alternative actions which might be taken.

Budget Control - The Project Manager controlled the project budget. Each month's cost and labor hours were reported to him by ABBES's Accounting Department. These results were compared to budgeted "percent spent" and "percent complete" data to accurately track project progress.

Internal and External Management Review - The Project Manager was responsible to keep the OCDO Program Manager, co-sponsors, and ABBES management informed of the progress of the project. The OCDO Program Manager was kept informed through:

- Monthly technical progress reports,
- Other special reports,
- Regular, day-to-day contact with ABBES Project Manager, and
- Immediate notification of serious malfunctions or problems, accidents, injuries, work stoppages, etc.

ABBES management was kept informed through:

- Quarterly progress reports including budget and schedule projections,
- Monthly progress reports,
- Weekly reports of significant results and problems,
- Weekly staff meetings, and
- Copies of appropriate project correspondence.

4. Project Deliverables

Work plans and test schedules were finalized and submitted to OCDO, as well as other cosponsors, for review. Management and technical personnel met with all cosponsors to present and discuss the plans and schedules when requested. The plans and schedules were implemented and monitored to assure timely completion.

The following reports were provided as deliverables to allow all participants to monitor project progress:

- Work plans, prior to the start of each phase, with periodic updates as needed,
- Monthly technical progress,
- Interim special reports, and
- The final project report.

Besides the above deliverables, ABBES also supplied topical reports on an as needed basis to the project contributors. Technical papers and presentations for various conferences, such as EPRI SO₂ Control Symposium, Pittsburgh Coal Conference, International Joint Power Generation Conference, etc. were produced and presented.

G. PROJECT PROCEDURES

During the execution of the project, all work tasks were performed in accordance with procedures that conformed to all applicable cosponsor and general industry standards. These standards were generally governed and dictated by nationally recognized organizations, such as the EPA, ASME, ABMA, AWWA, etc. The major work and control procedures for the project are discussed below.

1. Quality Assurance/Quality Control Procedures

ABBES has a Quality Assurance Office to approve and monitor the procedures of all company units involved in designing and fabricating products. The QA group audited the project on an annual basis to insure all procedures were proper and adhered to current codes. Quality Assurance/Quality Control Plan and Procedures were presented to OCDO after award of the contract.

The Quality Program is an integral part of the work plan, encompassing the engineering and design, equipment procurement and fabrication, erection, and plant construction through start-up and operation. Overall responsibility for the establishment and implementation of the program belonged to the Project Manager. The Quality Assurance Officer was responsible for ensuring that all matters that substantially affect the quality of the project were executed properly. The quality program relating to construction, installation, and erection was the responsibility of the Construction Superintendent and the Craft Supervisors. The Field Quality Control Officer is responsible for the inspection and surveillance activities at the site in accordance with the established field program.

Following are summaries of the key elements of the quality plan.

- **Engineering/Design Review** - The project engineering team will be responsible for the engineering and design quality of the project. Specifications, drawings, calculations, and other design-related activities will be reviewed by senior-level discipline engineers before being issued. The responsible engineering and design personnel will review vendor drawings for adequacy and suitability. Critical areas of engineering concern will be identified in advance and reviewed by the appropriate Chief Engineer and the Quality Assurance Engineer. Design changes will be controlled in a manner consistent with those controls applied to the original design.
- **Specification Review** - Draft specifications will be prepared and distributed for interdisciplinary review. After this initial internal review, the specification will be revised and submitted to the Supervising Discipline Engineer and Project Engineer for final review. After disposition of any comments, the specification will be released for procurement.

- **Procurement** - Specifications for engineered equipment and material will be issued to the Materials Management Department for procurement. Controls exercised over change orders will be the same as those associated with the original order.
- **Expediting** - The Expediting group will coordinate and monitor document submittals, material procurement, fabrication, inspection, and delivery. The expeditor will issue expediting reports and shipping schedules to ABBES Project Management, Quality Assurance, and Construction.
- **Vendor Surveillance** - The Vendor Surveillance group will begin their involvement with the project by reviewing the equipment specifications for critical items. Check plans, based on these specifications, will be prepared during the procurement phase. These will be comprehensive and cover:
 - Review and monitoring of the vendor's established quality control program.
 - Weaknesses in the vendor's program.
 - Witnessing of designated shop tests.
 - Final inspection and release of equipment.
 - Review of documentation.
 - Written notices of nonconformance.
 - Report of findings.

Surveillance performed on selected items at vendor's plants will verify that qualified procedures and personnel will have been used during fabrication in accordance with the requirements of the specifications and drawings.

The surveillance program will verify that the equipment used as acceptance media will have been calibrated and provided the accuracy necessary to ensure compliance with specifications and drawing requirements.

Nonconforming conditions identified during shop inspections by vendor surveillance personnel will be documented on a Vendor Notification Report. The project's Quality Assurance Officer will be responsible for notifying engineering of these nonconformances and for verifying that corrective action has been taken and accomplished before any equipment is shipped to the site. This shipment of equipment with unresolved VNR's will require the approval of the Project Engineer.

At final inspection of selected items, ABBES will inspect for identification, cleaning, painting, and shipping preparations.

2. Monitoring and Sampling Procedures

An extensive amount of data was collected during the demonstration plant's operating period to date. The Facility is fully instrumented and automated with state-of-the-art monitors and control/data acquisition system.

Gas sampling and analysis was conducted according to EPA approved methods, as published in the most recent Code of Federal Regulations. When EPA methods were not available for particular testing, industry standard test methods, as determined by the Electric Power Research Institute or a suitable stack-sampling subcontractor, were used. Liquid and solid sampling and analysis were conducted following published industry standard test methods, such as those available from the Electric Power Research Institute.

The following types of data were collected:

- SO₂ inlet and outlet loadings and removal efficiencies,
- Particulate matter (PM) loadings and removal efficiencies,
- Limestone utilization, liquid cyclone classification and fractionation,
- Particle Size Distribution (PSD) in all slurry streams,
- Roller mill PSD at various locations in the circuit,
- Liquid and solids analyses,
- Reheat efficiency, leakage, cleaning characteristics of reheater,
- Oxidation system performance,
- Mist carry-over, with mist characterization,
- Long term operational stability, corrosion, cleanliness, etc., and
- Process controllability.

Process parameters routinely monitored during system operation and parametric testing included the following:

- Reaction tank pH,
- Reaction tank solids content,
- Absorber L/G ratio,
- Limestone utilization,
- Calcium sulfite/sulfate oxidation ratio,
- Limestone grind size,
- Gypsum particle size, and
- SO₂ removal efficiency.

Stable process conditions were maintained for a sufficient length of time prior to data collection to insure that the system had reached steady-state equilibrium. This is necessary to accurately link the gathered data with the appropriate operating conditions. Operating conditions were examined before and after each parametric test period to verify that system variables had not changed significantly during testing. In this manner representative and reproducible data could be collected.

H. UNPLANNED EVENTS

As described above in the Process Description section, the LS-2 Demonstration Facility was envisioned and designed to incorporate technological advancements in virtually every subsystem of the wet limestone desulfurization process. The integration of these advancements, in some cases, required the use of equipment packages that had limited application references in WFGD service. Any demonstration of newer technologies and equipment, especially on the scale of this project (130 MW), can be expected to experience some unforeseen mechanical difficulties prior to attaining a level of operability that would be acceptable in a utility power plant environment. In fact, one implied objective of this project was to identify these types of problems and engineer appropriate solutions.

Some such problems did occur during the execution of the LS-2 Demonstration Project. These cases were, however, identified and corrected by ABB in an orderly and timely manner so as to limit cost and schedule impacts to the project.

The two most significant progress delays resulted from the integration of equipment with otherwise proven designs and performance characteristics into the WFGD process. First, the original method of injecting reagent limestone into the absorber was via an eductor system. This eductor system used a scrubber slurry slipstream as the motive fluid to pull limestone powder from a storage silo and slurry it prior to introduction to the absorber. The eductor system supplier had significant prior experience with limestone and many other powdered materials.

After commissioning of the plant, the eductor system exhibited many operational problems that included limited throughput, abrasion of lined surfaces, and plugging of the powder inlet to the eductor. This plugging resulted in interruptions of the reagent flow to the absorber and thus unwanted process variations. Several modifications were recommended by the manufacturer and implemented by ABB in an attempt to bring the equipment into acceptable operation. Unfortunately, a resolution could not be found.

Preconstructed, pretested, skid-mounted subsystems such as this reagent feed system had been specifically targeted during the design phase of the project in order to limit erection and commissioning costs. With the failure of this particular subsystem, ABB undertook to design, construct and install a new high-agitation reagent slurring tank that has since performed extremely well and allows for steady process conditions.

Second, limestone milling at the LS-2 plant is accomplished with a dry roller mill as opposed to the more conventional wet ball mills. This allows for lower capital and operating costs and a much finer reagent grind size. Roller mills have been proven successful in many other processes for many years. To eliminate the

conventional need to heat the transport air flowing through the roller mill, flue gas is used at the LS-2 plant as the drying and fluidizing media. The original design envisioned that heat-up of the roller mill circuit would be sufficiently rapid so as to limit periods of moisture condensation within the mill duct system. Thus a system preheat function prior to introduction of flue gas was not provided. Over time, however, it was shown that condensation, formed during mill preheat, was causing increased pressure drop in the mill circuit baghouse. To correct this, ABB designed and installed an electrically heated air recirculation loop for preheat of the mill system prior to flue gas introduction. This correction was immediately successful and the mill system has since performed as designed.

Another source of delay to process commissioning, tuning, and testing for the LS-2 Project was the varying and unpredictable availability of flue gas from the Niles plant boilers. Significant periods of time during the testing phase had only one of the two Niles boilers in operation. This limited the maximum load of the LS-2 plant as it is designed to treat slightly more than the flue gas leaving one boiler and thus needs both in operation to reach its highest loads. Lower load testing was performed during these periods. More serious delays occurred when both boilers were off-line due to either mechanical failure or dispatch priorities within the utility's system. Additionally, many tests had to be aborted and rescheduled when one or both boilers significantly varied or lost load during the execution of a test.

I. PROJECT RESULTS

During the Parametric Testing and Operation phase of the project, each subsystem, and the system as a whole, was extensively tested to evaluate actual versus predicted performance and to characterize that performance as a function of specific design parameters. The broad data set allows the application of the new technologies across a wide range of design conditions.

This type of design and performance verification was a key objective of the project and a necessary step in offering these technology advances as a viable product for utility use. The significant areas of investigation were the absorber itself, the gas-to-gas heat exchanger, the limestone pulverizer, the sulfite to sulfate oxidation system, and the byproduct dewatering system. Data was collected during specifically designed tests that systematically varied applicable design or operating setpoints at constant boiler conditions. Data was also collected during long-term operating periods at design setpoints but with natural fluctuations in boiler operation. The results obtained from each of these areas of concentration are presented below.

1. Absorber System

With regard to absorber performance the most important aspect to understand is sulfur dioxide removal as a function of liquid-to-gas ratio and reaction tank pH. These variables are known to be of significant importance in wet flue gas desulfurization plant design and represented the foremost parameters of study. Additionally, a beneficial effect of higher flue gas velocity through the absorber has been shown in other installations. This concept was integral to the sizing of the LS-2 vessel and the verification of this effect was also an objective.

In order to identify the relationship between absorber SO₂ removal and the reaction tank pH, system operating data was collected over the acceptable range of pH values. The pH setpoint was bounded on the upper end of the range by gypsum byproduct purity. Excessively high pH results in unacceptably high levels of calcium carbonate in the reaction tank slurry. This can yield a gypsum byproduct that does not meet the required specification for use in the production of wallboard. Typical data describing the affect of pH is presented in Figure 7.

The performance of the LS-2 scrubbing system exceeded predicted levels and the project data has allowed a more thorough understanding by which future installations can be designed. This understanding will result in lower risk levels that will translate into lower costs to the end users of these WFGD systems.

Another parameter with significant impact on the mechanical design and power consumption of WFGD systems is the relationship of liquid-to-gas ratio to SO₂ removal. It is important to minimize this parameter in order to reduce the size, and thus cost, of the reaction tank recirculation pumps. This minimized size also minimizes the power required to circulate the scrubbing slurry. Associated piping

and other support equipment is also kept at minimum cost. Therefore, the LS-2 scrubber was tested to characterize the desulfurization performance as a function of the liquid-to-gas ratio. Data typical of this relationship is shown in Figure 8.

Figure 7: SO₂ Removal vs. pH

Figure 8: SO₂ Removal vs. L/G

Finally, the effect of absorber tower gas velocity on SO₂ removal efficiency is of interest since higher gas velocities allow smaller absorber diameters and thus lower capital costs. While lower capital costs are achieved, however, pressure drop and power consumption are increased.

In theory, higher gas velocities result in more efficient SO₂ removal, thus allowing lower absorber slurry recirculation rates. These lower recirculation rates lower pumping power requirements. Therefore, it is possible to optimize the absorber size and recirculation rate to simultaneously reduce capital costs and net power consumption through the understanding of SO₂ removal versus tower velocity. The LS-2 Demonstration Project offered the opportunity to verify and further model this effect. Some typical data that demonstrate increased absorber performance as gas velocity increases is shown in Figure 9.

Figure 9: Effect of Gas Velocity

Since absorber sizing affects the operating costs of a wet flue gas desulfurization system, an understanding of the gas-side pressure drop as a function of liquid-to-gas ratio and gas velocity is important for proper process design and performance guarantee assessment. System-wide pressure measurements were taken throughout the scrubber at Niles to quantify these relationships. Even though all pressure drops were as anticipated in the project design phase, the Demonstration plant was tested over a wide operating range to fully correlate

these design parameters. The influence of liquid-to-gas ratio on spray zone pressure drop, as demonstrated by operation with one or two spray elevations in service and constant gas velocity, is shown in Figure 10.

Figure 10: Pressure Drop vs. L/G

Once the effect of varying L/G was isolated, the effect of varying velocity was also investigated. The spray zone pressure drop as a function of tower gas velocity with a constant number of spray levels in-service is graphed in Figure 11.

Figure 11: Pressure Drop vs. Velocity

2. Gas-To-Gas Heater Exchanger

The horizontal shaft gas-to-gas heat exchanger (GGH) used at Niles was an integral component in the cost reduction strategy. This orientation allows for reduction in the length of the absorber inlet and outlet ducts. These two duct sections are normally coated or constructed of higher alloy materials and thus are a significant capital cost.

The primary performance evaluation of the GGH consisted of measuring heat transfer rate and pressure drop as a function of plant load. Both of these performance criteria impact other design points within the WFGD plant and thus are important to verify and understand. The heat transfer rate in terms of BTUs per pound of flue gas is plotted in Figure 12 as a function of plant load.

Figure 12: GGH Heat Transfer vs. Load

The heat transfer rate proved consistent over the design range of the system and always produced flue gas reheat temperatures in excess of the 196 degree F minimum. This reheat temperature is the design parameter used to avoid wetting of the carbon steel ductwork downstream of the WFGD system.

Gas-side pressure drop of all system components must remain within design bounds to allow desired maximum loads. The pressure drops across both sides of the GGH at Niles were measured and are plotted in Figure 13.

Figure 13: GGH Pressure Drop vs. Load

These GGH pressure drops were always within the design limitations imposed on the manufacturer. They do, however, vary over time in a constant cycle. Some accumulation will normally collect on the surfaces of the heat exchanger and, as this occurs, pressure drop is expected to increase. When the maximum allowable pressure drop is reached, the heat transfer surfaces are washed with high-pressure water. To limit the frequency of these washings, the GGH is blown clean with compressed air once each shift.

Additionally, the effects of the GGH air cleaning cycle and mist eliminator wash cycle were observed over time. The optimum frequency for compressed air cleaning was found to be the previously predicted once per shift or three times per day. The GGH pressure drop cycle was unaffected by reasonable variations in the mist eliminator wash sequence as long as the sequence was not slowed to a point that allowed build-up on the mist eliminators and therefore poor performance, i.e. high mist breakthrough.

Likewise, the heat transfer rate of the GGH was virtually unaffected by reasonable variations in GGH or ME cleaning cycle. It was found that most of the GGH accumulations were located on the cold-face edge of each heat transfer element and not evenly distributed across the heat transfer surface. Therefore, as pressure drop increased, heat transfer efficiency was not significantly reduced.

Leakage within the GGH from the dirty side to the clean side can degrade overall system sulfur dioxide removal performance by allowing raw flue gas to bypass the scrubbing action of the absorber and pass directly to the outlet duct. Thus the GGH at Niles was designed with many high efficiency features that greatly minimize this leakage component in the outlet flue gas. The GGH leakage at Niles was calculated by measuring key gas constituents under worst-case conditions within the plant design bounds and found to be as expected. This low leakage is one feature that allows the Niles plant to reach the ultra-high removal efficiencies.

3. Pulverizer System

The WFGD system at the Niles Generating Station employs a unique method of limestone pulverization for the utility desulfurization market. This technique, known as dry roller milling, is widely used in other industries for grinding rock and like material. The key advantages of this type of grinding in a WFGD application are the elimination of feed slurry storage tanks and the ability to obtain very fine particle size distributions for the limestone reagent. Once the original checkout and setup was performed by the manufacturer, the maximum design throughput capacity of the unit was verified to be at the 7.5 tons per hour design value. Shortly after commissioning some operational problems related to condensation during the heat-up cycle were identified and corrected as discussed in an earlier section.

The operating parameters that required optimization were mill pressure drop, gas flow, and gas temperature. Once identified, adjustment of these setpoints is not necessary to improve particle size distribution performance. The one user manipulated variable that allows control of the product fineness is the speed of the turbine that classifies the limestone particles as they exit the top of the mill. A test campaign was executed to plot the relationship of the product fineness to the speed of the classifier. Once this relationship was known, the reagent grind size required for each test condition could be set by adjusting the turbine speed prior to the test start. The data collected from the mill system is presented in Figure 14. The figure has two data series, D(0.5) and D(0.9). D(0.5) represents the particle diameter whereby 50% by weight of the sample has a greater diameter and 50% has a lower diameter. D(0.9), however, indicates the particle diameter whereby 10% by weight of the sample has a larger diameter and 90% has a lower.

Normal operation for the LS-2 system at Niles uses a limestone grind size with a D(0.5) of about 10 μm . An on-site laser-defraction particle size analyzer was used to routinely measure and verify the particle size distribution of the limestone reagent being fed to the LS-2 absorber. A typical size distribution is shown in Figure 15.

Figure 14: Grind Size vs. Classifier Speed

Figure 15: Typical Limestone Reagent Particle Size Distribution

4. Oxidation Air System

Oxidation of sulfite ions, resulting from the absorption of sulfur dioxide, to sulfate ions is an important consideration in the design and operation of a wet scrubbing plant. Low sulfite oxidation can hinder process operation by decreasing the purity of the gypsum byproduct. As the Niles plant generates gypsum for wallboard manufacture, the byproduct is required to be greater than 95% calcium sulfate. Therefore, very complete oxidation is needed and even minimal degradation of the oxidation process could cause problems with byproduct acceptability.

With this in mind, it is necessary that the process be designed for optimal oxidation. This is accomplished by providing adequate amounts of oxidation air into the reaction tank slurry with uniform distribution and mixing. Excessive amounts of air and distribution hardware would result in larger compressors and more materials. Thus, the process operating conditions and hardware must be optimized to both provide sufficient oxidation and minimize capital and operating costs.

A lance type air injection system is utilized at Niles. One objective of the project's test program was to evaluate and further understand the performance of the lance system. The significant variables that influence oxidation efficiency are the ratio of oxidation air to the quantity of sulfur dioxide removed and the liquid level above the air injection point within the reaction tank. A parametric test battery around these operating variables was constructed and executed. The effect of each of these variables on sulfite oxidation, independent of the other, is shown in Figures 16 and 17, below.

Figure 16: Oxidation vs. Tank Level

Figure 17: Oxidation vs. Air Stoichiometry

The lance type oxidation air system was found to be a very efficient, cost effective means of achieving the desired process results. It was also found that the system maintained acceptable oxidation over a wider range of operating conditions than previously expected and future designs will capitalize on these findings by further minimization of the size of the oxidation air system.

5. Gypsum Dewatering System

Given the objective of the LS-2 process to produce a high quality gypsum product that meets or exceeds a commercial grade wallboard specification, a design that adequately washes and dewateres the end product is necessary. This can be accomplished using readily available equipment such as belt filters or centrifuges. Centrifuges were chosen at the Niles location since they can achieve slightly better dewatering efficiency and are more compact.

Two 100% capacity centrifuges (at design conditions) are installed. The centrifuges operate in batch mode as absorber bleed slurry accumulates in the centrifuge feed tank. Both centrifuges can operate in tandem if system operating conditions are such to produce gypsum at rates higher than the normal design.

The following instantaneous rates were specified for each centrifuge:

Stream	Instantaneous Flow Rate, Each Centrifuge
Feed slurry	650 gpm
Filter wash	130 gpm
Compressed air (80 – 100 psig)	<30 scfm
Dry gypsum production per cycle	3,412 lbs./cycle
Expected cycle length	635 seconds
Maximum dry gypsum product rate	19,355 lbs./hr

Table 5: Centrifuge Design Instantaneous Flow Rates

Because the centrifuges operate in batch mode, they receive slurry feed and wash water; and discharge centrate, wash effluent and cake at rates much higher than the time averaged rates. Time averaged rates for normal conditions are shown below:

Stream	Design Value
Required number of cycles per hour	4.34
Feed slurry (gpm)	47
Raw water wash (gpm)	25.1
City water wash (gpm)	19.6
Dry solids to bunker (lbs./hr)	14,820

Table 6: Centrifuge Time Averaged Flow Rates

After the initial commissioning of the centrifuges by the manufacturer, two significant operating parameters needed to be studied and optimized – cake wash time and drying time. The cake wash time is important to minimize since longer wash times consume more fresh water and represent additional expense. The purpose of the cake wash is to displace chloride laden process water in order to meet gypsum quality requirements. Thus, there is an operating point where a comfortable gypsum chloride level can be achieved with a minimum amount of fresh water. Data was collected for gypsum chloride content as a function of cake wash time with all other variables held constant and is presented in Figure 18.

Figure 18: Gypsum Chloride Content versus Cake Wash Time

It can be seen in Figure 18 that gypsum chloride concentration is fairly constant down to a wash time of about 50 seconds. Below 50 seconds residual chloride increases sharply into an unacceptable range. A wash time of about 50 seconds was selected for normal operation.

After identifying an optimum cake wash time, data was collected to characterize the relationship between gypsum product moisture and the length of the drying period of the centrifuge cycle, or drying time. It is important to minimize this time in order to minimize power consumption and minimize the overall cycle time for each centrifuge batch operation. The data collected is presented in Figure 18.

Figure 19 shows that gypsum moisture content steadily increases as drying time is reduced. A normal drying time of about 160 seconds was chosen and yields a consistent 8% moisture level in the gypsum product. This level is somewhat below the 12% limit imposed by the wallboard manufacturer but provides an operational cushion to allow for normal performance variations, upset conditions, and moisture pick-up during transportation.

The EPRI testing phase began in early 1997 and will probably run into the fourth quarter of 1998. Only preliminary reporting of the data collected has been released to date and final reporting will follow the completion of the program.

This verification test program will focus on the overall effects on system performance of variations in limestone grind size, reaction tank pH, liquid-to-gas ratio, tower gas velocity, and oxidation airflow. Also, incorporated in this testing is the demonstration of a utility version of EPRI's On-Line Chemistry Monitor (OLCM) which is capable of semi-continuous monitoring of the solid phase carbonate and liquid phase sulfite in the scrubber's reaction tank. This type of data would be useful in process tuning given the dynamic operating conditions of normal power plants. Time permitting, additional areas of interest, including the use of dibasic acid for performance enhancement, will be explored.

Phase IV - Task 3, the EPRI Test Program, is currently underway as of this writing. As planned, the Electric Power Research Institute has contracted with a third party testing company for the purpose of verifying the process performance of the LS-2 Facility at Niles, Ohio. The testing format and procedures are very similar to those previously employed by ABB Environmental Systems.

6. EPRI Test Program

Figure 19: Gypsum Moisture versus Drying Time

7. Design and Instrument Verifications

Early in the test program, it was necessary to perform manual stack sampling to verify certain design and operational aspects of the plant. The objectives of this testing were twofold: first, to verify that the inlet flue gas conditions were within design ranges and, second, to verify that the significant instruments throughout the plant were operating and calibrated properly to provide accurate data. This information was obtained via an outside testing company that was contracted to measure velocity, temperature, moisture, SO₂, CO₂, and O₂ at four key process test locations. These test locations were:

- System Inlet: Up-stream of the process fan,
- Absorber Inlet: Immediately up-stream of the absorber,
- Absorber Outlet: After the absorber mist eliminators, and
- System Outlet: Down-stream of the GGH treated gas outlet.

The results of this testing demonstrated that the flue gas inlet conditions were within the design ranges for all criteria used to engineer the LS-2 Facility. Furthermore, all of the process instrumentation proved to be installed, calibrated, and operating properly.

Later in the test program, a testing company was again contracted to verify the continued accurate performance of the plant's significant instrumentation as part of the project's quality assurance plan. All instrument performances were again found to be acceptable. Datasheets from both of these testing campaigns are attached to this report in the Appendices.

J. PROCESS BYPRODUCTS

In the current day regulatory environment regarding environmental protection, virtually every utility and industrial entity is concerned with eliminating or at least minimizing process waste streams. This simplifies permitting of new facilities and eases compliance with increasingly stringent regulations at existing units. ABB has duly considered these concerns of its customers and continues to develop each product line to further limit environmental impact.

These considerations played a major role in the development of many advancements used at LS-2. A simplified process flow diagram of the LS-2 Demonstration Plant is shown in Figure 20. This diagram shows all of the significant input and output streams of the process. These streams take one of three general forms – gas, liquid, or solid. The process receives inputs in all of these forms. The raw flue gas entering the system for treatment is represented as Stream 1. The reagent used to remove SO₂ from the flue gas is calcium carbonate, or limestone, which is metered into the scrubber (Stream 3). The limestone is originally received as ¾" by ¾" crushed rock that is further pulverized by the dry roller mill.

The SO₂ removal reactions take place in an aqueous media within the absorber and water is lost due to evaporation and other ways. This requires a make-up water source in the form of river water (Stream 4) and a small amount of fresh water. In order to produce a high purity gypsum product, an oxidation step must also take place. Air is required to accomplish this oxidation and is supplied through injection lances (Stream 5) into the absorber reaction tank slurry.

Over the course of desulfurizing the boiler flue gas to produce a clean stack gas (Stream 2), two discharges are generated. First is a clear water blowdown (Stream 6) which is sent, in the case of the Niles plant, to the existing coal pile run-off pond and eventually passes to a nearby river. This waste stream is needed to control the level of dissolved chlorides in the scrubbing system. Chlorides enter the process via the flue gas and are absorbed into the scrubbing liquor where they accumulate. Without some method of purging, these chlorides would reach extremely high levels and create a very harsh environment for the materials of construction used in the absorber system. Therefore, the blowdown stream is used to keep these levels within design boundaries. The LS-2 plant is, however, designed for high chloride levels and thus can keep this purge stream at a minimum. The second waste stream produced is the gypsum byproduct (Stream 7). This gypsum byproduct is of a very high quality that allows its use in the production of construction wallboard.

The compositions and flow rates of each process stream are presented in Tables 7 and 8. Table 7 contains data for gaseous process streams and Table 8 contains data for liquid and solid process streams.

Lbs./hr	STREAM 1	STREAM 2	STREAM 5
	System Inlet Flue Gas	System Outlet Flue Gas	Oxidation Air
Nitrogen	877,671	891,182	10,611
Oxygen	64,620	67,469	3,223
Water	62,498	87,197	180
Carbon Dioxide	243,814	246,027	-
Sulfur Dioxide	5,293	265	-
Hydrogen Chloride	113	1	-
Flyash	29	26	-
TOTAL, lbs./hr	1,254,038	1,292,167	14,014

Table 7: Gas Stream Mass Flowrates by Component

Lbs./hr	STREAM 3	STREAM 4	STREAM 6	STREAM 7
	Limestone Reagent	Make-up Water	Blowdown	Gypsum Product
Water	-	35,191	6,458	1,188
Calcium Carbonate	8,210	-	-	99
Calcium Sulfate	-	-	-	13,492
Calcium Sulfite	-	-	-	16
Other	80	-	163	67
TOTAL, lbs./hr	8,290	35,191	6,621	14,862

Table 8: Liquid and Solid Stream Mass Flow Rates by Component

The information presented in Tables 7 and 8 is based on normal design conditions for the LS-2 Demonstration plant. Normal conditions consist of treating 400,000 acfm of flue gas (~130 MWe) from the combustion of 2.8% sulfur Ohio coal with an overall absorber system sulfur dioxide removal efficiency of 95%.

The reagent used and gypsum produced (Streams 4 and 7, respectively) will vary directly with increases or decreases in the quantity of sulfur entering the system. Changes in inlet sulfur loading will result from variations in the coal sulfur concentration and the volume of flue gas treated by the LS-2 plant. Changes in the absorber operating parameters that result in higher or lower removals of SO₂ will also directly influence reagent usage and product generation. The same factors that influence the quantity of gypsum produced also affect oxidation air requirements (Stream 5) since there is a direct relationship between the quantity of sulfur removed and the quantity of oxygen needed to achieve sufficient oxidation.

Another important parameter that dictates byproduct generation is the capacity factor of the plant. When data from Tables 7 and 8 are annualized, the results must be adjusted to correct for plant outages and reduced load operation as this directly reduces all inputs and outputs of the process.

Blowdown flow rates, in addition to being affected by the plant capacity factor, are mainly adjusted based on the chloride levels in the absorber reaction tank which in turn are a direct function of the chlorine content in the coal being burned. Thus, increases or decreases in fuel chlorine content will necessitate higher or lower blowdown flows.

Ohio Edison, Niles Station LS-2 Process Flow Diagram

Figure 20: LS-2 Process Flow Diagram

K. BYPRODUCT DISPOSITION

Process byproducts can represent a significant cost to a utility operating a wet flue gas desulfurization plant. In order to limit these installation and operation costs, the Niles plant is designed first, to minimize the overall quantity of waste byproducts and second, to control the physical characteristics of the byproducts so that handling and disposal costs are eliminated or, at least, greatly reduced. As discussed in the previous section, the Niles system produces two waste streams – (1) clear water with dissolved solids and (2) dry, high-purity gypsum. All limestone-based WFGD systems will produce some form of these two waste streams. Many times they are combined into one waste slurry stream that is sent to a settling pond in order to decant off the clear liquor for disposal or reuse. The waste solids generated from the desulfurization process generally are disposed of by landfill, as they have no commercial value. Landfilling adds to capital and operating costs and also creates environmental concerns such as ground water contamination and land wastage.

Advanced WFGD systems are designed to generate a very high quality gypsum byproduct that has high calcium sulfate purity, consistent in physical characteristics, low moisture, and low chloride content. This high quality allows the gypsum to be used directly in the production of construction grade wallboard. The demonstration Facility has been very successful in producing wallboard quality gypsum in that all the gypsum generated at the Niles plant has been used to that end.

By producing a byproduct stream with commercial value, a major transformation results in the economic evaluation of the process's operating costs. Not only are disposal costs for the waste stream avoided, but revenue can actually be generated. In the case of synthetic gypsum, the commercial value is such that large revenues are not seen but in almost all cases the transportation costs to move the product to the wallboard producer are offset. In order to capitalize on the commercial value of the gypsum product certain quality specifications must be met. The applicable specifications for the Niles project are shown in Table 9.

	WALLBOARD	CONCRETE
Calcium Sulfate	>95%	>90%
Moisture	<12%	<12%
Chloride	<120 ppm	-

Table 9: Gypsum Quality Specifications

Wallboard quality material has a higher value than that only usable for concrete manufacture, however, should significant quantities of slightly off-specification material be produced, there is the possibility to place it within the concrete

industry. Any material generated that is below these two levels would require disposal in a landfill although this has not occurred at the Niles LS-2 plant.

There are no serious health and safety considerations relative to the handling of synthetic gypsum. Transportation is accomplished via standard bulk material trucks or railcars. In the case of Niles, the same trucks that supply the raw limestone reagent are used to back-haul the synthetic gypsum to the wallboard manufacturer. Loading of the trucks is performed with a conventional front-end loader.

The other waste effluent from the LS-2 plant at Niles is the clear water blowdown stream. This stream is currently sent directly to the Niles plant coal pile run-off pond. This waste stream does contain small amounts of dissolved solids and a negligible level of suspended solids. Under normal utility situations this liquid waste stream would not require further treatment, however, it would be possible to employ a crystallizer to collect the dissolved solids contained in the water. This option would bear a substantial expense to install and operate and would probably only be used in the presence of extreme environmental protection regulations. This stream has no commercial value and therefore cannot be sold.

As with the gypsum byproduct, no significant health and safety issues arise in dealing with this type of waste stream. The liquid is only mildly acidic and is normally isolated in piping or other equipment and not available for easy contact with plant personnel.

L. ECONOMIC EVALUATIONS

The cost advantages of the process advancements used at the LS-2 Facility have been thoroughly reviewed using standard EPRI guidelines as described in EPRI report GS-7193, "Economic Evaluation of Flue Gas Desulfurization Systems". Using these guidelines and a typical specify, bid, and procure project approach; the projected cost savings are significant. These cost estimates benefit from the incorporation of many of the project execution enhancements demonstrated through this project such as:

- Use of standardized designs.
- Pre-approval for standardized designs with customer review cycles only for interface points, materials of construction, component redundancy, and operating and maintenance procedures.
- Accelerated schedule from streamlined design procedures and pre-engineered construction packages.

Figure 21: Advanced WFGD Costs vs. Scrubber Size

Figure 21 above, presents the EPRI evaluated costs (based on 300 MWe size, 2.6% sulfur coal, 65% load factor) for a conventional WFGD design (EPRI GS-7193), a system such as the LS-2 project at Niles (LS-2 GS-7193), and a plant using further advancements based on the LS-2 plant experience (LS-2 Adv.). The figure shows that conventional wet FGD technology is not competitive with current costs for fuel switching in the normal boiler size range. A larger scale of the LS-2 plant at Niles enters the competitive range (\$150 to \$250 per ton of SO₂ removed) at or above 550 MWe. With additional cost savings available through streamlined project execution, the cost projections move into a competitive range near the 450 MW size.

These economic analyses revealed that the cost of SO₂ removal is, in addition to boiler size, extremely sensitive to the sulfur level of the fuel and the FGD system capacity factor. The FGDS capacity factor is defined as the average annual treatment rate divided by the design gas treatment rate. Figure 22 shows the cost of a ton of SO₂ removed is reduced dramatically as the FGD system capacity factor is increased.

Figure 22: Advanced WFGD Costs vs. Capacity Factor and Fuel %S

Figure 22 is again based on a 300 MW boiler size and, for the 2.6% sulfur fuel case, indicates that a Niles-type plant is cost competitive with fuel switching at a 90% capacity factor. Given present WFGDS reliability and availability levels, a 90% capacity factor is very attainable in a utility environment. The cost

projections also showed that at a fuel sulfur level of 4% and a 90% capacity factor, ABB's advanced WFGD processes are competitive down to 200 MW boiler sizes.

These FGD costs can also be calculated on a per ton of coal fired basis. Projected advanced WFGD costs are summarized in Table 10 for a 300 MW, 90% capacity factor, and 95% sulfur dioxide removal case.

Percent Sulfur	\$/ton SO₂ Removed	\$/ton Coal Fired
2.6	220	10.9
4.0	150	11.4

Table 10: Projected Advanced WFGD Levelized Costs

III. MARKETING AND COMMERCIALIZATION

M. COMMERCIALIZATION POTENTIAL

Presently, there are approximately 300,000 MW of coal-fired utility electricity generating capacity within the United States, of which about 80,000 MW burn coal of sufficient sulfur levels to require flue gas desulfurization to meet permit levels. With passage of the Clean Air Act Amendments of 1990, emissions of sulfur dioxide have been tied to historic levels. Therefore, if electric generating capacity increases, which it must for domestic economic growth, sulfur dioxide emissions per MW of electricity generated must be reduced. Application of this in the extreme could force the electric utility sector to switch to low-sulfur coals or natural gas to maintain a low cost of electricity. Hence, as long as growth is expected in the coal-fired utility market, a demand for cost-efficient flue gas desulfurization will exist.

ABB is committed to offering cost-effective technologies for both new and retrofit coal-fired electric utility generating stations. It is expected that due to the Clean Air Act Amendments of 1990, 91,000 MW of coal-fired generating capacity will require some change from present operation in order to comply with SO₂ emission limits. These units represent the population for which significant investment in plant modifications can be justified to allow continued production of cost competitive electric power.

In terms of unit design, these boilers include wall-fired, tangentially-fired, and cyclone units. Advanced WFGD systems can be applied to each of these boiler designs. There are no factors such as coal type, boiler size, age, heat release rate, geographic location, or steam conditions that would restrict utilization of advanced WFGD. These advanced systems would also be as applicable to new plants as well as retrofit situations. While the technology is applicable to new electric power plants, the most important market for the foreseeable future will be the retrofit of existing coal fired power stations facing Phase II regulation.

Present estimates indicate that less than 25% of the Phase II affected generating capacity will install some type of flue gas desulfurization, with the majority of coal-fired units choosing to switch to low-sulfur coal. The successful demonstration of advanced WFGD technology and verification of its process economics through the Niles project could possibly reverse some fuel-switching decisions.

On a worldwide basis, bubble markets for flue gas desulfurization continue to exist in certain areas as development increases demand for power or local legislation is enacted. Fossil fuels, primarily coal, remain the fuel of choice within developing countries creating new emissions sources and thereby new market

potential for WFGD. Often, some form of FGD is mandated by international financing bodies, such as the World Bank, when they provide funding for new projects. Wet FGD continues to be a proven and accepted technology by these organizations. Thus, as development continues around the globe, a continuing market for WFGD can be expected to coexist.

N. BYPRODUCT USES

Wet FGD systems produce a large quantity of byproducts. Oxidation of the calcium sulfite contained in the solids to calcium sulfate (gypsum) is preferred. Gypsum is an inert material that may be reused or landfilled directly without chemical stabilization or fixation. Typically, for every ton of SO₂ removed, 2.7 tons of gypsum are produced. Several electric utilities sell their FGD produced gypsum for use in wallboard manufacturing, but usually FGD gypsum must be beneficiated at some expense before it is a suitable raw material. The following excerpt from the February 1997 U.S. Geological Survey, Mineral Commodity Summary for gypsum makes this point:

"Some forecasts indicate that gypsum demand in North America will rise by approximately 3% per year throughout the 1990's. This demand will be driven primarily by the construction industry, particularly in the United States where more than 90% of the gypsum consumed is used for wallboard products, building plasters, and the manufacture of portland cement.

Utilization of byproduct gypsum from industrial processes and electric utility flue gas wastes will remain low. More favorable economic circumstances that support byproduct gypsum as a replacement for natural gypsum (e.g., rising ore costs) are necessary to encourage further substitution."

Because of several improvements that the LS-2 FGD technology uses, it produces a higher quality gypsum byproduct and provides these "more favorable economic circumstances". The need for beneficiation is eliminated making the gypsum an immediate candidate for reuse instead of landfill.

In 1996 gypsum consumption in the U.S. was about 26.5 million tons. Of this about 1.5 million tons were from FGD processes and used primarily for wallboard production. Therefore there is significant opportunity to increase this ~6% utilization of desulfurization byproduct in the domestic gypsum consumption market. The incentives for wallboard manufacturers to further substitute synthetic FGD gypsum for natural gypsum will increase as current mines play out and extraction costs increase.

Additional incentives will come from the utility power production side as increasing SO₂ removal requirements push utilities to find economically optimum solutions. Undoubtedly, these solutions will involve salable byproducts to avoid disposal costs and possibly generate additional revenue streams. With limestone forced oxidized WFGD being the premier utility flue gas desulfurization technology, advanced WFGD designs will meet these pressures in the future. As evidence of this, practically all new wallboard production plants, and current plant expansions, are being designed for or collocated in proximity to power plants with gypsum producing WFGD systems.

o. PROJECT IMPACT ON COMMERCIALIZATION

ABB considered a U.S. based demonstration project, operating on U.S. coals, with U.S. operators and facing the daily cycling demands of domestic power stations, as required to effectively market advanced WFGD technologies to the U.S. electric utility industry. There are several underlying reasons for this:

- Historically, the US electric utility industry has been very conservative in deploying new technologies. Reliable operation and proven long-term performance under similar conditions are prerequisites for acceptance. The industry does not accept extrapolation of fuels, plant size, and service duty. Hence, demonstration of the technology at the appropriate scale, fuel type, and service duty are mandatory for commercialization.
- After legislation is passed requiring increased emissions control, adequate time is not available to develop a plant or technology, test its performance, and evaluate its application for widespread use.
- In order for a pollution control supplier to provide a technology to a utility customer with the necessary performance guarantees at a competitive price, the supplier must have a reasonable understanding of the associated performance risks. While much can be learned from laboratory and other research methods, the most relevant information can only be obtained from very similar applications of the technology, such as a demonstration plant.

Hence, if advanced WFGD technologies were to be considered ready and available for widespread use by the U.S. electric utility industry within the Phase II time frame, the demonstration Facility at Niles was essential.

The design, installation, operation, and testing of the facility at Niles has been utilized extensively to promote the commercialization of advanced WFGD techniques in general. This has been accomplished in many ways. Information and details regarding the project have been widely distributed via media, trade show presentations, technical papers, and by the contributing partners of the project such as OCDO, OE, and EPRI. ABBES has also more directly promoted the project and its results by way of numerous plant tours and open houses and presentations to ABBES's customers and potential customers.

The LS-2 demonstration project has highlighted the enhanced performance and cost saving benefits possible through many technology advancements. As ABBES continues to market this technology, the results of this project will increasingly grow in importance as they provide the technical and economic understanding that will allow the utility customer to accept these technology advancements as viable. The execution of this project will also allow ABBES to supply the technology with lower performance risk and at a competitive price.

P. PROJECT IMPACT ON OHIO COAL USE

Most of the higher sulfur content coal produced in the U.S. is mined east of the Mississippi River, primarily from the Appalachian, Interior and Illinois Basins, from which Ohio coal is mined. Coals from these regions are also mined for export to European, Pacific Rim, and Central and South American countries. The majority of existing U.S. power plants expected to require SO₂ emission controls understandably lie in this same area or more specifically the eight-state region consisting of Pennsylvania, West Virginia, Kentucky, Ohio, Tennessee, Missouri, Illinois, and Indiana. All of these states are within the reasonable marketing area for Ohio coal.

As a result of the Clean Air Act Amendments, however, continued use of Ohio and other high-sulfur coals is dependant on the availability of FGD processes that are efficient and inexpensive when compared against fuel switching, particularly to low-sulfur Western coals. With the successful demonstration at Niles, an economically attractive alternative to fuel switching has become legitimately available to the utility power production industry. ABBES believes that the low capital and operating FGD costs made possible by the successful demonstration at Niles will help to support the current market consumption of higher-sulfur Ohio coals.

It is difficult to determine, with any degree of confidence, what the exact effects of the CAAA and advanced WFGD technologies will be on Ohio coal production. However, considering conventional technologies, it can be assumed that without advanced FGD technologies, high-sulfur coal consumption in the United States will decline. Ohio coal consumption would likewise be expected to decline.

Q. COMPETING WFGD TECHNOLOGIES

Wet flue gas desulfurization has matured significantly since the 1970s. With this has also come an increase in the number of vendors for WFGD and similar technologies. These conditions have resulted in significant price declines in the marketplace, especially since the early 1990s. Based on ABB's internal data, a full-scope WFGD project in 1980 cost approximately \$150/kW. By 1990 this price had dropped to near \$120/kW and by 1995 to about \$80/kW. These costs being what is known as Total Process Capital, or the cost for materials and services that would be provided by a WFGD process vendor such as ABB to design, engineer, procure, deliver, erect, and commission a full-scope project of average utility size.

Much of this price reduction has come from more efficient plant designs spawned from the experience base accumulated as the number of operating WFGD systems grew. Systematic process advancements have continuously emerged from innovative process suppliers such as ABB. Some specific cost reduction areas have been:

- **Sparing Philosophy**

As equipment and process reliabilities increased through experience, the need for sparing decreased. The most significant example of this is the elimination of complete spare absorber modules in current day WFGD offerings.

- **Absorber Size**

The size of an absorber module has increased and allowed the application of single modules where multiple modules were previously required. Before 1990 typical absorber sizes treated the equivalent of 200 MW of flue gas. Today absorber sizes of 1000 MW are commercially offered.

- **Materials Selection**

Over time, many conservative design features required by conventional utility customers have yielded to more cost-effective solutions. This is evident in the now prevalent use of absorber construction materials other than high alloys such as rubber or flake-glass lined carbon steel and FRP.

- **Equipment Reductions**

As the technology matured, some process areas were greatly scaled back through the use of more effective types of equipment or eliminated altogether. For instance, primary dewatering is now normally performed with very compact hydrocyclones as opposed to older thickener designs. Also, as the technology has tended toward usable byproducts, such as fully oxidized gypsum, waste handling and storage facilities have become more cost and space effective. In many cases, flue gas reheat equipment is eliminated.

- **Design and Installation Techniques**

Quality and efficiency of design and installation have also increased. Much of this is through design standardization, fabrication streamlining, and improvement of design tools and specifications.

All of these items have led to a decline in the cost to purchase, install, and operate a WFGD system. Heavy competition in the marketplace has also pressured other cost reductions.

Since the successful design and operation of the LS-2 Facility at Niles, ABB Environmental Systems has actively proposed many WFGD systems based on the advanced concepts demonstrated. These proposals have taken the information and experience gained at Niles and continued the cost reduction process. Current installed, full-scope advanced systems are being offered for total process capital costs in the range of \$60 to \$65/kW and further improvement potential has already been identified to reach \$55/kW price levels.

These costs represent significant savings to utility WFGD customers worldwide. The timeliness with which these price levels have been brought to market is, in part, a result of the full-scope, full-scale demonstration of the LS-2 Facility made possible by this OCDO project.

Being a mature technology, WFGD has developed a large vendor base and each supplier offers a certain variation of the basic scheme of SO₂ removal via limestone reagent. The significant differences generally involve the method by which good gas-liquid contact is achieved within the absorber tower. Of course, with these variations, technical advantages and disadvantages arise.

No readily attainable public information regarding current capital and operating costs of various WFGD systems was available for use in this report. However, in 1991 EPRI released economic comparisons of this type. The average Total Capital Required (all capital required by a customer for a WFGD project) and levelized costs in 1990 for a new 300 MW WFGD system with wallboard quality gypsum production, treating gas from 2.6% sulfur coal, were about \$190/kW and \$425/ton SO₂ removed, respectively.

Also of interest is a comparison with the cost of switching from high-sulfur to low-sulfur coal. Coal switching costs have been estimated in the range of \$150 to \$250 per ton of SO₂ removed for most mid-western and eastern U.S. markets. As was a goal of the LS-2 Niles demonstration project, the LS-2 advancements have proved to be a very competitive alternative to reach CAAA compliance versus coal switching.

R. NEAR-TERM TECHNICAL DEVELOPMENT

ABB supports and maintains a continuous, long-range research and development program for all its product lines. Wet flue gas desulfurization being a core ABB environmental technology offering, a considerable level of resources is devoted to its development. This demonstration project served as a significant tool to condense many of ABB's research efforts into a new advanced WFGD concept.

Near-term technical development for this product line will focus in two directions – design tool refinement and capital cost reduction through design standardization. The execution of the Niles demonstration project has generated a wealth of new process performance characterization data. This data is exceptionally relevant to the design of future plants since it is of commercial scale and has utility type design parameters and operation. The parametric test results from the project will be combined with ABB's already extensive database of utility WFGD performance to expand the design range of performance design tools. This allows higher confidence and lower risk in future designs – conditions that allow for more cost-effective solutions to the needs of the utility customer.

The data that will be utilized encompasses all performance criteria for the system such as SO₂ removal, limestone utilization, pressure drop, reagent preparation, and byproduct production. The ability to test each of these performance criteria in the presence of the other process advancements provides greater confidence in, and applicability of, the results since interactions between the process design changes were already included. Other types of information from the project will also be used to augment ABB's experience base, such as materials of construction, equipment performance, sparing philosophy, and vendor selections. All of these will lead to more cost-efficient execution of future WFGD projects.

One key way in which this type of information can be quickly transferred into cost savings is through the standardization of various sub-systems or sub-areas of the full system. Many mechanical standardizations, such as small pump packaging, were already successfully employed at Niles. After one iteration of the mechanical design and erection process, however, other areas of potential cost savings through standardization and off-site fabrication were identified. These possibilities will be further evaluated by cost/benefit analysis to determine exactly which design scenarios warrant the application of each technique.

As has been discussed previously, all of the individual subsystem advancements used at Niles had earlier been developed or explored under other venues such as at one of ABB's research facilities or at existing full scale WFGD systems. The advantage realized by the demonstration in conjunction with the Ohio Coal Development Office was to apply all these individual process improvements together in the form of a complete integrated advanced process.

The findings from the operation of the LS-2 plant at Niles will be used to develop and shape future process advancements. These future developments may include even higher tower gas velocities, lower reagent consumption, lower power requirements, higher value byproducts, and lower overall environmental impact.

s. MARKETING PLAN

ABB Environmental Systems is leading supplier of limestone WFGD systems to the power industry on a worldwide basis with over 29,000 MW of capacity installed or under contract. The technological advances resulting from the LS-2 project at Niles are and will be an important part of future offerings.

The current market for WFGD systems can be described as follows:

- Weak U.S. market due to reliance on fuel-switching and other measures to achieve compliance targets; some opportunities arising as a result of power plant purchases spurred by deregulation.
- Modest global market due to need for power in emerging markets and reliance on coal as primary energy source; this market is being delayed significantly by currency problems in SE Asia.
- Intense competition brought about by over capacity on the part of WFGD suppliers.

This situation has created a significant downward trend in prices paid for WFGD systems. Whereas, pricing levels for the Phase I Acid Rain market were typically \$175-225/kW, current levels in emerging markets are often 50% of that level due to low labor costs, technological advances, and competitive pressures.

ABB is meeting the challenges imposed by the current and future market with advanced WFGD technologies as follows:

Continued R&D

ABB's efforts to develop more cost-effective and reliable WFGD systems have not ended with the Niles demonstration. R&D programs are continuing at Corporate laboratories in Switzerland, Sweden, and the United States with special emphasis currently being placed on the use of sophisticated, proprietary instruments to study the mass transfer characteristics of spray tower absorbers. Field data from existing units are also being collected and used to calibrate process design models and provide scale-up information.

Standardization

Key aspects of the advanced WFGD processes demonstrated at Niles are being incorporated into ABB's standard commercial offerings. Features such as high velocity scrubbing and ultra-efficient spray zone design are part of ABB's state-of-the-art designs. Further, advanced WFGD concepts are employed in ABB's Reference Power Plant (RPP). The ABB RPP consists of a series of modular power plant designs that are providing low cost, quick turnaround solutions to expansion projects in the global power market.

Cost Reduction

The advanced concepts demonstrated at Niles are rendered even more cost-effective as a result of standardization (noted above) and supply management. By virtue of its size and global presence, ABB is able to use its purchasing power to bring about further cost savings. Under ABB's Supply Management program, frame agreements are in place with equipment suppliers and fabricators in low cost producer areas such as Eastern Europe, SE Asia, Mexico, etc. The frame agreements incorporate standard material specifications, QA/QC requirements, cost reduction targets, and pricing schedules. The savings achieved by this process are combined with the technical advances made at Niles to provide customers with low cost solutions to SO₂ emissions problems.

Promotion

ABB has and is actively promoting its advanced WFGD technology via multiple channels including:

- Technical papers presented at key meetings and conferences,
- Brochures and promotional material,
- ABB Environmental Systems website,
- Direct sales contacts with key clients, and
- Inclusion in the ABB Reference Power Plant.

Service Business

In addition to reducing the costs for new WFGD systems, concepts developed as part of the LS-2 demonstration project at Niles can be used to improve the performance and economics of existing systems. Examples include:

- Spray zone improvements. Advanced concepts related to the spray zone (e.g. orientation and placement of nozzles) can be used to improve the removal efficiency of spray tower absorbers.
- Mist eliminator upgrades. Mist eliminator designs and performance data from Niles can be used to reduce droplet carryover, particulate emissions, and operational problems at existing installations.
- Gypsum conversions. The wallboard quality gypsum technology demonstrated at Niles can be employed at other operating WFGD systems to eliminate waste disposal costs and legacy issues.

ABB is pursuing aftermarket opportunities such as those noted above in the U.S. and overseas through its network local business units.

Summary

ABB is using its global strength and technological leadership to provide cost-effective, reliable environmental solutions to the power industry on a worldwide basis. The technological improvements demonstrated at Niles form an important part of this strategy.

IV. FINAL BUDGET SUMMATION

T. PROJECT BUDGET

A summary of the project budget by major category and by the contributions of each cosponsor is presented below in Table 11.

LS-2 DEMONSTRATION PROJECT PROJECT BUDGET Summary					
CATEGORY	PHASE 1	PHASE 2	PHASE 3	PHASE 4	TOTAL
Total Personnel	\$3,488,802	\$430,010	\$1,597,041	\$1,423,556	\$6,939,409
OCDO	\$765,792	\$92,108	\$403,590	\$103,350	\$1,364,840
ABBES	\$2,723,010	\$337,902	\$1,193,451	\$200,206	\$4,454,569
Ohio Edison	\$0	\$0	\$0	\$850,000	\$850,000
EPRI	\$0	\$0	\$0	\$270,000	\$270,000
Total Equipment	\$0	\$9,197,509	\$46,960	\$200,000	\$9,444,469
OCDO	\$0	\$1,970,106	\$11,867	\$0	\$1,981,973
ABBES	\$0	\$7,227,403	\$35,093	\$0	\$7,262,496
Ohio Edison	\$0	\$0	\$0	\$200,000	\$200,000
EPRI	\$0	\$0	\$0	\$0	\$0
Total Supplies	\$0	\$0	\$0	\$450,000	\$450,000
OCDO	\$0	\$0	\$0	\$0	\$0
ABBES	\$0	\$0	\$0	\$0	\$0
Ohio Edison	\$0	\$0	\$0	\$450,000	\$450,000
EPRI	\$0	\$0	\$0	\$0	\$0
Total Contractual	\$880,917	\$107,443	\$9,430,883	\$521,000	\$10,940,243
OCDO	\$193,361	\$23,014	\$2,383,289	\$115,844	\$2,715,508
ABBES	\$687,556	\$84,429	\$7,047,594	\$5,156	\$7,824,735
Ohio Edison	\$0	\$0	\$0	\$0	\$0
EPRI	\$0	\$0	\$0	\$400,000	\$400,000
Total Travel	\$151,026	\$26,036	\$183,038	\$47,400	\$407,500
OCDO	\$7,551	\$1,302	\$9,152	\$2,370	\$20,375
ABBES	\$143,475	\$24,734	\$173,886	\$45,030	\$387,125
Ohio Edison	\$0	\$0	\$0	\$0	\$0
EPRI	\$0	\$0	\$0	\$0	\$0

Total Other	\$0	\$7,015	\$120,180	\$98,937	\$226,132
OCDO	\$0	\$1,503	\$30,371	\$21,998	\$53,872
ABBES	\$0	\$5,512	\$89,809	\$76,939	\$172,260
Ohio Edison	\$0	\$0	\$0	\$0	\$0
EPRI	\$0	\$0	\$0	\$0	\$0
Total Indirect Costs	\$497,282	\$1,074,482	\$1,251,592	\$301,498	\$3,124,854
OCDO	\$106,338	\$229,684	\$312,210	\$26,792	\$675,024
ABBES	\$390,944	\$844,798	\$939,382	\$274,706	\$2,449,830
Ohio Edison	\$0	\$0	\$0	\$0	\$0
EPRI	\$0	\$0	\$0	\$0	\$0
Total Project Costs	\$5,018,027	\$10,842,495	\$12,629,693	\$3,042,391	\$31,532,606
OCDO	\$1,073,042	\$2,317,717	\$3,150,478	\$270,354	\$6,811,591
ABBES	\$3,944,985	\$8,524,778	\$9,479,215	\$602,037	\$22,551,015
Ohio Edison	\$0	\$0	\$0	\$1,500,000	\$1,500,000
EPRI	\$0	\$0	\$0	\$670,000	\$670,000

Table 11: Project Budget Summary

U. OCDO EXPENDITURES

Table 12 below lists by line item the actual project expenditures and details the portion of each funded by the Ohio Coal Development Office.

LS-2 DEMONSTRATION PROJECT ACTUAL EXPENDITURES Summary		
	TOTAL	OCDO
CATEGORY	EXPENDITURE	PORTION
Personnel	\$5,674,863.28	\$1,116,245.61
Fringe Benefits	\$0.00	\$0.00
Travel	\$574,404.01	\$0.00
Equipment	\$9,469,877.46	\$1,987,727.28
Other	\$213,304.63	\$50,809.16
Contractual	\$12,013,647.50	\$2,981,787.31
Total Direct Charges	\$27,946,096.88	\$6,136,569.36
Indirect Charges	\$3,074,070.66	\$675,022.63
GRAND TOTAL	\$31,020,167.54	\$6,811,591.99

Table 12: Total Actual Expenditures and OCDO's Portion

V. APPENDICES

v. Design and Instrumentation Verification Test Data

w. Final Instrumentation Verification Test Data

V. Design and Instrumentation Verification Test Data

TEST DATA

Facility Name	ABB Environmental Systems	Project #	95-0713.02
Address	1047 Belmont Avenue	Method(s)	1-4, 6c, 8
City	Niles	Crew	TC,BS,CG,
State	Ohio	Source	Control
Zip	44446	Location	Inlet #1

Parameter	Units	Cond. #1	Cond. #2	Cond. #3	Cond. #1	Cond. #2	Cond. #3
Date	xx/xx/xx	09/06/95	09/06/95	09/06/95	10/30/95	10/31/95	10/31/95
Time of Day	24hr	1402-1541	1803-1901	2312-0026	1330-1418	1409-1509	1540-1631
Length of Test	minutes	75	75	75	75	75	75
Barometric Pressure (P_{bar})	in. Hg	29.45	29.45	29.45	29.4	29.4	29.4
Static Pressure (P_s)	in. H ₂ O	-1.5	-0.95	-0.95	-1	-0.93	-0.93
Pitot Coefficient (C_p)	unitless	0.84	0.84	0.84	0.84	0.84	0.84
Nozzle Diameter (D_n)	inches	0.217	0.217	0.217			
Area of Duct (A)	ft ²	100	100	100	100	100	100
Meter Correction Factor (Y_m)	unitless	1.01	1.01	1.01	1.01	1.01	1.01
Average sq. rt. Δp	in. H ₂ O	0.992	0.887	0.708	1.109	0.849	0.648
Average ΔH	in. H ₂ O	1.82	1.48	0.86	1.82	1.82	1.82
Average Stack Temperature (T_s)	°F	275.3	291.8	285.8	261.4	264.96	256.12
Average Meter Temperature (T_m)	°F	98.34	95.35	79.1	98.34	95.35	79.1
Meter Volume (V_m)	ft ³	54.96	47.73	36.40	54.96	47.73	36.40
Initial Impinger Volume	ml	200	200	200	200	200	200
Final Impinger Volume	ml	292	298	282	292	298	282
Initial Silica Weight	g	200.0	200.0	200.0	200.0	200.0	200.0
Final Silica Weight	g	209.9	206.1	206.2	209.9	206.1	206.2

ORSAT CO ₂	%	11.5	11.7	11.8	11.7	11.4	11.4
ORSAT O ₂	%	5.5	5.1	5.7	5.2	5	5.5
ORSAT CO	%	0	0	0	0	0	0
Method 3A CO ₂	%						
Method 3A O ₂	%						

METHOD 8

Normality of Barium Perchlorate (N)		0.010	0.010	0.010			
Volume of Solution (V_s)	ml	250	250	250			
Volume of Aliquot (V_a)	ml	100	100	100			
Average Volume of Sample Titrant (V_t)	ml	33	32.5	21.75			
Volume of Blank Titrant (V_b)	ml	1	1	1			

METHOD 6C

Average SO ₂ Concentration	ppm				2060.44	1844.96	2124.8
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TEST RESULTS

ABB Environmental Systems

Project # 95-0713.02

Method(s) 1-4, 6c, 8

Location inlet #1

PARAMETER	Cond. #1	Cond. #2	Cond. #3	Cond. #1	Cond. #2	Cond. #3
M _a (lb/lb-mole)	30.1	30.1	30	30.1	30	30
M _w (lb/lb-mole)	29	28.9	28.8	29.1	28.8	28.8
P _a (in. Hg)	29.3	29.4	29.4	29.3	29.3	29.3
V _a (ft/sec)	66.2	59.9	47.8	73.3	56	42.9
ACFM (ft ³ /min)	397070	359650	286520	439660	336210	257140
DSCFM (ft ³ /min)	255920	223780	178320	288660	216570	166410
V _{inlet} (ft ³)	51.9	45.3	35.5	51.8	45.2	35.5
V _{inlet} (ml)	4.8	4.91	4.16	4.8	4.91	4.16
B _{inlet} (%)	8.5	9.8	10.5	8.5	9.8	10.5
C _a (mg/mg)	1.32E-09	1.32E-09	1.32E-09	1.32E-09	1.32E-09	1.32E-09
W _a (g)	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
ISOKINETIC RATE (%)	105	105	103			
*8 SO ₂ E (lb/hr)	25.586	25.232	16.901			
*6c SO ₂ E (lb/hr)				5923.875	3979.647	3521.736

TEST RESULTS

ABB Environmental Systems						
Project #		95-0713.02				
Method(s)		1-4, 6c, 8				
Location		Inlet #2				
PARAMETER	Cond. #1	Cond. #2	Cond. #3		Cond. #1	
M _a (lb/lb-mole)	29.4	29.6	29.8		29.4	
M _w (lb/lb-mole)	28.3	28.5	28.7		28.3	
P _a (in. Hg)	30.2	30	30		30.2	
V _a (ft/sec)	64.4	57.8	49.4		63.2	
ACFM (ft ³ /min)	447250	401750	343130		438700	
DSCFM (ft ³ /min)	331510	296890	258550		327860	
V _{m(std)} (ft ³)	36.3	32.6	29.1		35.3	
V _{m(std)} (ml)	3.66	3.28	2.98		3.49	
B _{st} (%)	9.1	9.1	9.3		9	
C _a (mg/mg)	1.32E-09	1.32E-09	1.32E-09		0.000000	
W _a (g)	0.0001	0.0001	0.0001		0.0001	
ISOKINETIC RATE (%)	106	106	108		104	
*8 SO ₂ E (lb/hr)	42.944	71.576	36.017			
*6c SO ₂ E (lb/hr)	5398.508	4883.644	5396.553		5434.421	

[illegible]

TEST RESULTS

ABB Environmental Systems					
Project #		95-0713.02			
Method(s)		1-4, 6c, 8			
Location		Outlet #3			
PARAMETER	Cond. #1	Cond. #2	Cond. #3	Cond. #2	
M _a (lb/lb-mole)	29.8	29.8	29.8	29.8	
M _w (lb/lb-mole)	28.4	28.5	28.5	28.5	
P _a (In. Hg)	29.8	29.8	29.8	29.8	
V _a (ft/sec)	23.6	20.1	14.8	21.3	
ACFM (ft ³ /min)	352900	300710	222000	319300	
DSCFM (ft ³ /min)	284380	243310	179100	259280	
V _{m(std)} (ft ³)	43.4	38	29.4	43.4	
V _{m(std)} (ml)	5.57	4.78	3.77	5.32	
B _w (%)	11.4	11.2	11.4	10.9	
C _a (mg/mg)	1.32E-09	1.32E-09	1.32E-09	0.000000	
W _a (g)	0.0001	0.0001	0.0001	0.0001	
ISOKINETIC RATE (%)	98	100	105	107	
*8 SO _x E (lb/hr)	10.901	8.41	17.78		
*6c SO _x E (lb/hr)	725.922	576.858	390.143	623.321	

TEST DATA

Facility Name	ABB Environmental Systems	Project #	95-0713.02
Address	1047 Belmont Avenue	Method(s)	1-4, 6c, 8
City	Niles	Crew	RV, CK
State	Ohio	Source	
Zip	44446	Control	
		Location	Outlet #4

Parameter	Units	Cond. #1	Cond. #2	Cond. #3	Cond. #1	Cond. #2	Cond. #3
Date	xx/xx/xx	09/06/95	09/06/95	09/06/95	10/30/95	10/30/95	10/31/95
Time of Day	24hr	1030-1106	1932-2029	2200-2300	1450-1538	1650-1739	1659-1757
Length of Test	minutes	75	75	75	75	75	75
Barometric Pressure (P _{bar})	in. Hg	29.45	29.45	29.45	29.4	29.4	29.4
Static Pressure (P _s)	in. H ₂ O	0.85	0.85	0.85	0.82	0.83	0.83
Pitot Coefficient (C _p)	unitless	0.84	0.84	0.84	0.84	0.84	0.84
Nozzle Diameter (D _n)	inches	0.185	0.185	0.185			
Area of Duct (A _d)	ft ²	100	100	100	100	100	100
Meter Correction Factor (Y _m)	unitless	0.99	0.99	0.99	0.99	0.99	0.99
Average sq. rt. Δp	in. H ₂ O	0.932	0.861	0.704	0.872	0.755	0.6
Average ΔH	in. H ₂ O	0.83	0.69	0.45	0.83	0.69	0.45
Average Stack Temperature (T _s)	°F	212.92	213.08	214.6	215.04	215.4	216.44
Average Meter Temperature (T _m)	°F	100.84	93.46	76.53	100.84	93.46	76.53
Meter Volume (V _m)	ft ³	41.27	35.39	29.64	41.27	35.39	29.64
Initial Impinger Volume	ml	200	200	200	200	200	200
Final Impinger Volume	ml	292	286	265	258	235	228
Initial Silica Weight	g	200.0	200.0	200.0	200.0	200.0	200.0
Final Silica Weight	g	205.0	202.5	207.9	205.0	202.5	207.9

ORSAT CO ₂	%	9.4	11.3	11.3	11	11.1	11.2
ORSAT O ₂	%	8	5.7	5.7	5.6	5.7	5.7
ORSAT CO	%	0	0	0	0	0	0
Method 3A CO ₂	%						
Method 3A O ₂	%						

METHOD 8

Normality of Barium Perchlorate (N)		0.010	0.010	0.010			
Volume of Solution (V _s)	ml	250	250	250			
Volume of Aliquot (V _a)	ml	100	100	100			
Average Volume of Sample Titrant (V _t)	ml	23.2	20.85	17.94			
Volume of Blank Titrant (V _b)	ml	1	1	1			

METHOD 6C

Average SO ₂ Concentration	ppm				322.98	291.72	384.52
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TEST RESULTS

ABB Environmental Systems						
Project #		95-0713.02				
Method(s)		1-4, 6c, 8				
Location		Outlet #4				
PARAMETER	Cond. #1	Cond. #2	Cond. #3	Cond. #1	Cond. #2	Cond. #3
M _a (lb/lb-mole)	29.8	30	30	30	30	30
M _i (lb/lb-mole)	28.6	28.7	28.7	29.1	29.4	29.3
P _a (in. Hg)	29.5	29.5	29.5	29.5	29.5	29.5
V _a (ft/sec)	59.8	55.1	45.1	55.6	47.9	38.1
ACFM (ft ³ /min)	358850	330800	270520	333320	287300	228680
DSCFM (ft ³ /min)	247870	227210	186350	238050	209880	165880
V _{m(std)} (ft ³)	37.9	33	28.5	37.9	32.9	28.4
V _{m(std)} (ml)	4.57	4.17	3.44	2.97	1.77	1.69
B _{avg} (%)	10.8	11.2	10.8	7.3	5.1	5.6
C _a (mg/mg)	1.32E-09	1.32E-09	1.32E-09	1.32E-09	1.32E-09	1.32E-09
W _a (g)	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
ISOKINETIC RATE (%)	109	104	109			
*8 SO ₂ E (lb/hr)	23.543	22.161	17.96			
*6c SO ₂ E (lb/hr)				765.731	609.813	635.29

TEST DATA

[illegible]

TEST RESULTS

ABB Environmental Systems

Project # 95-0713.02

Method(s) 1-4, 6c, 8

Location Inlet #1

PARAMETER	Cond. #1	Cond. #2	Cond. #3	Cond. #1	Cond. #2	Cond. #3
M _a (lb/lb-mole)	30.1	30.1	30	30.1	30	30
M _r (lb/lb-mole)	29	28.9	28.8	29.1	28.8	28.8
P _a (in. Hg)	29.3	29.4	29.4	29.3	29.3	29.3
V _a (ft/sec)	66.2	59.9	47.8	73.3	56	42.9
ACFM (ft ³ /min)	397070	359650	286520	439660	336210	257140
DSCFM (ft ³ /min)	255920	223780	178320	288660	216570	166410
V _{actual} (ft ³)	51.9	45.3	35.5	51.8	45.2	35.5
V _{calculated} (ml)	4.8	4.91	4.16	4.8	4.91	4.16
B _{gas} (%)	8.5	9.8	10.5	8.5	9.8	10.5
C _a (mg/mg)	1.32E-09	1.32E-09	1.32E-09	1.32E-09	1.32E-09	1.32E-09
W _a (g)	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
ISOKINETIC RATE (%)	105	105	103			
*8 SO ₂ E (lb/hr)	25.588	25.232	16.901			
*6c SO ₂ E (lb/hr)				5923.875	3979.647	3521.736

W

[illegible]

TEST RESULTS

ABB Environmental Systems					
Project #		95-0713.02			
Method(s)		1-4, 6c, 8			
Location		Inlet #2			
PARAMETER	Cond. #1	Cond. #2	Cond. #3		Cond. #1
M _a (lb/lb-mole)	29.4	29.6	29.8		29.4
M _r (lb/lb-mole)	28.3	28.5	28.7		28.3
P _r (in. Hg)	30.2	30	30		30.2
V _r (ft/sec)	64.4	57.8	49.4		63.2
ACFM (ft ³ /min)	447250	401750	343130		438700
DSCFM (ft ³ /min)	331510	296890	258550		327860
V _{m(std)} (ft ³)	36.3	32.6	29.1		35.3
V _{m(std)} (ml)	3.66	3.28	2.98		3.49
B _{sr} (%)	9.1	9.1	9.3		9
C _s (mg/mg)	1.32E-09	1.32E-09	1.32E-09		0.000000
W _r (g)	0.0001	0.0001	0.0001		0.0001
ISOKINETIC RATE (%)	106	106	108		104
*8 SO ₂ E (lb/hr)	42.944	71.576	36.017		
*6c SO ₂ E (lb/hr)	5398.508	4883.644	5396.553		5434.421

TEST DATA

[illegible]

TEST RESULTS

ABB Environmental Systems

Project # 95-0713.02

Method(s) 1-4, 6c, 8

Location Outlet #3

PARAMETER	Cond. #1	Cond. #2	Cond. #3	Cond. #2
M _a (lb/lb-mole)	29.8	29.8	29.8	29.8
M _w (lb/lb-mole)	28.4	28.5	28.5	28.5
P _a (in. Hg)	29.8	29.8	29.8	29.8
V _a (ft/sec)	23.6	20.1	14.8	21.3
ACFM (ft ³ /min)	352900	300710	222000	319300
DSCFM (ft ³ /min)	284380	243310	179100	259280
V _{m(std)} (ft ³)	43.4	38	29.4	43.4
V _{m(std)} (ml)	5.57	4.78	3.77	5.32
B _{su} (%)	11.4	11.2	11.4	10.9
C _a (mg/mg)	1.32E-09	1.32E-09	1.32E-09	0.000000
W _a (g)	0.0001	0.0001	0.0001	0.0001
ISOKINETIC RATE (%)	98	100	105	107
*8 SO ₂ E (lb/hr)	10.901	8.41	17.78	
*6c SO ₂ E (lb/hr)	725.922	576.858	390.143	623.321

TEST DATA

Facility Name	ABB Environmental Systems	Project #	95-0713.02
Address	1047 Belmont Avenue	Method(s)	1-4, 6c, 8
City	Niles	Crew	TC,BS,CG,
State	Ohio	Source	
Zip	44446	Control	
		Location	Inlet #1

Parameter	Units	Cond. #1	Cond. #2	Cond. #3	Cond. #1	Cond. #2	Cond. #3
Date	xx/xx/xx	09/06/95	09/06/95	09/06/95	10/30/95	10/31/95	10/31/95
Time of Day	24hr	1402-1541	1803-1901	2312-0025	1330-1418	1409-1509	1540-1631
Length of Test	minutes	75	75	75	75	75	75
Barometric Pressure (P _{bar})	in. Hg	29.45	29.45	29.45	29.4	29.4	29.4
Static Pressure (P _s)	in. H ₂ O	-1.5	-0.95	-0.95	-1	-0.93	-0.93
Pilot Coefficient (C _p)	unitless	0.84	0.84	0.84	0.84	0.84	0.84
Nozzle Diameter (D _n)	inches	0.217	0.217	0.217			
Area of Duct (A _d)	ft ²	100	100	100	100	100	100
Meter Correction Factor (Y _c)	unitless	1.01	1.01	1.01	1.01	1.01	1.01
Average sq. rt. ^p	in. H ₂ O	0.992	0.887	0.708	1.109	0.843	0.648
Average ^H	in. H ₂ O	1.82	1.48	0.86	1.82	1.82	1.82
Average Stack Temperature (T _s)	°F	275.3	291.8	285.8	261.4	264.96	256.12
Average Meter Temperature (T _m)	°F	98.34	95.35	79.1	98.34	95.35	79.1
Meter Volume (V _m)	ft ³	54.96	47.78	36.40	54.96	47.73	36.40
Initial Impinger Volume	ml	200	200	200	200	200	200
Final Impinger Volume	ml	292	298	282	292	298	282
Initial Silica Weight	g	200.0	200.0	200.0	200.0	200.0	200.0
Final Silica Weight	g	209.9	206.1	206.2	209.9	206.1	206.2

ORSAT CO ₂	%	11.5	11.7	11.3	11.7	11.4	11.4
ORSAT O ₂	%	5.5	5.1	5.7	5.2	5	5.5
ORSAT CO	%	0	0	0	0	0	0
Method 3A CO ₂	%						
Method 3A O ₂	%						

METHOD 8

Normality of Barium Perchlorate (N)		0.010	0.010	0.010			
Volume of Solution (V _s)	ml	250	250	250			
Volume of Aliquot (V _a)	ml	20	20	20			
Average Volume of Sample Titrant (V _s)	ml	33	32.5	21.75			
Volume of Blank Titrant (V _b)	ml	1	1	1			

METHOD 6C

Average SO ₂ Concentration	ppm				2060.44	1844.96	2124.8
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TEST RESULTS

ABB Environmental Systems						
Project #		95-0713.02				
Method(s)		1-4, 6c, 8				
Location		Inlet #1				
PARAMETER	Cond. #1	Cond. #2	Cond. #3	Cond. #1	Cond. #2	Cond. #3
M ₁ (lb/lb-mole)	30.1	30.1	30	30.1	30	30
M ₂ (lb/lb-mole)	29	28.9	28.8	29.1	28.8	28.8
P ₁ (in. Hg)	29.3	29.4	29.4	29.3	29.3	29.3
V ₁ (ft/sec)	66.2	59.9	47.8	73.3	56	42.9
ACFM (ft ³ /min)	397070	359650	286520	439660	336210	257140
DSCFM (ft ³ /min)	255920	223780	178320	288660	216570	166410
V _{m(std)} (ft ³)	51.9	45.3	35.5	51.8	45.2	35.5
V _{m(std)} (ml)	4.8	4.91	4.16	4.8	4.91	4.16
B _{st} (%)	8.5	9.8	10.5	8.5	9.8	10.5
C ₁ (mg/mg)	1.32E-09	1.32E-09	1.32E-09	1.32E-09	1.32E-09	1.32E-09
W ₁ (g)	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
ISOKINETIC RATE (%)	105	105	103			
*8 SO ₂ E (lb/hr)	4336.923	3733.011	1959.502			
*6c SO ₂ E (lb/hr)				5923.875	3979.647	3521.736

TEST DATA

[illegible]

TEST RESULTS

ABB Environmental Systems

Project # 95-0713.02

Method(s) 1-4, 6c, 8

Location Inlet #2

PARAMETER	Cond. #1	Cond. #2	Cond. #3	Cond. #1
M _a (lb/lb-mole)	29.4	29.6	29.8	29.4
M _w (lb/lb-mole)	28.3	28.5	28.9	28.4
P _a (in. Hg)	30.2	30	30	30.2
V _a (ft/sec)	64.4	57.8	49.2	63.1
ACFM (ft ³ /min)	447100	401610	342080	438560
DSCFM (ft ³ /min)	332000	297330	262020	328340
V _{sc} (ft ³)	37	33.3	29.6	36
V _{sc} (ml)	3.66	3.28	2.51	3.49
B _{sc} (%)	9	9	7.8	8.8
C _a (mg/mg)	1.32E-09	1.32E-09	1.32E-09	0.000000
W _a (g)	0.0001	0.0001	0.0001	0.0001
ISOKINETIC RATE (%)	107	108	109	106
*8 SO ₂ E (lb/hr)	5098.748	4763.015	4346.981	
*6c SO ₂ E (lb/hr)	5406.487	4890.882	5468.98	5442.377

BAD

TEST DATA

Facility Name	ABB Environmental Systems	Project #	95-0713.02
Address	1047 Belmont Avenue	Method(s)	1-4, 6c, 8
City	Niles	Crew	DS, CG
State	Ohio	Source	
Zip	44446	Control	
		Location	Outlet #3

Parameter	Units	Cond. #1	Cond. #2	Cond. #3	Cond. #1
Date	xx/xx/xx	09/06/95	09/06/95	09/06/95	09/06/95
Time of Day	24hr	1003-1106	1932-2029	2200-2300	1142-1326
Length of Test	minutes	72	72	72	72
Barometric Pressure (P_{bar})	in. Hg	29.45	29.45	29.45	29.45
Static Pressure (P_s)	in. H ₂ O	4.9	4.9	4.9	4.9
Pitot Coefficient (C_p)	unitless	0.84	0.84	0.84	0.84
Nozzle Diameter (D_n)	inches	0.315	0.315	0.315	0.315
Area of Duct (A_d)	ft ²	249.69	249.69	249.69	249.69
Meter Correction Factor (Y_m)	unitless	1.00	1.00	1.00	1.002
Average sq. ft. Δp	in. H ₂ O	0.397	0.339	0.25	0.36
Average ΔH	in. H ₂ O	1.4	1.09	0.57	1.4
Average Stack Temperature (T_s)	°F	118.5	117.5	118	117
Average Meter Temperature (T_m)	°F	91.75	99.5	84	91.75
Meter Volume (V_m)	ft ³	45.78	40.68	30.68	45.78
Initial Impinger Volume	ml	200	200	200	200
Final Impinger Volume	ml	312	298	275	308
Initial Silica Weight	g	200.0	200.0	200.0	200
Final Silica Weight	g	206.2	203.4	205.0	205

ORSAT CO ₂	%	8.8	9.2	9.4	8.8
ORSAT O ₂	%	8.9	8.6	7.4	8.9
ORSAT CO	%	0	0	0	0
Method 3A CO ₂	%				
Method 3A O ₂	%				

METHOD 8

Normality of Barium Perchlorate (N)		0.010	0.010	0.010	
Volume of Solution (V_s)	ml	270	250	250	
Volume of Aliquot (V_a)	ml	20	20	20	
Average Volume of Sample Titrant (V_s)	ml	10.5	9.1	19	
Volume of Blank Titrant (V_b)	ml	1	1	1	

METHOD 6C

Average SO ₂ Concentration	ppm	256.29	238.04	218.71	241.37
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TEST RESULTS

ABB Environmental Systems					
Project #		95-0713.02			
Method(s)		1-4, 6c, 8			
Location.		Outlet #3			
PARAMETER	Cond. #1	Cond. #2	Cond. #3	Cond. #2	
M _a (lb/lb-mole)	29.8	29.8	29.8	29.8	
M _w (lb/lb-mole)	28.4	28.5	28.5	28.5	
P _a (in. Hg)	29.8	29.8	29.8	29.8	
V _a (ft/sec)	23.6	20.1	14.8	21.3	
ACFM (ft ³ /min)	352900	300710	222000	319300	
DSCFM (ft ³ /min)	284380	243310	179100	259280	
V _{m(Std)} (ft ³)	43.4	38	29.4	43.4	
V _{m(Std)} (ml)	5.57	4.78	3.77	5.32	
B _w (%)	11.4	11.2	11.4	10.9	
C _a (mg/mg)	1.32E-09	1.32E-09	1.32E-09	0.000000	
W _a (g)	0.0001	0.0001	0.0001	0.0001	
ISOKINETIC RATE (%)	98	100	105	107	
SO ₂ E (lb/hr)	1545.162	1043.892	1707.244		
SO ₂ E (lb/hr)	725.922	576.858	390.143	623.321	

BAD

TEST RESULTS

ABB Environmental Systems						
Project #	95-0713.02					
Method(s)	1-4, 6c, 8					
Location	Outlet #4					
PARAMETER	Cond. #1	Cond. #2	Cond. #3	Cond. #1	Cond. #2	Cond. #3
M ₁ (lb/lb-mole)	29.8	30	30	30	30	30
M ₂ (lb/lb-mole)	28.6	28.7	28.7	29.1	29.4	29.3
P ₁ (in. Hg)	29.5	29.5	29.5	29.5	29.5	29.5
V ₁ (ft/sec)	59.8	55.1	45.1	55.6	47.9	38.1
ACFM (ft ³ /min)	358850	330800	270520	333320	287300	228680
DSCFM (ft ³ /min)	247870	227210	186350	238050	209880	165880
V _{m/nd} (ft ³)	37.9	33	28.5	37.9	32.9	28.4
V _{m/nd} (ml)	4.57	4.17	3.44	2.97	1.77	1.69
B _{wr} (%)	10.8	11.2	10.8	7.3	5.1	5.6
C ₁ (mg/mg)	1.32E-09	1.32E-09	1.32E-09	1.32E-09	1.32E-09	1.32E-09
W ₁ (g)	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
ISOKINETIC RATE (%)	109	104	109			
*8 SO ₂ E (lb/hr)	2914.1	2388.446	1671.746			
*6c SO ₂ E (lb/hr)				765.731	609.813	635.29

BAD

TEST DATA

[illegible]

TEST RESULTS

ABB Environmental Systems						
Project #		95-0713.02				
Method(s)		1-4, 6c, 8				
Location		Outlet #4				
PARAMETER	Cond. #1	Cond. #2	Cond. #3	Cond. #1	Cond. #2	Cond. #3
M _a (lb/lb-mole)	29.8	30	30	30	30	30
M _i (lb/lb-mole)	28.6	28.7	28.7	29.1	29.4	29.3
P _i (in. Hg)	29.5	29.5	29.5	29.5	29.5	29.5
V _i (ft/sec)	59.8	55.1	45.1	55.6	47.9	38.1
ACFM (ft ³ /min)	358850	330800	270520	333320	287300	228680
DSCFM (ft ³ /min)	247870	227210	186350	238050	209880	165880
V _{m(std)} (ft ³)	37.9	33	28.5	37.9	32.9	28.4
V _{m(std)} (ml)	4.57	4.17	3.44	2.97	1.77	1.69
B _{stg} (%)	10.8	11.2	10.8	7.3	5.1	5.6
C _i (mg/mg)	1.32E-09	1.32E-09	1.32E-09	1.32E-09	1.32E-09	1.32E-09
W _i (g)	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
ISOKINETIC RATE (%)	109	104	109			
*8 SO _i E (lb/hr)	23.543	22.161	17.96			
*6c SO _i E (lb/hr)				765.731	609.813	635.29

Facility Name	ABB Environmental Systems		
Street Address	1047 Belmont Avenue		
City, State	Niles, OH 44446		
Source - Control	Fan		
Sampling Date	September 6, 1995		
Location	inlet #1		
Run #	RUN #1	RUN #2	RUN #3
Time of Day	2:02-3:41	6:03-7:01	11:12-12:26
Length of Test	75.0	75.0	75.0
Barometric Pressure	29.45	29.45	29.45
Static Pressure	-1.50	-0.95	-0.95
Stack Temperature	275.30	291.80	285.80
Square Root Delta P	0.992	0.887	0.708
Meter Volume	54.963	47.729	36.400
Meter Temperature	98.34	95.35	79.10
Delta H	1.82	1.48	0.86
Area of Duct	100.00	100.00	100.00
Pitot Coefficient	0.84	0.84	0.84
Initial Impinger	200	200	200
Final Impinger	200	200	200
Initial Silica	200.0	200.0	200.0
Final Silica	200.0	200.0	200.0
F factor O2	8710	8710	8710
PPM Average	1323.56	1639.16	1641.64
Orsat #	# 1	# 2	# 3
CO2 - 1	11.5	11.7	11.3
CO2 - 2	11.5	11.7	11.3
CO2 - 3	11.5	11.7	11.3
O2 - 1	5.5	5.1	5.7
O2 - 2	5.5	5.1	5.7
O2 - 3	5.5	5.1	5.7
CO - 1	0.0	0.0	0.0
CO - 2	0.0	0.0	0.0
CO - 3	0.0	0.0	0.0

Facility Name	ABB Environmental Systems
Street Address	1047 Belmont Avenue
City, State	Niles, OH 44446
Source – Control	Fan Condition #1 Run #2
Sampling Date	September 6, 1995
Location	inlet #1
Run #	RUN #2
Time of Day	4:02–4:53
Length of Test	75.0
Barometric Pressure	29.45
Static Pressure	–1.50
Stack Temperature	294.80
Square Root Delta P	0.981
Meter Volume	54.963
Meter Temperature	98.34
Delta H	1.82
Area of Duct	100.00
Pitot Coefficient	0.84
Initial Impinger	200
Final Impinger	200
Initial Silica	200.0
Final Silica	200.0
F factor O2	8710
PPM Average	1504.68
Orsat #	# 1
CO2 – 1	11.5
CO2 – 2	11.5
CO2 – 3	11.5
O2 – 1	5.5
O2 – 2	5.5
O2 – 3	5.5
CO – 1	0.0
CO – 2	0.0
CO – 3	0.0

CONCORD ENVIRONMENTAL SERVICES, INC.

1-800-252-3098

ABB Environmental Systems
1047 Belmont Avenue
Niles, OH 44446

Fan
USEPA Reference Methods 1-4, 6C
September 6, 1995

TEST RESULTS

inlet #1

	PARAMETER		RUN #1	RUN #2	RUN #3
1	Std. Volume of Gas Sample	Vmstd	51.39	44.83	35.17
2	Absolute Flue Gas Pressure	Ps	29.34	29.38	29.38
3	Standard Volume of H2O Vapor	Vwstd	0.00	0.00	0.00
4	Moisture Cont. of Gas Sample	Bws	0.0000	0.0000	0.0000
5	Gas Sample Dry Mole. Wt.	Md	30.06	30.08	30.04
6	Gas Sample Wet Mole. Wt.	Ms	30.06	30.08	30.04
7	Gas Stream Velocity	vs	65.0	58.8	46.7
8	Actual Flue Gas Flow Vol.	ACFM	390,272	352,520	280,441
9	Dry, Std Flue Gas Flow Vol.	DSCFM	274,809	243,113	194,960
10	SO2 Concentration, ppm	C	1323.56	1639.16	1641.64
11	SO2 Concentration, lbs/dscf	Cs	2.197E-04	2.721E-04	2.725E-04
12	SO2 Concentration, lbs/mbtu	E	2.597	3.135	3.264
13	SO2 Emissions Rate, lbs/hr	Es	3622.71	3969.07	3187.74

ABB Environmental Systems
1047 Belmont Avenue
Niles, OH 44446

Fan Condition #1 Run #2
USEPA Reference Methods 1-4, 6C
September 6, 1995

TEST RESULTS

inlet #1

PARAMETER		RUN #2			
1	Std. Volume of Gas Sample	Vmstd	51.39	0.00	0.00
2	Absolute Flue Gas Pressure	Ps	29.34	0.00	0.00
3	Standard Volume of H2O Vapor	Vwstd	0.00	0.00	0.00
4	Moisture Cont. of Gas Sample	Bws	0.0000	ERR	ERR
5	Gas Sample Dry Mole. Wt.	Md	30.06	28.00	28.00
6	Gas Sample Wet Mole. Wt.	Ms	30.06	ERR	ERR
7	Gas Stream Velocity	vs	65.2	ERR	ERR
8	Actual Flue Gas Flow Vol.	ACFM	391,029	ERR	ERR
9	Dry, Std Flue Gas Flow Vol.	DSCFM	268,228	ERR	ERR
10	SO2 Concentration, ppm	C	1504.68		
11	SO2 Concentration, lbs/dscf	Cs	2.498E-04	0.000E+00	0.000E+00
12	SO2 Concentration, lbs/mbtu	E	2.953	0.000	0.000
13	SO2 Emissions Rate, lbs/hr	Es	4019.83	ERR	ERR

Facility Name	ABB Environmental Systems		
Street Address	1047 Belmont Avenue		
City, State	Niles, OH 44446		
Source – Control	Fan		
Sampling Date	September 6, 1995		
Location	outlet #4		
Run #	RUN #1	RUN #2	RUN #3
Time of Day	10:30–11:06	7:32–8:29	10:00–11:00
Length of Test	75.0	75.0	75.0
Barometric Pressure	29.45	29.45	29.45
Static Pressure	0.85	0.85	0.85
Stack Temperature	212.92	213.08	214.60
Square Root Delta P	0.932	0.861	0.704
Meter Volume	41.267	35.390	29.640
Meter Temperature	100.84	93.46	76.53
Delta H	0.83	0.69	0.45
Area of Duct	100.00	100.00	100.00
Pitot Coefficient	0.84	0.84	0.84
Initial Impinger	200	200	200
Final Impinger	200	200	200
Initial Silica	200.0	200.0	200.0
Final Silica	200.0	200.0	200.0
F factor O2	8710	8710	8710
PPM Average	195.33	152.80	153.92
Orsat #	# 1	# 2	# 3
CO2 – 1	9.4	11.3	11.3
CO2 – 2	9.4	11.3	11.3
CO2 – 3	9.4	11.3	11.3
O2 – 1	8.2	5.8	5.8
O2 – 2	8.2	5.8	5.8
O2 – 3	8.2	5.8	5.8
CO – 1	0.0	0.0	0.0
CO – 2	0.0	0.0	0.0
CO – 3	0.0	0.0	0.0

Facility Name	ABB Environmental Systems
Street Address	1047 Belmont Avenue
City, State	Niles, OH 44446
Source - Control	Fan Condition #1 Run #2
Sampling Date	September 6, 1995
Location	outlet #4
Run #	RUN #1
Time of Day	11:42-1:26
Length of Test	75.0
Barometric Pressure	29.45
Static Pressure	0.85
Stack Temperature	200.00
Square Root Delta P	0.930
Meter Volume	41.267
Meter Temperature	100.84
Delta H	0.83
Area of Duct	100.00
Pitot Coefficient	0.84
Initial Impinger	200
Final Impinger	200
Initial Silica	200.0
Final Silica	200.0
F factor O2	8710
PPM Average	187.56
Orsat #	# 1
CO2 - 1	9.4
CO2 - 2	9.4
CO2 - 3	9.4
O2 - 1	8.2
O2 - 2	8.2
O2 - 3	8.2
CO - 1	0.0
CO - 2	0.0
CO - 3	0.0

CONCORD ENVIRONMENTAL SERVICES, INC.

1-800-252-3098

ABB Environmental Systems
1047 Belmont Avenue
Niles, OH 44446

Fan
USEPA Reference Methods 1-4, 6C
September 6, 1995

TEST RESULTS

outlet #4

PARAMETER			RUN #1	RUN #2	RUN #3
1	Std. Volume of Gas Sample	Vmstd	38.32	33.29	28.74
2	Absolute Flue Gas Pressure	Ps	29.51	29.51	29.51
3	Standard Volume of H2O Vapor	Vwstd	0.00	0.00	0.00
4	Moisture Cont. of Gas Sample	Bws	0.0000	0.0000	0.0000
5	Gas Sample Dry Mole. Wt.	Md	29.83	30.04	30.04
6	Gas Sample Wet Mole. Wt.	Ms	29.83	30.04	30.04
7	Gas Stream Velocity	vs	58.5	53.9	44.1
8	Actual Flue Gas Flow Vol.	ACFM	351,075	323,243	264,599
9	Dry, Std Flue Gas Flow Vol.	DSCFM	271,715	250,116	204,278
10	SO2 Concentration, ppm	C	195.33	152.80	153.92
11	SO2 Concentration, lbs/dscf	Cs	3.242E-05	2.536E-05	2.555E-05
12	SO2 Concentration, lbs/mbtu	E	0.465	0.306	0.308
13	SO2 Emissions Rate, lbs/hr	Es	528.62	380.65	313.17

CONCORD ENVIRONMENTAL SERVICES, INC.

1-800-252-3098

ABB Environmental Systems
1047 Belmont Avenue
Niles, OH 44446

Fan Condition #1 Run #2
USEPA Reference Methods 1-4, 6C
September 6, 1995

TEST RESULTS

outlet #4

PARAMETER		RUN #1			
1	Std. Volume of Gas Sample	Vmstd	38.32	0.00	0.00
2	Absolute Flue Gas Pressure	Ps	29.51	0.00	0.00
3	Standard Volume of H2O Vapor	Vwstd	0.00	0.00	0.00
4	Moisture Cont. of Gas Sample	Bws	0.0000	ERR	ERR
5	Gas Sample Dry Mole. Wt.	Md	29.83	28.00	28.00
6	Gas Sample Wet Mole. Wt.	Ms	29.83	ERR	ERR
7	Gas Stream Velocity	vs	57.8	ERR	ERR
8	Actual Flue Gas Flow Vol.	ACFM	346,942	ERR	ERR
9	Dry, Std Flue Gas Flow Vol.	DSCFM	273,773	ERR	ERR
10	SO2 Concentration, ppm	C	187.56		
11	SO2 Concentration, lbs/dscf	Cs	3.113E-05	0.000E+00	0.000E+00
12	SO2 Concentration, lbs/mbtu	E	0.446	0.000	0.000
13	SO2 Emissions Rate, lbs/hr	Es	511.44	ERR	ERR

ABB Environmental Systems

Location #1

Condition #1 410,000 ACFM

10/30/95

Point	Time	SO ₂ (ppm)	Δp	KSCFM	Temp. (°F)
1 Bottom	1:30	2100.00	1.10	283	260.00
2	1:32	2169.00	1.20	296	258.00
3	1:34	2068.00	1.10	283	261.00
4	1:36	2150.00	1.20	294	267.00
5	1:38	2105.00	1.10	282	265.00
1	1:40	2093.00	1.30	307	260.00
2	1:42	2053.00	1.20	296	258.00
3	1:44	1986.00	1.10	283	259.00
4	1:46	1999.00	1.30	307	261.00
5	1:48	1976.00	1.40	318	262.00
1	1:50	1988.00	1.20	294	267.00
2	1:52	2002.00	1.20	294	268.00
3	1:54	2078.00	1.40	319	261.00
4	1:56	2122.00	1.20	295	262.00
5	1:58	2154.00	1.30	307	262.00
1	2:00	2005.00	1.20	295	260.00
2	2:02	1982.00	1.30	309	253.00
3	2:04	1985.00	1.20	294	265.00
4	2:06	1983.00	1.30	308	258.00
5	2:08	2003.00	1.20	296	256.00
1 Top	2:10	2140.00	1.30	307	261.00
2	2:12	2145.00	1.20	295	261.00
3	2:14	2075.00	1.30	307	261.00
4	2:16	2016.00	1.20	294	267.00
5	2:18	2134.00	1.30	307	262.00
Average		2060.44	1.23	299	261.40

~~Not to take 5 minutes for the sample to be analyzed~~

Location #4

Condition #1 410,000 ACFM

10/30/95

Point	Time	SO ₂ (ppm)	^p	KSCFM	Temp. (°F)
1 Bottom	2:50	330.00	0.80	245	215.00
2	2:52	319.00	0.78	242	216.00
3	2:54	310.00	0.75	237	218.00
4	2:56	345.00	0.76	239	215.00
5	2:58	326.00	0.75	238	214.00
1	3:00	319.00	0.76	239	216.00
2	3:02	302.00	0.79	244	215.00
3	3:04	298.00	0.74	235	217.00
4	3:06	295.00	0.75	238	214.00
5'	3:08	295.00	0.69	228	216.00
1	3:10	305.00	0.76	238	218.00
2	3:12	305.00	0.78	242	216.00
3	3:14	328.00	0.75	238	214.00
4	3:16	357.00	0.74	236	215.00
5	3:18	346.00	0.74	236	216.00
1	3:20	333.00	0.79	244	214.00
2	3:22	312.00	0.71	231	214.00
3	3:24	325.00	0.79	244	212.00
4	3:26	343.00	0.73	235	213.00
5'	3:28	325.00	0.75	238	214.00
1 Top	3:30	326.00	0.79	243	216.00
2	3:32	347.00	0.72	232	216.00
3	3:34	324.00	0.74	236	215.00
4	3:36	335.00	0.81	247	214.00
5	3:38	324.00	0.76	239	213.00
Average		322.96	0.76	238	215.04

Location #4

Condition #2 354,000 ACFM

10/30/95

Point	Time	SO ₂ (ppm)	^p	KSCFM	Temp. (°F)
1 Bottom	4:50	290.00	0.55	206	215.00
2	4:52	300.00	0.54	204	216.00
3	4:54	310.00	0.65	224	218.00
4	4:56	305.00	0.54	204	218.00
5	4:58	300.00	0.57	210	214.00
1	5:00	297.00	0.58	212	213.00
2	5:02	278.00	0.68	230	214.00
3	5:04	285.00	0.65	224	215.00
4	5:06	286.00	0.49	195	216.00
5	5:08	268.00	0.56	208	214.00
1	5:10	270.00	0.57	210	217.00
2	5:12	269.00	0.53	203	215.00
3	5:14	296.00	0.53	202	216.00
4	5:16	308.00	0.57	210	217.00
5	5:18	310.00	0.53	203	214.00
1	5:20	320.00	0.57	210	215.00
2	5:22	305.00	0.59	214	216.00
3	5:24	276.00	0.62	219	217.00
4	5:26	289.00	0.56	208	217.00
5	5:28	298.00	0.57	210	216.00
1 Top	5:31	308.00	0.53	203	215.00
2	5:33	300.00	0.58	212	215.00
3	5:35	268.00	0.52	201	215.00
4	5:37	268.00	0.57	210	214.00
5	5:39	289.00	0.53	203	213.00
Average		291.72	0.57	209	215.40

Location #1

Condition #2 354,000 ACFM

10/31/95

Point	Time	SO ₂ (ppm)	Δp	KSCFM	Temp. (°F)
1 Bottom	2:09	1863.00	0.92	258	265.00
2	2:11	1920.00	1.00	269	266.00
3	2:13	1947.00	0.98	266	267.00
4	2:15	1827.00	0.94	261	265.00
5	2:17	1981.00	0.92	258	264.00
1	2:19	1850.00	0.78	238	266.00
2	2:21	1861.00	0.70	225	265.00
3	2:23	2112.00	0.68	222	267.00
4	2:25	1839.00	0.66	218	269.00
5	2:27	1804.00	0.75	232	270.00
1	2:29	1957.00	0.42	175	264.00
2	2:31	1910.00	0.43	176	265.00
3	2:33	2015.00	0.42	175	264.00
4	2:35	1874.00	0.61	211	263.00
5	2:37	1775.00	0.86	250	265.00
1	2:39	1744.00	0.62	212	264.00
2	2:41	1855.00	0.65	217	262.00
3	2:43	1750.00	0.76	235	265.00
4	2:45	1752.00	0.67	220	264.00
5	2:47	1795.00	0.76	235	265.00
1 Top	2:49	1835.00	0.82	244	266.00
2	2:51	1731.00	0.53	196	264.00
3	2:53	1703.00	0.58	205	263.00
4	3:07	1710.00	0.61	211	262.00
5	3:09	1712.00	0.63	214	264.00
Average		1844.96	0.71	225	264.96

Am - Flow
 AL - SO₂ in/out
 AG - Temp

Location #1

10/31/95

Condition #3 273,000 ACFM

Point	Time	SO ₂ (ppm)	Δp	KSCFM	Temp. (°F)
1 Bottom	3:40	2008.00	0.48	187	255.00
2	3:42	1990.00	0.45	180	258.00
3	3:44	2007.00	0.50	190	259.00
4	3:46	1982.00	0.65	217	258.00
5	3:48	1962.00	0.62	212	255.00
1	3:51	1885.00	0.38	166	257.00
2	3:53	2044.00	0.38	166	256.00
3	3:55	2083.00	0.45	181	253.00
4	3:57	2122.00	0.50	191	254.00
5	3:59	2086.00	0.42	174	256.00
1	4:01	2139.00	0.28	143	254.00
2	4:03	2160.00	0.26	137	257.00
3	4:05	2322.00	0.22	126	259.00
4	4:07	2328.00	0.28	142	256.00
5	4:09	2283.00	0.32	152	254.00
1	4:13	2166.00	0.32	152	258.00
2	4:15	2338.00	0.35	159	255.00
3	4:17	2353.00	0.32	153	252.00
4	4:19	2288.00	0.32	152	255.00
5	4:21	2154.00	0.46	182	257.00
1 Top	4:23	2127.00	0.40	170	255.00
2	4:25	2109.00	0.45	181	254.00
3	4:27	2115.00	0.55	199	258.00
4	4:29	2036.00	0.65	216	260.00
5	4:31	2033.00	0.58	205	258.00
Average		2124.80	0.42	173	256.12

Location #4

10/31/95

Condition #3 273,000 ACFM

Point	Time	SO ₂ (ppm)	^p	KSCFM	Temp. (°F)
1 Bottom	4:59	397.00	0.38	170	218.00
2	5:01	386.00	0.39	173	216.00
3	5:03	382.00	0.38	171	215.00
4	5:05	393.00	0.38	171	216.00
5	5:07	387.00	0.39	173	216.00
1	5:11	329.00	0.34	161	217.00
2	5:13	305.00	0.35	164	217.00
3	5:15	323.00	0.32	157	217.00
4	5:17	304.00	0.39	173	219.00
5	5:19	310.00	0.38	170	218.00
1	5:24	378.00	0.31	154	217.00
2	5:26	425.00	0.32	157	216.00
3	5:28	448.00	0.34	161	217.00
4	5:30	451.00	0.39	173	217.00
5	5:32	420.00	0.38	171	215.00
1	5:36	403.00	0.29	149	216.00
2	5:38	410.00	0.31	154	214.00
3	5:40	430.00	0.32	157	215.00
4	5:42	432.00	0.32	157	215.00
5	5:44	437.00	0.34	161	216.00
1 Top	5:49	402.00	0.37	168	216.00
2	5:51	392.00	0.41	177	218.00
3	5:53	366.00	0.39	173	217.00
4	5:55	353.00	0.40	175	216.00
5	5:57	350.00	0.43	181	217.00
Average		384.52	0.36	166	216.44

W. Final Instrumentation Verification Test Data

MOISTURE FIELD DATA SHEET

Client C. E. Nicks	Date 1/3/96
Project No.	Operator J. J. Nicks
Sampling Location -52 Inlet	Run No. 1
Barometric Pressure 29.65	Probe Number 2-8
Condensate 20 ml/s	Silica Gel 11.8
Meter Corr. Factor 1.989	Meter-Orifice 2.862
Sample Pt. Time 5 min	Leak Test Before After

[illegible]

G1

Total Source Analysis, Inc.
Environmental Testing Consultants

MOISTURE FIELD DATA SHEET

Client C.E. Niles	Date 11/27/96
Project No.	Operator M. H. S. 41
Sampling Location S-2 NW-1	Run No. 3
Barometric Pressure 29.65	Probe Number N-5
Condensate 32 ml	Silica Gel 7.1
Meter Corr. Factor 1.989	Meter-Orifice 2.862
Sample Pt. Time 5 min	Leak Test Before After

[illegible]

G3

Total Source Analysis, Inc.

Environnemental Technology Corporation

MOISTURE FIELD DATA SHEET

[illegible]

G5

Total Source Analysis, Inc.

MOISTURE FIELD DATA SHEET

Client O.E. Mills	Date 11/27/66
Project No.	Operator J. H. Miller
Sampling Location 25 - 2 inlet	Run No. 4
Barometric Pressure 14.65	Probe Number 10-5
Condensate 21 ml	Silica Gel 33
Meter Corr. Factor 1.957	Meter-Orifice 2.562
Sample Pt. Time 5:17:11	Leak Test Before 0.004 After 0.007

Sample Point	ΔH	Temperature °F				Vac. Pr (in. HG)	Dry Gas Meter Reading in Cu. Ft.
		Probe	Imp. Out	Meter In	Meter Out		
5:45							692.167
13:52		7					
1	1.71	250	51	53	42	2.0	695.470
2	1	250	51	55	42	2.0	699.690
3		250	51	62	42	2.0	703.470
4		250	51	63	42	2.0	707.210
5		250	51	63	42	2.0	711.020
6	1.	250	51	63	42	2.0	714.740
5:44							
1:22			51	59	42	2.0	72.1675
				(51)

G7

Total Source Analysis, Inc.

Client C. E. Davis	Date 11/12/20
Project No.	Operator M. J. Davis
Sampling Location C-12, 100 ft	Run No. 9
Barometric Pressure 29.65	Probe Number 10-15
Condensate 33 ml/s	Silica Gel 6.2
Meter Corr. Factor 1.98%	Meter-Orifice 2.362
Sample Pt. Time 5 min	Leak Test Before: 001 After: 003

Total Source Analysis, Inc.

VELOCITY TRAVERSE DATA SHEET

CLIENT O. E. N/A DATE 11/27/96
 PROJECT NO. _____ OPERATOR M. P. Moser
 SAMPLING LOCATION LS-2 N/A RUN NO. 2
 BAROMETRIC PRESSURE 29.68 ASSUMED % MOISTURE 11%
 TOT COEFFICIENT .84 PROBE NO. N-15
 PITOT # _____ AMBIENT TEMP. 30
 PITOT LEAK TEST BEFORE: OK AFTER: _____

SAMPLE POINT		Δ P	$\sqrt{\Delta}$ P	STACK TEMP.	STATIC PRESS.	CO2	O2
<u>A</u>	<u>1</u>	<u>.68</u>	<u>1825</u>	<u>220</u>		<u>13.33</u>	<u>5.50</u>
	<u>2</u>	<u>.80</u>	<u>1894</u>	<u>220</u>			
	<u>3</u>	<u>.86</u>	<u>1927</u>	<u>220</u>	<u>- .73</u>		
	<u>4</u>	<u>1.0</u>	<u>1000</u>	<u>220</u>			
	<u>5</u>	<u>.97</u>	<u>959</u>	<u>220</u>			
<u>B</u>	<u>1</u>	<u>1.0</u>	<u>1000</u>	<u>218</u>			
	<u>2</u>	<u>.62</u>	<u>787</u>	<u>218</u>			
	<u>3</u>	<u>.60</u>	<u>775</u>	<u>220</u>			
	<u>4</u>	<u>.92</u>	<u>959</u>	<u>220</u>			
	<u>5</u>	<u>1.5</u>	<u>1225</u>	<u>220</u>			
<u>C</u>	<u>1</u>	<u>1.3</u>	<u>1140</u>	<u>215</u>			
	<u>2</u>	<u>.79</u>	<u>889</u>	<u>215</u>			
	<u>3</u>	<u>.70</u>	<u>837</u>	<u>215</u>			
	<u>4</u>	<u>1.5</u>	<u>1225</u>	<u>215</u>			
	<u>5</u>	<u>2.0</u>	<u>1414</u>	<u>217</u>			
<u>D</u>	<u>1</u>	<u>.89</u>	<u>945</u>	<u>219</u>			
	<u>2</u>	<u>1.3</u>	<u>1140</u>	<u>219</u>			
	<u>3</u>	<u>1.4</u>	<u>1183</u>	<u>220</u>			
	<u>4</u>	<u>1.7</u>	<u>1304</u>	<u>220</u>			
	<u>5</u>	<u>1.4</u>	<u>1183</u>	<u>220</u>			
<u>E</u>	<u>1</u>	<u>1.3</u>	<u>1140</u>	<u>220</u>			
	<u>2</u>	<u>1.2</u>	<u>1095</u>	<u>220</u>			
	<u>3</u>	<u>1.3</u>	<u>1140</u>	<u>220</u>			
	<u>4</u>	<u>1.9</u>	<u>1379</u>	<u>220</u>			
	<u>5</u>	<u>1.1</u>	<u>1049</u>	<u>220</u>			
	<u>10:15</u>		<u>1.059</u>	<u>214.84</u>			

Which Port is North?

Check for Ambient Air ☐

POINTS

O =

L =

W =

VELOCITY TRAVERSE DATA SHEET

CLIENT GE Niles DATE 11/27/96
 PROJECT NO. _____ OPERATOR M. Mosler
 SAMPLING LOCATION LSZ RUN NO. 4
 BAROMETRIC PRESSURE 29.68 ASSUMED % MOISTURE 11%
 TOT COEFFICIENT .84 PROBE NO. N-15
 PITOT # 20M15 AMBIENT TEMP. 40
 TOT LEAK TEST BEFORE: OK AFTER: OK

SAMPLE POINT		Δ P	$\sqrt{\Delta}$ P	STACK TEMP.	STATIC PRESS.	CO2	O2
<u>A</u>	<u>1</u>	<u>.70</u>	<u>.837</u>	<u>220</u>		<u>12.99</u>	<u>5.68</u>
	<u>2</u>	<u>.75</u>	<u>.866</u>	<u>220</u>	<u>-.78</u>		
	<u>3</u>	<u>.84</u>	<u>.917</u>	<u>217</u>			
	<u>4</u>	<u>.90</u>	<u>.949</u>	<u>217</u>			
	<u>5</u>	<u>.92</u>	<u>.959</u>	<u>215</u>			
<u>B</u>	<u>1</u>	<u>1.1</u>	<u>1.049</u>	<u>220</u>			
	<u>2</u>	<u>.90</u>	<u>.866</u>	<u>220</u>			
	<u>3</u>	<u>.63</u>	<u>.794</u>	<u>219</u>			
	<u>4</u>	<u>.82</u>	<u>.906</u>	<u>220</u>			
	<u>5</u>	<u>1.5</u>	<u>1.225</u>	<u>220</u>			
<u>C</u>	<u>1</u>	<u>1.3</u>	<u>1.140</u>	<u>220</u>			
	<u>2</u>	<u>.75</u>	<u>.866</u>	<u>222</u>			
	<u>3</u>	<u>1.0</u>	<u>1.000</u>	<u>220</u>			
	<u>4</u>	<u>1.7</u>	<u>1.304</u>	<u>220</u>			
	<u>5</u>	<u>.95</u>	<u>.975</u>	<u>220</u>			
<u>D</u>	<u>1</u>	<u>1.2</u>	<u>1.095</u>	<u>220</u>			
	<u>2</u>	<u>1.2</u>	<u>1.095</u>	<u>219</u>			
	<u>3</u>	<u>1.3</u>	<u>1.140</u>	<u>220</u>			
	<u>4</u>	<u>1.9</u>	<u>1.373</u>	<u>221</u>			
	<u>5</u>	<u>1.1</u>	<u>1.049</u>	<u>222</u>			
<u>E</u>	<u>1</u>	<u>1.3</u>	<u>1.140</u>	<u>220</u>			
	<u>2</u>	<u>1.1</u>	<u>1.049</u>	<u>219</u>			
	<u>3</u>	<u>1.5</u>	<u>1.225</u>	<u>217</u>			
	<u>4</u>	<u>1.7</u>	<u>1.304</u>	<u>217</u>			
	<u>5</u>	<u>1.4</u>	<u>1.183</u>	<u>220</u>			
	<u>STOP TIME</u>						
	<u>11:20</u>						
		<u>1.053</u>		<u>219.44</u>			

Which Port is North?

Check for Ambient Air ☐

POINTS

VELOCITY TRAVERSE DATA SHEET

CLIENT C.E. Wilks DATE 11/27/96
 PROJECT NO. _____ OPERATOR M. Mosler
 SAMPLING LOCATION L5-2 RUN NO. 6
 BAROMETRIC PRESSURE 29.68 ASSUMED % MOISTURE 11%
 TOTAL COEFFICIENT .84 PROBE NO. N-15
 PITOT #: _____ AMBIENT TEMP. 40
 PITOT LEAK TEST BEFORE: OK AFTER: _____

SAMPLE POINT		Δ P	$\sqrt{\Delta}$ P	STACK TEMP.	STATIC PRESS.	CO2	O2
A	1	1.1	1.049	220		13.19	4.75
	2	1.3	1.140	220			
	3	1.2	1.095	220			
	4	.98	.990	214	~.74		
	5	1.0	1.000	219			
B	1	1.0	1.000	214			
	2	1.2	1.095	220			
	3	1.2	1.095	220			
	4	.98	.990	220			
	5	1.5	1.225	220			
C	1	1.3	1.140	220			
	2	1.0	1.000	220			
	3	.89	.943	213			
	4	1.1	1.049	215			
	5	1.8	1.342	215			
D	1	1.2	1.095	220			
	2	1.0	1.000	220			
	3	1.4	1.183	220			
	4	1.7	1.304	118			
	5	1.2	1.095	119			
E	1	1.0	1.000	220			
	2	1.0	1.000	220			
	3	1.5	1.225	220			
	4	1.8	1.342	220			
	5	.96	.980	220			
	STOP TIME						
	12:30	1.095	214.12				
			211.12				

Which Port is North?

Check for Ambient Air ☐

POINTS

O =

L =

W =

_____	_____
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VELOCITY TRAVERSE DATA SHEET

CLIENT	C.F. N. 145	DATE	11/27/96
PROJECT NO.		OPERATOR	M. Moler
SAMPLING LOCATION	45 - 24 in. 1		RUN NO. 8
BAROMETRIC PRESSURE	27.65	ASSUMED % MOISTURE	11%
TOT COEFFICIENT	.84	PROBE NO.	15-15
PITOT #:		AMBIENT TEMP.	40
PITOT LEAK TEST	BEFORE: OK	AFTER:	

SAMPLE POINT			Δ P	$\sqrt{\Delta}$ P	STACK TEMP.	STATIC PRESS.	CO2	O2
A	1	START TIME 13:30	1.0	1.000	220		13.17	6.37
	2		1.3	1.140	220	-1.78		
	3		1.2	1.095	220			
	4		1.6	1.265	220			
	5		1.4	1.183	220			
B	1		1.2	1.095	200			
	2		1.0	1.000	200			
	3		1.7	1.095	200			
	4		.90	.949	200			
	5		.87	.933	200			
C	1		1.0	1.000	205			
	2		.90	.949	209			
	3		.85	.922	213			
	4		.81	.900	213			
	5		.73	.854	217			
D	1		1.95	1.375	220			
	2		1.3	1.140	220			
	3		1.0	1.000	220			
	4		1.8	1.342	220			
	5		1.0	1.000	220			
E	1	STOP TIME 13:50	.98	.990	210			
	2		1.0	1.000	212			
	3		1.5	1.225	212			
	4		1.8	1.342	217			
	5		1.2	1.095	217			
				1.000	219.5			

Which Port is North?

Check for Ambient Air ☐

POINTS

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W =

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Aug 17

Client : OHIO EDISON
Site : NILES
Point : LS-2 INLET
Project : 96-495

Test Date : 11/27/96 Time : 09:04 thru 09:25

Page

	1031	1030	1029
	SO2	O2	CO2
Time	PPm	%	%
09:04:26	2910.10	5.86	13.26
09:05:26	2818.16	5.49	13.66
09:06:26	2890.75	5.64	13.39
09:07:26	2947.87	5.19	13.71
09:08:26	2887.00	5.52	13.42
09:09:26	2877.97	5.69	13.33
09:10:26	2864.36	5.58	13.41
09:11:26	2870.09	5.17	13.76
09:12:26	2790.01	5.71	13.36
09:13:26	2764.29	5.59	13.42
09:14:26	2784.29	5.60	13.42
09:15:26	2856.63	5.45	13.56
09:16:26	2813.33	5.36	13.69
09:17:26	2822.99	5.47	13.57
09:18:26	2825.65	5.61	13.52
09:19:26	2865.43	5.49	13.47
09:20:26	2841.48	5.84	13.26
09:21:26	2929.45	5.49	13.45
09:22:26	2844.77	5.77	13.33
09:23:26	2906.35	5.45	13.55
09:24:26	2875.14	5.45	13.49
Averages			
for 21			
Points	2856.48	5.54	13.47

Run 7

Client : OHIO EDISON
Site : NILES
Unit : LS-2 INLET
Project : 96-495
Test Date : 11/27/96

Time : 10:23 thru 10:44

Page 1

	1031	1030	1029
	S02	02	CO2
Time	PPm	%	%
10:23:31	2860.38	4.73	13.98
10:24:31	2796.83	5.11	13.72
10:25:31	2814.42	5.21	13.66
10:26:31	2785.60	5.24	13.65
10:27:31	2708.23	5.56	13.46
10:28:31	2689.31	5.53	13.47
10:29:31	2700.98	5.56	13.45
10:30:31	2657.86	5.62	13.47
10:31:31	2671.94	5.83	13.26
10:32:31	2684.25	5.66	13.40
10:33:31	2669.54	5.70	13.36
10:34:31	2666.66	5.74	13.35
10:35:31	2620.30	5.99	13.14
10:36:31	2625.57	5.80	13.33
10:37:31	2648.22	5.58	13.40
10:38:31	2665.81	5.69	13.42
10:39:31	2674.81	5.84	13.26
10:40:31	2712.09	5.48	13.53
10:41:31	2648.01	5.87	13.22
10:42:31	2641.40	5.85	13.21
10:43:31	2634.16	5.73	13.39
Averages			
for 21			
Points	2694.12	5.58	13.43

Client : OHIO EDISON
 Site : NILES
 Unit : LS-2 INLET
 Project : 96-495

Test Date : 11/27/96 Time : 11:40 thru 12:01

Page 1

	1031	1030	1029
	S02	02	CO2
Time	PPm	%	%
11:40:51	2698.54	5.99	12.60
11:41:51	2428.61	7.29	11.77
11:42:51	2388.93	7.23	11.99
11:43:51	2448.54	6.93	12.22
11:44:51	2640.49	5.90	12.94
11:45:51	2617.20	6.06	12.84
11:46:51	2612.55	6.07	12.83
11:47:51	2543.53	6.34	12.70
11:48:51	2717.89	5.40	13.38
11:49:51	2844.32	4.98	13.59
11:50:51	2684.46	5.76	13.09
11:51:51	2670.18	5.71	13.12
11:52:51	2718.78	5.57	13.21
11:53:51	2645.13	5.87	13.12
11:54:51	2633.24	5.75	13.17
11:55:51	2620.51	5.71	13.23
11:56:51	2587.71	5.81	13.08
11:57:51	2602.92	5.81	13.00
11:58:51	2586.57	5.58	13.31
11:59:51	2558.95	6.01	12.93
12:00:51	2589.26	5.58	13.22

Averages

for 21

Points 2611.34 5.96 12.92

1000

Client : OHIO EDISON
 Site : NILES
 Unit : LS-2 INLET
 Project : 96-495
 Test Date : 11/27/96

Time : 12:52 thru 13:13

Page 1

	1031	1030	1029
	SO2	CO	CO2
Time	PPm	%	%
12:52:17	2502.47	4.93	13.23
12:53:17	2495.44	4.86	13.45
12:54:17	2447.96	5.22	13.12
12:55:17	2458.90	5.13	13.23
12:56:16	2451.86	5.08	13.24
12:57:16	2479.41	5.12	13.19
12:58:16	2465.15	5.37	12.97
12:59:16	2482.53	5.05	13.24
13:00:16	2477.06	5.30	13.06
13:01:16	2473.54	5.22	13.13
13:02:16	2412.98	5.44	12.99
13:03:16	2439.55	5.34	13.09
13:04:16	2416.11	5.48	13.01
13:05:16	2421.38	5.41	13.04
13:06:16	2414.35	5.39	13.11
13:07:16	2440.73	5.14	13.23
13:08:16	2371.77	5.70	12.82
13:09:16	2421.00	5.29	13.16
13:10:16	2414.35	5.29	13.11
13:11:16	2365.30	5.60	12.96
13:12:16	2387.40	5.30	13.26
Averages			
for 21			
Points	2439.96	5.26	13.12

112 05 7

Client : OHIO EDISON
Site : NILES
Unit : LS-2 INLET
Project : 96-495

Test Date : 11/27/96 Time : 14:18 thru 14:39

Page 1

	1031	1030	1029
	S02	O2	CO2
Time	PPm	%	%
14:18:31	2426.85	6.05	12.99
14:19:31	2432.13	5.81	13.22
14:20:31	2421.96	5.74	13.21
14:21:31	2467.30	5.52	13.42
14:22:31	2530.20	5.34	13.53
14:23:31	2547.99	5.20	13.67
14:24:31	2595.88	4.94	13.81
14:25:31	2600.95	4.94	13.77
14:26:31	2587.09	5.06	13.79
14:27:31	2612.84	5.12	13.76
14:28:31	2582.23	5.05	13.78
14:29:31	2654.62	4.75	13.85
14:30:30	2604.26	4.92	13.78
14:31:30	2574.78	5.00	13.85
14:32:30	2599.61	5.14	13.69
14:33:30	2572.61	5.14	13.71
14:34:30	2488.01	5.59	13.40
14:35:30	2534.13	5.51	13.45
14:36:30	2490.56	5.59	13.42
14:37:30	2512.82	5.77	13.29
14:38:30	2556.58	5.46	13.44
Averages			
for 21			
Points	2542.54	5.21	13.56

MOISTURE FIELD DATA SHEET

[illegible]

G29

Total Source Analysis, Inc.
Environmental Testing Consultants

[illegible]

G31

Moisture Field Data Sheet

[illegible]

G33

TOTAL SOURCE ANALYSIS, INC.

SAMPLE POINT		Δ P	$\sqrt{\Delta}$ P	STACK TEMP.	STATIC PRESS.	CO2	O2
	START TIME						
A 1	11:43	.76	.872	200		13.9	6.33
2		.85	.922	200			
3		1.2	1.095	200			
4		1.2	1.095	200	4.68		
5		1.3	1.140	201			
B 1		1.1	1.049	200			
2		1.3	1.140	200			
3		1.3	1.140	200			
4		1.4	1.183	200			
5		1.3	1.140	200			
C 1		1.2	1.095	203			
2		1.0	1.000	200			
3		.99	.995	205			
4		1.05	1.025	205			
5		1.4	1.183	203			
D 1	1.0	1.000	200				
2	1.2	1.095	195				
3	1.0	1.000	200				
4	1.5	1.225	200				
5	1.3	1.140	200				
E 1	1.0	1.000	197				
2	.85	.922	200				
3	.92	.959	200				
4	.89	.943	200				
5	.94	.970	200				
	STOP TIME		1.137 1.053	200.52			
	12:10						

D =

G35

[illegible]

CLIENT C. E. Niles | DATE 11/26/96
 PROJECT NO. _____ | OPERATOR Bob Mosler
 SAMPLING LOCATION 25-2 04 X L.C.T. | RUN NO. 3
 BAROMETRIC PRESSURE 29.85 | ASSUMED % MOISTURE 11%
 PITOT COEFFICIENT .84 | PROBE NO. N-15
 PITOT #: _____ | AMBIENT TEMP. 42
 PITOT LEAK TEST BEFORE: OK | AFTER: _____

SAMPLE POINT		Δ P	$\sqrt{\Delta}$ P	STACK TEMP.	STATIC PRESS.	CO2	O2
<u>A</u>	<u>1</u>	<u>.79</u>	<u>1.039</u>	<u>205</u>		<u>14.31</u>	<u>15.79</u>
	<u>2</u>	<u>.95</u>	<u>1.075</u>	<u>205</u>			
	<u>3</u>	<u>1.0</u>	<u>1.000</u>	<u>205</u>			
	<u>4</u>	<u>.97</u>	<u>1.095</u>	<u>201</u>	<u>4.67</u>		
	<u>5</u>	<u>.83</u>	<u>.911</u>	<u>201</u>			
<u>B</u>	<u>1</u>	<u>1.1</u>	<u>1.049</u>	<u>203</u>			
	<u>2</u>	<u>1.1</u>	<u>1.049</u>	<u>203</u>			
	<u>3</u>	<u>1.4</u>	<u>1.183</u>	<u>200</u>			
	<u>4</u>	<u>1.6</u>	<u>1.265</u>	<u>200</u>			
	<u>5</u>	<u>1.3</u>	<u>1.140</u>	<u>200</u>			
<u>C</u>	<u>1</u>	<u>.97</u>	<u>1.095</u>	<u>209</u>			
	<u>2</u>	<u>1.0</u>	<u>1.000</u>	<u>206</u>			
	<u>3</u>	<u>1.2</u>	<u>1.095</u>	<u>206</u>			
	<u>4</u>	<u>1.4</u>	<u>1.183</u>	<u>201</u>			
	<u>5</u>	<u>.91</u>	<u>.954</u>	<u>201</u>			
<u>D</u>	<u>1</u>	<u>1.1</u>	<u>1.049</u>	<u>200</u>			
	<u>2</u>	<u>1.3</u>	<u>1.140</u>	<u>201</u>			
	<u>3</u>	<u>.84</u>	<u>.995</u>	<u>201</u>			
	<u>4</u>	<u>1.4</u>	<u>1.183</u>	<u>200</u>			
	<u>5</u>	<u>1.5</u>	<u>1.225</u>	<u>200</u>			
<u>E</u>	<u>1</u>	<u>1.3</u>	<u>1.140</u>	<u>200</u>			
	<u>2</u>	<u>1.3</u>	<u>1.140</u>	<u>200</u>			
	<u>3</u>	<u>1.3</u>	<u>1.140</u>	<u>200</u>			
	<u>4</u>	<u>1.2</u>	<u>1.095</u>	<u>200</u>			
	<u>5</u>	<u>1.2</u>	<u>1.095</u>	<u>200</u>			
	<u>STOP TIME</u>						
	<u>13:20</u>	<u>1.037</u>	<u>1.019</u>	<u>201.92</u>			
		<u>1.075</u>					

Which Port is North?

1.075

Check for Ambient Air ☐

POINTS

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L =

W =

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_____	_____
_____	_____

CLIENT <u>C.E. NLR</u>		DATE <u>11/26/96</u>
PROJECT NO.		OPERATOR <u>M. Mosher</u>
SAMPLING LOCATION <u>45-2 0.1 x 1.1</u>		RUN NO. <u>5-</u>
BAROMETRIC PRESSURE <u>29.85"</u>		ASSUMED % MOISTURE
PITOT COEFFICIENT <u>.86</u>		PROBE NO. <u>N-15</u>
PITOT #:		AMBIENT TEMP.
PITOT LEAK TEST BEFORE: <u>OK</u> AFTER:		

SAMPLE POINT		Δ P	$\sqrt{\Delta}$ P	STACK TEMP.	STATIC PRESS.	CO2	O2
A	1	1.2	1.095	210		73.4	5.18
	2	.94	.995	210			
	3	1.3	1.140	209	+ .67		
	4	1.4	1.183	205			
	5	1.0	1.000	200			
B	1	1.1	1.049	213			
	2	1.1	1.049	213			
	3	1.2	1.095	210			
	4	1.5	1.225	210			
	5	1.4	1.183	210			
C	1	.94	.995	211			
	2	1.1	1.049	210			
	3	1.3	1.140	207			
	4	1.2	1.095	205			
	5	.96	.999	200			
D	1	1.1	1.049	215			
	2	1.3	1.140	215			
	3	1.4	1.183	213			
	4	1.5	1.225	210			
	5	1.7	1.304	210			
E	1	.99	.995	210			
	2	1.2	1.095	210			
	3	1.3	1.140	209			
	4	1.05	1.025	205			
	5	1.5	1.225	205			
	STOP TIME						
	14:56	1.105		209.08			
				209.0			

Which Port is North?

Check for Ambient Air
☐

POINTS

D =

L =

W =

CLIENT C. E. N. K. | DATE 11/26/96
 PROJECT NO. _____ | OPERATOR M. Masler
 SAMPLING LOCATION L5-2 OUTLET | RUN NO: 7
 BAROMETRIC PRESSURE 29.85 | ASSUMED % MOISTURE _____
 PITOT COEFFICIENT .84 | PROBE NO. N-15
 PITOT #: _____ | AMBIENT TEMP. 40
 PITOT LEAK TEST BEFORE: OK | AFTER: OK

SAMPLE POINT		ΔP	$\sqrt{\Delta P}$	STACK TEMP.	STATIC PRESS.	CO2	O2
A 1	START TIME 15:58	.99	.995	215		13.08	6.11
2		1.0	1.000	215	4.69		
3		1.4	1.183	215			
4		1.2	1.095	214			
5		.99	.995	214			
B 1		1.0	1.000	210			
2		1.1	1.049	211			
3		1.2	1.093	215			
4		1.4	1.183	215			
5		1.2	1.093	215			
C 1		1.0	1.000	215			
2		1.4	1.183	215			
3		1.6	1.265	213			
4		1.2	1.093	215			
5		.99	.995	214			
D 1		1.1	1.049	217			
2		1.0	1.000	217			
3		1.4	1.183	215			
4		1.3	1.140	215			
5		1.4	1.183	215			
E 1		.99	.995	215			
2		1.1	1.049	217			
3		1.0	1.000	210			
4		1.4	1.183	211			
5		1.4	1.183	211			
	STOP TIME 16:10						
				214.16			

Which Port is North?

~~1.07~~
 1.086

Check for Ambient Air ☐

POINTS

D =

L =

W =

Handwritten: *Handwritten*

Client :OHIO EDISON
Site :NILES
Unit :LS-2OUTLET
Project :96-475

Test Date :11/26/96 Time :12:26 thru 12:47

Page 1

	1031	1030	1029
	S02	O2	CO2
Time	PPm	%	%
12:26:40	289.217	6.032	14.012
12:27:40	292.945	6.031	13.935
12:28:40	280.420	6.249	13.802
12:29:40	298.925	5.694	14.265
12:30:40	291.469	6.339	13.655
12:31:40	285.276	5.987	14.010
12:32:40	300.290	5.919	13.976
12:33:40	305.170	6.113	13.817
12:34:40	322.596	5.265	14.940
12:35:40	235.936	7.421	12.967
12:36:40	284.501	6.219	13.688
12:37:40	260.479	7.195	12.912
12:38:40	367.417	4.613	15.179
12:39:40	289.355	6.820	13.100
12:40:40	294.259	6.317	13.551
12:41:40	311.175	5.756	14.070
12:42:40	332.946	5.609	14.100
12:43:40	349.552	5.892	13.862
12:44:40	337.855	5.516	14.250
12:45:40	334.175	5.746	13.984
12:46:40	326.030	5.597	14.120
Averages for 21 Points	304.285	6.015	13.914

Run # 41

Client : OHIO EDISON
Site : NILES
Unit : LS-20UTLET
Project : 96-495
Test Date : 11/26/96 Time : 13:46 thru 14:07

Page 1

	1031	1030	1029
	S02	02	CO2
Time	PPm	%	%
13:46:28	294.89	6.27	13.91
13:47:28	297.38	6.20	13.97
13:48:28	316.10	6.04	14.09
13:49:28	305.08	6.15	14.02
13:50:28	305.27	6.22	13.96
13:51:28	291.96	6.18	14.00
13:52:28	298.08	6.14	14.00
13:53:28	283.42	6.40	13.84
13:54:28	300.85	6.08	14.10
13:55:28	297.57	6.22	14.00
13:56:28	302.27	6.22	13.88
13:57:28	284.27	6.28	13.92
13:58:28	302.85	6.24	13.94
13:59:28	307.90	5.93	14.20
14:00:28	297.97	6.20	13.98
14:01:28	293.12	6.29	13.89
14:02:28	304.14	6.07	14.09
14:03:28	292.72	6.27	13.89
14:04:28	314.87	6.25	13.88
14:05:28	335.25	5.87	14.24
14:06:28	343.60	5.85	14.21
Averages			
for 21			
Points	303.31	6.16	14.00

Client : OHIO EDISON
 Site : NILES
 Unit : LS-20OUTLET
 Project : 96-495
 Test Date : 11/26/96 Time : 15:13 thru 15:34

Page 1

	1031	1030	1029
	SO2	O2	CO2
Time	PPm	%	%
15:13:44	295.88	6.20	12.83
15:14:44	295.18	6.21	12.83
15:15:44	306.64	5.80	13.12
15:16:44	316.24	5.77	13.21
15:17:44	328.23	5.65	13.25
15:18:44	348.08	5.22	13.61
15:19:44	376.77	5.02	13.72
15:20:44	384.65	4.77	13.90
15:21:44	403.26	4.87	13.85
15:22:44	425.84	4.60	14.04
15:23:44	403.90	4.44	14.13
15:24:44	390.76	5.96	13.20
15:25:44	439.32	4.69	13.98
15:26:43	403.99	5.24	13.61
15:27:43	400.75	5.43	13.48
15:28:43	388.85	5.65	13.28
15:29:43	385.69	5.73	13.23
15:30:43	388.66	5.80	13.16
15:31:43	381.22	5.85	13.16
15:32:43	384.56	5.85	13.16
15:33:43	354.89	6.13	12.97
Averages			
Points	371.82	5.47	13.41