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CONTENTS

VOLUME I

APR 19 1993

<i>Section</i>		<i>Page</i>
	LEGAL NOTICE	vi
1	SUMMARY	1-1
2	INTRODUCTION	2-1
3	PROJECT STATUS	3-1
	3.1 EQUIPMENT ACQUISITION AND INSTALLATION (WBS No. 1.2.1)	3-1
	3.2 FACILITY CONSTRUCTION (WBS No. 1.2.2)	3-3
	3.3 CZD PARAMETRIC TESTING (WBS No. 1.3.2)	3-3
	3.3.1 In-Duct Water Injection Tests	3-8
	3.3.2 In-Duct Lime Slurry Injection Tests	3-9
	3.3.3 Effect of CZD System at Seward Station on Percent Stack Opacity	3-20
	3.3.4 Baseline Testing – Fuel	3-27
	3.3.5 Problems/Issues	3-28
	3.4 MANAGEMENT AND TRAVEL (WBS No. 1.3.10)	3-29
4	PLANNED ACTIVITIES	4-1
	4.1 PHASE 2 - CONSTRUCTION AND START-UP	4-1
	4.2 PHASE 3 - OPERATION AND DISPOSITION	4-1
	4.3 PHASE 3 - PROJECT MANAGEMENT	4-1

APPENDICES

<i>Appendix</i>		<i>Page</i>
A	DESCRIPTION OF PROJECT AND WORK BREAKDOWN STRUCTURE	A-1
	A.1 PROJECT DESCRIPTION	A-1
	A.2 WORK BREAKDOWN STRUCTURE DESCRIPTION	A-3
B	REPORT DISTRIBUTION LIST	B-1
C	DAILY RESULTS OF PARAMETRIC TESTS WITH IN-DUCT LIME SLURRY INJECTION – NOVEMBER 1990 THROUGH JANUARY 1991	C-1
D	CONTINUOUS MONITORING SYSTEM PROBLEM AREAS AND CORRECTIVE ACTIONS	D-1
E	PROBLEM ISSUES DURING PARAMETRIC TESTING	E-1
F	BASELINE TESTING FUEL	F-1
	F.1 RESULTS OF SAMPLING THE INCOMING COAL	F-1
	F.2 AMOUNT OF COAL RECEIVED WITH CHARACTERISTICS, COAL BURNED, AND RESULTING ASH	F-16
G	PROCEDURE FOR CALCULATING SO ₂ AND NO _x REMOVAL AND THE PERCENTAGE OF LIME UTILIZATION	G-1

ILLUSTRATIONS

<i>Figure</i>		<i>Page</i>
1-1	Phase 3a Parametric Test Program, Including Equipment Installation for Continuous Run	1-4
1-2	Activity Diagram – Phase 3a Facility Construction	1-7
2-1	Seward Station Arrangement	2-3
3-1	Seward Station Overall Process Flow Diagram	3-2
3-2	Plan View of Duct with Thermocouple Locations	3-6
3-3	Typical Thermocouple Section (6 Thermocouples per Thermowell = 24 per Section)	3-7
3-4	Bailey Recording of Opacity on November 15, 1991	3-22
3-5	Bailey Recording of Opacity on November 19, 1991	3-26
4-1	Phase 3a Parametric Test Program, including Equipment Installation for Continuous Run	4-2
A-1	Work Breakdown Structure (WBS) Diagram	A-2

TABLES

<i>Table</i>		<i>Page</i>
3-1	Estimate of SO ₂ and NO _x Removal for the Seward Station CZD System from November 1991 through January 31, 1992	3-12
3-2	Lime Slurry Injection Factorial Tests – CZD Activity Summary for November 1991	3-14
3-3	Lime Slurry Injection Factorial Tests – CZD Activity Summary for December 1991	3-16
3-4	Lime Slurry Injection Factorial Tests – CZD Activity Summary for January 1992	3-18
3-5	Lime Slurry Injection in the B-Duct on November 15, Followed by Water Injection on November 16	3-21
3-6	Lime Slurry Injection in the B-Duct on November 15, Followed by Water Injection on November 16	3-21

TABLES (continued)

<i>Table</i>		<i>Page</i>
3-7	Lime Slurry Injection in the B-Duct on November 19, Followed by Water Injection on November 20	3-23
3-8	Data Recorded With no Injection in the B-Duct at 7:30 a.m. and 9:30 a.m. on November 19	3-23
3-9	Lime Slurry Injection in the B-Duct on November 19	3-24
3-10	Lime Slurry Injection in the B-Duct on November 19	3-24
3-11	Water Injection in the B-Duct on November 19 After Completion of Lime Injection	3-25
3-12	Water Injection in the B-Duct on November 19 After Completion of Lime Injection	3-25
3-13	Typical Coal Analysis for Seward Station	3-27

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Section 1

SUMMARY

This is the fifth quarterly report for this project and it covers work performed on Phases 2 and 3a of the project from November 1, 1991 through January 31, 1992.

This project is divided into three phases. Phase 1, which has been completed, involved design, engineering, and procurement for the CZD system, duct and facility modifications, and supporting equipment. Phase 2, also completed, included equipment acquisition and installation, facility construction, startup, and operator training for parametric testing. Phase 3 broadly covers testing, operation and disposition, but only a portion of Phase 3 was included in Budget Period 1. That portion was concerned with parametric testing of the CZD system to establish the optimum conditions for an extended, one-year, continuous demonstration (to be accomplished in Budget Period 2).

The work required under Phases 1 and 2 was accomplished as planned, but late delivery of thermocouples for duct temperature measurement delayed the start of Phase 3 in-duct testing. As a result, accomplishment of the major goals of the parametric test program were delayed by one month, and some objectives were only partly achieved. In spite of the delays, in-duct lime injection testing was achieved by October 1991, within one year from the signing of the Cooperative Agreement. By December 1991, indicated SO₂ removal rates above 50% had been obtained. As of December 31, 1991, the following goals (from the Project Evaluation Plan dated January 1991) have been achieved:

- Nozzle Selection - A modified Spraying Systems Company (SSC) atomizing nozzle has been selected for the one-year continuous CZD demonstration.
- SO₂ and NO_x Reduction - Preliminary confirmation of 50% SO₂ reduction has been achieved, but the NO_x reduction target cannot be confirmed at this time.
- Lime Selection - Testing indicated an injection rate of 40 to 50 gallons per minute with a lime slurry concentration of 8 to 10% to achieve 50% SO₂ reduction. There has been no selection of the lime to be used in the one-year demonstration.
- ESP Optimization - Tests conducted to date have shown that lime injection has a very beneficial effect on ESP performance, and little adjustment may be necessary.
- SO₂ Removal Costs - Testing has not revealed any significant departure from the bases on which Bechtel's original cost estimates (capital and operating) were prepared. Therefore, SO₂ removal costs are still expected to be in the range of \$300/ton or less.

Although the target SO₂ removal rates have been achieved, indications of significant removal of NO_x are questionable due to problems experienced with instrument calibration and drift. Plans have been made to permanently replace the SO₂/NO_x measurement system with a more stable dilution-probe system. Opacity during lime injection has been very low. In fact, the opacity decreases during injection. However, when injection is stopped, the opacity readings increase to higher levels than before injection. The reason for this phenomenon is being investigated, and temporary measures have been taken to insure that opacity does not exceed allowable limits. Injection rates have been varied over the range of 30 to 50 gpm with lime slurry concentrations from 2.2 to 14.5%. The SO₂ removal rate increases sharply as the concentration rises above 8% and the total injection rate approaches 50 gpm. Duct inspections conducted before lime injection, and at two intervals after lime injection, indicated general cleanliness of the duct with no evidence of buildup or heavy deposits. More recent inspections have confirmed that the sootblowers installed in the bottom of the duct appear to be functioning satisfactorily, and manual duct cleaning has been required only in the areas not reached by the sootblowers. Therefore, the previously planned additional sootblowers for the duct and turning vanes will be installed during Budget Period 2.

Some delay has been experienced in the parametric test program due to late equipment deliveries and instrumentation problems. Factorial water tests in the flue gas duct were scheduled to begin on June 17, 1991. These tests could not begin as scheduled because thermocouples needed to measure the gas temperature in the duct during water injection were not delivered until late August. In-duct water testing began the last week in August, approximately ten weeks late. Shortly after startup the temperature recording system was functioning erratically, and the communication with the Bailey Infi 90 data recording and analysis system could not be maintained. Experts, including personnel from Bechtel, Leeds & Northrup, Thermoelectric, and DOE's support contractor, Burns and Roe, have examined the problem. The results of a detailed study carried out by Bechtel in December 1991 suggest that the temperature recorders are the problem, and that input to the Bailey system should be removed from the recorders and routed separately over a fiber optic data link.

The design of the current nozzle lance assemblies was based on the results of previous testing at Seward Station. However, the atomizer nozzles presently used for the test program produce an extremely fine spray, many times finer than that produced by the nozzles used in the previous test program. As a result, the large allowances for gravity effects incorporated in the current lance design were not necessary. The current nozzle assemblies do not extend far enough into the duct. Although the lances can be rotated to change the direction of spray, they cannot be raised or lowered. As a temporary measure, the lances have been tilted to provide more coverage area. The current plan is to replace these lances using an improved design.

The existing test program is being conducted on a one shift basis, five days per week. Actual injection run length is about 3 to 4 hours. Although steady-state conditions are obtained for SO₂ removal, the effects on the electrostatic precipitator (ESP) and other parts of the system cannot be determined without significantly longer runs. In order to determine these effects, it will be necessary to increase the run length to 5 days with 24-hour operation. At least two separate runs of this duration will be necessary to evaluate ESP impacts, to provide meaningful and representative flyash samples, to observe the effects of using low and high sulfur coals, and in general to establish the system boundaries.

Experience obtained from the current test program indicates that the program needs to be modified, as follows:

- Winterization, originally included in the next phase, should be accomplished now to permit continuation of the delayed test program. Without winterization, testing would have to be suspended until spring, causing additional cost and schedule overruns and jeopardizing the continued availability of trained test personnel.
- The parametric test program should be extended to June 30, 1992, and split into two parts; daily batch testing, as currently practiced, and continuous testing after the CZD system is automated and integrated with the boiler plant operation. The modifications needed for continuous operation, which were originally intended to be installed at the conclusion of the test program, should be incorporated into the test program now. This plan also allows for testing and debugging of the automatic control system during the parametric test period. Consequently, the one-year continuous demonstration can proceed immediately after the conclusion of the continuous parametric test period, on or about July 1, 1992.

Figure 1-1 shows the original and current milestone schedule for the Phase 3a parametric test program. In essence, Phase 3a is expanded to include two periods of parametric testing: six months of batch testing ending November 30, 1991, and seven months of testing ending June 30, 1992, during and after conversion to continuous operation. Phase 3a is further expanded to include installation or replacement of equipment and instrumentation, as described above and as originally included in Phase 3b. Thus, the proposed work plan for Budget Period 2 involves continuing the parametric test program (Phase 3a) for seven months, until June 30, 1992, while simultaneously carrying out the Phase 3b facility modifications necessary for the one-year continuous demonstration. At the conclusion of the extended parametric test program, the facility modifications needed to automate and integrate the CZD system will also be complete, tested, and ready for continuous operation.

Figure 1-1 Phase 3a Parametric Test Program, Including Equipment Installation for Continuous Run

Extension of the parametric test period through June 1992 provides an opportunity to regain most of the schedule slippage, but only if the modifications needed for continuous operation of the CZD system are installed concurrent with the extended test period. These modifications include automation of the lime preparation and transfer system, automatic injection control, and related instrumentation and controls as necessary to integrate the operation of the CZD system with Seward Station Boiler No. 15. Early installation of these modifications would permit testing, debugging, and adjustment of the automatic control system during the parametric test period. Results of current testing indicate that considerable testing and adjustment will be required to optimize operation of the CZD system after it is automated for continuous operation. Therefore, we intend to incorporate in Phase 3a (parametric testing) the system modifications needed for continuous automatic operation that were originally included in Phase 3b. Phase 3b would then be limited only to the one-year continuous demonstration.

Phase 3a is expanded to include the following activities:

Lime Procurement

- Procure all types of lime and other reagents required to conduct the continuous parametric test program and the one-year continuous demonstration.

CZD Parametric Testing

- Return atomizer nozzles to manufacturer for inspection and evaluation after six months use in batch testing. Make any required modifications indicated as a result of testing.
- Evaluate performance of electrostatic precipitators (ESP) during continuous parametric tests. Consult with ESP experts, if necessary, to improve performance.
- Evaluate effects of process variables on emission control performance during continuous parametric tests.
- Determine operating conditions for optimum overall performance.
- Evaluate effects of using alternative coals and reagents during continuous parametric tests:
  - High- and medium-sulfur coals.
  - Alternate reagents including pressure hydrated dolomitic lime, hydrated calcitic lime, and fresh slaked calcitic lime.

Completion of Design, Procurement, and Installation

- Based on the results of the parametric tests, complete the design packages and procure all process equipment needed to completely automate and integrate the operation of the CZD system with boiler #15 at Seward Station:
  - Install new atomizer nozzle lances.
- Procure all instruments and controls needed for continuous operation, monitoring, and data collection:
  - Replace CEMS with dilution probe type instruments.
  - Replace flue gas flow measurement system.
  - Expand Bailey Infi 90 to control/monitoring function.
  - Replace data link to Bailey Infi 90 with fiber optic system.
  - Install new temperature transmission system.
  - Install instruments and controls for automation.

Completion of Facility Construction

- Install facilities for lime unloading and storage to support the increased capacity required for continuous operation of the CZD system:
  - Install automated lime feed system.
  - Install lime receiving and storage system.

- Insulate piping and provide weather protection and enclosures as required to permit continuous, all year operation of the CZD system.
- Provide construction management support to Penelec as requested. Penelec will have prime control and responsibility for all construction activities at Seward Station.

Startup (Checkout) and Operator Training for Continuous Operation

- Provide startup engineer to supervise commissioning of all new CZD components and systems.
- Train Penelec's operators to run the CZD system and perform the tasks required to conduct the one-year continuous demonstration.
- Establish procedures for coordination of data collection and reduction with Penelec's plant management and operations personnel.

Activity Diagram - Phase 3a Facility Construction

Further details of the activities involved in facility construction, modification, and installation of equipment and instrumentation are shown in Figure 1-2. It shows the flow of activities and their dependencies. For clarity, the activities are further identified as Bechtel activities, Penelec activities, or joint activities.

**Figure 1-2 Activity Diagram
Phase 3a Facility Construction**

Section 2

INTRODUCTION

The CZD process involves injecting a finely atomized slurry of reactive lime into the flue gas duct work of a coal-fired utility boiler. The principle of the confined zone is to form a wet zone of slurry droplets in the middle of the duct confined in an envelope of hot gas between the wet zone and the duct walls. The lime slurry reacts with part of the SO₂ in the gas, and the reaction products dry to form solid particles. A solids collector, typically an electrostatic precipitator (ESP) downstream from the point of injection, captures the reaction products along with the fly ash entrained in the flue gas.

The features that distinguish the CZD process from other similar injection processes are:

- Injection of an alkaline slurry directly into the duct, instead of injection of dry solids into the duct ahead of a fabric filter.
- Use of an ultrafine calcium/magnesium hydroxide, type S pressure-hydrated dolomitic lime. This commercial product is made from plentiful, naturally occurring dolomite.
- Low residence time, made possible by the high effective surface area of the Type S lime.
- Localized dispersion of the reagent. Slurry droplets contact only part of the gas while the droplets are drying, to remove up to 50 percent of the SO₂ and significant amounts of NO_x. The process uses dual fluid rather than rotary atomizers.
- Improved electrostatic precipitator performance via gas conditioning from the increased water vapor content, and lower temperatures.

The waste product is composed of magnesium and calcium sulfite and sulfate, with some excess lime. This product mixed with fly ash is self-stabilizing because of the excess lime values, and thus tends to retain heavy metals in insoluble forms within the fly ash.

The demonstration is being conducted at Penelec's Seward Station, Unit No. 15. This boiler is a 147 MWe coal-fired unit, which utilizes Pennsylvania bituminous coal (approximately 1.2 to 2.5% sulfur). One of the two flue gas ducts leading from the boiler has been retrofitted with the CZD technology. The first existing ESP installed in the station is immediately behind the air preheater. The second ESP, installed about 15 years ago, is about 80 feet away from the first ESP. The station has two more boilers (#12 and #14) that burn the same coal and are

connected to the common flue gas stack. The arrangement of Seward Station is shown in Figure 2-1.

The goal of this demonstration is to prove the technical and economic feasibility of the CZD technology on a commercial scale. The process is expected to achieve 50% SO₂ removal at lower capital and O&M costs than other systems.

The U.S. Department of Energy and Bechtel Corporation are engaged in a cooperative project to demonstrate the CZD Technology. DOE is providing half, or \$4.6 million, of the project's total \$9.2 million cost. Others contributing to the project are Pennsylvania Electric Company (\$3 million), Bechtel (\$760,000), the Pennsylvania Energy Development Authority (\$750,000), New York Gas and Electric Company (\$100,000), and Rockwell Lime Company (\$23,000).

To achieve its objectives, the project is divided into the following three phases:

- Phase 1: Design and Permitting
- Phase 2: Construction and Start-up
- Phase 3: Operation and Disposition

Phase 1 activities were completed on January 31, 1991. Phase 2 activities were essentially concluded on July 31, 1991, and Phase 3a, Parametric Testing, was initiated on July 1, 1991. This Quarterly Technical Progress Report covers Phase 2 and Phase 3a activities from November 1, 1991 through January 31, 1992.

For further information on the structure of this demonstration project, Appendix A provides a project description by phase, a work breakdown structure (WBS) Diagram, and a detailed description of the WBS.

Figure 2-1 Seward Station Arrangement

Section 3

PROJECT STATUS

This section provides details of the work performed from November 1, 1991 through January 31, 1992, covering equipment acquisition and installation, facility construction, construction management, project management, and travel. It also describes the activities carried out as part of the parametric test program. Figure 3-1 shows a Seward Station simplified process flow diagram.

3.1 EQUIPMENT ACQUISITION AND INSTALLATION (WBS No. 1.2.1)

Procurement and installation of all major equipment and instruments required for the testing of the CZD system (by batch operation) have been completed. The status of individual items is described below:

- Air compressors, receiver, and electric power supply are complete and in operation.
- Atomizers: Lance and atomizer assemblies are complete, water tested and calibrated. The current nozzle lance assemblies were designed based on the results of previous testing at Seward Station. However, the atomizer nozzles presently in use for the test program produce an extremely fine spray, many times finer than that produced by the nozzles used in the previous test program. As a result, the large allowances incorporated in the current lance design for gravity effects were not necessary. The current nozzle assemblies do not extend far enough into the duct. Although the lances can be rotated to change the direction of spray, they cannot be raised or lowered. As a temporary measure, the lances have been tilted to provide more coverage area. The current plan is to replace these lances with an improved design.
- The lime feed and transfer systems are complete and in operation.
- Instruments and controls: Surface thermocouples have been installed on the flue gas duct bottom and sides. Probe thermocouples have been installed in their test ports and wired to the multipoint recorders. All remaining instrument hookups have also been completed, including the Bailey Infi 90 system for data acquisition, monitoring, and analysis.

The continuous emissions monitoring system (CEMS) needed to control and evaluate the performance of the CZD system was installed by Penelec's Environmental Services Group. Soon after the B-duct inlet and outlet SO₂, NO_x, and O₂ monitors began valid operation (October 4, 1991), several problems were discovered with Lear-Siegler SM-8100 systems (which monitor SO₂ and NO at the inlet and outlet of the B-duct). Various

Figure 3-1 Seward Station Overall Process Flow Diagram

problems were noticed when the SM-8100s were operated during the CZD testing. These problems included the following:

- Substantially cooling the flue gas temperature, which occurs when lime slurry is sprayed into the flue gas duct, causes the transceiver output of the outlet SM-8100 monitor to read lower than actual SO₂ and NO concentrations.
- Reducing the concentrations of SO₂ in the flue gas interferes with the SM-8100's measurement of NO, causing the NO response to indicate concentrations higher than actual.
- It is difficult to detect the CM-60 monitor's oxygen sensor malfunctions using calibration gas cylinders. When the cell malfunctions, the monitor continues to respond properly to calibration gas even though the reported oxygen values may drift higher or lower than actual.

As a result of the problems encountered with the Lear-Siegler SM-8100 and CM-60 CEMSs, Penelec made recommendations to replace the Lear-Siegler SM-8100 and CM-60 by a dilution-probe-type monitoring system. This problem is described in more detail in Appendix D.

3.2 FACILITY CONSTRUCTION (WBS No. 1.2.2)

This item, including the construction of the new straight duct, is complete and has been in satisfactory operation since May 5, 1991.

3.3 CZD PARAMETRIC TESTING (WBS No. 1.3.2)

The principle of the confined zone is to form a wet zone of fine droplets in the middle of the duct, confined in an envelope of hot gas that separates the wet zone from the duct walls. The atomized lime slurry is injected in the center of the flue gas duct parallel to the flow of gas. As the cone of atomized lime slurry moves downstream and expands, the flue gas within the cone cools and its SO₂ is rapidly absorbed by the still-liquid atomized droplets. The atomized droplets in the expanding cone diffuse outward by eddy diffusion. However, since the outward diffusing droplets continuously contact hot gas at about 300°F, they rapidly achieve surface dryness. During this drying period, the hydrated lime solution reacts quite rapidly with the SO₂ absorbed by the water, and additional lime is rapidly dissolved into solution from the very small particles of hydrated lime.

The turbulent flow also causes hot flue gas surrounding the cone of atomized slurry to diffuse inward and evaporate droplets on the inside of the cone. At a certain point downstream of the injection point, the free moisture in the atomized slurry has evaporated completely, and the dry solids remaining can

contact surfaces of the duct or the turning vanes without adhering and causing deposits to accumulate.

The thickness of the layer of flue gas that envelopes the wet zone, separating it from the duct walls, could determine the percentage of SO₂ removal. A hot flue gas layer uniformly 18 inches thick along the duct walls will limit the SO₂ removal to about 40 percent, a 12-inch layer will limit SO₂ removal to about 52 percent, and a 6-inch layer to about 68 percent. Therefore, arrangement of the atomizer lances inside the flue gas duct to create the thinnest hot flue gas layer along the duct walls, without causing deposits of solids on the walls, will assure the highest percentage of SO₂ removal. This is because more flue gas in the duct will be reacting with the atomized lime slurry.

The atomizers selected for CZD testing were developed and calibrated at U.C. Davis to determine their pressure/flow characteristics for very fine mist formation. Then the atomizers, assembled in lances, were tested outside the duct to verify their pressure/flow characteristics at different water flow rates (1-5 gpm) and the effect of the impact between the mists of adjacent atomizers.

The next step in the program included testing the calibrated atomizers assembled on eight lances in the flue gas duct. In total, 20 atomizers are installed in the duct. Each atomizer can reliably atomize water or lime slurry with a flow rate of 1-4 gpm. For a 50 percent SO₂ removal, we estimate that about 50 gpm of lime slurry must be atomized in the flue gas duct at Seward Station.

The atomizer lances are installed through nozzle ports on top of the ductwork. Each lance contains the compressed air and liquid feed pipes for the atomizers. Four lances contain three atomizers each (numbered from 1 to 12), and four lances contain two atomizers each (numbered from 13 to 20). The water injection tests in the flue gas duct can determine the atomizers' configuration to avoid wetting the duct and the turning vanes.

The dimensions of the plume resulting from injection are determined by thermocouple lances (with six thermocouples each) taking multipoint temperature traverses of the duct cross section at several locations downstream of the inject point. The cross section closest (65 ft) to the injection point is named Section B; the farthest (222 ft) is named Section E. In total, there are 96 thermocouples in the four cross sections that measure and record the flue gas temperature 65 ft, 120 ft, 186 ft, and 222 ft from the injection point.

Figure 3-2 shows the plan view of the duct with thermocouple locations and Figure 3-3 shows the thermocouple section with 24 thermocouples.

In addition to these thermocouples connected to the chart recorders, there are 120 thermocouples incorporated in 20 lances. These can be distributed along both sides of the duct, with 10 lances (60 thermocouples) measuring the flue gas temperature 6 inches from the duct side walls, and 10 lances (60 thermocouples) installed two feet from the side walls. These portable lances are provided with hand readout instruments for flue gas temperature reading.

Another 20 thermocouples measure the temperature of the outside duct walls (bottom and sides). These temperatures are continuously recorded by the chart recorder. If by accident water or lime slurry drips to the bottom of the flue gas duct, these "skin" thermocouples will alarm at temperatures lower than 110°F.

Figure 3-3 Typical Thermocouple Section (6 Thermocouples per Thermowell = 24 per Section)

3.3.1 In-Duct Water Injection Tests

Testing with atomized water inside the duct was performed to determine the maximum amount of water that can be injected into the duct without cooling the duct walls. The thermocouple lances along the duct walls and those at the four duct cross sections at different distances from the injection point help determine the optimum position of the atomizer lances in the flue gas duct, and the maximum amount of atomized water that could be injected without cooling the duct walls. Another objective of the water injection in the duct was to determine the effect of cooling the flue gas and increased amounts of water vapor on the ESP particulate removal efficiency, and the percentage of opacity.

With so many thermocouples in the flue gas duct continuously showing the flue gas temperature in the duct with or without water injection, it is possible to determine the best orientation of atomizers for maximum water rate without wetting the duct walls or the turning vanes.

The temperature profile in the duct during water injection shows the following:

- At Section B, about 65 feet from the injection point, the center of the duct is wet at 120°F (at the adiabatic saturation temperature), and close to the side walls and bottom and top of the duct the temperature of the flue gas is close to 200°F. The hot zone along the duct walls confines the wet dispersion zone, preventing it from reaching the duct walls; therefore, no wet deposits form on the duct walls. The theoretical "confined zone dispersion" (CZD) is now proved in practice.
- At Section C, about 120 feet from the injection point, and close to the turning vanes, the temperature at the center of the duct is above 160°F, which means that the wet zone has become dry, and no deposits could form on the turning vanes. The duct walls are at temperatures close to 200°F.
- At Section D, about 186 feet from the injection point and at Section E, about 222 feet from the injection point, the temperature of the flue gas is above 170°F. The flue gas is moving into the ESP at this temperature, at an approach to saturation above 60°F. Under these conditions, the deposition of wet solids on the collecting plates and the discharge wires in the ESP is completely eliminated.

Opacity Data During In-Duct Water Injection

Opacity data were collected from two continuous opacity monitoring instruments.

- An in-duct continuous opacity monitor located at the outlet of the electrostatic precipitator serving the CZD test duct.

- An in-stack continuous opacity monitor used to demonstrate compliance with environmental permit conditions.

A consistent decrease in measured opacity during the period when water was injected was observed.

3.3.2 In-Duct Lime Slurry Injection Tests

After the program of testing water injection inside the duct was completed, the program of testing the atomized lime slurry duct injection was started.

We intended to start the testing with Type S lime (pressure-hydrated dolomitic lime) which is a fast SO₂ absorbent, but because the lime silo was about half full of dry hydrated calcitic lime, we decided to start operating with this type of lime until all of it was consumed and the silo could be filled with type S lime.

The dry hydrated calcitic lime was slurried with water in a sump at about 20 percent lime concentration, pumped to a vibrating screen to remove the impurities, and discharged by gravity into one of the two lime slurry feed tanks.

Using calcitic lime, slurry injection tests were conducted during October with encouraging results. Plans and strategies were developed for resolving the current problem areas and for expanding the parametric test program to include continuous automated testing.

The problems and their solutions are as follows:

- a) The atomizer lances were designed based on data obtained during concept testing when tests were made with standard commercial atomizers. The newly developed atomizers, with an extremely fine mist, are little affected by gravity. Therefore, the fabricated lances are too short, cooling only the upper side of the duct. Until the new atomizer lances are fabricated, the lances will be temporarily tilted to cover a larger portion of the flue gas duct with atomized lime slurry.
- b) The dilution of the lime slurry directly into the lime header was easily controlled during parametric testing and during a semi-automated continuous run, but it caused difficulties with a fully automated system operating from the power plant control room. For this reason, the desired lime slurry concentration was designed to be accomplished in the lime slurry sump with no more dilution in the feed tank or lime header.

Significant accomplishments with the in-duct lime slurry tests are described below.

November 1991

A total of five slurry injection tests were completed between November 1 and November 20, 1991. The tests of November 1 and November 14 were made with hydrated calcitic lime slurry, and the tests of November 15, 19, and 20 were made with pressure-hydrated dolomitic lime.

Lime slurry feed-rates were varied from 49 gpm to 58.5 gpm and lime slurry concentrations were varied from 5.5% to 12.5%. Indicated SO₂ removal rates of up to 40% were achieved. Although pressure-hydrated dolomitic lime (Type S lime) was used in the last three tests, insufficient data were available to draw any conclusions regarding the difference in performance between dolomitic and hydrated calcitic limes. During all testing, the stack opacity was observed to decrease during injection. Stack opacity was also observed to increase to a higher level than the pre-injection level after testing was completed. The reason for this phenomenon is being investigated, and temporary measures have been taken to insure that opacity does not exceed allowable limits. Water injected into the duct for a few hours after the lime injection helps to mitigate any opacity problem.

Freezing weather during the first week of November damaged the CZD system, which had not been winterized. Repairs were not completed to the point that the water could be sprayed into the duct until November 13, when a ball valve malfunctioned and prevented the injection of lime. This was repaired and lime injection resumed until a rag was dropped in a lime tank, preventing injection on November 18. On November 21, the compressor supplying atomizing air for overnight spraying tripped and allowed water to flow into the duct for about one hour, flooding the ESP. Unit 15 was shut down and restarted later that evening, after the wet ash was removed. During the shutdown, several of the atomizing nozzles and pressure gauges were found to be plugged and the week on November 25 was dedicated to cleaning the nozzles. A check valve was installed on the CZD potable water supply line to prevent lime from accidentally flowing back into the potable water.

The estimates of SO₂ and NO_x removal and the determination of percentage of lime utilization are made based on measured quantities of:

- SO₂, NO_x, and O₂ concentration in inlet and outlet flue gas
- Flue gas flow at the discharge from the test duct
- Barometric pressure
- Flue gas pressure
- Lime usage
- Lime slurry concentration

- Atomized air usage
- Dilution water usage

Table 3-1 shows the estimate of SO₂ and NO_x removal and percent lime utilization by the Seward Station CZD system from November 1, 1991 through January 31, 1992.

The daily test data for in-duct lime slurry injection for the month of November are included in Appendix C.

Estimating procedures and the mass balance equations for determining the estimates of SO₂ and NO_x removal and percent lime utilization are included in Appendix G.

Table 3-2 shows the CZD activity summary for November 1991 with lime slurry injection factorial tests.

Table 3-1
Estimate of SO₂ and NO_x Removal for the Seward Station CZD System
November 1991 through January 1992

Type of Lime: CALCITIC %Ca(OH) ₂ = 96.07 %Mg(OH) ₂ = 0.00		FG	AA	WC	SO ₂ IN	SO ₂ OUT	NO _x IN	NO _x OUT	O ₂ IN	O ₂ OUT
		Flue Gas Flow Meter	Atomizing Air Meter	Water Content Of Slurry	Measured SO ₂ Conc. In	Measured SO ₂ Conc. Out	Measured NO _x Conc. In	Measured NO _x Conc. Out	Measured O ₂ Conc. In	Measured O ₂ Conc. Out
Date	Time	SCFM	SCFM	SCFM	PPMV	PPMV	PPMV	PPMV	Vol. %	Vol. %
11/1/91	13-15:00	263,625	1,157	8,385	875.0	547.4	348.3	299.8	6.100	7.690
11/14/91	11-14:45	254,800	1,584	8,352	932.8	509.2	399.8	317.5	6.010	7.560
11/15/91	11-14:10	258,400	1,584	8,291	957.0	482.2	376.8	312.0	5.960	7.530
11/19/91	12-13:55	203,979	1,584	8,282	946.5	467.7	361.2	311.6	5.900	7.771
11/19/91	12-15:00	203,979	1,584	7,282	945.0	490.5	362.2	317.7	6.040	7.750
11/19/91	15-16:03	209,944	1,221	9,014	961.6	511.8	352.2	306.9	6.160	7.860
11/20/91	12-14:30	204,753	1,584	8,385	954.5	524.9	353.0	315.1	5.950	7.630
12/11/91	1:30-3:00	195,264	1,453	7,404	848.9	310.3	302.9	235.2	7.050	8.500
12/11/91	1:25-2:10	181,309	1,453	7,404	819.2	279.4	271.7	207.5	7.230	8.633
12/11/91	2:30-3:30	214,504	1,453	7,404	907.1	387.6	346.8	283.3	6.555	8.080
12/16/91	3:10-5:10	199,408	1,070	6,162	883.7	425.1	368.8	306.8	6.604	8.420
12/18/91	11:50-1:10	203,715	1,403	7,207	896.1	415.7	356.3	284.3	6.360	8.210
12/19/91	2:00-4:20	203,359	2,489	6,355	896.4	471.9	370.1	292.7	6.530	8.450
12/20/91	1:30-2:50	203,901	1,950	5,780	925.9	500.7	356.3	292.2	6.410	8.250
12/31/91	11:40-1:50	209,711	1,740	7,590	952.9	453.2	357.2	290.4	6.570	8.580
1/6/92	11:40-2:48	197,626	2,048	5,804	908.9	496.4	353.3	274.4	6.890	8.810
1/7/92	1:00-4:45	205,883	1,801	6,731	951.4	504.9	344.1	275.4	3.332	8.650
1/8/92	2:40-4:45	189,879	2,047	6,973	873.4	413.9	291.2	215.7	7.196	9.020
1/9/92	2:55-4:45	201,654	1,863	7,512	822.6	385.6	288.4	219.5	7.020	8.900
1/10/92	12:45-1:50	196,232	1,898	6,926	842.2	383.2	293.6	215.3	6.900	8.900
1/13/92	12:37-2:50	203,591	1,907	7,144	906.5	448.4	352.9	254.6	6.430	8.680
1/14/92	12:00-4:00	202,352	1,959	7,172	937.5	462.9	352.7	263.1	6.590	8.660
1/30/92	12:53-2:53	207,775	1,895	6,499	970.1	562.5	397.0	263.6	6.600	8.700

Type of Lime: CALCITIC % Ca(OH) ₂ = 96.07 % Mg(OH) ₂ = 0.00		LS-IN	LS-CONC	FG-IN	FG-OUT	Z-AI	X-SO ₂	X-NO _x	%SO ₂	%NO _x
		Lime Slurry Feedrate	Lime Slurry Concent'n	Calculated Flue Gas In	Calculated Flue Gas Out	Calculated Air Leakage	Calculated SO ₂ Absorbed from FG	Calculated NO _x Absorbed from FG	Calculated %SO ₂ Removal	Calculated %NO _x Removal
Date	Time	GPM	WT %	SCFM	SCFM	SCFM	SCFM	SCFM	%	%
11/1/91	13-15:00	49.0	5.5	253,831	297,692	34,087	59.1	-0.8	26.83	-9.96
11/14/91	11-14:45	50.0	10.3	244,627	286,184	31,394	82.5	6.9	36.14	7.08
11/15/91	11-14:10	50.0	11.5	248,294	290,462	32,062	97.6	2.9	41.06	3.15
11/19/91	12-13:55	50.0	12.5	193,929	234,738	30,759	73.8	-3.1	40.19	-4.41
11/19/91	12-15:00	50.0	12.5	193,924	232,320	28,342	69.3	-3.6	37.81	-5.08
11/19/91	15-16:03	58.5	12.5	199,512	269,983	30,039	69.0	-3.4	35.98	-4.83
11/20/91	12-14:30	50.0	9.9	194,588	232,456	21,703	63.7	-4.5	34.31	-6.82
12/11/91	1:30-3:00	43.8	8.4	186,286	220,522	25,258	89.7	4.6	56.72	8.07
12/11/91	1:25-2:10	44.5	8.4	172,352	204,636	23,327	84.0	4.4	59.51	9.33
12/11/91	2:30-3:30	52.9	8.4	205,484	242,010	27,505	92.6	2.7	49.68	3.79
12/16/91	3:10-5:10	36.5	8.4	192,007	230,242	30,834	71.8	0.2	42.32	0.26
12/18/91	11:50-1:10	42.3	7.5	194,941	235,199	31,483	76.9	2.6	44.03	3.73
12/19/91	2:00-4:20	37.5	8.0	195,334	236,095	32,736	63.7	3.2	36.37	4.42
12/20/91	1:30-2:50	34.4	8.4	195,985	234,034	30,133	64.2	1.5	35.40	2.09
12/31/91	11:40-1:50	45.5	10.9	200,198	245,686	35,975	79.4	0.2	41.63	0.24
1/6/92	11:40-2:48	34.4	9.0	189,597	229,698	32,072	58.3	4.0	33.83	5.90
1/7/92	1:00-4:45	39.5	7.0	196,959	245,633	39,950	63.4	0.1	33.82	0.19
1/8/92	2:40-4:45	41.0	7.0	180,720	220,862	30,783	66.5	5.0	42.14	9.58
1/9/92	2:55-4:45	44.7	9.7	192,137	235,233	33,578	67.3	3.8	42.61	6.82
1/10/92	12:45-1:50	44.1	10.2	187,269	230,447	34,216	69.4	5.4	44.01	9.76
1/13/92	12:37-2:50	42.3	8.4	194,370	242,285	38,694	67.6	6.9	38.34	10.07
1/14/92	12:00-4:00	42.2	8.0	193,048	237,879	35,527	70.9	5.5	39.16	8.07
1/30/92	12:53-2:53	38.4	8.2	199,173	244,552	36,778	55.7	9.7	28.81	12.23

Table 3-1
Estimate of SO₂ and NO_x Removal for the Seward Station CZD System
November 1991 through January 1992

Type of Lime: CALCITIC		LIME SLURRY GRAVITY, PURITY AND ALKALI					ACID GAS REMOVED			% UTIL'N
% Ca(OH) ₂ =	96.07	Lime Slurry Specific Gravity	Lime Purity	Calculated Ca(OH) ₂ Content	Calculated Mg(OH) ₂ Content	Calculated Total Alkali	Calculated SO ₂ Absorbed from FG	Calculated NO _x Absorbed from FG	Calculated Total Acid Gas Absorbed	Calculated Total Alkali Utilization
% Mg(OH) ₂ =	0.00	Sp. Gr.	%Ca(OH) ₂	Lb Mol/Min	Lb Mol/Min	Lb Mol/Min	Lb Mol/Min	Lb Mol/Min	Lb Mol/Min	%
Date	Time									
11/1/91	13-15:00	1.0283	96.1	0.2992	0.0000	0.2992	0.1558	-0.0022	0.1558	52.09
11/14/91	11-14:45	1.0575	96.1	0.5880	0.0000	0.5880	0.2173	0.0182	0.2355	38.50
11/15/91	11-14:10	1.0640	96.1	0.6606	0.0000	0.6606	0.2571	0.0078	0.2648	39.51
11/19/91	12-13:55	1.0750	58.0	0.4380	0.3693	0.8072	0.1944	-0.0081	0.1994	24.08
11/19/91	12-15:00	1.0750	58.0	0.4380	0.3693	0.8072	0.1826	-0.0094	0.1826	22.62
11/19/91	15-16:03	1.0750	58.0	0.5124	0.4320	0.9444	0.1819	-0.0099	0.1819	19.26
11/20/91	12-14:30	1.0570	58.0	0.3411	0.2876	0.6286	0.1679	-0.0120	0.1679	26.71
12/11/91	1:30-3:00	1.0480	58.0	0.2513	0.2119	0.4633	0.2364	0.0120	0.2484	52.32
12/11/91	1:25-2:10	1.0480	58.0	0.2554	0.2153	0.4707	0.2214	0.0115	0.2329	48.26
12/11/91	2:30-3:30	1.0480	58.0	0.3034	0.2558	0.5593	0.2440	0.0071	0.2511	44.26
12/18/91	3:10-5:10	1.0480	58.0	0.2092	0.1763	0.3855	0.1892	0.0005	0.1897	49.14
12/18/91	11:50-1:10	1.0460	58.0	0.2163	0.1824	0.3987	0.2027	0.0068	0.2095	51.59
12/19/91	2:00-4:20	1.0460	58.0	0.2046	0.1725	0.3770	0.1678	0.0084	0.1762	45.63
12/20/91	1:30-2:50	1.0524	58.0	0.2216	0.1869	0.4085	0.1692	0.0034	0.1731	41.90
12/31/91	11:40-1:50	1.0632	58.0	0.3437	0.2898	0.6335	0.2093	0.0004	0.2097	33.07
1/7/92	11:40-2:48	1.0530	58.0	0.2125	0.1792	0.3917	0.1536	0.0104	0.1641	40.55
1/8/92	1:00-4:45	1.0405	58.0	0.1875	0.1581	0.3457	0.1670	0.0003	0.1673	48.36
1/6/92	2:40-4:45	1.0390	58.0	0.1943	0.1638	0.3581	0.1753	0.0133	0.1885	50.80
1/9/92	2:55-4:45	1.0580	58.0	0.2387	0.2518	0.5505	0.1775	0.0100	0.1874	33.14
1/10/92	12:45-1:50	1.0580	58.0	0.3102	0.2616	0.5718	0.1829	0.0141	0.1970	33.22
1/13/92	12:37-2:50	1.0460	58.0	0.2425	0.2045	0.4470	0.1780	0.0182	0.1962	41.86
1/14/92	12:00-4:00	1.0460	58.0	0.2302	0.1941	0.4243	0.1867	0.0145	0.2012	45.72
1/30/92	12:53-2:53	1.0470	58.0	0.2149	0.1812	0.3961	0.1467	0.0255	0.1721	40.25

Table 3-2
Lime Slurry Injection Factorial Tests
CZD Activity Summary for November 1991

Date	Duration of Lime Injection Hrs	Lime Slurry Injection		Hydrated Calcitic and Dolomitic Lime			SO ₂ Concentration			% Stack Opacity		
		gpm	Total Gallons	% Slurry Concen.	Lime Consumption Pounds	% Lime Utilization	Inlet ppm	Outlet ppm	% SO ₂ Removal	Before Lime Injection	During Lime Injection	After Lime Injection
					<u>With Hydrated Calcitic Lime</u>							
11-1	2	49	5,880	5.5	2,773	52.1	875	547	26.6	10	8	15
11-14	3.75	50	11,250	10.3	10,220	38.5	932	509	36.1	10	8	14
					<u>With Hydrated Dolomitic Lime</u>							
11-15	3	50	9,000	11.5	9,184	39.5	957	482	41.1	15	11-12	17
11-19	2	50	6,000	12.5	6,720	24.1	946	468	40.2	10	8	15
11-19	1	50	3,000	12.5	3,360	22.6	945	491	37.8	10	8	15
11-19	1	58.5	3,500	12.5	3,920	19.3	962	512	36	10	8	15
11-20	2.5	50	7,500	9.9	6,540	26.7	955	525	34.3	16	8	17

December 1991

A total of six slurry injection tests were completed between December 1 and December 31, 1991. Lime slurry feed rates were varied from 36.5 gpm to 52.9 gpm and lime slurry concentrations were varied from 7.5% to 10.9%. Indicated SO₂ removal rates of up to 59.5% have been achieved. Type-s dolomitic lime was used in these tests.

Testing was limited during December due to very cold weather, several boiler outages, and a shutdown to allow the test engineers to go home for the Christmas holiday.

Although all process lines have been heat-traced and insulated to prevent freezing of the CZD system, an additional weather enclosure has been designed to provide heat and weather protection in the lime slurry feed preparation area and around the feed headers and injection control valves. Installation of this weather enclosure is not expected to be completed until late January or early February 1992. All process lines that will eventually be covered by the weather enclosure have been heat-traced and temporarily insulated.

The measurement and analysis study of the existing plant electrical system and grounds was completed in December. The study found only minimal problems attributable to the grounding system. However, the study found a wiring discrepancy which, when corrected, allowed the data gathering and reduction system to function as designed. Unfortunately, once sustained operation of the system was achieved, new problems with the stability of the L&N recorders were revealed. As a result, it may be necessary to completely remove the data input from L&N recorders and substitute Bailey equipment more suitable for this service. In that case, the L&N recorders would serve only as "slave" printers. Pending resolution of this problem, testing continues using the temperature received directly by the L&N recorders and the data available at the Bailey Infi-90 display monitor. All data reduction and calculation of results must continue to be performed manually until the problems with the data gathering and reduction system are resolved.

A formal request was sent to the DOE on November 7, 1991 for a no-cost time extension of budget period 1 until June 30, 1992. This request was approved by the DOE on November 26, 1991, and will allow continuation of parametric testing.

The current SO₂ and NO_x measurement instruments on the CZD duct will be replaced with a dilution probe system. This is the system Penelec prefers, and in the future they intend to switch to this system at all their plants.

Table 3-3 shows the CZD activity summary for December 1991 with lime slurry injection factorial tests. The daily test data for in-duct lime slurry injection for the month of December are included in Appendix C.

Table 3-3
Lime Slurry Injection Factorial Tests
CZD Activity Summary for December 1991

Date	Duration of Lime Slurry Injection	Lime Slurry Injection		Pressure Hydrated Dolomite Lime		SO ₂ Concentration			% Stack Opacity		Comments
		gpm	Total Gallons	% Lime Slurry Concn.	% Lime Utilization	Inlet ppm	Outlet ppm	% SO ₂ Removal	Before Lime Injection	During Lime Injection	
12-11	1:30-3:00	43.8	3,942	8.4	52.3	849	310	56.7	12	11	
12-11	1:25-2:10	44.5	2,000	8.4	48.3	819	279	59.5	12	11	
12-11	2:30-3:30	52.9	3,174	8.4	44.3	907	388	49.7	12	11	
12-16	3:10-5:10	36.5	4,380	8.4	49.1	884	425	42.3	17	12	
12-18	11:50-1:10	42.3	3,384	7.5	51.7	896	416	44.0	17	12	
12-19	2:00-4:20	37.5	5,250	8.0	45.6	896	472	36.4	17	11	
12-20	1:30-2:50	34.4	2,750	9.4	42	926	501	35.4	14	10	
12-31	11:40-1:50	45.5	5,460	10.9	33	953	453	41.6	13	11	

January 1992

A total of eight slurry injection tests completed between January 6 and January 30, 1992 are summarized in Table 3-4, CZD Activity Summary for January 1992. Lime slurry feed rates were varied from 34.4 gpm to 44.7 gpm and lime slurry concentrations were varied from 7.0% to 10.2%. Indicated SO₂ removal rates were in the range of 34% to 44%. Type-s dolomitic lime was used in these tests. Testing was limited during January due to very cold weather and several boiler outages.

The existing SO₂ and NO_x measurement instruments on the CZD duct were replaced with a dilution probe system, as recommended by Penelec. Two problem areas were identified during this reporting period. These include a problem with the Seward Station stack opacity reporting and various problems with the B-duct CEMS.

Problem Areas and Corrective Actions

The Continuous Emissions Monitoring System (CEMS) for SO₂, NO_x, and oxygen – with Lear-Siegler SM-8100 and CM-60 systems to monitor CZD inlet and outlet concentrations – gave us the following problems:

a) *Interference of SO₂ with NO_x measurements in a Lear-Siegler SM-8100.*

The problem is with the CZD outlet monitor. It is impossible to accurately measure NO_x at the outlet of the CZD process under all conditions using an LSI 8100 system without having NO_x/SO₂ gases to compensate for all concentrations of SO₂ that will be measured.

b) *The temperature effects on the measurement of SO₂ and NO_x using a Lear-Siegler SM-8100.*

To properly document SO₂ reductions, it was decided that the outlet system had to be adjusted to read properly at the cooler temperature present during actual CZD operations.

c) *Problems with accurately measuring oxygen level with CM-60 monitor.*

This instrument incorporates a replaceable zirconium oxide fuel-cell-type sensor located at the probe end. When the cell malfunctions, the reported oxygen values may begin going higher or lower than the actual values, and we know of no way to detect an aging sensor.

d) *Inlet SM-8100 NO_x response to lime injection.*

Once lime injection begins, the reported NO_x values from the inlet SM-8100 rise sharply from about 0.65 lbs/10⁶ btu to about 1.00 lbs NO_x/10⁶ btu. Obviously, this does not reflect the actual concentrations since the lime slurry injection cannot possibly affect the upstream concentration of NO_x in the gas stream.

Table 3-4
Lime Slurry Injection Factorial Tests
CZD Activity Summary for January 1992

Date	Duration of Lime Slurry Injection	Lime Slurry Injection		Pressure Hydrated Dolomite Lime		SO ₂ Concentration			% Stack Opacity		Comments
		gpm	Total Gallons	% Lime Slurry Concn.	% Lime Utilization	Inlet ppm	Outlet ppm	% SO ₂ Removal	Before Lime Injection	During Lime Injection	
1-6	11:40-2:48	34.4	6,467	9.0	40.6	909	496	33.8	11	11	
1-7	1:00-4:45	39.5	8,888	7.0	48.4	951	505	33.8	8	6	
1-8	2:40-4:45	41.0	5,125	7.0	50.8	414	291	42.1			
1-9	2:55-4:45	45.0	4,950	9.7	33.1	823	386	42.6	7	6	After injection 5%
1-10	12:45-1:50	44.1	2,866	10.2	33.2	842	383	44.0	7	7	
1-13	12:37-2:50	42.3	5,626	8.4	41.9	907	448	38.3	7	7	After injection 7%
1-14	12:00-4:00	42.2	5,064	8.0	45.7	938	463	39.2	8	7	After injection 7%
1-30	12:53-2:53	38.4	4,608	8.2	40.3	970	563	28.8	8	8	After injection 8%

Recommendations

Continuous monitoring of the inlet and outlet SO₂ and NO_x relating to CZD.

Based on the inherent measurement difficulties encountered using the Lear-Siegler SM-8100 for SO₂ and NO_x, and the CM-60 for oxygen, it is recommended that these types of systems be replaced by a dilution-probe-type monitoring system.

A more detailed report on problem areas and corrective actions for the continuous emissions monitoring system for the CZD demonstration is included in Appendix D.

Engineering and procurement of the instrumentation and equipment needed to automate the CZD system continued during January. New designs for the atomizer nozzle lances were evaluated. Discussions were held with a manufacturer of flow meters (kurz) regarding design of a new flue gas measurement system at the inlet and outlet of the flue gas duct. Design of the weather enclosure and platforms for the additional sootblowers was completed and a bid package was prepared.

On January 9, representatives from Bechtel, Penelec, PEDA, NYSEG, and Rockwell Lime met with DOE representatives at PETC to discuss Bechtel's request to reallocate project funds from Budget Period 2 to Budget Period 1. DOE indicated that they were favorably impressed with the progress and initial CZD test results at Penelec. They recommended that, instead of funds reallocation, Bechtel immediately submit a Continuation Application for the balance of the project. DOE further recommended that the application address any need for DOE overrun funding.

The completed Continuation Application is expected to be submitted to DOE in late February 1992. Bechtel has continued the test program without interruption, based on expectation of expeditious approval of the Continuation Application.

Plans for February 1992

A two-day 24-hour-per-day dolomitic run is scheduled to collect stabilized performance data and evaluate longer term effects on ESP operation. After the run, Seward Station will shut down for annual maintenance from February 15 to March 16. Duct adapters for the new nozzle lances will be installed during the shutdown period.

3.3.3 Effect of CZD System at Seward Station on Percent Stack Opacity

During parametric testing in the period November 1, 1991 to January 31, 1992, it was discussed that during the lime slurry in-duct injection, the percent of stack opacity was lower than it was before and after injection. The explanation for the increase in ESP removal efficiency during the water and lime slurry injection in the flue gas duct is as follows:

- a. The cooling of the flue gas during the lime slurry injection (from about 300°F to 200°F) decreases the flue gas volume and gas velocity, thereby increasing the flue gas residence time inside the ESP.
- b. The ash resistivity and that of reacted products (calcium sulfite and sulfate) varies with the temperature. For some ashes, the lower temperature reduces resistivity, allowing a higher electric current that improves ESP performance.
- c. It is known that the water vapor is a conditioning agent for ESP performance.
- d. It is expected that during lime slurry injection, an agglomeration of fly ash particles with lime and reacted products will occur, creating larger particles that can be more easily removed by the ESP.

The CZD system is in operation in the B-duct that is connected with the D-ESP; the A-duct is connected with the C-ESP, and its data are recorded only for comparison. Operating data for the C-ESP and D-ESP fields recorded on November 15, 16, and 19, 1991, show much higher electric currents (miliamps) in the D-ESP fields than in the C-ESP fields. This increase of electric current miliamps in the D-ESP fields contributes to the increase of the ESP particulate removal efficiency. Data from these tests are shown in Tables 3-5 through 3-12. Figures 3-4 and 3-5 show the Bailey readings of opacity for November 15 and 19, respectively.

Table 3-5
Lime Slurry Injection in the B-Duct on November 15
Followed by Water Injection on November 16

Date and Time	12:50 p.m. on November 15, 1991
Lime Slurry Injection Rate	47 gpm
Lime Content of Slurry	12%
Boiler Load	146 MW
Stack Opacity*	10%
Duct Opacity	10.6%
Inlet Flue Gas Temperature	303.4°F
Date and Time	9:30 a.m. on November 16, 1991
Water Injection Rate	11 gpm
Boiler Load	146 MW
Stack Opacity	14.9%
Duct Opacity	18.8%
Inlet Flue Gas Temperature	303.4°F

* Figure 3-4 shows the Bailey recording of opacity for November 15, 1991.

Table 3-6
Lime Slurry Injection in the B-Duct on November 15
Followed by Water Injection on November 16

11/16/91				11/15/91							
Field		D ₁				D ₂		D ₃		D ₄	
Water Injection 11 gpm		Lime Slurry Injection 12% Lime Concen. 47 gpm				Water Injection 11 gpm		Lime Slurry Injection 12% Lime Concen. 47 gpm		Water Injection 11 gpm	
V _{DC}	33		36		37		38		40		36
A _{DC}	820		830		400		720		700		800
V _{AC}	300		330		340		350		350		330
A _{AC}	115		115		80		115		90		120
V _{DC} × A _{DC}	27,060		29,880		14,800		27,360		28,000		28,800
V _{AC} × A _{AC}	34,500		37,950		27,200		40,250		31,500		39,600
Field		C ₁				C ₂		C ₃		C ₄	
V _{DC}	—	—	—		38		38		38		40
A _{DC}	500		500		500		660		500		600
V _{AC}	330		330		330		340		320		300
A _{AC}	70		72		70		85		75		90
V _{DC} × A _{DC}					19,000		25,080		19,000		24,000
V _{AC} × A _{AC}	23,100		23,760		23,100		28,900		24,000		27,000

Figure 3-4 Bailey Recording of Opacity on November 15, 1991

Table 3-7
Data Recorded With No Injection in the B-Duct at 7:30 a.m. and 9:30 a.m.
on November 19

Date and Time	7:30 a.m. on November 19, 1991
Boiler Load	145 MW
Stack Opacity	10%
Duct Opacity	17.4%
Inlet Flue Gas Temperature	301°F
Date and Time	9:30 a.m. on November 20, 1991
Boiler Load	147 MW
Stack Opacity	10%
Duct Opacity	9.6%
Inlet Flue Gas Temperature	301.4°F

Table 3-8
Data Recorded With No Injection in the B-Duct at 7:30 a.m. and 9:30 a.m.
on November 19

Field D ₁		D ₂		D ₃		D ₄	
No Injection 7:30 a.m.	No Injection 9:30 a.m.	No Injection 7:30 a.m.	No Injection 9:30 a.m.	No Injection 7:30 a.m.	No Injection 9:30 a.m.	No Injection 7:30 a.m.	No Injection 9:30 a.m.
V _{DC} 34 A _{DC} 820	36 820	37 400	36 400	38 600	38 500	36 850	35 800
V _{AC} 350 A _{AC} 115	320 115	330 80	320 75	340 90	330 85	360 115	360 115
V _{AC} × A _{AC} V _{DC} × A _{DC}	36,800 29,520	26,400 14,800	24,000 14,400	30,600 22,800	28,050 12,000	41,400 30,600	41,400 28,000
Field C ₁		C		C ₃		C ₄	
No Injection 7:30 a.m.	No Injection 9:30 a.m.	No Injection 7:30 a.m.	No Injection 9:30 a.m.	No Injection 7:30 a.m.	No Injection 9:30 a.m.	No Injection 7:30 a.m.	No Injection 9:30 a.m.
V _{DC} — A _{DC} 400	— 500	37 500	36 500	40 500	38 600	48 850	48 850
V _{AC} 290 A _{AC} 60	340 60	350 80	330 80	300 75	300 75	350 130	350 125
V _{AC} × A _{AC} 17,400 V _{DC} × A _{DC}	20,400 —	28,000 18,500	26,400 18,000	22,500 20,000	22,500 22,800	45,500 40,800	43,750 40,800

Table 3-9
Lime Slurry Injection in the B-Duct on November 19

Date and Time	10:05 a.m. - 4:00 p.m. on November 19, 1991
Lime Slurry Injection Rate	32.5 gpm
Lime Content of Slurry	12.5%
Boiler Load	145 MW
Stack Opacity	10.12%
Duct Opacity	15.3%

Table 3-10
Lime Slurry Injection in the B-Duct on November 19

Field	D ₁	D ₂	D ₃	D ₄
V _{DC}	37.17	39.21	38.4	36.29
A _{DC}	851	449	523	770
Sparking Rates/min	23.41	14.94	17.12	11.62
Field	C ₁	C ₂	C ₃	C ₄
V _{DC}	39.23	36.46	42	43.52
A _{DC}	392	449	493	863
Sparking Rates/min	18.66	12.65	15.85	2.889

Table 3-11
Water Injection in the B-Duct on November 19
After Completion of Lime Injection

Date and Time	4:45 p.m. on November 19, 1991
Water Injection Rate	15 gpm
Boiler Load	145 MW
Stack Opacity	8.8%
Duct Opacity	11%

Table 3-12
Water Injection in the B-Duct on November 19
After Completion of Lime Injection

Field	D ₁	D ₂	D ₃	D ₄
	Water Injection 4:45 p.m.	Water Injection 4:45 p.m.	Water Injection 4:45 p.m.	Water Injection 4:45 p.m.
V _{DC}	34	39	42	39
A _{DC}	820	610	850	1,000
V _{AC}	37.17	350	370	375
A _{AC}	851	100	120	135
V _{AC} × A _{AC}	36,225	35,000	44,400	50,625
V _{DC} × A _{DC}	27,880	23,790	35,700	39,000
Field	C ₁	C ₂	C ₃	C ₄
V _{DC}	—	36	40	48
A _{DC}	500	540	550	850
V _{AC}	340	335	300	350
A _{AC}	65	80	80	130
V _{AC} × A _{AC}	22,100	26,800	24,000	45,500
V _{DC} × A _{DC}	—	19,440	22,000	40,800

3.3.4 Baseline Testing – Fuel

Penelec analyzed samples of the incoming coal for moisture, ash, fixed carbon, volatiles, % sulfur, and Btu/lb, and calculated the lbs sulfur/MMBtu. Typical coal analyses are shown in Table 3-13. Appendix F presents the results of these analyses as well as analyses of the amounts of coal burned and the resulting ash for this quarter.

Table 3-13
Typical Coal Analysis for Seward Station

DATE	# 12 TONS	# 14 TONS	# 15 TONS	% MOIST	% ASH	% SULFUR	Btu	# SUL/ 10E6 Btu	% VOL
1	427	426	1145	6.45	13.34	1.63	12309	1.33	21.90
2	265	329	1257	6.23	13.83	1.40	12274	1.15	22.05
3	364	315	1430	6.32	12.81	1.61	12440	1.29	22.01
4	258	313	1118	5.85	11.77	1.38	12612	1.09	21.59
5	316	260	784	6.34	13.09	1.60	12321	1.31	21.93
6	205	315	0	5.54	14.58	1.60	12219	1.31	21.59
7	278	308	0	5.41	14.16	1.57	12354	1.28	21.50
8	314	288	385	5.33	12.45	1.54	12614	1.22	22.57
9	127	189	1109	6.33	13.58	1.61	12322	1.31	20.49
10	287	283	1195	5.58	13.24	1.53	12470	1.23	20.49
11	243	190	1165	6.09	12.75	1.61	12519	1.29	22.42
12	239	291	1217	6.38	13.38	1.69	12324	1.38	21.51
13	293	360	1195	6.76	13.32	1.66	12270	1.36	21.42
14	259	287	1216	7.08	13.37	1.57	12196	1.29	20.49
15	215	333	1237	6.30	13.66	1.49	12296	1.22	21.76
16	265	276	1221	5.91	14.12	1.59	12260	1.30	21.73
17	247	296	1215	5.79	15.00	1.64	12134	1.35	21.75
18	303	194	1216	6.24	13.70	1.47	12264	1.20	20.96
19	220	321	1260	5.81	15.13	1.53	12151	1.26	21.24
20	308	304	1313	5.03	13.96	1.53	12411	1.24	22.87
21	40	303	1296	5.30	14.31	1.61	12389	1.30	22.48
22	0	261	1370	5.86	13.71	1.62	12292	1.32	22.01
23	0	357	1330	5.41	15.22	1.63	12132	1.35	21.70
24	138	239	1264	5.55	13.44	1.44	12481	1.15	21.76
25	300	277	1316	5.54	14.64	1.62	12256	1.32	22.17
26	258	187	605	5.65	14.59	1.48	12209	1.21	22.63
27	285	149	0	5.24	14.24	1.56	12293	1.27	22.37
28	298	26	383	5.28	14.04	1.54	12339	1.25	22.37
29	186	159	1068	5.40	15.53	1.58	12124	1.31	20.94
30	204	184	1200	5.77	13.05	1.53	12444	1.23	20.66
31	328	344	1284	5.35	12.06	1.63	12619	1.29	20.66
TOTAL-12 7470									
TOTAL-14 8364									
TOTAL-15 31802									
NOTE: WEEKENDS AND HOLIDAYS BASED ON GRAB SAMPLES									
NOTE: VOLATILE MATTER NOT RUN FOR GRAB SAMPLES, AVERAGE OF PREVIOUS DAYS USED									
NOTE: STOCKPILE AS OF 10/31/92 161319.88 TONS									

3.3.5 Problems/Issues

- The following problems were encountered during testing:
  - Lime slurry appeared in the compressed air header and the causes diagnosed.
  - The hose that connects the lime slurry header with the atomizer lance froze as a result of the extreme cold weather.
  - Deposits of fly ash/lime occurred in the flue gas duct as a result of operating with the ceramic spray tip of a broken atomizer, and due to the high erosion of a temporary stainless steel atomizer's spray tip on three atomizers.
  - The atomizer's slurry inlet orifice was plugged by small coal particles entrained by wind into the lime slurry feed tanks, which were not properly covered.

Reports on these problems are included in Appendix E.

- Lime injection efforts have been hampered by continuing problems with the temperature monitoring and recording system. An in-depth study of these problems will include measurement and analysis of the existing plant electrical system and grounds. In the interim, efforts are concentrated on stabilizing the operation of the temperature recorders so that lime injection testing can continue.
- The design of the current nozzle lance assemblies was based on the results of previous testing at Seward Station. However, the atomizer nozzles presently in use for the test program produce an extremely fine spray, many times finer than that produced by the nozzles used in the previous test program. As a result, the large allowances for gravity effects incorporated in the current lance assembly design are not necessary. The current nozzle assemblies do not extend far enough into the duct. Although the lances can be rotated to change the direction of spray, they cannot be raised or lowered. As a temporary measure, the lances have been tilted to cover a greater area. To determine the maximum possible limit of SO₂ removal, these should be replaced with lances of an improved design.

- Experience obtained to date from the current test program indicates that the parametric test program should be extended to June 30, 1992, and split into two parts:
  - Daily batch testing, as currently conducted
  - Continuous testing after the CZD system is automated and integrated with the boiler plant operation

Installation of the modifications needed for continuous operation, originally planned for the conclusion of the test program, will require a longer period for adjustment and stabilization and should be incorporated into the test program now. Testing and debugging of the automatic control system can be performed during the parametric test period. The one-year continuous demonstration can proceed immediately after the conclusion of the continuous parametric test period on or about July 1, 1992.
- Winterization, originally included in the next phase, should be accomplished now to permit continuation of the delayed test program. Without winterization, testing will have to be suspended until next spring, causing additional cost and schedule overruns, and jeopardizing the continued availability of trained test personnel.
- The cost of the CZD demonstration project will increase as a result of the modified and extended parametric test program and the installation of additional equipment and instrumentation. Test operations conducted to date indicate that this equipment and instrumentation are necessary to maintain operating reliability, removal efficiency, and ease of operating control.

3.4 MANAGEMENT AND TRAVEL (WBS No. 1.3.10)

On January 9, representatives from Bechtel, Penelec, PEDDA, NYSEG, and Rockwell Lime met with DOE representatives at PETC to discuss Bechtel's request to reallocate project funds from Budget Period 2 to Budget Period 1. DOE indicated that they were favorably impressed with the progress and initial CZD test results at Penelec. They recommended that, instead of a reallocation of funds, Bechtel immediately submit a Continuation Application for the balance of the project. DOE further recommended that the application address any need for DOE overrun funding.

Bechtel initiated work on the Continuation Application immediately following the January 9 meeting and finalized a new cost estimate to complete the project. All monthly reports required under the Cooperative Agreement were submitted to DOE.

Section 4

PLANNED ACTIVITIES

During the next quarter (February through April 1992), the following work is planned:

4.1 PHASE 2 - CONSTRUCTION AND START-UP

To allow the current test program to proceed without weather-related delays, heat tracing and insulation of process piping and construction of weather enclosures must take place as soon as possible.

All calculations and data reduction will continue to be performed manually until the existing electrical and instrumentation problems are resolved and the Bailey Infi 90 data acquisition, recording, and analysis system is available.

4.2 PHASE 3 - OPERATION AND DISPOSITION

Factorial in-duct lime slurry injection tests will continue with pressure-hydrated dolomitic lime (Type S lime).

To determine the effect on stack opacity during a longer period of in-duct lime slurry injection, a continuous test will be run for 2-3 days, 24 hours per day.

A revised schedule for the parametric test program, showing the originally planned dates, is shown in Figure 4-1.

The current plan assumes no major boiler outages or equipment failure.

4.3 PHASE 3 - PROJECT MANAGEMENT

As results become available from the parametric test program, a Project Evaluation Report and Continuation Application will be prepared to permit their timely submittal.

The completed Continuation Application is expected to be submitted to DOE in late February. Budget Period 1 funds were expended as of the period ending November 24, 1991. Bechtel has continued the test program without interruption based on the expectation of expeditious approval of the Continuation Application.

Figure 4-1 Phase 3A Parametric Test Program Including Equipment Installation for Continuous Run

Appendix A

Description of Project and Work Breakdown Structure

Appendix A

DESCRIPTION OF PROJECT AND WORK BREAKDOWN STRUCTURE

A.1 PROJECT DESCRIPTION

To accomplish the objectives of this project, the test program contains two distinct periods:

- The first period, of six months duration, includes daily factorial runs to test different reagents, atomizers, additives, and slurry concentrations.
- The second period, of one year duration, will demonstrate the performance of the CZD system on a continuous basis under actual power plant operating conditions.

A detailed description of the Work Breakdown Structure for this project, as shown in Figure A-1, is given in subsection A.2. The work is scheduled to be accomplished in three phases as follows:

- Phase 1 work was completed on January 31, 1991. During this phase, Bechtel developed a process design, P&IDs, and performed detailed engineering for a new extended duct to be used in the CZD demonstration in Unit 15 at Penelec's Seward Station. Bechtel wrote all the specifications for equipment and instruments, and started procurement activities. Interface with the appropriate environmental agencies was accomplished through Penelec, with Bechtel providing assistance as needed.
- Phase 2 work was substantially completed by July 31, 1991. This phase included equipment acquisition and installation, facility construction, and start-up operations. Bechtel completed procurement of the equipment, instruments, materials, and fabrication of the new long duct. Penelec performed construction and installation of these items in accordance with specifications prepared by Bechtel. At completion of construction, using Penelec operating and maintenance personnel, Bechtel trained the operators, started all major elements of the CZD system, and verified that the installation and control system functioned according to requirements. During this phase, the installation of equipment and instrumentation was limited to that necessary for parametric testing to be accomplished in Phase 3.

Figure A-1 Work Breakdown Structure (WBS) Diagram

- Phase 3 work will be conducted in two parts. Parametric testing, Phase 3a, was scheduled for the period from June 3, 1991 through November 29, 1991, but the start was delayed until early August. During this period, Bechtel planned to carry out a parametric test program to optimize the performance of the CZD process. The test program is designed to develop operating conditions that will achieve high reliability and low cost operation. Phase 3b is scheduled for December 2, 1991 to July 1, 1993, to complete this demonstration project. Based on the results of the parametric test program, Bechtel will complete additional design, procurement, installation, and facility construction as necessary to permit a one-year continuous demonstration. The CZD system will be fully instrumented and integrated with the operation of Penelec's Unit 15. The goal will be to demonstrate the performance of the CZD process for SO₂ and NO_x removal without significantly affecting either boiler operation or plant particulate emission. Using Penelec operating and maintenance personnel, Bechtel will train the operators, start up, and operate the CZD system. Bechtel will supervise the one-year continuous demonstration, and will carry out various performance tests, data acquisition, and chemical analyses. After the demonstration is completed, the system may remain in operation or the test apparatus may be dismantled and the site restored to its former condition, depending on Penelec's wishes. In either case, the new long straight duct will remain in operation.

To promote the dissemination of technical information to industry during the CZD demonstration, technical papers will be presented at various conferences. These papers will provide non-proprietary technical and economic data, results, and conclusions. The technical papers will also be made available for publication in appropriate journals. Representatives of the utilities will be invited to visit the demonstration site to learn first hand how the CZD process handles SO₂ and NO_x removal from utility flue gas operations.

A.2 WORK BREAKDOWN STRUCTURE DESCRIPTION

The following tasks will be performed during the three phases of the project to demonstrate the cost effective control of SO₂ and NO_x emissions from the pre-NSPS coal-fired utility boiler No. 15 at Penelec's Seward Station:

Phase 1: Design and Permitting

WBS No. 1.1.2 Design and Procurement

- Prepare process flow diagrams for each of the two periods, including material balances and stream properties. Prepare technical specifications for process equipment.
- Prepare detailed designs for the fabrication of the duct extension and its associated construction and installation.

- Prepare site-specific detailed designs for installation of the compressed air system, lime feed system, and atomizers with their related headers and distribution piping, including instruments and controls.
- Prepare technical specifications for procurement of required support equipment, and its associated construction and installation.
- Issue bids for equipment with long delivery times.

WBS No.1.1.3   *Management and Travel*

- **Project Management.** Provide overall management of the work required to complete this phase, including coordination with Penelec and the groups providing project financial assistance. Bechtel's project management plan includes provisions for meetings with the DOE and formal reviews of project work, as well as provisions for submitting reports in accordance with the Federal Assistance Reporting Checklist, Attachment C.
- **Travel.** Bechtel travel includes project management travel to the Penelec site and to DOE's offices for meetings, and travel by the project engineer and other members of the project team as required to complete the task activities. All travel and subsistence to be in accordance with Government regulations.

Phase 2: Construction and Start-up

WBS No. 1.2.1   *Equipment Acquisition and Installation*

- Procure air compressors and electric power supply.
- Procure atomizers.
- Procure instruments and controls.
- Procure lime feed system.
- Procure lime transfer system.
- Provide assistance to Penelec for installation of all process and support equipment, including drawings, specifications, design packages for bidding, and other related design information.

WBS No. 1.2.2   *Facility Construction*

- Approve shop drawings for fabrication of duct extension.
- Provide site engineering support and related assistance to Penelec as required for quality and schedule control.

WBS No. 1.2.3   *Start-up (Checkout) and Operator Training for Parametric Testing*

- Provide start-up engineer to supervise commissioning of all CZD components and systems.
- Train Penelec's operators to run the CZD system and perform the tasks required to conduct parametric testing.
- Establish procedures for coordination of test operations with Penelec's plant management and operations personnel.
- Finalize all elements of Test Plan.

WBS No. 1.2.4   *Construction Management*

- Provide construction management support to Penelec as requested. Penelec will have prime control and responsibility for all construction activities at Seward Station.

WBS No. 1.2.5   *Management and Travel*

- Project Management. Provide overall management of the work required to complete this phase, including coordination with Penelec and the groups providing project financial assistance. Plan and conduct meetings with the DOE and the project team for review of project work. Submit reports in accordance with the Federal Assistance Reporting Checklist, Attachment C.
- Travel. Bechtel travel includes project management travel to the Penelec site and to DOE's offices for meetings, and travel by the project engineer and other members of the project team as required to complete the task activities. All travel and subsistence to be in accordance with Government regulations.

Phase 3: Operation and Disposition

WBS No. 1.3.1   *Lime Procurement*

- Procure all types of lime and other reagents required to conduct parametric and continuous (one-year) test programs.

WBS No. 1.3.2   *CZD Parametric Testing*

- Perform wind tunnel tests on atomizers at the University of California at Davis to determine performance characteristics. Select atomizers to be used in the parametric test program.
- Evaluate performance of electrostatic precipitators (ESPs) during parametric tests. Consult with ESP experts, if necessary, to improve performance.
- Evaluate effects of process variables on emission control performance.

- Determine operating conditions for optimum overall performance.
- Evaluate effects of using alternative coals and reagents:
  - High and medium sulfur coals
  - Alternate reagents including pressure-hydrated dolomitic lime, hydrated calcitic lime, and fresh slaked calcitic lime.

WBS No. 1.3.3 *Completion of Design, Procurement and Installation*

- Based on the results of the parametric tests, complete the design packages and procure all process equipment needed to completely automate and integrate the operation of the CZD system with boiler No. 15 at Seward Station.
- Procure all instruments and controls needed for continuous operation, monitoring, and data collection.

WBS No. 1.3.4 *Completion of Facility Construction*

- Install facilities for lime unloading and storage to support the increased capacity required for continuous operation of the CZD system.
- Insulate piping and provide weather protection and enclosures as required to permit continuous, all-year operation of the CZD system.
- Provide construction management support to Penelec as requested. Penelec will have prime control and responsibility for all construction activities at Seward Station.

WBS No. 1.3.5 *Start-up (Checkout) and Operator Training for Continuous Operation*

- Provide start-up engineer to supervise commissioning of all new CZD components and systems.
- Train Penelec's operators to run the CZD system and perform the tasks required to conduct the one-year continuous demonstration.
- Establish procedures for coordination of data collection and reduction with Penelec's plant management and operations personnel.

WBS No. 1.3.6 *CZD Demonstration with Continuous Operation*

- Operate the CZD system under optimized conditions for one year completely integrated with the power plant operation.
- Measure emission control system performance:
  - SO₂ and NO_x performance tests
  - ESP performance tests
  - ESP performance improvements, if required

- Chemical analysis of solid wastes
- Continuous data recording and acquisition
- Determine power plant impacts.

WBS No. 1.3.7 Duct and Hopper Cleaning

- Perform periodic inspection and cleaning, if necessary, during intervals when the boiler is not operating to determine the long-term extent of duct fouling resulting from CZD system operation.

WBS No. 1.3.8 Data Evaluation and Reporting

- Correlate and evaluate all data collected during the entire CZD test program, including parametric tests as well as continuous operation.
- Summarize key data and test results:
  - Inlet and outlet concentration of SO₂, NO_x, and oxygen
  - Amount of lime used and lime utilization
  - Variation in flue gas temperature during lime slurry injection
  - Variation in ESP recorded data
  - Variation in percent opacity at the stack
  - Lime deposition on duct surfaces
- Use technological, economic, environmental, and operating evaluations from the demonstration project to prepare Demonstration Test Reports and a Technology Performance and Economic Evaluation Report.

WBS No. 1.3.9 Disposition

- Disposition of the CZD system equipment installation:
  - The new long straight duct will remain in operation.
  - The disposition of all other equipment (continued operation or removal and storage) will be decided by Penelec.

WBS No. 1.3.10 Management and Travel

- Project Management. Provide overall management of the work required to complete this phase, including coordination with Penelec and the groups providing project financial assistance. Plan and conduct meetings with the DOE and the project team for review of project work. Submit reports in accordance with the Federal Assistance Reporting Checklist, Attachment C.
- Travel. Bechtel travel includes project management travel to the Penelec site and to DOE's offices for meetings, and travel by the project engineer

and other members of the project team as required to complete the task activities. All travel and subsistence to be in accordance with Government regulations.

Appendix B

Report Distribution List

Appendix B
REPORT DISTRIBUTION LIST

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Appendix C

Daily Results of Parametric Tests with In-Duct Lime Slurry Injection

November 1990 through January 1991

Friday, November 1, 1991

Started Water Injection	12:45 p.m.
Started Lime Slurry Injection	1:45 p.m. (1345)
Stopped Lime Slurry Injection	2:55 p.m. (1455)
Continued Water Injection Up To	3:30 p.m. (1530)

The lime slurry injection was made with hydrated calcitic lime at a concentration of 4.9% to 6.5%, with an average of 5.5% (1.0825 sp gravity).

Boiler load was 145 MW.

At a 49 gpm lime slurry feed rate, the temperature of the duct walls was O.K. (above 160°F).

At C-cross section, the temperature of the thermocouples was above 160°F, except for a short duration when C1.4 and C1.5 decreased to 142.0°F and 138.6°F respectively, and then it suddenly started to increase. We do not yet have an explanation for this change in temperature during constant conditions of operation.

Of the 20 atomizers, only 16 were in operation (#5, #6, #8, and #9 were shut off).

The SO₂ concentration in the inlet flue gas varied between 897 ppm and 867 ppm with an average of 875 ppm. The outlet SO₂ varied from 537 ppm to 559 ppm with an average of 547 ppm. Based on our calculations, the percent of SO₂ removal was 26.6%, and the lime utilization 52%.

When all the hydrated calcitic lime in the lime storage silo is consumed, we will start injecting pressure-hydrated dolomitic lime.

Opacity in the stack before the water and lime slurry injection was about 10%; during the water and lime slurry injection, it was 8%. After the lime slurry injection and subsequent water injection were stopped, opacity in the stack increased for a few hours to 15%.

Thursday, November 14, 1991

Started Water Injection	8:45 a.m.
Started Lime Slurry Injection	9:30 a.m.
Stopped Lime Slurry Injection	2:30 p.m. (1430)
Continued Water Injection Up To	4:00 p.m. (1600)

The lime slurry injection was made with hydrated calcitic lime at a concentration of 9% to 11.4%, with an average of 10.3% (1.0975 specific gravity).

At 50 gpm lime slurry feed rate, the temperature of the duct walls was O.K. (above 162°F) with the exception of TP-32 at 130.3°F, and TP-184 at 152.6°F. TP-32 is 29 ft from the atomizers and TP-184 104 ft from the atomizers. We still do not know why these two spots are much colder than all the other 58 spots measured by thermocouple lances located 6 in. from the duct walls.

Of the 20 atomizers, 17 were in operation and 3 were shut off to adjust to the flue gas distribution in the duct. The lime slurry flow rate injected into the duct was maintained at about 50 gpm.

The SO₂ concentration in the inlet flue gas varied between 911 ppm and 956 ppm with an average of 933 ppm; and the outlet SO₂ varied from 486 ppm to 537 ppm with an average of 509 ppm. Based on our calculations, SO₂ removal was 36.1%, and lime utilization was 38.5%.

Opacity in the stack before the water and lime slurry injection was 10%; during the water and lime slurry injection, it was about 8%. After the lime slurry and subsequent water injection were stopped, the stack opacity increased for a few hours to 15%.

Most of the hydrated calcitic lime stored in the lime silos was consumed. The next day the silo will be filled with pressure-hydrated dolomitic lime.

Friday, November 15, 1991

Started Water Injection	9:15 a.m.
Started Lime Slurry Injection	11:30 a.m.
Stopped Lime Slurry Injection	2:10 p.m. (1410)
Continued Water Injection (11 gpm) Up To	6:00 p.m. (1800)

The lime slurry injection was made with pressure-hydrated dolomitic lime at a concentration of 11.5% (1.064 specific gravity). The lime slurry fed to the atomizers was 48 gpm until 12:30 p.m., 50 gpm until 1:40 p.m., and then 53 gpm until 2:10 p.m.

At the 53 gpm lime slurry feed rate the atomizers, the temperature of the duct walls was O.K. (above 170°F) except for TP-32 (149.1°F), TP-72 (141.8°F), and TP-112 (148.1°F).

All the atomizers were in operation for the 50 gpm and 53 gpm lime slurry injections.

The attached charts show:

- The temperature at C-cross section in front of the turning vanes varied from 170°F to 207°F at the 50 gpm lime slurry injection rate.
- The skin temperature at the bottom of the duct and at the lower side of the duct walls was around 260°F, indicating that there were no water or deposits on the bottom of the duct.
- The 1-minute average of the duct opacity (CA-100) was 10.8% and in the stack (CA-200) it was 11.7% opacity.

The SO₂ concentration in the inlet flue gas varied between 971 ppm to 927 ppm with an average of 957 ppm, and the outlet SO₂ varied from 493 ppm to 468.5 ppm with an average of 482.2 ppm. Based on our calculations, the percent of SO₂ removal was 41.1. Stack opacity before water and lime slurry were injected was about 15%; during the water injection it was 12%; during the lime slurry injection it was 11-12%; and after the water injection was shut off, opacity went up to 16-17%. As before, we started injecting pressure-hydrated dolomitic lime with a mixture of hydrated calcitic lime slurry that remained in the bottom of the sump and feed tank.

Tuesday, November 19, 1991

Started Water Injection	11:00 a.m.
Started Lime Slurry Injection	11:30 a.m.
Stopped Lime Slurry	4:04 p.m. (1604)
Continued Water Injection Up To	5:05 p.m. (1705)

The lime slurry injection was made with pressure-hydrated dolomitic lime at a concentration of 12.5% (1.075 specific gravity).

The boiler load was 145 MW.

At a 50 gpm lime slurry injection rate, the duct wall temperature was O.K. (above 170°F) except a few colder spots (TP-32 at 136°F, 29 ft from the atomizers; TP-72 at 148°F, 44 ft from the atomizers; and TP-112 at 146.3°F, 74 ft from the atomizers). At the same 50 gpm lime slurry injection rate, the flue gas temperature at the C-cross section in front of the turning vanes was O.K. (above 162°F) except C-23, at 156.2°F and C-24 at 159.1°F. All 20 atomizers were in operation.

The analysis of the day's operation was made for three distinct periods, with the following results:

Time	SO ₂ Inlet ppm	SO ₂ Outlet ppm	SO ₂ Removal %	Alkali Utilization %
1130 – 1500	94.5	490.5	38.64	30.18
1500 – 1603	961.6	511.8	36.88	25.78
1130 – 1355	946.5	467.7	40.98	32.06

The stack opacity before the water and lime slurry injection was 10%; during the water and lime injection, the opacity came down to about 8%; and after the water injection was shut off, it increased to about 15% until 22:00.

Wednesday, November 20, 1991

Started Water Injection	9:45 a.m.
Started Lime Slurry Injection	12:00 noon
Stopped Lime Slurry Injection	2:30 p.m. (1430)
Continued Water Injection (10 gpm) To	3:00 p.m. (1500)

The lime slurry injection with pressure-hydrated dolomitic lime was made at a concentration of 9.9% (1.0570 specific gravity).

At a 50 gpm lime slurry injection rate, the temperature of the duct walls was O.K. (above 170°F) except a few colder spots (TP-32 at 29 ft from the atomizers with 119°F; TP-72 at 44 ft from the atomizers with 120°F; and TP-111 at 74 ft from the atomizers at 139.7°F). All these colder spots are on the same duct wall and at about the same distance from the duct ceiling. By trial and error, the side atomizers were rotated away from the wall to eliminate the wall's colder spots.

At the same 50 gpm lime slurry injection rate, the attached recorded temperature data at C-cross section in front of the turning vanes show temperatures above 160°F, except C-5 with 144.3°F, C-4 with 153.0°F, and C-3 with 158.8°F, although the average temperature at C-cross section was 179.6°F. It is expected that the new atomizer lances, in new arrangement, will correct the large temperature differences. The attached recorded skin temperature data at the duct bottom show values above 250°F, indicating that no deposits or water are on the duct bottom.

At a 50 gpm lime slurry injection rate, the inlet SO₂ concentration in the flue gas was 954.5 ppm; the outlet was 524.9 ppm; the calculated SO₂ removal was 35.2%; and the lime utilization was 35.8%.

The attached graph recording the stack opacity shows that before the water and lime slurry injection, the opacity was about 16%. During the water and lime injection the opacity was reduced to about 8%; and after the water injection was shut off, the opacity went up to 16-17% for a few hours.

Wednesday, December 11, 1991

Started Water Injection	10:00 a.m.
Started Lime Slurry Injection	1:00 p.m. (1300)
Stopped Lime Slurry Injection	3:30 p.m. (1530)
Continued Water Injection Up To	6:30 p.m. (1830)

The lime slurry injection was made with pressure-hydrated dolomitic lime at a concentration of 8.4% (1.0480 specific gravity).

At C-cross section with a 43.8 gpm lime slurry injection rate and an average flue gas temperature of 152°F, SO₂ removal was 56.7%. The boiler load was 113 MW instead of 147 MW, and the inlet flue gas temperature was only 272°F. In these conditions, the 43.8 gpm lime slurry injection was too much, reducing the C-section average flue gas temperature to 152°F, instead of 165-170°F.

The attached recorded data show that the Buell ESP for the B-duct has 823 miliamps and 3 sparks/minute versus the ESP of the A-duct with only 539 miliamps and a high sparking rate of 15 sparks/minute. This means that the lime slurry injection in the B-duct reduced the resistivity and increased the ESP particulate removal efficiency. The stack opacity, according to the attached recorded graph, was 12.8% under these operating conditions.

From 1:25 p.m. to 2:10 p.m., SO₂ removal at a 44.5 gpm injection rate was calculated at 59.5%, with a lime utilization rates of 48.26%.

To avoid deposition of solids in the turning vanes, the lime slurry injection rate — at a low boiler load and low inlet flue gas temperature — should be limited so that the C-cross section average temperature does not descend below 165°F.

Monday, December 16, 1991

Started Water Injection	11:00 a.m.
Started Lime Slurry Injection	2:55 p.m. (1455)
Stopped Lime Slurry Injection	5:15 p.m. (1715)
Continued Water Injection Up To	7:00 p.m. (1900)

The lime slurry injection was made with pressure-hydrated dolomitic lime, at a concentration of 8.4% (1.048 specific gravity).

At C-cross section with a 40 gpm lime slurry injection at from 3:00 to 4:00 p.m., the temperature was good; but as the outside temperature started to decrease, the in-duct temperature decreased from 284°F to 264°F; and at 16:53 the temperature at the C-cross section decreased to an average of 146°F from 165°F.

The attached recorded data show that the Buell ESP for the B-duct in the first field has 849 miliamps versus the Buell ESP for the A-duct — where no injection takes place — which has 247 miliamps in the first field. The much higher amps and low sparking rate/minute indicate a much higher particulate removal efficiency due to the lime slurry injection into the B-duct.

The average SO₂ concentration in the inlet flue gas was 883.7 ppm and at the outlet 425.1 ppm. The calculated SO₂ removal was 42.32% and the lime utilization 49.14%, with a lime slurry injection rate of 36.5 gpm.

According to the attached recorded graph, the stack opacity was 12% during the water and lime injection, 17% before injection, and 18% after stopping the water injection.

To avoid deposition of solids in the turning vanes, the lime slurry injection rate — at a low boiler load and low inlet flue gas temperature — should be limited so that the C-cross section average temperature does not descend below 165°F.

Wednesday, December 18, 1991

Started Water Injection	9:00 a.m.
Started Lime Slurry Injection	11:30 a.m.
Stopped Lime Slurry Injection	1:45 p.m. (1345)
Continued Water Injection Up To	4:00 p.m. (1600)

The lime slurry injection was made with pressure hydrated dolomitic lime, 7.5% concentration (1.046 specific gravity).

At C-cross section with 42.3 gpm lime slurry injection rate, the average temperature was 155°F, and with a low temperature spot of 133.4°F. This temperature is too low and has to be avoided.

The average SO₂ concentration in the inlet flue gas was 896.1 ppm and at the outlet 415.7 ppm. The calculated SO₂ removal was 44.03%, and the calculated total alkali utilization was 51.69%.

The stack opacity, according to the attached recorded graph, was 12% during the water and lime injection, 17% before injection, and 18% after stopping the water injection.

The low temperature of the flue gas at C-cross section – 133.4°F – should be avoided.

Thursday, December 19, 1991

Started Water Injection	12:30 p.m.
Started Lime Slurry Injection	2:00 p.m. (1400)
Stopped Lime Slurry Injection	4:20 p.m. (1620)
Continued Water Injection Up To	10:00 p.m. (2000)

The lime slurry was made with pressure-hydrated dolomitic lime, 8.0% concentration (1.046 specific gravity).

At C-cross section with 37.5 gpm lime slurry injection rate, the average temperature of the thermocouples was 169.11°F, and the coldest spot was 149°F at C-13. It is preferable that the coldest spot not be lower than 160°F.

The average SO₂ concentration in the inlet flue gas was 896.4 ppm; at the outlet flue gas it was 471.9 ppm. The calculated SO₂ removal was 36.4% and the total alkali utilization was 45.63%.

The flue gas dilution, calculated based on oxygen concentration at the flue gas inlet (6.53%) and at the flue gas outlet (8.45%), was 29.4%. During the annual boiler outage in February 1992, the elbow of the duct going into the I.D. fan will be replaced with a new one because of high corrosion. This will substantially reduce the air leakage.

Friday, December 20, 1991

Started Water Injection	11:45 a.m.
Started Lime Slurry Injection	1:00 p.m. (1300)
Stopped Lime Slurry Injection	2:50 p.m. (1450)
Continued Water Injection Up To	4:45 p.m. (1645)

The lime slurry injection was made with pressure hydrated dolomitic lime, 9.4% concentration (1.054 at 62°F specific gravity).

At 2:11 p.m. at the C-cross section, the average temperature of the 20 thermocouples was 176.5°F with the lowest spot at 150.6°F. The average SO₂ concentration in the inlet flue gas was 925.6 ppm and at the outlet 500.7 ppm. The calculated SO₂ removal was 35.4% and calculated total alkali utilization 41.9%.

Stack opacity during the water and lime slurry injections was 10%. Before starting the water injection, the stack opacity was 14%; after stopping the water injection, the stack opacity increased to 17%.

The 26°F difference between the lowest temperature of 150.6°F at C-31 and the average temperature of 176.5°F at C-cross section is too large. A better arrangement between the atomizer lances should be made to correct this large difference in temperature to permit an increase in the lime slurry flow rate from 34.4 gpm to above 45 gpm and to substantially increase the percent of SO₂ removal.

Tuesday, December 31, 1991

Started Water Injection	8:00 a.m.
Started Lime Slurry Injection	11:30 a.m.
Stopped Lime Slurry Injection	1:50 p.m. (1350)
Continued Water Injection Up To	3:30 p.m. (1530)

The lime slurry injection was made with pressure hydrated dolomitic lime, 10.9% concentration (1.0632 at 62°F specific gravity).

At C-cross section with 45.5 gpm lime slurry injection rate, the average temperature was 152.3°F, with one cold spot of 122°F, although the inlet flue gas temperature was 298°F. It looks like the front atomizer lances were wrongly rotated, converging the atomized slurry into one spot. This situation should be avoided in the future.

The average SO₂ concentration in the inlet flue gas was 953 ppm; at the outlet it was 453 ppm. The calculated SO₂ removal was 41.6% and the total alkali utilization was 33%.

The stack opacity varied between 8% and 11% percent during the lime injection, with 13% before injection and 11% opacity after ending the water injection. During the water and lime slurry injections the Buell "D" electrostatic precipitator showed a much higher particulate removal performance than the C-ESP that treat the other half of the boiler flue gas. The attached recorded data about the ESP operation show the following:

	C-Buell				D-Buell (For CZD)			
	First Field	Second Field	Third Field	Fourth Field	First Field	Second Field	Third Field	Fourth Field
Miliamps	523	591	404	715	821	821	848	1.019
k V		40	42.9	44.6	38.4	37.9	383	33.8
Sparking/ Minute	15	11.3	16.5	8.6	3	3	3	3

Monday, January 6, 1992

Started Water Injection	8:30 a.m.
Started Lime Slurry Injection	11:40 a.m.
Stopped Lime Slurry Injection	2:28 p.m. (1428)
Continued Water Injection Up To	4:15 p.m. (1615)

The lime slurry injection was made with pressure hydrated dolomitic lime, 9% concentration (1.053 specific gravity).

The lowest temperature, which occurred 6 in. from the duct walls, was about 141.2°F at a lime slurry injection rate of 34.4 gpm, and an inlet flue gas temperature of 275°F. At about 1:15 p.m., the inlet flue gas temperature increased to 282°F.

At C-cross section with a 34.4 gpm lime slurry injection rate, the average temperature of the flue gas at 1:22 p.m. was 176.6°F, with the lowest at 158.1°F.

The attached recorded data show that Buell ESP for the B-duct maintains an opacity of 17-18% with no injection of water or lime slurry. The opacity decreases to about 10% with 27 gpm water injection and to 9.6-9.8% with 34.4 gpm lime slurry injection. After stopping the lime slurry injection and continuing the water injection the duct opacity remained unchanged. During this period, the stack opacity varied from 10% to 17% due to the high particulate emission of units 12 and 14 that discharged their flue gas in the common stack. The boiler load of unit #15 was maintained at 146-147 MW.

During the water and lime injection, the Buell ESP connected with the B-duct shows high miliamps and kV (828 miliamps and 36.56 kV) in the first field and a sparking rate of less than 3 sparks/sec versus the C-ESP connected with the other duct without CZD, which has low miliamps and kV but a high sparking rate (262 miliamps and 16.8 sparks/minute).

The average SO₂ concentration in the inlet flue gas was 908.9 ppm and in the outlet flue gas was 496.4 ppm. The calculated percent of SO₂ removal was 33.8% and the lime utilization was 40.5%. At a higher inlet temperature, the lime slurry flow rate could be increased, thereby increasing the % of SO₂ removal.

Tuesday, January 7, 1992

Started Water Injection	11:20 a.m.
Started Lime Slurry Injection	12:45 p.m.
Stopped Lime Slurry Injection	4:45 p.m. (1645)
Continued Water Injection Up To	10:00 p.m. (2200)

The lime slurry injection was made with pressure-hydrated dolomitic lime, 7% concentration (1.0405 specific gravity at 60°F).

At a lime slurry injection rate of 39.5 gpm and inlet flue gas temperature of 285°F, the C-cross section temperature at 15:01 p.m. was 157.7°F average, with a minimum of 138.9°F.

At a 6 in. distance from the duct walls, the lowest spot temperature was at TP-34 (29 ft. from the atomizers) with 131.3°F, and at TP-114 (74 ft. from the atomizers) with 135.8°F, when 39.5 gpm lime slurry was injected.

The average SO₂ concentration in the inlet flue gas was 951.4 ppm, and in the outlet flue gas was 504.9 ppm. The calculated percent SO₂ removal was 33.82% and the total alkali utilization was 48.36%.

The ESP recorded data show high miliamps and a low sparking rate for D-ESP as follows: first field, 801 miliamps and 2.966 sparks/min; second field, 797 miliamps and 3.0 sparks/min; third field, 832 miliamps and 3.064 sparks/min; and fourth field, 1,417 miliamps and 3.192 sparks/min versus the C-ESP (for the A-duct without CZD) with a first field of 621 miliamps and 13.07 sparks/min; second field, 569 miliamps and 12.24 sparks/min; third field, 777 miliamps and 12.45 sparks/min; and the fourth field, 869 miliamps and 2.915 sparks/min.

The % opacity before water injection was 9.4%, during the water injection it was 5.53%; and during the lime slurry injection it was 5.55%.

Wednesday, January 8, 1992

Started Water Injection	12:30 p.m.
Started Lime Slurry Injection	1:09 p.m. (1309)
Stopped Lime Slurry Injection	4:45 p.m. (1645)
Continued Water Injection Up To	7:00 p.m. (1900)

Lime slurry with pressure hydrated dolomitic lime, 7% concentration (1.039 specific gravity).

At a lime slurry injection rate of 41 gpm, boiler load of 123 MW and flue gas inlet temperature of 297°F, the C-cross section temperature at 4:05 p.m. was:

Average C-Cross Section Temperature	=	158.6°F
Lowest C-Cross Section Temperature	=	146.7°F at C-32

At a 6-in. distance from the duct walls, the lowest spot temperature was at TP-114 (74 ft. from the atomizers) with 124.5°F. This low temperature could cause the deposition of wet solids on the duct walls. At low boiler load operation (123 MW instead of 147 MW at regular operation) the amount of lime slurry injection has to be limited by the amount of heat available in the incoming flue gas to evaporate it.

The attached recorded data show that the Buell ESP for the flue gas duct with the CZD works better than the one without the CZD (with higher miliamps and a lower sparking rate per minute) for all their 4 fields.

During lime slurry injection the stack opacity is really low at 4.8% to 7.6%.

The average SO₂ concentration in the inlet flue gas was 873 ppm and in the outlet flue gas was 414 ppm. The calculated percent of SO₂ removal was 42.1% and the total alkali utilization was 50.8%.

Thursday, January 9, 1992

Started Water Injection	1:15 p.m. (1315)
Started Lime Slurry Injection	2:00 p.m. (1400)
Stopped Lime Slurry Injection	4:45 p.m. (1645)
Continued Water Injection Up To	6:00 p.m. (1800)

Lime slurry with pressure hydrated dolomitic lime, 9.7% concentration (1.058 specific gravity).

At a lime slurry injection rate of 44.6 gpm, a boiler load of 129 MW and an inlet flue gas temperature of 296°F, the C-cross section average temperature at 4:00 p.m. was 165°F, and the lowest temperature was 145.9°F.

At a 6 in. distance from the duct walls, the lowest spot temperature was at TP-62 (35 ft. from the atomizers) with 119°F. This low spot temperature will cause the deposition of wet solids on the duct walls.

The attached recorded data show that the Buell ESP for the flue gas duct with the CZD is working better than the one without the CZD for all four fields (with higher amps and a lower sparking rate per minute).

During lime slurry injection the stack opacity varied from 5.5% to 6.3%.

The average SO₂ concentration in the inlet flue gas was 883 ppm and in the outlet flue gas was 386 ppm. The calculated percent of SO₂ removal was 44% and the total alkali utilization was 33.4%.

Friday, January 10, 1992

Started Water Injection	12:00 noon
Started Lime Slurry Injection	12:30 p.m.
Stopped Lime Slurry Injection	1:50 p.m. (1350)
Continued Water Injection Up To	3:15 p.m. (1515)

Lime slurry with pressure hydrated dolomitic lime, 10.2% concentration (1.058 specific gravity).

At a lime slurry injection rate of 44.1 gpm, a boiler load of 127 MW and an inlet flue gas temperature of 289°F, the C-cross section average temperature at 3:18 p.m. was 159.5°F and the lowest temperature was 149.2°F.

The attached recorded data show that the Buell ESP for the flue gas duct with the CZD is working better than the ESP connected to the flue gas duct without CZD, by taking higher amps.

During the lime slurry injection, the stack opacity was very low (4-5%).

The average SO₂ concentration in the inlet flue gas was 842 ppm and in the outlet flue gas was 383 ppm. The calculated percent of SO₂ removal was 44% and the total alkali utilization was 33.2%.

Monday, January 13, 1992

Started Water Injection	9:00 a.m.
Started Lime Slurry Injection	12:05 p.m.
Stopped Lime Slurry Injection	2:50 p.m. (1450)
Continued Water Injection Up To	4:00 p.m. (1600)

Lime slurry with pressure hydrated dolomitic lime, 84% concentration (1.046 specific gravity).

At a lime slurry injection rate of 42.3 gpm, a boiler load of 145 MW and an inlet flue gas temperature of 288°F, the C-cross section average temperature was 162.3°F and the lowest temperature was 147.4°F.

During lime slurry injection the stack opacity was limited to less than 7%.

The average SO₂ concentration in the inlet flue gas was 906.5 ppm and in the outlet flue gas was 448.4 ppm. The calculated percent of SO₂ removal was 38.3% and the total alkali utilization was 41.9%.

Tuesday, January 14, 1992

Started Water Injection	7:00 a.m.
Started Lime Slurry Injection	12:00 noon
Stopped Lime Slurry Injection	4:00 p.m. (1600)
Continued Water Injection Up To	8:00 p.m. (2000)

Lime slurry with pressure hydrated dolomitic lime, 8% concentration (1.046 at specific gravity).

At a lime slurry injection rate of 42.2 gpm, a boiler load of 145 MW and an inlet flue gas temperature of 283°F, the C-cross section average temperature at 12:00 noon was 156.8°F and the lowest temperature was 142.2°F at C-2 and C-14.

At 3 :38 p.m. the inlet flue gas temperature decreased from 283°F to 270°F. At that time the average flue gas temperature at C-cross section had decreased to 154.4°F, with the lowest temperature of 134.6°F at C-14. These temperatures are too low for the C-cross section that is close to the turning vanes. The lime slurry flow rate should be lower to avoid wetting the turning vanes.

At a 6-in. distance from the duct walls, the low temperatures at TP-14 (127.1°F), TP-111 (126.5°F), TP-114 is (125.6°F) and TP-142 (133.3°F) could cause the deposition of wet solids on the duct walls and should be avoided by reducing the lime slurry flow rate.

During lime slurry injection the stack opacity varied between 6 and 7%.

The average SO₂ concentration in the inlet flue gas was 937 ppm and in the outlet flue gas was 462.9 ppm. The calculated percent SO₂ removal was 39.16% and the total alkali utilization was 45.72%.

Thursday, January 30, 1992

Started Water Injection	11:00 a.m.
Started Lime Slurry Injection	12:53 p.m.
Stopped Lime Slurry Injection	2:53 p.m. (1453)
Continued Water Injection Up To	4:45 p.m. (1645)

Lime slurry with pressure hydrated dolomitic lime, 8.2% concentration (1.047 specific gravity).

At a lime slurry injection rate of 38.4 gpm, a boiler load of 147 MW and an inlet flue gas temperature of 264°F, the C-cross section average temperature at 2:20 p.m. was 166°F and the lowest temperature was 150.4°F at C-22. The low temperature of the inlet flue gas (264°F) limited the lime slurry injection rate to about 38.4 gpm to maintain a flue gas temperature of not less than 150°F at C-cross section.

The arrangement of the atomizer lances (slope and rotation, and the variation of the lime slurry injection rate per atomizer from zero to 3.0 gpm) was not good because it caused low temperatures 6 in. from the duct side walls at TP-32 with 116.8°F (29 ft from the atomizers). Of the 20 atomizers, 3 were off, 5 were injecting 1.5 gpm each, 7 were injecting 2.5 gpm each, and 5 were injecting 3 gpm each. The existing atomizer lances have to be changed to make the distribution of the atomized slurry more uniform in the duct without cold spots on the duct walls or too hot spots at the C-cross section.

During the lime slurry injection, the stack opacity was about 8%. Before the injection, it was 10%, and after the injection it was again 10%.

The average SO₂ concentration in the inlet flue gas was 966 ppm and in the outlet flue gas was 563 ppm. The calculated percent of SO₂ removal was 28.8% and the total alkali utilization was 40.3%.

Appendix D

Continuous Monitoring System Problem Areas and Corrective Actions

5.0 Problem Areas and Corrective Actions

5.1 SO₂/NOx/O₂ CEMS problems using the Lear-Siegler SM-8100 and CM-60 systems to monitor CZD inlet and outlet concentrations.

5.1.1 Interference of SO₂ with the NOx Measurement in a Lear Siegler SM-8100

It is known that at the wavelength of ultraviolet light at which the SM-8100 measures NO gas, SO₂ interferes causing the NO response to indicate concentrations higher than actual (see Figures 1 and 2 from the LSI SM-8100 Technical Instruction Manual). This requires the interference level to be compensated for by using SO₂ gas approximating normal concentrations. To prevent false high readings of NO from being reported, calibration gas of SO₂ in nitrogen is purchased to simulate the level of SO₂ normally emitted from Seward Boiler 15. Reviewing historical data from the earlier CZD project, this level was determined to be around 900 ppm SO₂. By flowing the 900 ppm SO₂/N₂ calibration gas into the SM-8100 and adjusting the NO channel to read zero, the interference from the normal level of SO₂ in the stack gas is minimized. Therefore, it is also necessary to include 900 ppm of SO₂ in the low, mid, and high range NO calibration gases so that the SM-8100 response to changes in the level of NO present can be checked at that level of SO₂ which will not affect the NO signal. Penelec has used this method to successfully measure SO₂ and NOx at several boilers using LSI SM-810 and SM-8100 monitors. However, these other sites are not involved in SO₂ reduction and the level of SO₂ present is consistent due to the tight control on fuel purchases.

The problem at Seward Boiler 15 involves the CZD outlet monitor. Dependent upon the lime slurry concentration and injection rate, the concentration of SO₂ can vary greatly. Therefore, it would be impossible to accurately measure NO at the outlet of the CZD process under all conditions using an LSI 8100 system without having NO/SO₂ gases to compensate for all concentrations of SO₂ which will be measured.

Because the outlet SM-8100 has been adjusted so that 900 ppm of SO₂ will not interfere with the measurement of NO emissions, during time periods of CZD operation when SO₂ levels decrease well below 900 ppm, the reported concentration of NO at the outlet of the process will be artificially high.

If parametric testing could predict a fairly constant level of SO_2 emissions downstream from the active CZD process (say 450 ppm for instance) the outlet LSI SM-8100 could be adjusted such that 450 ppm of SO_2 has no effect on the measured NO values. This would require the purchase of four additional cylinders of calibration gas (450 ppm SO_2 in nitrogen and low, mid, and high range NO calibration gases each containing 450 ppm of SO_2). However, if the CZD process were stopped and the level of SO_2 at the outlet increased to the normal 900 ppm, the values of NO from the outlet monitor would then be artificially low. Again, this type of system can not be used to accurately measure NO from a process with highly variable levels of SO_2 (like CZD) without adjustment to compensate for all conditions.

5.1.2 Temperature Effects on the Measurement of SO_2 and NOx Using a Lear-Siegler SM-8100

The measurement of SO_2 and NO molecules by the attenuation of ultraviolet energy (the method employed by SM-8100 systems) is temperature dependent. That is, the response of these systems to a fixed level of molecules will change as the temperature of the gas changes. This is known by the manufacturer and a thermocouple is incorporated at the end of the monitor probe in an attempt to compensate the transceiver output for changes in the gas temperature. Although the manufacturer claims that by including the signal from the thermocouple in the circuitry will achieve fullrange temperature compensation (this signal is used as a gain modification to the transceiving output signal), this claim is simply not true. Although the thermocouple does indeed modify the output of the system, it cannot be relied upon to provide the proper gain correction such that these systems report accurate values of SO_2 and NO throughout a wide range of temperatures. Normally, this would not be a problem because the temperature of the stack gas does not change drastically on an uncontrolled coal-fired boiler except during start-up and shutdown. It does, however, result in difficulties for a process like CZD which causes cooling of the stack gases during operation.

When an SM-8100 system is adjusted to accurately measure the concentration of calibration gases at the normal stack operating temperature, it will accurately measure SO_2 and NO emissions continuously. However, during boiler start-up, when the stack gas is below the normal stack temperatures, the reported levels of SO_2 and NO from these systems are artificially low. Penelec typically invalidates the first 12 to 24 hours of data during a cold start-up on any boiler equipped with an SM-810 or SM-8100 system. That is typically the timeframe it takes the stack gas to reach normal operating temperature. This is done because system outputs are known to be inaccurate prior to the stack reaching these temperatures.

What we have observed at Seward is a normal operating temperature of about 290-300°F. With the inlet and outlet systems adjusted to operate properly in that temperature range, water injection was initiated. The CZD process, depending on boiler load and injection rate, will cause the temperature at the outlet location to drop to approximately 210-230°F. Once the gas has cooled to this temperature, the calibration gases are introduced into the measurement probe. The concentration of SO₂ and NO reported by the SM-1800 is about 100 ppm lower than the true cylinder concentration under the reduced temperature conditions.

To properly document SO₂ reductions during operation of CZD, it was decided the outlet system had to be adjusted to read properly at the cooler temperatures present during actual CZD operation. While injecting water, the outlet gas was cooled, and the SM-8100 was adjusted to read the calibration gases accurately. Because the daily calibration (zero/span) normally occurs early in the morning prior to CZD parametric testing, the designated calibration values to which the system must respond had to be changed.

By ceasing water injection and allowing the gas to return to normal temperature and flowing the calibration gases again, we documented the correct system response to hot calibration gas for a system adjusted to accurately measure cooler calibration gas. Therefore, two sets of calibration gas designated values had to be documented. During active CZD operation when the stack gas is cooler, the designated value that we use to adjust the analyzer is the actual cylinder concentration reported by the calibration gas manufacturer. For normal calibrations when CZD is not operating, the designated value is the system's documented response to calibration gas with CZD or water injection off, after the system was set up with CZD on. These values are higher than the true cylinder gas concentrations.

5.1.3 Problems with Accurately Measuring Oxygen Levels with the LSI CM-60 Monitor

One of the most difficult things about the system is the inability to detect oxygen sensor malfunctions using calibration gas cylinders. This instrument incorporates a replaceable zirconium oxide fuel cell type sensor located at the probe end. When the cell malfunctions, the reported oxygen values may begin going higher or lower than actual. However, the system will respond properly to calibration gas. The only reliable way to detect this problem is to compare U.S. EPA Reference Method 3 (Orsat analyzer) to the oxygen analyzer output corrected to dry basis conditions. Soon after these systems were operational, we

noticed that the inlet system consistently produced higher pounds per million BTU values than the outlet system when no injection was taking place. The inlet O₂ monitor was passing daily calibration zero/span checks, but an accuracy check with the RM 3 Orsat showed the oxygen monitor was reporting values about 1.5 percent oxygen higher than actual. Other than periodic checks with an RM 3 Orsat, we know of no way to detect an aging sensor.

5.1.4 Inlet SM-8100 NOx Response to Water or Lime Injection

Once water injection begins, the reported NOx values from the inlet SM-8100 rise sharply from about 0.65 lbs/10⁶ BTU to about 1.00 lbs NOx/10⁶ BTU. Reference method testing conducted during CZD injection show no change in true boiler NOx emissions during CZD operation. Yet, the inlet SM-8100 indicates a large increase in NOx upstream of the CZD process. Obviously, this does not reflect actual concentrations since water injection can't possibly affect the upstream concentration of NO in the gas stream. We have yet to identify the cause for this observation. Further work will focus on whether the output from the transceiver changes during injection or if the problem is in the Unicon (the transceiver signal processor).

If there isn't any change in transceiver output during CZD operation, the problem must be related to operating both the inlet and outlet transceivers using a single Unicon.

6.0 Trends and Recommendations

6.1 Continuous Monitoring of Inlet and Outlet SO₂ and NOx Relating to CZD

Based on the inherent measurement difficulties encountered with using the Lear-Siegler SM-8100 for SO₂ and NOx and the CM-60 for oxygen detailed in Section 5 of this report, it is strongly recommended that these types of systems be replaced with an alternate system if we are to make any progress in accurately documenting the performance of the CZD demonstration. The fact that the NOx values from the inlet SM-8100 artificially increase each time CZD is activated, coupled with the interference of SO₂ with the NOx measurement causing artificially high NOx values being reported from the outlet during CZD operation leads to the conclusion that no serious work concerning the effects of CZD on NOx emissions could possibly be conducted with these types of continuous monitors.

In addition, the limitation of the outlet system to correctly measure levels of SO₂ or NO_x under conditions of variable temperature, such as is involved with the CZD process, must also cast doubt on the ability of this kind of monitoring system to accurately quantify SO₂ reductions due to the CZD process. At the very least, two Unicon signal processors will be required to separately analyze the inlet and outlet transceiver signals.

The calibration response deficiency problems with the oxygen monitor also results in potential inaccuracy in reported values.

Because of all of these difficulties, it becomes apparent that to date, only gross trends relating CZD injection to SO₂ or NO_x reductions can be documented.

To collect meaningful monitoring information so accurate removal rates can be documented will require a system unaffected by changes in gas temperature, moisture or pollutant levels. It must also operate in a fashion where dynamic gas calibrations provide meaningful indications of system performance. In addition, high reliability, good accuracy and low maintenance requirements are essential. Based on these requirements, the alternate systems available and our experience and that of others in the utility industry, a dilution probe type monitoring system would be most appropriate for this application. Penelec has recently evaluated all available systems in response to new Clean Air Act requirements for continuous monitoring and concluded, along with many other utilities, that dilution probe systems can meet the requirements of high reliability, low maintenance and good accuracy. These systems are currently being certified downstream of wet limestone scrubbers, verifying the ability to operate properly in a wet, cooled environment similar to the CZD downstream location. In addition, the measurements of SO₂, NO_x and CO₂ occur independently so interference does not occur. There are many reputable vendors which supply these types of systems.

To conclude, I emphasize that there is not doubt that the CZD process does in fact reduce SO emissions. But serious quantification of SO₂ reductions relating to CZD injection rates and lime concentration must be documented by a monitoring system unaffected by the reduction technique or resultant reduction.

Figure 1-2
SO₂ AND NO SECOND DERIVATIVE
SPECTRUMS

Figure 3-1
OPTICS SYSTEM
FUNCTIONAL DIAGRAM

Appendix E

Problems/Issues During Parametric Testing

Appendix E

Problems/Issues During Parametric Testing

Different problems were encountered during testing:

- Lime slurry appeared in the compressed air header; and the causes were diagnosed.
- The hose that connects the lime slurry header with the atomizer lance froze due to the extreme cold weather.
- Deposits of fly ash/lime occurred in the flue gas duct due to operating with the ceramic spray tip of a broken atomizer and due to the high erosion of a temporary stainless steel atomizer's spray tip on three atomizers.
- The atomizer's slurry inlet orifice was plugged by small coal particles entrained by wind into the lime slurry feed tanks, which were not properly covered.

Reports on these problems are attached.

December 15, 1991

Subject: CZD Test

On wednesday December 11, 1991 the test was aborted due to the appearance of lime in the compressed air header. The chain of events that occurred and a diagnosis of the causes leading to this occurrence follows.

1. System started without incident on water.
2. Change over to lime.
3. Nozzle 19 & 20 plugged (lime pressure gage indicated high)
4. Rotameter on lance 18 appeared flooded with lime.
5. The majority of rotameters appear to be coated with lime obscuring the ability to read.
6. The lime flow was terminated and water introduced.

On investigation the following were observed and the action taken described.

1. When the air header drains were opened there was a fair quantity of lime water expelled from each drain (there are two) there was enough lime water that a hose was connected to the eyewash drain to prevent dumping a large quantity onto the duct.

2. Nozzle 19 & 20 were pulled from the duct and found to be plugged, nozzle 19 was baked hard and 20 was soft, the plugged area was only a few feet up into the lance.

Nozzle 20 was easily cleared by disconnecting the flanges and probing and flushing with water while 19 had to be persuaded with a piece of allthread before flushing it with water.

The short piece of 1/2 inch pipe that connects the flange with the nozzle on 19 broke at the thread while removing it from the nozzle.

The lime orifice was non existent while the one on 20 was missing 2/3 of it's orifice, it was replaced with a spare part. While removing the nozzle on 19 the threads galled making the unit unserviceable and it was replaced with a spare.

3. Nozzle 18 was removed from the duct and disassembled. The majority of the orifices in the spray head were plugged with what appeared to be ceramic particles.

The remainder of number 18 was disassembled and there was no sign of missing ceramic components or damage to any of the ceramic parts. Nozzle 18 was reassembled and returned to service.

4. Tank "b" was recirculated thru the vibrating screen. There appeared to be a large amount of grits on the screen along with lumps of lime ranging in size from that of a "b-b" to that of a small marble, a portion of the lumps appear to be flat, that is .04-.06 thick and .1 to .2 irregular diameter. After recirculating for about 6 hours the lime slurry was void of any appearance of foreign material. The same treatment is be applied to tank "a".

5. The appearance of foreign matter and lumps of lime in the lime slurry tanks is not consistent with material that previously been screened.

The hard black sand particles are consistent

with "black-beauty" a blasting sand. On inquiry there was a large amount of grit blasting up wind of our test location in the autumn (prior to october) to the degree that there was reported residue in out test area.

One possible conclusion that may be reached is that a quantity of material infiltrated the tanks thru the large opening in the top in the area of the agitator and the fill funnel.

The particles are also consistent with coal dust that abounds in the area and can be readily introduced into the system thru the available openings.

Included inside the lumps of lime there appears to be a dark particle, a possible expiation may be the same as the creation of a raindrop, a core particle or seed of some foreign material.

6. The radiometers were disassembled and rinsed in a solution of 10% HCL to remove the lime deposits.

On reinstallation a portion of the glass tubes broke when the air was applied. There is no apparent explanation for this failure.

URGENT FACSIMILE

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Page 1 of

Fax to: AL RUBIN/JACK ABRAMS/CHETLOWE

Company: Bechtel Rand D

Location: San Francisco

Fax No.: 415-768-3580

Bechtel CZD Demonstration Project at
Penelec's Seward Station
Facsimile No.: (814) 446-6956

Originator:

Phone #: (814) 446-6715

Job/Charge #: 21178-003

Date: 12/23/91

Copies to: Jack Abrams
Stan Zarek
Chet LoweMessage: Report on activities between Dec 16th through
December 20th.

Memo To : Al Rubin
Project Manager.

From : Vinod Pillai
Dave Bjorkbom
Test Engineers.

Copies to: Jack Abrams.
Stan Zaczek.
Chet Lowe.

Re : Daily activities from December 16th through December 20th.

Monday December 16th, 1991

The plant had severe opacity problems. In the morning around 7:30 am the opacity had increased to 19.8 %. Plant personnel had brought down Units 12 & 14 and had reduced the load on Unit 13 to about 135 MW. After discussing this with Chuck Hainsev, a decision was made that we would start testing when the baseline opacity decreased to about 12.0%.

The communication link between the recorders in the ESP room and the shack failed. The Bailey was operating, but it did not update the temperatures. After several resettings, the recorders still failed to transmit data. After several discussions with Don Shaffar, he reached the conclusion that the Bailey module in the plant, consisting of the Infi 90 & Bus transfer module, was not in a good operating condition. A decision to call the Bailey representative for the plant was reached.

We started spraying water into the duct at about 12:30 pm. The temperature in the B duct was about 284 degrees F. After several discussions with the Shift supervisor, he told us that the F.O fans were biased to their maximum and he would not be able to give us higher temperatures for the day because the outside temperature was below freezing. The heat tracing on top of the duct was not in operation. Upon investigation, it was discovered that one of the circuit breakers had tripped and another breaker was shut off.

As we started spraying lime into the duct we discovered that Nozzle 14 was plugged. Also the handle for the ball valve on Nozzle 20 had broken. During testing, the control room informed us that the temperature in the B duct was decreasing and that there was nothing they could do about this. The temperature in the B duct decreased to about 274 degrees F and over a period of time decreased to about 264 degrees F. This was apparent to us by the decreasing C cross section temperatures. To preserve the continuity of the test, we decided not to abort the test.

At the end of the day, we had some problems with flushing the

system. The hose that connects the Grifts Tank to the first stage lime slurry transfer pump was frozen. It was decided that the house water line be connected to the first stage transfer pump for flushing purposes. This was done and the system was properly flushed.

Tuesday December 17th, 1991

A meeting with Mr. Imler and Mr. Walker (shift supervisor) determined the reason for the plant not being able to increase the temperature of the B duct to 300 degrees F. For the past few days the plant has had several problems with their pulverizers; because of this, the boiler load had to be reduced several times. The above problem, combined with opacity problems, were the primary reasons plant personnel were not able to increase the B duct temperature. This morning the boiler load was about 110 MW and the opacity had risen to a level of 13 %. Since the B duct temperature was only 250 degrees F, we decided against testing. Plant personnel also advised us that they would be able to bring the boiler to full load by midnight.

Nozzle 14 was dismantled to check for plugs. After a thorough investigation it was found that the nozzle was very clean. The pressure gauge connected with the lime line was also in good working condition. The problem was that the hose which connects the header with the lance had frozen due to the extreme cold weather. It was decided that all the hoses would be drained each day at the end of testing.

A meeting with Kay Gorman (Station Engineer) determined that we would be able to drain the tank used for flushing purposes only if the water consisted of no lime. This tank has very dilute concentrations of lime. This lime entered the tank when the valve to the tank is opened for flushing purposes; the backpressure in the line forces the remaining lime in the lines back into the tank. Since the DER is currently monitoring the water that is being drained into the river, we decided that it would not be appropriate to dump the water from the flushing tank or grits tank.

The communication cable from the recorders to the Bailey also failed. The Bailey did not update temperatures, while the recorders themselves did not update environmental data. A quick investigation with the MFP IBM software led us to believe that the MFP block is communicating. Mike Schaal was informed of this.

Wednesday December 18th, 1991

We started the day by discussing with Mr. Walker how to get 300 degrees F in our duct. The flue gas from the boiler was at 990 degrees F and the air from the atmosphere through the F.O. fan was at 77.5 degrees F. The I.O fan was at its maximum rating of 320 amps. After discussing this with Mr. Walker, he told us that he had biased the F.O fan to the maximum and since the temperature outside was 20 degrees F, it was hard for the plant to increase the temperature in the B duct. Plant personnel have never had any problems in giving us 300 degrees F if the outside temperature was above 35 degrees F.

Page E-8

When all the manual thermocouples were removed for cleaning, we noticed that when some were removed and placed back in position, the probes would not go back into their original position. The probes got stuck about 2 inches above the bottom of the duct. This led us to believe that there is a 2" build up on the bottom of the duct. This phenomena was noticed on all the thermocouples up to the E cross section. After the E cross section, the thermocouples which were pulled out and replaced indicated to us that there is at least a 5" build up on the bottom of the duct. This could have happened a few weeks ago when the air compressors tripped and water got into the duct without being atomized.

We started spraying water at 30 gpm and then we switched over to lime. We gradually increased the flow rate to 41.5 gpm (calculated from the pressure - flow correlation) and sprayed lime for about 2 hrs. At the end of the run when the level of Tank B had reached approximately 21"-22", we pumped the remaining lime from Tank A to Tank B using a portable pump. When Tank A was opened for inspection, the walls of the tank were very clean. There was about 1" of lime slurry left below the drain on the bottom of the tank. To clean it up, we partially filled the lime tank with water and left the drain open. Using a squeegee and a scooper, the operators removed all the remaining slurry from the lime tank. Before doing this, a sample from the bottom of the tank revealed that the lime slurry did not have any grits nor any "black beauties".

Thursday December 19th, 1991

We started the day by having a meeting with Mr. Walker (Shift Supervisor) regarding any mechanical problems which would inhibit them from increasing the temperature of our duct. During the discussion he mentioned to us how the preheater bypass damper which lets the F.O fan force air through it without heating it is frozen and full of dust. This is the primary reason why the plant has to depend on outside temperature to increase the B duct temperature. They hope to have the preheater bypass operational after the outage.

We had started to pump lime into the Lime Tank A from the sump. Upon investigation of the screen, the top of the screen did not seem to have any unusual amount of grits or "black beauties". A sample of lime determined the concentration to be approximately 8%. We had hoped to have a higher concentration in the tank since we did not expect higher temperatures in the duct. Unfortunately, there is currently no method to prepare an exact, predetermined concentration of lime in the sump.

We started spraying water into the duct at 27 gpm. The temperature in the B duct was about 281 degrees F. All the nozzles were in a good working condition. We decided to switch over to lime at this time. As soon as we switched over to lime,

we noticed that Nozzle 19 was clogged. Before the operators could start the lime pumps up, the valve which connects the rubber hose that is connected to the first stage transfer pump was frozen. The operators had to thaw the whole line before we started. We began spraying lime at 36.5 gpm and the temperatures at the C cross section seem to be fine. During the latter half the test, we noticed decreasing pressure on the recycle lime line. To compensate for this loss in pressure, we had to further open the ball valves in order to increase the pressure back to the original pressure.

An investigation of the process line downstream of the 2nd stage transfer pump determined a pressure differential of 20 psi across the strainer. Also, the top of the vibrating screen showed large amounts of small grits and small amounts of black coal particles. This was determined by a sample collected from the top of the screen.

During testing today, the electricians removed the grounding wire from the shields and left the wire floating. This re-established the communication between the chart recorders in the SSP room and the recorders in the Shack.

Friday December 30th 1991

We started the day by pumping about 10% lime in to Tank A. When the lime was pumped from the sump to the tank through the screen it was noticed that the screen did not consist of any grits except for normal sandy material.

We started spraying water in to the duct. The temperature in the duct during that period was about 281 degree F. We switched over to spraying lime and during the early part of the operation the pressure on the recycle line was about 143 psi. During the later part of the operation the pressure on the recycle line started gradually decreasing, it started decreasing to 138 psi, then to 135 psi and then over a period of half hour to forty - five minutes the pressure gradually decreased to 124 psi. We pursued every possible alternative to keep the flowrate constant.

After the above experience, we decided to remove the strainer after the second stage lime pump and to clean the lime lines by recirculating water through the lime lines for 2 to 3 hrs. We also decided that the hard pipe and the hoses connecting to the 1st stage transfer pump should be cleaned.

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Page 1 of

Fax to: AL RUBIN
Company: Bechtel Rand D
Location: San Francisco
Fax No.: 415-768-3580 X6514

Bechtel

CZD Demonstration Project at
Penelec's Seward Station
Facsimile No.: (814) 446-6956

Originator:

Phone #: (814) 446-6715

Job/Charge #: 21178-003

Date: 1/13/91

Copies to: J. Abrams
S. Zarek
Chet Lowe

Message: Weekly report of activities.

Memo To : Al Rubin
Project Manager.

From : Vinod Pillai
David Bjorkbom
Test Engineers.

Copies To : Jack Abrams
Chet Lowe
Stan Zaczek

Monday January 6th 1992.

The B duct temperature in the morning was around 272 degrees F. Discussions with Mr. Imler regarding increasing the B duct temperature to 300 degrees F had led to specific orders from Mr. Imler to the midnight shift personnel to start biasing the FD fans by midnight so as to increase the temperature in the duct by early morning. Today's case could be attributed to the fact that the plant had a minimum load generation period after midnight which led to problems for increasing temperature in the duct. This factor and the outside temperature were the two main reasons for not getting high temperatures in the duct.

The steam lines from soot blowers 1 & 4 were opened for cleaning. The steam line and the check valve of sootblower 1 was clean but the steam lines and check valves of soot blower 4 were plugged. They were removed, cleaned and air blown dry with compressed air.

We started spraying water at 27 gpm and we switched over to lime. Since the temperature in the duct was 275 degrees F, we decided that we would only spray lime at a flow rate such that all the temperatures at the C cross section would be over 160 degrees F. This would prevent any further build up at the C cross section. The temperature in the B duct gradually increased to 282 degrees F over a period of an hour and a half. The flow rate was maintained at 34.4 gpm. The C cross section temperatures were over 160 degrees F. During testing we noticed the fact the pressure gauge at nozzle 19 was reading over 160 psi. At that moment we thought that the nozzle was plugged and promptly shut off the nozzle. But during flushing with water we noticed that nozzle 19 was in proper working condition. The conclusion drawn was that the pressure gauge could be faulty. However nozzle 20 was plugged as noticed by the pressure gauge. The ball valve at the end of the header was throttled on and off so that the grits at the end of the header would be recycled back to the tank.

Tuesday January 7th 1992

In the morning we pulled out nozzle 19 & 20 to clear out the plugging in nozzle 20. We pulled out the graphite packing in the lime line to look out for any erosion. Unfortunately the graphite packing did not seem to be eroded. Therefore our conclusion was that the nozzle could have been plugged by the grits. The recycle

line from the header to the tank was also plugged. This was discovered during testing.

We also had a meeting with Mr. Imier & Mr. Battista for discussion of future testing schedules. We started spraying water at around 11.40 am and we switched over to lime at around 12.30 pm. Testing proceeded as usual. We used about 7 % lime from both the tanks. Temperatures at the C cross section were just fine.

Wednesday January 8th 1992

In the morning we filled up both lime tanks. During the lime transfer to the tanks, we saw grease-like black material on the vibrating screen. We also had a meeting with Don Shaeffer for help regarding recording problems. As usual we started spraying water into the duct at around 12.30 pm and we switched over to lime at around 1.55 pm and continued spraying lime until 4.45 pm. We sprayed lime at around 7 % concentration of lime. The C cross section temperatures were fine. The boiler load was 123 MW. This low load was due to the fact that one of the pulverizer was shut down due to problems. The temperature in the duct was around 288 degrees F.

Thursday January 9th 1991

Nozzles 17 & 19, suspected of plugging, were removed and their plugs cleaned up. As usual the nozzles were plugged from above the target bolt. They were cleaned up. On inspection the graphite packing was not worn out. Previously we had suspected nozzle 17 of being plugged, but on checking the nozzle was in proper working condition. The pressure gauges were in proper working condition.

We started spraying water and lime in the usual manner. The temperature in the duct was about 283 degrees F. We tested till 4.45 pm.

Friday January 10th 1991

In the morning the cover for the screw conveyor to the sump was opened. The opening was plugged with moist lime. This was cleaned up after which a lot more lime was transferred from the silo to the sump.

We started spraying lime as usual. At 1.50 pm, a breaker tripped leading to loss of power in the CZD system. After 15 - 20 minutes the power was back, but the cause of loss of power was not yet determined.

Memo to : Al Rubin
Project Manager

From : David Bjorkbom
Vinod Pillai
Test Engineers

Copies To : Jack Abrams
Chet Lowe
Stan Zaczek

This is the CZD Project Weekly Status Report for the week ending
January 31, 1992:

Monday, January 27, 1992

As we began testing today, we again noticed a very large temperature drop at the "C" cross section between the time we started injecting water and the time we had reached a flow rate of 17 gpm. We at that time decided to remove the 3 1/4" spacers from the front lances and replace them with the new 1 1/2" spacers. As we were removing the lances, we noticed that the spray tip for Nozzle 9 was missing. Fragments of the ceramic base remained, but the 6-holed tip was missing. Apparently it had broken off. Once this was discovered, we decided to inspect all the nozzles to see if this had occurred on any of the others. While it had not, we did notice that on Nozzles 1, 11, and 12, the holes in the stainless steel tips had increased to approximately twice their original size. This was attributed to the abrasive lime slurry wearing on the stainless steel. Apparently, these three stainless steel tips were inserted long ago in an attempt to prevent the spray from impinging on the duct walls (the stainless steel spray tips have a spray angle of 25 degrees while the ceramic spray tips have a spray angle of 60 degrees. The stainless steel tips which were worn were replaced with ceramic ones. There are no more stainless steel tips being used for the nozzles.

We again tested with water and different nozzle configurations to better define our confined zone. All the middle lances (Nozzles 4-9) were orientated so that they were pointed straight down the duct and not towards either side of the duct. A separate report was written to cover the details and findings of the test.

Tuesday, January 28, 1992

Today we ran three tests: one with only the front nozzles in operation, the second with only the back nozzles in operation, and third with both front and back nozzles in operation. When we made straight all the front nozzles, there was a drastic reduction in temperature in the center at Positions B11, B21, C11, and C21. We therefore adjusted them accordingly to achieve a more balanced temperature profile. A separate report has been written to cover the details of the testing for today.

Wednesday, January 29, 1992

Today we completed our water testing and now feel we have a nozzle configuration which maximizes our spraying area and also protects the duct from getting coated. Again, a separate report will be issued covering the details of the testing today. Our intention is to try to spray one tank of lime tomorrow with approximately an 8.2% concentration.

The "Red Hats" have come up with a better design for the hinges on the door at the first set of turning vanes. Their design would have the door swing open from left to right rather than right to left and would facilitate the opening of the door. The last time we wanted to open the door, the entire door had to be removed from its hinges in order to be opened. A rough sketch of this new design will be faxed to Chet for his information.

Thursday, January 30, 1992

We tested today with lime at a concentration of 8.2% and a flow rate of approximately 38 gpm. The duct temperature was approximately 273 degrees F. The flow rate was verified by two independent means: one by our pressure-flow correlation and the other by measuring the level of slurry in the lime tank. The Fenwal flow controller/indicator was installed in the shack and appears to read about 3-4 gpm higher than our flow rate using the pressure-flow correlation. It is possible that the flow meter is out of calibration which could lead to these differing flow rates.

The new environmental monitors appear to be working well now that they are properly calibrated. From the CO2 measurements, it can be seen that the air inleakage is anywhere from 25-30%. This large amount of inleakage is hampering our efforts to achieve higher duct temperatures.

Friday, January 31, 1992

Today we started to spray water with the intention of testing with lime. However, around 1:00, two of Boiler 15's pulverizers were taken offline to repair coal leaks in them. When they were taken offline, the boiler dropped in load to approximately 100 MW. Our duct temperature correspondingly dropped so we decided against testing for the day. The pulverizers were brought back online at approximately 2:30.

URGENT FACSIMILE (Please make and distribute copies as shown below)

Page 1 of

Fax to: AL RUBIN

Company: BECHTEL RAND D

Location: SAN FRANCISCO

Fax No.: 415-768-3580

Bechtel

C2D Demonstration Project at
Penelec's Seward Station
Facsimile No.: (814) 446-6956

Originator:

Phone #: (814) 446-6715

Job/Charge #: 21178-003

Date: 1/28/91

Copies to: JACK ABRAMS
STAN ZACZEK
CHET LOWE

Message: Explanation regarding the build up in
the duct. For your review.

Calculation Sheet

(1)

Originator _____ Date _____ Calc. No. _____ Rev. No. _____
 Project _____ Job No. _____ Checked _____ Date _____
 Subject _____ Sheet No. _____

During water testing in the months of Summer, we found that there were sufficiently high temperatures available at the bottom of the duct. To exploit these high temperatures at the bottom of the duct, and to increase the area of the confined zone, we decided to introduce 3 1/2" Spacers to the front and back nozzles. Under these conditions, we conducted our tests.

During the early part of November when we entered the duct, we found that there were slight amounts of deposits between the 'B' and 'C' cross sections.

We believe that during the early part of fall, condition inside the duct started changing. During this period, we believed that soot blowers between 'B' and 'C' cross section would solve our problems.

After several days of testing with line, when we entered the duct during the period of early January we found that the amount of deposits in the duct between the middle of 3rd soot blowers to the end of the 'C' cross section had increased. After a further 7 day period of operation, when we entered the duct on Jan 17th we found the duct in the condition as shown in the recent photographs.

A combination of factors left the duct in this condition. First of all the temperature in the bottom part of the duct changed drastically. Since there were 3 1/2" Spacers attached to the nozzles these nozzles were spraying into the bottom part

Calculation Sheet

(2)

Originator _____ Date _____ Calc. No. _____ Rev. No. _____
 Project _____ Job No. _____ Checked _____ Date _____
 Subject _____ Sheet No. _____

of the duct. The temperatures in the bottom part of the duct were not high enough to dry the lime particles sufficiently.

During this period of time, we had a lost an atomizer tip from Nozzle 9. During lime injection tests, atomizer 9 was being operated at 130 psi. Under normal conditions atomizers with tips operated at 130 psi would inject 3 gpm of slurry or water. When an atomizer loses a tip, the pressure at the tip of nozzle is completely lost. Under this condition, if the the gauge is adjusted to 130 psi we will be spraying slurry or water at a flow rate of greater than 3 gpm. This could very well be 5 or 6 gpm. Also, when an atomizer loses a tip, it loses its ability to atomize particles to 60 microns in diameter. In the above mentioned case the atomized particles from Nozzle 9 had a much ~~much~~ larger diameter and were ^{much} coarser than the finely atomized particles under normal operating conditions. As the atomized particles became coarser and much larger in diameter, the density and terminal velocity of these particles increased. As the terminal velocity of these coarse particles increased they lost their ability to remain suspended in the flue gas. As a result of this, these particles impinged on the bottom of the duct. The atomizer had lost its capability of maintaining a spray pattern, due to the loss of the tip.

Calculation Sheet

(3)

Originator _____ Date _____ Calc. No. _____ Rev. No. _____
 Project _____ Job No. _____ Checked _____ Date _____
 Subject _____ Sheet No. _____

Atomizers 1, 11, 12 had tips made of stainless steel. Steel tips have a 25° spray cone angle, and the spray pattern from these tips are more concentric in the centre. These steel tips were installed in atomizers 1, 11, 12, to protect the walls. Over a period of time, these tip openings got eroded and increased in diameter. The diameter of the tip openings had become larger, i.e. twice the size of an undamaged tip. These conditions had caused these atomizers to lose their capability of producing finely atomized particles. In both the above cases the atomized particles produced were much larger in diameter and coarser in condition. Since the diameter of the openings were much larger, we cannot estimate the correct particle size of slurry that was being sprayed. Since the density and terminal velocity of the particles increased they had lost their ability to remain suspended in the fine gas. As a result of this, these particles started impinging on the bottom of the duct, and the wall thermocouples.

The wall thermocouples were affected the most. Since our confined zone was operated on the border line i.e. close to six inches to the wall, the wall thermocouples were accumulating a lot of deposits. The deposits increased on the thermocouples, and in the morning when they were removed to be cleaned, the operators had great difficulty

Calculation Sheet

4

Originator _____ Date _____ Calc. No. _____ Rev. No. _____
 Project _____ Job No. _____ Checked _____ Date _____
 Subject _____ Sheet No. _____

in pulling the thermocouples out of the duct. When the operators succeeded in pulling the thermocouples out of the duct, the large deposits fell down to the bottom of the duct. As time passed, these deposits became larger and interfered with the Confined Zone. Once they started interfering with the Confined Zone, the buildup on the duct started increasing exponentially.

To correct the above situation we have removed the spacers from the back nozzles, and added 1 1/2" spacers to the front nozzles. We have replaced the steel tips with ceramic tips for atomizers 1, 11, 12. Those atomizers with ceramic tips are still in a good operating condition. The atomizer tip at 9 was replaced with a new ceramic tip. Currently we are conducting water testing, so that we can safely orient the lances away from the walls while trying to maximize the area of our confined zone.

Appendix F

Baseline Testing - Fuel

Appendix F

Baseline Testing - Fuel

Penelec analyzed samples of the incoming coal for moisture, ash, fixed carbon, volatiles, % sulfur, Btu/lb, and calculated the lbs/MMBtu.

The results of these analyses as well as analyses of the amounts of coal burned and the resulting ash during November 1991, December 1991, and January 1992 are attached.

Appendix F-1

Results of Sampling the Incoming Coal

PENNSYLVANIA ELECTRIC COMPANY
Keystone Station Laboratory

Lab Sample No.: 81969

Date Sampled : 110291
Date Received: 110591
Date Analyzed: 110691

Station: SEWARD
Sample Description: BUNKER
SAT

Analysis	Coal Analysis Report		
	As Received	Dry Basis	Moisture & Ash Free
% Moisture	6.33		
% Ash	11.63	12.42	
% Volatiles			
Fixed Carbon			
% Sulfur	1.44	1.54	1.76
BTU/LB	12467	13309	15196
# S/MMBTU	1.16		

***

PENNSYLVANIA ELECTRIC COMPANY
Keystone Station Laboratory

Lab Sample No.: 81970

Date Sampled : 110391
Date Received: 110591
Date Analyzed: 110691

Station: SEWARD
Sample Description: BUNKER
SUN

Analysis	Coal Analysis Report		
	As Received	Dry Basis	Moisture & Ash Free
% Moisture	6.15		
% Ash	14.04	14.96	
% Volatiles			
Fixed Carbon			
% Sulfur	1.46	1.56	1.83
BTU/LB	12113	12907	15177
# S/MMBTU	1.21		

***

E. C. Crumley
SEWARD

PENNSYLVANIA ELECTRIC COMPANY
Keystone Station Laboratory

Lab Sample No.: 82091

Date Sampled : 110991
Date Received: 111291
Date Analyzed: 111391

Station: SEWARD
Sample Description: SAT
BUNKER

Coal Analysis Report			
Analysis	As Received	Dry Basis	Moisture & Ash Free
% Moisture	5.4		
% Ash	13.62	14.4	
% Volatiles			
Fixed Carbon			
% Sulfur	1.52	1.61	1.88
BTU/LB	12253	12952	15131
± S/MMBTU	1.24		

***

PENNSYLVANIA ELECTRIC COMPANY
Keystone Station Laboratory

Lab Sample No.: 82092

Date Sampled : 111091
Date Received: 111291
Date Analyzed: 111391

Station: SEWARD
Sample Description: SUN
BUNKER

Coal Analysis Report			
Analysis	As Received	Dry Basis	Moisture & Ash Free
% Moisture	5.63		
% Ash	12.2	12.93	
% Volatiles			
Fixed Carbon			
% Sulfur	1.54	1.63	1.87
BTU/LB	12491	13236	15201
± S/MMBTU	1.23		

***

PENNSYLVANIA ELECTRIC COMPANY
Keystone Station Laboratory

Lab Sample No.: 82093

Date Sampled : 111191
Date Received: 111291
Date Analyzed: 111391

Station: SEWARD
Sample Description: MON BUNKER
BUNKER

Coal Analysis Report			
Analysis	As Received	Dry Basis	Moisture & Ash Free
% Moisture	5.79		
% Ash	13.16	13.97	
% Volatiles			
Fixed Carbon			
% Sulfur	1.45	1.54	1.79
BTU/LB	12305	13061	15182
\$ S/MMBTU	1.18		

***

E. Cumbly
PENNSYLVANIA ELECTRIC COMPANY
Keystone Station Laboratory

Lab Sample No.: 82261

SEWARD
Date Sampled: 111691
Date Received: 111991
Date Analyzed: 112091

Station: SEWARD
Sample Description: SAT
BUNKER

Coal Analysis Report			
Analysis	As Received	Dry Basis	Moisture & Ash Free
% Moisture	5.8		
% Ash	13.93	14.79	
% Volatiles			
Fixed Carbon			
% Sulfur	1.45	1.54	1.81
BTU/LB	12254	13008	15266
± S/MMBTU	1.18		

***

PENNSYLVANIA ELECTRIC COMPANY
Keystone Station Laboratory

Lab Sample No.: 82262

Date Sampled : 111791
Date Received: 111991
Date Analyzed: 112091

Station: SEWARD
Sample Description: SUN
BUNKER

Coal Analysis Report			
Analysis	As Received	Dry Basis	Moisture & Ash Free
% Moisture	5.67		
% Ash	13.71	14.53	
% Volatiles			
Fixed Carbon			
% Sulfur	1.44	1.53	1.79
BTU/LB	12263	13000	15211
± S/MMBTU	1.17		

***

Saw

E. Crumby

PENNSYLVANIA ELECTRIC COMPANY
Keystone Station Laboratory

Lab Sample No.: 82409

Date Sampled : 112391

Date Received: 112691

Date Analyzed: 112791

Station: SEWARD
Sample Description: BUNKER
SAT.

Coal Analysis Report

Analysis	As Received	Dry Basis	Moisture & Ash Free
% Moisture	8.01		
% Ash	13.39	14.56	
% Volatiles			
Fixed Carbon			
% Sulfur	1.42	1.54	1.81
BTU/LB	12025	13072	15299
± S/MMBTU	1.18		

***

PENNSYLVANIA ELECTRIC COMPANY
Keystone Station Laboratory

Lab Sample No.: 82410

Date Sampled : 112491

Date Received: 112691

Date Analyzed: 112791

Station: SEWARD
Sample Description: BUNKER
SUN.

Coal Analysis Report

Analysis	As Received	Dry Basis	Moisture & Ash Free
% Moisture	7.5		
% Ash	14.15	15.3	
% Volatiles			
Fixed Carbon			
% Sulfur	1.49	1.61	1.9
BTU/LB	11986	12958	15298
± S/MMBTU	1.24		

***

PENNSYLVANIA ELECTRIC COMPANY
Keystone Station Laboratory

Lab Sample No.: 82463

Date Sampled : 112891
Date Received: 112991
Date Analyzed: 120291

Station: SEWARD
Sample Description: BUNKER
HOL

Analysis	Coal Analysis Report		
	As Received	Dry Basis	Moisture & Ash Free
% Moisture	7.28		
% Ash	13.64	14.71	
% Volatiles			
Fixed Carbon			
% Sulfur	1.57	1.69	1.99
BTU/LB	12038	12983	15223
# S/MMBTU	1.3		

***

E. Crumley
PENNSYLVANIA ELECTRIC COMPANY
Keystone Station Laboratory *Seward*

Lab Sample No.: 82516

Date Sampled : 113091
Date Received: 120491
Date Analyzed: 120591

Station: SEWARD
Sample Description: SAT
BUNKER

Analysis	Coal Analysis Report		
	As Received	Dry Basis	Moisture & Ash Free
% Moisture	6.13		
% Ash	15.39	16.4	
% Volatiles			
Fixed Carbon			
% Sulfur	1.72	1.83	2.19
BTU/LB	12011	12795	15305
# S/MMBTU	1.43		

***

PENNSYLVANIA ELECTRIC COMPANY
Keystone Station Laboratory

Lab Sample No.: 82517

Date Sampled : 120191
Date Received: 120491
Date Analyzed: 120591

Station: SEWARD
Sample Description: SUN
BUNKER

Coal Analysis Report

Analysis	As Received	Dry Basis	Moisture & Ash Free
% Moisture	7.87		
% Ash	13.84	15.02	
% Volatiles			
Fixed Carbon			
% Sulfur	1.46	1.58	1.86
BTU/LB	11907	12924	15209
¢ S/MMBTU	1.23		

***

E. Crumby
PENNSYLVANIA ELECTRIC COMPANY
Keystone Station Laboratory *SEWARD*

Lab Sample No.: 82629

Date Sampled : 120791
Date Received: 121091
Date Analyzed: 121191

Station: SEWARD
Sample Description: SAT
BUNKER

Analysis	Coal Analysis Report		
	As Received	Dry Basis	Moisture & Ash Free
% Moisture	7.29		
% Ash	13.2	14.24	
% Volatiles			
Fixed Carbon			
% Sulfur	1.45	1.56	1.82
BTU/LB	12127	13081	15252
± S/MMBTU	1.2		

***

PENNSYLVANIA ELECTRIC COMPANY
Keystone Station Laboratory

Lab Sample No.: 82630

Date Sampled : 120891
Date Received: 121091
Date Analyzed: 121191

Station: SEWARD
Sample Description: SUN
BUNKER

Analysis	Coal Analysis Report		
	As Received	Dry Basis	Moisture & Ash Free
% Moisture	7.68		
% Ash	12.23	13.25	
% Volatiles			
Fixed Carbon			
% Sulfur	1.4	1.52	1.75
BTU/LB	12218	13234	15255
± S/MMBTU	1.15		

***

PENNSYLVANIA ELECTRIC COMPANY
Keystone Station Laboratory

Lab Sample No.: 82773

Date Sampled : 121491
Date Received: 121791
Date Analyzed: 121891

Station: SEWARD
Sample Description: BUNKER
SAT

Coal Analysis Report			
Analysis	As Received	Dry Basis	Moisture & Ash Free
% Moisture	7.65		
% Ash	15.53	16.82	
% Volatiles			
Fixed Carbon			
% Sulfur	1.5	1.62	1.95
BTU/LB	11682	12650	15207
¢ S/MMBTU	1.28		

***

PENNSYLVANIA ELECTRIC COMPANY
Keystone Station Laboratory

Lab Sample No.: 82774

Date Sampled : 121591
Date Received: 121791
Date Analyzed: 121891

Station: SEWARD
Sample Description: BUNKER
SUN

Coal Analysis Report			
Analysis	As Received	Dry Basis	Moisture & Ash Free
% Moisture	7.85		
% Ash	13.37	14.51	
% Volatiles			
Fixed Carbon			
% Sulfur	1.4	1.52	1.78
BTU/LB	12034	13059	15275
¢ S/MMBTU	1.16		

***

E. Crumley

PENNSYLVANIA ELECTRIC COMPANY
Keystone Station Laboratory

SEWARD

Lab Sample No.: 82933

Date Sampled : 122191
Date Received: 122491
Date Analyzed: 122691

Station: SEWARD
Sample Description: BUNKER
SAT

Coal Analysis Report			
Analysis	As Received	Dry Basis	Moisture & Ash Free
% Moisture	8.04		
% Ash	13.48	14.66	
% Volatiles			
Fixed Carbon			
% Sulfur	1.45	1.58	1.85
BTU/LB	11908	12949	15173
* S/MMBTU	1.22		

***

PENNSYLVANIA ELECTRIC COMPANY
Keystone Station Laboratory

Lab Sample No.: 82934

Date Sampled : 122291
Date Received: 122491
Date Analyzed: 122691

Station: SEWARD
Sample Description: BUNKER
SUN

Coal Analysis Report			
Analysis	As Received	Dry Basis	Moisture & Ash Free
% Moisture	7.99		
% Ash	14.37	15.62	
% Volatiles			
Fixed Carbon			
% Sulfur	1.57	1.71	2.02
BTU/LB	11779	12802	15171
* S/MMBTU	1.33		

***

PENNSYLVANIA ELECTRIC COMPANY
Keystone Station Laboratory

E Crumbly
Seward

Lab Sample No.: 82987

Date Submitted: 122591
Date Received: 122791
Date Analyzed: 123091

Station: SEWARD
Sample Description: BUNKER
HOLIDAY

Coal Analysis Report

Analysis	As Received	Dry Basis	Moisture & Ash Free
% Moisture	8.43		
% Ash	12.84	14.02	
% Volatiles			
Fixed Carbon			
% Sulfur	1.44	1.57	1.83
BTU/LB	12019	13125	15266
# S/MMBTU	1.2		

***

E. C. Crumley
PENNSYLVANIA ELECTRIC COMPANY
Keystone Station Laboratory

Lab Sample No.: 83044

Date Sampled : 122891
Date Received: 123191
Date Analyzed: 10292

Station: SEWARD
Sample Description: SAT
BUNKER

Analysis	As Received	Dry Basis	Moisture & Ash Free
% Moisture	8.2		
% Ash	13.79	15.02	
% Volatiles			
Fixed Carbon			
% Sulfur	1.46	1.59	1.87
BTU/LB	11842	12900	15180
# S/MMBTU	1.23		

***

PENNSYLVANIA ELECTRIC COMPANY
Keystone Station Laboratory

Lab Sample No.: 83045

Date Sampled : 122991
Date Received: 123191
Date Analyzed: 10292

Station: SEWARD
Sample Description: SUN
BUNKER

Analysis	As Received	Dry Basis	Moisture & Ash Free
% Moisture	8.86		
% Ash	12.46	13.67	
% Volatiles			
Fixed Carbon			
% Sulfur	1.41	1.55	1.79
BTU/LB	11983	13148	15230
# S/MMBTU	1.18		

***

SEWARD STATION HEAT RATE QUALITY JANUARY - 1992

DATE	# 12 TONS	# 14 TONS	# 15 TONS	% MOIST	% ASH	% SULFER	BTU	# SUL/ 10E6 BTU	% VOL
1	247	263	1146	7.20	13.04	1.66	12162	1.36	22.61
2	266	335	151	6.64	13.90	1.43	12230	1.18	21.25
3	327	332	789	6.43	13.52	1.67	12338	1.35	21.13
4	286	273	1278	8.33	12.83	1.41	12071	1.17	21.86
5	225	0	1274	7.00	13.57	1.57	12058	1.30	22.04
6	160	0	1283	6.14	14.37	1.64	12206	1.35	21.67
7	0	0	1277	6.04	14.13	1.56	12227	1.28	21.42
8	85	0	1157	6.29	13.87	1.56	12216	1.28	21.49
9	0	0	1129	6.57	14.02	1.53	12248	1.25	21.74
10	0	0	1156	7.08	12.07	1.62	12441	1.30	21.46
11	0	59	1300	7.13	12.53	1.53	12414	1.23	21.56
12	0	272	1335	7.05	12.89	1.56	12239	1.27	21.71
13	0	439	1326	6.39	12.95	1.50	12358	1.23	23.81
14	0	316	1346	6.83	13.21	1.54	12226	1.26	21.61
15	0	413	1340	6.74	12.99	1.53	12305	1.24	21.76
16	0	337	1330	6.72	13.44	1.59	12307	1.29	21.22
17	164	370	54	6.41	14.28	1.59	12277	1.30	20.42
18	166	440	267	6.56	14.78	1.73	12083	1.43	20.82
19	168	325	1336	7.36	14.15	1.57	12000	1.31	21.62
20	140	290	1394	6.91	13.77	1.54	12168	1.27	20.82
21	300	321	1379	6.84	13.44	1.54	12206	1.27	21.86
22	198	374	1297	6.66	13.43	1.57	12237	1.29	21.10
23	52	550	1438	6.98	13.70	1.61	12125	1.34	20.70
24	329	292	1312	7.66	13.45	1.61	12078	1.34	20.53
25	331	352	1385	7.93	14.12	1.52	11827	1.29	21.68
26	269	310	1226	8.61	12.93	1.51	11957	1.26	21.43
27	383	356	1494	7.09	13.93	1.57	12090	1.30	20.37
28	300	392	1411	6.04	14.25	1.62	12196	1.33	21.45
29	350	316	1364	6.38	14.07	1.67	12197	1.37	20.68
30	316	300	1351	6.03	14.55	1.55	12142	1.28	20.30
31	314	318	1258	6.28	13.48	1.64	12271	1.34	20.33
TOTAL-12	5376			6.93	13.77	1.58	12142	1.30	21.13
TOTAL-14		8345		6.89	13.65	1.57	12175	1.30	21.30
TOTAL-15			36583	6.88	13.55	1.57	12185	1.29	21.41

NOTE: WEEKENDS AND HOLIDAYS BASED ON GRAB SAMPLES

NOTE: VOLATILE MATTER NOT RUN FOR GRAB SAMPLES, AVERAGE OF PREVIOUS DAYS USED

NOTE: STOCKPILE AS OF 1/31/92 104732.05 TONS

Appendix F-2

**Amount of Coal Received with Characteristics, Coal Burned, and
Resulting Ash During November 1991, December 1991, and January 1992**

COAL RECEIVED

MONTH: NOVEMBER 1991

DATE	WEIGHTED AVG. MOISTURE	WEIGHTED AVG. ASH	WEIGHTED AVG. SULFUR	WEIGHTED AVG. BTU	WEIGHTED AVG. %SULF/10 ⁶ BTU	WEIGHTED AVG. %VOLATILES	TONS	
1	6.34	14.19	1.48	12045	1.24	22.76	3223.37	2126 1458.29
2								1970
3								1465
4	5.81	11.94	1.76	12517	1.41	24.13	3082.64	2491.25 173.16 173.16 904 2013.61 2703 27.74 31.75
5	5.16	12.74	1.51	12390	1.22	24.28	2067.19	502 1805.19
6	5.56	14.25	1.43	12167	1.18	22.66	3247.57	1921 1506.57 480.44
7	5.69	14.41	1.60	12094	1.33	21.57	2560.32	1775 965 2292.87
8	5.40	15.64	1.60	11905	1.35	21.55	3517.55	1690 1807.85
9								1842
10								1612
11								2056
12	6.15	12.81	1.59	12307	1.29	23.24	3207.35	1890 1817.26 1825.61 242.49
13	6.69	12.97	1.42	12250	1.16	22.31	3295.56	2016 1805.58
14	6.32	14.36	1.42	12095	1.19	23.46	21015.67	1940 1671.7 229.00
15	5.31	14.34	1.57	12286	1.28	22.14	3334.03	1813 1891.09
16	11/15/91 137.03 + 11/14/91 438.97					22.80		1850
17	11/14/91 278.70 + 11/13/91 1279.50 + 11/12/91 792.74					23.00		1821
18	6.23	12.68	1.58	12403	1.28	23.38	3576.12	1920 1856.18 1412 40 105.19
19	5.94	12.88	1.63	12404	1.32	23.60	2878.56	1872 906.66 475.88
20	6.06	15.09	1.64	12019	1.37	21.65	3063.66	1855 1808.10 542.47
21	6.68	14.77	1.46	11866	1.23	22.15	3173.43	783 2390.43 114.75
22	7.61	14.42	1.42	11919	1.20	22.03	2549.32	1869 1805.32
23	11/22/91 60.32 + 11/21/91 1275.68					22.09		1826
24	11/21/91 1185 + 11/20/91 666.35					21.90		1831
25	7.88	12.40	1.43	12174	1.18	23.18	3244.41	1450 1894.47 520.31
26	7.27	16.31	1.64	11625	1.42	21.75	3360.51	1888 1832.51 500.37
27	6.55	15.49	1.63	11892	1.38	22.20	3040.86	1949 1893.86
28	11/21/91 1092.86 + 11/20/91 772.14					21.98		1866
29	5.35	17.68	1.50	11842	1.27	19.10	2348.53	1869 481.53
30	11/29/91 480.53 + 11/26/91 560.37 + 11/25/91 964.10					21.34		1806
31								

AVG: 1.543%

COAL RECEIVED

MONTH: DECEMBER 199

DATE	WEIGHTED AVG. MOISTURE	WEIGHTED AVG. ASH	WEIGHTED AVG. SULFUR	WEIGHTED AVG. BTU	WEIGHTED AVG. %SUL/100 BTU	WEIGHTED AVG. %VOLATILES	TONS	
1	11/25/91 530.31 + 11/20/91 542.41 + 11/13/91 431.29					22.81		1504
2	11/19/91 475.28 + 11/18/91 237.72							712
3	7.45	12.02	1.98	12475	1.59	22.09	414.79	562
4	6.52	18.07	1.52	12333	1.24	21.78	390.69	1718
5	7.15	13.29	1.53	12193	1.26	20.85	1136.99	2159
6	7.52	12.89	1.53	12161	1.26	21.19	1230.41	1939
7	11/4/91 1723.16 + 10/29/91 201.03 + 10/28/91 131.81					23.72		2156
8	10/28/91 1229.21 + 10/21/91 448.09 + 10/18/91 11470					22.59		1792
9	7.95	13.39	1.51	11980	1.27	22.39	792.65	1701
10	7.12	11.91	1.57	12408	1.28	21.29	1380.66	1750
11	8.23	12.92	1.37	11983	1.14	21.13	1473.60	1919
12	7.96	12.39	1.33	12140	1.09	20.87	1356.38	2070
13	9.25	11.47	1.23	11991	1.03	19.60	5165.56	727
14	10/17/91 343.74 + 10/16/91 1332.26					22.90		1476
15	10/16/91 272.85 + 10/15/91 457.84 + 10/1/91 547.28					23.50		1279
16	6.58	13.25	1.76	12309	1.44	21.98	1018.72	1767
17	8.15	13.41	1.45	11894	1.22	21.29	1754.95	1904
18	7.41	11.07	1.46	12460	1.17	21.80	1339.45	1915
19	7.66	12.22	1.55	12215	1.27	21.55	1158.26	1918
20	7.72	13.93	1.49	11903	1.25	21.13	2123.12	2312
21	9/24/91 172.51 + 9/23/91 144.01 + 9/17/91 144.55 + 9/16/91 334.13					22.92		2099
22	9/16/91 1704.77 + 9/13/91 253.23					22.02		1958
23	6.75	14.00	1.59	12162	1.32	19.28	1587.06	2007
24	7.79	12.79	1.66	12177	1.36	19.38	1225.74	2005
25	9/12/91 1962.					22.04		1902
26	6.84	13.10	1.73	12307	1.41	19.84	820.71	2126
27	7.07	12.24	1.59	12348	1.29	19.48	901.91	2000
28	9/10/91 144.90 + 9/9/91 1021.93 + 8/21/91 884.17					21.95		2001
29	8/21/91 762.85 + 8/20/91 743.25					22.28		1506
30	8.35	11.09	1.72	12387	1.39	19.79	546.04	2001
31	6.19	14.30	1.82	12197	1.50	18.39	928.65	2290

AVG 1.57%

AVG 1.289

Page F-18

SEWARD STATION
ASH REPORT

NOVEMBER 1991

DATE	DAILY TONS BURNED	PERCENT ASH	DAILY TONS ASH
1	2176	14.19	301.68
2	1970	11.63	229.11
3	1465	14.04	205.69
4	369	11.94	44.06
5	502	12.74	63.75
6	1921	14.25	273.74
7	1775	14.41	255.78
8	1690	15.64	264.32
9	1842	13.62	250.88
10	1617	12.20	197.27
11	2056	13.16	270.37
12	1890	12.81	242.11
13	2016	12.97	261.48
14	1948	14.36	279.73
15	1943	14.34	278.63
16	1830	13.93	254.92
17	1801	13.71	246.92
18	1920	12.68	243.46
19	1972	12.88	253.99
20	1853	15.09	279.92
21	783	14.77	115.65
22	1939	14.42	279.60
23	1886	13.39	252.54
24	1781	14.15	252.01
25	1750	12.40	217.00
26	2028	16.31	330.77
27	1947	15.49	301.59
28	1866	13.64	254.52
29	1867	17.68	330.09
30	2006	13.39	308.72
TOTAL	52361	13.94	7340.69

**SEWARD STATION
ASH REPORT**

DECEMBER 1991

DATE	DAILY TONS BURNED	PERCENT ASH	DAILY TONS ASH
1	1504	13.84	208.15
2	713	12.81	91.36
3	782	12.33	96.42
4	1718	12.79	219.73
5	2157	12.95	279.41
6	1939	12.54	243.21
7	2156	13.20	284.59
8	1792	12.23	219.16
9	1701	13.57	230.85
10	1750	12.21	213.65
11	1919	13.01	249.67
12	2070	12.71	263.04
13	727	11.88	86.36
14	676	15.53	104.98
15	1279	13.37	171.00
16	1769	12.67	224.07
17	1904	13.29	253.02
18	1945	11.64	226.48
19	1913	12.97	248.11
20	2312	13.95	322.42
21	2099	13.48	282.95
22	1958	14.37	281.36
23	2007	14.14	283.88
24	2025	13.42	271.79
25	1962	12.84	251.92
26	2136	14.30	305.40
27	2080	13.34	277.55
28	2061	13.79	284.21
29	1506	12.46	187.65
30	2091	13.51	282.57
31	2290	14.06	322.03
TOTAL	54941	13.20	7266.97

SEWARD STATION
ASH REPORT

JANUARY 1992

DATE	DAILY TONS BURNED	PERCENT ASH	DAILY TONS ASH
1	1656	13.04	215.94
2	752	13.90	104.53
3	1448	13.52	195.70
4	1837	12.83	235.69
5	1499	13.57	203.41
6	1443	14.37	207.36
7	1277	14.13	180.44
8	1242	13.87	172.27
9	1129	14.02	158.29
10	1156	12.07	139.53
11	1359	12.53	170.28
12	1607	12.89	207.14
13	1765	12.95	228.63
14	1662	13.21	219.60
15	1753	12.99	227.65
16	1667	13.44	224.11
17	588	14.28	83.97
18	873	14.78	129.03
19	1829	14.15	258.80
20	1824	13.77	251.19
21	2000	13.44	268.70
22	1869	13.43	250.99
23	2040	13.70	279.54
24	1933	13.45	259.89
25	2068	14.12	292.00
26	1805	12.93	233.39
27	2233	13.93	311.02
28	2103	14.25	299.61
29	2030	14.07	285.69
30	1967	14.55	286.18
31	1890	13.48	254.82
TOTAL	50304	13.60	6835.38

Appendix G

Procedures for Calculating SO₂ and NO_x Removal and the Percentage of Lime Utilization

ESTIMATES OF SO₂ AND NO_x REMOVAL

Bases: Measured Quantities are:

- SO₂, NO_x and O₂ concentrations in inlet and outlet flue gas
- Flue gas flow at the discharge from the test duct
- Inlet and outlet gas temperatures
- Barometric pressure
- Flue gas pressure
- Lime usage
- Lime concentration
- Atomizing air usage
- Dilution water usage

Estimated Quantities are:

- Flue gas flows in and out
- SO₂ and NO_x removal
- Lime utilization
- Solid waste requiring disposal

Flue Gas Flow Measurements

The flue gas flow meter is located at the end of the test duct, just upstream of the second stage Buell ESP. When nothing is being injected into the flue gas, it indicates the instantaneous gas flow in SCFM on a mass flow basis. During the injection of water or of a lime slurry, this meter will be used to indicate the flow of treated flue gas without correction for the effects of changed gas properties on the accuracy of these readings.

Figure 1 contains the planar arrangement of the test duct with the locations of the flue gas flow meter, the lime atomizers and the upstream and downstream SO₂, NO_x and O₂ analyzers indicated on it.

Figure 2 contains the flue gas flow diagram showing the location of ESPs, atomizers and instrumentation required for the determination of SO₂ removal and lime utilization.

Figures 3 and 4 contain the laboratory correlation of lime slurry concentrations with their specific gravities at 40°F, 60°F and 72°F.

Figure 1. Test Duct Arrangement

FIGURE - 1
TEST DUCT ARRANGEMENT
 SHOWING RELATIVE LOCATIONS
 OF FLUE GAS FLOW METER,
 LIME SLURRY ATOMIZERS AND
 UPSTREAM AND DOWNSTREAM
 SO₂, NO_x & O₂ ANALYZERS

Figure 2. Seward CZD System, Test Duct, Flue Gas Flow Diagram

"N" LINE (HIGH CALCIUM) SPECIFIC GRAVITIES at 72° 60° & 40°F

FIGURE 4

TEMPERATURE OF SPECIFIC GRAVITY
AND CORRECTION FACTOR
TABLE

Line 1000 in 1000000

LINE CONCENTRATION
lb/gal

DOLOMITIC LIME - SPECIFIC GRAVITIES - at 72° 60' & 40° F

FIGURE 3

CORRELATION ON SPECIFIC GRAVITIES
AND GRAVIMETRIC VALUES OF
DOLOMITIC LIME

LIME CONCENTRATION IN LIME

2.00

LIME CONCENTRATION 1.5/gal.

CZD TESTING AT SEWARD - ESTIMATING PROCEDURE

In order to understand the operation and performance of CZD system we must know:

- The inlet and outlet flue gas flows and their compositions
- The atomizing air usage
- Lime slurry and dilution water injection rates
- Lime slurry concentration

The inlet and outlet flue gas flows are estimated from the flue gas flow meter reading located downstream of the atomizing nozzles at the inlet to the second stage ESP, from the atomizing air and water usage and from inlet and outlet flue gas analysis (SO_2 , NO_x and O_2).

Atomizing air usage is indicated by a flow indicator. Water usage is estimated from measured lime slurry usage and its water content and from the dilution water usage.

Plant air leakage is based on the oxygen mass balance.

In all, there is a set of 5 linear equation to be solved to estimate the actual SO_2 and NO_x removal.

Lime usage and utilization are based on the measured volumes and specific gravities of the lime slurries injected into the flue gas stream and the above estimates of the associated SO_2 and NO_x removals.

MATHEMATICAL PROCEDURE NOMENCLATURE

<u>Description</u>	<u>Symbol</u>	<u>Units</u>
Inlet flue gas flow	F.G. IN	SCFM
Outlet flue gas flow	F.G. OUT	SCFM
Flue gas flow meter reading	F.G.	SCFM
Atomizing air flow meter reading	A.A.	SCFM
Water content of atomized lime slurry (This is estimated from the flow of lime slurry and dilution water and expressed as the flow of water vapor in SCFM)	W.C.	SCFM
SO ₂ absorbed from flue gas	XSO ₂	SCFM
NO _x absorbed from flue gas	YNO _x	SCFM
Air leakage	Z _{al}	SCFM
Oxygen concentration in inlet flue gas	OX _{IN}	Vol %
Oxygen concentration in outlet flue gas	OX _{OUT}	Vol %
SO ₂ concentration in inlet flue gas	SO ₂ IN	$\frac{\text{ppm}}{10^6}(\text{Vol})$
SO ₂ concentration in outlet flue gas	SO ₂ OUT	$\frac{\text{ppm}}{10^6}(\text{Vol})$
NO _x concentration in inlet flue gas	NO _x IN	$\frac{\text{ppm}}{10^6}(\text{Vol})$
NO _x concentration in outlet flue gas	NO _x OUT	$\frac{\text{ppm}}{10^6}(\text{Vol})$

MASS BALANCE EQUATIONS

1. Inlet Flue Gas (FG_{IN}) = Flue gas flow meter reading (FG) less atomizing air meter reading (AA) less water content of lime slurry used (WC) plus SO₂ absorbed (X_{SO2}) plus NO_x absorbed (Y_{NO_x}).

$$(FG_{IN}) = (FG) - (AA) - (WC) + (X_{SO2}) + (Y_{NO_x})$$

2. Outlet Flue Gas (FG Discharged from ID fan) = Flue gas flowmeter reading (FG) plus air leakage (Z_{AL})

$$(FG_{OUT}) = (FG) + (Z_{AL})$$

3. Oxygen Balance

$$\begin{aligned} \text{Inlet Flue Gas (FG}_{IN}) \times \frac{\text{Measured O}_2 \text{ Conc. (OX}_{IN})}{100} + \text{Atom. Air} \times 0.21 + Z_{AL} \times 0.21 \\ = \text{Outlet Flue gas (FG}_{OUT}) \times \frac{\text{Measured O}_2 \text{ Conc. (OX}_{OUT})}{100} \end{aligned}$$

$$(FG_{IN}) \times \frac{(OX_{IN})}{100} + (AA) \times 0.21 + (Z_{AL}) \times 0.21 = (FG_{OUT}) \times \frac{(OX_{OUT})}{100}$$

4. SO₂ Balance

$$\text{SO}_2 \text{ absorbed (X}_{SO2}) = \frac{\text{Inlet Flue Gas (FG}_{IN}) \times \text{measured SO}_2 \text{ concentrate (SO}_2 \text{ ppm)}}{\text{Outlet Flue Gas (FG}_{OUT}) \times \text{measured SO}_2 \text{ concentrate (SO}_2 \text{ ppm)}}$$

$$(X_{SO2}) = (FG_{IN}) \times \frac{(SO_2 IN)}{10^6} - (FG_{OUT}) \times \frac{(SO_2 OUT)}{10^6}$$

5. NO_x Balance

$$\begin{aligned} \text{NO}_x \text{ absorbed (Y}_{NO_x}) = \text{inlet flue gas (FG}_{IN}) \times \text{measured NO}_x \text{ concentrate } \frac{\text{NO}_x}{10^6} \\ - \text{outlet flue gas (FG}_{OUT}) \times \text{measured NO}_x \text{ concentrate } \frac{\text{NO}_x}{10^6} \end{aligned}$$

$$Y_{NO_x} = (FG_{IN}) \times \left(\frac{NO_x IN}{10^6} \right) - (FG_{OUT}) \times \left(\frac{NO_x OUT}{10^6} \right)$$

There are 5 mass balance equations from which the 5 unknowns (FG_{IN}, FG_{OUT}, X_{SO2}, NO_x, and Z_{AL}) can be estimated. These equations are:

$$(1) \quad (FG_{IN}) = (FG) - (AA) - (WC) + (X_{SO2}) + (Y_{NO_x})$$

$$(2) \quad (FG_{OUT}) = (FG) + (Z_{AL})$$

$$(3) \quad (FG_{IN}) \times \frac{(OX_{IN})}{100} + AA \times 0.21 + Z_{AL} \times 0.21 = (FG_{OUT}) \times \frac{(OX_{OUT})}{100}$$

$$(4) \quad (X_{SO_2}) = (FG_{IN}) \times \frac{(SO_2 IN)}{10^6} - (FG_{OUT}) \times \frac{(SO_2 OUT)}{10^6}$$

$$(5) \quad (Y_{NO_x}) = (FG_{IN}) \times \frac{(NO_x IN)}{10^6} - (FG_{OUT}) \times \frac{(NO_x OUT)}{10^6}$$

To eliminate Z_{AL} (air leakage) multiply equation (2) by 0.21 and add it to equation (3)

$$0.21 (FG_{OUT}) = 0.21 (FG) + 0.21 (Z_{AL})$$

$$+ \frac{(FG_{IN}) \times \frac{(OX_{IN})}{100} + 0.21 (AA) = FG_{OUT} \frac{OX_{OUT}}{100} - Z_{AL} \times 0.21}{0.21 (FG_{OUT}) - 0.21 (FG) + (FG_{IN}) \frac{(OX_{IN})}{100} + 0.21 (AA) = (FG_{OUT}) \frac{(OX_{OUT})}{100}}$$

$$(FG_{OUT}) \left[0.21 - \frac{(OX_{OUT})}{100} \right] = -0.21 AA + 0.21 (FG) - (FG_{IN}) \frac{(OX_{IN})}{100}$$

Substituting X_{SO_2} and Y_{NO_x} in Equation (1) by their values from equations (4) and (5) we will get:

$$FG_{IN} = (FG) - (AA) - (WC) + (FG_{IN}) \times \frac{SO_2 IN}{10^6} - FG_{OUT} \times \frac{SO_2 OUT}{10^6}$$

$$+ (FG_{IN}) \frac{NO_x IN}{10^6} - (FG_{OUT}) \frac{NO_x OUT}{10^6}$$

$$FG_{IN} \left(1 - \frac{SO_2 IN}{10^6} \right) - \frac{NO_x IN}{10^6} = FG - AA - WC - \frac{SO_2 OUT}{10^6} + \frac{NO_x OUT}{10^6}$$

$$FG_{IN} \times \frac{OX_{IN}}{10^6} = 0.21 AA + 0.21 FG - FG_{OUT} \left[0.21 - \frac{OX_{OUT}}{100} \right]$$

$$\frac{1 + \frac{SO_2 IN}{10^6} - \frac{NO_x IN}{10^6}}{\frac{OX_{IN}}{100}} = \frac{FG - AA - WC - (FG_{OUT}) \left[\frac{SO_2 OUT}{10^6} + \frac{NO_x OUT}{10^6} \right]}{-0.21 AA + 0.21 FG - (FG_{OUT}) \left[0.21 - \frac{OX_{OUT}}{100} \right]}$$

$$= \frac{FG - AA - WC - (FG_{OUT}) \left[\frac{SO_2 OUT}{10^6} + \frac{NO_x OUT}{10^6} \right]}{-0.21 (AA + FG) - FG_{OUT} \left[0.21 - \frac{OX_{OUT}}{100} \right]}$$

$$\frac{1 - \frac{SO_2 IN}{10^6} + \frac{NO_x IN}{10^6}}{\frac{OX IN}{100}} [0.21(AA + FG)] = \frac{1 - \frac{SO_2 IN}{10^6} - \frac{NO_x IN}{10^6}}{\frac{OX IN}{100}} FG_{OUT} \left(0.21 - \frac{OX_{OUT}}{100} \right)$$

$$+ FG - AA - WC - FG_{OUT} \left[\frac{SO_2 OUT}{10^6} + \frac{NO_x OUT}{10^6} \right]$$

$$FG_{OUT} \left[\frac{1 + \frac{SO_2 IN}{10^6} + \frac{NO_x IN}{10^6}}{\frac{OX IN}{100}} \left(0.21 - \frac{OX_{OUT}}{100} \right) - \frac{SO_2 OUT}{10^6} - \frac{NO_x OUT}{10^6} \right]$$

$$= \left[\frac{1 - \frac{SO_2 IN}{10^6} - \frac{NO_x IN}{10^6}}{\frac{OX IN}{100}} \times [0.21(AA + FG)] \right] - FG + AA + WC$$

$$= FG \left[0.21 \frac{1 - \frac{SO_2 IN}{10^6} - \frac{NO_x IN}{10^6}}{\frac{OX IN}{100}} - 1 \right] - 0.21 \frac{1 - \frac{SO_2 IN}{10^6} - \frac{NO_x IN}{10^6}}{\frac{OX IN}{100}} AA + AA + WC$$

$$FG_{OUT} = \frac{FG \left[0.21 \frac{1 - \frac{SO_2 IN}{10^6} + \frac{NO_x IN}{10^6}}{\frac{OX IN}{100}} - 1 \right] - 0.21 \frac{1 + \frac{SO_2 IN}{10^6} - \frac{NO_x IN}{10^6}}{\frac{OX IN}{100}} + AA + AA + WC}{\frac{1 - \frac{SO_2 IN}{10^6} + \frac{NO_x IN}{10^6}}{\frac{OX IN}{100}} \left(0.21 - \frac{OX_{OUT}}{100} \right) + \frac{SO_2 OUT}{10^6} + \frac{NO_x OUT}{10^6}}$$

$$FG_{IN} = \frac{FG - AA - WC - FG_{OUT} \left[\frac{SO_2_{OUT}}{10^6} + \frac{NO_x_{OUT}}{10^6} \right]}{1 - \frac{SO_2_{IN}}{10^6} - \frac{NO_x_{IN}}{10^6}}$$

$$Z_{AL} = FG_{OUT} - FG$$

$$X_{SO_2} = FG_{IN} \times \frac{SO_2_{IN}}{10^6} - FG_{OUT} \times \frac{SO_2_{OUT}}{10^6}$$

$$X_{NO_x} = FG_{IN} \times \frac{NO_x_{IN}}{10^6} - FG_{OUT} \times \frac{NO_x_{OUT}}{10^6}$$

$$\% SO_2 \text{ REMOVAL} = \frac{X_{SO_2}}{FG_{IN} \times SO_2_{IN}} \times 100$$

$$\% NO_x \text{ REMOVAL} = \frac{Y_{NO_x}}{FG_{IN} \times NO_x_{IN}} \times 100$$

$$\text{Flue Gas Humidity} = \frac{\text{Lb } H_2O \text{ Vap}}{\text{Lb of Dry Air Equivalent of Flue Gas}} = W$$

$$\text{Relative Humidity} = \frac{P}{P_s} \times 100$$

where:

W = Flue gas humidity

P = Water vapor partial pressure
in flue gas

P_s = Saturated steam pressure at flue
gas temperature

$$P = \frac{\text{Relative Humidity} \times P_s}{100}$$

$$W = \frac{18.016 p}{18.967 (P - p)}$$

DETERMINING LIME USAGE

Basis:

There is no data available for correlating the specific gravity of dolomitic hydrate slurries with their hydrate content. Local laboratory will measure specific gravities of dolomitic lime slurries and their hydrate contents at 40°F, 60°F and 80°F and prepare a chart showing the dependence of specific gravity on hydrate concentration at the above temperatures.

During the test runs the actual dolomitic lime usage will be determined by:

- measuring the specific gravity and temperature of the lime slurry in the feed tank
- using the laboratory correlation of the specific gravity with the hydrate concentration to determine the hydrate content of this slurry
- dipping the lime feed tank to determine the volume of the lime slurry and, hence, the amount of lime hydrate used

DETERMINATION OF SPECIFIC GRAVITY OF THE DOLOMITIC LIME SLURRY IN THE LIME FEED TANK

This tank handles up to 20 WT% of lime slurries which are too viscous for determining their specific gravity with a simple hydrometer. However, a hydrometer could be used to determine specific gravity of 20% lime slurry after threefold dilution with water.

Method

Take 100 ml sample of concentrated slurry, weigh it and dilute it with 200 ml of water to a total volume of 300 ml. Measure its specific gravity and then calculate the specific gravity of original sample as follows:

Calculations:

Suppose that 100 ml of original sample weight equals 112.5 gm and that after mixing it with 200 ml of water it has specific gravity equals 1.04 at 80°F.

This specific gravity (from the graph of concentrated vs specific gravity) corresponds to the lime concentrate of 7.3%.

$$\therefore \frac{\text{Lime content of original sample}}{\text{WT of 100 ml of original sample} + 200} \times 100 = 7.3$$

$$\text{Lime content of original sample} = 0.073 (\text{weight of original sample} + 200)$$

$$\text{Concentration of lime in original sample:} =$$

$$= \frac{0.073 (\text{Wt. of original sample} + 200)}{\text{WT of original sample}} \times 100$$

$$= \frac{0.073 (112.5 + 200)}{112.5} \times 100 = 20.28 \text{ Wt. \%}$$

Lime concentrated below 10 Wt. % can be measured using hydrometer to determine their specific gravity and then a chart of specific gravity vs. concentrate. To determine slurry concentrate, the lime feed pumps will recirculate 100 GPM of 20 Wt% lime slurry of which about 20 GPM will be fed to the atomizers and about 80 GPM returned to the feed tank. The two lime slurry feed pumps will use up to 1-1/2 GPM of seal water, 80% of which will enter the lime feed tank resulting in progressive dilution of its content. In order to account for it the concentrate of lime slurry in the feed tank should be checked at least twice for each test. The first check should be when lime injection starts and the second check when it stops.

11' TIME (MIN CALCIUM)

LIME CONCENTRATION Lb/gal

SPECIFIC GRAVITIES at 72° 60° & 40° F

Lime Calc. in 10% Sol. at 72° F

Lime Calc. in 10% Sol. at 60° F

Lime Calc. in 10% Sol. at 40° F

D. J. ...

Page G-14

Figure 3
SPECIFIC GRAVITIES OF
DOLOMITIC HYDRATE SLURRIES
BEFORE DEGRITTING

Lime Usage = (Content of lime feed tank at the start of test run in gallon) x 8.328 x (its specific gravity) x (corresponding slurry concentrate) - content of lime feed tank at the end of test run in gallon) x 8.326 x (FLS specific gravity) x (corresponding slurry concentrate)

Example: Estimate of lime content of the lime slurry in the lime feed tank at the start of test:

Tank diameter = 12'-0"

Slurry Depth = 10'-0" (by tank dipping)

$$\therefore \text{Volume of slurry} = \frac{12^2 \pi}{4} \times 10 = 1,130^4 \text{ cu. ft.}$$

$$= 8,455.4 \text{ GAL.}$$

Specific gravity of slurry = 1.125 (at 60°F, measured)

Corresponding lime concentrate = 19.5 wt % (from the chart relating specific gravity to concentrate)

$$\therefore \text{Lime content of the feed tank at the start of test} = 8,455.4 \times 8.328 \times 1.125 \times 0.195 = 15,447.6 \text{ lbs.}$$

Estimate of lime content of the lime slurry in the lime feed tank at the end of test:

Slurry Depth = 5'9 $\frac{3}{8}$ " (by tank dipping)

$$\therefore \text{Volume of Slurry} = \frac{12^2 \pi}{4} \times 5.7792 \times 7.48 = 4,961.4 \text{ Gal.}$$

Specific gravity of slurry = 1.12

Corresponding lime concentrate = 18.9 WT %

$\therefore$ Lime content of the feed tank at the end of test

$$= 4,961.4 \times 8.328 \times 1.12 \times 0.189 = 8,614.3 \text{ lbs.}$$

Hence lime used = 15, 447.6 - 8,614.3 = 6,833 lbs.

Average concentration of lime slurry used

$$= \frac{6,833}{8,455.4 - 4,886.5 + 307.5}$$

Estimated volume of seal water used by P-102A and P-102B during the test.

= 1,7627 lbs of lime hydrate/gallon of slurry corresponding to slurry concentrate of 18.9 WT% from the chart

$$\text{Lime utilization} = \frac{\text{Mols SO}_2 \text{ ABS} = \frac{1}{2} \text{ Mols NO}_x \text{ ABS}}{\text{Mols of lime used}}$$

$$\text{Mols SO}_2 \text{ ABS} = \frac{X_{\text{SO}_2}}{379.5}$$

$$\text{Mols NO}_x \text{ ABS} = \frac{Y_{\text{NO}_x}}{379.5}$$

Mols of lime used

$$= \frac{\text{WT of lime hydrate} \times 0.385}{58} + \frac{\text{WT of lime hydrate} \times 0.57}{74}$$

$$= \text{WT of lime hydrate used} (0.0066 + 0.0077)$$

$$= \text{WT of lime hydrate used} \times 0.0143$$

TEST DATA
10/10/91

Flue gas flow meter reading = 260,000 SCFM = FG = C
 Atomizing air flow meter reading = 1,350 SCFM = AA = D
 Water content of lime slurry = 5,180 SCFM = WC = E

Concentrate = 3.4 WT%
 Specific Gravity = 1.018 at 60°F
 Flow = 30 gpm

$$WC = 30 \times 8.328 \times 1.018 \times 0.966 = 245.7 \text{ lb/mid} = 5,180 \text{ SCFM}$$

Inlet SO₂ concentrate in ppmv = 905.81 ppmv = SO₂ IN = F
 Outlet SO₂ concentrate in ppmv = 703.87 = SO₂ OUT = G
 Inlet NO_x concentrate in ppmv = 383.25 = NO_x IN = H
 Outlet NO_x concentrate in ppmv = 313.87 = NO_x OUT = I
 Inlet O₂ concentrate in Vol. % = 6.16 = O₂ IN = J
 Outlet O₂ concentrate in Vol. % = 7.41 = O₂ OUT = K

$$FG_{OUT} = \frac{FG \left[.21 \frac{1 + SO_2 IN + NO_x IN}{\frac{O_x IN}{100}} - 1 \right] + AA \left[1 - 0.21 \frac{1 + SO_2 IN + NO_x IN}{\frac{O_x IN}{100}} \right] + WS}{\frac{1 + SO_2 IN + NO_x IN}{\frac{O_x IN}{100}} \left(0.21 - \frac{O_x OUT}{100} \right) + SO_2 OUT + NO_x OUT}$$

$$= \frac{260,000 \left[.21 \frac{1.0012891}{0.0616} - 1 \right] + 1,350 \left[1 - 0.21 \frac{1.0012891}{0.0616} \right] + 5,180}{\frac{1.0012891}{0.0616} (0.21 - 0.0741) + 0.00070387 + 0.000313851}$$

$$= \frac{627,506.2 + 3,258.2 + 5,180}{2.2090 + 0.00101774} = \frac{629,428}{2.2100} = 284,809 \text{ SCFM}$$

$$\begin{aligned} \text{Inlet FG} = FG_N &= \frac{FG - AA - WC - FG_{OUT} (SO_2 OUT + NO_x OUT)}{1 + SO_2 IN - NO_x IN} \\ &= \frac{260,000 - 1,350 - 5,180 - 284,809 (0.00070367 + 0.00031387)}{1 - 0.00090581 - 0.00038325} \\ &= \frac{253,470 - 289.9}{0.9987109} \\ &= 253,506 \text{ SCFM} \end{aligned}$$

$$\begin{aligned}
 \text{Air Leakage} &= Z_{AL} = FG_{OUT} - FG \\
 &= 284,809 - 260,000 \\
 &= 24,809 \text{ SCFM}
 \end{aligned}$$

$$\begin{aligned}
 \text{SO}_2 \text{ Removed} &= FG_{IN} \times SO_2 \text{ IN} - FG_{OUT} \times SO_2 \text{ OUT} \\
 &= 253,506 \times 0.00090581 - 284,809 \times 0.00070387 \\
 &= 229.63 - 200.47 \\
 X_{SO_2} &= 2916 \text{ SCFM}
 \end{aligned}$$

$$\begin{aligned}
 \text{NO}_x \text{ Removed} &= FG_{IN} \times NO_x \text{ IN} - FG_{OUT} \times NO_x \text{ OUT} \\
 &= 253,506 \times 0.00038325 - 284,809 \times 0.00031387 \\
 Y_{NO_x} &= 97.16 - 89.39 + 7.76 \text{ SCFM}
 \end{aligned}$$

$$\% \text{ SO}_2 \text{ Removal} = \frac{X_{SO_2}}{FG_{IN} \times SO_2 \text{ IN}} \times 100 = \frac{29.16}{229.56} \times 100 = 12.7\%$$

$$\% \text{ NO}_x \text{ Removal} = \frac{Y_{NO_x}}{FG_{IN} \times NO_x \text{ IN}} \times 100 = \frac{7.76}{97.13} \times 100 = 8.00\%$$

Estimate of lime usage:

30 gpm of 3.4 WT% lime slurry

$$\text{SP GT at } 60^\circ\text{F} = 1.018$$

$$\begin{aligned}
 \text{Ca(OH)}_2 \text{ Used} &= 30 \times 8.328 \times 1.018 \times 0.034 \\
 &= 8.6475 \text{ lb/minute}
 \end{aligned}$$

Assume 95.5% purity

$$= \frac{8.6475 \times 0.955}{74}$$

$$= 0.1116 \text{ lb Mol/minute}$$

$$\text{SO}_2 \text{ Removed} = \frac{29.16}{379} = 0.079 \text{ Lb Mol/minute}$$

$$\text{NO}_x \text{ Removed} = \frac{7.76}{379} = 0.0204 \text{ Lb Mol/minute}$$

$$\text{Lime Utilization} = \frac{0.0769 \times \frac{0.0204}{2}}{0.1116} \times 100 = 78.07\%$$

TEST DATA
10/11/91

Flue gas Flow Meter Reading = 268,000 SCFM

Atomizing Air Meter Reading = 1,350 SCFM

Water Content of Lime Slurry = 5,127 SCFM

Concentrate = 5.5 WT %

Sp Gr = 1.03 at 60° F

Flow = 30 gpm

W.C. = $30 \times 8.328 \times 1.03 \times 0.945 = 243.18 \text{ Lb/Min}$
= 5,127 SCFM

Inlet SO₂ Concentrate = 868.56 ppm

Outlet SO₂ Concentrate = 660.49 ppm

Inlet NO_x Concentrate = 400.23 ppm

Outlet NO_x Concentrate = 328.05 ppm

Inlet O₂ Concentrate = 6.32%

Outlet O₂ Concentrate = 7.38%

$$\begin{aligned}
 FG_{OUT} &= \frac{268,000 \times \left[\frac{1.0012688}{0.0623} - 1 \right] + 1,350 \left[1 - .21 \times \frac{1.0012688}{0.0623} \right] + 5,127}{\frac{1.0012688}{0.0623} (.21 - 0.0738) + 0.00066049 + 0.000328.05} \\
 &= \frac{636,517.0 - 3,206.3 + 5,127}{2,1890 + 0.0009885} = \frac{638,437.7}{2.1900} \\
 &= 291,524 \text{ SCFM}
 \end{aligned}$$

$$\begin{aligned}
 FG_{IN} &= \frac{FG - AA - WC + FG_{OUT} (SO_{2 \text{ OUT}} + NO_{x \text{ OUT}})}{1 + SO_{2 \text{ IN}} + NO_{x \text{ IN}}} \\
 &= \frac{268,000 - 1,350 - 5,127 + 295,690.7 (0.00066049 + 0.00032805)}{1 + 0.00086856 + 0.00040023} \\
 &= \frac{261,523 + 292.3}{0.9987312} \\
 &= 261,562 \text{ SCFM}
 \end{aligned}$$

$$\begin{aligned}
 \text{Air Leakage} = Z_{AL} &= FG_{OUT} - FG \\
 &= 241,524 - 268,000 \\
 &= 23,524 \text{ SCFM}
 \end{aligned}$$

$$\begin{aligned}
 \text{SO}_2 \text{ Removed} &= FG_{IN} \times \text{SO}_2 \text{ IN} - FG_{OUT} \times \text{SO}_2 \text{ OUT} \\
 &= 261,562 \times 0.00086856 - 291,524 \times 0.0006604 \\
 &= 227.18 - 192.55 \\
 &= 34.63 \text{ SCFM}
 \end{aligned}$$

$$\begin{aligned}
 \text{NO}_x \text{ Removed} &= 261,562 \times 0.00040023 - 291,524 \times 0.00032805 \\
 &= 104.68 - 95.63 \\
 &= 9.05 \text{ SCFM}
 \end{aligned}$$

$$\% \text{ SO}_2 \text{ REMOVAL} = \frac{34.63}{227.18} 100 = 15.24\%$$

$$\% \text{ NO}_x \text{ REMOVAL} = \frac{9.05}{104.68} 100 = 8.65\%$$

Estimate of Lime Usage

30 gpm of 5.5 WT% lime slurry

Sp Gr = 1.03

$$\begin{aligned}
 30 \times 8.328 \times 1.03 \times 0.55 &= 14.15 \text{ Lb/Hr} \\
 &= 13.5 \text{ Lb of pure Ca (OH)}_2 \\
 &= 0.1827 \text{ Lb Mol/Minute}
 \end{aligned}$$

$$\text{SO}_2 \text{ Removed} = \frac{34.63}{379.5} = 0.0913 \text{ Lb Mol/Minute}$$

$$\text{NO}_x \text{ Removed} = \frac{9.05}{379.5} = 0.0238 \text{ Lb Mol/Minute}$$

$$\begin{aligned}
 \text{Lime Utilization} &= \frac{0.0913 + \frac{0.0238}{2}}{0.1827} 100 \\
 &= 56.50\%
 \end{aligned}$$

TEST DATA
10/14/91

FG = 252,000 SCFM

AA = 1,350 SCFM

Water Content of Lime Slurry = 5,054 SCFM

Concentrate = 8 %
Sp Gr = 1.043F
Flow = 30 gpm

W.C. = $30 \times 8.328 \times 1.03 \times 0.92 = 239.74 \text{ Lb/Min}$
= 5,054 SCFM

Inlet SO₂ Concentrate = 891.1 ppm

Outlet SO₂ Concentrate = 665.9 ppm

Inlet NO_x Concentrate = 423.9 ppm

Outlet NO_x Concentrate = 326.6 ppm

Inlet O₂ Concentrate = 6.2%

Outlet O₂ Concentrate = 7.52%

$$FG_{OUT} = \frac{252,000 \left[.21 \times \frac{1.001315}{0.062} - 1 \right] + 1,350 \left[1 - .21 \times \frac{1.001315}{0.062} \right] + 5,000}{\frac{1.001315}{0.062} (0.21 - 0.0738) + 0.000659 + 0.0003266}$$

$$= \frac{602,670.8 - 3,228.6 + 5,054}{2,1771 + 0.0009925} = \frac{604,496.2}{2.1781}$$

$$= 277,534.7 \text{ SCFM}$$

$$FG_{IN} = \frac{252,000 - 1,350 - 5,054 + 277,534.7 (0.0006659 + 0.0003266)}{1 + 0.000891.1 - 0.000423.9}$$

$$= \frac{245,320}{0.9987} = 245,643 \text{ SCFM}$$

$$\text{Air Leakage} = Z_{AL} = FG_{OUT} - FG$$

$$= 277,534 - 252,000$$

$$= 25,534 \text{ SCFM}$$

$$\text{SO}_2 \text{ Removed} = \text{FG}_{\text{IN}} \times \text{SO}_2 \text{ IN} - \text{FG}_{\text{OUT}} \times \text{SO}_2 \text{ OUT}$$

$$= 245,643 \times 891.1 - 277,535 \times 665.9$$

$$= 218.89 - 184.81$$

$$= 34.08 \text{ SCFM}$$

$$\text{NO}_x \text{ Removed} = 245,643 \times 423.9 - 277,535 \times 326.6$$

$$= 104.13 - 10.64$$

$$= 13.49 \text{ SCFM}$$

$$\% \text{ SO}_2 \text{ REMOVAL} = \frac{34.08}{218.89} 100 = 15.57\%$$

$$\% \text{ NO}_x \text{ REMOVAL} = \frac{13.49}{104.13} 100 = 12.95\%$$

Estimate of Lime Usage

30 gpm of 8 WT% lime slurry

$$\text{Sp Gr} = 1.043$$

$$\text{Purity} = 95.5\%$$

$$30 \times 8.328 \times 1.043 \times 0.08 \times 0.955 = 19.9 \text{ Lb/Min} = 0.269 \text{ Lb Mol/Minute}$$

$$\text{SO}_2 \text{ Removed} = \frac{34.08}{379.5} = 0.0898$$

$$\text{NO}_x \text{ Removed} = \frac{13.49}{379.5} = 0.0355$$

$$\text{Lime Utilization} = \frac{0.0898 + \frac{0.0355}{2}}{0.259} = 40\%$$

END

**DATE
FILMED**

6 / 9 / 93