DOE/PC/79796--T48-Vol. 4

ENHANCING THE USE OF COALS BY GAS REBURNING-SORBENT INJECTION

Volume 4 - Gas Reburning-Sorbent Injection at Lakeside Unit 7 City Water, Light and Power, Springfield, Illinois

Prepared Under:

U. S. Department of Energy Cooperative Agreement DE-FC22-87PC79796
Gas Research Institute Contract No. 5087-254-149
Illinois Department of Commerce and Community Affairs

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Final Report
U.S. DOE Patent Clearance is Not Required Prior to the Publication of this Document

March, 1996

Energy and
Environmental
Research Corporation

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ABSTRACT

A demonstration of Gas Reburning-Sorbent Injection (GR-SI) has been completed at a cyclone-fired utility boiler in a Clean Coal Technology Round 1 Program. The Energy and Environmental Research Corporation (EER) has designed, retrofitted and tested a GR-SI system at City Water Light and Power's 33 MW_e Lakeside Station Unit 7. The program goals of 60% NO_x emissions reduction and 50% SO_2 emissions reduction were exceeded over the long-term testing period; the NO_x reduction averaged 63% and the SO_2 reduction averaged 58%. These were achieved with an average gas heat input of 22% and a calcium (sorbent) to sulfur (coal) molar ratio of 1.8. The peak NO_x reductions achieved with adequate combustion completion (i.e. CO emissions below 200 ppm) were 65% at full load and 71% at mid load. These required gas heat inputs of 23 to 24%. GR-SI resulted in a reduction in thermal efficiency of approximately 1% at full load due to firing natural gas which forms more moisture in flue gas than coal and also results in a slight increase in air heater exit gas temperature. Minor impacts on other areas of unit performance were measured and are detailed in this report.

GR-SI is a co-application of two emissions control technologies, GR for NO_x control and SI for SO_2 control. In GR, natural gas is used as a reburning fuel and injected into the furnace above the coal burners to create a slightly fuel rich zone where NO_x is reduced to N_2. The gas heat input required to achieve 60% reduction is typically in the 18 to 24% range. Overfire air is injected higher up in the furnace to complete the combustion process. In SI, hydrated lime sorbent is injected dry into the upper furnace cavity, near the boiler arch. The sorbent, injected at a rate corresponding typically to a Ca/S molar ratio of 2.0, reacts with SO_2 to form calcium sulfate and calcium sulfite. These solids are collected by the particulate collector, an electrostatic precipitator in this case.

The project at Lakeside was carried out in three phases, in which EER designed the GR-SI system (Phase 1), completed construction and start-up activities (Phase 2), and evaluated its performance with both short parametric tests and a long-term demonstration (Phase 3). This program was one of two full-scale GR-SI demonstrations conducted at utility boilers in the state

of Illinois. A GR-SI demonstration has also been completed at Illinois Power Company's Hennepin Station Unit 1, a 71 MW_e tangentially-fired unit. This report is one of five volumes presenting the results of the GR-SI demonstrations. It contains design and technical performance data; the economics data for all sites are presented in the final volume.

ACKNOWLEDGEMENTS

Energy and Environmental Research Corporation wishes to express appreciation to the project sponsors and their project managers for assistance received in conducting this project:

U. S. Department of Energy - Mr. Harry Ritz
Gas Research Institute - Mr. John Pratapas
Illinois Department of Commerce and Community Affairs - Mr. Paul Pierre-Louis

The assistance and cooperation of the personnel of City Water, Light and Power's Lakeside Station, especially Mr. Tom Booker, is also appreciated.

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LIST OF ABBREVIATIONS

AFT	Ash Fluid Temperature
AHT	Ash Hemispherical Temperature
AST	Ash Softening Temperature
ASME	American Society of Mechanical Engineers
B&W	Babcock and Wilcox
BACT	Best Available Control Technology
BMS	Burner Management System
BPMS	Boiler Performance Monitoring System
BSF	Boiler Simulation Furnace
CAAA	Clean Air Act Amendments
CCT	Clean Coal Technology
CEMS	Continuous Emissions Monitoring System
CFR	Code of Federal Regulations
CSA	Coal Stoichiometric Air
CWLP	City Water, Light and Power
DOE	U.S. Department of Energy
EER	Energy and Environmental Research Corporation
EMP	Environmental Monitoring Plan
ESP	Electrostatic Precipitator
EPRI	Electric Power Research Institute
EPA	U.S. Environmental Protection Agency
FD	Forced Draft
FEGT	Furnace Exit Gas Temperature
FGD	Flue Gas Desulfurization
FGR	Flue Gas Recirculation
FSI	Furnace Sorbent Injection
GR	Gas Reburning
GR-LNB	Gas Reburning-Low NO_x Burners
GR-SI	Gas Reburning-Sorbent Injection
GRI	Gas Research Institute
GSA	Gas Stoichiometric Air
HHV	Higher Heating Value
ID	Induced Draft
IDT	Initial Deformation Temperature
IEPA	Illinois Environmental Protection Agency
LHS	Left Hand Side
LHSW	Left Hand Side Wall
MACT	Mitsubishi Advanced Combustion Technology
MCC	Motor Control Center
MCR	Maximum Continuous Rating
NDIR	Nondispersive Infrared

LIST OF ABBREVIATIONS (CONTINUED)

NDUV	Nondispersive Ultraviolet
NG	Natural Gas
NPDES	National Pollutant Discharge Elimination System
NSPS	New Source Performance Standards
OFA	Overfire Air
PSD	Prevention of Significant Deterioration
PSH	Primary Superheater
PTC	Performance Test Code
RHS	Right Hand Side
RHSW	Right Hand Side Wall
SI	Sorbent Injection
SSH	Secondary Superheater
TA	Total Air
TBD	To Be Determined
TCLP	Toxicity Characteristic Leaching Procedure
TSS	Total Suspended Solids
UT	Ultrasonic Thickness
WDPF	Westinghouse Distributed Process Families

LIST OF UNITS

acfm	Actual Cubic Foot per Minute
Btu	British Thermal Unit
Btu/ft^3-hr	British Thermal Unit per Cubic Foot per Hour
Btu/kW-hr	British Thermal Unit per Kilowatt-Hour
Btu/lb	British Thermal Unit per Pound
Btu/scf	British Thermal Unit per Standard Cubic Foot
°C	Degree Celsius
cm	Centimeter
°F	Degree Fahrenheit
ft^2	Square Foot
ft^2/1000 acfm	Square Foot per 1000 Actual Cubic Feet per Minute
ft/s	Foot per Second
g/m^3	Gram per Cubic Meter
gr/dscf	Grain per Dry Standard Cubic Foot
kJ/kg	Kilojoule per Kilogram
kJ/kW-hr	Kilojoule per Kilowatt-Hour
kg/s	Kilogram per Second
kPa	Kilopascal
l/s	Liter per Second
lb/hr	Pound per Hour
m^2	Square Meter
m^3	Cubic Meter
m^2/m^3/s	Square Meter per Cubic Meter per Second
MBtu	Million British Thermal Unit
mg/l	Milligram per Liter
mg/MJ	Milligram per Megajoule
mm	Millimeter
MW	Megawatt
MW$_e$	Megawatt Electric
Nm^3	Normal Cubic Meter
Nm^3/s	Normal Cubic Meter per Second
ppm	Part per Million
psig	Pound per Square Inch Gauge
scfm	Standard Cubic Foot per Minute
%	Percent
"	Inch
’	Foot

LIST OF SYMBOLS

Al_2O_3	Aluminum Oxide (Alumina)
BaO	Barium Oxide
$CaCO_3$	Calcium Carbonate
CaO	Calcium Oxide
$Ca(OH)_2$	Calcium Hydroxide
$CaSO_3$	Calcium Sulfite
$CaSO_4$	Calcium Sulfate
CO	Carbon Monoxide
CO_2	Carbon Dioxide
Fe_2O_3	Ferric Oxide
H_2	Hydrogen
HC	Hydrocarbon
HCN	Hydrogen Cyanide
H_2O	Water
H_2S	Hydrogen Sulfide
K_2O	Potassium Oxide
MgO	Magnesium Oxide
$Mg(OH)_2$	Magnesium Hydroxide
MnO	Manganese Oxide
N_2	Nitrogen
Na_2O	Sodium Oxide
NH_3	Ammonia
$NH_4(OH)$	Ammonium Hydroxide
NO_x	Nitrogen Oxides
O_2	Oxygen
P_2O_5	Phosphorus Pentoxide
SiO_2	Silicon Dioxide (Silica)
SO_2	Sulfur Dioxide
SO_3	Sulfur Trioxide
SrO	Strontium Oxide
TiO_2	Titanium Dioxide

1.0 EXECUTIVE SUMMARY

A Gas Reburning-Sorbent Injection (GR-SI) demonstration has been completed at City Water, Light and Power's Lakeside Station Unit 7 located in Springfield, Illinois. The project was carried out under the sponsorship of the U.S. Department of Energy as a Clean Coal Technology Round 1 Program. Co-sponsorship was provided by the Gas Research Institute and the Illinois Department of Commerce and Community Affairs. The project goal was to reduce acid rain precursor gases NO_x and SO_2 by 60 and 50%, respectively. The host unit is a 33 MW_e cyclone-fired unit which burns medium to high sulfur Illinois bituminous coal.

Gas Reburning (GR) involves injection of natural gas as a reburning fuel into the furnace above the main burners. A slightly fuel rich zone is formed in which NO_x is reduced to a variety of intermediates and finally to N_2. In the Lakeside GR systems, recirculated flue gas was used to propel the natural gas into the furnace. The reburning fuel, accounting typically for 24% of the total heat input, was injected from nozzles on the boiler rear and side walls just above the primary refractory lined furnace. To complete the combustion process, overfire air (OFA) was injected higher up in the furnace from rear wall ports.

Sorbent Injection (SI) involves injection of micron-sized sorbent into the upper furnace cavity near the boiler arch. Hydrated lime was used at Lakeside; a hydrate or carbonate calcium based sorbent may be used. Sorbent reacts with SO_2 to form calcium sulfate ($CaSO_4$) and calcium sulfite ($CaSO_3$), which are solids captured with the particulate collector, an ESP in the case of Lakeside Unit 7. The design calcium (sorbent) to sulfur (coal) ratio was 2.0 for 50% SO_2 reduction in combination with GR. Note that GR reduces SO_2 emissions at a level equal to the gas heat input since natural gas is sulfur free.

The project was carried out in three phases, in which EER designed the GR-SI system and obtained necessary construction and testing permits (Phase 1), constructed the system and completed start-up activities (Phase 2), and evaluated its performance with short parametric tests and a long term demonstration period (Phase 3). At the conclusion of the demonstration period, an alternate sorbent supplied by NovaCon Energy Systems of Bedford, NY, was tested.

1.1 Testing at Lakeside Unit 7

The evaluation of the GR-SI system consisted of parametric tests, to optimize GR and SI process parameters, followed by a planned year long GR-SI demonstration with the unit under normal dispatch load control. Parametric GR testing was initiated in July, 1993 and included an evaluation of gas heat input, FGR flow, furnace zone stoichiometric ratios, and two sizes of reburning fuel injectors. Following GR parametric tests, SI system performance was evaluated. Process parameters tested include Ca/S molar ratio, SI carrier air flow, and the impact of load on the sorbent-SO_2 capture process.

Long-term GR-SI testing was initiated in October, 1993 and concluded in June, 1994. The unit was operated over its normal duty cycle. During this period GR and SI were usually operated together, with a gas heat input of 20 to 26% and, while the Ca/S molar ratio varied according to the operating load, it was typically in the range of 1.5 to 2.2.

1.2 Emissions Control

Over the long-term GR-SI demonstration the average NO_x reduction was 63% and the average SO_2 reduction was 58%. These were achieved with average gas heat input of 22% and an average Ca/S molar ratio of 1.8. Higher NO_x reductions were measured at low loads, due likely to formation of more uniform reducing conditions in the reburning zone, while higher SO_2 reductions were achieved at elevated loads, due to more favorable gas temperatures for sorbent sulfation. The maximum NO_x reductions by GR while maintaining adequate CO burnout were 65% at full load and 71% at mid (25 MW_e), achieved with gas heat inputs of 23 to 24% respectively. At a moderate Ca/S molar ratio of 1.9 and gas heat inputs of 22 to 26%, the maximum SO_2 reductions were 65% at full load and 61% at mid load. Emissions of CO_2 were reduced by approximately 8% due to fuel switching, since coal and natural gas have different carbon/hydrogen ratios. Emissions of CO, which indicate lack of combustion completion, were increased under GR, necessitating use of more burnout air than expected. Over the long-term GR-SI demonstration the CO emissions averaged 185 ppm (@ 3% O_2). Particulate emissions under GR-SI at full load were maintained well below the 0.1 lb/10^6Btu (43 mg/MJ) limit, at 0.016 lb/10^6Btu (6.9 mg/MJ). Opacities were maintained in the 2 to 7% range.

1.3 Thermal Performance Impacts of GR, SI, and GR-SI Operation

GR-SI operation had limited impacts on the units thermal performance. Steam temperatures were maintained at 10 to 20°F (5.6 to 11.1°C) below the design point of 910°F (488°C). Under GR, the attemperation heat absorption increased by a small amount due to input of fuel (heat) higher up in the furnace. The boiler efficiency, calculated by the heat loss method, was reduced under GR-SI operation. A reduction of approximately 1% was determined at full load, while at mid load (25 MW_e) it was approximately 2% and at low load (20 MW_e) efficiency was reduced by approximately 3%. These resulted from two effects, an increase in air heater gas exit temperature and an increase in heat loss due to moisture from combustion. Sootblowing in the convective pass was carried out almost continuously when injecting sorbent to enhance heat transfer to superheaters, thereby limiting the rise in gas temperature.

1.4 Boiler Impacts

In order to assess the impact of GR-SI on the boiler, a series of inspections were performed both prior to and following the GR-SI testing. EER established the baseline condition of the unit and determined the existence and rate of both degradation and equipment failures. The following areas were evaluated:

- Boiler tubes
- Regenerative air heater
- Electrostatic precipitator (ESP)
- Chimney
- Boiler performance

1.4.1 Boiler Tubes

A visual inspection performed following the testing showed no abnormal conditions in either the boiler furnace or cyclone barrels. Some sorbent accumulations were noted in the air side duct work, due to carryover from the air heater, but are no cause for concern.

Eight tube samples were extracted from the boiler for metallurgical examination. Three were removed prior to testing and five after testing. Locations encompass the reducing regions of the boiler. All tube samples were found to be in acceptable metallurgical condition, with no differences noted from before and after test conditions.

To determine the extent of tubewall wastage due to GR-SI, ultrasonic thickness measurements were made at 3200 points in the boiler both before and after testing. Specific areas were targeted where high rates of corrosion and/or erosion are possible. By comparing the thicknesses of the two tests, the rate of wear can be determined. The results of this analysis show that there was no significantly measurable wear of tubes as a result of GR-SI operation. All differences (both positive and negative noted) fall within the accuracy band of the process. When projecting the life of the tubes, analysis indicates that the scheduled life of the boiler will not been compromised either with or without continued use of the GR-SI system.

1.4.2 Regenerative Air Heater

The air heater was inspected both before and after testing. No adverse conditions resulted from operation of GR-SI. There was some minor basket degradation due to sootblower operation. Should the utility elect to retain the SI system, it is recommended that wear plates be installed at the inboard extent of the sootblower travel to protect the basket elements.

1.4.3 Precipitator

The ESP was inspected both before and after testing. The inspections concluded that the ESP had adequately accommodated the changes in ash loading and resistivity with the presence of sorbent in the ash. A number of mechanical deficiencies were noted in the second inspection, but these were not attributed to the GR-SI operation.

1.4.4 Chimney

The chimney was inspected both before and after testing. The inspections show normal wear and deterioration over the period of the test program, but no adverse effects resulting from GR-SI operation.

1.4.5 Boiler Performance

EER's retrofit of GR-SI required installation of several furnace wall openings for items such as GR nozzles, OFA nozzles, SI nozzles, and test ports. Whenever the GR-SI systems are not operated during boiler operation, a cooling medium is required in order to prevent nozzle overheating. Cooling air fans are used for the GR and SI nozzles and a percentage of the total OFA (re-directed secondary air) is used to cool the OFA nozzles. Test ports are cooled using seal air.

Although the cooling air is not part of the combustion stream, it has minor impact on boiler excess air levels (14% increase), and flue gas flow (47,500 lbs/hr increase) resulting in a minimal decrease in boiler efficiency. As noted earlier in this report, the reduction in efficiency when operating the GR system is 1.4%.

1.5 Enhancements

The CCT project has provided a number of permanent enhancement to Lakeside Unit #7 in support of the GR-SI system and at the request of CWLP. These enhancements, listed below, were provided to CWLP at no cost.

- Replacement of the boiler control system with a new Westinghouse distributed control system including custom screen graphics
- Replacement of the steam drum internals to improve circulation
- Replacement of all sootblowers and wallblowers with new equipment including a new sootblower control system, motor control center, piping, and control valves
- Asbestos abatement and re-insulation in affected areas
- Upgrade of the Ronan annunciator system
- Installation of a fly ash collection silo to reduce the demand on the ash pond
- Installation of a natural gas main and local metering station

1.6 Restoration

The decision to restore all, or part of, the GR-SI system rests solely with CWLP with the exception of certain equipment noted in the CWLP/EER Host Agreement. If CWLP elects to require equipment removal, title to the equipment will remain with EER. EER will then remove the subject equipment and restore the Host Unit in accordance with the Host Agreement. In the event CWLP elects to retain the equipment, CWLP is required to accept the equipment on an as-is, where-is basis. Title to equipment will pass to CWLP as soon as EER submits to CWLP a Bill of Sale.

2.0 PROJECT OVERVIEW

The Energy and Environmental Research Corporation (EER) has conducted a Gas Reburning-Sorbent Injection (GR-SI) demonstration at a cyclone-fired utility boiler in Springfield, Illinois. GR-SI was applied to reduce acid rain precursor gases NO_x and SO_2 by 60% and 50% respectively. The host unit, City Water Light and Power's (CWLP) Lakeside Station Unit 7, was retrofitted with a GR-SI system designed by EER then underwent short optimization tests and a long-term demonstration to evaluate emissions reduction and boiler performance. The project was part of Round 1 of the U.S. DOE's Clean Coal Technology (CCT) Program. Sponsors included the DOE, the Gas Research Institute (GRI), the Illinois State Department of Commerce and Community Affairs, and the host utility. The GR-SI demonstration program at CWLP's 33 MW_e (net) cyclone-fired Lakeside Station Unit 7, was one of three Gas Reburning (GR) demonstrations conducted by EER at units with different firing configurations. A GR-SI demonstration has been completed at Illinois Power Company's Hennepin Station Unit 1, a 71 MW_e (net) tangentially-fired unit. A Gas Reburning-Low NO_x Burner (GR-LNB) demonstration has been completed at Public Service of Colorado's Cherokee Station Unit 3, a 172 MW_e (gross) wall-fired unit, in a U.S. DOE CCT Round 3 Program. One of the CCT Round 1 GR-SI demonstration programs, at the front-wall-fired Central Illinois Light Company's Edwards Station Unit 1, was discontinued after completion of the design phase due to insufficient ESP capacity and costly upgrade requirements at this site.

2.1 Purpose of the Report

The purpose of this report is to present the process and engineering design of the GR-SI system and to fully detail its performance. The first part of the report contains design information for the GR and SI subsystems, GR-SI performance predictions in the areas of emissions control and thermal performance, and discussion of potential environmental concerns. The latter part of the report describes the performance of the GR-SI system, quantified during short optimization tests and a long-term demonstration. The NO_x and SO_2 emissions control achieved and impacts on thermal efficiency, steam conditions, slagging/fouling, electrostatic precipitator (ESP) performance, and impacts on the local environment are discussed. This volume does not contain economic data, which is presented in Volume 5. This document is Volume 4 of a five volume report prepared by EER for GR-SI demonstrations at three sites. The contents of these are as follows:

Volume 1	Summary - This provides an overview of the CCT Round 1 Program, including design information and performance data from two of the three GR-SI demonstration sites.
Volume 2	Gas Reburning-Sorbent Injection at Hennepin Station Unit 1 of Illinois Power - This report contains design information and testing results for the GR-SI demonstration at a 71 MW_e (net) tangentially-fired unit.
Volume 3	Gas Reburning-Sorbent Injection at Edwards Station Unit 1 of Central Illinois Light Company - This is a design report for the GR-SI demonstration at the 117 MW_e (net) wall-fired unit. The program at this site was suspended after completion of the design phase due to the small size of the ESP, requiring costly upgrade for sorbent injection (SI).
Volume 5	Guideline Manual - This volume presents all of the economic data, including capital and operating costs. The cost of the technology is compared to that of other available technologies. An analysis of the market for GR-SI and GR technologies is also presented.

2.2 Site Description

Lakeside Station Unit 7 is a cyclone-fired unit which has a rated nominal capacity of 33 MW_e (net) and peak capacity of 39.8 MW_e (net). The unit was supplied by Babcock and Wilcox (B&W) and has two 7 foot diameter cyclone furnaces on the front wall firing crushed coal. At its Maximum Continuous Rating (MCR) the unit produces 320,000 lb/hr (40.3 kg/s) of steam at a temperature of 910°F (488°C) and pressure of 875 psig (6030 kPa). It has a design efficiency of 88.10%. Figure 2-1 is a schematic of the unit and Table 2-1 contains the design specifications.

The normal fuel supply is a medium to high sulfur Illinois bituminous coal. The cyclone furnaces operate at a very high heat release rate, creating molten slag which is captured on the cyclone walls and flows to a slag tap at the bottom of the furnace. Combustion gases pass through a narrow refractory-lined primary furnace, a radiative secondary furnace, then through a convective pass consisting of secondary and primary superheaters, a two drum steam generating bank and a regenerative air heater. The flue gas then passes through an ESP and is discharged to the stack. Steam temperature control is achieved with a drum attemperator mounted in the upper steam drum. For control of fireside deposits, the unit is equipped with 8 wall blowers (IR) in the radiant furnace and 7 retractable sootblowers (IK) in the convective pass. The sootblowers use 250 psig (1720 kPa) steam supply and are shown in Figure 2-2.

The ESP is a relatively new F.L. Smidth unit providing 500 ft^2 of collecting plate area per 1000 actual cubic feet per minute of flue gas (98 $m^2/m^3/s$). Flue gases from Units 7 and 8, both of which have a nominal capacity of 33 MW_e (net) flow through the same ESP. The ESP was designed to receive flue gas from four units (two of which have been decommissioned); therefore, it is oversized when receiving flue gas from just two units. Typically only 2 of the 4 fields were used prior to initiation of the GR-SI project.

2.2.1 Baseline NO_x and SO_2 Emissions

Baseline emissions were characterized in two field tests prior to the GR-SI retrofit. Emissions of NO_x and CO, which were measured in August 1988 and September/October 1991, are shown in Figure 2-3. In 1988 the average full load NO_x emissions were 0.97 lb/10^6Btu (417 mg/MJ) at a boiler O_2 level of 3.29%. In the 1991 tests, NO_x emissions at full load averaged 0.95 lb/10^6Btu (409 mg/MJ) at an average boiler O_2 level of 2.77%. Emissions of CO were lower in the 1991 tests, with levels below 10 ppm at boiler O_2 above 2.5%. Baseline NO_x emissions

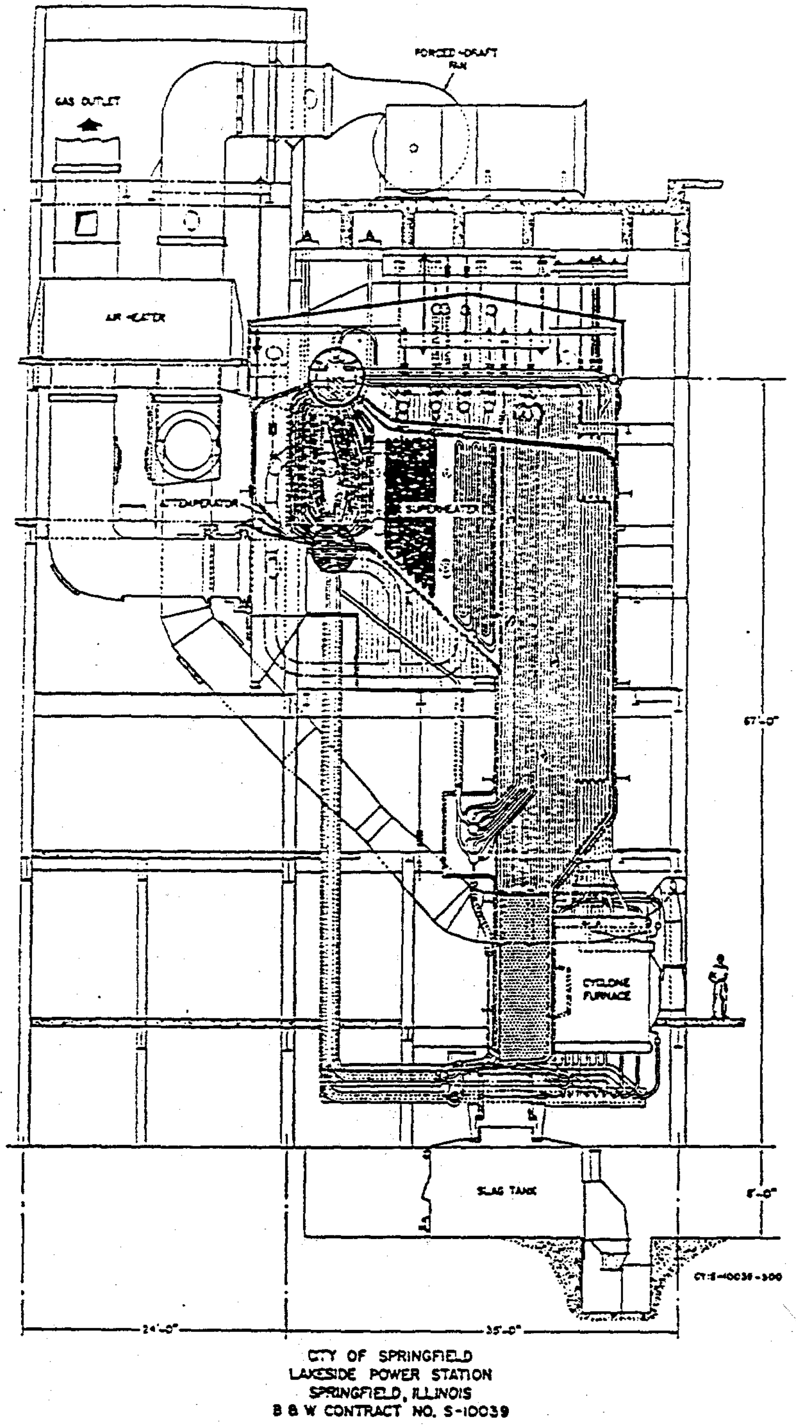


Figure 2-1. Schematic of Lakeside Station Unit 7

TABLE 2-1. SPECIFICATIONS FOR LAKESIDE UNIT 7

Manufacturer	Babcock and Wilcox
Fuel Type	Illinois Bituminous Coal
Boiler Firing Configuration	Front Wall, Cyclone
Number and Size of Cyclones	2 Cyclones 7-ft Diameter
Superheat Steam Flow	320,000 lbs/hr @ MCR
Superheat Steam Temperature	910°F
Steam Pressure	875 psig
Design Efficiency	88.10 Percent
Furnace Dimensions:	
Primary Furnace	18'0" W x 4'6" D
Secondary Furnace	18'0" W x 10'3" D
Furnace Heat Release Rate	46,200 Btu/ft ^{3} hr
Heating Surface Area:	
Boiler	11,854 ft ^{2}
Water-Wall	5,164 ft ^{2}
Primary Superheater	9,634 ft ^{2}
Secondary Superheater	4,013 ft ^{2}

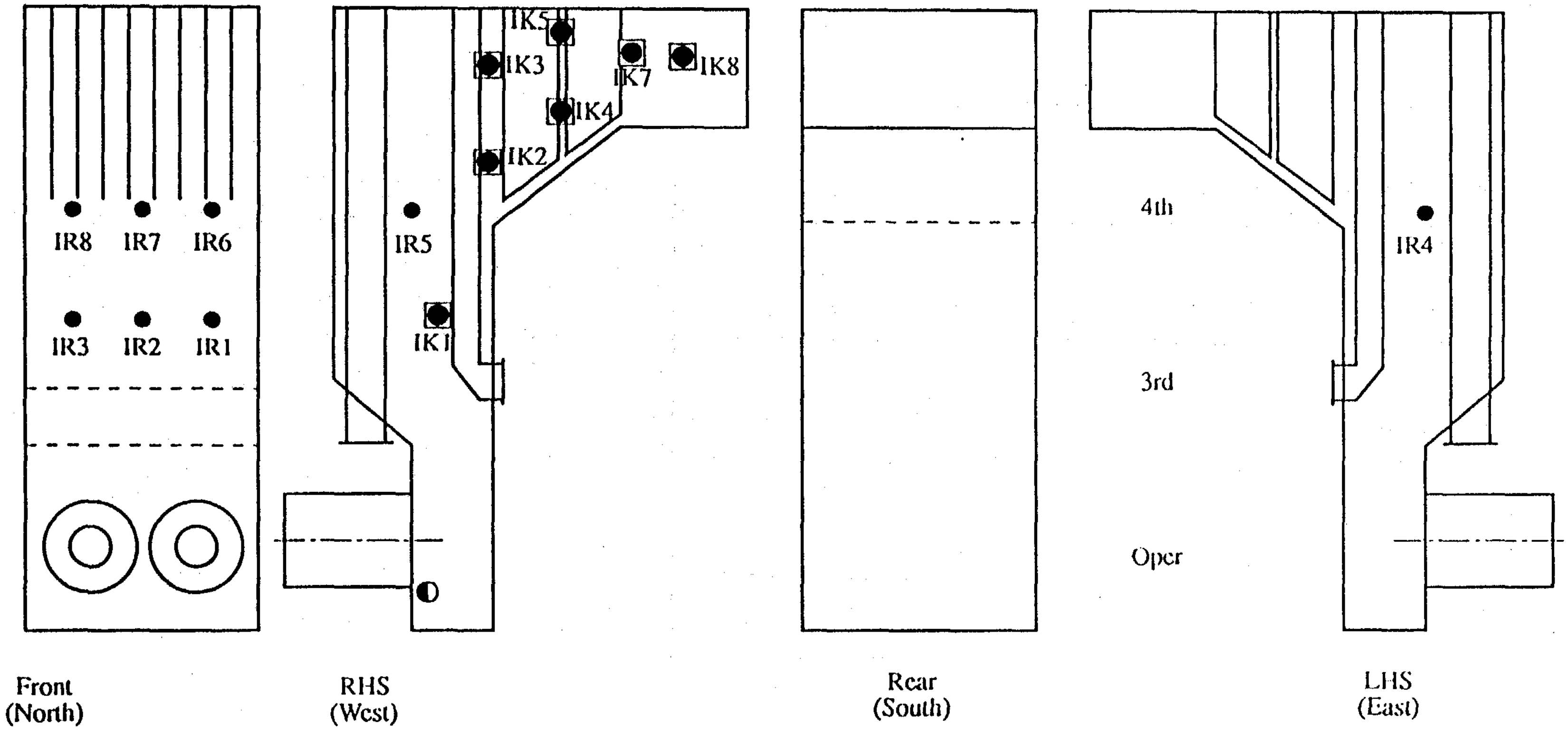


Figure 2-2. Sootblower Locations.

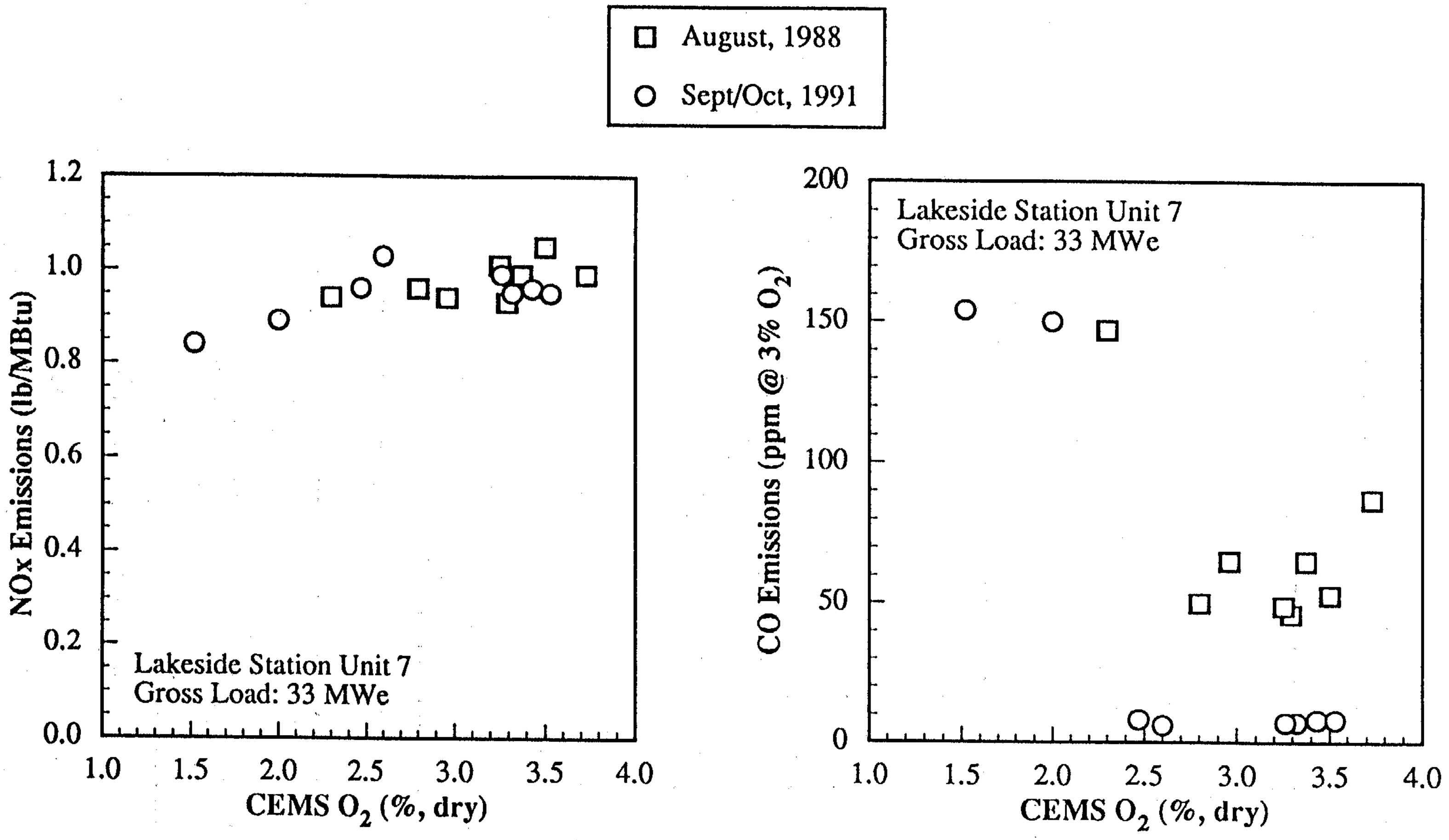


Figure 2-3. Pre-project baseline NO_x and CO emissions

measured during the GR-SI demonstration period (1993 - 1994) were 0.97 lb/10^6Btu (417 mg/MJ) at full load, 0.84 lb/10^6Btu (361 mg/MJ) at a mid load of 25 MW_e, and 0.80 lb/10^6Btu (344 mg/MJ) at a low load of 20 MW_e.

Emissions of SO_2 were 5.0 lb/10^6Btu (2150 mg/MJ) in the 1988 test, 5.4 lb/10^6Btu (2320 mg/MJ) in the 1991, and 5.9 lb/10^6Btu (2540 mg/MJ) during the GR-SI demonstration. The 5.9 lb SO_2/10^6Btu level is consistent with the coal sulfur content (Table B-1).

2.3 Description of the Project

The project evaluated an advanced emissions control technology, GR-SI, for reduction of acid rain precursor gases NO_x and SO_2. These gases, which are emitted by a variety of sources including coal-fired utility boilers, are believed to have contributed to damage to lakes, streams and vegetation in the northeastern U.S. and eastern Canada. The project was initiated in June, 1987 before promulgation of federal acid rain legislation in the 1990 Clean Air Act Amendments (CAAA). Title IV Phase 1 of CAAA limits NO_x emissions from wall-fired units to 0.5 lb/10^6Btu (220 mg/MJ) and from tangentially-fired units to 0.45 lb/10^6Btu (190 mg/MJ). No NO_x limit is specified for cyclone-fired units since widely applicable NO_x control technologies for this type of unit are still under development. More stringent NO_x limits are in place or are being considered for regions which have not attained ambient ozone standards.

The technology tested at Lakeside Unit 7 is a co-application of two complementary technologies, GR and SI. GR involves injection of natural gas as a reburning fuel into the furnace above the cyclones. The reburning fuel typically accounts for 15 to 25% of the total heat input. The reburning fuel forms a sub-stoichiometric reducing zone in which the primary NO_x formed in the cyclones is reduced to HCN and NH_3 and the more desirable N_2. Burnout (overfire) air is injected higher up in the furnace to complete the fuel combustion. GR also reduces SO_2 emissions relative to the percentage of natural gas heat input, since natural gas is a zero sulfur fuel. SI involves the injection of dry calcium-based sorbent, either a hydrate ($Ca(OH)_2$) or a carbonate ($CaCO_3$), into the furnace for SO_2 capture. In the furnace, the sorbent is calcined to form highly reactive calcium oxide (CaO), which reacts with SO_2 to form mostly calcium sulfate ($CaSO_4$) and calcium sulfite ($CaSO_3$). These solids are collected with the fly ash by the particulate collection device, an ESP or baghouse fabric filter.

The goal of this CCT Round 1 Program was to demonstrate a viable emissions control technology for older units which previously had no NO_x limits. Units constructed after 1971 are required to meet New Source Performance Standards (NSPS) while older units are restricted only if local ambient ozone levels exceed the standard. GR-SI demonstrations have been conducted at units with firing configurations that are representative of the majority of units in operation. GR-SI demonstrations have been completed at cyclone- and tangentially-fired units and a GR-LNB demonstration has been completed at a wall-fired unit. The units selected for GR-SI demonstrations and targeted for future applications are older with low capacity factors for which this cost-effective technology is especially attractive.

The project was conducted in three phases: Phase 1 - Design and Permitting, Phase 2 - Construction and Start-Up and Phase 3 - Operation, Data Collection, Reporting, and Disposition. The work scope of each phase is outlined below.

2.4 Objectives of the Project

The primary objective of the project was to demonstrate GR-SI technology for reduction of NO_x by 60% and SO_2 by 50%. NO_x emissions at full load would be reduced from a baseline of 0.97 $lb/10^6Btu$ (430 mg/MJ) to 0.39 $lb/10^6Btu$ (170 mg/MJ), while the SO_2 emissions would be reduced from 5.9 $lb/10^6Btu$ (2,540 mg/MJ) to 2.95 $lb/10^6Btu$ (1,270 mg/MJ). It was expected that this goal could be met without significant adverse impacts on other areas of unit performance including generating capacity, steam conditions, furnace slagging, convective pass fouling, particulate matter collection, and impacts on the local environment. Process design work carried out in Phase 1 of the project indicated that application of GR-SI to the Lakeside boiler would result in minor impacts on these areas. All project costs were documented so that a database of costs could be developed for future applications of the technology. All costs associated with the technology are presented in the Guideline Manual, Volume 5.

2.5 Project Schedule

The project was initiated in June, 1987, with the signing of Host Agreements with three utilities. The project was carried out in three phases in which the GR-SI system was designed and permitting matters were completed, the GR-SI system was erected and system start-up completed, and the GR-SI system performance was evaluated with short parametric tests and through a long-term demonstration. After the long-term GR-SI demonstration, which used Linwood hydrated lime as the baseline sorbent, an alternate sorbent prepared by NovaCon Energy Systems Inc. of Bedford, New York was tested. Phase 1 was completed in March, 1989, Phase 2 was completed in June 1993, and Phase 3 testing was finished in March 1995. Figure 2-4 shows the time frame for various project tasks.

The tasks completed in each phase are described below.

Phase 1 - Design and Permitting

Task 1 - Project Management: This task involved the planning and scheduling of all tasks and directing all EER and subcontractor work, review of relevant new technical developments, and keeping project sponsors informed of progress in the process and engineering design of the GR-SI system.

Task 2 - Process Design: In this task process requirements were established and the GR-SI process design was developed to meet these criteria. The host units were characterized to provide inputs to computer and physical models. Small scale tests were used to specify a process design and to study the impacts of various process parameters.

Task 3 - Project Engineering: A site specific engineering plan was prepared. This included full drawings of each GR-SI subsystem. A construction plan, cost estimate and test plan were also prepared.

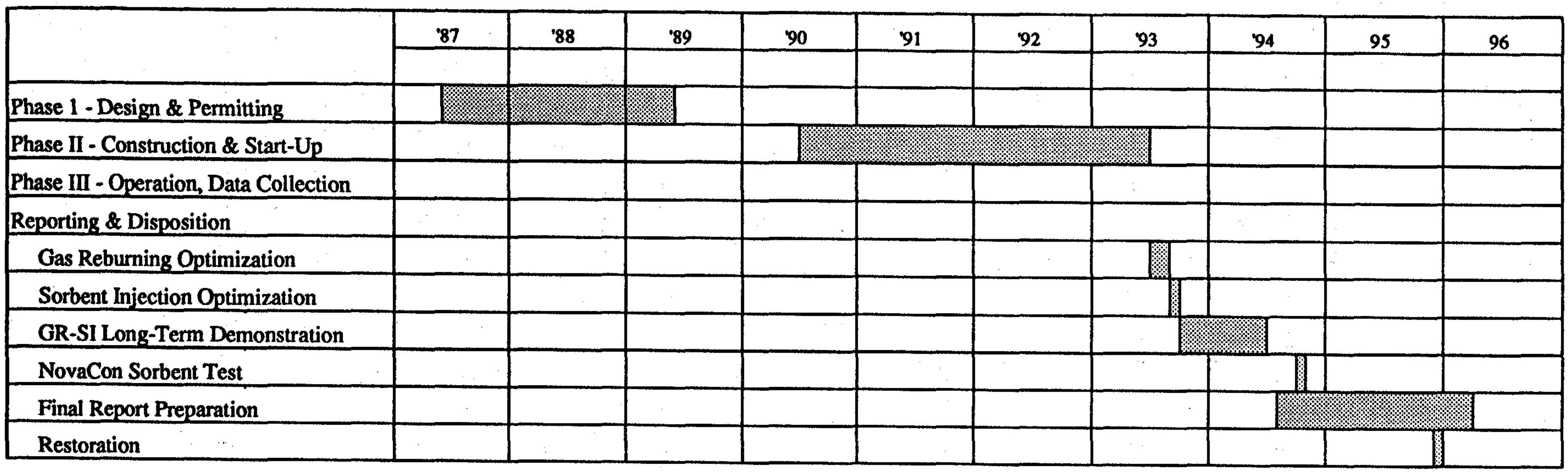


Figure 2-4. Schedule for GR-SI demonstration at the Lakeside Station

Task 4 - Environmental & Permitting Considerations: An Environmental Monitoring Plan (EMP) was prepared and environmental data were submitted to program sponsors in quarterly environmental reports. Permits for construction and testing of the GR-SI system were obtained from the regulatory agency, the Illinois Environmental Protection Agency (IEPA).

Task 5 - Technology Transfer: An industry panel was convened to evaluate the GR-SI system design and develop plans for commercialization of the technology following its successful demonstration.

Phase 2 - Construction & Start-Up

Task 1 - Project Management: This task was a continuation of the Phase 1 Project Management Task. Project review meetings were held at regular intervals throughout the project.

Task 2 - Installation and Checkout: The GR-SI system and auxiliary equipment were installed. Functional checkout and calibration of equipment and instrumentation was completed.

Task 3 - Technology Transfer: This task was a continuation of the Phase 1 Technology Transfer Task. Industry panel meetings were continued.

Task 4 - Restoration: A decision point was reached to continue with the GR-SI demonstration in lieu of restoration at this time.

Phase 3 - Operation, Data Collection, Reporting and Disposition

Task 1 - Project Management: This task was a continuation of the Phase 1 and Phase 2 Project Management Tasks. It involved directing testing activities and ensuring that appropriate test data were gathered. It led to the final review meeting at the conclusion of the project.

Task 2 - Technology Demonstration: The GR-SI system was operated through both short optimization tests and a long-term demonstration period. The GR and SI optimization test results were used to assess the performance of the system and to establish the process conditions for the long-term demonstration. Various areas of unit performance and operation were monitored to determine boiler changes due to GR-SI. All costs associated with the process and overall economic performance of the unit were documented while operating GR-SI.

Task 3 - Evaluation and Demonstration Results: This task involved analysis and correlation of test data. Data summaries were prepared in graphic and tabular form and the Final Report was generated.

Task 4 - Restoration: A report containing GR-SI performance data and an evaluation of long-term impacts on wear of boiler components was submitted to the utility for its decision on whether to retain the system or restore the unit per the Host Agreement.

Task 5 - Technology Transfer: This task was a continuation of the Phase 1 and Phase 2 Technology Transfer Tasks. Test data were presented at industry panel meetings and technical papers were submitted to various industry and scientific conferences.

2.6 Significance of the Project

This GR-SI demonstration was one of the first applications of GR technology to a utility boiler in the U.S. GR-SI has been demonstrated to be a feasible, low cost and easily retrofitted NO_x and SO_2 control technology. Since the inventory of available NO_x control technologies for cyclone-fired units is limited, an important and potentially widely applicable NO_x control technology has been developed. The performance results of this demonstration permit comparison of performance and economic factors for agent injection (ammonia or urea) technologies in catalytic or noncatalytic systems and other techniques currently in use to control NO_x emissions at cyclone-fired units.

Furnace sorbent injection (FSI) is a low cost and easily retrofitted SO_2 reduction technology for up to 50% control. Currently the common method used for moderate reduction of SO_2 is switching to low sulfur coal. This practice has in some cases resulted in extreme economic hardship in regions of the midwest where medium to high sulfur coal is mined. Therefore, SI allows the continued firing of medium to higher sulfur coals, while maintaining emissions below federal standards, thereby maintaining the economic situation in these regions. Other Flue Gas Desulfurization (FGD) processes include wet limestone scrubbing which has high capital cost and is therefore unattractive for application to older units with a low capacity factor.

2.7 Role of the DOE, GRI, and ENR in the Project

The DOE, GRI and ENR had two roles in this project. The first role is as funding organizations for development of the technology and its long-term demonstration. The DOE provided approximately one-half of project funds with the remainder coming from GRI, ENR and the host utility. These organizations also functioned as technical reviewers and advisors. In each phase of the project, project review meetings were held to present the progress made to that point.

3.0 TECHNOLOGY DESCRIPTION

This section presents a brief overview of GR and SI processes and their development history. Reburning for NO_x control has been under development for the past two decades. Early work in the use of hydrocarbon (HC) fragments to reduce NO_x was conducted by J. Wendt at Shell Development; additional early work in reburning was carried out by the John Zink Company (Reed, 1969). The process was first applied on a full scale unit in Japan, where it is known as the Mitsubishi Advanced Combustion Technology (MACT), by Mitsubishi Heavy Industries Ltd. and Ishikawajima-Harima Heavy Industries Ltd. (Takahashi, et al., 1981). Since 1980, EER has carried out extensive bench and pilot scale testing to characterize process parameters and for development of appropriate scale-up methodology for full scale application to U.S. boilers firing indigenous fuels (Chen et al.; 1983, Greene et al., 1985; McCarthy et al., 1985; Chen et al., 1986) . The GR demonstrations at three sites conducted by EER are among the first full scale applications of GR to coal-fired utility boilers in the U.S.. GR has also been applied to units in Italy, Ukraine, and Sweden.

Prior to the GR-SI demonstrations at Lakeside Station Unit 7 and Hennepin Station Unit 1, EER demonstrated FSI at Richmond Power and Light's Whitewater Valley Station Unit 2, in Richmond, Indiana (England, 1993). The experience gained in retrofitting this 61 MW_e tangentially-fired unit with an SI system was of great value in the design and of succeeding SI systems. The sulfation of sorbent is highly dependent on the injection temperature, the temperature quench rate, and the manner in which the sorbent is injected into the boiler. The SO_2 reductions achieved in the Richmond unit were correlated to SI process and boiler performance parameters including calcium (sorbent)-to-sulfur (coal) molar ratio, SI configuration (injectors in service), injection velocity, and the furnace exit gas temperature (FEGT). The results of that program added to EER's understanding of the impacts of process parameters and aided in optimizing future designs. The Richmond FSI project was co-sponsored by the Electric Power Research Institute (EPRI) and the U.S. Environmental Protection Agency (EPA).

3.1 Overview of GR-SI Technology

GR-SI is a co-application of two processes which may be applied separately for NO_x and SO_2 control. In GR, natural gas is injected into the furnace above the cyclones to form a slightly reducing region in which hydrocarbon fragments and free radicals reduce NO_x initially to HCN, NH_3, and the more desirable N_2. The reduced intermediates are subsequently either converted to N_2 or oxidized back to NO (See Figure 3-1). In first-generation GR systems (such as at Lakeside Unit 7) an inert carrier gas is used to enhance the mixing and dispersion of reburning fuel in the furnace. Flue gas recirculation (FGR) serves this purpose. Burnout OFA is injected higher up in the furnace to complete the combustion, resulting in low CO emissions and unburned carbon in fly ash. The furnace plane where burnout air is added is optimum for CO burnout and the temperature is sufficiently low to prevent formation of NO_x. The GR process divides the furnace into three zones, as illustrated in Figure 3-1. The zones are as follows:

Coal (Primary) Zone - Coal-fired through the burners corresponds typically to 75 to 85% of the total heat input, resulting in a NO_x level termed "primary NO_x". The gas heat input required to achieve a certain NO_x reduction is site specific. The coal zone is operated at as low an excess air as permitted by constraints such as flame stability, slagging, and fly ash carbon loss. Reduced burner heat release and excess air result in a lower "primary NO_x" level. For the Lakeside unit the O_2 level was not changed.

Reburning Zone - This zone is formed above the burners by the injection of reburning fuel. Reburning fuel is injected at a rate corresponding to 15 to 25% of the total heat input. The injection location, number of injectors, and amount of carrier gas are optimized to achieve rapid mixing of reburning fuel with the furnace gas and for thorough dispersion through the furnace. The upper furnace volume and gas residence time are limited in most small coal-fired boilers. A residence time of 0.3 to 0.5 seconds in the reburning zone is preferred, but residence time as low as 0.25 seconds as in the Lakeside boiler can still yield good performance. The gas temperature in the reburning zone is another parameter which impacts reburning efficiency; higher temperatures have a positive impact on reaction kinetics.

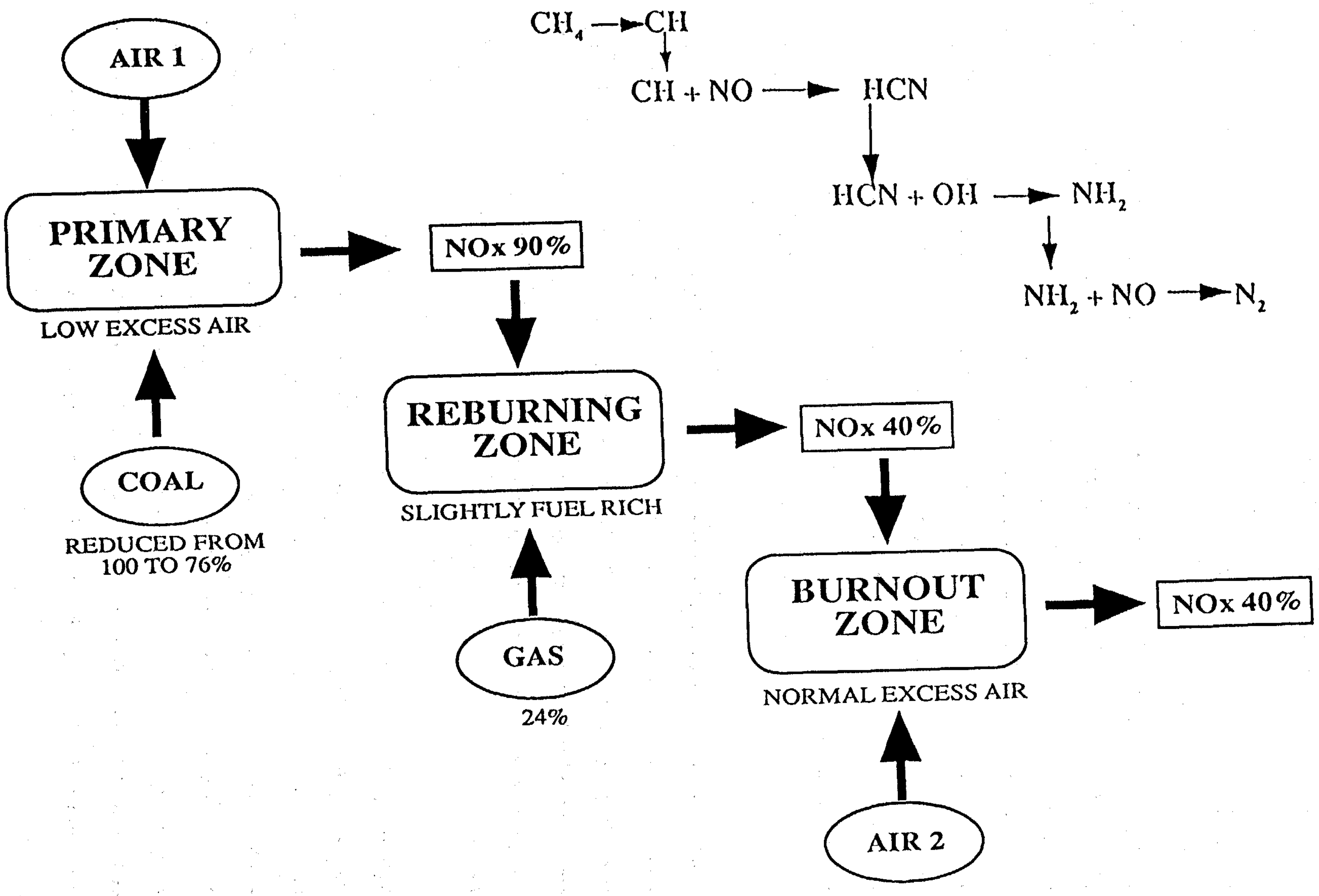


Figure 3-1. Overview of Gas Reburning process.

Burnout Zone - In the final zone, OFA is added to burn out the fuels under normal boiler excess air. OFA is injected at a sufficiently high temperature to burn out CO and carbon in fly ash. To minimize gas temperature quenching, preheated secondary combustion air is used.

Each of the three zones has a unique stoichiometric ratio, which can be calculated from the following equations:

Primary Zone $$SR_1 = \frac{TA - OFA}{CSA}$$

Reburning Zone $$SR_2 = \frac{TA - OFA}{CSA + GSA}$$

Burnout Zone $$SR_3 = \frac{TA}{CSA + GSA}$$

The symbols used in these equations are defined as follows:

TA = Total air, scfm or Nm^3/s
OFA = Overfire air, scfm or Nm^3/s
CSA = Coal stoichiometric air, scfm or Nm^3/s
GSA = Natural gas stiochiometric air, scfm or Nm^3/s

The design reburning zone stoichiometric ratio is 0.90.

When SI is applied with GR a final zone is created, commonly labeled "exit zone." This results from injection of sorbent transport and injection air, which are used to carry sorbent into the upper furnace. The exit zone stoichiometric ratio is only slightly higher than the burnout zone stoichiometric ratio. The level of NO_x control achieved by GR depends on boiler-specific details, such as the "primary NO_x" level, reburning fuel injection details such as reburning zone residence time and temperature, as well as the type and quantity of reburning fuel.

In SI, micron-sized sorbent, such as hydrated lime $Ca(OH)_2$, is injected into the furnace to capture SO_2. The sorbent reacts with SO_2 to form calcium sulfate ($CaSO_4$) and calcium sulfite ($CaSO_3$) which are captured by the fly ash collector, an ESP or baghouse fabric filter. In the furnace, sorbent first undergoes calcination to form highly reactive calcium oxide, CaO. Calcium oxide reacts with SO_2 and O_2 to form $CaSO_4$ and $CaSO_3$. These steps are illustrated in Figure 3-2. The sulfation process is dependent on the injection temperature, gas temperature quench rate, sorbent type, sorbent properties such as mean particle size.

Extensive evaluation of a variety of sorbents was undertaken both at EER's test facility in Santa Ana, California and in the other GR-SI demonstration programs. Linwood hydrated lime was found to perform well and to be cost effective relative to other commercially available sorbents. Since this sorbent was selected for the tangentially-fired boiler, it was also used at Lakeside for comparison purposes. The composition and properties of Linwood hydrated lime are listed in Table 3-1. The small size of porous sorbent particles results in high surface area per mass, which is optimum for reaction with SO_2. The composition listed is a design composition which has a $Ca(OH)_2$ purity of 96%. The mechanism for reaction with SO_2, impact of sorbent properties and limitation caused by sorbent pore blockage, are illustrated in Figure 3-3. The SO_2 control possible by SI is limited by the quantity of solid matter which may be input ahead of the superheaters, while maintaining acceptable convective pass fouling. Typically a minimum calcium (sorbent) to sulfur (coal) molar ratio of 2.0 is needed to achieve 50% SO_2 reduction.

Sorbent sulfation occurs over the temperature range of 1600°F (870°C) to 2200°F (1200°C). If the sorbent is exposed to temperatures exceeding 2330°F (1280°C), loss in process efficiency results due to loss in reactive surface area ("deadburning"). Therefore, the injection point is critical to achieving high process efficiencies. Thermal modeling of the Lakeside boiler was used to evaluate the mean gas temperature under baseline and expected shifts due to GR-SI. This type of analysis along with physical flow modeling with a geometrically scaled isothermal physical flow model was used to select the injection point, number of injectors, and the level of transport air. The SI system design also had to meet constraints created by the presence of radiant waterwall platens.

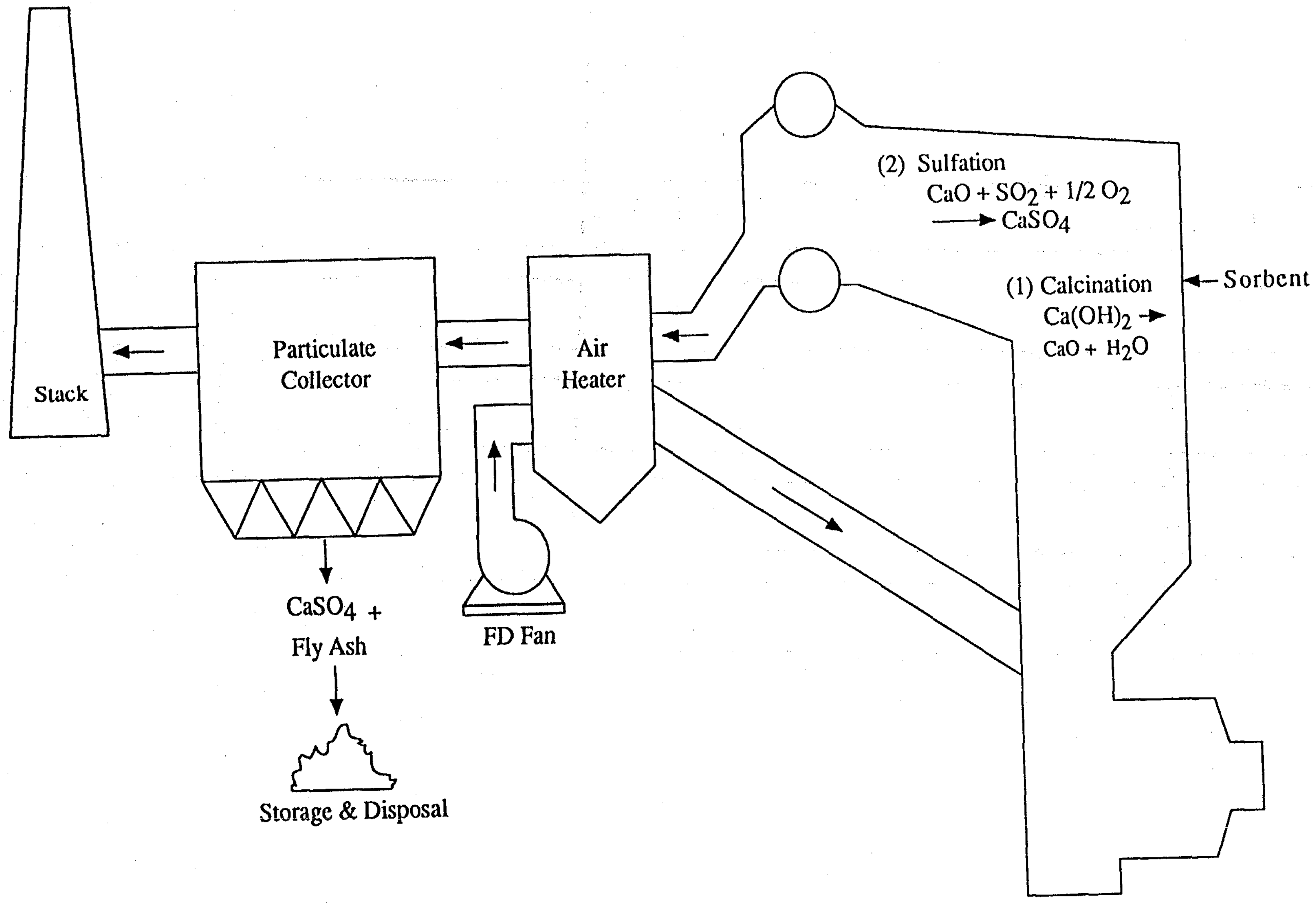


Figure 3-2. Overview of Sorbent Injection process

TABLE 3-1. PROPERTIES OF LINWOOD HYDRATED LIME

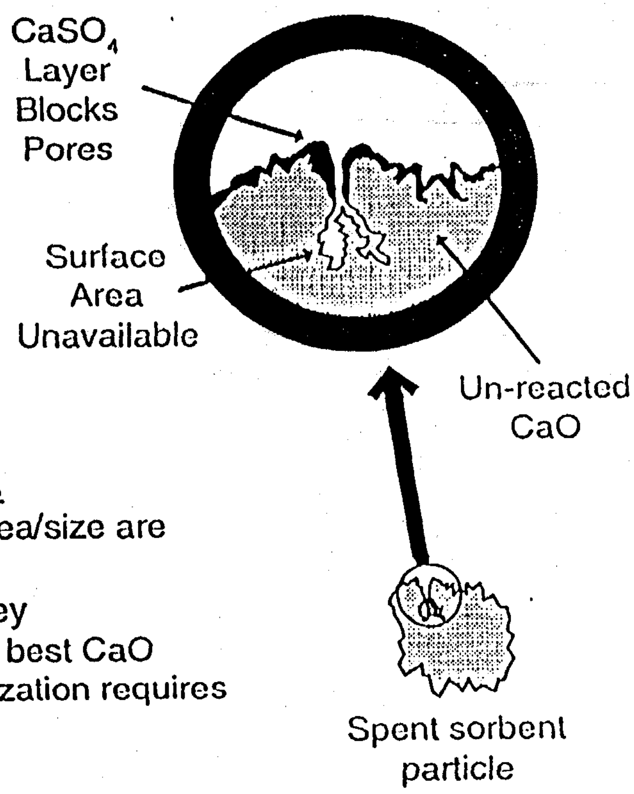
Surface Area (m^2/g)	15.5
Mass Median Particle Size (microns)	2.88
Density (g/cm^3)	2.18
Bulk Density, Loose (lb/ft^3)	25
Bulk Density, Settled (lb/ft^3)	30
Composition (Weight Percent)	
$Ca(OH)_2$	96.20
$Mg(OH)_2$	1.44
$CaCO_3$	1.22
SiO_2	1.66
Fe_2O_3	0.50
Al_2O_3	0.60
SO_3	0.08
Na_2O	0.00

Mechanisms

SO_2 transport to particle
SO_2 Transport in pores
(limiting)
Sulfation reactions

Sorbent Properties

Sorbent surface area/size are
second order
CaO structure is key
$Ca(OH)_2$ produces best CaO
Sorbent characterization requires
combustion test



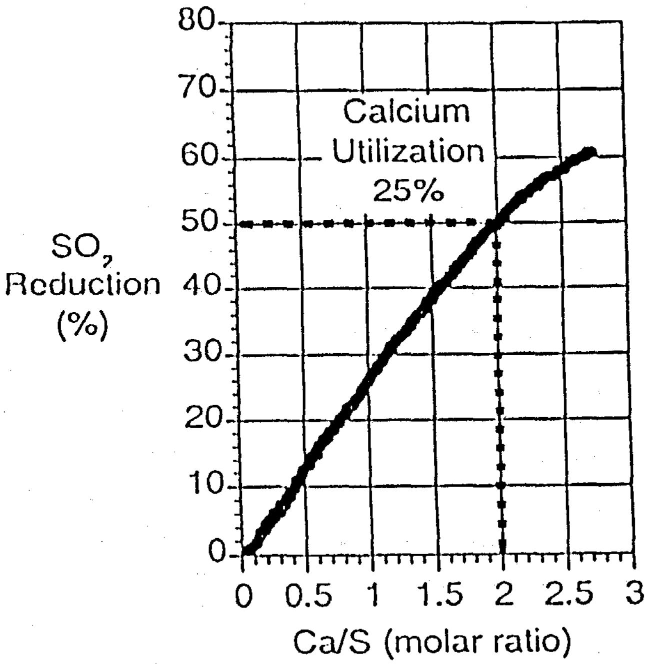


Figure 3-3. Key sorbent properties, sulfation mechanisms and typical SO_2 control

Air was used as the sorbent transport gas to facilitate rapid mixing and dispersion in the boiler. Sorbent must be injected through multiple ports to achieve rapid mixing before gas temperatures decrease below the sulfation window. A residence time of 1.0 second in the sulfation temperature window is desired.

3.2 Process Design Tools

A standardized methodology was used to design the Lakeside GR-SI system. This included field measurements of furnace gas velocity and gas temperature profile. Field data were used to calibrate the heat transfer model, define the flow field in the reduced-scale physical flow model, and provided inputs to NO_x and SO_2 reduction kinetics models. These were used to evaluate boiler specific GR-SI process requirements to achieve targeted emissions reductions and to evaluate candidate injector systems. Potential impacts of GR-SI on fireside conditions (slagging/fouling), tubewall wastage, particulate collection by the ESP and solid waste disposal were also assessed. Figure 3-4 is illustrates the technical approach used in the design of the GR-SI system. Field data, including gas temperature and velocity measured at several planes, gaseous emissions, fuel compositions, water/steam cycle data, efficiency/heat rate data, and boiler operating data, were obtained during two field tests during the design phase of the project. The models were used to evaluate the performance of candidate reburning fuel, OFA and SI systems.

A 2-dimensional steady state heat transfer code (2-D Code) was used to predict heat absorptions by the furnace and convective pass and the mean gas temperature profile. The model determined the gas side temperature distribution under each operating condition: baseline, GR, and GR-SI. The code divided the boiler into axial and radial grids. At its heart is a radiation model which accounts for emission of radiant energy, gas phase attenuation, reflection, and absorption to a numerical tolerance. Convective heat transfer is also accounted for. The flow field is not calculated but prescribed from actual measurements and modeling data. The 2-D Code does not perform a steam side energy balance, therefore its output is fed to a boiler code, which calculates steam temperatures. The boiler code also calculates gas side temperatures in regions

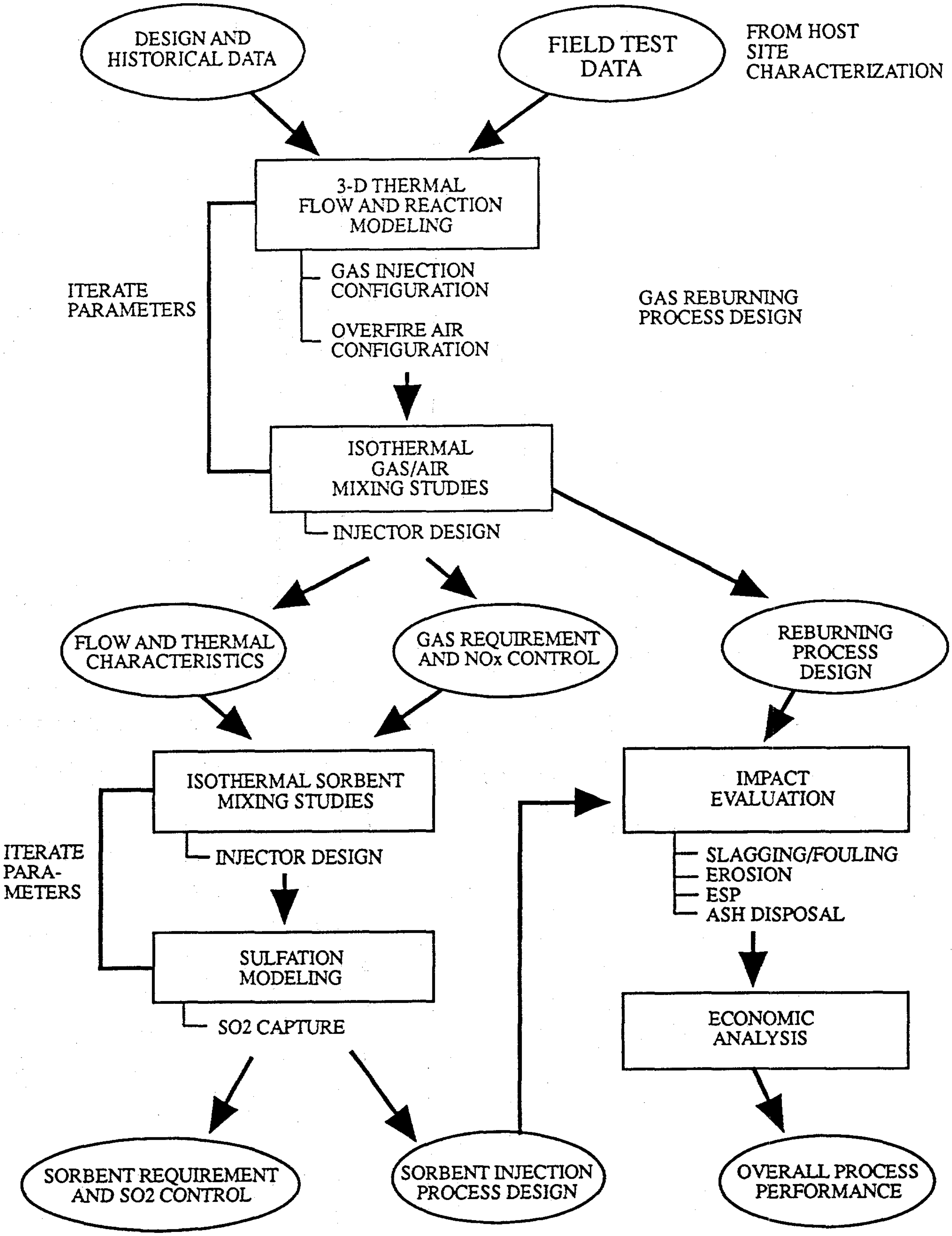


Figure 3-4. Technical approach to process design

not covered by the 2D Code, such as the two drum steam generating bank.

The furnace flow field was characterized with a 1/8th scale isothermal physical flow model. The model was scaled geometrically and fully accounted for flow parameters such as cyclone swirl and convective pass pressure drop. The model flow field was evaluated with velocity measurements, visual jet mapping, and tracer dispersion measurements. The model was used to evaluate various potential injection configurations for introducing reburning fuel, burnout air and sorbent. The selection of the final injector configuration was an iterative process in which potential injection configurations were evaluated with jet visualization techniques using smoke and neutrally buoyant bubbles and dispersion measurements with methane tracer. The final injector configurations were expected to optimally cover the injection plane and to rapidly mix with the furnace gas.

Sulfation rates were evaluated both through an empirical approach and with a more sophisticated technique incorporating jet-in-cross-flow, heat transfer, and sulfation models. The empirical approach predicted sulfation rates using gross features of the process which have been correlated to measured results. Correction factors were used to account for injection temperature, quench rate, and measured dispersion rate. The more sophisticated sulfation modeling technique combined the three models listed above. The starting point was the temperature profile for the area above the SI plane, which was calculated with the heat transfer model. The jet-in-cross-flow results were used to yield time-temperature profiles of sorbent jets. The sulfation model was then incorporated to calculate sorbent utilization and SO_2 reductions. The sulfation model is a "pore" model which is believed to be most fundamentally correct in modeling reactions on the surface of porous sorbent.

4.0 PROCESS DESIGN CRITERIA

The criteria for the GR-SI system design for Lakeside Station Unit 7 are presented in this section. The primary design criterion for the GR-SI system was that it reduce emissions of NO_x by 60% and SO_2 by 50%, from uncontrolled levels. The design methodology included extensive field testing to characterize the boiler emissions/performance and to evaluate furnace velocity and temperature profiles. Using reaction (sorbent sulfation and NO_x reduction) modeling and isothermal physical flow modeling, the process stream inputs and injection details of the GR and SI systems were finalized. Heat transfer modeling was then conducted to determine the impacts on heat absorptions by each heat exchanger and steam side and gas side temperatures. Potential impacts on various areas of boiler performance including fuel burnout, furnace slagging, waterwall wastage, and ESP performance were also evaluated.

4.1 GR-SI System Design Criteria

The goal in the design of the GR-SI system was to achieve the emissions control goals while minimizing impacts on other areas of unit performance. The design criteria for the GR-SI system are listed in Table 4-1. It was expected that application of GR-SI would not hinder the operation of the unit at its rated capacity and normal steam conditions (temperature/pressure). A slight reduction in thermal efficiency and correspondingly an increase in net heat rate were expected. The composition and characteristics of the fuel used in the design phase are shown in Table 4-2. The normal coal supply at the Lakeside Station is a medium-to-high sulfur Illinois bituminous coal, which has seen reduced demand due to provisions of the Clean Air Act Amendments of 1990.

The GR system was designed to achieve 60% NO_x reduction, from 1.0 lb/10^6Btu (430 mg/MJ) to 0.4 lb/10^6Btu (170 mg/MJ) at full load, by replacement of 23.6% of the coal heat input with natural gas. The three GR zones have the following design stoichiometric ratios: primary zone 1.15, reburning zone 0.9, and burnout zone 1.15. The cyclone stoichiometric ratio is limited to minimize NO_x formation in this region and to reduce the quantity of reburning fuel needed to achieve the target NO_x reduction. The minimum stoichiometric ratio for this zone is based

TABLE 4-1. DESIGN CRITERIA FOR LAKESIDE GR-SI SYSTEM

Boiler Net Load	
Nominal Capacity (MWe)	33
Peak Capacity (MWe)	39.8
Boiler Thermal Efficiency (%)	86.55
Net Heat Rate (Btu/kW-hr)	13,500
Steam Conditions (Nominal Capacity)	
Steam Flow (klb/hr)	310
Secondary Superheater Outlet Temperature (F)	890
Secondary Superheater Outlet Pressure (psig)	875
Gas Reburning System	
NOx Reduction (%)	60
Uncontrolled NOx Emissions At Full Load (lb/MBtu)	1.0
Natural Gas Heat Input (% of Total)	23.6
Minimum Reburning Zone Residence Time (sec)	0.25
Cyclone Stoichiometry	1.15
Reburning Zone Stoichiometry	0.90
Burnout Zone Stoichiometry	1.15
Flue Gas Recirculation (% of Total Flue)	5
Sorbent Injection System	
Total SO2 Reduction (%)	50
Sorbent SO2 Reduction (%)	35
Uncontrolled SO2 Emissions (lb/MBtu)	5.9
Calcium to Sulfur Molar Ratio	2.0
Sorbent Injection Air (% of Combustion Air)	5
Ash Distribution	
Slag Tap (%)	75
Boiler Exit Hopper (%)	2
ESP (%)	23
Spent Sorbent & CaSO4	
ESP (%)	100

TABLE 4-2. COAL AND NATURAL GAS COMPOSITION USED IN THE DESIGN PHASE

COAL (As Received)			
Proximate Analysis (%):		Ultimate Analysis (%):	
Total Moisture	17.80	Moisture	17.80
Volatile Matter	34.04	Carbon	57.76
Fixed Carbon	39.38	Hydrogen	3.99
Ash	8.78	Oxygen	7.51
		Nitrogen	1.16
HHV (Btu/lb)	10,406	Sulfur	3.00
		Ash	8.78
Ash Chemical Analysis (%):			
SiO2	50.65	Ash Fusion Temperatures (°F):	
Al2O3	13.91	Reducing	
TiO2	0.89	IDT	1930
Fe2O3	18.88	AST	2000
CaO	6.26	AHT	2150
MgO	0.85	AFT	2260
Na2O	1.36	Oxidizing	
K2O	1.52	IDT	2230
P2O5	0.18	AST	2400
SO3	5.72	AHT	2480
Undetermined	0.00	AFT	2580

NATURAL GAS			
Constituent (Volume %):			
CH4	89.52	i-C5H12	0.03
C2H6	4.07	Other Hydrocarbons	0.03
C3H8	1.39	CO2	0.57
n-C4H10	0.17	N2	5.10
i-C4H10	0.12	Specific Gravity	0.622
n-C5H12	0.77	HHV (Btu/SCF)	999

on factors such as fuel burnout and lower furnace slagging. Higher levels of cyclone air help burn out fuel and prevent slag formation in the furnace. Injection of reburning fuel accounting for 23.6% of the total heat input results in a reburning zone stoichiometric ratio of 0.90. Natural gas is injected with recirculated flue gas, corresponding to 5% of the total flue gas, to enhance jet penetration into the furnace and reduce mixing times. This was deemed necessary in the design since the furnace volume and reburning zone residence time are limited in cyclone-fired units. The reducing conditions in the reburning zone form a variety of hydrocarbon fragments and free radicals which reduced NO_x to HCN, NH_3, and the desirable species, N_2. Burnout air (OFA) is injected higher up in the furnace to complete the fuel combustion under a boiler excess air level of 15%. The OFA system is designed to effectively burn out all fuel combustible matter, limiting CO emissions and unburned carbon-in-ash.

The GR-SI system injectors are illustrated in Figure 4-1. The original design called for two types of natural gas injectors, one type utilizing recirculated flue gas, and the other type using natural gas only. Six injectors (four on the rear wall and one on each side wall) would use recirculated flue gas, while four other rear wall injectors would use natural gas only. These injectors were designed to cover different areas of the furnace flow field. In practice, only the injectors using the flue gas carrier were put into service in the long-term GR-SI demonstration. The OFA system utilized the high temperature secondary air to minimize gas quenching. Six rear wall injectors were used, the secondary air pressure being sufficient without the requirement of a booster fan. Considered in the placement of reburning fuel and OFA injectors were the reburning zone and burnout zone residence times and the expected shift in the furnace temperature to accommodate the SI system.

GR operation was not expected to significantly impact furnace conditions such as slagging and waterwall corrosion. While ash fusion temperatures are lower under reducing conditions, waterwall temperatures were expected to decrease due to the impact of recirculated flue gas. Lower wall temperatures as well as the reduction in the ash input to the furnace (from replacement of coal with natural gas) help prevent slagging. The potential for reducing conditions to form species with deleterious effects on the waterwall, such as H_2S, was

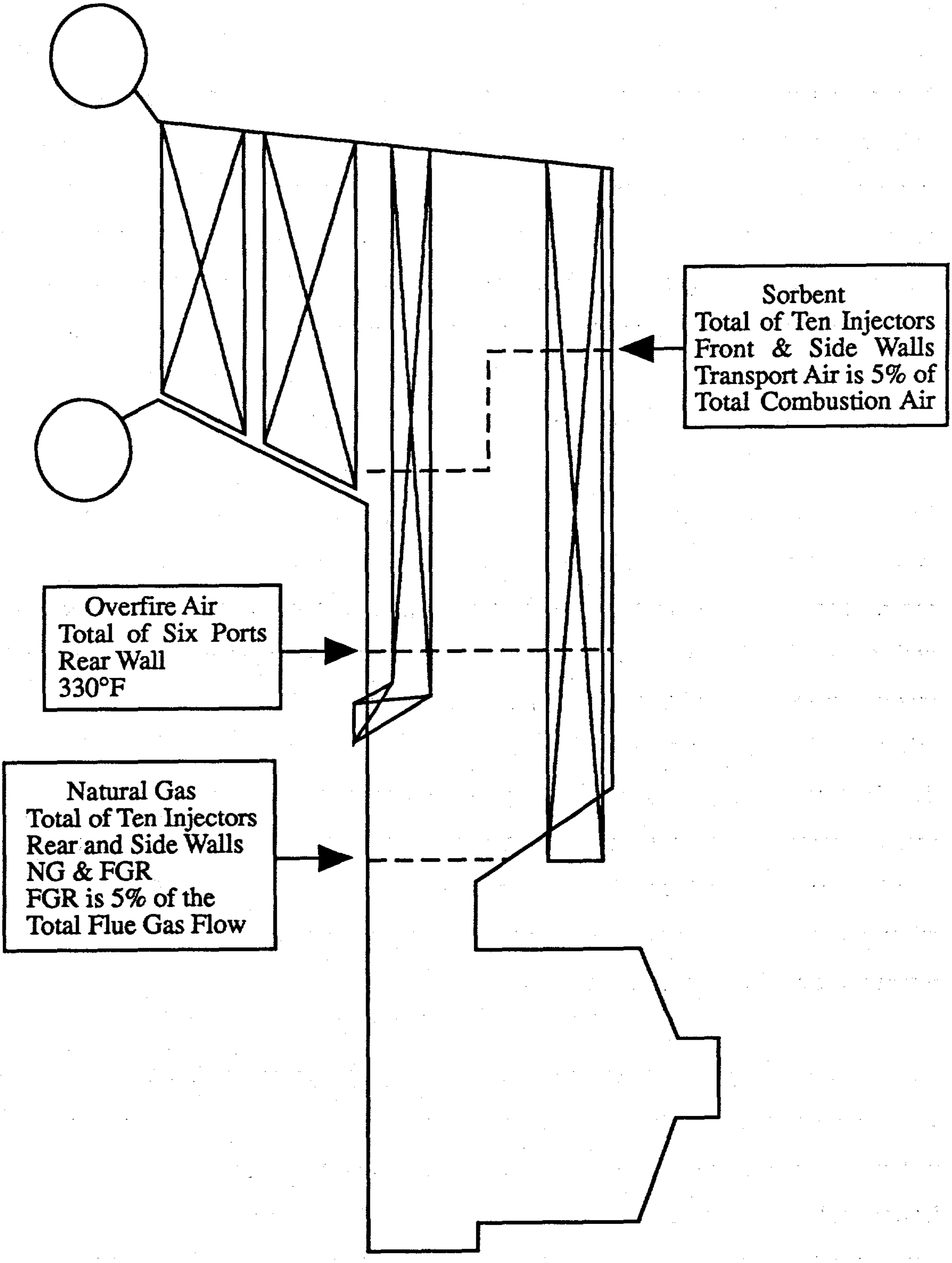


Figure 4-1. GR-SI injector specification

considered. To evaluate the impacts on furnace waterwall wear, extensive tubewall ultrasonic thickness measurements were planned.

The SI system was designed for 50% SO_2 reduction from the 5.9 lb/10^6Btu (2540 mg/MJ) baseline. Reduction in SO_2 results from both sorbent SO_2 capture and replacement of coal with the sulfur free natural gas. Replacement of 23.6% of coal heat with that from natural gas results in an equivalent reduction in SO_2. Therefore, the SO_2 reduction required from sorbent capture was 35%. The GR-SI system design specified a Ca/S molar ratio of 2.0 to achieve this. A safety margin was included in this; design studies indicated that a Ca/S of 1.5 would be sufficient. Sorbent was injected into the upper furnace through multiple ports on the front and side walls. The injection location was selected based on the optimum sulfation temperature range of 1600°F (870°C) to 2200°F (1200°C). An injection temperature of 2330°F (1280°C) and higher results in reduced sorbent reactivity due to loss in active surface area. Rapid mixing of sorbent jets with furnace gas is required to enhance SO_2 capture. Injection air, corresponding to 5% of the combustion air, was used to increase the sorbent jet mass and enhance entrainment of furnace gas. The injection configuration (number and placement of injectors, total mass flow) was designed to completely cover the furnace flow field.

Results from the EER's previous FSI project, at Richmond Power & Light's Whitewater Valley Unit 2, indicated that sorbent deposition in the convective pass must be considered. To enhance heat transfer to the two pendant superheater sections when injecting sorbent, an increase in the operation of sootblowers was anticipated. The unit is equipped with 8 wallblowers in the radiant furnace and 7 long retractable sootblowers in the convective pass. All of the sootblowers in the unit were replaced since they were originally (before the GR-SI project) in poor condition and their usage was expected to increase. These sootblowers utilize saturated steam from the steam drum, after its pressure has been reduced to 250 psig (1720 kPa). It was expected that the use of the sootblowers would increase from 2 hours/day under normal operation to 6 hours/day under GR-SI.

In applying FSI, the impact of the increased particulate loading into the ESP was considered.

The expected ash split under GR-SI operation is for 75% of the ash to be collected through the slag tap, 2% to be collected in the boiler exit hopper, and 23% to be carried into the ESP. It was expected that 100% of the reacted and spent sorbent would flow to the ESP, since sorbent particles are smaller than fly ash. The particulate collection device (ESP or baghouse fabric filter) must have sufficient capacity to handle the added loading and altered electrical characteristics of the fly ash. Under SI, the quantity of particulate matter would be expected to increase by 6 fold, while its resistivity would increase by 2 to 3 orders of magnitude. The Lakeside unit is equipped with an ESP which was designed for four units (two of which have been decommissioned); therefore, it is oversized for the two units in service. The added solids loading and change in characteristics were not expected to be problematic in maintaining particulate emissions and stack opacity below compliance limits.

4.2 Expected Thermal Impacts of GR-SI Operation

GR-SI was expected to have relatively minor impact on the boiler thermal performance. It was expected that the unit would produce steam at its normal rated capacity at the same final temperature as in baseline operation. GR-SI impacts on the unit's thermal performance are summarized in Tables 4-3 and 4-4. The minor reduction in steam output shown in Table 4-1 results from a reduction in thermal efficiency, since these two modeled cases consider equal heat input. Secondary superheater steam temperature of 890°F (480°C) is expected in both cases, Reflecting a 20°F safety margin from the design level of 910°F (490°C). A shift in the heat absorption profile was expected, with lower heat absorption by the furnace and secondary superheater, but higher absorption by the steam drum (including the attemperator). This is due to both GR, in which heat is input higher up in the furnace, and to SI, which results in an increase in particulate deposition on convective heat exchangers. Minor changes in the gas temperature profile were anticipated, with a small rise in air heater exit temperature. A reduction in thermal efficiency of approximately 1.1% was anticipated under GR-SI, due mostly to an increase in the moisture formation from natural gas combustion. Natural gas has a higher hydrogen/carbon ratio and therefore forms more moisture on combustion. A minor increase in the heat loss due to combustible matter in refuse is also expected.

TABLE 4-3. PROJECTED IMPACTS OF GR-SI ON THERMAL PERFORMANCE

	Baseline 100% Load	GR-SI 100% Load
Steam/Water Mass Flow (1000 lb/hr)		
Into Drum	308.6	304.8
Exit Superheater	308.6	304.6
Steam Side Temperature (°F)		
Into Primary Superheater	536	536
Exit Primary Superheater	737	743
Into Secondary Superheater	624	623
Exit Secondary Superheater	890	890
Heat Transfer to Steam (MBtu/hr)		
Drum (Including Heat Flux from Drum Attemperator)	79.0	82.3
Waterwall (Including Heat Fluxes to Wing Walls and Radiant Platens)	178.9	173.1
Primary Superheater	51.9	51.8
Secondary Superheater	50.1	49.9
Gas Side Temperature (°F)		
Into Secondary Superheater	1995	1940
Into Primary Superheater	1589	1558
Into Drum Section	1265	1251
Into Air Heater	761	759
Exit Air Heater	319	322

TABLE 4-4. PROJECTED IMPACT OF GR-SI ON GROSS BOILER EFFICIENCY

	Baseline 100% Load	GR-SI 100% Load
Heat Loss (%)		
Dry Gas	4.93	4.82
Moisture from Fuel	1.91	1.46
Moisture from Combustion	4.04	5.61
Combustible in Refuse	0.57	0.69
Radiation *	0.50	0.50
Unmeasured *	1.50	1.50
Total Losses	13.45	14.58
Gross Efficiency (%)	86.55	85.42

* Note: Value Taken From B&W Design Report

The expected changes in the gas temperature profile are shown in Figure 4-2. Both GR and GR-SI result in downward shifts in furnace gas temperatures. The reduced coal heat input results in reduction in lower furnace gas temperature. Addition of natural gas with 5% recycled flue gas results in a further drop in gas temperature. Injection of OFA results in a more significant local drop in temperature.

4.3 Expected Environmental Impacts

GR-SI was expected to impact the local environment in several ways, necessitating the implementation of an environmental monitoring plan. Monitoring was planned and executed in two major areas, gaseous emissions and aqueous discharges. Gaseous emissions were monitored by the Continuous Emissions Monitoring System (CEMS) and were supplemented with particulate matter and opacity measurements. Flue gas was sampled continuously from a 16 point grid at the boiler exit and analyzed for NO_x, SO_2, CO, CO_2, CO and hydrocarbons (HC). Aqueous discharges were monitored by plant personnel as required by the Illinois Environmental Protection Agency's (IEPA) National Pollutant Discharge Elimination System (NPDES) permit.

The expected impacts of GR-SI on air emissions are positive, including significant reductions in NO_x and SO_2. Only modest changes in the emissions of other species were expected. A reduction in CO_2 emissions of 10% was expected from replacing 23.6% of coal with natural gas. Coal combustion produces CO_2 at a rate of 203 $lb/10^6Btu$ (87.3 g/MJ), while natural gas combustion produced CO_2 at a rate of 120 $lb/10^6Btu$ (51.5 g/MJ). Low emissions of CO and HC were expected from judicious design of the OFA system. CO emissions were expected to be in an acceptable range for coal-fired utility boilers (under 200 ppm). Because of the large capacity of the ESP (specific collection area of 500 $ft^2/1000$ acfm flue gas) emissions of particulate matter and opacity at the ESP outlet were expected to fall within regulatory limits Applicable limits are 0.1 $lb/10^6Btu$ (43 mg/MJ) of particulate matter and an opacity of 30%. Detailed evaluation of the baseline ESP performance data and computer modeling of ESP performance indicated no ESP performance enhancement would be required. Stack sampling of particulate matter, under GR-SI operation, was conducted at the conclusion of the test

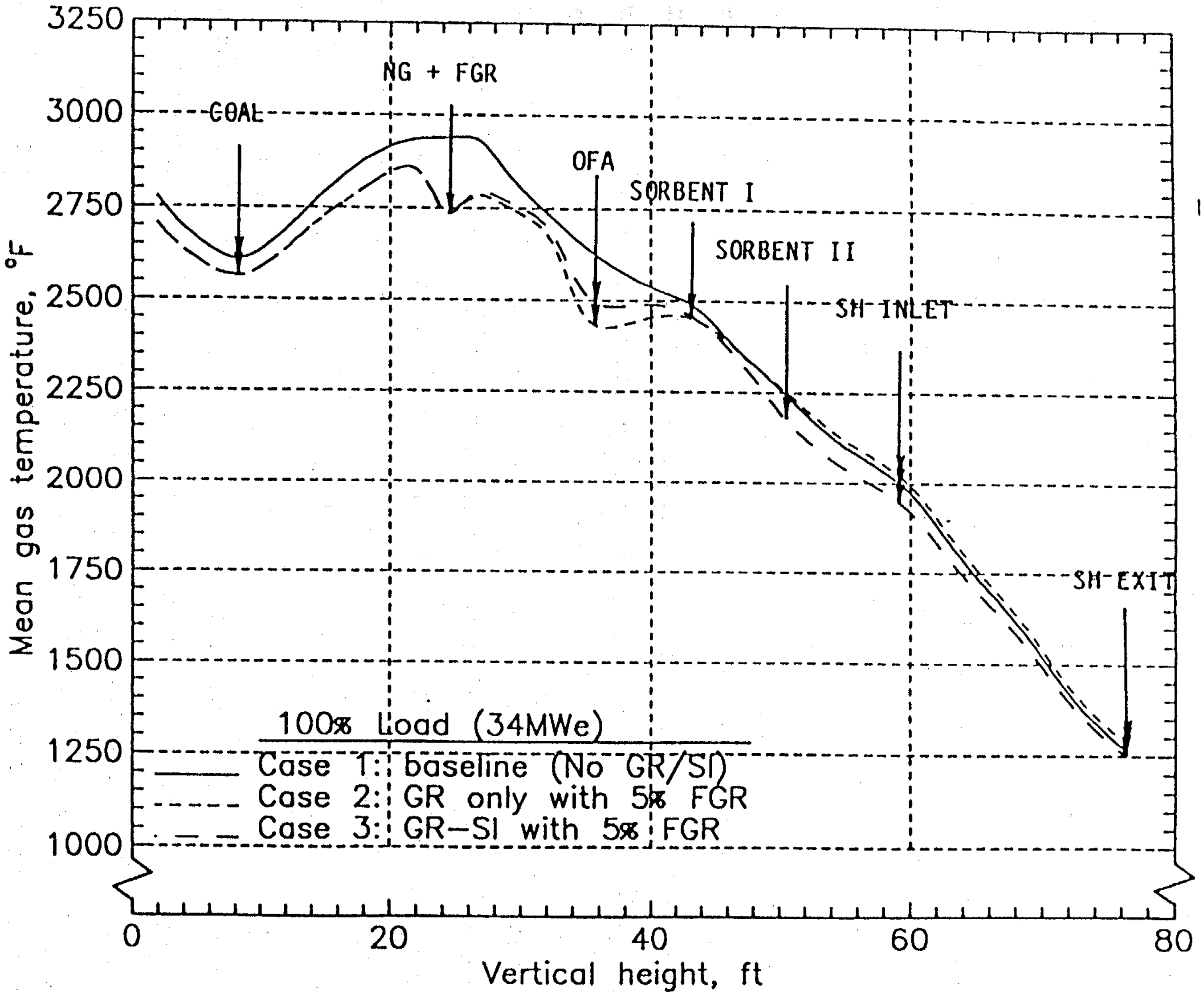


Figure 4-2. Mean gas temperature profile for the Lakeside boiler under baseline, GR, and GR-SI

program, while opacity measurements were made continuously.

The major GR-SI waste product is a high calcium fly ash, which was thoroughly characterized in Phase I of the project. Leaching characteristics were tested and the negative results indicate that it is a non-hazardous waste. The GR-SI system incorporated a fly ash silo adjacent to the sorbent storage silo. The fly ash has been observed to have pozzolanic characteristics, i.e. it forms into a cementicious material upon addition of water. The buildup of this material may render an ash sluicing system inoperable. Therefore, fly ash was collected in hoppers under the ESP, then conveyed pneumatically to the storage silo. It was loaded onto trucks with a dustless unloader which added a small quantity of water to help prevent fugitive dust emissions. The fly ash was then disposed of at an off-site landfill.

No change in the makeup and characteristics of the aqueous discharges were expected. Only the bottom ash was sluiced to the ash pond and its makeup was not expected to change due to GR-SI. Sorbent was injected into the upper furnace, too high in the furnace to fall to the boiler bottom. In addition, its small size ensures that it is entrained in the flue gas. Therefore, the ash pond discharge into Lake Springfield was not expected to change under GR-SI operation. The other aqueous stream which could have been affected is the coal pile runoff, because sorbent is unloaded in this area. The NPDES permit required regular monitoring of these steams for pH, Total Suspended Solids (TSS), oil/grease, and other constituents.

GR-SI involved changes in the material inputs to the boiler. A complete material balance is presented in the Section 5. The design material balance called for injection of 1978 scfm (0.93 Nm^3/s) of natural gas at peak load (39.6 MWe, net). Using a capacity factor of 25% (the unit typically operates only during late spring and summer) the annual natural gas requirement would be 260 million cubic feet ($7.37x10^6$ Nm^3). The coal usage is reduced annually by 12,500 tons (11,350 tonne). Nominally, 5200 lb/hr (0.656 kg/s) of hydrated lime sorbent is required, which is equivalent to an annual consumption of 5,700 tons (5170 tonne).

5.0 PROCESS AND ENGINEERING DESIGN

This section presents details of the process and engineering designs for the GR-SI application to Lakeside Unit 7. Material and heat energy balances, used as the basis in selecting GR-SI system hardware, are provided. The GR-SI system components and their operating ranges are described. The method used to collect and treat the fly ash/spent sorbent waste material and sootblowing system modifications are also discussed. The chapter concludes with a projection of GR-SI auxiliary power requirement and a description of the GR-SI control system.

5.1 GR-SI System Overview

Figure 5-1 shows the major components of the GR-SI system. Natural gas is carried to 10 injection nozzles on the boiler rear and side walls. Six of the injectors mix recirculated flue gas to enhance jet penetration and mixing and four inject natural gas only. During operation, only the reburning injectors with recirculated flue gas were required to achieve proper penetration and dispersion across the furnace plane. The design natural gas input accounts for 23.6% of the total heat input and the recirculated flue gas corresponds to 3 to 5% of the total boiler exit flow. The FGR system incorporates a high static booster fan and a multiclone dust collector.

OFA air is injected through six ports on the rear wall of the furnace. OFA is extracted from two secondary air ducts which have sufficiently high static pressure, therefore the system did not require an OFA booster fan. The flow of OFA through each port is controlled by flow dampers.

The SI system was designed to inject sorbent at a rate corresponding to a Ca/S molar ratio of 2.0. The single sorbent/transport air stream is divided into 10 equal streams, which are then carried to 10 injectors on the front and side walls. Additional air, denoted as SI air to enhance sorbent jet penetration and mixing, is provided by a high static fan.

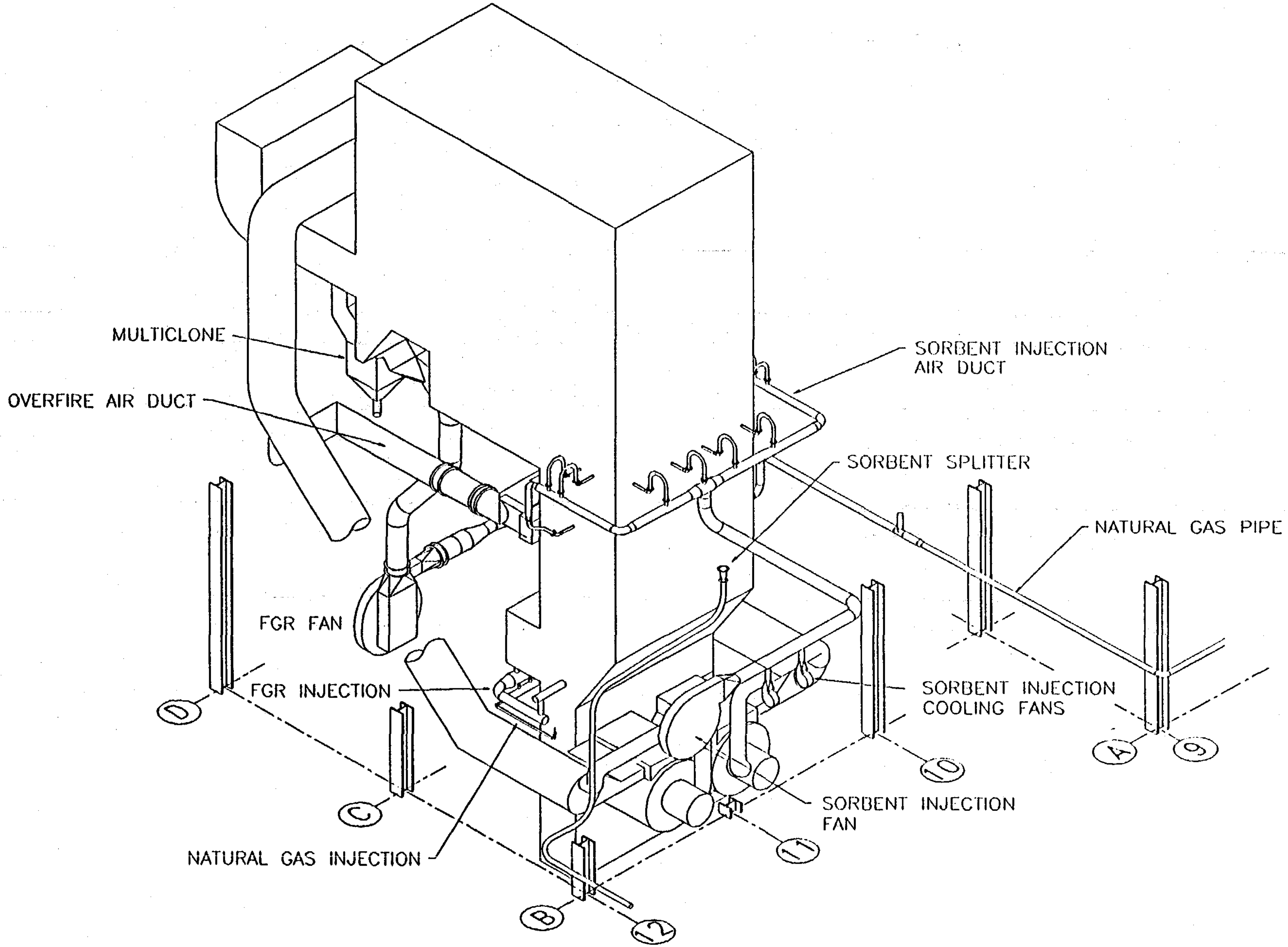


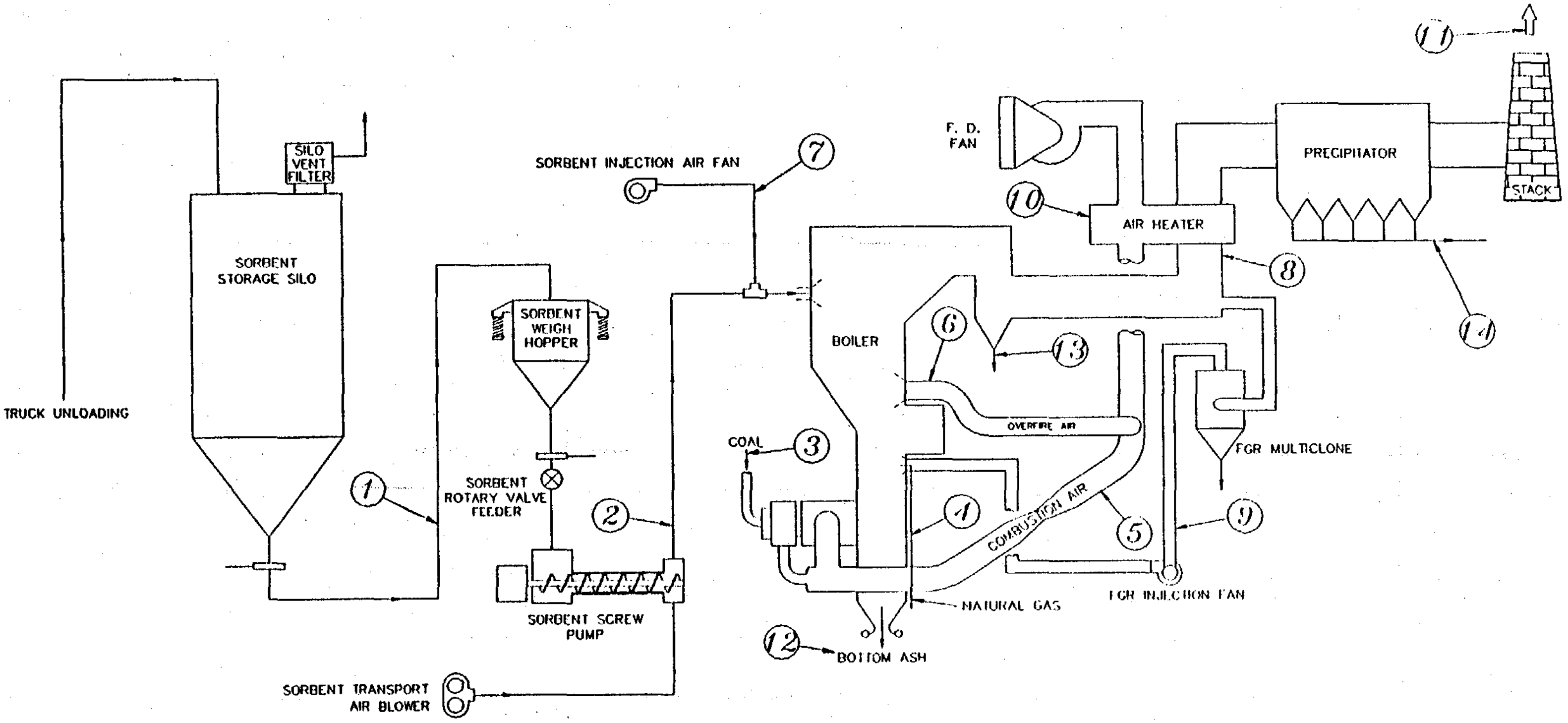
Figure 5-1. Lakeside Unit 7 GR-SI system

5.1.1 Material and Heat Energy Balances

The material balance used to size GR-SI system equipment is shown in Figure 5-2. It is based on GR-SI operation at the peak load (39.6 MW_e, net). A heat energy balance for operation at full load (33 MW_e, gross) is shown in Figure 5-3. The GR-SI system was designed for operation at peak load; however, the system was usually operated at 33 MW_e.

The material balance was prepared for the design capacity of 39.6 MW_e (net) using a net heat rate of 13,500 Btu/kwh (14,240 kJ/kwh). It incorporates a coal higher heating value of 10,442 Btu/lb (24,267 kJ/kg) and natural gas heating value of 21,415 Btu/lb (49,769 kJ/kg). The stoichiometric air demand for these fuels are 7.834 lb/lb coal and 15.507 lb/lb natural gas. These air demands are based on compositions shown in the previous section. Coal is fired into the twin cyclone furnaces with primary and secondary air at a stoichiometric ratio of 1.15. Natural gas is injected with recycled flue gas to form a reburning stoichiometric ratio of 0.90. OFA, input at a rate equivalent to the fraction of reburning fuel heat input (i.e. 24% of combustion air), is injected higher up to bring the boiler exit stoichiometric ratio to 1.15. Sorbent is pneumatically conveyed from a silo with transport air of 227 scfm (0.107 Nm^3/s). It is injected into the boiler with a more substantial air stream of 2,828 scfm (1.34 Nm^3/s).

The energy balance incorporates heat input from the two fuels, heat transfer to steam/water through each heat exchanger, and heat losses due to five of the major sources plus unmeasured losses. Heat absorption by each heat exchanger was obtained from modeling with the 2D heat transfer code. Heat losses were calculated via the ASME Heat Loss Method Performance Test Code (PTC) 4.1. The efficiency according to the heat loss method utilized outputs of heat transfer modeling. The predicted thermal efficiency from modeling of heat absorption was 88.67%, while the efficiency calculated from heat losses was 85.42%.



STREAM NUMBER	1	2	3	4	5	6	7	8	9	10	11	12	13	14
DESCRIPTION	STORAGE SILO TRANSFER	SORBENT FEED	COAL	NATURAL GAS	COAL COMBUSTION AIR	OVERFIRE AIR	SORBENT INJECTION AIR	FLUE GAS	FLUE GAS RECIRC	AIR LEAKAGE	STACK GAS	BOTTOM ASH	OUTLET HOPPER ASH	ESP ASH
GAS SIDE														
AIR LBS/HR		1042			365,527	87,523	12,970			60,000				
AIR SCFM		227			79,705	19,084	2828			13,033				
NATURAL GAS LBS/HR				5512										
NATURAL GAS SCFM				1978										
FLUE GAS LBS/HR								510,432	15,313		560,432			
FLUE GAS SCFM								110,419	3313		123,502			
SO_2 LBS/HR								1366						
SO_2 LBS/MBTU								2.66						
SO_3 PPM														
NOx LBS/MBTU														
H_2O LBS/HR														
TEMPERATURE				–	500°F	500°F	100°F	690°F	690°F		340°F			
PRESSURE				15 psig	45"	45"	75"	4"	30"					
SOLID SIDE														
COAL (combustibles) LBS/HR			36,590											
FUEL INERTS LBS/HR			3819									2864	191	764
SORBENT LBS $Ca(OH)_2$/HR	5212	5212												
$CaSO_4$ LBS/HR														1870
CaO LBS/HR														3174
TOTAL SOLIDS LBS/HR	5212	5212	40,409									2864	191	5808
MAX. DESIGN FLOW LBS/HR		7819		5989		164,216	22,557							
BASIS		3:1 Ca/S		25% HEAT INPUT		25% GAS INPUT	5% OF TOTAL							

Figure 5-2. Lakeside Unit 7 GR-SI material balance

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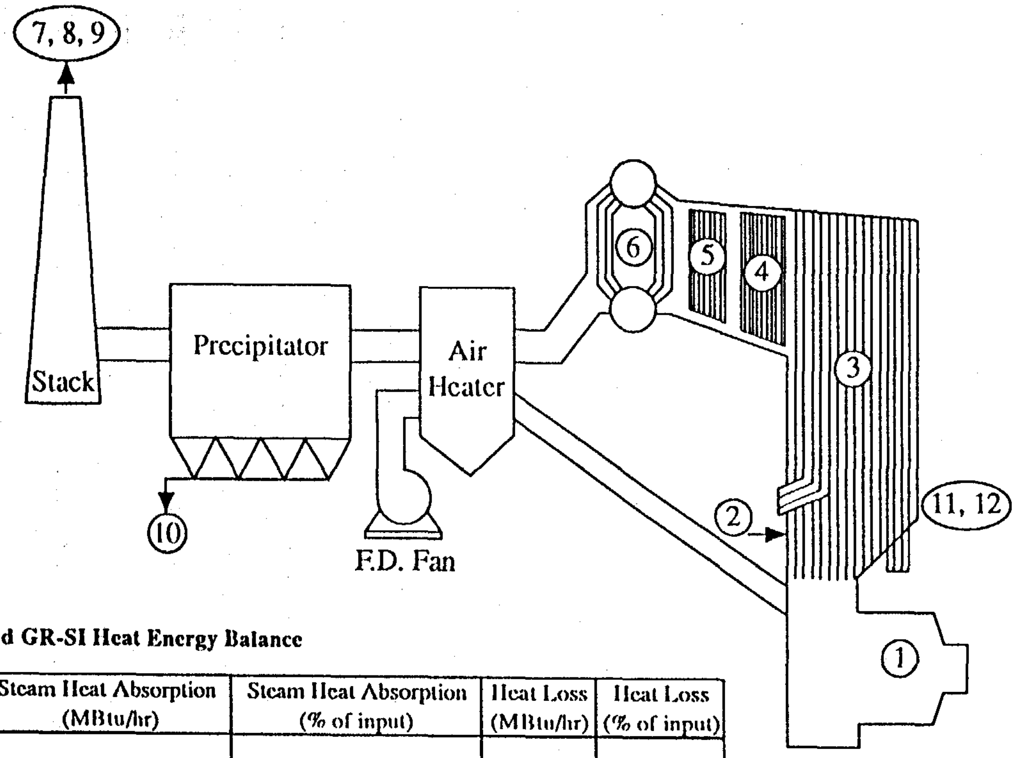

Full Load GR-SI Heat Energy Balance

No	Source/ Device	Heat Input (MBtu/hr)	Heat Input (% if total)	Steam Heat Absorption (MBtu/hr)	Steam Heat Absorption (% of input)	Heat Loss (MBtu/hr)	Heat Loss (% of input)
1	Coal	307.8	76.4				
2	Natural Gas	94.9	23.6				
3	Furnace Waterwall			173.1	42.98		
4	Secondary Superheater			49.9	12.39		
5	Primary Superheater			51.8	12.86		
6	Drum			82.3	20.44		
7	Dry Gas					19.4	4.82
8	Moisture in Fuel					5.9	1.46
9	Moisture from Combustion					22.6	5.61
10	Combustible in Refuse					2.8	0.69
11	Radiation					2.0	0.50
12	Unmeasured					6.0	1.50
Total		402.7	100.0	357.1	88.67	58.7	14.58

Figure 5-3. Lakeside Unit 7 GR-SI energy balance

5.1.2 Gas Reburning System

The GR system was designed to convey, meter and inject natural gas through nozzles into the region above the refractory lined primary furnace (reburning zone). The Lakeside Station had no gas firing capability prior to this project; therefore, the gas supplier installed a 6" (15 cm), 25 psig header to the boiler house with a metering and pressure reducing station. An 8" (20 cm) tie-in line was then installed to carry the natural gas from this station to the reburning fuel flow/pressure regulation and metering system. The natural gas train, common to all injection nozzles, incorporates a pressure reducing valve, flow meter, flow control valve, safety shut-off valve, and vent valves. Natural gas is reduced to a pressure of 15 psig (103 kPa), for injection at a pressure of 2 to 4 psig (14 to 28 kPa). The design gas flow is 1978 scfm (0.9334 m^3/s), with equal flow of 198 scfm (0.0933 m^3/s) through each nozzle.

The nozzles protrude 1 1/2" (3.8 cm) beyond the tubewall into the furnace. This feature helps keep slag from building up and interfering with reburning fuel flow. The nozzles are water cooled, requiring 25 gpm (1.6 l/s) water flow, to prevent overheating and to further reduce slag deposition. Several types and sizes of injection nozzles were evaluated in this project including ceramic nozzles, which had significantly reduced cross-sectional area than originally specified, and stainless steel sleeves, which did not project into the furnace and had no water cooling. Most testing, however, was conducted with nozzles originally specified by the design. Nozzle penetrations required bent tube sections. The nozzle wallboxes were designed to permit nozzle cleaning with the unit on line, through use of aspirating air. This was necessary for personnel protection since the unit is a positive draft design.

Flue gas was extracted from the breeching between the boiler exit and the air heater gas inlet. This location was selected since it is upstream of the air heater, where air leakage increases the O_2 concentration. The normal recirculated flue gas flow was 19,900 lb/hr (2.51 kg/s) with a test block specification of 23,900 lb/hr (3.01 kg/s). Flue gas was directed through a multiclone dust collector which removes particulate matter to prevent wear of the booster fan. The dust loading was reduced from approximately 11 gr/dscf (25 g/m^3) to 2 gr/dscf (5 g/m^3). The flue gas was then directed to a high static fan which increased the static pressure from approximately +1" W.C. (0.25 kPa) to +20" W.C. (5.0 kPa) normal, with a test block specification of 24" W.C. (6.0 kPa). Flue gas was then routed to a venturi for flow measurement, then to the six nozzles where dampers regulated the flow to each injector. The FGR fan was equipped with tight shut-off dampers to prevent gas leakage to the boiler exit when the GR-SI system was not in use.

OFA was obtained from the two secondary air ducts which carry 500°F (260°C) combustion air. Since the unit is a positive draft design, the secondary air is relatively high in pressure, at 45" W.C. (11 kPa); therefore, no booster fan was required. OFA was ducted to six ports on the rear wall of the furnace. Butterfly dampers controlled the air flow to each port. The dampers were not tightly shut off, allowing cooling air to flow to the nozzles when the reburning system was not in operation.

5.1.3 Sorbent Injection System

The SI system was designed to store, meter, and convey micron-sized sorbent to nozzles on the front and side walls of the upper furnace. The baseline sorbent used throughout this program was Linwood hydrated lime, which was on average 93% $Ca(OH)_2$. It has a mass mean diameter under 3 microns and a bulk density of approximately 30 lb/ft^3 (480 kg/m^3). Sorbent was conveyed with transport/injection air to 10 nozzles on the front and side walls of the upper furnace. Two sizes of injectors, placed at two elevations, were used to completely cover the furnace flow field. The SI system was comprised of the following major components: sorbent storage silo, weigh hopper, rotary valve feeder, screw pump, air transport blower, conveying line, sorbent splitter, SI air fan, and injection nozzles. The function of each of these is described below.

A sorbent storage silo with an internal diameter of 25 ft (7.6 m) and volume of 16,300 ft^3 (462 m^3) was erected near the boiler house. It holds nominally 3 days supply for continuous operation at a Ca/S of 3.0. Pre-pulverized sorbent was carried to the site in tanker trucks. The trucks were unloaded with truck mounted blowers; the transport line was equipped with an industry standard quick connect coupling. The sorbent was transported to the top/center of the silo using conveying air and discharged into a target box. The conveying air was discharged through a filtered vent. Polyester pleated filter vent cartridges, with a total area of 600 ft^2 (56 m^2), were used with cartridge cleaning from reverse air pulse jets using compressed air. Cleaning air to these filters was provided by a small air compressor, with a capacity of 130 scfm (0.061 m^3/s) at 100 psig (690 kPa). The unit was equipped with a regenerative air dryer. To enhance sorbent discharge through the conical bottom of the silo, six fluidizing air slides were installed. These are 20' (6.1 m) long by 10" (25 cm) wide and nominally used 334 cfm (0.158 m^3/s) of air at a pressure of 3 psig (21 kPa), supplied by an air blower. Upon discharge from the silo, sorbent flowed through an automatic slide gate valve, then to a weigh hopper. The weigh hopper has a total volume of 200 ft^3 (5.66 m^3), with 120 ft^3 (3.40 m^3) being usable volume occupied by sorbent. The conical bottom of the weigh hopper was also equipped with fluidizing air slides. There were four air slides, with dimensions 4' (1.2 m) long by 8" (20 cm) wide, using 118 cfm (0.056 m^3/s) of air at 3 psig (21 kPa). The weigh hopper was mounted on four load cells, which are microcell strain gauges, to monitor the quantity of sorbent flow through the rate of weight loss. A rate of weight loss transmitter was used to convey the weight loss signal to the sorbent feed control system.

From the weigh hopper the sorbent flowed through a manually controlled slide gate valve to a rotary valve feeder. The operation of this variable speed feeder determined the rate of sorbent flow to the boiler. The rotary valve feeder, with a capacity of 0.235 ft^3/revolution (0.00665 m^3/rev.), operated at 8 to 25 revolutions per minute, delivering sorbent at a rate of 2,450 to 7,800 lb/hr (0.309 to 0.984 kg/s). Directly below the weigh hopper was the sorbent screw pump, which is used to discharge the sorbent into the transport line. It has an 8" (20 cm) screw, which compressed sorbent and continuously delivers a "plug" of sorbent into its windbox. This solid "plug" prevented leakage of air back into the sorbent delivery system. Above the screw pump were polyester felt vent filters, with a total area of 180 ft^2 (16.7 m^2), used to discharge feed system air. These were also cleaned with reverse air pulse jets. Sorbent transport air was supplied by a positive displacement blower, which has a constant output of 798 scfm (0.377

m^3/s) at a pressure of 12 psig (83 kPa). The conveying air was injected through nozzles in the screw pump windbox, where it entrained sorbent and carried it into the transport line. The transport line was a 5" (13 cm) I.D. 1/8" (3.2 mm) rubber lined hose, with a 2 ply high tensile polyester fabric carcass over wire helix. It was designed to transport 150°F (66°C) gas; the transport air had a temperature in the 130 to 150°F (54 to 66°C) range. The transport line carried the sorbent/transport air to the sorbent splitter, which divides the single stream into 10 equal streams for injection at the nozzles. The double conical design splitter had a 5" (13 cm) inlet and 10 1 1/2" (3.8 cm) outlet lines equally spaced on an annulus. Ten 1 1/2" (3.8 cm) conveying lines were then used to carry sorbent/transport air to the furnace. A more substantial air stream, provided by a high static radial type fan with capacity of 28,560 lb/hr (3.60 kg/s) at 70" W.C. (17 kPa), is mixed with the sorbent/transport air stream at the injection nozzles. Double concentric injectors are used with sorbent/transport air introduced into the center and the more substantial injection air introduced into the outer passage of the nozzle. These streams mix in the barrel of the nozzle before injection into the boiler. The portion of the injection nozzles extending into the furnace was stainless steel. The SI system also has redundant air cooling fans to cool nozzles when the system is not in use.

5.2 Waste Handling

The major waste product of GR-SI, a mixture of coal ash and spent and unreacted sorbent, is collected in a newly erected ash silo for later off-site disposal. This material is similar to high calcium ash that results from firing western coal. It exhibits pozzolanic reactivity, i.e. it has cementicious properties when mixed with water. If it is handled with a wet sluicing system discharging to an ash pond, it can build up as scale on the hydrovactor and the conveying pipe, thereby rendering such a system inoperable. Various waste handling alternatives were considered and dry handling and off-site disposal were chosen. The unit therefore had two methods of handling fly ash, the new dry ash handling system and the previously used wet sluicing system. A local control switch allowed selection of either system by the operator.

The fly ash/sorbent mixture was collected from ESP bottom hoppers, the boiler outlet hopper and the multiclone. The material was then pneumatically conveyed to the top of the ash silo using air drawn through air intakes upstream of the ash hoppers. At the top of the 20' (6.20 m) I.D. ash silo, the ash and conveying air were separated with an air separator/filter. This inertially separated the ash from the air, which then underwent a secondary ash separation step with a fabric filter before being ducted to the vacuum blower. The solid material fell to the bottom of the silo. The ash silo was equipped with two discharge systems, one for completely dry loading of pneumatic tankers using a telescopic chute, the other a conventional dustless unloader with water addition. These were incorporated to permit sale of dry ash for use as a fill material, or for normal loading of trucks for transport to a landfill. The ash silo was also equipped with fluidizing air slides to facilitate ash discharge. The design incorporated air heaters to prevent caking of the solid material.

5.3 Sootblowing System Modifications

The boiler is equipped with wallblowers in the radiant furnace and retractable sootblowers in the convective pass. There are 8 wallblowers (type IR) in the furnace, which are used on an as-needed basis to control slag deposits, and 7 sootblowers (type IK) in the convective pass, which come into service to maintain SSH steam temperature near the design point. These sootblowers utilize saturated steam from the main drum with the pressure reduced. The condition of these blowers was suspect at the initiation of the project; therefore, all sootblowers were replaced at project expense. It was expected that the wallblowers would continue to see limited use, but that the sootblowers in the convective pass would be used more frequently (an expected increase from 2 hours per day to 6 hours per day). In practice, SI required virtually continuous operation of IK sootblowers, as will be discussed in Section 7.

5.4 Auxiliary Power

The power distribution system was designed to supply power to GR-SI system auxiliaries, making provision for overload and fault protection. Power is received from a 12.5 kV line, converted by a 1000 KVA transformer to 480V, and fed to two Motor Control Centers (MCC).

These distribute power to various 3 phase, 480V loads. Circuit breakers and starters provide means for isolating loads from MCC buses and provide overload and fault protection. Two dry type transformers, 30 KVA and 15 KVA, transform the 480V power to 120/208V for distribution to smaller loads. These supply 120 V, three phase, 4 wire panelboards. The power is carried through 20 A circuit breakers which provide switching, overload, and fault protection to 120V, single phase loads. The GR-SI system power consumption as well as changes in power usage by other plant equipment (e.g. ID and FD fans, pumps, ESP, etc) were monitored in the field test. Power for the nozzle cooling fans was supplied by the plant grid.

5.5 Control System

The GR-SI control system was designed to monitor and modulate all GR-SI equipment and instrumentation to ensure safe boiler operation. A Westinghouse Distributed Process Families (WDPF) control system was selected for this purpose. The SI inputs including sorbent, sorbent transport air, and SI air were based on the desired Ca/S molar ratio and the operating load. The GR inputs including natural gas, recycled flue gas, OFA, as well as coal and cyclone air were also modulated according to the desired gas heat input and the total heat input required to achieve the desired load. The WDPF receives input signals from various devices including flow transmitters, thermocouples, etc., and compares the actual flows with the boiler master set points, then sends corrective signals as required. The WDPF replaced the existing boiler control system and tied into the original Square D Burner Management System (BMS). Table 5-1 lists the data passed between these systems. The Master Fuel Trip signal was passed from the BMS to the WDPF when conditions warrant shutdown. The WDPF then initiated shut off of natural gas flow valves, simultaneously opening vent valves, and SI system components.

The WDPF microprocessor control system provided a full complement of measurements to control room operators, so that the status of the GR-SI system was readily determined. It permitted full control of the GR-SI system from the control room. The system incorporated permissive and trip signals to ensure safe boiler conditions were met before GR operation was permitted, and to trip the system in case of unsafe conditions. The system did not incorporate

TABLE 5-1. DATA SHARED BY BOILER MANAGEMENT SYSTEM AND WESTINGHOUSE WDPF

TO BMS FROM WDPF

Total Air Flow Greater Than 25%
Drum Level Low
East Coal Feeder @ Minimum
West Coal Feeder @ Minimum
Air Heater Air In Temperature
Air Heater Air Out Temperature
Air Heater Gas Out Temperature
Main Steam FLow
East O2
Furnace Pressure
East Feeder Speed
West Feeder Speed
East Cyclone Air Flow
West Cyclone Air Flow
Steam Temperature Valve Position
Drum Level
Main Steam Temperature
Main Steam Pressure
West O2

TO WDPF FROM BMS

Boiler Master Fuel Trip
East Coal In Service
FD Fan Run Status
West Coal In Service

flame scanners to sight the reburning fuel since its combustion did not produce a luminous flame. Optical pyrometers were used to ensure high furnace temperatures for rapid ignition of natural gas. The control system included cross limits to ensure that the OFA input was sufficient to burn out the reburning fuel and that there was sufficient recycled fuel gas for rapid mixing of reburning jets.

6.0 DEMONSTRATION PROGRAM

The GR-SI demonstration at Lakeside Unit 7 was performed according to a test plan prepared in Phase I of the project. The plan outlined the number of tests, test conditions, duration of tests, and the measurements to be taken. The plan also prescribed short parametric tests to optimize the GR-SI system performance and long-term tests to verify its performance over a one-year period during the units normal duty cycle. Measurements were recorded/calculated with EER's state-of-the-art Boiler Performance Monitoring System (BPMS) which records data such as process stream inputs (coal, cyclone air, natural gas, FGR, OFA, sorbent, SI air), flue gas temperature and pressure at several locations, feedwater flow, steam temperature and pressure, and a variety of other parameters. The BPMS calculated the heat transfer to each heat exchanger and Heat Absorption Ratios (HAR), which relate the heat absorbed under the test condition to that under baseline operation. Boiler efficiency was calculated according to heat losses as well as heat input and output. The BPMS also recorded the measurements of the Continuous Emissions Monitoring System (CEMS) gas analyzers, which were used to characterize flue gas constituents at the boiler exit. These data were supplemented with a variety of other measurements, such as fly ash sampling for combustible matter analysis and particulate matter sampling at the ESP outlet, to fully evaluate the impacts of GR-SI on boiler performance.

6.1 Test Plan

The Test Plan served as a blueprint for optimizing the GR-SI system performance. Testing was divided into test series designed to evaluate one process parameter at a time. GR optimization tests were designed to evaluate the full complement of GR process parameters. Following GR optimization, SI-only parametric testing was conducted. These were to be followed by GR-SI optimization tests, but since sufficient process information was obtained during the GR and SI optimization period, GR-SI long-term testing immediately followed GR and SI optimization tests. At the conclusion of long-term testing with the baseline sorbent, an alternate sorbent, supplied by NovaCon Energy Systems of Bedford, New York, was evaluated. This test was planned to offer flexibility in sorbent selection for future demonstrations or commercial applications of the technology.

6.1.1 Optimization Testing

GR-SI system optimization was conducted through parametric testing over a wide range of loads. Table 6-1 lists the GR process parameters and the ranges prescribed for evaluation in the test plan. Table 6-2 is a similar table for SI-only testing. Table 6-3 lists the actual ranges of each parameter evaluated in the field for GR-only, SI-only and GR-SI conditions. Each parameter was evaluated individually, i.e. several tests were conducted daily, typically of one hour duration, in which a single operating parameter was varied as widely as practical. The tests were preceded by determination of baseline emissions/boiler performance and each test period was preceded by a condition or load stabilization period.

Parametric testing was conducted primarily at three loads: full load (33 MW_e), mid load (25 MW_e), and low load (20 MW_e). The GR parameters evaluated include:

- Gas Heat Input
- Recycled Flue Gas
- OFA
- Coal (Cyclone) Zone Stoichiometric Ratio

These are independent variables, with reburning and burnout zone stoichiometric ratios as dependent process variables. In GR, the burnout and exit zone stoichiometric rratios are the same; the exit zone stoichiometric ratio includes SI air flow which is zero under this condition. Measurements taken during GR optimization include gaseous emissions at the boiler exit and opacity at the ESP outlet. Boiler operation data were recorded by the BPMS, which calculated the thermal efficiency and heat absorption by each heat exchanger. Supplemental measurements include sampling of coal at each feeder, for determination of composition and heating value, and fly ash sampling at the air heater exit, for analysis of combustible matter.

TABLE 6-1. PLANNED GAS REBURNING OPTIMIZATION TESTS AT LAKESIDE UNIT 7

Parameters	Units	FULL LOAD			75% LOAD		60% LOAD	
		Baseline	Normal Design	Evaluation Range	Baseline	Evaluation Range	Baseline	Evaluation Range
Gross Load	MWe	33	33	33	25	25	20	20
Natural Gas	% Heat Input	0	23.6	0 to 25	0	0 to 25	0	0 to 25
Recycled Flue Gas	% Total Flue	0	5	3 to 7	0	3 to 7	0	3 to 7
Overfire Air	% Combustion Air	0	22	0 to 30	0	0 to 30	0	0 to 30
Coal Zone Stoichiometry		1.08 to 1.20	1.15	1.05 to 1.15	1.10 to 1.20	1.05 to 1.15	1.10 to 1.20	1.05 to 1.15
Reburning Zone Stoichiometry		1.08 to 1.20	0.9	0.87 to 1.00	1.10 to 1.20	0.87 to 1.00	1.10 to 1.20	0.87 to 1.00
Burnout Zone Stoichiometry		1.08 to 1.20	1.15	1.05 to 1.17	1.10 to 1.20	1.08 to 1.20	1.10 to 1.20	1.08 to 1.20
Exit Zone Stoichiometry		1.08 to 1.20	1.15	1.05 to 1.17	1.10 to 1.20	1.08 to 1.20	1.10 to 1.20	1.08 to 1.20

TABLE 6-2. PLANNED SORBENT INJECTION TESTS AT LAKESIDE UNIT 7

Parameters	Units	FULL LOAD			75% LOAD		60% LOAD	
		Baseline	Normal Design	Evaluation Range	Baseline	Evaluation Range	Baseline	Evaluation Range
Gross Load	MWe	33	33	33	25	25	20	20
Ca/S		0	2	1 to 3	0	1 to 3	0	1 to 3
Injection Air	% of Combustion Air	0	5	2 to 5	0	2 to 5	0	2 to 5
Sorbent Type	Hydrated Lime or Alternate Sorbent (TBD)		Hydr. Lime	Hydr. Lime Alternate		Hydr. Lime Alternate		Hydr. Lime Alternate
Sootblowing Cycle		Normal	Varied	Varied	Normal	Varied	Normal	Varied

TABLE 6-3. TEST CONDITIONS EVALUATED AT LAKESIDE UNIT 7.

Condition	Parameter	Unit	HIGH LOAD		MID LOAD		LOW LOAD	
			Range	Average	Range	Average	Range	Average
Baseline	Gross Load	MWe	32 to 34	33	23 to 28	25	19 to 21	19
Baseline	Coal Zone SR		1.13 to 1.34	1.17	1.04 to 1.16	1.14	1.06 to 1.23	1.15
Baseline	Reburning Zone SR		1.14 to 1.35	1.18	1.04 to 1.18	1.15	1.08 to 1.24	1.16
Baseline	Burnout Zone SR		1.22 to 1.43	1.26	1.16 to 1.28	1.26	1.22 to 1.36	1.28
Baseline	Exit Zone SR		1.22 to 1.44	1.27	1.17 to 1.29	1.27	1.22 to 1.36	1.29
Baseline	OFA	%	6 to 8	7	5 to 10	9	9 to 12	10
GR	Gross Load	MWe	32 to 34	33	23 to 27	25	19 to 21	19
GR	Gas Heat Input	%	12.0 to 25.7	23.3	14.8 to 26.1	22.6	8.4 to 25.9	22.6
GR	FGR	scfm	3000 to 6000	5450	2940 to 6000	5510	3020 to 6000	5250
GR	Coal Zone SR		1.09 to 1.29	1.15	1.05 to 1.18	1.15	0.95 to 1.28	1.12
GR	Reburning Zone SR		0.83 to 1.16	0.90	0.82 to 1.03	0.91	0.76 to 1.04	0.90
GR	Burnout Zone SR		1.20 to 1.40	1.28	1.20 to 1.41	1.28	1.11 to 1.47	1.28
GR	Exit Zone SR		1.21 to 1.40	1.28	1.20 to 1.41	1.29	1.12 to 1.49	1.29
GR	OFA	%	18 to 36	30	20 to 42	29	19 to 40	30
SI	Gross Load	MWe	33 to 34	33	23 to 26	23	19 to 21	19
SI	Burnout Zone SR		1.22 to 1.24	1.23	1.19 to 1.26	1.24	1.27	1.27
SI	Exit Zone SR		1.26 to 1.31	1.29	1.23 to 1.35	1.31	1.33 to 1.40	1.36
SI	Ca/S		1.10 to 2.87	2.10	1.14 to 2.24	1.75	1.23 to 3.46	1.88
SI	Sorbent Flow	lb/hr	2820 to 7460	5240	2200 to 4630	3510	1850 to 5290	2990
SI	Injection Air	scfm	1810 to 4530	3620	1530 to 4530	2880	2020 to 4950	3180
GR-SI	Gross Load	MWe	32 to 34	33	23 to 27	24	One Test Only	20
GR-SI	Gas Heat Input	%	14.2 to 25.6	21.2	14.9 to 26.2	22.0		22.5
GR-SI	FGR	scfm	5760 to 6000	5930	4570 to 5990	5500		6000
GR-SI	Coal Zone SR		1.13 to 1.16	1.15	1.10 to 1.20	1.15		1.16
GR-SI	Reburning Zone SR		0.87 to 1.01	0.92	0.86 to 1.00	0.92		0.93
GR-SI	Burnout Zone SR		1.24 to 1.35	1.27	1.20 to 1.35	1.27		1.35
GR-SI	Exit Zone SR		1.27 to 1.39	1.32	1.26 to 1.41	1.33		1.42
GR-SI	OFA	%	19 to 31	27	19 to 32	27		30
GR-SI	Ca/S		1.49 to 1.90	1.72	.78 to 2.70	1.88		2.10
GR-SI	Sorbent Flow	lb/hr	3080 to 4000	3510	1240 to 4130	2950		2860
GR-SI	Injection Air	scfm	1900 to 4230	3630	1780 to 4630	3480		3740

The design gas heat input, to achieve 60% NO_x reduction, was 23.6%. The test plan specified evaluation of gas heat input in the 0 to 25% range, at each load. The design recycled flue gas flow was 5% of the total flue gas. The range prescribed for evaluation was 3 to 7%, which at full load and 25% excess air, corresponds to 2,700 to 6,100 scfm. The design coal zone stoichiometric ratio was 1.15, which was determined to be suitable for coal burnout and formation of slagging conditions in the cyclones. Since the coal (cyclone) air can significantly impact the "primary NO_x" level, the test plan specified its evaluation down to a stoichiometric ratio of 1.05. The fraction of combustion air diverted to the OFA ports under the design condition was 22%. The test plan called for evaluation of OFA up to 30% of the total combustion air. The design reburning zone stoichiometric ratio was 0.9; testing down to 0.87 was planned. A lower limit for reburning zone stoichiometric ratio is typically observed since there is potential for increase in waterwall wastage under reducing conditions. The design burnout zone stoichiometric ratio was 1.15; testing up to 1.17 was planned. Generally, the burnout zone stoichiometric ratio is limited to reduce dry gas heat loss. This must be balanced with achieving good fuel burnout, i.e. low CO emissions and combustible matter-in-ash. GR testing at reduced load was planned similarly, except with higher burnout zone stoichiometries. At less than full load, steam generating units are typically operated with higher excess air to increase convective heat transfer which depends on flue gas mass velocity as well as temperature. High excess air operation therefore helps maintain the steam temperature near its design point.

Table 6-3 shows that GR process parameters were evaluated over wide ranges. In addition to the ranges, average conditions are listed. While GR operation in the 0 to 25% gas heat input range was planned, the actual range tested at full load was 12 to 26%. At minimum load, the gas heat input was evaluated down to 8%. The GR system control limits the lower level of gas input. FGR flows of 3000 to 6000 scfm were evaluated, but flows of 5500 to 6000 scfm were most commonly used. The coal zone stoichiometric ratio was evaluated in the range of 1.09 to 1.29 at full load, but down to 0.95 at minimum load. The low points for coal and reburning zone stoichiometries at the minimum load were short-term tests and not representative of normal GR conditions. One of the major differences between the design case and actual test conditions was in the area of burnout zone stoichiometric ratio. The design case burnout stoichiometric ratio was 1.15, but in practice burnout stoichiometries exceeding 1.25 were required to maintain low CO emissions. The OFA flow was typically 30% of the combustion air, with a maximum at full load of 36%.

SI optimization testing also involved variation of process parameters over wide ranges. Again, the test plan specified testing at three loads. The Ca/S molar ratio, which had a design value of 2.0, was to be evaluated in the 1.0 to 3.0 range. The SI air, which affects the rate of dispersion and mixing in the furnace, was 5% of the combustion air in the design case. SI air variation in the 2 to 5% range was planned. Since Linwood hydrated lime was used in the GR-SI demonstration at Illinois Power Company's Hennepin Unit 1, it was selected as the baseline sorbent for this site. An alternate sorbent test was planned to provide a data base for the performance of other sorbents. In addition to the measurements listed above, sorbent compositions were to be obtained from the supplier. Sootblowing cycles were to be evaluated against steam temperature and boiler efficiency.

The conditions listed in Table 6-3 indicate that wide ranges for each SI parameter were evaluated. At full load, Ca/S molar ratios of 1.10 to 2.87 were tested. At minimum load Ca/S up to 3.46 was tested. At full load, the range of SI air flows was 1800 to 4500 scfm. These correspond roughly to 2.0 to 5.0% of the combustion air, at a burnout stoichiometric ratio of 1.24. Throughout this phase of testing the same sorbent, Linwood hydrated lime, was used. While variations in the sootblowing cycle were planned, in practice almost continuous operation of IK sootblowers was required to maintain tube cleanliness in the convective pass.

6.1.2 Long-Term Testing

The test plan called for long-term GR-SI testing for a period of one year. Since the unit typically operates during the spring, late summer, and fall months, a total of nine months of long-term GR-SI demonstration was realized. The GR-SI system was to be evaluated at a set point, while the unit operated over its normal duty cycle. GR-SI conditions were to be selected from evaluation of GR and SI optimization testing. The conditions listed in Table 6-3 indicated that there were modest variations in GR-SI operating conditions. On average, the gas heat input was 21 to 22% and the FGR flow typically was in the 5500 to 6000 scfm range. At high and mid loads, the average stoichiometries for the coal and reburning zones were near the design case at 1.15 and 0.92, respectively. However, more burnout air was used than in the design resulting on average in a burnout stoichiometric ratio of 1.27 and exit stoichiometries of 1.32 to 1.33. At minimum load, higher burnout zone stoichiometric ratio (excess air) was used, as is typical for steam generating units. The sorbent inputs were generally below the Ca/S design case of 2.0. At high and mid loads, the Ca/S averaged 1.72 and 1.88, respectively. The SI air flow was varied widely, but averaged in the area of 3500 to 3700 scfm for all loads.

6.1.3 Alternate Sorbent Testing

The alternate sorbent test was planned to provide a performance data base for sorbents other than Linwood hydrated lime. This was expected to be of relatively short duration (under one week) and over a wide range of boiler operation. Sorbent provided by NovaCon Energy Systems of Bedford, New York, were tested at the conclusion of the GR-SI test program. This test followed characterization of the alternate sorbent in EER's Boiler Simulation Furnace (BSF), at the California research facility. The results of these tests were described in a separate report, included here as Appendix 4.

6.2 Data Acquisition

Data were acquired from plant instrumentation and stored by EER's customized BPMS. CEMS analyzer data were also recorded by the BPMS, which corrected these measurements to a standard O_2 concentration or to a mass per heat input basis. In addition to BPMS data, control room data for each test condition were hand recorded as a backup to storage of data by the BPMS. Manual sampling data were hand recorded on run sheets and sample custody sheets and laboratory analyses reports were provided by a commercial laboratory.

6.2.1 Boiler Performance Monitoring System

The BPMS used to monitor the performance of the GR-SI system and boiler thermal characteristics at Lakeside Unit 7 was customized for this application. It recorded a host of inputs (see Table 6-4) performed process calculations, then output data in prescribed formats. Table 6-5 is a list of outputs. The flows of coal, cyclone air, natural gas, OFA, and SI air were used to calculate the four zone stoichiometries. Utilizing standard coal and natural gas compositions. The combustion air and flue gas temperatures, standard fuel compositions, and design specifications or empirical model results were used to calculate heat loss efficiency. A combustion and heat transfer model calculated the heat absorption by each heat exchanger: furnace and wing walls, secondary superheater, primary superheater, generating bank, attemperator, and air heater. HAR, relating the heat absorbed under the specific test condition to the baseline case at the same load, were also calculated. These gave an indication of the extent of deposition on the heat exchanger surface, i.e. furnace slagging and convective pass fouling. The BPMS also compiled data output from the CEMS gas analyzers, and corrected emissions to 3% O_2 and calculated mass of emissions per heat input.

EER's BPMS heat transfer and combustion model can receive up to 300 inputs and update them as frequently as every 5 seconds. It can perform process calculations including heat absorptions by various heat exchangers, gas temperature changes, heat loss efficiency, and emissions correction to standard O_2 and in terms of mass per heat input. It can calculate the coal flow based on steam heat absorption and the input-output efficiency equivalent to the heat loss efficiency. It displays data on-line for real time trending and archives data on an optical disk. It also has capability for remote monitoring of data and file exchange. Typically, Lakeside BPMS one minute average data were evaluated over the test periods. Over the test periods, the average, maxima, and minima were calculated, then output in the form of customized reports.

TABLE 6-4. INPUTS TO THE LAKESIDE BPMS HEAT TRANSFER AND COMBUSTION MODEL

Class of Input	Input data	Method of Acquisition	Comment
Fuel characteristics	Proximate analysis	Operator	Must be representative
	Ultimate analysis		
	Heating value		
ASME heat loss method	Combustible in refuse	Operator	From design specification or field test
	Radiation heat loss	Operator	From design specification or empirical formula
	Unmeasured heat loss	Operator	From design specification or empirical formula
Ambient conditions	Relative humidity	Instrumentation signal	
	Barometric pressure	Instrumentation signal	
	Ambient temperature	Instrumentation signal	
Boiler instrumentation - flue gas side	Boiler bank inlet temperature	Instrumentation signal	
	Boiler bank outlet temperature	Instrumentation signal	
	Air heater outlet temperature	Instrumentation signal	
	Boiler outlet gas O_2	Insturmentation signal	
GR-SI Instrumentation	FGR flow rate	Instrumentation signal	
	Natural gas flow rate	Instrumentation signal	
	Overfire air flow rate	Instrumentation signal	
	Sorbent transport air flow rate	Instrumentation signal	
	Sorbent transport air temperature	Instrumentation signal	
	Sorbent transport air pressure	Instrumentation signal	
	Sorbent injection air flow rate	Instrumentation signal	
	Sorbent mass flow rate	Instrumentation signal	
Continuous emissions monitoring	*Gaseous concentrations of:*		
	CO_2, CO, NO_x, SO_2, O_2, and	Instrumentation signal	CEMS signals
	hydrocarbons	Instrumentation signal	CEMS signals
Combustion air	East cyclone air flow	Instrumentation signal	
	West cyclone air flow	Instrumentation signal	
	Air heater air inlet temperature	Instrumentation signal	
	Air heater air outlet temperature	Instrumentation signal	
Tube metal temperatures	Superheater tube wall temperature	Instrumenation signal	
Boiler instrumentation - of water/steam side	Feedwater flow to steam drum	Instrumentation signal	
	Feedwater temperature to steam drum	Instrumentation signal	
	Boiler drum pressure	Instrumentation signal	
	Primary superheater outlet temperature	Instrumentation signal	
	Superheat attemperator outlet temperature	Instrumentation signal	
	Secondary superheater outlet temperature	Instrumentation signal	
	Secondary superheater outlet pressure	Instrumentation signal	
Power generation	Generator gross power	Instrumenation signal	

TABLE 6-5. OUPUT DATA OF THE LAKESIDE BPMS HEAT TRANSFER AND COMBUSTION MODEL

Class of Output	Output Data
Heat input	Total heat input Heat input to cyclones Reburn gas heat input
Heat absorption	Furnace including wing walls Secondary superheater Primary superheater Generating bank Drum attemperator Air heater
Boiler efficiency based on ASME heat loss method	Heat loss due to dry gas Heat loss due to moisture in fuel Heat loss due to H2O from combustion of H2 Heat loss due to combustible in refuse Heat loss due to radiation Heat loss due to unmeasured sources
Boiler efficiency based on heat absorption method	Efficiency based on gross heating value Efficiency based on lower heating value
Heat Absorption Ratio (Relative to Baseline Case)	Furnace including wing walls Secondary superheater Primary superheater Generating banks Drum attemperator Air heater
Stoichiometric Ratio	Coal burning zone Reburning zone Burnout zone Exit Zone
Ratio of Sorbent Calcium to Coal Sulfur	Ca/S
Emissions control data	Gaseous species concentrations of CO2, CO, NOx, O2, SO2, and hydrocarbons in the form of: Volume % (or ppm), dry Corrected to 3% O2 and Pounds per million Btu heat input

6.2.2 Continuous Emissions Monitoring System

A CEMS was used to continuously monitor gaseous emissions at the boiler outlet. The CEMS, illustrated in Figure 6-1, measured concentrations of NO_x, SO_2, CO, CO_2, and O_2. Early in the test program, measurements of total hydrocarbon (HC) were also taken. Due to the rigorous demands of sampling flue gas, which were anticipated, HC measurements were taken only during early GR optimization tests. The O_2 measurement was used to correct the emissions of NO_x and SO_2 to the standard 3% O_2 concentration. The CO_2 measurement was used verify the O_2 concentration based on a carbon mass balance. The CO concentration, which is typically below 200 ppm for coal fired units, is an indicator of combustion completion.

Flue gas was extracted from a sixteen point grid at the boiler exit. The CEMS used a stainless steel sampling grid, heated lines to prevent moisture condensation, rotameters to balance gas flow, a mixing manifold, a chiller for moisture removal, and the analytical instruments calibrated with zero, mid-span and span gases. During periods of SI operation, phase discrimination probes were used to separate particulates from the gas sampled. This ensured that SO_2 in the sampling system did not interact with reactive particulate (sorbent). Table 6-6 lists the analytical instruments, constituent they measure, detection principle, and the concentration ranges. These instruments were calibrated at least twice daily with zero, mid-span, and span gases. Figures 6-2 and 6-3, illustrate the sampling location and the sampling grid, respectively. The sampling location is upstream of the air heater; therefore, dilution from air heater leakage is avoided. While a location downstream of the dust collector is preferred, it was not used in this case since flue gases from both Units 7 and 8 pass through the same ESP.

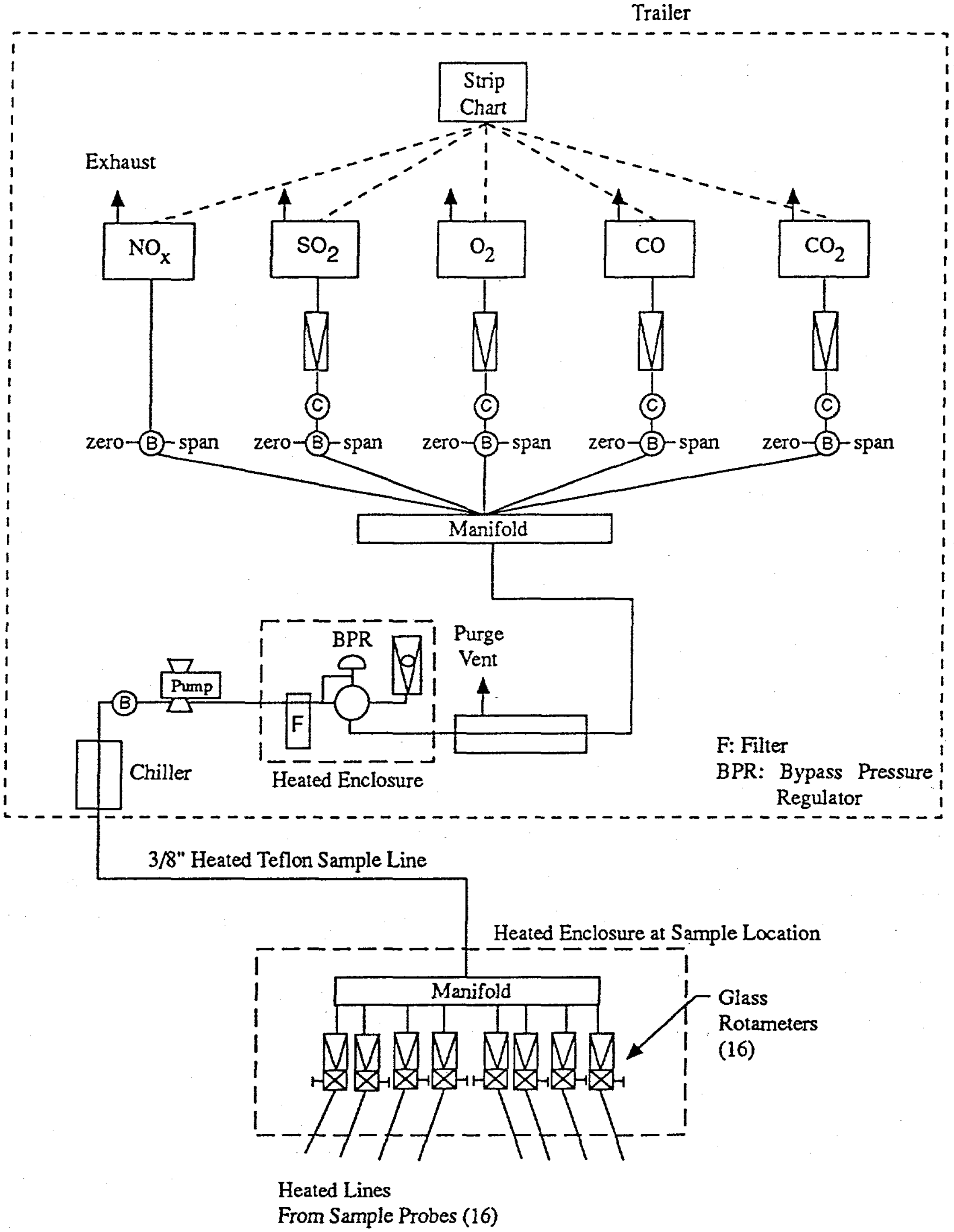

Figure 6-1. Schematic of continuous emissions monitoring system

TABLE 6-6. CEMS INSTRUMENTS

Gas Measured	Detection Principle	Manufacturer	Model No.	Range
CO	Nondispersive Infrared (NDIR)	TECO	48	0 to1,000 ppm
CO_2	Nondispersive Infrared (NDIR)	Fuji	3300	0 to 20%
NO_x	Chemiluminescence	Thermo Electron Corp.	10A	0 to 10,000 ppm
O_2	Paramagnetic	Taylor Servomex	1400	0 to 10%
SO_2	Nondispersive Ultraviolet (NDUV)	Western Research	721-AT2	0 to 5,000 ppm
THC	Flame Ionization Detection	Jum	VE7	0 to 5,000 ppm CH_x

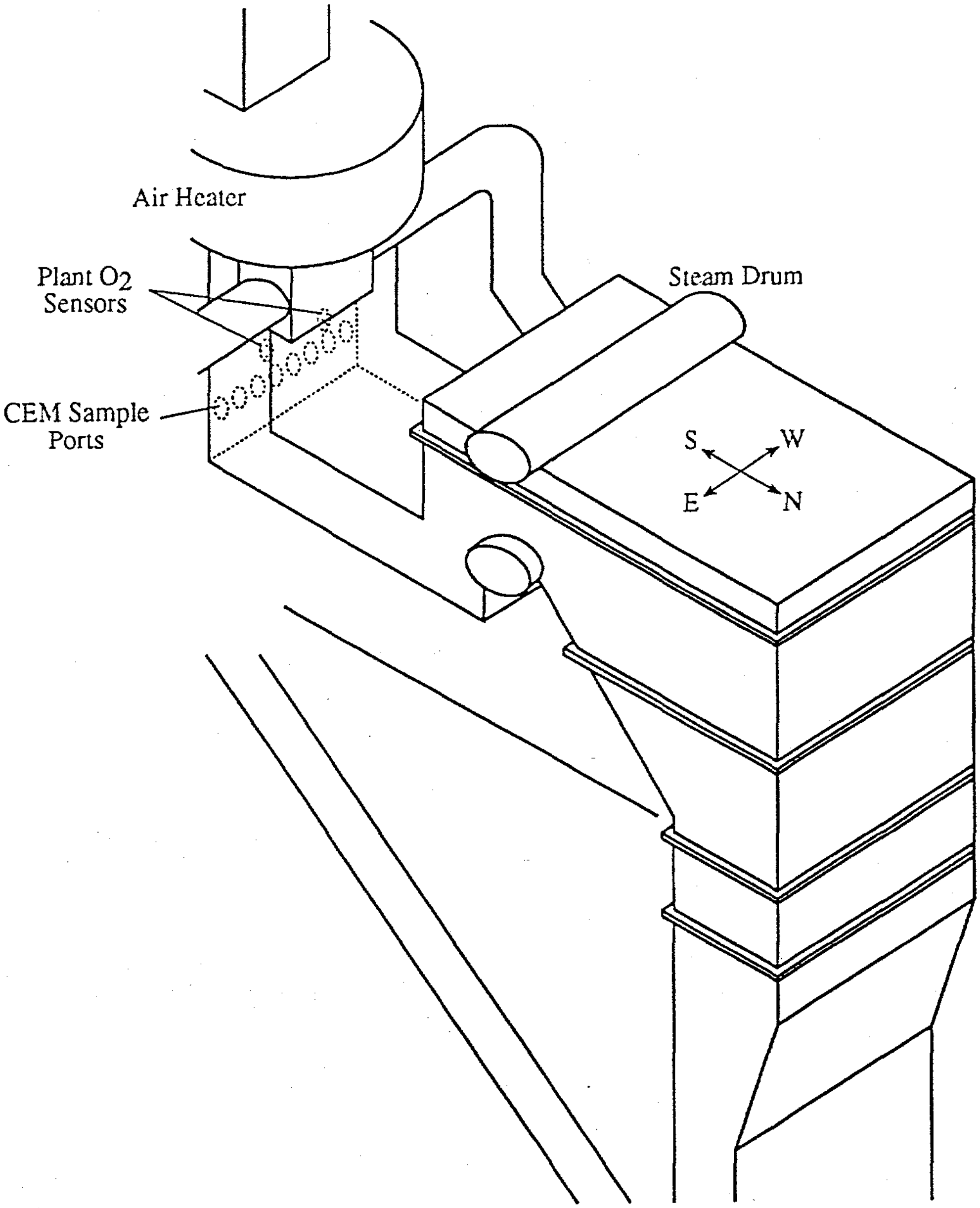

Figure 6–2. CEMS sampling location

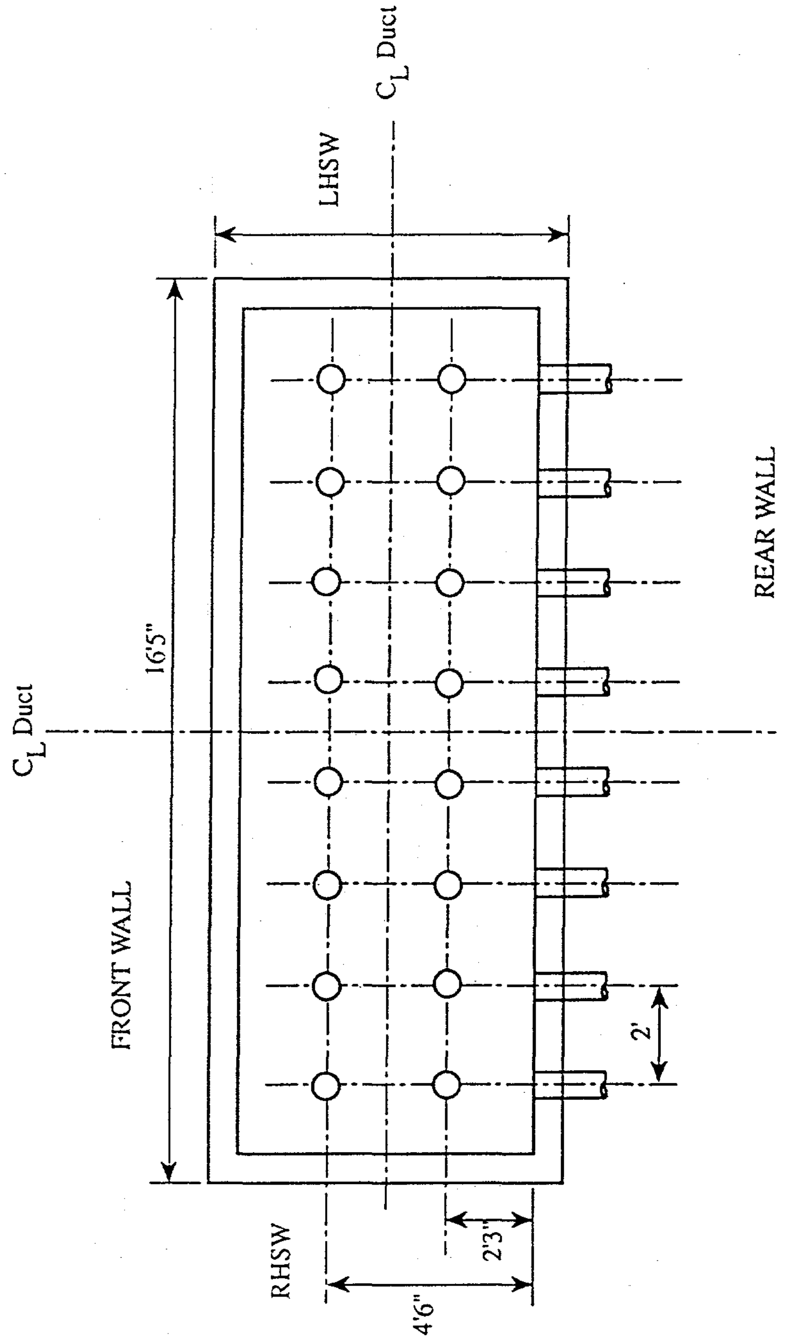

Figure 6-3. CEMS sampling grid

6.3 Data Analysis Methodology

The performance of GR and SI systems was correlated to process parameters, as detailed in Section 7. The NO_x control achieved in GR is related to gas heat input, reburning zone stoichiometric ratio, and coal zone stoichiometric ratio. The SO_2 control achieved by SI may be correlated to Ca/S and SI air flow. This section identifies the major GR process variables which have to be fixed in order to fix the system. A fixed system would be expected to emit a consistent and reproducible NO_x level.

The major process parameters in GR are the zone stoichiometries. These are defined by the following equations.

$$SR_1 = (TA - OFA)/CSA \qquad (1)$$

$$SR_2 = (TA - OFA)/(CSA + GSA) \qquad (2)$$

$$SR_3 = TA/(CSA + GSA) \qquad (3)$$

Where:

TA = Total Air (scfm)
OFA = OFA (scfm)
CSA = Coal Stoichiometric Air (scfm)
= coal theoretical air (scf/lb) x coal flow (lb/min)
GSA = Gas Stoichiometric Air (scfm)
= gas theoretical air (scf/scf) x gas flow (scfm)

Under GR operation, the SI air is limited to nozzle cooling flow. Therefore it is neglected here.

The above equations may be rearranged to yield the following:

$$\text{Coal air fraction} = (TA - OFA)/TA = SR_2/SR_3 \qquad (4)$$

$$\text{OFA fraction} = OFA/TA = (SR_3 - SR_2)/SR_3 \qquad (5)$$

In addition, the following approximations are presented. These are useful for data correlation purposes only and were not used to actually calculate these parameters.

$$\text{Coal fraction} = \text{CSA}/(\text{CSA} + \text{GSA}) = \text{SR}_2/\text{SR}_1 \qquad (6)$$

$$\text{Natural Gas fraction} = 1 - \text{Coal fraction} = (\text{SR}_1 - \text{SR}_2)/\text{SR}_1 \qquad (7)$$

Therefore, seven process variables (SR_1, SR_2, SR_3, coal fraction, natural gas fraction, coal air fraction, and OFA fraction) are related by four equations (4 though 7). To fix the system, three variables must be held constant. Examples of sets of process variables which define a fixed system include (SR_1, SR_2, SR_3), (SR_1, natural gas fraction, SR_3), and (SR_1, SR_2, OFA fraction). In plotting NO_x as a function of natural gas fraction or SR_2, two process variables should be held constant. In such plots, the variables most commonly held constant are SR_1 and SR_3. Alternatively, two other variables which may be held constant are SR_1 and OFA fraction. Holding two variables constant in data plots results in a minimum of data scattering and permits reproduction of trends.

7.0 TECHNICAL PERFORMANCE

This section presents results of GR, SI, and GR-SI testing in the areas of boiler emissions, combustion completion, thermal efficiency, steam conditions, and other performance areas. The impacts of these technologies on boiler operation including furnace slagging, convective pass fouling, and ESP performance are also addressed. The flue gas constituents at the boiler exit were characterized continuously with EER's CEMS. Test averaged emissions of NO_x, SO_2, CO, and CO_2 are presented in Appendix 2. In this section, the emissions are correlated with GR-SI system and boiler operating conditions. Following presentation of emissions data, the impacts of GR-SI on boiler thermal performance are evaluated. It was important to quantify impacts on heat transfer efficiency, combustion completion, steam conditions, steam attemperation rate, and flue gas temperatures. These parameters were continuously recorded or calculated by the BPMS. Following presentation of these results, GR-SI impacts on ash deposition in the furnace, fouling of convective heat exchangers with ash/sorbent, performance of the ESP, and wear of boiler components are presented. The wastage rate of boiler tubewalls was determined via Ultrasonic Thickness (UT) measurements taken before and after the GR-SI demonstration. Metallurgical examination of tubewall samples was conducted before and after GR-SI testing. Visual inspections of the cyclones, furnace, convective pass, ESP, and chimney were conducted by EER personnel and contractors to assess changes due to GR-SI. The section concludes with a discussion of adjustments made to the GR-SI system during the test program to enhance its performance.

Reburn NO_x reduction performance depends on a range of different process parameters, which include: initial NO_x level; temperature at the reburn and burnout zones; reburn zone stoichiometric ratio; stoichiometric ratio in the main combustion and burnout zones; residence times in the reburn and OFA zones; and mixing rates of the reburn fuel and OFA. data gathered during EER's various reburn demonstration programs have been reported in graphical format, where measured NO_x reduction performance has been compared with most of the above variable parameters, and where reasonably good correlations with individual parameters can be seen. However, given the rather complex inter-relationship between the various controlling parameters and reburning system performance, EER has elected not to present statistical correlations of the data. We believe that the use of such correlations can be misleading, particularly with respect to extrapolating system performance to other boilers and boundary conditions. To successfully correlate the data requires more complex process models, such as those used by EER during the development of designs for each of the different boiler applications. These process/design models have been validated during the course of the demonstration projects, and have been shown to accurately reflect performance trends as a function of the various process parameters and for boilers of very different design. For business reasons, and because of their importance in developing commercial guarantees, EER prefers not to make public any details of the process models.

7.1 Coal Analyses and Sorbent Composition

Proximate and ultimate analyses of coal fired at the Lakeside Station during Phase I baseline testing and the GR-SI demonstration are compared with a design composition in Table 7-1. The coal fired during the demonstration had a lower heating value, reduced fixed carbon/volatile matter and higher moisture content than that fired previously. The average coal sulfur content of 3.03% and carbon content of 55.75% correspond to a theoretical SO_2 level of 6.01 lb/10^6Btu (2580 mg/MJ) and CO_2 level of 203 lb/10^6Btu (87.3 g/MJ). The coal has a stoichiometric air requirement of 7.58 lb air/lb coal on the basis of 21% O_2 requirement. It is a slagging type coal, i.e. it has relatively low ash fusion temperatures, suitable for firing in cyclone furnaces.

The makeup of Linwood Hydrated Lime sorbent, i.e. $Ca(OH)_2$ and free H_2O content, was determined by the supplier. Table B-3 lists these constituents. The average $Ca(OH)_2$ content was 93.0%, with a high of 94.7% and a low of 91.0%, while the average free moisture content was 0.8%, with a high of 1.3% and a low of 0.3%.

TABLE 7-1 SUMMARY OF PREVIOUS AND CURRENT COAL COMPOSITIONS

Component	Unit	Design Coal	1988 Baseline Testing Average	1991 Baseline Testing Average	1993 - 1994 GR-SI Demonstration Average
Proximate Analysis					
Fixed Carbon	%	43.70	39.38	38.66	38.53
Volatile Matter	%	32.30	34.04	33.62	32.56
Moisture	%	13.70	17.80	17.78	19.24
Ash	%	10.30	8.78	9.94	9.67
Higher Heating Value	Btu/lb	10,606	10,406	10,250	10,077
Ultimate Analysis					
Carbon	%	59.40	57.76	56.96	55.75
Hydrogen	%	3.90	3.99	4.01	3.88
Oxygen	%	8.00	7.51	7.24	7.34
Nitrogen	%	1.10	1.16	1.06	1.09
Sulfur	%	3.60	3.00	3.00	3.03
Theoretical Emissions					
SO2	lb/MBtu	6.79	5.77	5.85	6.01
CO2	lb/MBtu	205	204	204	203

7.2 Gas Reburning Results

The performance of the GR system in controlling NO_x and its impacts on other gaseous emissions including CO, CO_2, and SO_2 are presented in this section. The program goal was to reduce NO_x by 60% at full load. GR operation was expected to modestly reduce CO_2 and SO_2, with no change in CO achieved through judicious design of the OFA system. CO_2 is a major product of fossil fuel combustion and has been associated with the greenhouse global warming effect, SO_2 is precursor for acidic compounds associated with acid rain, and CO is used as an indicator of combustion completion. To evaluate the GR system, parametric tests typically lasting one to two hours were conducted, with as many as seven completed in a day. Each process parameter was varied individually in order to evaluate its impact independent of the others.

7.2.1 NO_x Control

Reductions in NO_x were calculated from a correlation of baseline NO_x with gross load as follows: $NO_x = 0.0134 * \text{(gross load)} + 0.522$. This correlation is generally valid over the full load range of 19 to 34 MW_e. The process parameters relevant to NO_x control by GR include the stoichiometric ratio of each zone (coal, reburning, and exit), the gas heat input, reburning fuel injection details, and the FGR flow.

7.2.1.1 Gas Heat Input

Gas heat inputs in the range 10 to 26% were evaluated. Figure 7-1 shows NO_x emissions at full load as a function of gas heat input. The measurements indicate that 60% reduction, 0.39 $lb/10^6Btu$ (167 mg/MJ) at full load, was met under some conditions at gas inputs of 20 to 26%. The variations in NO_x are due to ranges in coal (cyclone), reburning and exit zone stoichiometric ratios and other parameters tested. Figure 7-2 shows NO_x data at mid and low load as a function of gas heat input. In these cases, 60% reductions to 0.34 $lb/10^6Btu$ (146 mg/MJ) at mid load and 0.32 $lb/^6Btu$ (138 mg/MJ) low load, were achieved at gas inputs of 20 to 25%. Improved

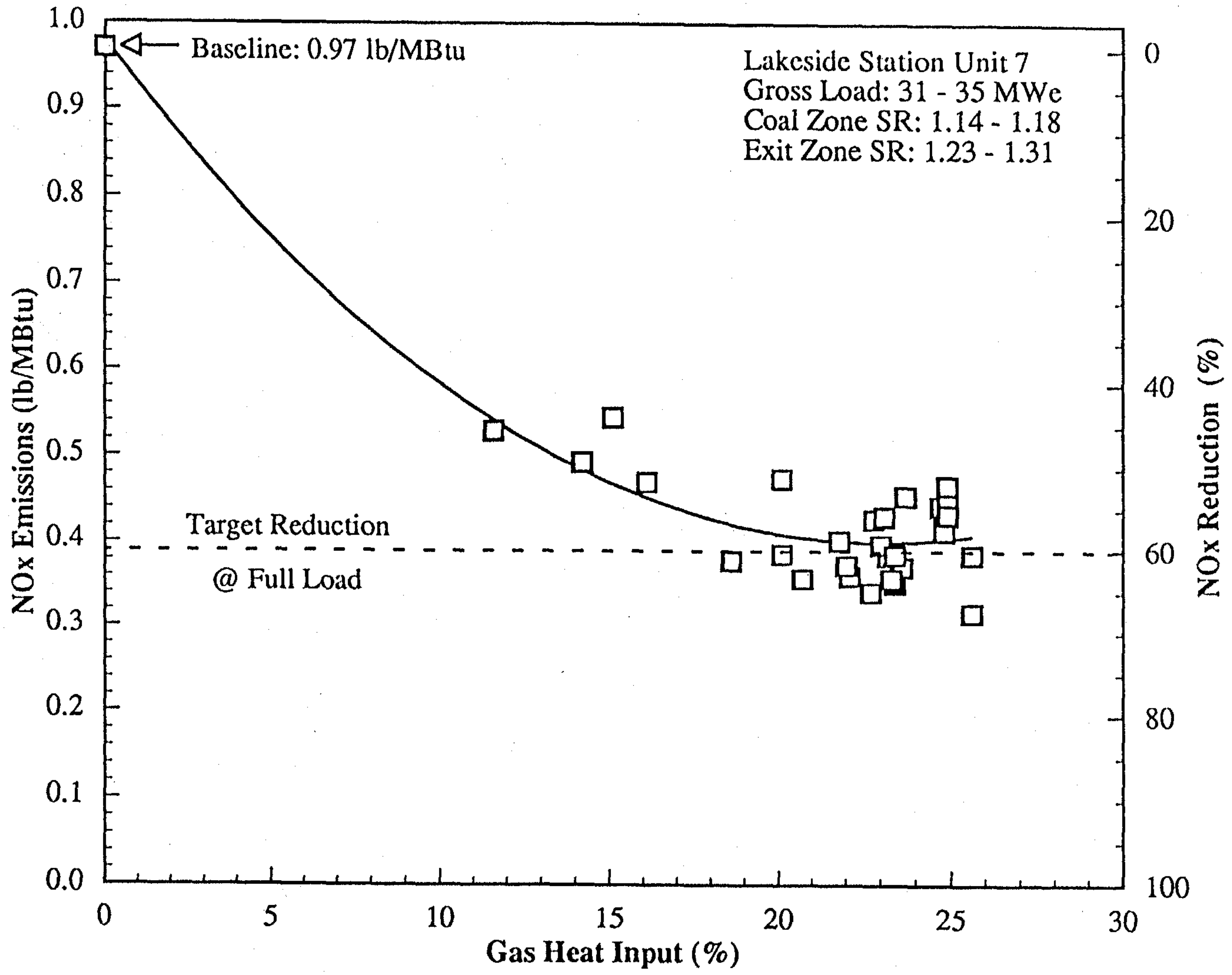

Figure 7-1. NO_x emissions as a function of gas heat input at full load

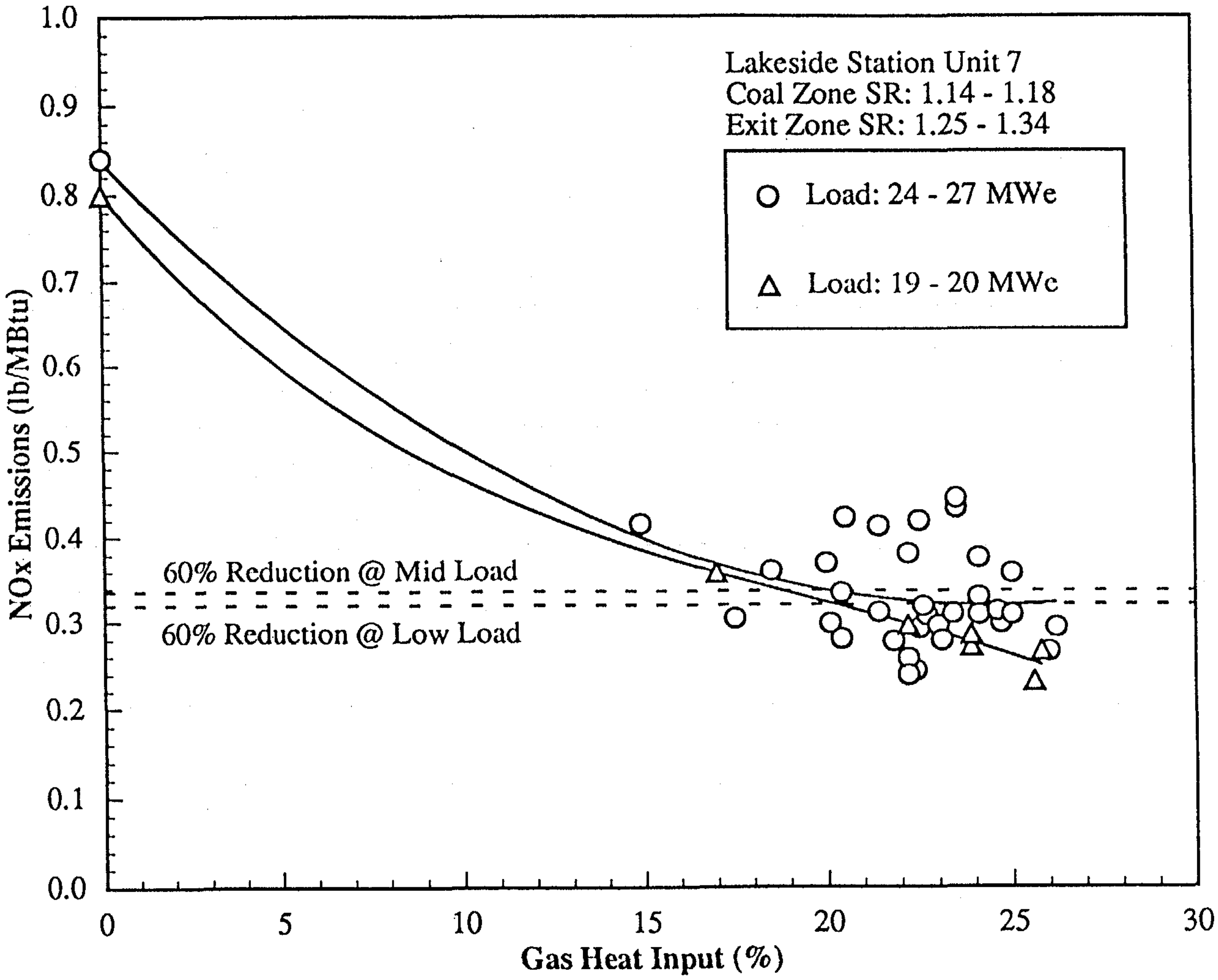

Figure 7-2. NO_x emissions as a function of gas heat input for mid and low load operation

NO_x reductions were measured at low load (19 to 20 MW_e), relative to that at other loads. This is likely due to enhanced mixing of reburning fuel with the primary combustion gas under this condition to form a more uniform reducing zone. At full load the maximum NO_x reduction was 69%, at a gas heat input of 25%, while at mid and low loads NO_x reduction as high as 71% was measured at gas heat inputs of 23 to 26%. In some of these cases, CO emissions were higher than generally acceptable, i.e. above 200 ppm, as will be discussed below. The maximum NO_x reductions achieved with adequate fuel burnout were 65% at full load and 71% at mid load.

7.2.1.2 Furnace Zone Stoichiometric Ratios

The stoichiometric ratios of the three zones significantly impact the NO_x control process. Limiting the coal zone stoichiometric ratio limits the formation of NO_x in this high temperature zone. Low coal zone stoichiometric ratio also result in a reduction in the O_2 level in the reburning zone, and therefore lower reburning zone stoichiometric ratios. The impacts of coal and reburning zone stoichiometric ratios at full load are shown in Figure 7-3. The data show that operation at coal stoichiometric ratio of 1.08 and reburning zone stoichiometric ratio of 0.83 resulted in the highest NO_x reduction at full load (67% for the conditions indicated), while operation at a coal zone stoichiometric ratio of 1.15 and reburning zone stoichiometric ratio of 0.9 achieved the target NO_x reduction of 60%.

The impacts of exit zone stoichiometric ratio on NO_x and CO emissions at full and reduced loads are shown in Figures 7-4 and 7-5, respectively. Burnout air is used to complete combustion, therefore, lower CO levels are expected at higher exit zone stoichiometric ratios. At full load, an exit zone stoichiometric ratio of 1.20 was expected to achieve fuel burnout. However, in practice an exit zone stoichiometric ratio of 1.30 was needed to maintain CO emissions below 200 ppm. At mid and low loads, an exit zone stoichiometric ratio of 1.35 was needed. The exit zone stoichiometric ratio has a relatively minor impact on the final NO_x level since the gas temperature at the point of OFA addition is relatively low. At mid and low load, there was essentially no change in NO_x with excess air.

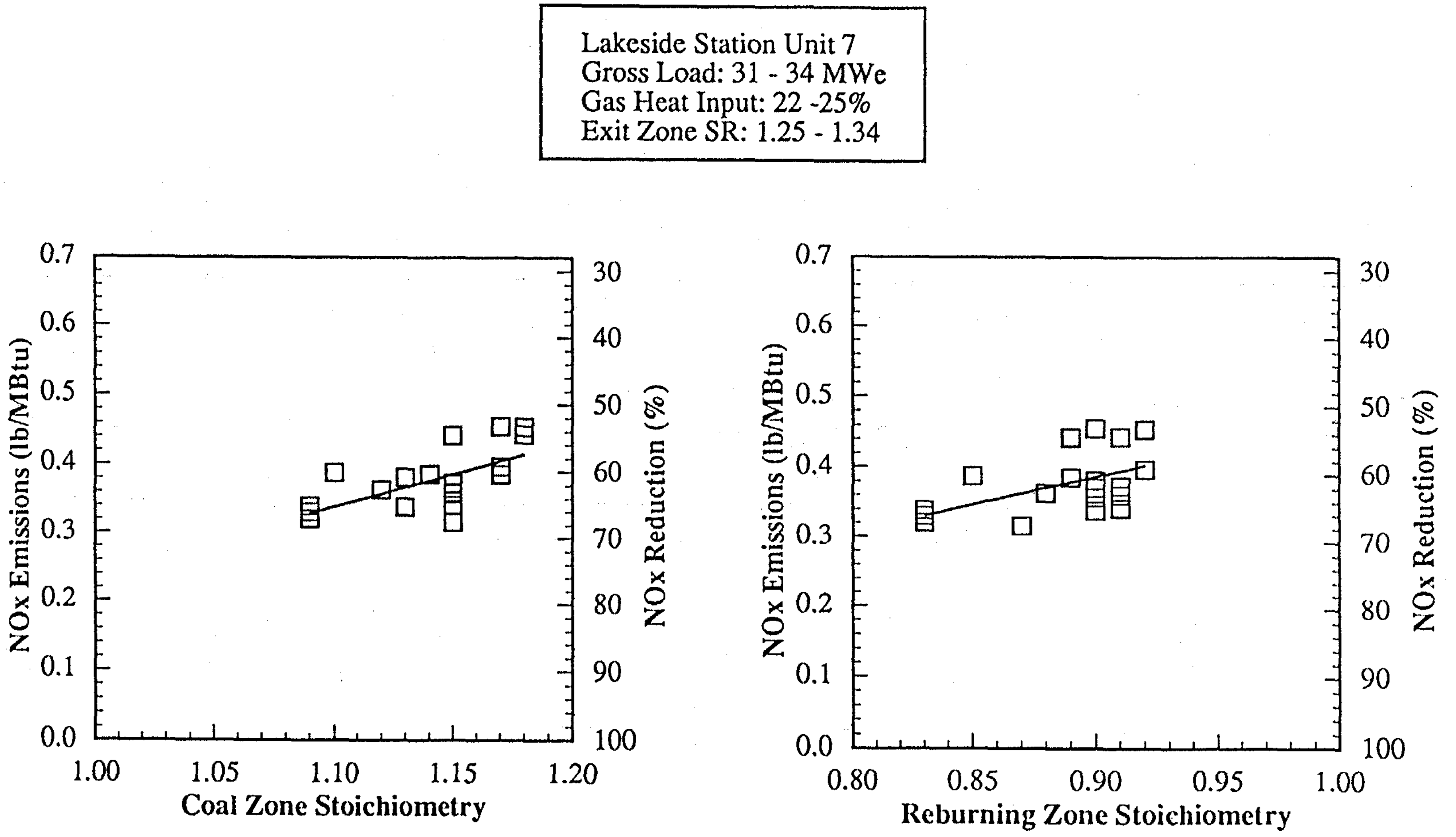

Figure 7-3. NO_x emissions as a function of coal and reburning zone stoichiometries at full load

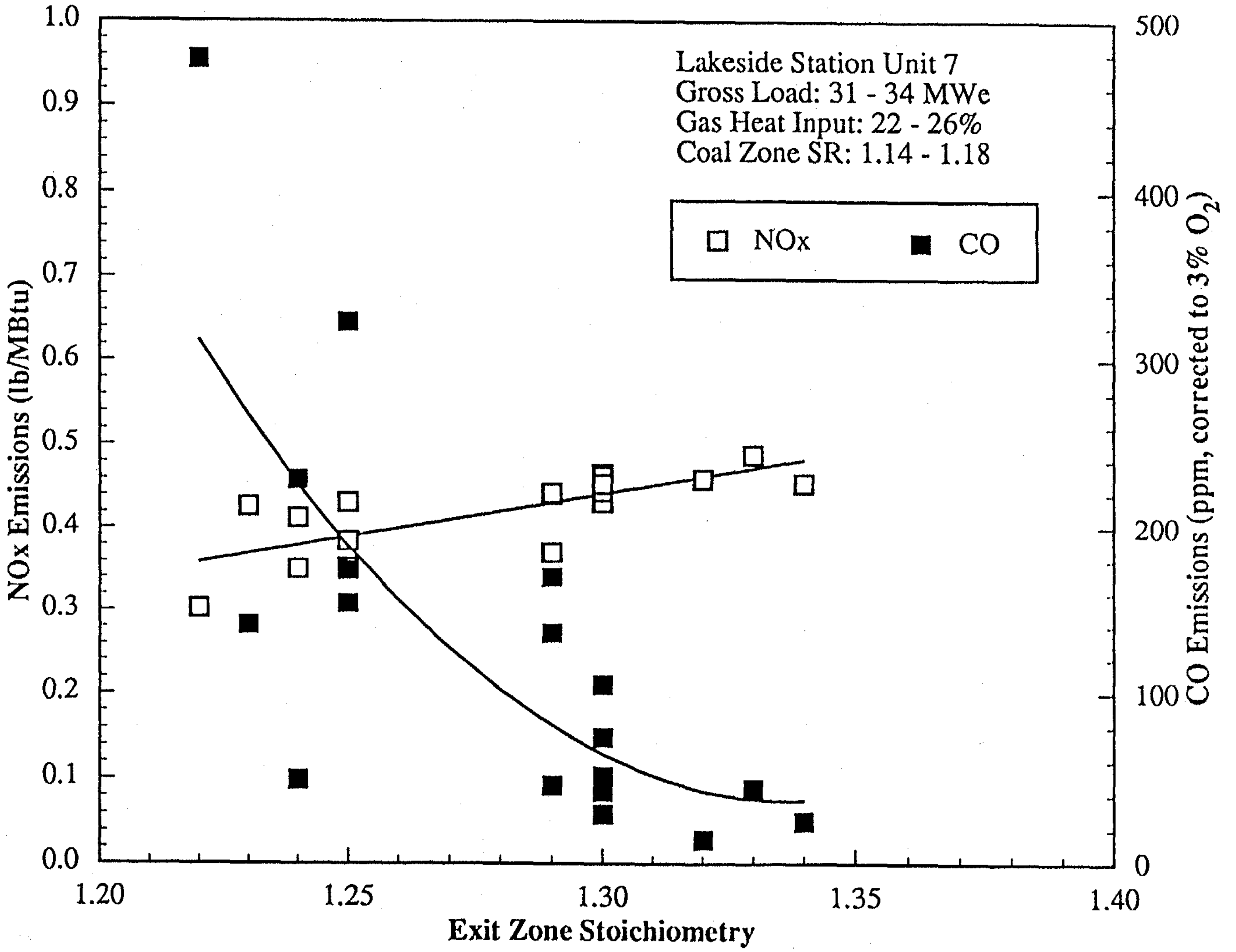

Figure 7-4. NO_x and CO emissions as a function of exit zone stoichiometry at full load

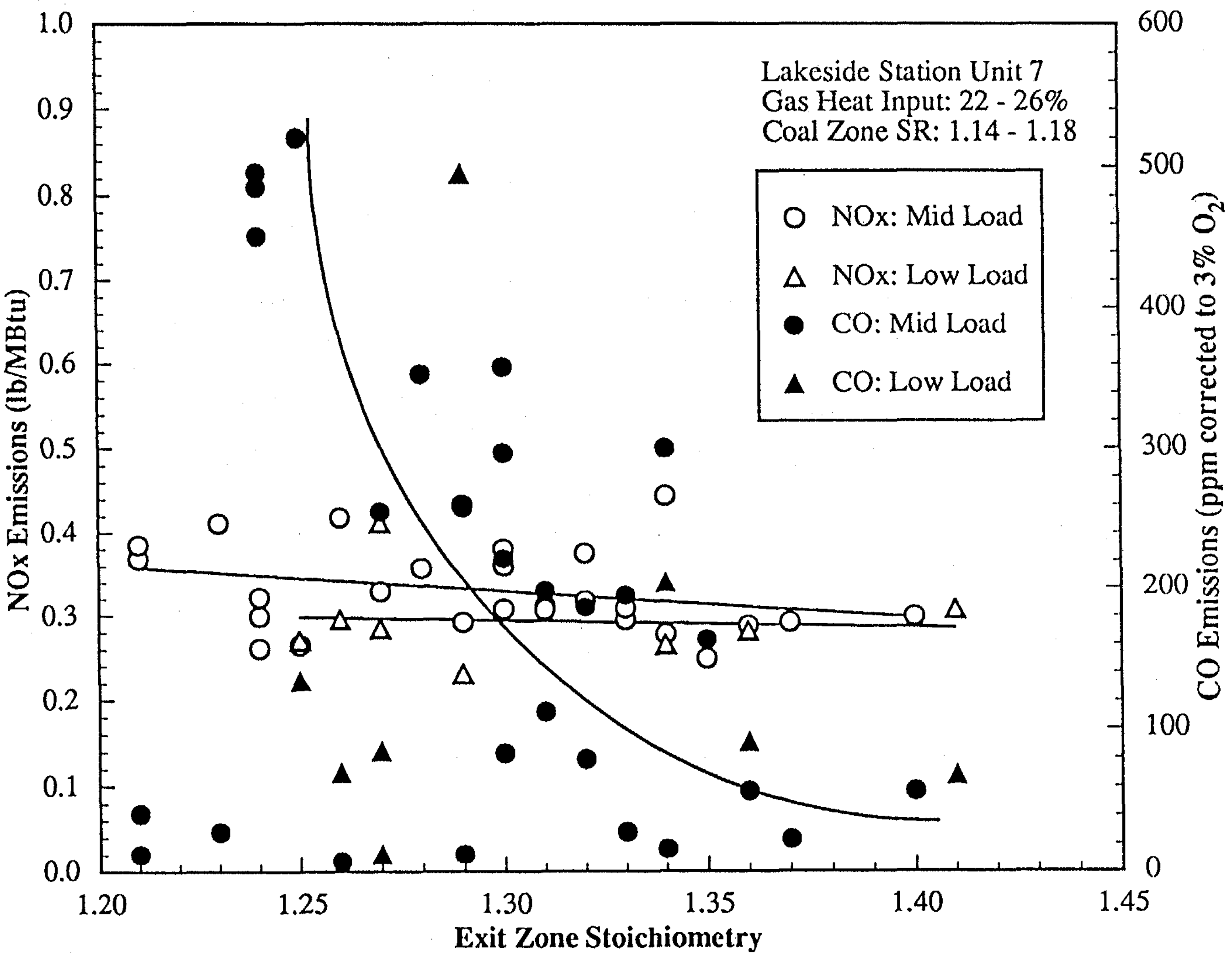

Figure 7-5. NO_x and CO emissions as a function of exit zone stoichiometry for mid and low load operation

7.2.1.3 Reburning Fuel Injector Size

In the Lakeside GR-SI demonstration, two sizes of reburning fuel injectors were tested. The early tests were conducted with relatively large injectors, which had relatively low injection velocity. These were larger than originally specified by the process design studies. At the completion of several parametric tests, an evaluation of test data was undertaken which included furnace flow modeling. This evaluation showed that improved NO_x reductions may be attained with smaller diameter injectors. The smaller injectors were installed and used throughout the long-term GR-SI demonstration.

The impacts of injector optimization on NO_x emissions at full and mid load are shown in Figure 7-6. In both cases, the smaller injectors improved NO_x reduction. This is due to improved reburning fuel jet mixing with primary (cyclone) combustion products. The final (optimized) injectors had a velocity near to that originally specified by the process design studies. On average, NO_x reductions improved by 3 to 5% with the smaller reburning fuel injectors.

7.2.1.4 Recirculated Flue Gas

The FGR flow was varied widely, from 3000 to 6000 scfm (1.42 to 2.83 Nm^3/s). FGR was used as a carrier gas to improve the mass flux of the reburning fuel jets and thereby reduce the mixing time. As expected, higher flows of FGR helped achieve the lowest NO_x level. This was most clearly the case at low load (19 to 20 MW_e). The impacts of FGR, expressed as a percentage of total flue gas, at full, mid, and low loads are shown in Figures 7-7 and 7-8. At full load, FGR of 6 to 7% achieved optimum results, while at mid load 8 to 9% achieved highest NO_x reduction, and at minimum load 9 to 10% was optimum.

7.2.2 SO_2 and CO_2 Emissions

Emissions of SO_2 and CO_2 were modestly reduced in GR-only operation. This resulted from the differences in composition of coal and natural gas, since natural gas is essentially sulfur free and

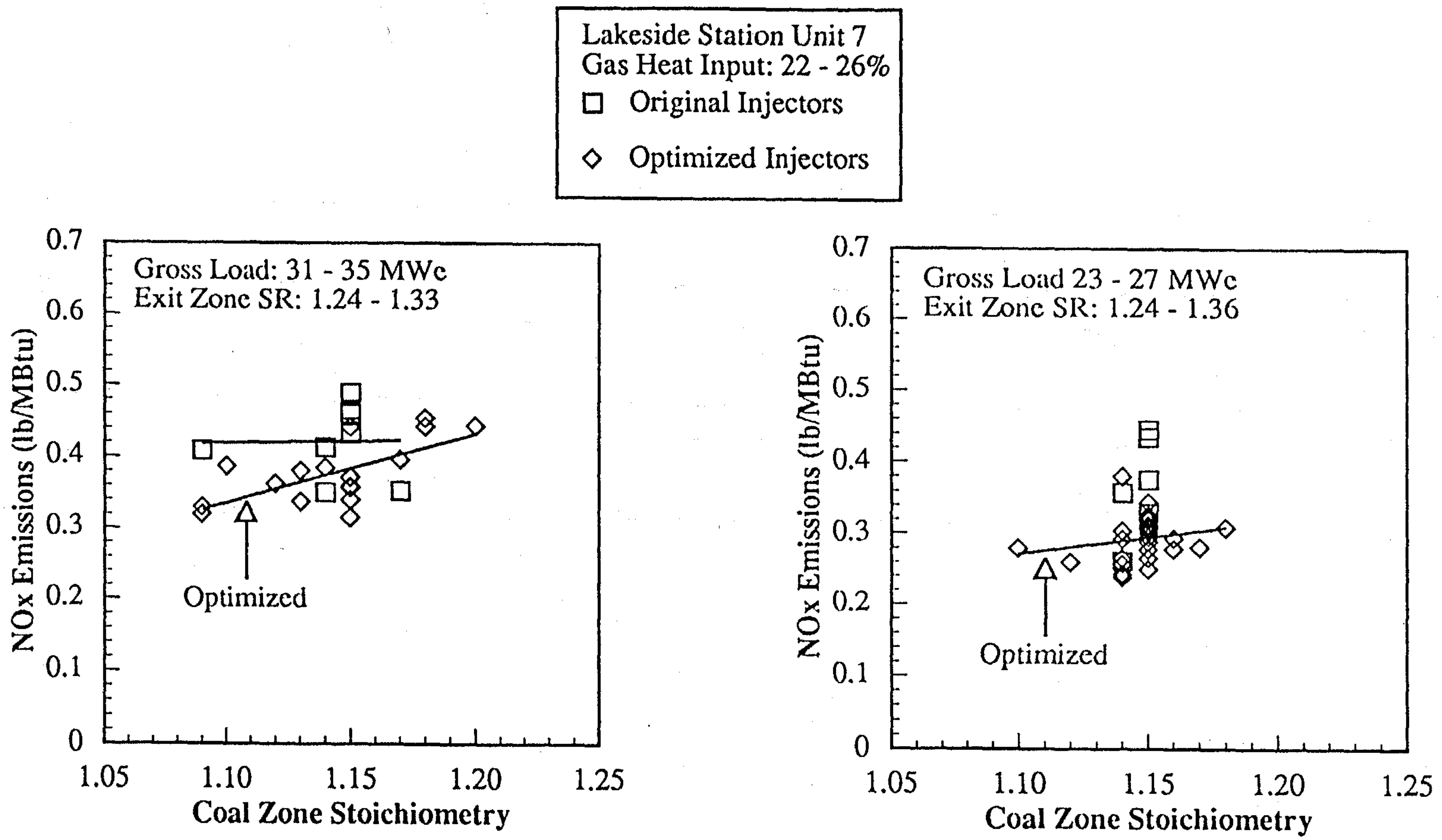

Figure 7- 6. Impacts of reburning fuel injector optimization on NO_x emissions at full and mid loads

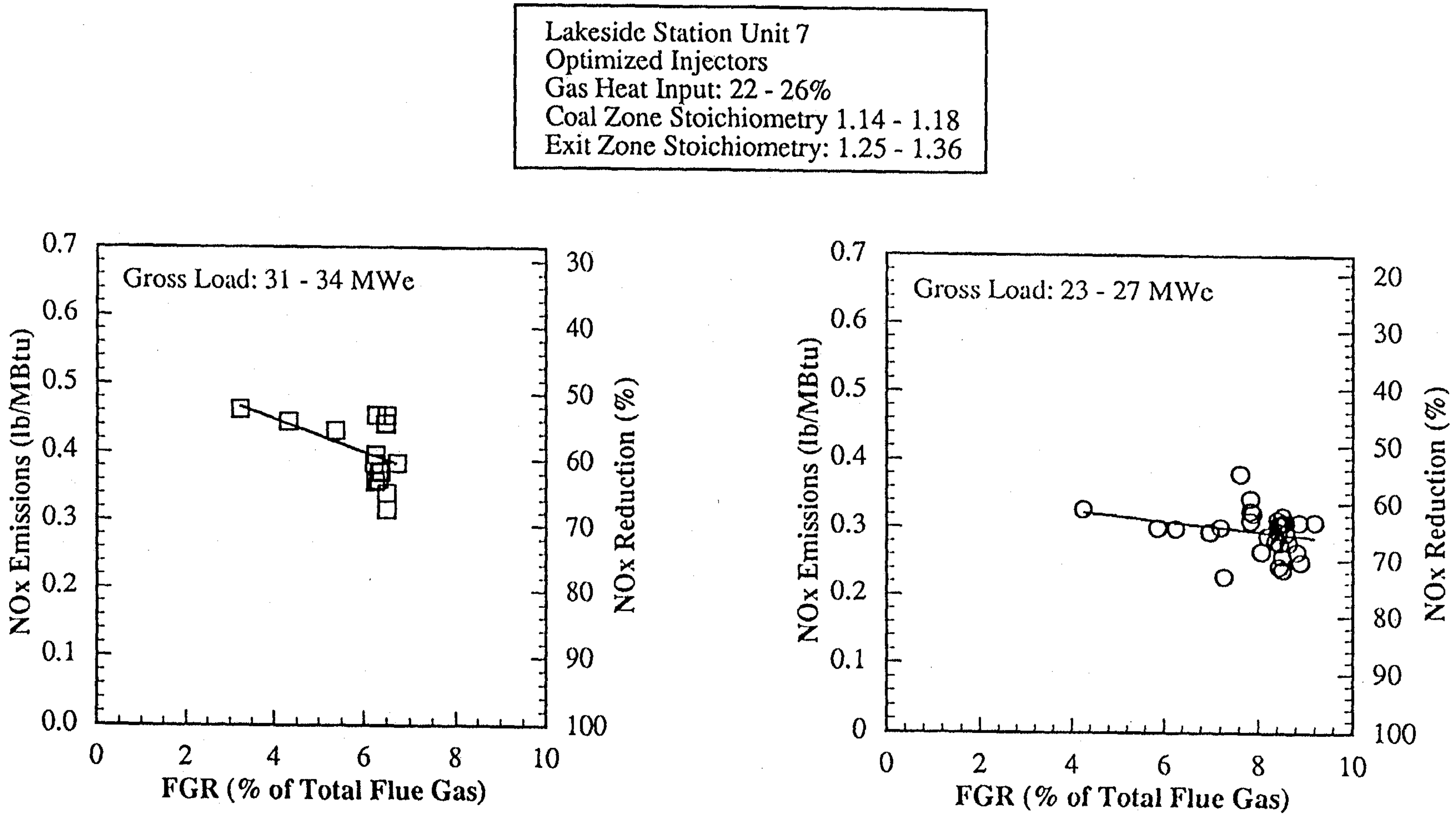

Figure 7-7. Impacts of recirculated flue gas at full and mid loads

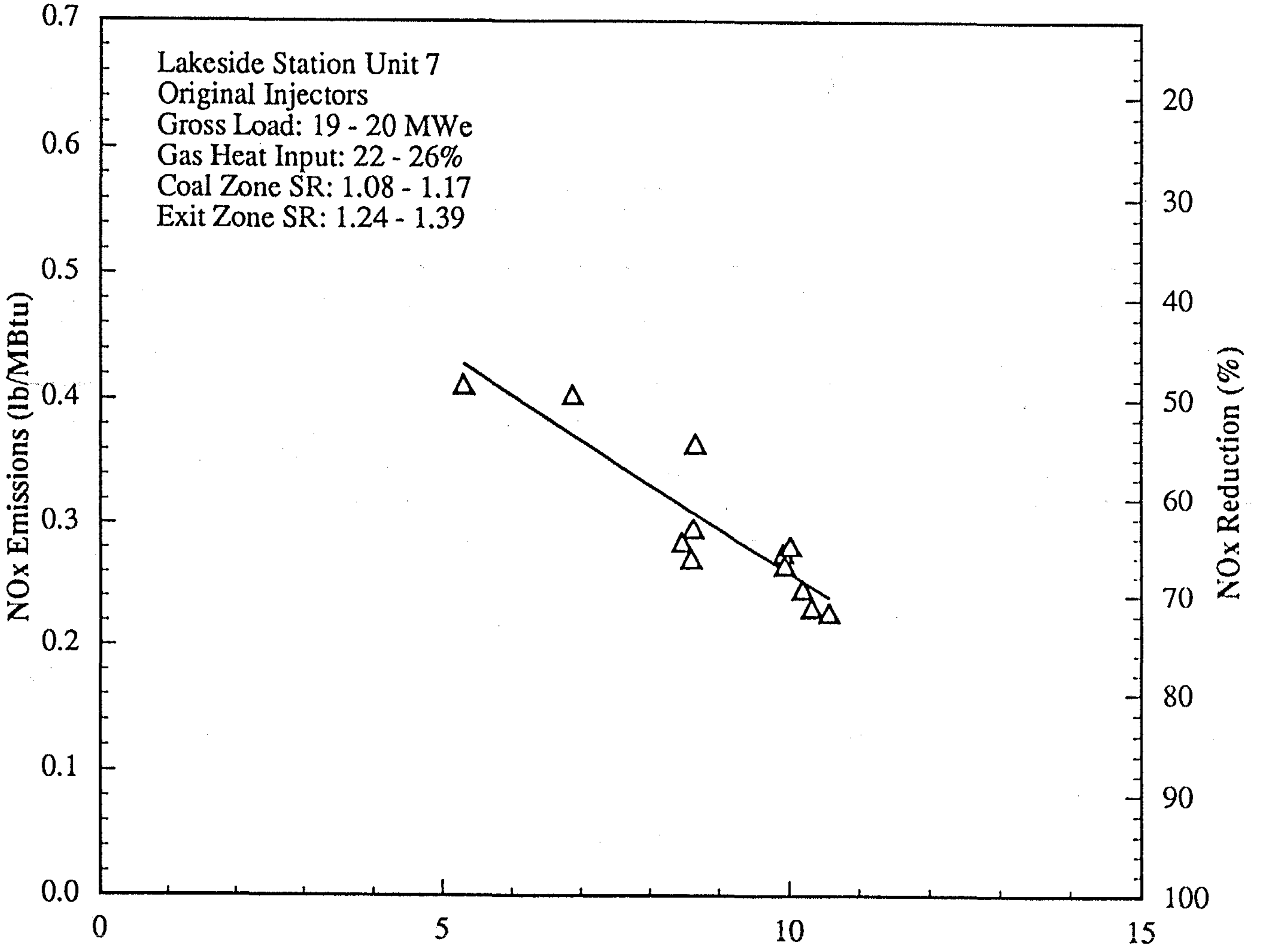

Figure 7-8. Impact on recirulcated flue gas on NO_x emissions

has a higher hydrogen/carbon ratio than coal. Emissions of SO_2 as a function of gas heat input are shown in Figure 7-9. A reduction in SO_2 equivalent to the gas heat input was observed. Therefore, SO_2 reductions were generally 20 to 25%, which is the range of gas heat input most commonly evaluated.

Emissions of CO_2 were also moderately reduced by GR. As shown in Figure 7-10, the CO_2 concentration in the flue gas was reduced by 8%, from 15.4% (volume basis) for baseline operation to 14.2% at a gas heat input of 25%. The results are consistent with theoretical calculations which give CO_2 emissions of 203 lb/10^6Btu (87.3 g/MJ) for baseline coal-only operation and 120 lb/10^6Btu (51.5 g/MJ) for natural gas alone. Replacement of 25% of the coal heat input with natural gas would result in CO_2 emissions of about 182 lb/10^6Btu (78.3 g/MJ), representing a reduction of about 10%.

7.3 Sorbent Injection Results

The performance of the SI system was initially evaluated with parametric SI-only tests. This was followed by a co-application of both GR and SI technologies over the long-term testing period. The parameters which impact SO_2 capture in SI are the Ca/S molar ratio, the SI air flow, and the injection temperature (and indirectly the load). Sorbent characteristics, such as type (hydrate or carbonate) and fineness also impact SO_2 capture. Linwood hydrated lime was the baseline sorbent during the long-term GR-SI evaluation. In addition, two sorbents supplied by NovaCon Energy Systems of Bedford, NY, were tested at the conclusion of the field test. Appendix 4 presents results of the alternate sorbents test.

7.3.1 SO_2 Control

FSI has been developed for SO_2 reductions in the 25 to 50% range. When combined with GR, higher SO_2 reductions can occur due to coal replacement. Limited SI-only testing was characterized to optimize the process. The process was evaluated over the full load range with Ca/S molar ratios from 1.0 to 3.0. SI air flows were evaluated in the range 1800 to 4600 scfm

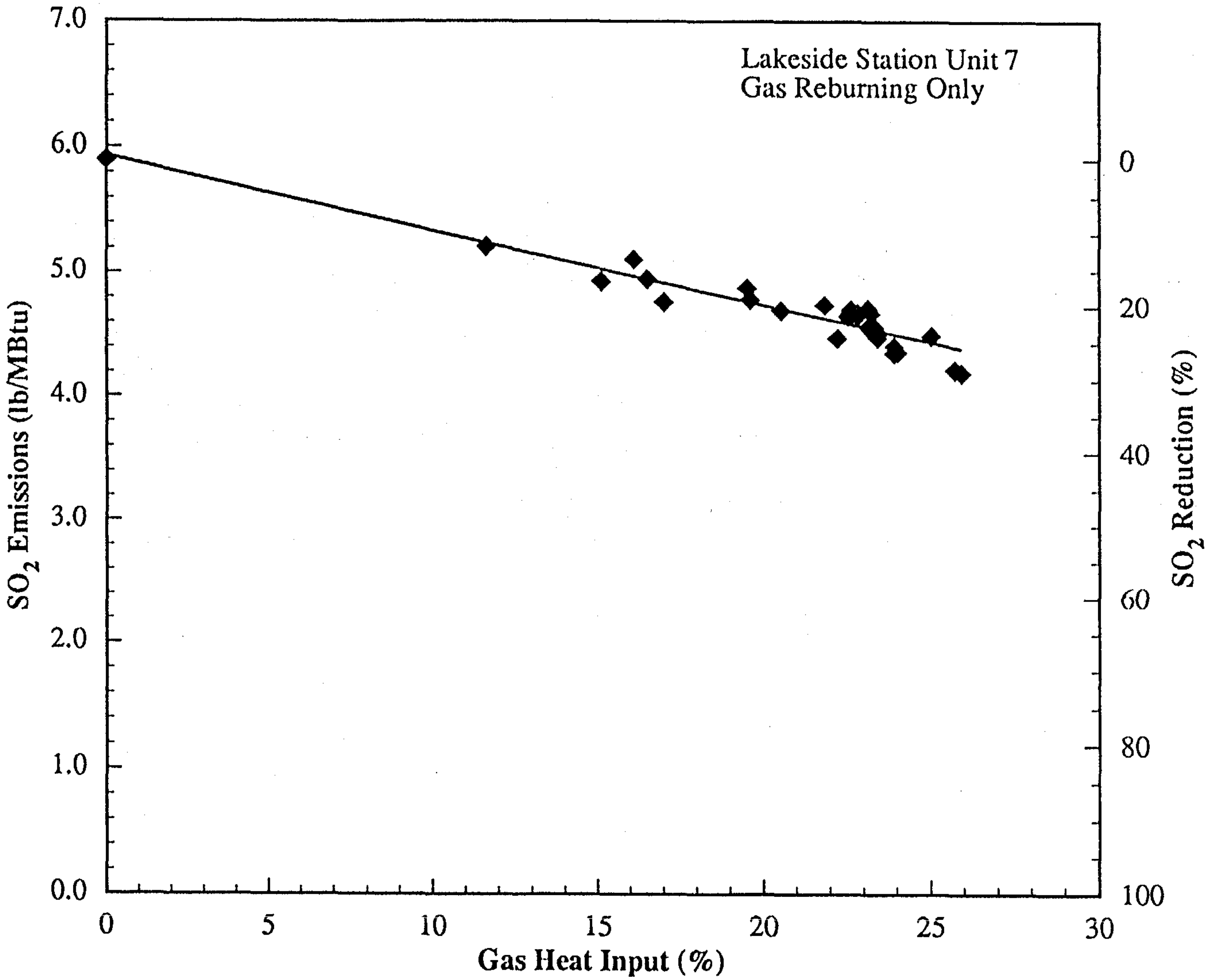

Figure 7-9. SO_2 emissions as a function of gas heat input (sorbent injection: off)

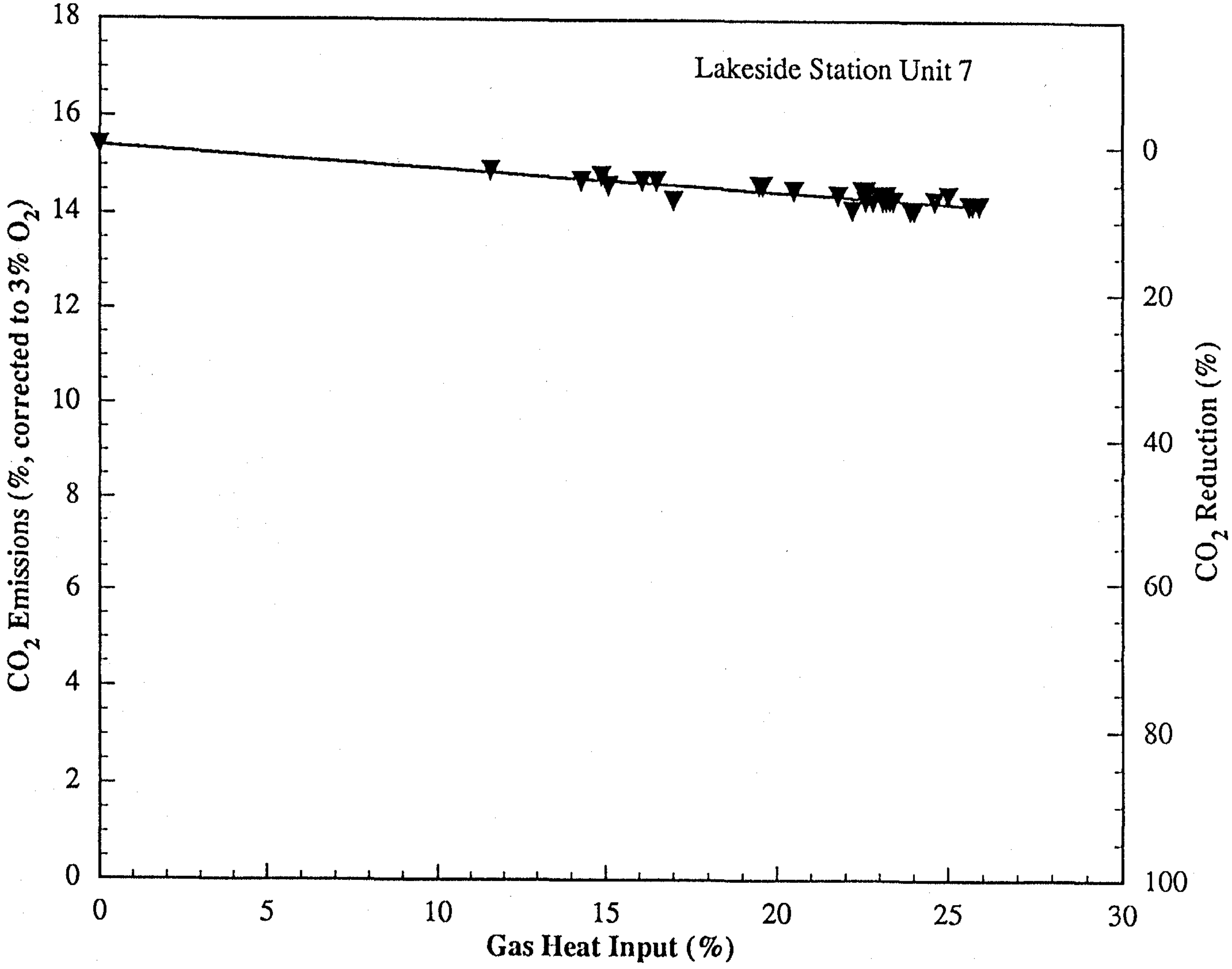

Figure 7-10. CO_2 emissions as a function of gas heat input

(0.85 to 2.17 Nm^3/s). Reductions in SO_2 were calculated from the 5.9 lb/10^6Btu (2540 mg/MJ) baseline.

7.3.1.1 Ca/S Molar Ratio

The SO_2 emissions/reductions under SI operation, for the range of load 19 to 34 MW_e, are shown in Figure 7-11. While succeeding figures differentiate data at different loads, on average the SO_2 reductions were 25% at a Ca/S of 1.1 and 42% at a Ca/S of 2.1. Figure 7-12 shows the SO_2 levels under GR-SI operation with gas heat inputs of 22 to 25%. On average, the SO_2 reductions were 51% at a Ca/S of 1.1 and 61% at a Ca/S of 2.1. In the majority of GR-SI cases with 22 to 25% gas heat input the design level of 50% SO_2 reduction, corresponding to 2.95 lb/10^6Btu (1270 mg/MJ), was achieved. The maximum SO_2 reduction measured under GR-SI was 68% at a Ca/S of 2.09 and gas heat input of 23%.

The injection temperature and indirectly the operating load had strong impacts on SO_2 reduction and calcium utilization. Figure 7-13 shows full load data for two operating conditions, SI-only and GR-SI, over a range of Ca/S molar ratio. While SI was evaluated with parametric tests over a wide range of Ca/S molar ratio, full load GR-SI operation was generally conducted with Ca/S in the 1.5 to 2.0 range. The data show that sorbent SO_2 capture was 4 to 6% higher when GR was applied with SI. GR resulted in an upward shift in the gas temperature at the sorbent injection planes, to a more suitable temperature for SO_2 capture. The corresponding Ca utilizations are shown in Figure 7-14. SI, with hydrated lime, generally results in a Ca utilization in the 20 to 30% range. That was the case in this application. On average, a 1.5 to 2.5% increase in Ca utilization resulted from GR-SI operation over levels for SI-only operation under full load. However, at reduced loads the impact of GR on the SO_2 capture process was more significant. Figure 7-15 shows calcium utilizations for Ca/S molar ratios of 1.9 to 2.2 over the load range. With GR-SI, calcium utilization increased by as much as 7% at 20 MW_e to 3% at 33 MW_e.

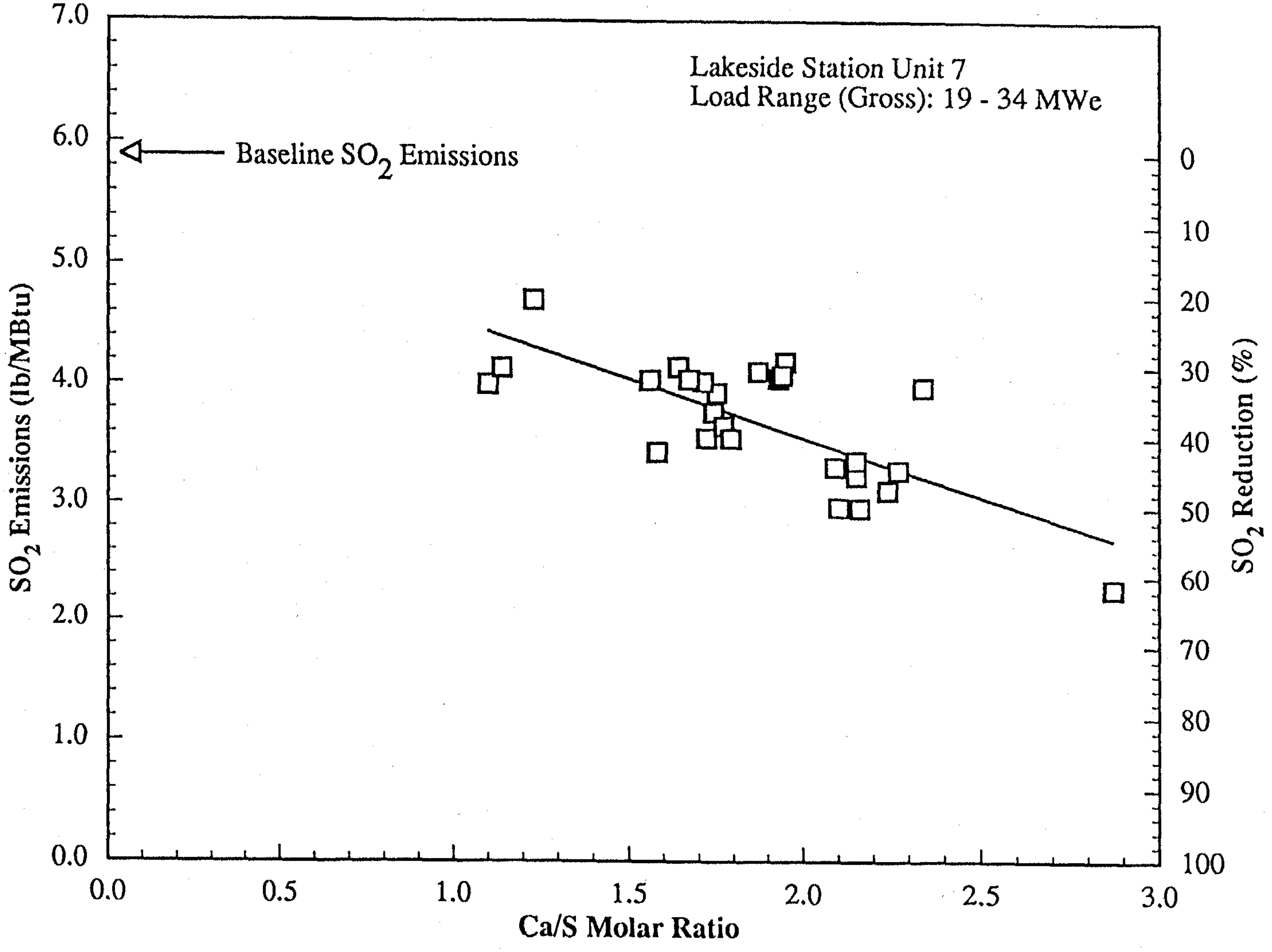

Figure 7-11. SO_2 emissions under SI-only operation

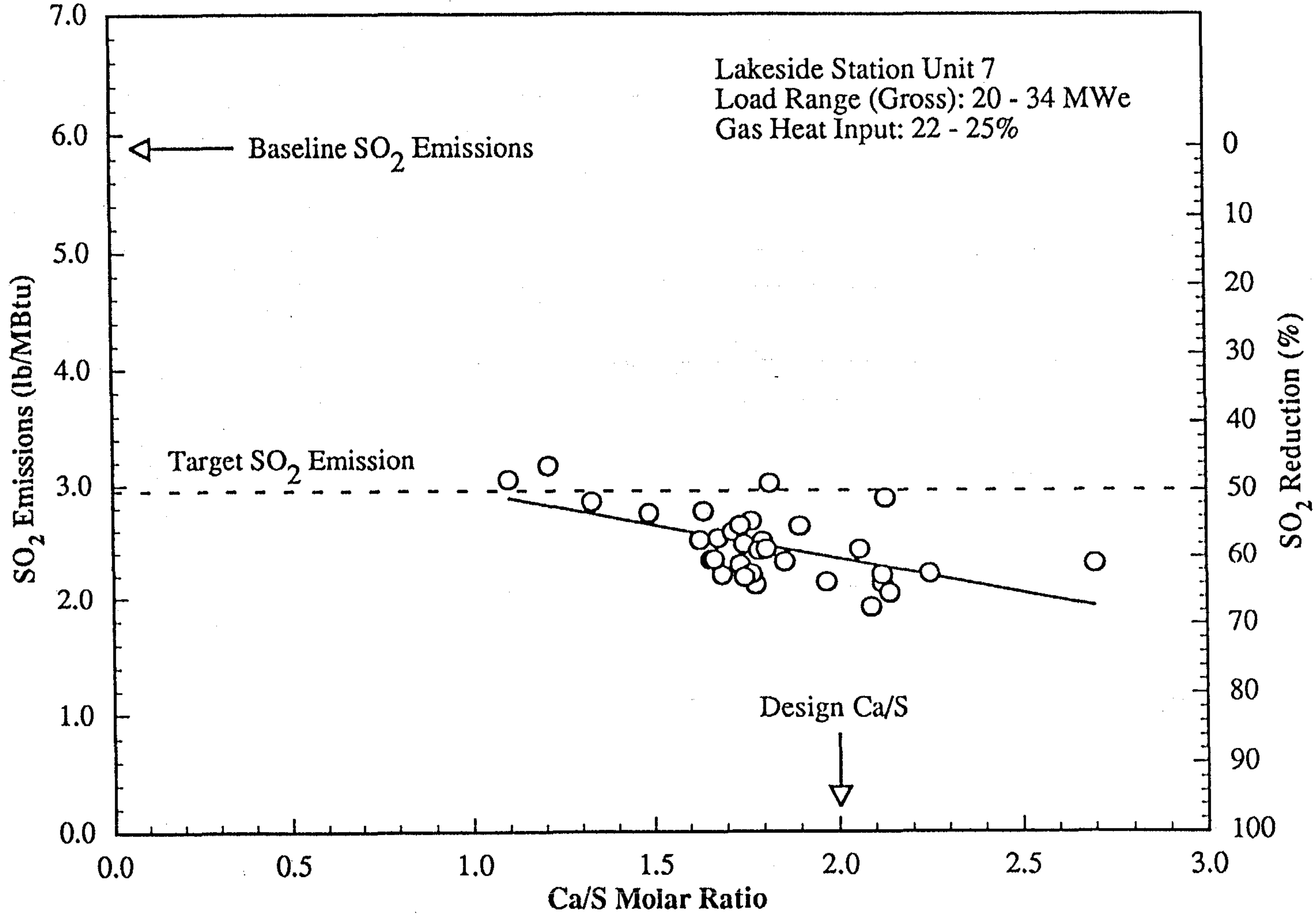

Figure 7-12. SO_2 emissions under GR-SI operation.

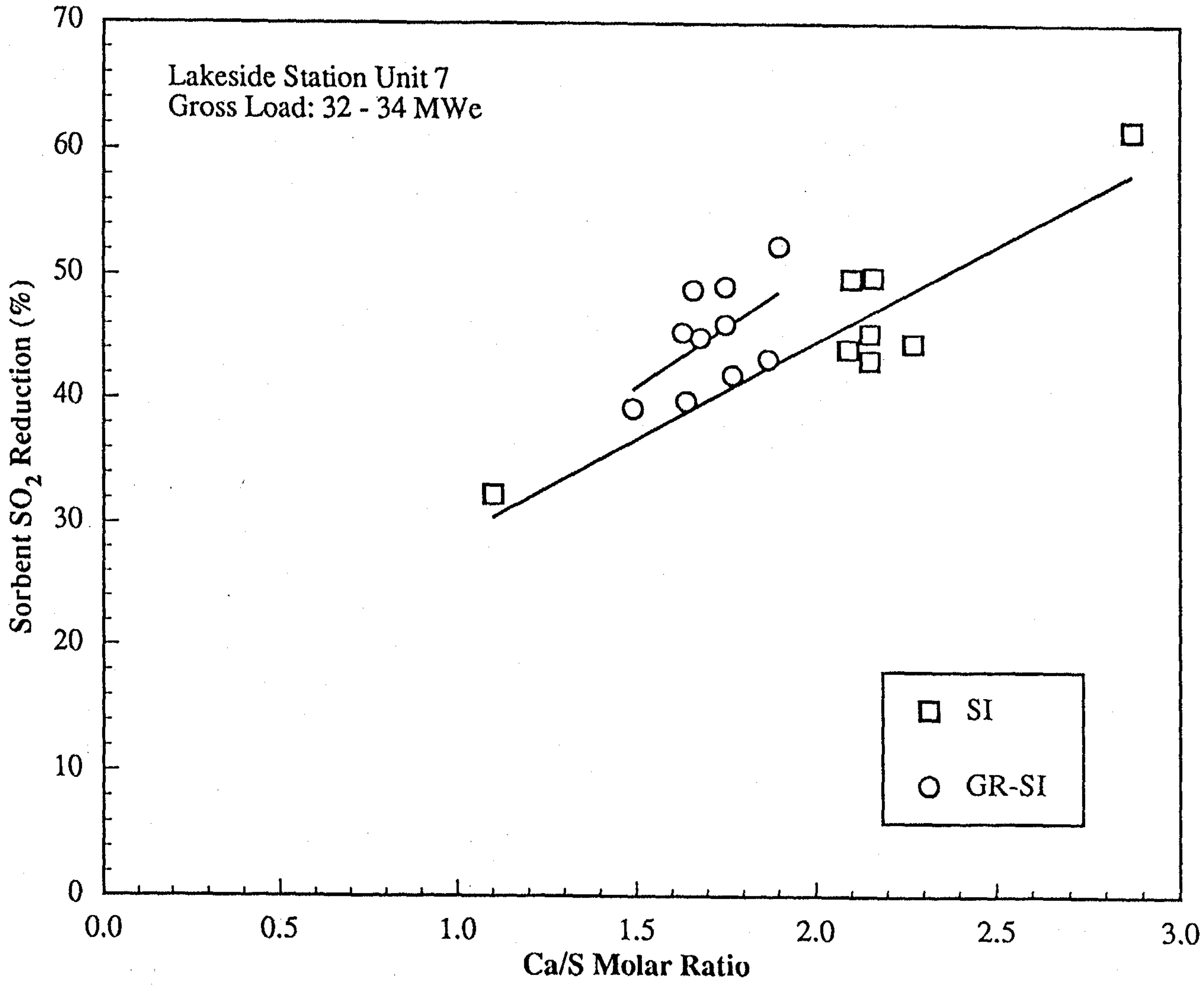

Figure 7-13. Reductions in SO_2 emissions due to sorbent capture.

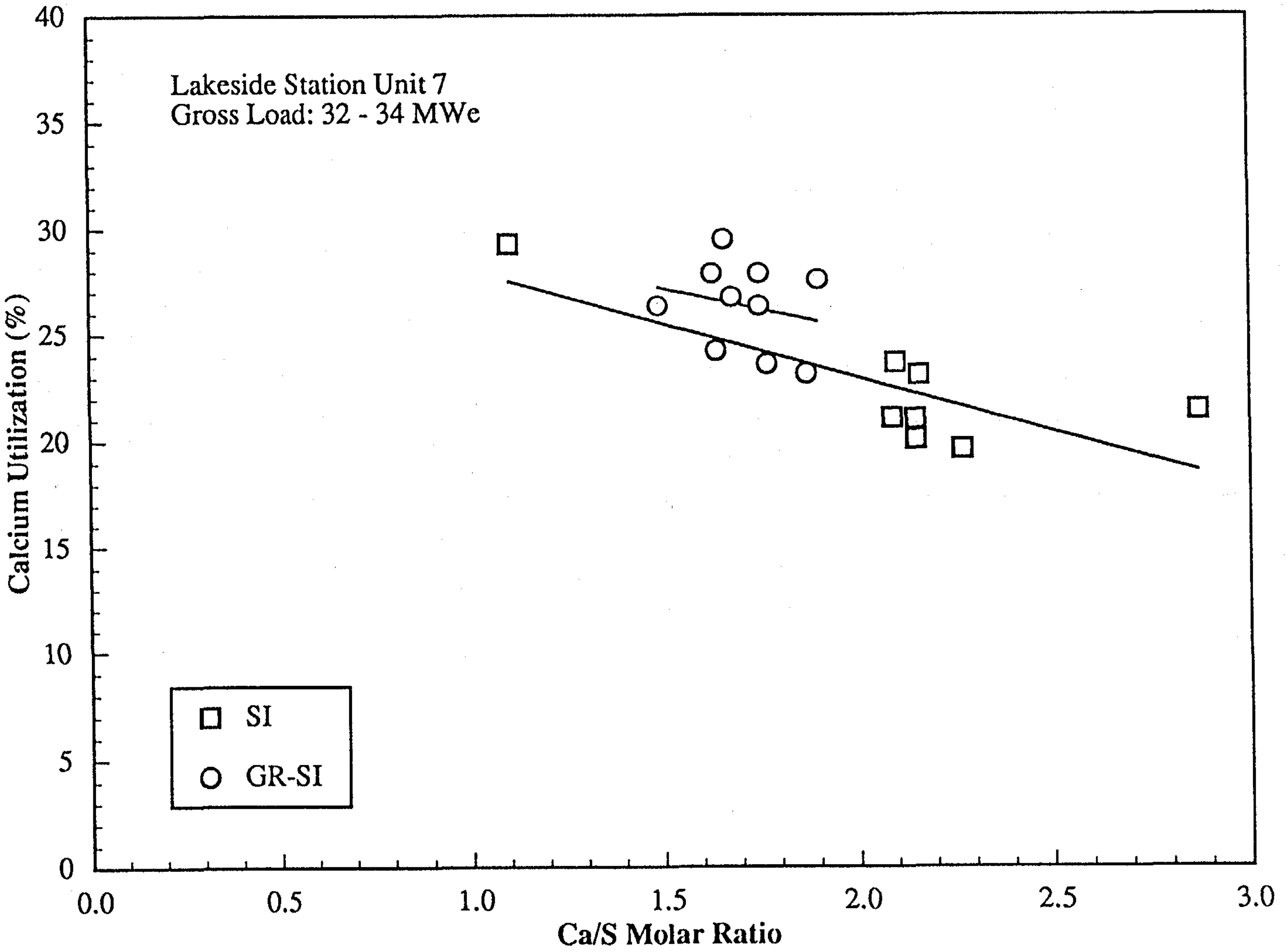

Figure 7-14. Calcium utilization as a function of Ca/S molar ratio.

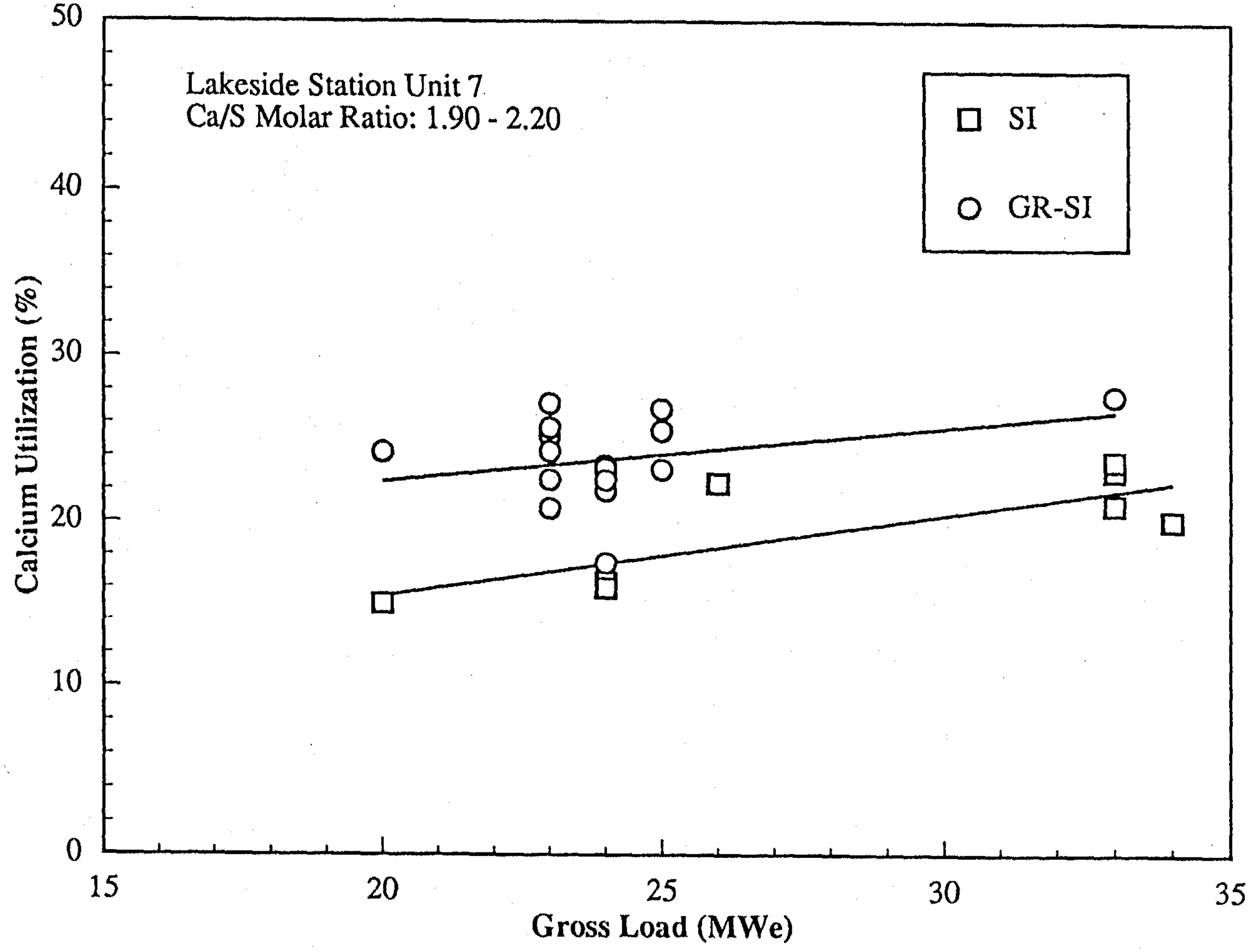

Figure 7-15. Calcium utilization as a function of electric load.

7.3.1.2 Sorbent Injection Air Flow

SI air was used to increase the mass flux of sorbent jets and thereby enhance mixing. Since the process is temperature dependent, rapid mixing with the flue gases at the exit of the furnace must take place, otherwise a loss in process efficiency results. Figure 7-16 shows SO_2 emissions under GR-SI and SI-only operation at full load, for a range of SI air flows. Modest reductions in SO_2 emissions were measured at high SI air flows. Under GR-SI, the SI air flow of 3700 scfm (1.75 Nm^3/s) was commonly used and optimum results were achieved with 4600 scfm (2.17 Nm^3/s).

7.4 GR-SI Long-Term Results

Data for long-term GR-SI demonstration were recorded from October 4, 1993 to June 3, 1994. This period includes scheduled months of relatively heavy use of the unit. Generally, GR and SI systems were both in operation; however, at times only GR was in operation.

7.4.1 NO_x and SO_2 Control

The NO_x and SO_2 reductions measured over this period are shown in Figure 7-17a and b. The target reductions of 60% for NO_x and 50% for SO_2 are also shown. Generally, gas heat inputs of 22 to 24% were used, which approximate the design level of 24%, and Ca/S was in the range of 1.5 to 1.9 at full load and 1.9 to 2.1 at reduced load. On average, the Ca/S during the long-term testing period was below the design level of 2.0. Over the long-term testing period, NO_x reduction averaged 63% and SO_2 reduction averaged 58%.

7.5 Impacts of GR, SI, and GR-SI on Boiler Thermal Performance

In this section the impacts of GR, SI, and GR-SI operation on boiler thermal performance are discussed. In steam generating units, the heat released from combustion of fuels must be absorbed by heat exchangers with high efficiency. These include the furnace waterwall, the

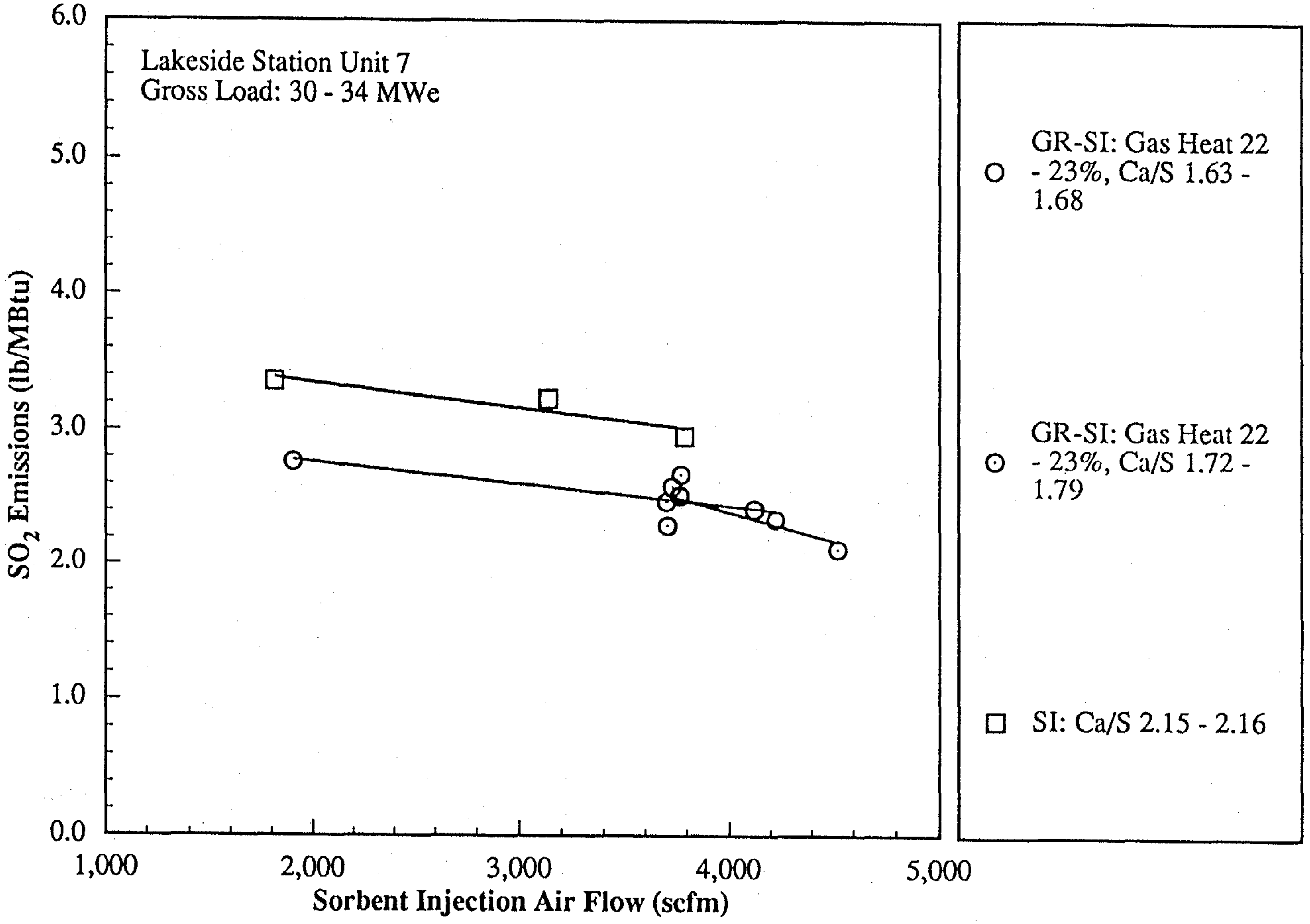

Figure 7-16. SO_2 emissions as a function of sorbent injection air flow

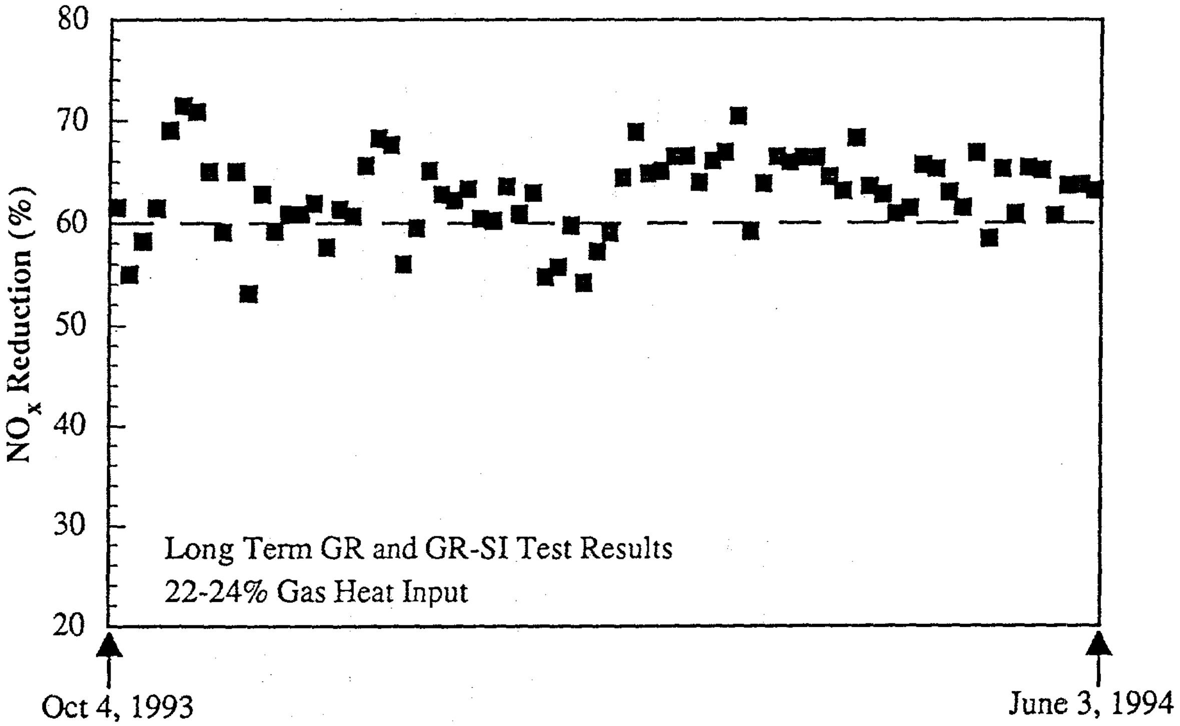

Figure 7-17a. Long-term operation results for NO_x reduction

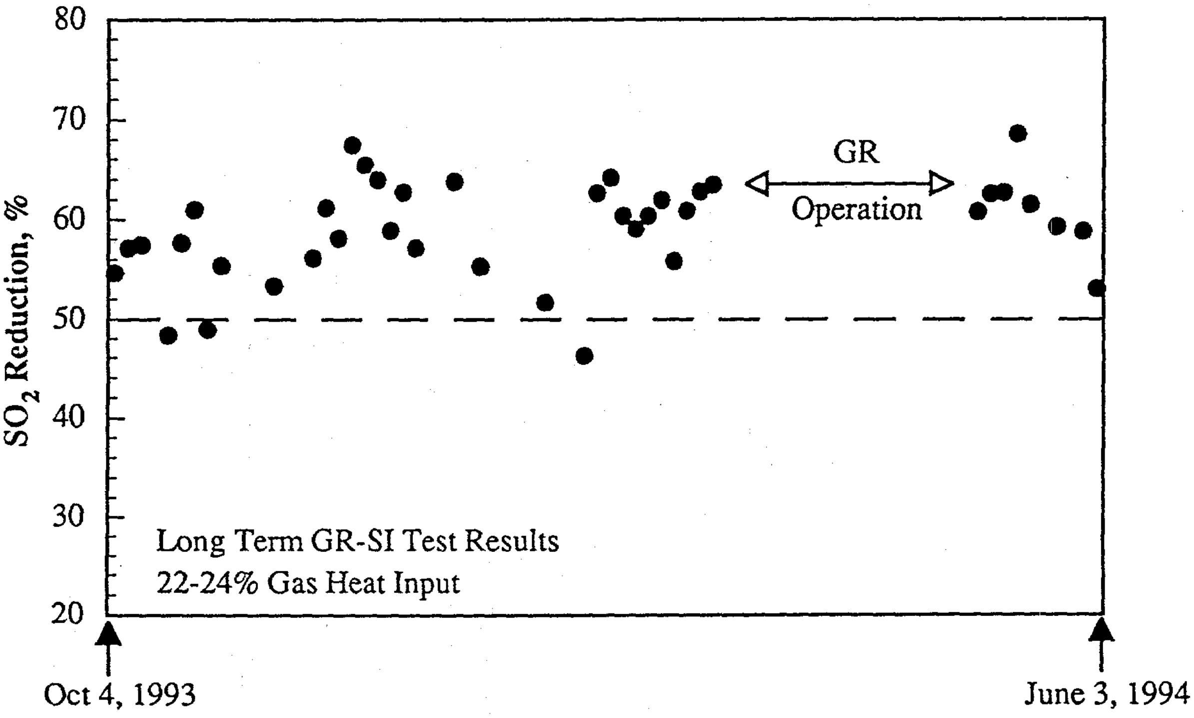

Figure 7-17b. Long-term operation results for SO_2 reduction.

secondary superheater, primary superheater, generating bank, and air heater. Lakeside Unit 7 is not equipped with either a reheat cycle or an economizer. The unit must generate steam at conditions (temperature and pressure) near to the design point to drive the steam turbine and generator. The design final steam conditions are a temperature of 910°F (488°C) and pressure of 875 psig (6030 kPa). Elevated steam temperature and pressure are preferred since they result in the lowest heat rate. The unit must operate with minimum deposition of ash on the furnace waterwall and convective heat exchangers.

The thermal performance of Lakeside Unit 7 under baseline, GR, SI, and GR-SI operation are summarized in Table 7-2 through 7-5. Averages of steam temperatures, gas temperatures, heat absorptions by each heat exchanger, Heat Absorption Ratios (HAR), and heat losses are presented for full (33 MW_e), mid (25 MW_e), and low (20 MW_e) loads. The HAR relate the quantity of heat absorbed to that absorbed under a specific baseline case. Under full load baseline operation the boiler was operated with an average O_2 level of 3.54%. The final steam temperature was 891°F (477°C) at a pressure of 881 psig (6074 kPa). The boiler bank gas outlet temperature was 674°F (357°C) and the air heater gas outlet temperature was 336°F (169°C). The attemperation heat absorption was 21 10^6Btu/hr (6.2 MW_t). The heat absorption ratios for the furnace, secondary superheater, primary superheater, and generating bank were 1.01, 0.95, 1.00, and 0.93, respectively. The boiler efficiency, calculated by the heat loss method, was 85.13%, with dry gas heat loss accounting for 5.95%, and moisture from combustion of H_2 in the fuel resulting in a 4.11% loss. Under GR at full load with 24% gas heat input the average boiler O_2 level was 4.02%. The final steam temperature under GR was 890°F (477°C) at a pressure of 882 psig (6081 kPa). The flue gas temperatures increased slightly over baseline to 677°F (358°C) at the boiler bank exit and 337°F (169°C) at the air heater exit. The steam attemperation rate rose slightly to 30 10^6Btu/hr (8.8 MW_t). The HAR for the furnace, secondary superheater, primary superheater and generating bank were 0.95, 1.05, 1.06, and 1.01, respectively. This reflects a shift in heat absorption with a reduction in the furnace and an increase by the convective heat absorbers. The boiler efficiency was reduced by less than 1%, to 84.20%. The change in efficiency resulted from a reduction in the heat loss from moisture in the fuel and an increase in heat loss due to moisture formed in combustion.

TABLE 7-2. THERMAL PERFORMANCE UNDER BASELINE WITH OFA STAGING

Gross Load (MWe)	20	25	33
Coal (Cyclone) Zone SR	1.16	1.15	1.18
Exit Zone SR	1.30	1.27	1.28
OFA (% of Combustion Air)	9.12	9.03	9.32
Boiler O2 (%, dry)	4.31	3.59	3.54
Secondary Superheater Outlet Temperature (°F)	895	892	891
Secondary Superheater Outlet Pressure (psig)	884	880	881
Primary Superheater Outlet Temperature (°F)	771	782	811
Drum Attemperator Outlet Temperature (°F)	723	712	701
Boiler Drum Pressure (psig)	897	906	934
Boiler Bank Gas Outlet Temperature (°F)	609	641	674
Air Heater Gas Outlet Temperature (°F)	304	322	336
Heat Absorption (MBtu/hr)			
Furnace	152	175	215
Secondary Superheater	20	26	36
Primary Superheater	37	47	67
Generating Bank	13	18	26
Attemperation	6	10	21
Air Heater	25	30	40
Heat Absorption Ratio			
Furnace	1.02	1.02	1.01
Secondary Superheater	0.97	0.96	0.95
Primary Superheater	0.98	0.97	1.00
Generating Bank	0.91	0.94	0.93
Drum Attemperator	0.86	0.86	0.98
Air Heater	1.16	1.10	1.07
Heat Loss (%)			
Dry Gas	5.21	5.67	5.95
Moisture In Fuel	1.93	1.94	1.95
Moisture From Combustion	4.06	4.09	4.11
Combustible Matter in Refuse	0.81	0.81	0.81
Radiation	0.87	0.72	0.55
Unmeasured	1.50	1.50	1.50
Total Losses (%)	14.38	14.73	14.87
Boiler Efficiency (%)	85.62	85.27	85.13

TABLE 7-3. THERMAL PERFORMANCE UNDER GAS REBURNING

Gross Load (MWe)	20	25	33
Gas Heat Input (%)	23	23	24
Coal (Cyclone) Zone SR	1.17	1.15	1.18
Reburning Zone SR	0.93	0.91	0.91
Exit Zone SR	1.34	1.30	1.29
Boiler O2 (%, dry)	4.63	4.33	4.02
Secondary Superheater Outlet Temperature (°F)	896	892	890
Secondary Superheater Outlet Pressure (psig)	881	881	882
Primary Superheater Outlet Temperature (°F)	785	812	837
Drum Attemperator Outlet Temperature (°F)	725	699	682
Boiler Drum Pressure (psig)	893	906	941
Boiler Bank Gas Outlet Temperature (°F)	620	645	677
Air Heater Gas Outlet Temperature (°F)	308	326	337
Heat Absorption (MBtu/hr)			
Furnace	146	168	204
Secondary Superheater	19	27	40
Primary Superheater	38	50	72
Generating Bank	16	20	29
Attemperation	7	16	30
Air Heater	24	27	42
Heat Absorption Ratio			
Furnace	0.99	1.00	0.95
Secondary Superheater	0.97	1.03	1.05
Primary Superheater	1.03	1.06	1.06
Generating Bank	1.20	1.13	1.01
Drum Attemperator	1.14	1.40	1.36
Air Heater	1.17	1.07	1.11
Heat Loss (%)			
Dry Gas	5.48	5.76	5.91
Moisture In Fuel	1.48	1.49	1.48
Moisture From Combustion	5.62	5.68	5.76
Combustible Matter in Refuse	0.62	0.62	0.61
Radiation	0.91	0.75	0.54
Unmeasured	1.50	1.50	1.50
Total Losses (%)	15.61	15.80	15.80
Boiler Efficiency (%)	84.39	84.20	84.20

TABLE 7-4. THERMAL PERFORMANCE UNDER SORBENT INJECTION

Gross Load (MWe)	20	25	33
Ca/S Molar Ratio	2.2	1.8	2.1
Coal (Cyclone) Zone SR	1.15	1.15	1.15
Exit Zone SR	1.36	1.26	1.29
Boiler O2 (%, dry)	5.74	5.01	4.06
Secondary Superheater Outlet Temperature (°F)	881	889	897
Secondary Superheater Outlet Pressure (psig)	884	881	885
Primary Superheater Outlet Temperature (°F)	753	815	801
Drum Attemperator Outlet Temperature (°F)	724	687	706
Boiler Drum Pressure (psig)	895	903	936
Boiler Bank Gas Outlet Temperature (°F)	661	658	741
Air Heater Gas Outlet Temperature (°F)	347	363	396
Heat Absorption (MBtu/hr)			
Furnace	152	181	224
Secondary Superheater	18	28	36
Primary Superheater	34	50	66
Generating Bank	13	17	22
Attemperation	4	18	19
Air Heater	26	30	44
Heat Absorption Ratio			
Furnace	1.02	1.07	1.04
Secondary Superheater	0.90	1.09	0.95
Primary Superheater	0.93	1.07	0.97
Generating Bank	0.97	0.94	0.77
Drum Attemperator	0.54	1.55	0.84
Air Heater	1.25	1.19	1.17
Heat Loss (%)			
Dry Gas	6.71	6.66	7.52
Moisture In Fuel	1.96	1.97	1.99
Moisture From Combustion	4.13	4.16	4.21
Combustible Matter in Refuse	0.81	0.81	0.81
Radiation	0.90	0.77	0.54
Unmeasured	1.50	1.50	1.50
Total Losses (%)	16.01	15.87	16.57
Boiler Efficiency (%)	83.99	84.13	83.43

TABLE 7-5. THERMAL PERFORMANCE UNDER GAS REBURNING-SORBENT INJECTION

Gross Load (MWe)	20	25	33
Gas Heat Input (%)	23	22	21
Ca/S Molar Ratio	2.1	1.6	1.7
Coal (Cyclone) Zone SR	1.16	1.15	1.15
Reburning Zone SR	0.93	0.92	0.92
Exit Zone SR	1.42	1.33	1.31
Boiler O2 (%, dry)	5.67	4.63	3.79
Secondary Superheater Outlet Temperature (°F)	885	890	894
Secondary Superheater Outlet Pressure (psig)	881	881	881
Primary Superheater Outlet Temperature (°F)	799	815	833
Drum Attemperator Outlet Temperature (°F)	702	684	682
Boiler Drum Pressure (psig)	891	905	929
Boiler Bank Gas Outlet Temperature (°F)	655	673	686
Air Heater Gas Outlet Temperature (°F)	351	361	343
Heat Absorption (MBtu/hr)			
Furnace	154	172	212
Secondary Superheater	21	29	39
Primary Superheater	40	51	68
Generating Bank	14	18	26
Attemperation	12	19	28
Air Heater	25	29	38
Heat Absorption Ratio			
Furnace	1.03	1.00	1.04
Secondary Superheater	1.06	1.10	1.09
Primary Superheater	1.08	1.06	1.06
Generating Bank	1.05	0.95	1.04
Drum Attemperator	1.81	1.59	1.41
Air Heater	1.31	1.12	1.12
Heat Loss (%)			
Dry Gas	6.85	6.67	5.96
Moisture In Fuel	1.52	1.54	1.52
Moisture From Combustion	5.67	5.65	5.65
Combustible Matter in Refuse	0.62	0.63	0.62
Radiation	0.99	0.76	0.60
Unmeasured	1.50	1.50	1.50
Total Losses (%)	17.15	16.75	15.85
Boiler Efficiency (%)	82.85	83.25	84.15

A higher flue gas moisture content results from firing natural gas which has a higher hydrogen-to-carbon ratio than coal.

Under SI at full load and at a Ca/S molar ratio of 2.1, the unit was operated at a boiler O_2 of 4.06%. Under this condition the average final steam temperature was 897°F (481°C) at a pressure of 885 psig (6102 kPa). The temperature is higher than under either of the previous two cases, which is likely due to operating at a higher control-room set-point. Flue gas temperatures increased to 741°F (394°C) at the exit of the boiler bank and to 396°F (202°C) at the air heater exit. The attemperation heat absorption was 19 10^6Btu/hr (5.6 MW_t). The HAR of the furnace, secondary superheater, primary superheater, and boiler bank were 1.04, 0.95, 0.97, and 0.77, respectively. These reflect an increase in heat absorbed by the furnace and reductions in convective heat absorption due to sorbent fouling, especially in the generating bank. The IK sootblowers were used almost continuously in order to maintain steam temperatures near the design point and limit upward excursions of flue gas temperature. The boiler efficiency was 83.43%, with the dry gas heat loss increasing to 7.52% of the heat input due to the rise in boiler exit gas temperature.

At full load, GR-SI operation was tested at an average gas heat input of 21%, Ca/S molar ratio of 1.7, and a boiler O_2 level of 3.79%. The final steam conditions were a temperature of 894°F (479°C) and a pressure of 881 psig (6074 kPa). The gas temperature increase was not as significant as in the SI case, with a boiler bank exit temperature of 686°F (363°C) and an air heater gas exit temperature of 343°F (173°C). The heat absorbed by the drum attemperator averaged 28 10^6Btu/hr (8.2 MW_t). The HAR of the furnace, secondary superheater, primary superheater, and generating bank were 1.04, 1.09, 1.06 and 1.04, respectively. This indicates that sootblowing was effective in maintaining cleanliness of the convective heat exchangers with enhanced heat transfer. The boiler efficiency was 1% less than the baseline case, at 84.15% on average. While the dry gas heat loss was essentially at the baseline level, the loss due to moisture in fuel dropped by 0.43% and the moisture from combustion of H_2 in the fuel increased by 1.54%.

The impacts of the three operating modes are compared to baseline impacts in Figures 7-18 through 7-29. Figures 7-18 through 7-21 show full load impacts, while Figures 7-22 through 7-25 considers mid load (25 MW_e) impacts, and 7-26 through 7-29 show low load (20 MW_e) impacts. Figure 7-18 shows that at full load, GR and GR-SI resulted in roughly a 1% decrease in boiler efficiency, while SI resulted in a 1.7% reduction due mainly to a significant increase in boiler exit gas temperature. The impacts on final steam conditions were minor, as shown in Figure 7-19. GR and GR-SI resulted in relatively small increases in steam attemperation rates, and corresponding reductions in the drum attemperator outlet temperature. These modes also resulted in increases in the steam temperature exiting the primary superheater, due to the upward shift in the gas temperatures. Minor changes in the heat absorptions by the heat exchangers were measured, with GR resulting in a reduction in furnace heat absorption and an increase in convective pass absorption, while SI resulted in the opposite, an increase in furnace heat absorption and reduction in convective pass absorption. Figure 7-12 shows that the gas temperature at the exit of the air heater was most significantly increased by SI at a Ca/S of 2.1, while the impacts of GR and GR-SI (at a Ca/S of 1.7) were very minor.

Figure 7-22 shows the boiler efficiencies and O_2 levels at mid load. GR and SI resulted in efficiency reductions of 1.1 and 1.2%, respectively, while GR-SI resulted in a 2.0% reduction from the baseline. At mid load, the final steam conditions did not change significantly. However, as shown in Figure 7-23, increases in the steam temperature from the primary superheater and attemperation rate were measured for GR, SI, and GR-SI. Changes in heat absorption profiles were very minor, with GR resulting in a reduction in furnace heat absorption and SI resulting in an increase. Under SI and GR-SI, the gas temperature at the air heater exit increased by approximately 40°F (22°C), from a baseline of 322°F (161°C) to 363°F (184°C) and 361°F (183°C), respectively.

The thermal performance impacts at low load (20 MW_e) are shown in Figures 7-26 through 7-29. The thermal efficiency dropped more sharply in the higher load cases, due to more significant increases in boiler O_2 level under SI and GR-SI. The baseline efficiency of 85.62% was reduced to 84.39% under GR, 83.99% under SI, and to 82.85% under GR-SI. The baseline

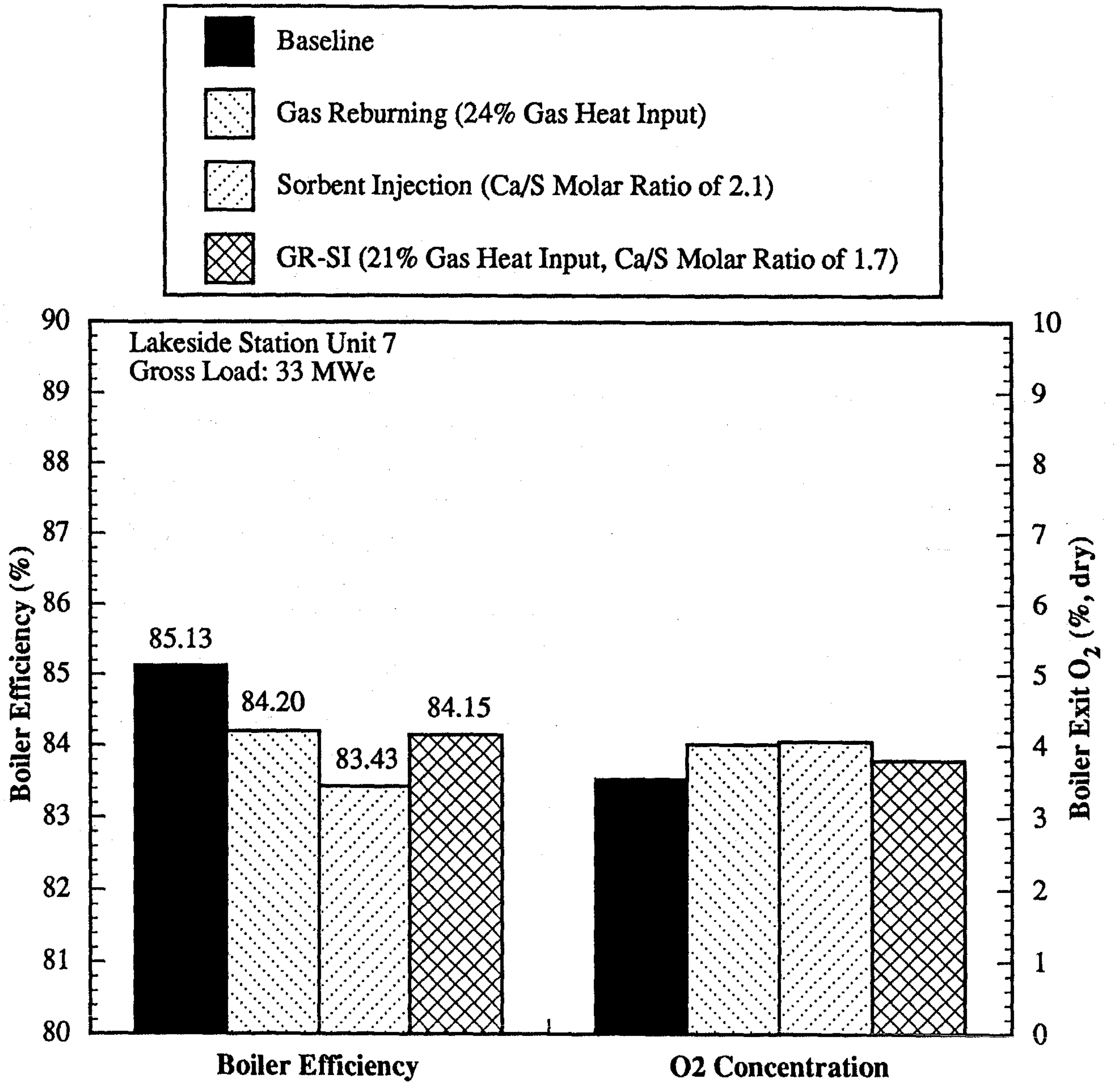

Figure 7-18. Boiler efficiency under full load Baseline, GR, SI, and GR-SI

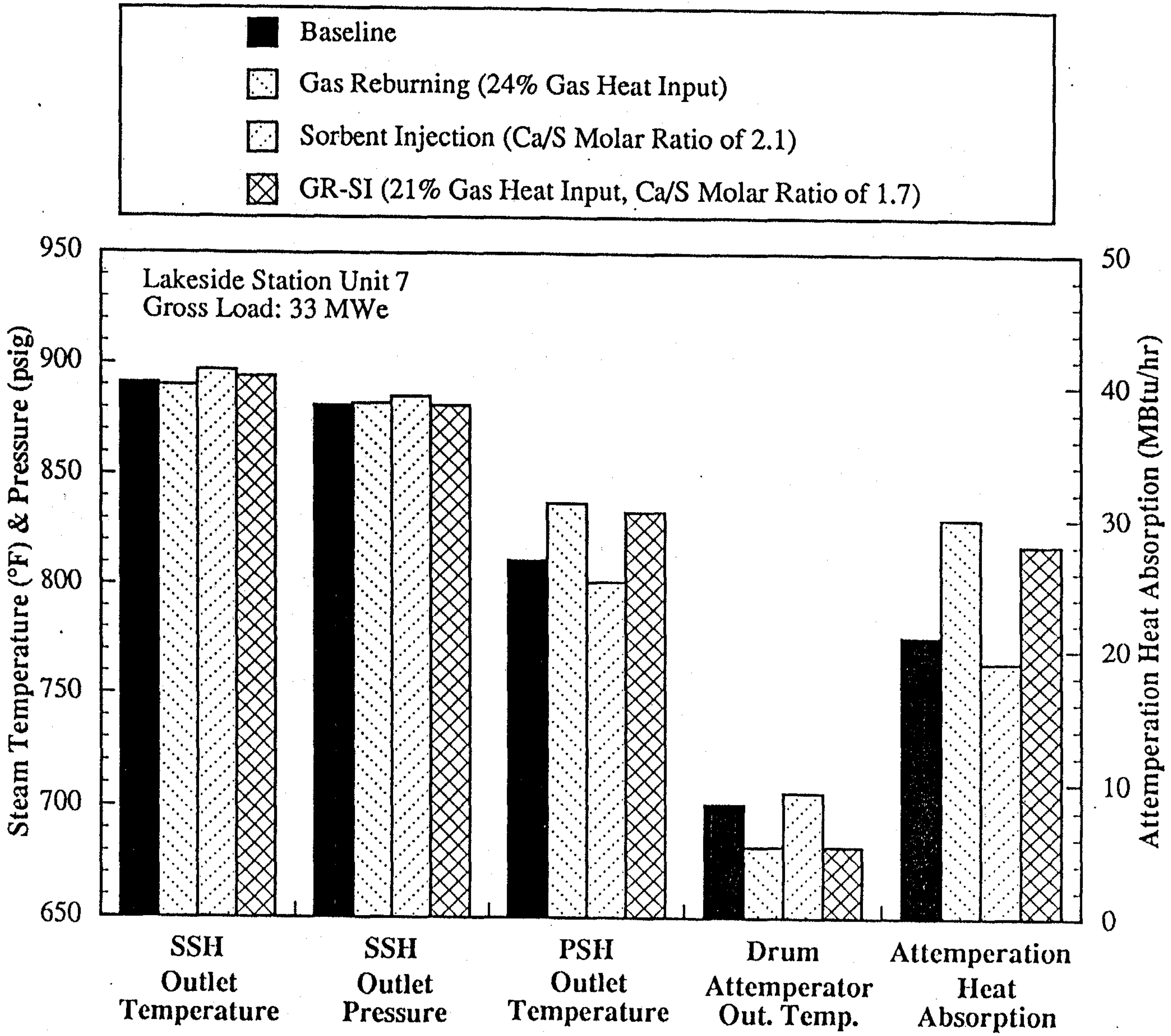

Figure 7-19. Steam conditions under full load Baseline, GR, SI, and GR-SI

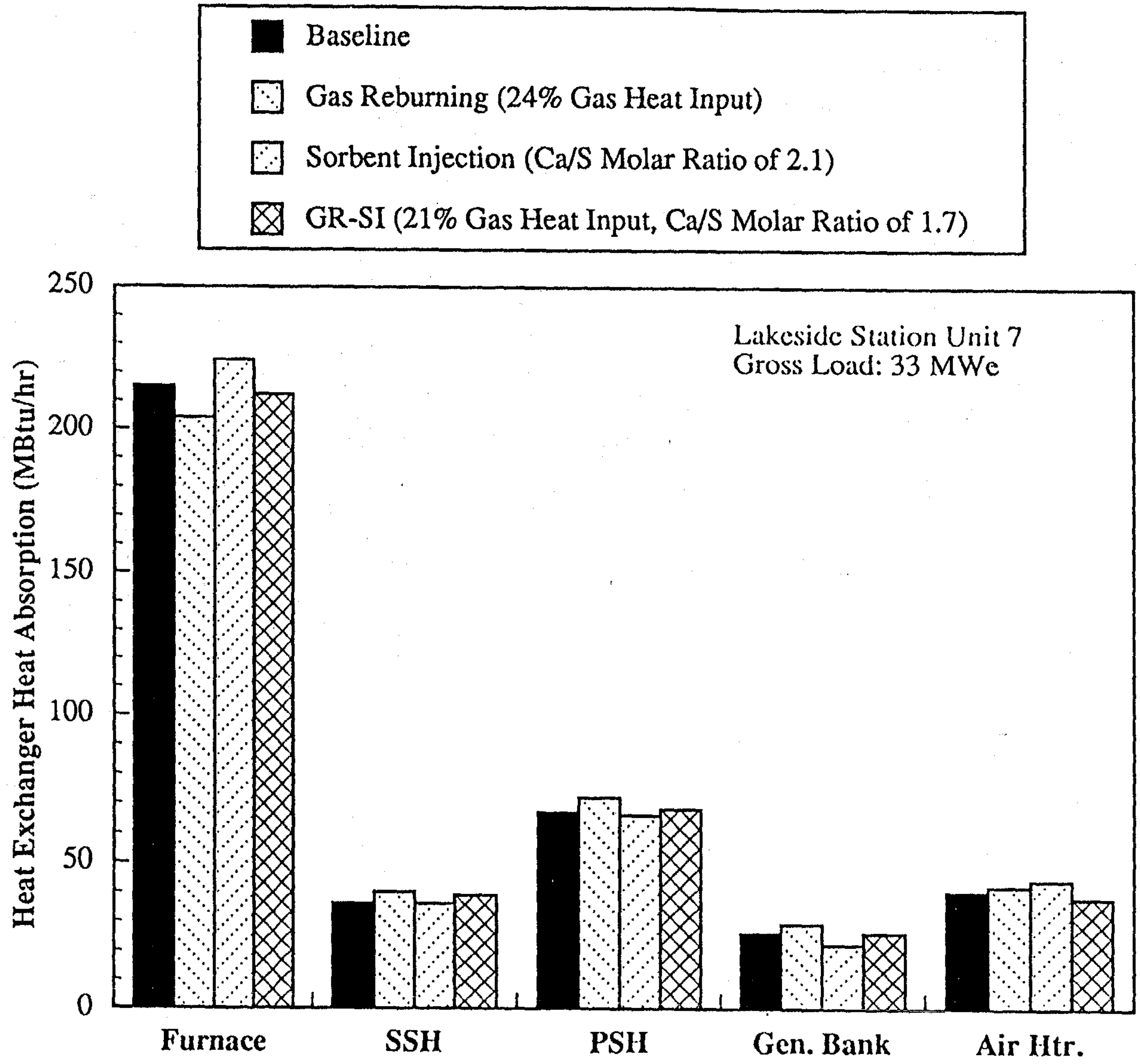

Figure 7-20. Heat absorption profiles under full load Baseline, GR, SI, and GR-SI

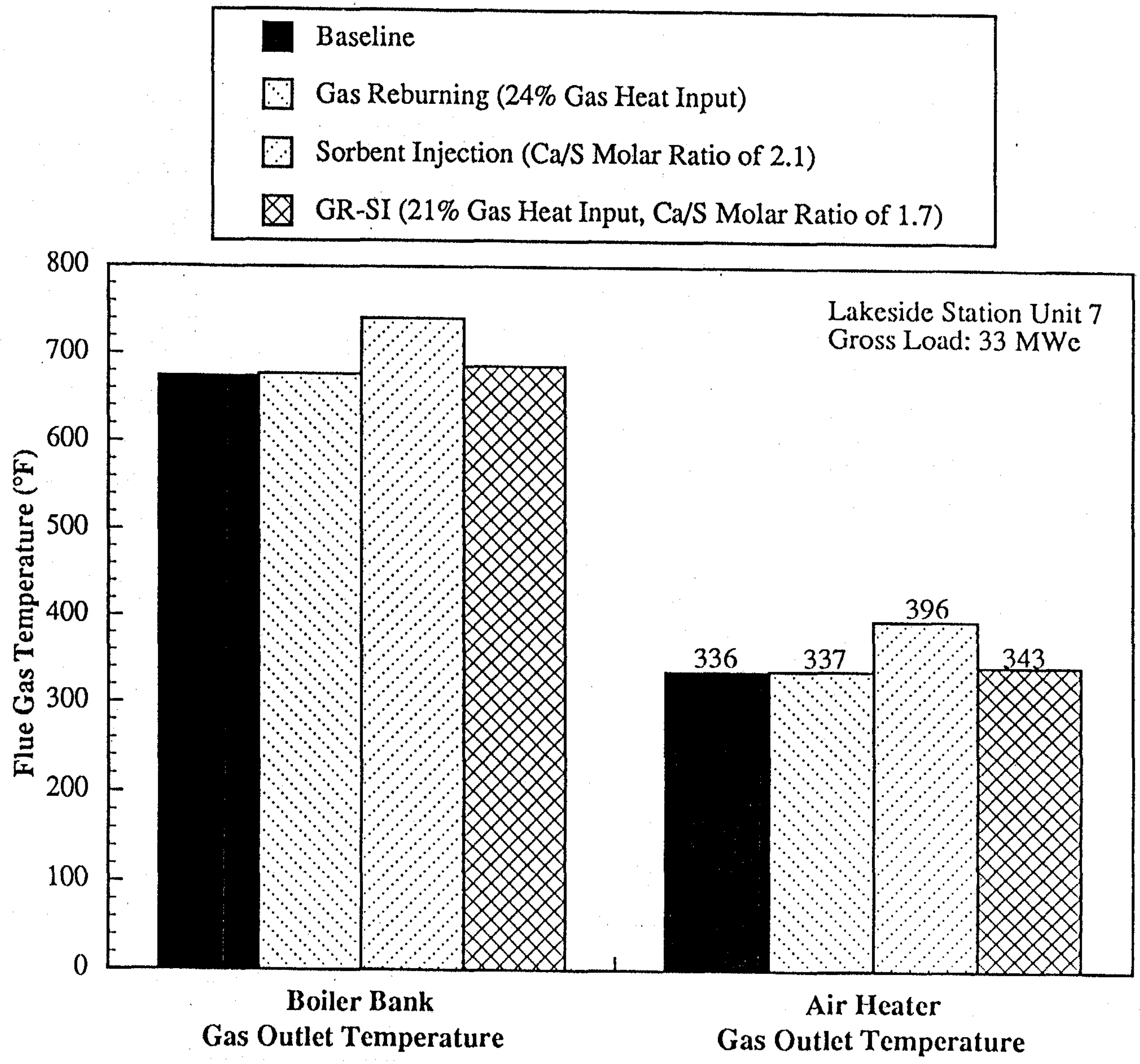

Figure 7-21. Flue gas temperatures under full load Baseline, GR, SI, and GR-SI

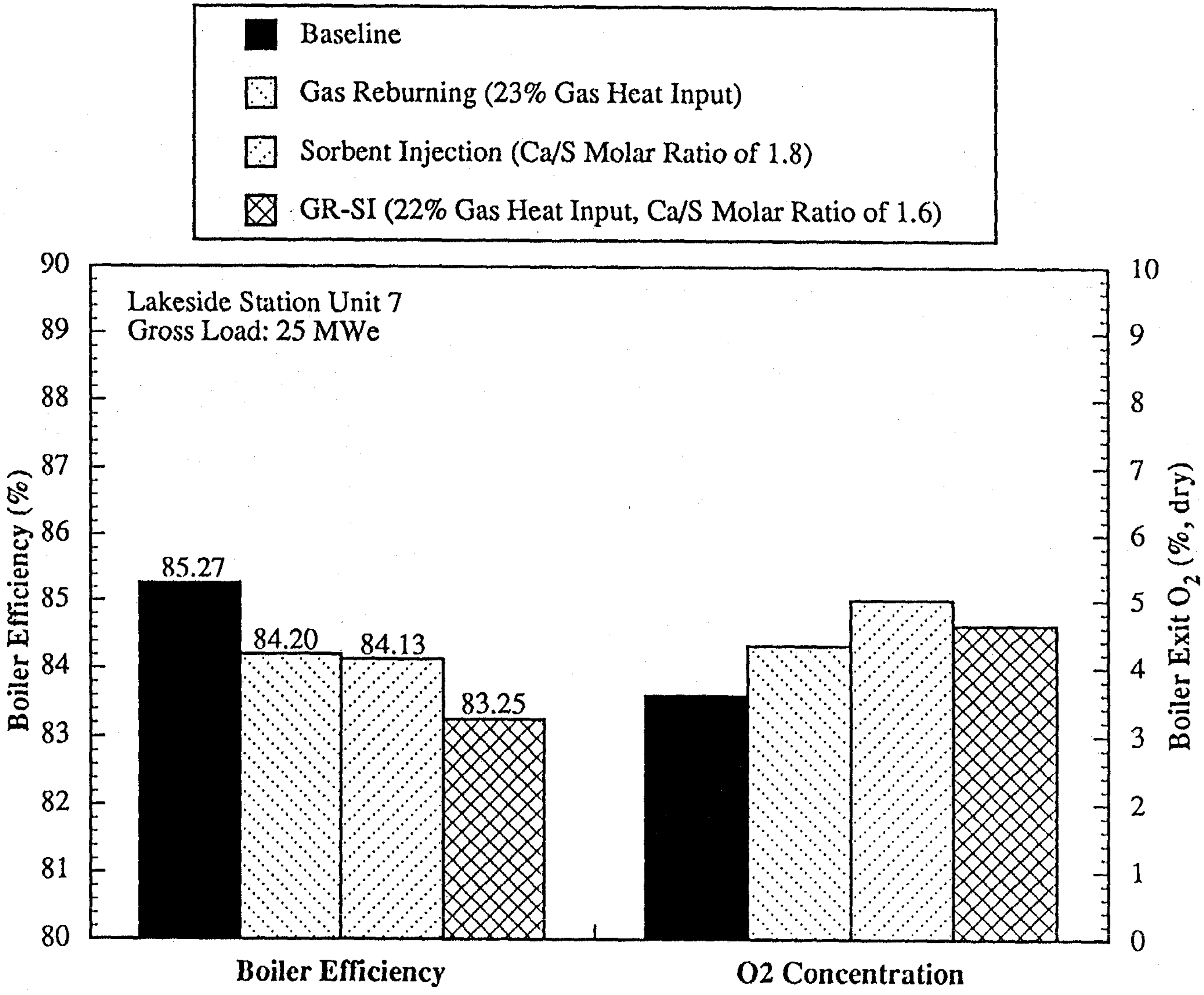

Figure 7-22. Boiler efficiency under mid load Baseline, GR, SI, and GR-SI

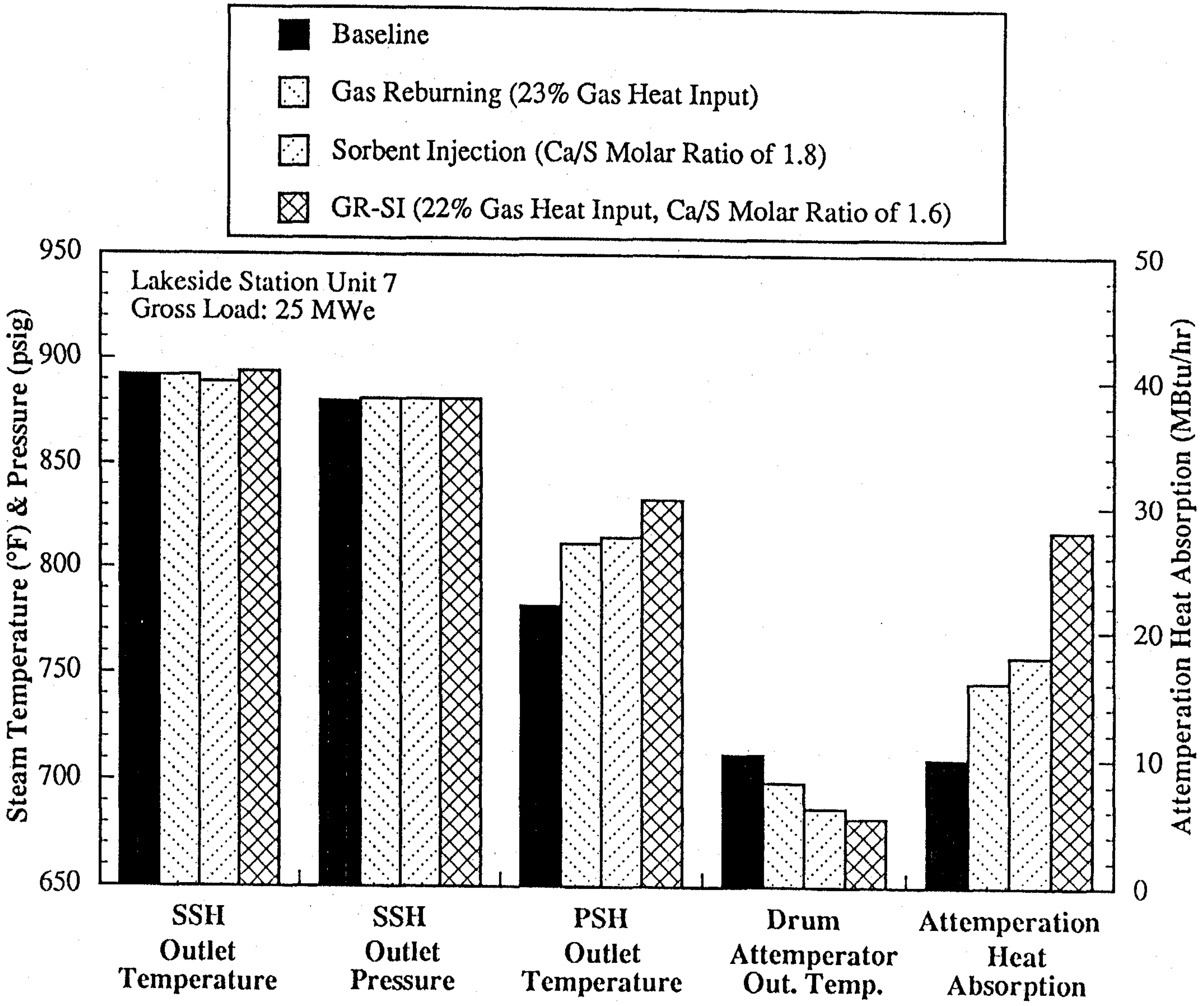

Figure 7-23. Steam conditions under mid load Baseline, GR, SI, and GR-SI

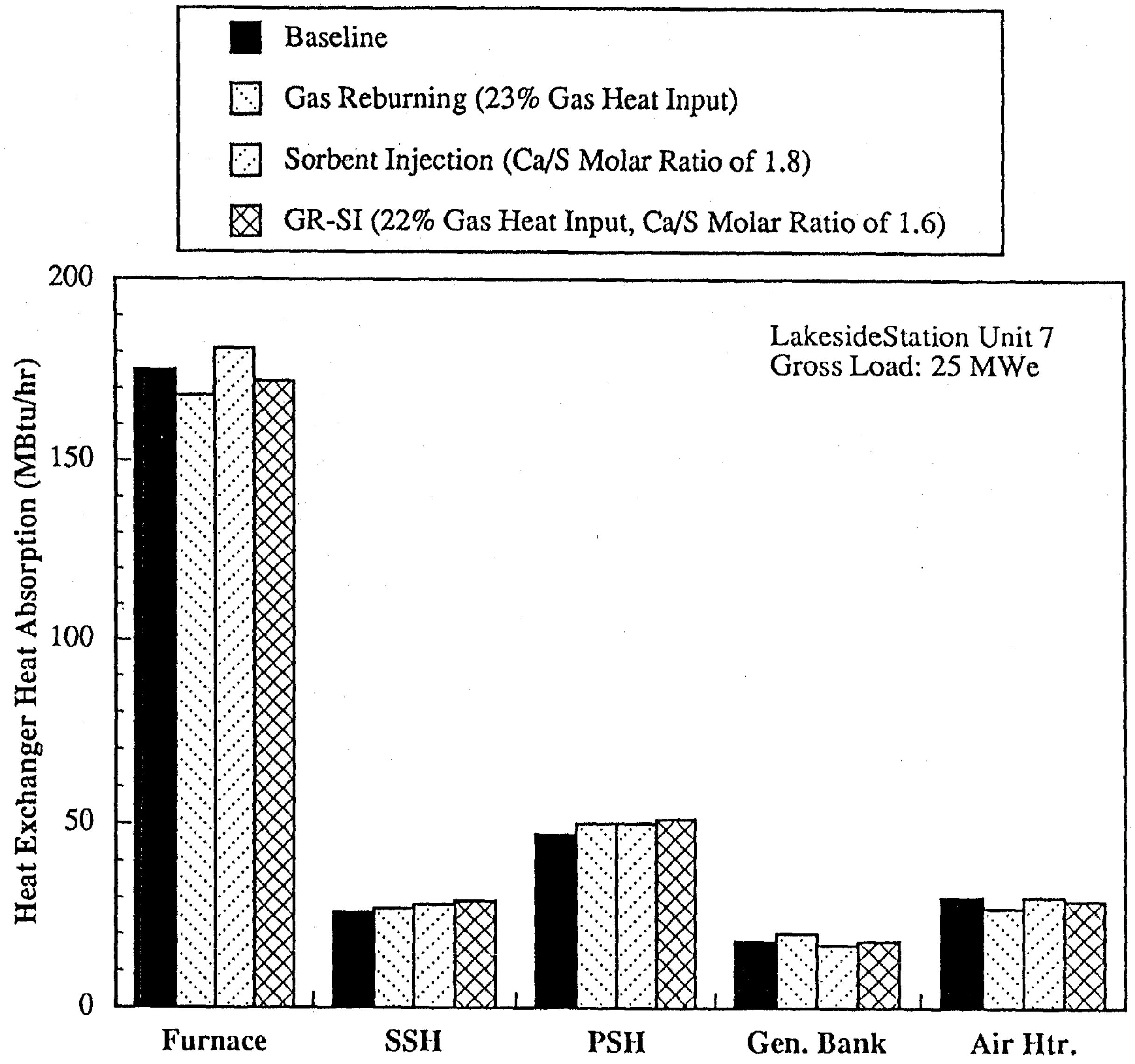

Figure 7-24. Heat absorption profiles under mid load Baseline, GR, SI, and GR-SI

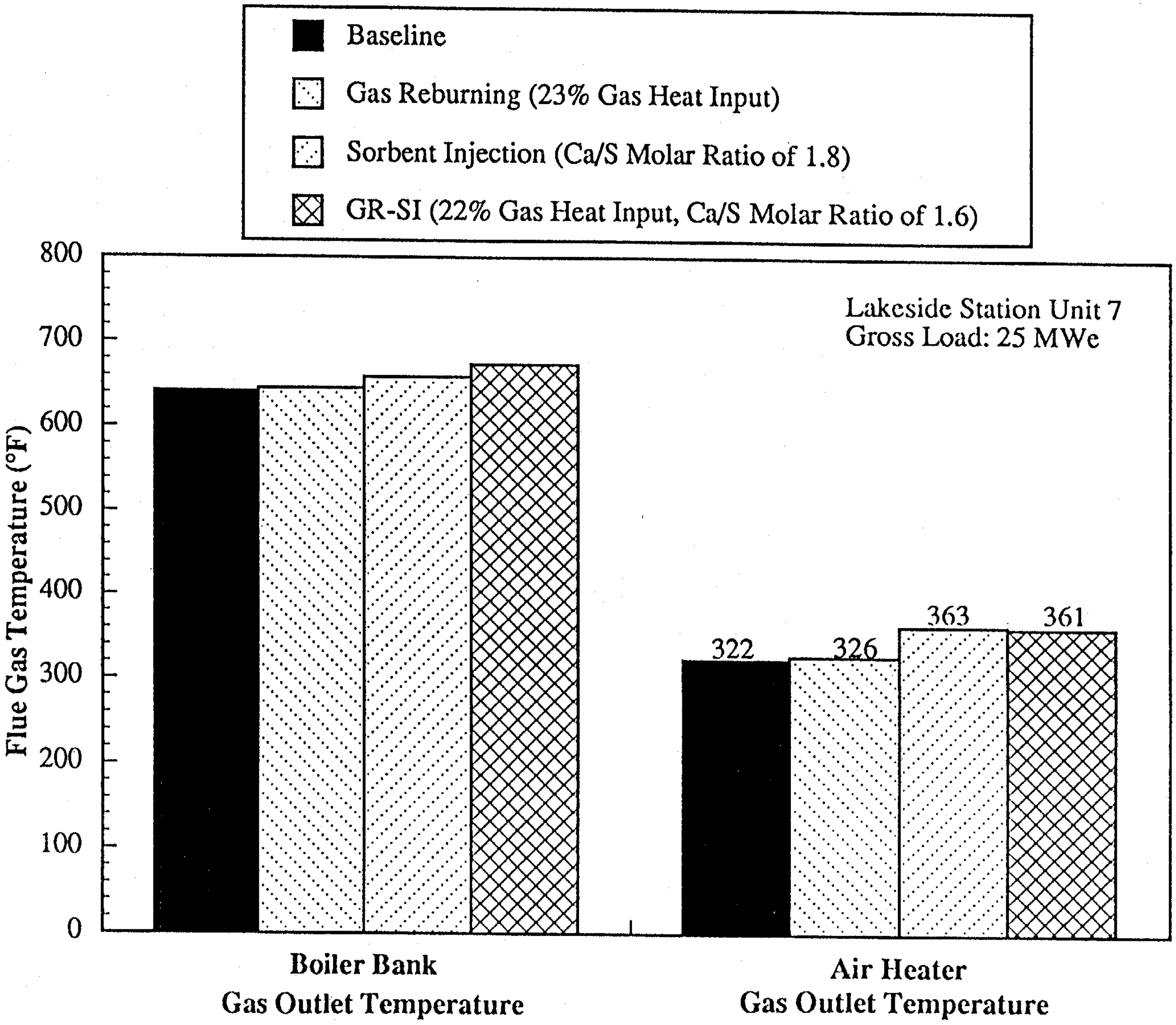

Figure 7-25. Flue gas temperatures under mid load Baseline, GR, SI, and GR-SI

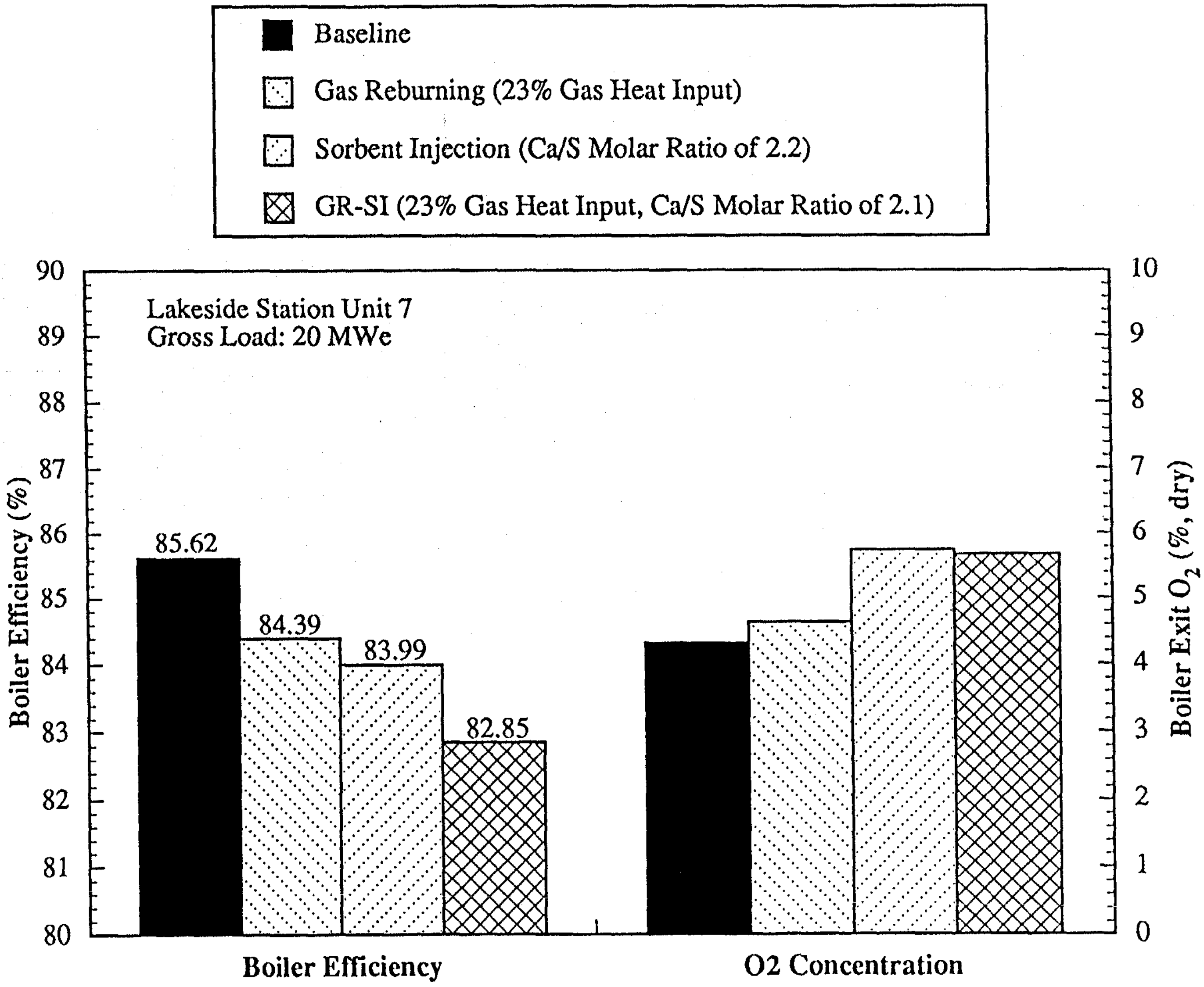

Figure 7-26. Boiler efficiency under low load Baseline, GR, SI, and GR-SI

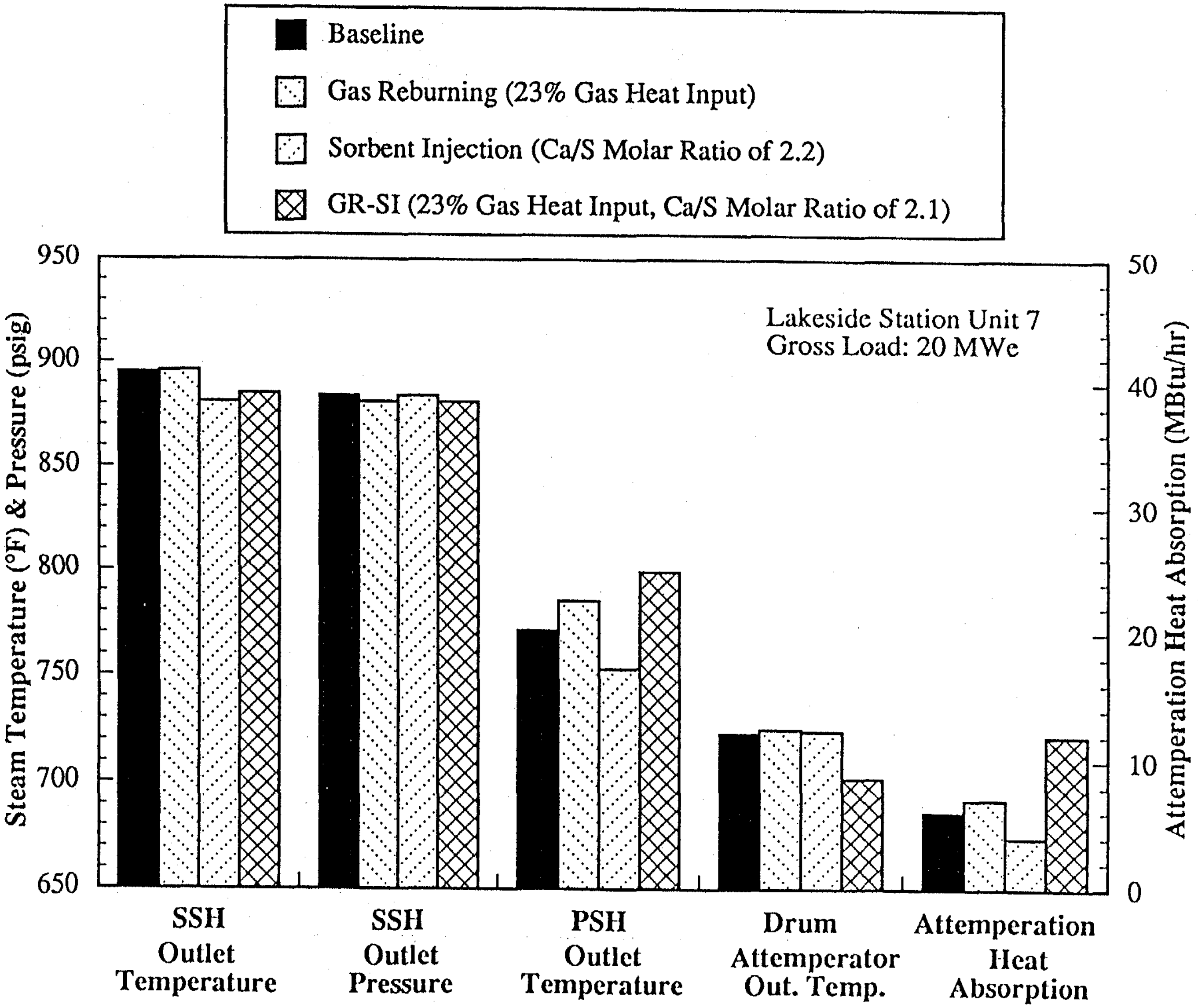

Figure 7-27. Steam conditions under low load Baseline, GR, SI, and GR-SI

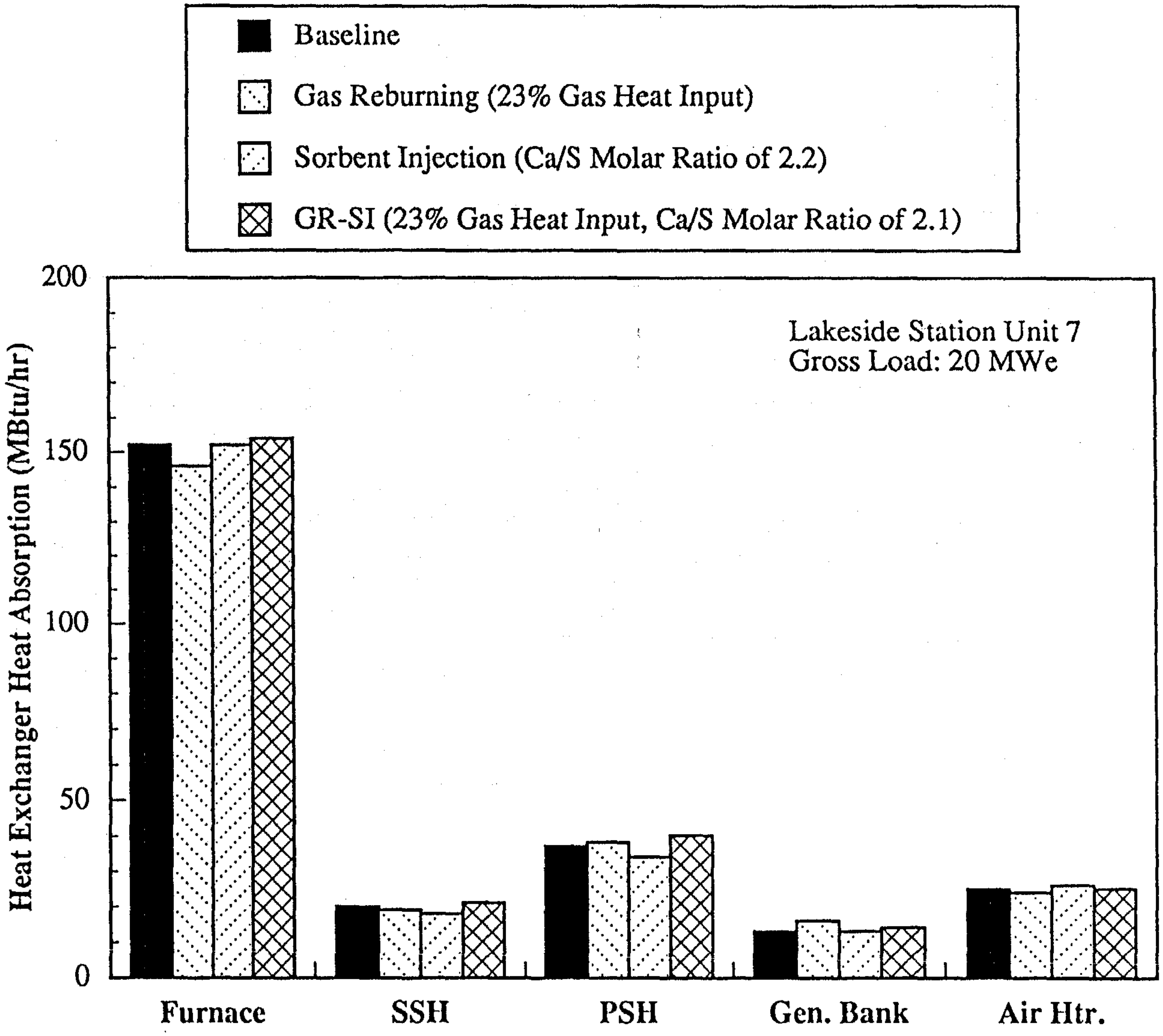

Figure 7-28. Heat absorption profiles under low load Baseline, GR, SI, and GR-SI

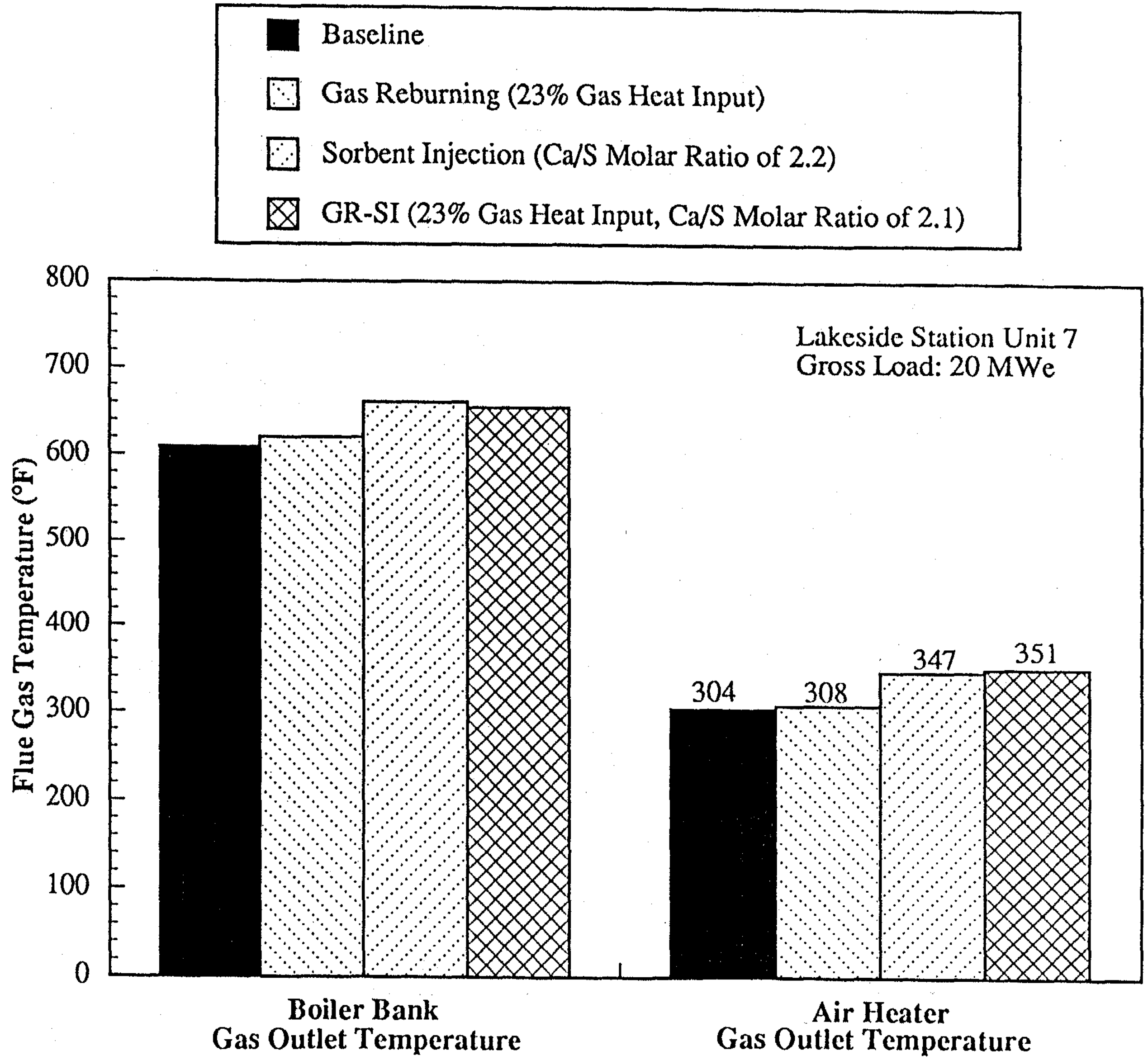

Figure 7-29. Flue gas temperatures under low load Baseline, GR, SI, and GR-SI

boiler O$_2$ concentration of 4.31% increased to 4.63% under GR, 5.74% under SI, and 5.67% under GR-SI. Final steam temperatures were higher under baseline and GR, at 895°F (479°C) and 896°F (480°C), respectively, compared to 881°F (472°C) and 885°F (474°C), under SI and GR-SI, respectively. Steam attemperation rates were low at this load, with a maximum at 12 10^6Btu/hr (3.5 MW$_t$) under GR-SI. This indicates that higher steam temperature could have been achieved under this condition by adjustment of steam temperature controls. The gas temperature exiting the air heater increased when injecting sorbent, from a baseline to 304°F (151°C) to 347°F (175°C) under SI and 351°F (177°C) under GR-SI.

Limited evaluation of fly ash combustible matter was undertaken during the test program. In cyclone-fired units, roughly 20% of the ash input to the unit is converted to fly ash, with the majority of the ash tapped through the slag tap. Therefore, the combustible matter in ash corresponds to a much smaller heat loss than in pulverized coal-fired units. The fly ash combustible matter content for baseline and GR operation are shown in Figure 7-30 for three loads. The baseline data, obtained during the 1991 baseline test, indicated a range of 2% to 8%. Under GR, the fly ash carbon content increased from 12 to 14% over the range of gas heat inputs of 15 to 25%. At full load, GR had a smaller effect, with fly ash carbon content increasing from 7 to 10%. While in pulverized coal-fired units an increase of 5% in carbon-in-fly ash results in a 1% increase in heat loss, for cyclone-fired units an increase of 20% in carbon-in-fly ash results in a 1% increase in heat loss.

7.6 Impacts of GR, SI, and GR-SI on Other Areas of Boiler Operation

In this section the impacts of the co-application of GR and SI on boiler performance areas other than heat transfer efficiency are discussed. These include furnace slagging, convective pass fouling, and ESP performance.

In order to assess the impact of gas GR-SI on the boiler, a series of inspections were performed both prior to and following the GR-SI testing. EER established the baseline condition of the unit and determined the existence and rate of both degradation and equipment failures. The

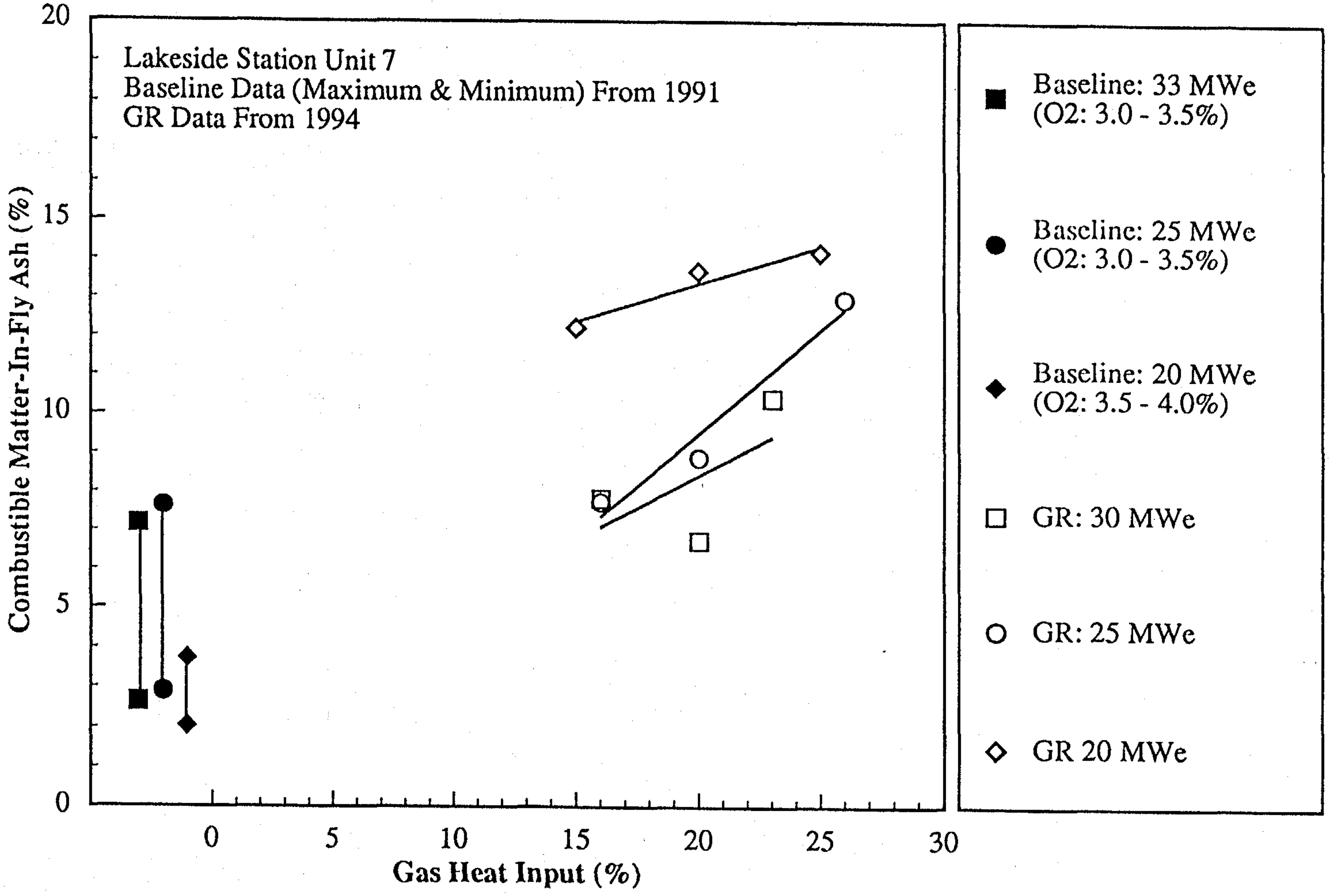

Figure 7-30. Comparison of combustible matter-in-fly ash under Baseline and GR

following areas were evaluated:

- Boiler tubes
- Regenerative air heater
- Electrostatic precipitator
- Chimney
- Boiler performance

These areas are discussed in detail in the GRSI Boiler Impact Report located in Appendix 1.

7.6.1 Slagging

Slagging in the furnace was evaluated by visual inspection of furnace conditions. In coal-fired units, buildup of slag on furnace walls is generally dependent on coal qualities such as ash fusion temperatures and boiler operating parameters such as stoichiometric ratio (excess air), gas temperature profile, and furnace wall temperatures. In the design of units, slag buildup is minimized by requiring high furnace volume, limiting heat input per plan area, and limiting the FEGT. Since ash fusion temperatures are lower under reducing conditions, areas in the furnace which are deficient in excess air may have increased slag buildup. In cyclone-fired units a slagging type coal is used, i.e. with low ash fusion temperature, in order to tap molten slag through the bottom of the furnace. Typically, only 20% of the ash input to cyclone-fired units forms fly ash; the majority of the ash is removed through the slag tap.

It was found through observation that the injection of natural gas and FGR promoted formation of slag patterns, i.e. there were slag accumulations around the nozzles forming "eyebrows" and on the waterwall areas above the natural gas/FGR injectors. Slag deposits were observed up to the rear section of the furnace wing walls. The sloped front wall and the upper furnace were generally free of slag, with the exception of the lower portion of the east front wall division panel.

A cleaning feature was incorporated in the GR system design, which allowed for the nozzles to be rodded out as needed to remove slag deposits on the nozzle periphery. At the beginning of each test day, the accumulations and the necessity for rodding out were assessed. Usually small amounts of slag deposits were removed weekly. The small natural gas only injectors, which were not in use during the long-term demonstration, were found to be completely obstructed.

7.6.2 Convective Pass Fouling

Fouling of the convective pass due to GR-SI was quantified through heat absorption ratios (HAR) calculated by the BPMS. The HARs are not direct indicators of the extent of fouling since they do not take into account temperature changes which drive heat transfer. HAR for the secondary superheater, primary superheater, and generating bank for a GR-SI test, conducted on April 6, 1994, are shown in Figure 7-31. The data presented in this figure were calculated every five minutes over the test period. In this test, GR operation was initiated at 10:15 AM, while SI was initiated at 11:15 AM. It is evident that the increased upper furnace gas temperature due to reburning fuel heat input above the coal cyclones and the nearly continuous sootblowing used during SI operation resulted in enhanced heat absorption by the secondary and primary superheaters. For these heat exchangers the HAR's were consistently above 1.0. The generating bank HAR was, however, below 1.0 in many cases. Figure 7-32 shows the flue gas temperatures at the inlet and exit of the boiler bank and at the exit of the air heater. As is evident in this figure, initiation of SI resulted in upward shifts in gas temperatures at these locations. The temperature shifts of 30°F (17°C) to 40°F (22°C) are near to those quoted earlier for mid load GR-SI operation. Under SI, IK sootblowers were in operation between 80 to 90% of the time.

7.6.3 ESP Performance

The performance of the ESP was determined through particulate sampling according to U.S. EPA Method 5 while the unit was under full load GR-SI operation. The sampling data are summarized in Table 7-6. The average particulate emissions were 0.016 lb/10^6Btu (6.9 mg/MJ),

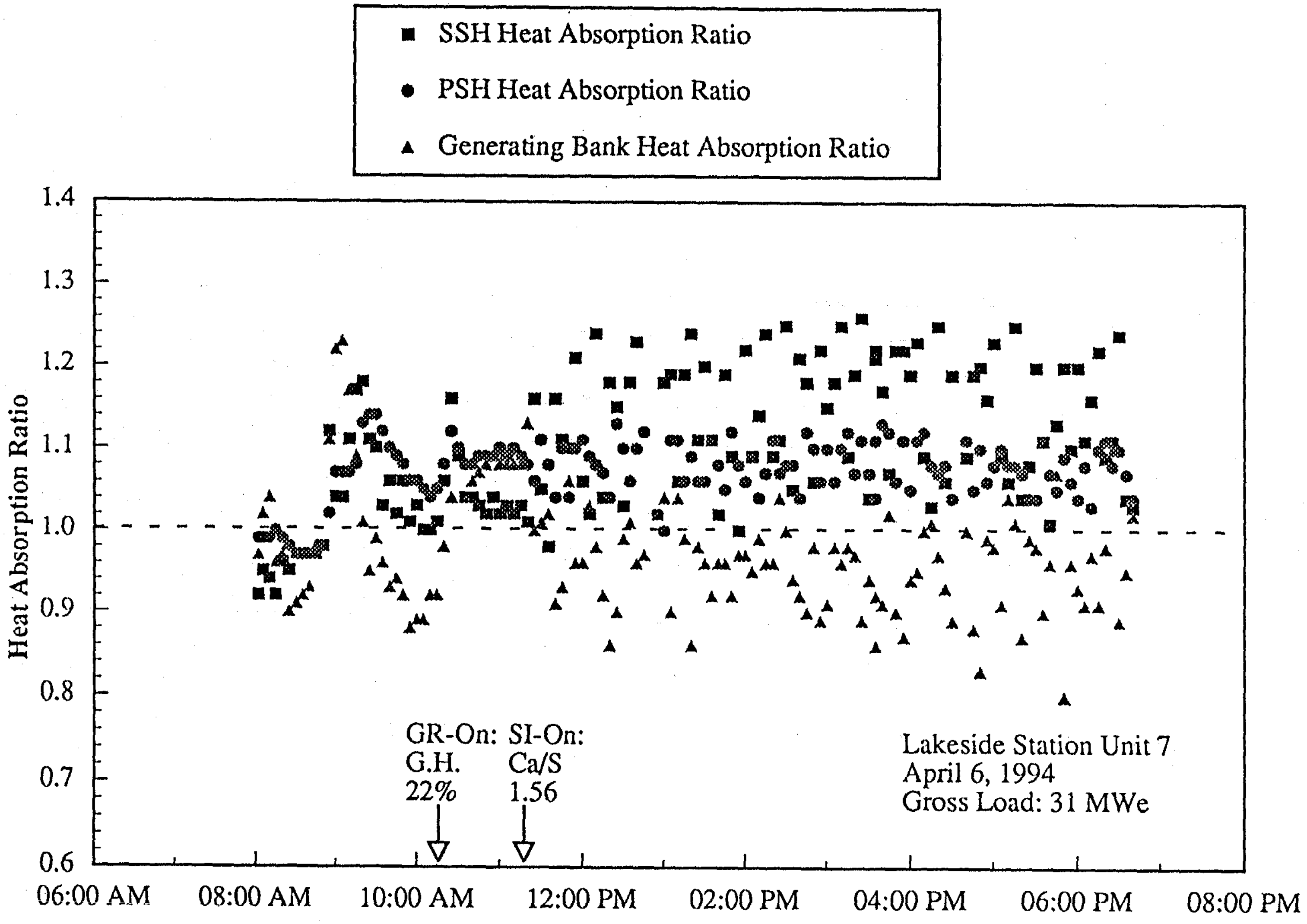

Figure 7-31. Heat absorption ratios under GR-SI operation.

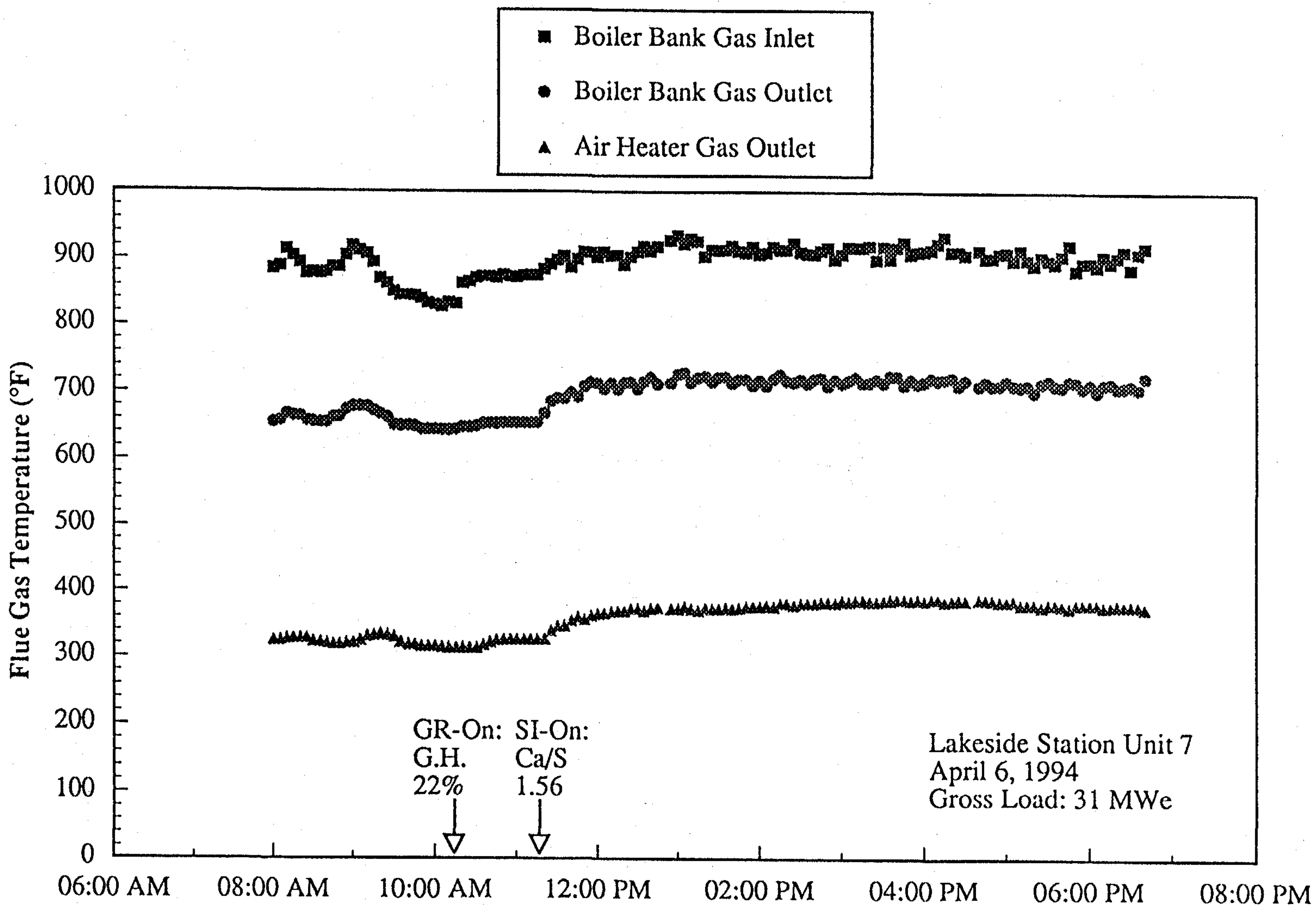

Figure 7-32. Flue gas temperature profile under GR-SI operation.

TABLE 7-6. PARTICULATE MATTER SAMPLING UNDER GR-SI AT FULL LOAD

Test Run	1	2	3	Avg.
Sampling Location	Stack	Stack	Stack	
Test Date	2-Jun-94	2-Jun-94	2-Jun-94	
Sampling Period	10:45-11:55	13:11-14:18	14:46-15:53	10:45-15:53
Particulate Concentration				
grains/acf	0.0048	0.0058	0.0034	0.0047
grains/dscf	0.0081	0.0100	0.0059	0.0080
Emissions Rate				
pounds/hour	9.47	10.58	6.23	8.76
pounds/MBtu (F = 9,780)	0.016	0.019	0.012	0.016
Average Volume Flow Rate:				
@ Flue Conditions, acfm	231,172	212,144	214,753	219,356
@ Standard Conditions, scfm	136,174	123,393	123,553	127,707
Gas Temperature (°F)	324	327	331	327
Gas Velocity (ft/s)	21.8	20.01	20.25	20.69
Moisture Content (%, Volume)	10.73	11.58	12.06	11.46

far below the 0.1 lb/10^6Btu (43 mg/MJ) limit, with an average grain loading of 0.0080 gr/dscf (0.018 g/m^3). The grain loading is somewhat higher than that measured under baseline operation in 1988. In those tests, with both units 7 and 8 operating at full load (66 MW_e total), the average grain loading for three runs was 0.0036 gr/dscf (0.0082 g/m^3). The flue gas moisture content, which may impact the acid dew point temperature and hence metal corrosion rate, averaged 11.46% by volume. This is an increase from the baseline flue gas moisture content of 8.89%. Inspections of the ESP were conducted by contractors to determine its condition prior to initiation and after completion of the GR-SI testing. The findings are described below in the boiler inspections section.

7.6.4 GR-SI System Auxiliary Power

Measurements of auxiliary power consumed by the GR-SI system were not made regularly, i.e. at intervals during GR-SI testing. However, an estimate of auxiliary power usage has been made based on equipment power rating. This indicates that GR operation consumed approximately 350 kW while SI operation required 362 kW. Therefore, the estimated total auxiliary power usage by GR-SI is 712 kW. Since these are maximum power usages based on equipment rating, i.e. the actual power consumption should be less especially under reduced loads. These also do not directly reflect the change in total auxiliary power consumed by Unit 7.

7.7 GR-SI Demonstration Troubleshooting

Adjustments made to boiler and GR-SI system operation are addressed in this section. In general, the GR-SI equipment performed well after early optimization. Several problems were encountered during start-up which required attention from CWLP or an outside contractor. These included the FGR fan, rear pass hoppers, flue gas leakage, and sootblower operation. In addition to problems in these areas, which were rectified during start-up, several problems were encountered during operation over the nine month demonstration period. Adjustments/repairs were needed in the operation of flame scanners, cyclone air transmitters, the WDPF control system, and the ash handling system. During start-up, adjustments were made to the FGR fan, the rear pass hoppers, the retractable sootblowers and to the boiler insulation. The FGR fan clutch failed twice necessitating repair. Once adjustments to the drive and control system were made, few problems with the FGR fan were encountered throughout the rest of the testing program. The rear pass hoppers tended to plug up. When the material was dislodged, some of the ash would flow through an opening in the floor to the base of the FGR fan and interfere with the spring suspension mounts. A metal box was installed in this opening to capture the ash and hence prevent its buildup near the FGR fan mounts. All of the retractable sootblowers were replaced during the construction phase of the project. Early problems with sagging and misalignment were corrected by the CWLP boiler crew. These efforts were successful, and the sootblowers were used almost continuously while injecting sorbent. The boiler insulation had cracks in several areas necessitating asbestos abatement, repair of cracks, and installation of mineral wool based insulation. Since the unit is a positive pressure design, these cracks resulted in outward leakage of gas before they were repaired.

During GR-SI operation several operational problems were encountered. One problem was a shutdown of the reburning system from the cyclone flame scanner signal. One of the requirements of continued reburning operation was that both cyclones be in operation. If the cyclone flame scanner did not detect the presence of a flame, then the coal feeder and natural gas valves would trip. This problem was corrected by a Forney field service representative, who found several problems including incorrect installation and recommended an increase in the flow of purge air.

Another area where adjustments were made was with the indicated cyclone air flow. The original cyclone air transmitters were not well temperature compensated, therefore resulting in inaccuracy in the flow measurement. The air flow transmitters were replaced by a "smart" air flow transmitter manufactured by Rosemount, which corrected the flows according to the air temperature. After these transmitters were installed, the process efficiency and repeatability greatly improved.

The area which required greatest attention was the ash handling system. On one occasion a serious tube leak occurred in the boiler bank. When the operators detected the leak they pulled all of the ash hoppers. Since the ash was being conveyed to the ash silo instead of the sluice pond, significant problems arose. The moisture with the ash resulted in formation of cementitious material when it contacted the free lime in the silo. This material required two months of work to clean out. Another problem relating to the disposal of ash was with the addition of water to the ash when it was loaded onto trucks. This process was not properly controlled, therefore the ash either had too little moisture (was too dusty) or too much moisture. A third problem relating to the ash handling system was with the lock hopper valves. These valves, which were essentially plates of 1/8" to 3/16" (3.2 to 4.8 mm) in thickness, wore out due to ash erosion. This led first to frequent high level alarm and later to caking of ash on baghouse screens and destruction of these screens. Eventually, both the valves and screens were replaced.

8.0 ENVIRONMENTAL PERFORMANCE

Environmental monitoring was conducted to evaluate the performance of the GR-SI system, to ensure environmental acceptability of the process, and to compile a database of environmental impacts for future applications. Monitoring of gaseous and aqueous discharges from the site was conducted as directed by the Environmental Monitoring Plan (EMP). The EMP, prepared in Phase I of the project, described potential impacts of GR-SI on the local environment and outlined testing required to evaluate these impacts. Environmental measurements were divided into those required to satisfy operating permits issued by the Illinois Environmental Protection Agency (IEPA), and supplemental measurements. The Lakeside Station is permitted as both an air emissions source and a source of aqueous discharge. The aqueous discharges are regulated by the National Pollutant Discharge Elimination System (NPDES) permit. Compliance monitoring was conducted by plant personnel, who issued monthly reports to IEPA. Supplemental measurements were made in the areas of gaseous emissions, stack particulate loading, and solid waste (fly ash/spent sorbent) characterization.

The major product of GR-SI is a solid material, which is a mixture of spent sorbent and fly ash. Prior to initiation of the project, the fly ash was sluiced to an on-site pond. Due to the change in its chemical composition, from the presence of spent and unreacted sorbent, the dry ash/spent sorbent was conveyed to a newly constructed silo for off-site disposal. The characteristics of the fly ash/spent sorbent mixture were evaluated in Phase I with material produced in EER's test furnace. At the initiation of Phase III GR-SI testing, material from Lakeside Unit 7 was tested to obtain the required waste disposal permit.

8.1 Environmental Monitoring Results

This section presents results of environmental monitoring in the areas of gaseous and particulate matter emissions and aqueous discharges. Gaseous emissions were measured continuously during GR, SI, and GR-SI operation from a sampling grid at the boiler exit. The CEMS, described in Section 6, met the requirements of U.S. EPA Methods 3A "Determination of

Oxygen and Carbon Dioxide Concentrations in Emissions From Stationary Sources," 6C "Determination of Sulfur Dioxide Emissions from Stationary Sources," 7E "Determination of Nitrogen Oxides Emissions from Stationary Sources," and 10 "Determination of Carbon Monoxide Emissions from Stationary Sources." Particulate matter emissions were evaluated primarily with a plant opacity meter, which transmitted data continuously to the BPMS. At the conclusion of the GR-SI demonstration, stack particulate matter emissions were measured manually according to U.S. EPA Method 5, "Determination of Particulate Emissions From Stationary Sources." Aqueous discharges were tested regularly by plant personnel, as dictated by the NPDES permit. Two discharge streams were of interest in this project, the ash pond discharge (Outfall 004) and the coal pile runoff (Outfall 008).

Table 8-1 summarizes the gaseous emissions under the three operating conditions, over the Phase III demonstration period. From July 28, 1993 to June 3, 1994, GR-only operation was conducted for 288 hours, SI-only operation was conducted for 38 hours, and GR-SI were operated simultaneously for 202 hours. GR was operated with an average gas heat input of 23.1%, SI had an average Ca/S of 1.93, and GR-SI was operated at an average gas heat input of 22.0% and a Ca/S of 1.81. Reductions in SO_2 emissions were calculated from the 5.9 lb/10^6Btu (2500 mg/MJ) baseline and reductions in NO_x were calculated from the correlated baseline, NO_x (lb/10^6Btu) = 0.522 + 0.0134 * gross load (MW_e).

In GR-only operation, NO_x emissions averaged 0.356 lb/10^6Btu (153 mg/MJ). This is a reduction of 60% from the baseline level. SO_2 emissions averaged 4.483 lb/10^6Btu (1930 mg/MJ), which represents a direct reduction according to the gas heat input. Emissions of CO_2 averaged 14.3%, which is approximately 7% less than the baseline level. CO emissions were on average in the upper end of the acceptable range, at 180 ppm. HC emissions were very low, at 6.2 ppm. After obtaining several HC measurements, testing for this species was discontinued due to difficulty in maintaining the HC analyzer operability. The opacity of the flue gas was on average 4.6%, which is far below the regulatory limit of 30%.

SI-only operation resulted in average SO_2 emissions of 3.621 lb/10^6Btu (1560 mg/MJ). This is

TABLE 8-1 SUMMARY OF AIR EMISSIONS UNDER GR, SI, AND GR-SI

Operating Mode	Total Duration (Hours)	Gross Power (MWe)	Gas Heat (%)	Ca/S Molar Ratio	CEMS O2 (%, dry)	Plant O2 (%, wet)	CO (ppm @ 3% O2)	CO2 (% @ 3% O2)	NOx (ppm @ 3% O2)	NOx (lb/MBtu)	SO2 (ppm @ 3% O2)	SO2 (lb/MBtu)	HC (ppm @ 3% O2)	Opacity (%)
GR	288	27	23.1	0.00	4.18	3.30	180	14.3	268	0.356	2412	4.483	6.2	4.6
SI	38	26	0.0	1.93	4.88	3.78	14	15.3	657	0.896	1900	3.621	NA	5.7
GR-SI	202	28	22.0	1.81	4.22	2.97	179	14.2	251	0.334	1335	2.486	NA	5.0

Notes: Testing Period: July 28, 1993 To June 3, 1994

NA: Not Available

a 39% reduction from the baseline level and has an associated calcium utilization of 20%. Emissions of CO were very low in this case, with an average of 14 ppm. Emissions of CO_2 were equal to the baseline level, while NO_x was reduced a small amount due to air staging under this condition. The opacity was maintained very low at 5.7%, even with the increased particulate loading into the ESP.

Under GR-SI the NO_x emissions were reduced to 0.334 lb/10^6Btu (144 mg/MJ), a 63% reduction, and SO_2 emissions were reduced to 2.486 lb/10^6Btu (1070 mg/MJ), a 58% reduction. GR-SI operation followed modification of the reburning fuel injectors to optimize their performance. These modifications resulted in improvement in NO_x reduction over the GR-only case. The SO_2 reduction reflects a 22% reduction due to natural gas switching and a further reduction of 46% due to SI. The sorbent calcium utilization in this case was 25%. Emissions of CO_2 and CO were as in the GR-only case, a 7% reduction in CO_2 and CO emissions of 179 ppm. Opacity of the flue gas averaged 5.0%, indicating effective capture of particulate matter by the ESP.

The manual particulate loading measurements, presented in Section 7, showed that emissions were well below the limit of 0.1 lb/10^6Btu (43 mg/MJ). Three sampling runs were conducted at the stack while the unit was under full load GR-SI operation. The emissions averaged 0.016 lb/10^6Btu (6.9 mg/MJ), with an average grain loading of 0.0080 gr/dscf (0.018 g/m^3).

Table 8-2 summarizes the measurements of aqueous discharges potentially affected by GR-SI. These compliance measurements were conducted by plant personnel and reported to IEPA on a monthly basis. One of the potential impacts was an increase in pH due either to the possible but unexpected contamination of bottom ash with sorbent or to the spillage of the lime in the area of the coal pile. Outfall 004 - the ash pond discharge - includes water used in sluicing bottom ash to the ash pond. The NPDES limits the pH of this stream to the 6 to 9 range, concentration of Total Suspended Solids (TSS) for a 30 day average to 15.0 mg/l and daily maximum to 30.0 mg/l, and concentration of oil and grease to a 30 day average of 15 mg/l and daily maximum of 20 mg/l. Table 8-2 data show that for only one monitoring period was the

TABLE 8-2. AQUEOUS DISCHARGE MONITORING DATA

(OUTFALL 004 - ASH POND DISCHARGE)

Measurement Period	Flow (MGD)			pH			Total Suspended Solids (mg/l)			Oil & Grease (mg/l)			Boron (mg/l)		
	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.
9/1/93 - 10/1/93	5.19	5.19	5.19	7.4	8.3	8.9	2	9	17	1	1	2	5.2	5.3	5.4
10/1/93 - 11/1/93	0.00	4.61	6.63	8.5	8.7	9.0	5	7	11	1	2	3	3.5	4.1	4.8
11/1/93 - 12/1/93	5.91	5.91	5.91	8.3	8.6	8.8	2	8	18	1	1	1		4.4	5.2
12/1/93 - 1/1/94	0.00	5.23	5.91	7.6	8.3	8.4	3	5	8	2	3	3	6.1	6.2	6.3
1/1/94 - 2/1/94	5.19	5.19	5.19	7.9	8.1	8.5	4	12	26	2	2	2	6.0	6.3	6.5
2/1/94 - 3/1/94	5.19	5.73	5.91	8.1	8.3	8.4	7	11	15	2	3	4	4.6	4.7	4.9
3/1/94 - 4/1/94	5.19	5.91	6.63	8.1	8.3	8.8	8	15	28	1	1	1		5.2	5.8
4/1/94 - 5/1/94	0.00	3.46	5.19	8.0	8.5	9.0	13	24	34	0.2	2	4	1.8	2.0	2.2
5/1/94 - 6/1/94	5.19	5.37	5.91	7.7	8.5	9.3	6	12	19	2	2	2	4.6	4.8	4.9

(OUTFALL 008 - COAL PILE RUNOFF)

Measurement Period	Flow (MGD)			pH			Total Suspended Solids (mg/l)			Oil & Grease (mg/l)			Total Iron (mg/l)			Dissolved Iron (mg/l)		
	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.
10/1/93 - 11/1/93	0.00	0.05	0.72	7.8	7.9	8.1	5	7	9	3	3	4	0.2	0.2	0.2	0.02	0.06	0.09
4/1/94 - 5/1/94	0.00	0.01	0.24			8.1			72			0.36						

Note: No Discharge During Periods Not Shown daily maximum pH limit exceeded and for only one period were the 30 day average and daily maximum TSS exceeded. During all the other monthly monitoring periods the limits were met. Outfall 008 - the coal pile runoff - has the same limits as Outfall 004 with an additional limit for total iron of 2.0 mg/l, averaged over 30 days, and 4.0 mg/l for the maximum daily. The data show that during the demonstration period there was rarely a discharge from this stream. On one occasion the daily maximum TSS limit was exceeded. The pH levels indicate that spillage of lime, if any, did not change the neutrality of this discharge stream.

8.2 Fly Ash/Spent Sorbent Disposal

The physical and chemical characteristics of the spent sorbent/fly ash were evaluated in the design phase of the project and then later at the initiation of testing at the Lakeside Station. Coal from the Lakeside Station was fired in a test furnace with the sorbent. The fly ash/spent sorbent mixture was then evaluated by EER and a commercial laboratory. The composition was 52% calcium oxide (CaO), 18% silica (SiO_2), 16% sulfur trioxide (SO_3), and 5% alumina (Al_2O_3). The evaluation indicated that concentrations of 8 metals tested for in the EP toxicity test were below hazard levels. The material was found to increase in temperature when hydrated, therefore care in its handling was recommended. Pozzolanic activity tests indicated that the spent sorbent/fly ash was probably not suitable as a cement admixture material. A paint filter test indicated that the material did not have a liquid component. Overall, the fly ash/spent sorbent was determined to be non-hazardous, and dry collection and off-site disposal at a landfill was selected.

To obtain the necessary landfill disposal permit, a Toxicity Characteristic Leaching Procedure (TCLP) analysis was carried out with fly ash/spent sorbent from Lakeside Unit 7. A high volume SLM dust sampler was used to collect a sample from the convective pass, while the unit was operating SI. The results of the analysis are shown in Table 8-3. A 10% solution was found to be alkaline, with a pH of 12.26. The constituents of raw sample, shown in the "Total" column, and of the TCLP extract were very low in the metals tested. The concentrations of organic compounds in the TCLP were found to be below 50% of the regulatory limit in each

TABLE 8-3. EVALUATION OF THE FLY ASH/SPENT SORBENT MIXTURE

Total Alkalinity	30.5% as NH4OH		
Soluble Alkalinity	6.6% NH4OH		
Insoluble Alkalinity	25.3% as Ca(OH)2		
Ash Content	100.00%		
Odor of Sample	None		
Open Cup Flash Point	> 180 F		
Paint Filter	Pass		
Physical Appearance	Grey Ash		
Reactive Sulfide	< 5.0		
Total Cyanide	< 5.0		
Total Phenolics	< 10.0		
Total Solids	100.0%		
Water Reactivity	Dissolved in Water		
pH (10% solution)	12.26 (units)		
	Total		TCLP
Arsenic	19		0.25
Barium	26		—
Cadmium	4		< 0.1
Chromium	32		< 0.1
Copper	25		< 0.1
Lead	34		0.29
Mercury	0.09		—
Nickel	38		0.1
Selenium	10		0.35
Silver	< 2.5		—
Zinc	130		< 0.1

Note: Unless Otherwise Indicated, All Results Expressed as ppm

TABLE 8-3. EVALUATION OF THE FLY ASH/SPENT SORBENT MIXTURE (CONTINUED) ANALYSIS OF EXTRACT FROM TCLP

Compound	Concentration	Method Detection Limit	Regulatory Limit
1. Benzene	<0.25	0.01	0.50
2. Carbon Tetrachloride	<0.25	0.01	0.50
3. Chlorobenzene	<50	0.01	100.00
4. Chloroform	<3.0	0.01	6.00
5. o-Cresol	<100.0	0.01	200.00
6. m-Cresol	<100.0	0.01	200.00
7. p-Cresol	<100.0	0.01	200.00
Toal Cresol	<100.0	0.01	200.00
8. 1,4-Dichlorobenzene	<3.75	0.01	7.50
9. 1,2-Dichloroethane	<0.25	0.01	0.50
10. 1,1-Dichloroethene	<0.35	0.01	0.70
11. 2,4-Dinitrotoluene	<0.07	0.01	0.13
12. Hexachlorobenzene	<0.07	0.01	0.13
13. Hexachloro-1,3-butadiene	<0.25	0.01	0.50
14. Hexachloroethane	<1.50	0.01	3.00
15. Methyl Ethyl Ketone	<100.0	0.01	200.00
16. Nitrobenzene	<1.00	0.01	2.00
17. Pentachlorophenol	<50.0	0.01	100.00
18. Pyridine	<2.50	0.01	5.00
19. Tetrachloroethylene	<0.35	0.01	0.70
20. Trichloroethylene	<0.25	0.01	0.50
21. 2,4,5-Trichlorophenol	<200.00	0.01	400.00
22. 2,4,6-Trichlorophenol	<1.00	0.01	2.00
23. Vinyl Chloride	<0.10	0.01	0.20

Note: All Results Expressed as ppm

case.

8.3 Potential Environmental Concerns

The environmental monitoring results indicate that GR-SI has no deleterious impacts on the local environment. The applicable standards for air and aqueous discharges were met while operating GR-SI. The solid waste product was non-hazardous and was readily collected in a silo, then transported off-site for disposal.

The only performance parameter addressed in IEPA's Construction Permit was PM_{10} (particulate matter with an aerodynamic diameter under 10 microns) emissions. It was estimated in the permitting process that PM_{10} emissions could increase by as much as 129 tons/yr (117 tonne/a), requiring review of the project under federal Prevention of Significant Deterioration (PSD) provisions. IEPA ruled in its Construction Permit that the GR-SI demonstration met PSD provisions as outlined in 40 CFR 52.12. It also stated that the use of fabric filters in the sorbent silo, sorbent surge hopper, fly ash silo, and fly ash separator met the requirement for use of Best Available Control Technology (BACT). It required a particulate emissions test to verify that the emissions limit of 0.1 lb/10^6Btu (43 mg/MJ) was met. In this test, as described above, the full load average loading was found to be 8.76 lb/hr (1.10 g/s). Using a capacity factor of 25%, this corresponds to a particulate emissions rate of 9.6 tons/yr (8.7 tonne/a), significantly less than the stated PM_{10} limit of 152.3 ton/yr (138.3 tonne/a).

The Construction Permit also addressed resumption of normal operating mode at the completion of the demonstration. It stated that resumption of the normal operating mode would not be considered a modification requiring implementation of NSPS, as found in 40 CFR 60, Subparts a and Da. It also specified that resumption of the normal operating mode would not be considered a modification under the federal PSD rules, as outlined in 40 CFR 52.12.

9.0 CONCLUSIONS AND RECOMMENDATIONS

A demonstration of GR-SI at Lakeside Station Unit 7 exceeded the target emissions reductions of 60% for NO_x and 50% for SO_2. Over the long-term GR-SI demonstration period, NO_x reduction averaged 63% and the SO_2 reduction averaged 58%. These were achieved with an average natural gas heat input of 22% and average Ca/S molar ratio of 1.8.

Several GR process parameters were found to have significant impacts on NO_x control efficiency. These include the stoichiometric ratios of the coal (cyclone), reburning, and exit zone, the quantity of FGR used, and the size of reburning fuel injection nozzles. Also, NO_x control varied with operating load. At full load stoichiometric ratios of 1.15, 0.92, and 1.30 for coal, reburning and exit zones, respectively, the project achieved the NO_x control goal. FGR was found to improve NO_x reduction at all loads, with a flow of 6,000 scfm (2.83 Nm^3/s) determined to be optimum. Two sizes of reburning fuel injectors were tested, with the smaller size resulting in improved performance. NO_x control increased at reduced loads, due to more uniform reducing conditions in the reburning zone, since the primary flue gas flow is reduced as load drops.

SI in combination with GR exceeded the SO_2 control goal at sorbent inputs below design. Several parameters affected SO_2 capture by sorbent including, most importantly, the Ca/S molar ratio, the sorbent injection air flow, the operating load, and whether the GR system was also in operation. The impacts due to load and GR operation are tied to shifts in gas temperature, with higher temperatures resulting in improved sorbent-SO_2 reaction. Therefore, as load dropped below full load, higher levels of Ca/S were required to maintain equivalent SO_2 reductions. During the GR-SI demonstration full load Ca/S molar ratios of 1.5 to 1.9 were used, while at reduced loads Ca/S molar ratios of 1.9 to 2.2 were needed. The sorbent injection air flow had a minor impact, due to its effect on sorbent dispersion, with maximum flow of 4600 scfm (2.17 Nm^3/s) determined to be optimum.

Emissions of other species were affected by GR-SI. CO_2 emissions were reduced by approximately 8% due to differences in the hydrogen/carbon ratios of the fuels. Emissions of CO increased under GR, requiring use of higher exit stoichiometric ratios to maintain reasonable CO levels. Over the long-term GR-SI demonstration, CO emissions averaged 185 ppm. Emissions of particulate matter maintained far below the 0.1 lb/10^6Btu (43 mg/MJ) regulatory limit. Stack sampling indicated an average emissions rate of 0.016 lb/10^6Btu (6.9 mg/MJ) during full load GR-SI operation.

There were definite but relatively small impacts on unit thermal performance. Final steam temperature was maintained at approximately 10 to 20°F (5.6 to 11.1°C) below the design point of 910°F (488°C) with a drum attemperator mounted in the upper steam drum. The impacts of GR-SI on boiler thermal efficiency, calculated by the heat loss method, varied with load. At full load the drop in efficiency was approximately 1.0%, while at mid load (25 MW_e) it was 2% and at low load (20 MW_e) the efficiency was reduced by approximately 3%. GR-SI resulted in shifts in heat absorption, with a minor reduction in furnace heat absorption and an increase in the convective pass heat absorption. Virtually continuous sootblowing was required during SI to maintain heat transfer to the superheaters and to limit the rise in boiler exit temperature.

The impacts of GR-SI on other areas of boiler performance were minor. No change in cyclone and lower furnace conditions was noted. Injection of reburning fuel was found to promote slag buildup around the injectors up to the bottom of the furnace wing walls. Some deposition of loose ash was also noted in the overfire air ducts. Further downstream, some deposition of sorbent was found in the flue gas duct common to Units 7 and 8 and in the clean air duct near the air heater, which likely was transferred there by leakage at the regenerative air heater. Inspections of the ESP revealed higher levels of dust on the collecting plates, indicating a need for adjustments/repair of the plate rapping system and change in rapping frequency.

Ultrasonic thickness measurements taken before initiation of GR-SI and at the conclusion of testing indicated no acceleration of tubewall wastage. Measurements were taken at 3200 points throughout the lower and upper furnace and in the convective pass. The data showed scatter, with latter measurements being larger than previous measurements in many cases. Overall, no acceleration in wastage rates was determined. Tubewall samples taken before and after GR-SI testing were submitted for metallurgical study. No unusual wear of the tubewall exterior or preferential grain-boundary attack were evident; however, somewhat higher levels of iron sulfide were measured in samples taken from the reburning zone after GR-SI testing.

Overall, the process was applied successfully without adverse impacts to the unit or the local environment. Further commercial application of the technology is recommended to further the acceptance of GR alone, or GR-SI.

ENHANCING THE USE OF COALS BY GAS REBURNING-SORBENT INJECTION

GR-SI BOILER IMPACT REPORT
CITY WATER, LIGHT AND POWER'S LAKESIDE STATION UNIT 7

PREPARED UNDER:
U.S. DEPARTMENT OF ENERGY COOPERATIVE AGREEMENT DE-FC22-87PC79796
GAS RESEARCH INSTITUTE CONTRACT NO. 5087-254-149
ILLINOIS STATE DEPARTMENT OF ENERGY AND NATURAL RESOURCES

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May, 1995

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1.0 SUMMARY

In order to assess the impact of gas reburning-sorbent injection on the boiler, a series of inspections were performed both prior to and following the GR-SI testing. EER established the baseline condition of the unit and determined the existence and rate of both degradation and equipment failures. The following areas were evaluated:

- Boiler tubes
- Regenerative air heater
- Electrostatic precipitator
- Chimney
- Boiler performance

Boiler Tubes

A visual inspection performed following the testing showed no abnormal conditions in either the boiler furnace or cyclone barrels. Some sorbent accumulations were noted in the air side duct work due to carryover from the air heater, but are no cause for concern.

Eight tube samples were extracted from the boiler for metallurgical examination. Three were removed prior to testing and five after testing. Locations encompass the reducing regions of the boiler. All tube samples were found to be in acceptable metallurgical conditions, with no differences noted from before and after test conditions. Metallic sulfides were present on all tube samples, but were slightly higher on the post-test samples.

To determine the extent of tubewall wastage due to GR-SI, ultrasonic thickness measurements were made at 3200 points in the boiler both before and after testing. Specific areas were targeted where high rates of corrosion and/or erosion are possible. By comparing the thicknesses of the two tests, the rate of wear can be determined. The results of this analysis show that there was no significantly measurable wear of tubes as a result of GR-SI operation.

Evaluation of the baseline and projected tube wear indicate that the scheduled life of the boiler has not been compromised with or without use of the GR-SI system.

Regenerative Air Heater

The air heater was inspected both before and after testing. No adverse conditions resulted from operation of GR-SI. There was some minor basket degradation due to sootblower operation. Should the utility elect to retain the sorbent injection system, it is recommended that wear plates be installed at the inboard extent of the sootblower travel to protect the basket elements.

Precipitator

The electrostatic precipitator was inspected both before and after testing. The inspections concluded that the precipitator had adequately accommodated the changes in ash loading and resistivity with the presence of sorbent in the ash. A number of mechanical deficiencies were noted in the second inspection, but these were not attributed to the GR-SI operation.

Chimney

The chimney was inspected both before and after testing. The inspections show normal wear and deterioration over the period of the test program, but no adverse effects resulting from GR-SI operation.

Boiler Performance

EER's retrofit of gas reburning and sorbent injection required installation of several furnace wall openings for items such as gas reburning nozzles, overfire air nozzles, sorbent injection nozzles, and test ports. Whenever the GR-SI systems are not operated during boiler operation, a cooling medium is required in order to prevent nozzle overheating. Cooling air fans are used for the gas reburning and sorbent injection nozzles and a percentage of the total overfire air (re-directed secondary air) is used to cool the overfire air nozzles.

Although the cooling air is not part of the combustion stream, it has a minor impact on boiler excess air levels, and flue gas flow resulting in a slight decrease in boiler efficiency. Note that the reduction in efficiency when operating the gas reburning system is 1.4%.

2.0 INTRODUCTION

Energy and Environmental Research Corporation (EER) is the prime contractor for a project entitled, "Enhancing the Use of Coals by Gas Reburning-Sorbent Injection." The objective of this project is to evaluate and demonstrate a cost effective emission control technology for acid rain precursors, oxides of nitrogen (NO_x) and sulfur (SO_2), on two coal-fired boilers in Illinois. The units selected are representative of pre-NSPS design practices: tangential and cyclone-fired. The project targets are for reductions of 60-percent in NO_x and 50-percent in SO_2 emissions by a combination of two developed technologies, gas reburning (GR) and sorbent injection (SI).

This document discusses the measured and observed impacts to the cyclone-fired boiler, City Water, Light & Power's Lakeside Unit #7 in Springfield, Illinois. The unit is a 33 MWe Babcock & Wilcox boiler that serves the utility as a load peaking unit. The following areas are addressed and evaluated:

- Boiler tubes
- Regenerative air heater
- Electrostatic precipitator
- Chimney
- Boiler Performance

3.0 BOILER TUBES

Three intensive inspections and evaluations were performed to determine if operation of the gas reburning-sorbent injection system produced degradation on the boiler tubes. The first was a visual inspection from within the boiler to assess the conditions of cyclone furnaces, tube surfaces and ductwork. The second evaluation involved removing tube samples and performing metallurgical examination to determine if the grain structures had changed from the pre-test tube conditions. The third evaluation involved determining the baseline and GR-SI tube surface wear rate using ultrasonic thickness measurements and projecting the remaining useful life of the tubes.

3.1 Boiler Visual Inspection

3.1.1 Inspection Report

EER, accompanied by an engineer from CWLP, visually inspected the boiler on October 24 and 27 1995. A copy of the inspection report is included in Appendix A. No abnormal conditions were found in the cyclone furnaces or the cyclone throats. Normal maintenance is required for the replacement of coal wear liners and cyclone barrel tube studs. The arrangement of slag deposits on the furnace walls and floor indicate that the slag tap at the furnace bottom had been flowing freely.

Deposits of sorbent material were found in the secondary air and overfire air ducts. An inspection of the air heater noted that the air heater top (gas outlet - air inlet) was free of sorbent deposits but there was an accumulation of sorbent on the surface of the gas inlet (bottom). The inspection report notes that the sorbent apparently rotated from the gas to the clean air duct and left deposits in both the secondary and overfire air ducts. These deposits were about 1 to 2 inches deep and were removed by a boiler maintenance crew during an outage. It is normal for particulate (ash/sorbent) to be transferred from the gas duct to the air duct by the operation of the regenerative air heater and for deposits to accumulate in regions of duct work with lower velocities (i.e., recirculation zones).

The air nozzles, both secondary combustion and overfire air, were found to be free of warpage. This indicates that the ducts had adequate cooling during non GR-SI operation.

3.1.2 Conclusions

There were no visual indications of adverse effects of GR-SI operation on the boiler condition. Should the utility consider retaining the sorbent injection system, the deposition of sorbent in the air side duct work should be monitored to determine if deposits become steady state (normal deposition in low velocity regions of the duct) or continue to accumulate as a function of GR-SI operating time. Large amounts of deposits in the air side duct work may require reduced air heater seal clearances or modifications to the duct work such as ash hoppers.

3.2 Boiler Tube Metallurgical Examination

3.2.1 Metallurgical Report

Eight tubes sections, representing various areas of the furnace were extracted from the boiler for metallurgical examination. These tubes are as follows:

Sample No.	Description
1	Burnout zone, front wall, elevation 607'-0"
2	Reburning zone, front wall, elevation 596'-0"
3	Reburning zone, rear wall, elevation 586'-0"
4	Reburning zone, east side wall, elevation 586'-0"
5	Lower-furnace zone, rear wall, elevation 572'-6"
6	Over fire air zone, elevation 597'-9½"
7	Sorbent Injection zone, elevation 586'-0"
8	Reburning zone, elevation 586'-0"

Tube sample numbers 1 through 5 were removed from the furnace during the October 1994 outage inspection following long term GR-SI operation. Tube sample numbers 6 through 8 were removed from the furnace in 1991 during the installation of the tube openings for the GR-SI system nozzles. These tubes were stored in the EER/CWLP warehouse at the site since being removed from the furnace.

The tubes were provided to David N. French Inc., Metallurgists, for examination. This specialist was selected based on recommendations from the utility. The required work included examination of the tube microstructures, Rockwell B Hardness measurements, and sulfur prints of selected tubes. Unrequested tube thickness measurements were also provided. A copy of the report is included in Appendix B.

3.2.2 Observations

Examination of the tube internal microstructures revealed normal conditions with no evidence of thermal abuse or difference between the hot (fire) and cold sides. Microstructures at the outer diameter of the tube numbers 3 and 4 show the wastage to be uniform and with no preferential grain-boundary attack. Sulfur prints were made on all tubes removed from the 586' elevation, these being tubes numbers 3 and 4 from the post-GR-SI samples and tube no. 8 from the pre-GR-SI samples. All three tubes were positive for metallic sulfides, with the post-GR-SI tubes showing slightly higher levels than the pre-GR-SI tubes.

Tube sample numbers 5 and 8 were supplied with refractory retention studs intact. Examination of the microstructures at the interface of the studs and the tube outside diameter showed no thermal-fatigue cracks.

Examination of the microstructures at the inner diameter of the tubes revealed the normal, thin, iron oxide layer with minimal pitting and no corrosion evident. Metallic copper is evident on the inner diameter of the tubes, indicative of corrosion or leaks in the feedwater heaters or condenser.

Anomalies in Rockwell B Hardness were noted in some of the tube ring sections, but this was attributed to the heat affected zone adjacent to electric-resistance welds.

3.2.3 Conclusions

The tube samples were found to be in excellent metallurgical condition with no major differences noted from tube-to-tube. As noted above, metallic sulfides were present on both the pre- and post-GR-SI tube samples and sulfide levels were slightly higher in the post GR-SI tubes.

3.3 Boiler Tube Wear Evaluation

This section presents an evaluation of the tubes to determine the surface wear during both baseline and GR-SI operation. Also presented is a projection of the impact of measured wear on the useful life of the boiler. The tube wear resulting from GR-SI operation is calculated using pre-and post-test ultrasonic (U.T.) thickness measurements of the tubes. The baseline wear is determined using an operational history of the boiler coupled with the U.T. measurements. Both are used to project the life of the tubes.

3.3.1 Host Site Agreement Requirements

EER's Host Agreement with CWLP requires an evaluation of the baseline DEGRADATION rate of the various boiler tubewall thicknesses. "The evaluation of baseline DEGRADATION shall include a nominal DEGRADATION rate and a standard deviation of the DEGRADATION rate. The standard deviation analysis shall be based upon direct analysis of the specific data obtained from the HOST UNIT inspections, augmented by manufacturing data, expert opinion of consultants, etc."

"At the completion of the Phase 3 tests ..., EER and the HOST shall conduct another inspection. The restoration requirements shall be based on the increased DEGRADATION rate and equipment failures over the baseline DEGRADATION rates. In areas where baseline data may not be available, any excessive DEGRADATION or equipment failures shall be based on manufacturers data or other data mutually accepted by EER and the HOST."

3.3.2 Scope

The basic approach is to use ultrasonic tube thickness measurements to determine boiler tube wear rates for each area of the boiler. Tube wall thicknesses were measured by a non-destructive examination (NDE) testing firm at strategic locations in the furnace and convection pass. These measurements were obtained in November 1991 and again at corresponding areas in October 1994.

Other data used for the determination of DEGRADATION rates include the manufacturer sales data, referenced tube material specifications (ASME Code Section II, Part A) for manufacture, and operation history of the Lakeside Unit 7 boiler unit. DEGRADATION rates are determined over specific time periods, and more specifically, over the load-averaged time durations the boiler unit was in use. CWLP has supplied some of the history of this unit. Capacity factors of the unit are available since 1980. Previous to 1980, a parametric study of different capacity factors has been employed (see Section 3.3.6). It is assumed that the capacity factor previous to 1980 was higher than post-1980.

3.3.3 Testing Methods

All of the ultrasonic tube wall measurements (with the exception of that performed on tube samples; see Section 3.3.6.3) were obtained by "Conam Inspection, Inc." of Itasca, Illinois. The testing personnel were SNT-TC-1A certified NDE technicians. The pre-GR-SI data was obtained in November 1991 and the post-GR-SI data was gathered in October 1994. At each tube location, measurements were taken at the center of the tube (facing the furnace gases) and at each side (approximately 60° from the center). The lowest reading of the three measurements was recorded. Each of the 1991 and the 1994 tubewall thickness data include approximately 3200 separate ultrasonic readings.

The 1991 tubewall thickness data was obtained with a 132 DG ultrasonic thickness meter and an A-scan display oscilloscope combination unit. Surface preparation was accomplished by sandblasting using local labor and abrasive disks and/or wire brushes by UT technicians. In 1994 the tubewall thicknesses were obtained with a Panametric 26 DL ultrasonic thickness meter. Preparation of the tube surfaces was done by hydroblast process.

The measurement accuracy of the UT instruments is ± 5 mils (0.13 mm), i.e. the instrument measurements are within ± 5 mils of the actual tubewall thickness. There are several sources of inaccuracy in these measurements. One source results from measurement of tubewall thicknesses at points proximate to the original locations, but not at precisely the same points. The measurement locations were denoted through distances from specific points in the boiler. Therefore, in repeating the measurements at two-year intervals, it is possible that measurements were taken at points near the original points, but not precisely the same locations. Significant variation in tubewall thickness with position along the same tube has been observed.

Another source of inaccuracy is in the preparation of the surface, since two methods of surface preparation were used. Tube preparation by abrasive disks and wire brushing is done by hand, therefore the extent of this preparation will vary with the person applying the technique. In general, any surface preparation results in some error of the measurements. When a new or newly cleaned steel tube is initially exposed to combustion products, accelerated wastage occurs before a layer of oxide products forms on the tube surface. The wastage rate then actually decreases as the oxide layer builds and acts to protect the tubewall. When a surface is repeatedly cleaned for thickness measurements, the tubewall may experience significant wastage in the period after cleaning. As a result, the wastage rate measured over a short time interval will reflect (in part) the accelerated wastage immediately following cleaning. Therefore, tubewall wastage rates calculated during GR-SI operation (1991-1994) are impacted by the surface preparation.

3.3.4 Test Results

The U.T. testing involved 12 tube measurement zones which were identified prior to the 1991 test (see Figure 1). These same zones were also inspected in 1994. The governing criteria was to select areas of the boiler with the potential for tube degradation resulting from operation of the GR-SI system. Degradation is indicative of either corrosion from localized reducing conditions or erosion from the increased particulate loading. Based on this criteria, the majority of the measurement zones were located in the upper furnace and the convection tube banks. Note that testing of zones in the superheater and generating banks was performed to measure erosion from particulate and from sootblower operation only.

CWLP has historically experienced tube wastage in the lower furnace of Lakeside #7 as a result of a localized reducing environment and these tubes were replaced in 1982. While operation of the gas reburning system should not aggravate this problem (since excess air is not lowered near the cyclones during GR-SI), this U.T. measurement information is provided for information only. These zones are located in the furnace floor and lower furnace and identified as zones 1 and 2.

The 12 measurement zones corresponding to Figure 1 are follows:

Zone No.	Elevation	Zone Description
1	560'-0"	Furnace floor and lower furnace walls
2	575'-0"	Furnace walls at cyclone elevation
3	593'-0"	Furnace walls in reburn zone
4	608'-0"	Furnace walls above reburn zone and above sorbent injection zone

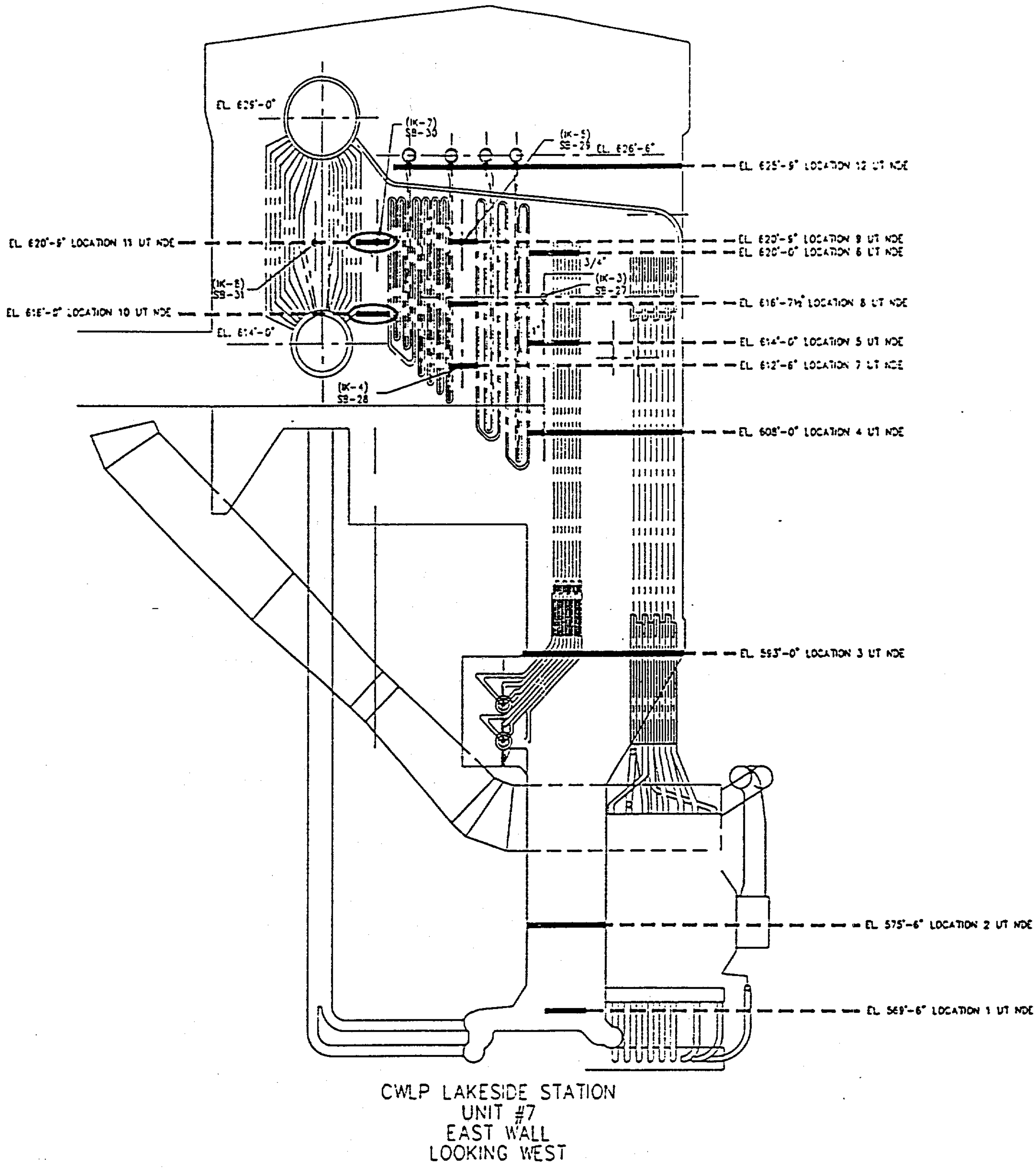

Figure 1. Ultrasonic Thickness Measurement Locations

5	614'-0"	Furnace walls above sorbent injection zone; superheater tubes above sorbent injection zone
6	620'-0"	Furnace walls above sorbent injection zone; superheater tubes above sorbent injection zone
7	612'-0"	Secondary superheater gas outlet; primary superheater gas inlet
8	616'-0"	Secondary superheater gas outlet; primary superheater gas inlet
9	620'-0"	Secondary superheater gas outlet; primary superheater gas inlet
10	616'-0"	Primary superheater outlet generating bank inlet
11	620'-0"	Primary superheater outlet generating bank inlet
12	Penthouse	West furnace walls East furnace walls North furnace walls Header pipes north side wall

Tube thicknesses were measured ultrasonically by Conam Inspection Inc. The 1991 and 1994 inspection reports produced by Conam are included in Appendices C and D respectively. Included are both per-tube raw data and color bar charts for each of the zones. EER has generated line plots of the data which are included in Appendix E (note that "location" and "zone" are used interchangeably. The reader should be cognizant of the following when reviewing these charts:

- A number of outliers (points greater than three standard deviations from the mean) exist in the data. This is particularly evident in Zones 1 and 4. Some of the outliers are due to the doubling effect of the ultrasonic instrument. In this phenomenon, twice the thickness reading is displayed on the meter due to anomalies in the material. Others can be attributed to accuracy of the process (see Section 3.3.3). In certain instances outliers can be removed from the analysis.

- The number of measurement samples recorded in 1991 is not necessarily the same as recorded in 1994 for each zone. It was not a requirement that each tube be measured. However, provided a significant number of samples is measured in the zone, an adequate analysis can be performed. The reader is advised not to attempt to use the charts in Appendix E to compare tube-to-tube. The charts are used to indicate trends in the data.

- Not all of the inspection points were measured in each year as evident in Zones 1-side wall (1991 only), 4-screen tubes (1994 only), and 7-header pipes north side (1994 only). This condition does not impact the overall study.

- The charts for Zone 12 indicate a consistent .040" decrease in tube thickness. However, due to the consistent pattern of the data, it is obvious that the tubes measured in 1991 are not the same as in 1994.

- Zone 13 (penthouse, primary superheater inlet) was added in 1991 by Conam; EER provides this data for information only in Appendix E. Note that Zone 13 was not in the original scope. Data for this location is not available for 1994 since the area was inaccessible due to a heavy fly ash buildup.

The data is summarized in Table 1 which presents the averages, means, standard deviations, and number of samples for each zone.

Table 1. Ultrasonic Tube Thickness Measurements - Data Summary

Loc.	Elev	Description	Data From Test Reports					Changes		Notes
			Year	Ave.	Mean	Stdev	# Smpl	Ave.	Mean	
7	612	Primary Superheater Inlet	91	189	187	8	70	6	6	
			94	195	193	14	71			
		Secondary Superheater Outlet	91	309	311	8	23	18	16	
			94	327	327	13	23			
8	616	Primary Superheater Inlet	91	198	198	10	70	4	3	
			94	202	201	10	71			
		Secondary Superheater Outlet	91	245	245	4	23	6	4	
			94	251	249	6	23			
9	620	Primary Superheater Inlet	91	193	192	9	71	3	4	
			94	196	196	11	71			
		Secondary Superheater Outlet	91	243	245	6	23	6	5	
			94	249	250	10	23			
10, 11	616	Primary Superheater Outlet	91	185	185	10	70	4	3	
			94	189	188	9	71			
	620	Primary Superheater Outlet	91	174	175	12	70	17	15	
			94	191	190	11	71			
	616	Generating Bank Inlet	91	141	141	3	59	1	1	
			94	142	142	3	59			
	620	Generating Bank Inlet	91	146	146	5	59	6	6	
			94	152	152	4	59			
12	628	West Furnace Water Wall	91	182	169	20	35	-19	-6	Inconsistent tube location.
			94	163	163	4	30			
	627	East Furnace Water Wall	91	179	167	20	32	-12	0	Inconsistent tube location.
			94	167	167	3	30			
	626	North Furnace Wall	91	166	166	4	30	0	0	
			94	166	166	5	35			
	628	Header Pipes North Side	91	n/a	n/a	n/a	n/a	n/a	n/a	
			94	172	172	3	11			

All measurements are in thousanths of inches

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n/a - not available

Table 1. Ultrasonic Tube Thickness Measurements - Data Summary

Loc.	Elev	Description	Data From Test Reports					Changes		Notes
			Year	Ave.	Mean	Stdev	# Smpl	Ave.	Mean	
1	560	Furnace floor (north location)	91	285	280	21	36	-3	0	Potential outliers. Possible doubler.
			94	282	280	13	67			
		Furnace floor (south location)	91	285	283	6	28	-7	-6	
			94	278	277	8	65			
		South-West corner, 12 inches off floor	91	276	312	53	9	n/a	n/a	
			94	n/a	n/a	n/a	n/a			
		South-East corner, 12 inches off floor	91	276	280	54	10	n/a	n/a	
			94	n/a	n/a	n/a	n/a			
2	575	North wall lower furnace water wall	91	276	273	16	38	9	13	
			94	285	286	9	39			
		South wall lower furnace water wall	91	212	210	12	70	4	4	
			94	216	214	4	70			
		East wall lower furnace water wall	91	210	211	4	18	14	11	
			94	224	222	5	19			
		West wall lower furnace water wall	91	215	215	4	19	0	0	
			94	215	215	5	17			
3	593	North wall furnace water wall	91	168	168	4	69	7	3	
			94	175	171	10	69			
		South wall furnace water wall	91	202	202	8	71	3	3	
			94	205	205	9	72			
		East wall furnace water wall	91	184	171	20	40	7	17	Possible doubler.
			94	191	188	36	40			
		West wall furnace water wall	91	183	171	20	40	1	1	
			94	184	172	21	40			
		Rear Wing Wall	91	151	150	4	11	12	13	
			94	163	163	7	11			
		Front Wing Wall	91	307	307	10	2	18	18	
			94	325	325	15	2			

All measurements are in thousanths of inches

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n/a - not available

Table 1. Ultrasonic Tube Thickness Measurements - Data Summary

Loc.	Elev	Description	Data From Test Reports					Changes		Notes
			Year	Ave.	Mean	Stdev	# Smpl	Ave.	Mean	
4	608	North Wall Furnace Water Wall	91	191	176	43	65	-25	-10	Potential outliers. Possible doublers.
			94	166	166	4	69			
		West Wall Furnace Water Wall	91	173	172	9	36	-4	-4	Possible doublers.
			94	169	168	7	40			
		Superheater Section East Wall	91	174	171	12	40	-7	-5	
			94	167	166	6	40			
		Superheater First Row South Wall	91	236	233	18	23	6	9	
			94	242	242	13	23			
		Rear Wing Wall	91	172	170	8	11	-6	-4	
			94	166	166	1	11			
		Front Wing Wall	91	317	317	7	2	6	6	
			94	323	323	5	2			
		Superheater Screen Tubes	91	n/a	n/a	n/a	n/a	n/a	n/a	
			94	323	323	5	2			
5	614	Superheater Screen Tubes	91	169	169	4	23	0	0	
			94	169	169	3	23			
		Rear Wing Wall	91	171	170	3	11	-1	0	
			94	170	170	2	11			
	615	Secondary Superheater First Row	91	236	236	11	19	26	28	
			94	262	264	15	23			
		Front Wing Wall	91	333	333	0	1	-165	-165	
			94	168	168	0	1			
6	620	Superheater Screen Tubes	91	172	172	3	23	-7	-7	
			94	165	165	5	23			
		Rear Wing Wall	91	n/a	n/a	n/a	n/a	n/a	n/a	
			94	168	167	2	11			
	621	Secondary Superheater First Row	91	231	229	10	23	3	6	
			94	234	235	7	23			

All measurements are in thousanths of inches

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n/a - not available

3.3.5 GR-SI Wear Rate

The tube thickness measurement data obtained in 1991 and 1994 are used to determine if operation of the GR-SI system resulted in tube wear at measurable significance within a reasonable confidence level. The evaluation of wear is performed on a per-zone basis using the following statistical method:

1. Calculate the change in means between the 1991 and 1994 data and determine if the tube thickness mean has decreased (indicated by a negative number in Table 1). If a decrease is noted, further evaluation is required.

2. Perform a statistical hypothesis evaluation of the 1991 and 1994 data means to determine if a correlation exists. Calculate the potential wear rate where a correlation does not exist and perform additional evaluation.

3. Evaluate the potential wear rate with respect to the measurement accuracy of the process. Support the conclusions with additional analysis.

4. Where measurable wear exists, project the wear rate to the end of the projected boiler life and determine if the wear rate will shorten this life. Two scenarios are evaluated:
   a. No additional operation of GR-SI.
   b. Continued operation of GR-SI.

3.3.5.1 Evaluation of the Change in Means

The change in means for each measured location is presented in Table 1. A review of this data shows a number of locations where the change is negative, indicating potential tube wear. These are as follows:

- Location 1, Elevation 560, Furnace floor (south location)--.006"
- Location 4, Elevation 608, North wall furnace water wall--.010"
- Location 4, Elevation 608, West wall furnace water wall--.004"
- Location 4, Elevation 608, Superheater section east wall--.005"
- Location 4, Elevation 608, Rear wing wall--.004"
- Location 6, Elevation 620, Superheater screen tubes--.007"
- Location 12, Elevation 620, West furnace water wall--.006"

The remaining locations have a zero or positive change and are not considered for further analysis.

3.3.5.2 Statistical Hypothesis Evaluation

The statistical hypothesis used in the evaluation compares two samples of data (i.e., 1991 data and 1994 data) and determines if a correlation exists within a reasonable confidence level. The evaluation uses the means and standard deviations of the two samples and assesses the potential for both sets of data to have been taken from a single sample, which would indicate no tube wear (Reference: "Applied Statistics: A Business Orientation", Second Edition, by H.L. Taylor, K.A. Klafehn, G.E. Meek, and K.A. Dunning, Department of Management, University of Akron, 1981).

The determination of what is reasonable is specified in advance by selecting the confidence level ($1 - \alpha$). For an hypotheses test, the assumed value is stated and an alternative specified. Then a value for α (Type I error level) is selected and this in turn specifies what samples will be considered unreasonable when the stated hypothesis is true. Any sample whose probability of occurrence is less than α is termed unreasonable and leads to rejection of the null hypothesis.

The hypothesis test is performed using the following seven steps:

1. State the hypothesis and an alternate hypothesis.
2. Choose the Type I error level.
3. Select a working statistic to standardize the sample data.
4. Establish the decision rule to be used.
5. Perform the calculations for standardizing the sample.
6. Make a statistical decision.
7. Make a managerial decision.

1. The null hypothesis for this case is the condition where the means of the two samples are the same, i.e. H_o: $\mu_1 = \mu_2$, where μ = mean. The alternative is H_a: $\mu_1 <> \mu_2$. The test is an attempt to show that there is no significant difference between what is hypothesized and what is indicated by the samples.

2. The selection of the Type I error level (α) establishes the probability that one is willing to reject the null hypotheses when, in fact, it is true. The confidence interval selected for this test is 99%. In other words, one sample must fall theoretically somewhere within a 99% region of the statistical curve of the other sample. The α is calculated as 1.00 - .99 = .01. If the test calculation falls below α, then the null hypotheses is rejected and potential tube wear is indicated.

3. The working statistic applicable to this analysis is the t-distribution. This statistic is a function of the X^2 distribution which is the determination of the distribution of the variance of a random sample taken from a normal population. The formula for the t-distribution is:

$$t = \frac{(x - \mu)}{S_x/n^{1/2}}$$

where:

x = sample mean
μ = population mean
S_x = variance
n = number of samples

4. The null hypothesis (H_o: $\mu_1 = \mu_2$) is rejected at the level α if $P(X > x) < \alpha/2$. The α is halved since we are concerned with only one end of the statistical curve (wear only and not tube thickness increase)

5. In this analysis the means and standard deviations are known. The test is to determine if the means of the samples differ significantly from one another. The formula for the calculation is as follows:

$$Z = \frac{(X_1 - X_2) - (\mu_1 - \mu_2)}{\sigma_1^2/n_1 + \sigma_2^2/n_2}$$

where:

X_1 = mean of sample 1
X_2 = mean of sample 2
$\mu_1 - \mu_2 = 0$ (null hypothesis)
σ = standard deviation
n = number of samples

6. The results of the calculations are presented in Table 2 and are discussed below.

Location 1, Furnace floor (south location)

The null hypothesis is rejected. The hypothesis would have been accepted had the change in means been smaller by .003". Therefore, the analysis indicates a potential wear of .003" during GR-SI operation.

Location 4, North wall furnace water wall

The null hypotheses is accepted. Therefore no wear is indicated. However, due to the high standard deviation for 1991 data, the analysis is extended further to remove outliers (measurements at least three standard deviations from the mean). In this instance the null hypothesis is rejected. The hypothesis would have been accepted had the change in means been smaller by .007". Therefore, the analysis indicates a potential wear of .007".

Table 2. Null Hypothesis Evaluation of Means using t-Distribution

Location	Elevation	Description	Year	Mean	Stddev	#Smpls	Change Mean	Z	Acceptable Alpha	Accept/ Reject
1	560	*Furnace floor (south location)*	1991	283	6	28	-6	-3.982	0.001	Reject
			1994	277	8	65				Note 2
4	608	North wall furnace water wall	1991	176	43	65	-10	-1.867	0.025	Accept
			1994	166	4	69				
		(without outliers)	1991	175	5	52	-9	-10.661	0.000	Reject
			1994	166	4	69				Note 3
4	608	West wall furnace water wall	1991	172	9	36	-4	-2.146	0.010	Accept
			1994	168	7	40				
		(without outliers)	1991	170	5	33	-2	-1.420	0.050	Accept
			1994	168	7	40				
4	608	Superheater section east wall	1991	171	12	40	-5	-2.357	0.005	Accept
			1994	166	6	40				
4	608	Rear wing wall	1991	170	8	11	-4	-1.646	0.050	Accept
			1994	166	1	11				
6	620	*Superheater screen tubes*	1991	172	3	23	-7	-5.757	0.000	Reject
			1994	165	5	23				Note 4
12	628	West furnace water wall	1991	169	20	35	-6	-1.735	0.025	Accept
			1994	163	4	30				Note 5

Note 1: Criteria is 99% acceptance interval (alpha = .005 for *one tail acceptance*; $Z<t=2.576$)
Note 2: Location 1 accepted at alpha=.005 for .003" wear.
Note 3: Location 4, north without 1991 outliers, accepted at alpha =.005 for .007" wear.
Note 4: Location 6 accepted at alpha=.005 for .004" wear.
Note 5: Although acceptance is indicated, 1991 data and 1994 data do not correlate.

Location 4, West wall furnace water wall

The null hypotheses is accepted; the null hypothesis is also accepted following removal of outliers. Therefore no wear is indicated.

Location 4, Superheater section east wall

The null hypotheses is accepted. Therefore no wear is indicated.

Location 4, Rear wing wall

The null hypotheses is accepted. Therefore no wear is indicated.

Location 6, Superheater screen tubes

The null hypothesis is rejected. The hypothesis would have been accepted had the change in means been smaller by .004". Therefore, the analysis indicates a potential wear of .004".

Location 12, West furnace water wall

The null hypotheses is accepted. Therefore no wear is indicated.

7. The null hypothesis is rejected at three locations indicating potential tube wear in these areas. The greatest of these is at Location 4 (.007"), North wall furnace water wall, which is in the vicinity of the natural gas injectors. These three areas require further evaluation.

3.3.5.3 Measurement Accuracy

Two types of error are associated with U.T. measurement of boiler tubes for thickness. The first is error that exists due to variations in tube condition and tube preparation. The error is minimized by taking large sample sizes which was done in most cases. The second is due to the U.T. process itself. As stated in Section 3.3.3, the measurement accuracy of the U.T. process is ±.005". The recognition of this error can be reinforced by reviewing the changes in means in Table 1 and noting both positive and negative changes (average = +.004, mean = +.003, standard deviation = .008, and 83% of means are zero or positive). Realistically, a positive difference in means is not possible since this indicates that the tube thickness increased during operation of the boiler. It can be concluded that error does indeed exist in this process.

With a ±.005" error associated with the means of both 1991 and 1994 data, an assumption can be made that only changes in means above .010" can be considered significant. The greatest change calculated using the statistical hypothesis evaluation is .007". Thus, it is concluded that there exists no measurable difference in the two sets of data and therefore no tube wear has resulted from operation of the GR-SI system.

To verify this assumption, analysis was performed on the tube samples removed from the boiler in the vicinity of Location 4 (see Section 3.2). This is the area of the highest potential tube wear (.007"). Tube samples 1 and 2 (post-test) and tube sample 7 (pre-test) were used for this evaluation. Thickness measurements were recorded for each tube sample at 12 points around the circumference and at 3 linear positions (see Table 3). The measurement instrument was a Kratkramer Branson DM2E Ultrasonic Thickness Gauge. Measurements were verified using a micrometer. The data was reduced to a casing-side average thickness and a fire-side average thickness. The difference between these two values is considered to be the relative wear of the tube on the fireside. Evaluation of the one pre-test tube sample indicates that the total baseline tube wear was .001" to .002". Evaluation of the two post-test tube samples indicated that the tube wear was also .001" to .002". In addition, the average thickness measurements on both casing-sides and fire-sides for both pre- and post-test tube samples range from .165" to .170",

Table 3. Tube Sample Thickness Measurements

				CASING SIDE						BOILER SIDE				7 POINT AVERAGE			5 POINT AVERAGE		
TUBE NO.														CASING AVE	BOILER AVE	TOTAL WEAR	CASING AVE	BOILER AVE	TOTAL WEAR
1																			
TOP	0.166	0.168	0.168	0.173	0.168	0.171	0.168	0.166	0.167	0.168	0.168	0.167	0.166	0.169	0.167	0.002	0.170	0.167	0.002
MID	0.164	0.168	0.166	0.167	0.166	0.168	0.165	0.164	0.165	0.166	0.164	0.165	0.164	0.166	0.165	0.002	0.167	0.165	0.002
BOT	0.165	0.167	0.168	0.166	0.167	0.169	0.168	0.165	0.165	0.167	0.168	0.168	0.165	0.167	0.167	0.001	0.167	0.167	0.001
AVE	0.165	0.168	0.167	0.169	0.167	0.169	0.167	0.165	0.166	0.167	0.167	0.167	0.165	0.167	0.166	0.001	0.168	0.166	0.002
2																			
TOP	0.172	0.169	0.171	0.170	0.167	0.172	0.166	0.169	0.165	0.167	0.165	0.167	0.172	0.170	0.167	0.002	0.170	0.167	0.003
MID	0.168	0.169	0.168	0.166	0.166	0.164	0.166	0.168	0.165	0.167	0.163	0.165	0.168	0.167	0.166	0.001	0.167	0.166	0.001
BOT	0.170	0.168	0.169	0.167	0.168	0.170	0.167	0.169	0.166	0.168	0.164	0.167	0.170	0.168	0.167	0.001	0.168	0.167	0.001
AVE	0.170	0.169	0.169	0.168	0.167	0.169	0.166	0.169	0.165	0.167	0.164	0.166	0.170	0.168	0.167	0.001	0.168	0.167	0.002
7																			
TOP	0.167	0.168	0.169	0.169	0.167	0.169	0.170	0.167	0.169	0.166	0.177	0.168	0.167	0.168	0.169	-0.001	0.168	0.169	-0.001
MID	0.164	0.167	0.168	0.168	0.168	0.168	0.168	0.166	0.167	0.164	0.167	0.165	0.164	0.167	0.166	0.001	0.168	0.165	0.002
BOT	0.166	0.166	0.169	0.170	0.170	0.168	0.170	0.168	0.169	0.165	0.167	0.166	0.166	0.168	0.167	0.001	0.169	0.167	0.002
AVE	0.166	0.167	0.169	0.169	0.168	0.168	0.169	0.167	0.168	0.165	0.170	0.166	0.166	0.168	0.167	0.001	0.168	0.167	0.001

closely approximating the 1994 fire-side data. Therefore, it can be concluded that no measurable wear resulted from operation of the GR-SI and the process error assumption stated above is admissible.

3.3.6 Baseline Wear Rate

EER's Host Agreement with CWLP requires an evaluation of the baseline degradation rate of the various boiler tubewall thicknesses. The data obtained through this evaluation is presented in Table 4. An assumption is made in the evaluation that the boiler operated at a high capacity from 1960 to 1980 and a low capacity from 1980 to 1991. The wear rate calculations are performed accordingly. Initial tube thicknesses are based on specifications from the boiler Original Equipment Manufacturer (OEM), the Babcock & Wilcox Company. Current tube thickness are obtained from the recent U.T. measurements (see Section 3.3.4), conservatively using the lower of the 1991 and 1994 measurements.

3.3.6.1 Original Tube Specification

In Table 4, the original tube specification thickness are listed as maximum and minimum. The minimum values are the specified OEM minimum thickness for each tube. The maximum thickness number represents the minimum thickness plus a margin that tube manufacturers used to assure that the tubes meet thickness tolerance. For the floor tubes, this margin represents an additional 0.005 inches or 5 mils. For all other tubes, the values represent an additional 10 mils. In 1960 when this boiler was erected, the tube suppliers commonly added 10 mils to the specified thickness to assure that the tubes were supplied to the buyer with the minimum specified wall thickness. In 1980, when the floor tubes were replaced, tube manufacturers possessed improved control over their manufacturing processes and commonly added only 5 mils to the specified thickness.

Table 4. Baseline Tube Degradaton Rate

Location No.	Location Description	Original Tube Spec Max	Original Tube Spec Min	1980 Thk Max	1980 Thk Min	1991-1994 Min. Mean	1960-1980 Max	1960-1980 Min	1980-1991 Max	1980-1991 Min
		Mils		Mils		Mils	Mils/Yr		Mils/Yr	
1	Furn Floor '	285	280	281	280	280	N/A	N/A	0.07	0.00
1	Furn Floor '	285	280	178	278	277	N/A	N/A	0.11	0.04
2	Lwr Furn Wall N	290	280	276	274	273	0.69	0.29	0.22	0.09
2	Lwr Furn Wall S	260	250	219	217	210	2.04	1.63	0.66	0.00
2	Lwr Furn Wall E	260	250	220	218	211	2.00	1.59	0.64	0.00
2	Lwr Furn Wall W	260	250	223	221	215	1.84	1.43	0.00	0.00
3	593 N. Furn Wall	175	165	169	168	168	0.29	0.00	0.09	0.00
3	593 S. Furn Wall	210	200	203	202	202	0.33	0.00	0.00	0.00
3	593 E Furn Wall	175	165	172	171	171	0.16	0.00	0.05	0.00
3	593 W. Furn Wall	175	165	172	171	171	0.16	0.00	0.05	0.00
3	593 R Wing Wall	175	165	155	153	150	1.02	0.61	0.33	0.20
3	593 F Wing Wall	330	320	311	309	307	0.94	0.53	0.30	0.17
4	608 N Furn Wall	175	165	168	166	166	0.37	0.00	0.12	0.00
4	608 W Furn Wall	175	165	169	168	168	0.29	0.00	0.09	0.00
4	608 SH E Wall	175	165	168	166	166	0.37	0.00	0.12	0.00
4	608 SH 1st Rowl	250	240	236	234	233	0.69	0.29	0.00	0.00
4	608 R Wing Wall	175	165	168	166	166	0.37	0.00	0.12	0.00
4	608 F Wing Wall	330	320	319	318	317	0.53	0.12	0.17	0.04
4	608 SH Screen	175	165	173	172	172	0.12	0.00	0.04	0.00
5	615 SH 1st Row	250	240	237	236	236	0.57	0.16	0.18	0.05
5	614 SH Screen	175	165	169	169	169	0.24	0.00	0.08	0.00
5	615 Front Wing	330	320							
5	614 Rear Wing	175	165	170	170	170	0.20	0.00	0.07	0.00

Table 4. Baseline Tube Degradaton Rate

Location No.	Location Description	Original Tube Spec		1980 Thk		1991-1994	1960-1980		1980-1991	
		Max	Min	Max	Min	Min. Mean	Max	Min	Max	Min
		Mils		Mils		Mils	Mils/Yr		Mils/Yr	
6	621 Pri SH Inlet	250	240	229	229	229	0.86	0.45	0.28	0.14
6	620 Pri SH Inlet	175	165	168	167	165	0.41	0.00	0.13	0.00
6	620 Pri SH Inlet	175	165	169	168	168	0.29	0.00	0.09	0.00
7	612 Pri SH Inlet	175	165	187	187	187	0.00	0.00	0.00	0.00
8	616 Pri SH Inlet	175	165	203	201	198	0.00	0.00	0.00	0.00
9	620 Pri SH Inlet	175	165	192	192	192	0.00	0.00	0.00	0.00
7	612 SSH Outlet	330	320	311	311	311	0.78	0.37	0.25	0.12
8	616 SSH Outlet	250	240	245	245	245	0.20	0.00	0.07	0.00
9	620 SSH Outlet	250	240	245	245	245	0.20	0.00	0.07	0.00
10,11	616 Pri SH Out	210	200	185	185	185	1.02	0.61	0.00	0.00
10,11	620 Pri SH Out	175	165	175	175	175	0.00	0.00	0.00	0.00

3.3.6.2 Current Tube Thickness

Ultrasonic thickness readings of boiler tubes were obtained in fall of 1991 and again in the fall of 1994. Table 1 lists a summary of the data for 12 different locations in this boiler. The table contains averages, means, standard deviations, and sample sizes. For wear rate calculations, the minimum mean values between the 1991 and 1994 data have been conservatively selected in order to maximize the tube degradation rate. Note that EER has found no change in wear rate resulting from operation of the GR-SI system (1991 to 1994) (See Section 3.3.5), validating this approach.

3.3.6.3 Unit Capacity Factor

CWLP supplied EER with unit generation of net kilowatt hours for the years of 1980 through 1994. The capacity factors per year vary from 15.06% to 46.64% with a weighted average computed as 25.77%. The capacity factors from 1960 to 1980 were not available. Therefore an assumption was made for this period that the overall weighted capacity factor was 80%. EER believes that during this period Units 7 & 8 were the newest units in the CWLP system and were the primary boilers employed to generate electricity.

While the overall tube degradation from 1960 to 1991/1994 is measured and known, the calculated degradation rates are effected by the varying capacity factors. If the 1960 to 1980 capacity factor is greater than the 1980 to 1991/1994 capacity factor, calculated tube wear will be greater for that period. The opposite is true if the earlier capacity factor is less than the known 25.77% for the latter period. With the latter period experiencing a lower capacity factor, the tube wall degradation rate compared to the earlier period will be lower.

3.3.6.4 Tube Degradation Rates

The degradation rates are presented as mils per year for different sections in the boiler. The minimum means between 1991 and 1994 are listed and represent the only measured values of the tubes. The other "known" tube wall thickness values are from the original tube specifications. These specification values are shown as minimum and maximum. The minimum values are the specified numbers from the OEM. The maximum original tube wall thickness values represent the specified thickness plus the additional margin used by the manufacturer to assure that the tubes possess the minimum required thickness. This margin is 10 mils except for the newer floor tubes supplied in 1980 which have a margin of 5 mils.

Since there are two values for the original tube specification, there are also two values for the calculated tube wall degradation rates. The maximum degradation rates represent the tube wear resulting between the original maximum tube wall specification (Minimum thickness specification plus margin) and the 1991/1994 value (minimum). Conversely, the minimum degradation represents the thickness difference the specified minimum and the 1991/1994 value. The values for the 1980 wall thickness are calculated by pro-rating the two wear rates.

3.3.7 Wear Rate Projection

Table 5 presents the projected tube wall thickness at the end of boiler life, December 31, 2023. These predictions are based upon a continued unit capacity of 25.77% and the calculated wear rate of the 1980 to 1994 period (See Table 4). Also presented in this figure is a "Flag Point" value of the tube wall thickness. This flag point represents a value that is 70% of the specified tube wall thickness for saturated service. For superheated service this flag point represents 80% of the specified tubewall thickness. EER has selected these Flag Points as the lowest allowable tube wall thicknesses for operating this boiler.

The greatest calculated degradation rates occur in the lower furnace south and east wall tubes (location No. 2) at approximately 2 mils per year. Even with this high degradation rate, the tube wall thickness is expected to remain above the flag point throughout the expected life of the boiler. The projected tube wall thickness for these tubes at December 31, 2023 is 190 mils, approximately 15 mils above the flag point.

Table 5. Tubewear Predictions

Location No.	Location Description	1991-1994 Min Mean Mils	1991 - 2023 Wear Rate Max	Min Mils/Yr	2023 Thickness Max	Min Mils	Flag Point Mils
1	Furn Floor	280	0.07	0.00	280	278	196
1	Furn Floor	277	0.11	0.04	276	274	196
2	Lwr Furn Wall N	273	0.22	0.09	270	266	196
2	Lwr Furn Wall S	210	0.66	0.53	194	190	175
2	Lwr Furn Wall E	211	0.64	0.51	196	192	175
2	Lwr Furn Wall W	215	0.59	0.46	201	197	175
3	593 N. Furn Wall	168	0.09	0.00	169	165	116
3	593 S. Furn Wall	202	0.11	0.00	203	199	140
3	593 E. Furn Wall	171	0.05	0.00	173	169	116
3	593 W. Furn Wall	171	0.05	0.00	173	169	116
3	593 R. Wing Wall	150	0.33	0.20	144	140	116
3	593 F. Wing Wall	307	0.30	0.17	302	298	224
4	608 N Furn Wall	166	0.12	0.00	166	162	116
4	608 W Furn Wall	168	0.09	0.00	169	165	116
4	608 SH E Walll	166	0.12	0.00	166	162	116
4	608 SH 1st Wall	233	0.22	0.09	230	226	168
4	608 R Wing Wall	166	0.12	0.00	166	162	116
4	608 F Wing Wall	317	0.17	0.04	316	312	224
4	608 SH Screen	172	0.04	0.00	175	171	116
5	615 SH 1st Row	236	0.18	0.05	234	230	192
5	614 SH Screen	169	0.08	0.00	171	167	132
5	615 Front Wing						224
5	615 Rear Wing	170	0.07	0.00	172	168	116

Table 5. Tubewear Predictions

Location No.	Location Description	1991-1994 Min Mean Mils	1991 - 2023 Wear Rate Max Mils/Yr	1991 - 2023 Wear Rate Min Mils/Yr	2023 Thickness Max Mils	2023 Thickness Min Mils	Flag Point Mils
6	621 Pri SH Inlet	229	0.28	0.14	225	221	192
6	620 Pri SH Inlet	165	0.13	0.00	165	161	132
6	620 Pri SH Inlet	168	0.09	0.00	168	165	132
7	612 Pri SH Inlet	187	0.00	0.00	196	187	132
8	616 Pri SH Inlet	198	0.00	0.00	211	198	132
9	620 Pri SH Inlet	192	0.00	0.00	203	192	132
7	612 Pri SH Outlet	311	0.25	0.12	307	304	256
8	616 Pri SH Outlet	245	0.07	0.00	247	243	192
9	620 Pri SH Outlet	245	0.07	0.00	247	243	192
10, 11	616 Pri SH Out	185	0.00	0.00	179	185	160
10, 11	620 Pri SH Out	175	0.00	0.00	179	175	132

3.3.8 Conclusions

The purpose of this analysis is to determine the tube wear, if any, resulting from operation of the GR-SI system. Through examination of the difference in means between the pre- and post-test data, the potential for tube wear in some zones is indicated. However, this conclusion is discounted based on the following three factors:

- The Null hypothesis analysis of the difference in means has determined that all except three differences are not sufficient to indicate measurably significant wear. The highest potential tube wear is .007".
- All differences in means are within a boundary established by the accuracy of the of the process; i.e., .010".
- An evaluation of tube sample specimens local to the highest potential tube wear determined indicate that there is no measurable wear.

A second part of the analysis was to determine the baseline tube wear and project this wear to the end of the useful boiler life. A range of baseline tube wear was calculated using the maximum and minimum as-installed thickness (See Section 3.3.6.1). Historical capacity factor information was used to perform this calculation. When projecting the life of the tubes, the data indicate that the scheduled life of the boiler has not been compromised either with or without use of the GR-SI system.

4.0 REGENERATIVE AIR HEATER

The air heater on Lakeside Unit No. 7 is a regenerative, basket-type designed by ABB Air Preheater. The unit has a vertical shaft arrangement, rotating in the horizontal plane, with vertical gas and air inlet and outlet ducts. Recognizing the increased particulate loading (sorbent) to be experienced during the test program, the air heater cleaning equipment was inspected by ABB Air Preheater in February of 1991. Several repairs were recommended by the vendor based on this inspection and the anticipated future service. In November of 1991, EER contracted Air Preheater for replacement parts and field service for supervision of the parts installation by the utility maintenance staff.

Following completion of the GR-SI test program and additional sorbent injection tests performed for The Illinois Clean Coal Institute, the utility contracted ABB Air Preheater to conduct an inspection in order to assess the impact of the test program on the unit. This inspection was completed during the boiler outage held in October of 1994. Results of each inspection are detailed below, with copies of the vendors inspection reports provided in the Appendices F and G.

4.1 1991 Inspection

A complete inspection was performed on the air heater sootblowing equipment including the blower lance and nozzle, the drive system, and mounting brackets. The lance was found in good condition with only a minor amount of wear to the nozzle. The lance sweep was tested electrically and sweep limits re-adjusted to provide full coverage of the baskets. During this process significant wear was noted in the mechanical linkage which operates the lance. The sootblower drive system components comprised of the gear drive and speed reducer were opened, cleaned, found in good condition, and re-lubricated. The drive system mounting bolts were tightened to the correct torque and dowel pins were secured. During the inspection of the lance it was noted that the air heater cold end radial seals had eroded and replacement was recommended.

Based on the findings of the inspection and recommendations of the vendor and the expected increased service and reliability required by this equipment during GR-SI operation, EER procured the following replacement parts for installation by the utility and contracted ABB Air Preheater to oversee the installation;

- Cold end radial rotor seals with new holding strips and fasteners
- Sootblower lance connecting linkage arm and bushings
- Linkage arm pin and eccentric arm pin
- Cleaning medium joint ball swivel

Due to the anticipated increased level of sootblower operation, ABB Air Preheater recommended several spare parts to be stocked by the utility (see report for description). The utility did not require the test program to maintain the recommended spare parts inventory.

4.2 1994 Observations

ABB Air Preheater Company was contracted by the utility to perform an air heater inspection to assess any impact of GR-SI operation on the condition of the unit. This inspection included the air heater baskets, rotor, and rotor seals. All cold end heating baskets were found free of deposits except in the area inboard of the sootblower travel. Several cold end "B" baskets were removed to check the top of the hot end baskets. No fouling or mechanical degradation was found. Inspection from the hot end revealed deposits in the inboard eight inches of several "A" baskets. These deposits were noted as characteristic of an incomplete previous washing. Two areas of mechanical degradation were found that are indicative of excessive dwell time of the sootblower lance at the point of innermost travel. This degradation included erosion at the cold end and element sheets in "A" baskets at the hot end which were driven down over the basket spider bars. Air Preheater recommended installation of a plate at the cold end over this section of the baskets to prevent further degradation.

Radial, circumferential and post seals were found in good condition. No seal clearance problems were noted as a result of wear. Air Preheater recommended re-setting cold end circumferential seal clearances.

Air Preheater noted continued degradation of weld repairs made to the diaphragms in 1985. A complete description of weld fractures is provided in the vendors report. Air Preheater has made long term recommendations for repair of the diaphragms which included installation of inserts or at least additional diaphragm support.

No adverse conditions were noted as a direct result of GR-SI operation. The minor basket degradation noted above resulted from the excessive dwell time of the sootblower lance at the innermost position, for which ABB Air Preheater has offered an inexpensive modification. This situation would occur with or without GR-SI operation, but increased sootblowing requirements due to GR-SI operation have most likely accelerated degradation. The continued degradation of the diaphragm weld repairs is the result of flexing of the diaphragms during normal operation as the diaphragms rotate from the gas and air sides; the degree of flexing is proportional to the air-to-gas side differential pressure. EER test data indicates that this differential pressure was not adversely affected during GR-SI operation and therefore did not contribute to the continued degradation of the diaphragms and weld repairs.

4.3 Conclusions

Should the utility decide to retain the sorbent injection system, EER recommends installation of wear plates at the inboard extent of the sootblower travel to protect the basket elements.
This recommendation is based on the increased air heater sootblower operation necessary with sorbent injection.

The diaphragm problem noted above and also in the Air Preheater report pre-existed GR-SI operation by eight years. Air Preheater informed EER that at the time of the 1985 repairs the utility opted for the less preferred (by APH Co.) and less costly repair method, and the failures found during the last inspection are not unexpected. GR-SI operation can be excluded as the root cause of this situation.

5.0 ELECTROSTATIC PRECIPITATOR

The precipitator which services the Lakeside station was inspected on two occasions during the test program. The precipitator is a F.L. Smidth design and was originally sized to service all four Lakeside units. Two of the Lakeside boilers have been removed from service, so the ESP is now generously sized for the current ash loading and has accommodated dry sorbent injection without any type of performance enhancement (i.e., flue gas conditioning).

The first inspection was completed by AirPol Inc. on November 12 and 13 of 1991, following completion of the gas reburning-sorbent injection (GR-SI) parametric test series. The second (final) inspection was completed on October 28, 1994 by EPSCON-FLS, Inc., following completion of the GR-SI long term tests and additional sorbent injection tests performed by EER for the Illinois Clean Coal Institute (ICCI). It should be noted that despite the inspections being contracted to two different firms, the actual inspections were completed by the same individual. Both inspections were predominately mechanical in nature but included inspection of the high voltage support insulators. A copy of both inspection reports (with photos) is provided in the Appendices H and J.

5.1 1991 Observations

The first inspection found the unit to be in very good overall condition. Maintenance recommendations included removal of links on the internal and external (drive) chains to achieve proper chain tension and adjustment of the guide rollers on the external drives. Dust build-up was noted on the inlet screens and on the second field collecting plates. Recommendations were made to rap these areas prior to unit start-up. All high voltage support insulators were found in good condition.

5.2 1994 Observations

This inspection was intended to compare the precipitator condition to that noted above and the inspection following one year of long term GR-SI operation. The most notable change was the inordinate amount of ash and sorbent material remaining on the collecting plates, outlet screens, outlet nozzle, and ash hoppers. EPSCON attributed the build-up on the collecting plates to the condition of the rapping system. Several of the chains on the external drives were either broken or stretched to the extend that they would jump teeth during operation, resulting in poor rapping. Maintenance is also required on the internal drive shaft bearings and drive chains. It should be noted that the increased ash accumulation was not evident on the discharge electrodes despite the noted condition of the associated rapping drives. The utility has speculated that some other mechanism may be responsible for the ash build-up on the outlet screen and in the ash hoppers, i.e., operating below the acid dew point with only one boiler in service. Recommendations were made to complete a power-off rap of the unit, perform a second inspection of the internal rapping system, and restore all components of the rapping system to original capability for future service.

EPSCON also completed an inspection of the high voltage support insulators and found conditions acceptable as in the 1991 inspection.

The utility took exception to some of the findings and recommendations in the 1994 inspection report provided by EPSCON since the report reflected conditions which were contrary to feedback provided by the plant maintenance staff. CWLP held a meeting of maintenance staff to review the EPSCON report and identify the necessary corrective actions. The results of that conference have been provided by the utility in the form of meeting minutes, a copy of which are provided in the Appendix J.

Due to the differences between EPSCON and the utility regarding the inspection report, EER contacted EPSCON and requested a review of the report based on the exceptions noted by CWLP. EPSCON has provided clarification on several of the exceptions offered. None of these issues reflect upon the GR-SI the test program, but are offered here for the benefit of the utility.

1. Recommendations were made by EPSCON for replacement of several of the internal rapper shafts. Being cast iron, the shaft support bearings take the predominate portion of the wear, but some shaft wear is possible. It is the EPSCON inspector's opinion that wear on some of the shafts was significant and some shafts could not be inspected due to the high dust levels. When bearings have worn on both sides and must be replaced since the clearance has exceeded the limits as prescribed in the FLS manual, the shaft has usually worn to a point that a special replacement bearing is required which incorporates a sleeve to fit over the shaft in the area of wear. Several bearing replacements may have to take place before the shaft wear is significant. Since the shaft is worn, replacement with a standard bearing will result in wear tolerances being met before the bearing surface is completely worn, requiring early replacement. The entire shaft must be removed for installation of a more expensive, special bearing and it is therefore cost effective to replace the shaft and the bearings at the time that shaft wear is unacceptable.

2. The maximum wear on any one side of a slide bearing is 5/16". The 1" measurement referred to in the manual is from the bottom of the shaft to the bottom of the bearing housing representing the maximum allowable bearing wear.

3. EPSCON reviewed the design drawings for this precipitator with regard to the rapper hammer attachment. Keys are provided on the rapper shafts to prevent lateral movement of the hammers, and are not designed to prevent the hammers from turning on the shafts. If the hammers come loose and can turn on the shafts, they will eventually be stopped (in-line) by the keys designed to limit lateral movement. According to EPSCON, the hammers should be angularly staggered around the shaft in equal arcs of separation. This staggering limits the re-entrainment factor as the rapping of plates in the same field do not occur at the same time. If the hammers are allowed to turn and align at the same position on the shafts, the downstream fields may be overloaded during rapping leading

to opacity spikes. This effect may not be apparent on the Lakeside unit due to the sizing of the precipitator and loading with only one or two boilers in service.

4. Replacement of rapper drive chains is mentioned in several locations in the EPSCON report. Aside from the chains which had obviously failed, it was the opinion of the inspector that several of the chains that were apparently intact had worn to the point of unacceptable stretch and reliability. Once a chain has stretched to the point that no further adjustment of the idler sprocket will provide the required tension, it is possible that the chain will slip around the drive or driven sprockets and reduce the desired rapping. Once a chain has worn to this point, it is also more likely to fail under load and not be noticed for some time during precipitator operation.

5. The inspector noticed the high amounts of dust accumulation at the outlet screen and nozzle, recognizing this as an unacceptable condition for a normal installation since gas flow may be adversely affected. Upon further consideration of the original precipitator sizing and service load (four boilers), the velocities through the precipitator with one or two boilers in operation is considerably lower than design, and fallout due to lower velocities is most likely responsible for this situation. Also due to the sizing of the unit, this accumulation most likely does not have an adverse impact on gas pressure drops through the unit.

5.3 Conclusions

Results of the first precipitator inspection performed after several months of GR-SI parametric testing indicated that the precipitator had accommodated the changes in ash loading and resistivity with the presence of reacted (and un-reacted) sorbent in the ash, as evident by the lack of ash accumulation as found in the second inspection. It is speculated that the accumulation found during the second inspection is a result of any one or combination of the following:

- Degraded performance of the rapping system

- Higher levels of ash loading with long term and continuous sorbent injection testing

- Higher levels of moisture in the flue gas as a result of boiler tube leaks (as found in the October 1994 boiler outage inspection)

- Adverse changes in fly ash resistivity and other properties as a result of injection of the NovaCon sorbent materials (just prior to ESP inspection)

- Operation of the precipitator at or below the acid dew point with lower loads or one unit in service

Being reserve units, Lakeside has historically operated at a lower than average capacity factor and precipitator maintenance schedules may have been adjusted accordingly prior to initiation of GR-SI testing. The GR-SI test program added significant operating time beyond what would have been normally experienced in that time period and maintenance schedules may not have been re-adjusted. Should the utility consider full time GR-SI operation, several changes should be incorporated to increase the performance of the precipitator. The utility has already implemented most of the necessary repairs and increased preventative maintenance plans. Consideration should be given to optimizing the precipitator rapping scheme during sustained sorbent injection and evaluating precipitator operating temperatures as the possible root cause of the ash build-up noted on the final precipitator inspection.

6.0 CHIMNEY

The chimney which services Lakeside Units 7 & 8 was inspected on two occasions during the test program. The first inspection was conducted in October of 1991 following completion of the gas reburning-sorbent injection (GR-SI) parametric test series. The second and final inspection was completed in October of 1994 following completion of the GR-SI long term testing and additional sorbent injection testing conducted by EER for the Illinois Clean Coal Institute (ICCI). Both inspections were completed by International Chimney Corporation. Copies of the inspection reports (with photos) are provided in the Appendices K and L.

6.1 1991 Observations

As reported by International Chimney, the Lakeside stack was found to be in good operating condition. The concrete column was generally found in solid and sound condition. Two normal stress relief cracks were found in the concrete column. A complete description and location of these cracks is provided in the report. The coating on the exterior of the column was found to be tightly bonded but has faded and discolored with time. Inspection of the steel chimney cap revealed that the seam which attaches the outer skirt to the cap was approximately 80% deteriorated. Weld repairs were recommended by the inspector. The steel chimney lining was found to be in good condition with ultrasonic thickness measurements made at ten foot (10') intervals from the chimney top to the false bottom. The ladder and platform system were found intact but rusting freely especially in the top third of the stack.

The lightning protection system was found intact, but it was noted that the six air terminals were severely deteriorated with the lead coating absent and the rods thinning. Two anchors on the encircling cable and down lead were broken. The inspector recommended replacement of the air terminals and repair of the cable anchors.

6.2 1994 Observations

The second inspection in the Fall of 1994 also found the chimney in good operating condition. No changes were found in the stress cracks of the concrete column that were observed during the initial inspection of 1991. Condition of the concrete coating was reported the same as that found earlier with some minor peeling noted at the top of the column. Based on recommendations as a result of the first inspection, the utility had made repairs to the weld seam on the steel chimney cap. The ladder and platform system continues to rust freely, but was found to be sound. An inspection was again made of the steel chimney lining with ultrasonic thickness measurements being made at ten foot intervals from the top to the false bottom. In light of the accuracy of the measurement equipment and procedures, comparison of the thickness readings indicate no appreciable wastage of the steel chimney liner over the test period.

The lightning protection system was found essentially in the condition as noted in 1991, with the exception that a total of nine encircling cable anchors were found broken at the time of the inspection.

6.3 Conclusions

Based on the inspections performed, the chimney shows normal wear and deterioration over the period of the test program, indicating no adverse effects from GR-SI operation. The inspector has made general recommendations for repairs to preserve the present good condition and extend the life of the column. These repairs include:

- Installation of a new coating system throughout the top of the column including the platform and columns. This coating would seal the existing stress cracks, preventing any growth from weathering, and would also extend the life of the ladder and platform system.

- Replacement (or removal) of the air terminals of the lightning protection system, and repairs to the cable anchors.

7.0 BOILER PERFORMANCE

7.1 Cooling Requirements

The retrofit of Gas Reburning-Sorbent Injection System (GR-SI) to Lakeside Unit 7 has resulted in the installation of several furnace wall openings. Many of the components in these openings are not water cooled and require protection from the hot furnace gases. Such openings include gas reburning, OFA, and sorbent injection nozzles, and test ports, temperature ports, etc. During GR-SI operation these components are cooled by the input fluids. Natural gas cools the reburning nozzles, overfire air cools the OFA nozzles, and sorbent injection air cools the sorbent injection nozzles. Furnace ports for testing and temperature monitoring are cooled by seal air during both GR-SI operation and non GR-SI operation.

During non GR-SI operation a protective cooling air blanket is directed to and through the GR-SI furnace wall openings to provide the required protection from the hot furnace gases. The protective blanket for the overfire ports uses a small amount of hot secondary air that passes through the OFA control dampers. The dampers have a minimum open position which assures enough air passage to give a velocity of 50 ft/sec or greater through the ports. The remainder of the GR-SI furnace wall openings are protected by cold seal air. Seal air originates from the Forced Draft Fan outlet and is transported via piping to the seal boxes of the different tubewall openings. Without this protection, hot flue gases under positive pressure would be forced from the furnace enclosures and cause overheating of the non-water cooled components.

7.2 Excess Air/Unit Thermal Efficiency

While protective air is not part of the combustion stream, it adds to the excess air resulting in increased flue gas flow through the convection passes and out the stack and increases the energy lost to the environment. The extra excess air and increased losses can be expressed in the following terms:

Increased excess O_2	Approximately 2 per cent
Increased excess air	Approximately 14 per cent
Increased flue gases	Approximately 47,500 lbs/hr
Decreased thermal efficiency	Approximately 0.6 per cent

These increased excess air quantities and energy losses will remain as long as the GR-SI furnace tubewall openings remain and the unit is operated in a non GR-SI mode. If all of the openings are closed off (replaced with refractory), these losses will be eliminated. If part of the openings are closed off, then a portion of these losses will be eliminated.

The seal air, increased excess O_2, increased excess air, and decreased efficiency per GR-SI furnace wall opening type are displayed in the table below:

GR-SI PROTECTIVE COOLING AIR

	Quantity Lbs/Hr	Excess O_2 %	Excess Air %	Δ Efficiency %
		Hot Secondary Air		
OFA	23,400	0.98	6.9	-0.295
		Seal Air		
FTT	600	0.03	0.2	-0.008
FGR	5,800	0.24	1.7	-0.074
SI	11,800	0.50	3.5	-0.149
TEST	5,900	0.25	1.7	-0.074
		Total Cooling Air		
TOTAL	47,500	2.00	14.0	-0.600

This table is presented to assist CWLP in deciding which type (if any) of GR-SI openings to close off during restoration. Four possible scenarios can be discussed. >

<u>Scenario 1</u> Maintain all GR-SI Openings

CWLP retains the ability to operate both the gas reburning and sorbent injection systems. In addition, test ports remain for temperature test and flue gas analysis. During non GR-SI operation, flue gas flow increases due to seal air requirements.

Efficiency is decreased by 0.6 per cent.

<u>Scenario 2</u> Maintain all GR-SI Openings except FTT and Test Ports

This is very similar to Scenario 1 except furnace openings for temperature test and flue gas analysis have been removed.

Efficiency is decreased by 0.52 per cent.

<u>Scenario 3</u> Maintain FGR and OFA Ports

CWLP retains the ability to operate the gas reburning system. The ability to operate the Sorbent Injection System, temperature test furnace flue gas analysis will be removed.

Efficiency will be reduced by 0.37 per cent.

<u>Scenario 4</u> Maintain only the OFA Ports

CWLP retains only the OFA ports. Gas reburning, sorbent injection, temperature test and gas analysis will not be available.

Efficiency will be reduced 0.3 per cent.

7.3 Conclusions

In the restoration decision, the impact of cooling air must be considered along with the anticipated use of all or part of the GR-SI system. If either or both of the gas reburning or sorbent systems are retained and are expected to be available for immediate operation, the injection nozzles and the respective cooling air systems must be left intact. Should either system be retained, but operation is reserved for a later time, operational benefits are gained by removing the injection nozzles for that system and subsequently the associated cooling air for that system. Boiler wall boxes from which nozzles are removed can be sealed with refractory castings which bolt directly to the wall box flanges. These castings were used during the original GR-SI system installation and have been retained in the on-site warehouse facility. The design of the gas and sorbent injection nozzles are well suited for this procedure. The overfire air system, however, does not incorporate nozzles which are separate from the duct work, and an alternative procedure would be necessary.

ENERGY & ENVIRONMENTAL RESEARCH CORPORATION

PROJECT CORRESPONDENCE

CCT GR-SI
CITY WATER, LIGHT, & POWER, LAKESIDE NO. 7
SPRINGFIELD, ILLINOIS

TO: Don Engelhardt
Orrville

DATE: November 2, 1994

CC: TMS
T. Booker - CWLP
B. Fitzgerald - CWLP

FROM: Elliott Mecchia
Joppa

SUBJECT: Lakeside No. 7 Boiler Inspection

During the recent planned outage on Unit No. 7 of City Water, Light, and Power's Lakeside Station, I performed two separate inspections of the boiler and have reported the findings below. I completed the first inspection shortly after arriving at the site on Monday, October 24. This inspection included only the lower furnace, and was done prior to the high pressure water wash and installation of the scaffolding and lighting. For the second inspection conducted Thursday, October 27, I was accompanied by Brian Fitzgerald of CWLP's engineering staff. Photographs were taken by myself on the first inspection and by Mr. Fitzgerald on the second. CWLP will arrange for development of all photographs and forward copies to the Orrville office. A copy of my photograph log for the first inspection is attached for your reference.

Furnace Inspection / Pre-Water Wash

1. No abnormal conditions were noted in the cyclone furnaces. Normal maintenance would be required for replacement of coal wear liners and cyclone tube pin and flat studs.

2. The cyclone throats and the lower furnace below the stud line were found in normal condition. Slag deposits on the lower furnace walls and floor indicated that the slag tap had been flowing freely.

3. Significant eyebrows were noted on all FGR/NG nozzles, with the heaviest deposits on the west rear wall and west side wall FGR nozzles. These deposits were large enough to obstruct the flow from the nozzles and would have required removal prior to FGR operation. The east nozzles had significant deposits, but the flow would not have been obstructed. All center NG nozzles were slagged over completely. Later inspection showed these nozzles to have their bores completely plugged with ash and slag.

4. The cooling water jacket on the east wall FGR nozzle was found to have a slow leak (weeping). This leak was on the bottom side of the nozzle at the weld interface of the end cap and outer tube of the nozzle. Flyash erosion of the cooling water jacket in the area of the leak was clearly evident. A weld repair of this nozzle was planned by the boiler contractor.

5. The presence of the FGR/NG nozzles has promoted slag deposition well above the stud line on the rear and side walls, completely around the nozzles and into the bottom of the rear furnace wing walls. The front slope wall and the remainder of the upper furnace were free of slag deposits with the exception of the lower portion of the east front wall division panel.

Boiler and Duct Inspection - Post Water Wash

1. The flue gas duct common to Units No. 7 and 8 was generally found to be clean. A 1 to 2" deposit of ash and sorbent was noted on the north side of the duct, downstream of the Unit No. 8 duct entrance. This deposit is most likely due to a recirculation flow in that area. The deposit was dry powder and easily moved. Small duct leaks were noted at the floor / wall joint at the east end of this common duct. Duct expansion joints were found in good condition. The Unit No. 7 damper frame channels were clear, suggesting good operation of the seal air fan.

2. An air heater inspection was being completed at the time of this inspection. Results are being forwarded under separate cover. Brian Fitzgerald noted that the top of the air heater (gas outlet - air inlet) was free of sorbent deposits, but that sorbent had apparently accumulated on the face surfaces of the gas inlet side of the air heater baskets and had been rotated into the clean air duct and deposited into the clean air duct downstream of the air heater. This deposit was mostly sorbent and was approximately 1 to 2" deep, and was removed by the boiler crew during the outage.

3. Inspection of the Over Fire Air and Sorbent Nozzles revealed no warpage or deterioration. A significant amount of ash carryover and deposition was noted in the overfire air ducts. This accumulation existed in the north-south runs of both ducts, primarily in the area of the pitot grids. The accumulation in the east duct was approximately 2 to 3", and nearly 12" deep in the west duct. These accumulations were loose, powdery deposits.

4. The generating bank and primary superheater were found in good condition. Several of the secondary superheater assemblies were found to be hanging out of plumb, significantly affecting the gas lane spacing. The SSH assembly at the east wall had three tubes at the rear of the assembly which were badly bowed out of the plane of the assembly, well into the gas lane.

Recommendations

1. The condition of the water jackets on the existing FGR nozzle should be monitored closely, since leaks can adversely affect the ability to tap slag and therefore unit availability. If the system is to be retained for future use with the water cooled nozzles in lieu of the ceramic nozzles, consideration should be given to the wear resistance capabilities of the nozzle portion in the furnace, such as materials of construction, wear plates on the underside of the nozzle, or addition of studs and refractory.

2. Depending on the system performance impact, consideration should be given to removal of the center gas only nozzles for future operation.

3. It may be possible to remove the ash deposits from the over fire air ducts during the next unit start-up by opening the control dampers to 100% open and maintaining a high velocity through the duct for a period of time.

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February 23, 1995

Mr. Elliott Mecchia, Performance Engineer
Energy & Environmental Research Corp.
1345 North Main St.
Orrville, Ohio 44667

Dear Mr. Mecchia,

Enclosed are two copies of our revised report 94-117, originally sent to you on December 29, 1994. Per your conversation today with Dr. French, I have made copies of the previously faxed revision and replaced the original text with the new one. The photos are the same.

After you have read the report, should you have any questions, please feel free to call and ask them. We are glad to help in any way that we can.

Very truly yours,

Louise M. French

Louise M. French, Corporate Factotum
David N. French, Inc., Metallurgists

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ENERGY & ENVIRONMENTAL RESEARCH CORP.
METALLURGICAL EVALUATION OF SELECTED TUBE SAMPLES FROM SPRINGFIELD, IL CITY WATER LIGHT & POWER LAKESIDE UNIT #7

P.O. NO. 70933-8659, REPORT 94-117

DNFrench.

David N. French, Sc.D., President
David N. French, Inc., Metallurgists
December 28, 1994

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ENERGY & ENVIRONMENTAL RESEARCH CORP.
METALLURGICAL EVALUATION OF SELECTED TUBE SAMPLES FROM SPRINGFIELD, IL CITY WATER LIGHT & POWER LAKESIDE UNIT #7

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INTRODUCTION

Table I lists the eight samples submitted. Tubes numbered 1 through 5 were removed after the test program, and Tubes 6, 7, and 8 were removed prior to the test program.

TABLE I

SAMPLES SUBMITTED

#1	Burnout zone, front wall, elev. 607'-9"
#2	Reburning zone, front wall, elev. 596'-0"
#3	Reburning zone, rear wall, elev. 586'-0"
#4	Reburning zone, east sidewall, elev. 586'-0"
#5	Lower-furnace zone, rear wall, elev. 572'-6"
#6	PRE-GR-SI-OFA overfire air zone, elev. 597'-9½"
#7	PRE-GR-SI-SI Tube 1, sorbent injection zone, elev. 613'-0"
#8	PRE-GR-SI-FGR reburning zone, elev. 586'-0"

CONCLUSIONS

1. No wastage was measured on any tubes except #3 and #4, and that wastage is slight, 0.015" and 0.025", respectively.
2. No evidence of any overheating on any tube. The microstructures on both the fireside and cold or casing side are normal ferrite and pearlite, and any differences tube-to-tube reflect only the final heat-treatment by the tubing manufacturer.
3. No thermal-fatigue cracks were noted at the refractory-retention studs on Tubes #5 and #8.
4. The ID scale contains metallic copper, suggestive or corrosion or leaks in the pre-boiler circuits tubed with copper alloys.
5. There is slight, less than 2 mils deep, ID pitting.
6. The OD wastage on Tubes #3 and #4 is uniform, with no preferential, grain-boundary oxidation or corrosion attack.
7. Based on the wastage noted in the reburn zone (Tubes #3 and #4), sulfur prints were made on all tubes from this area. All are positive for metallic sulfides, but Tubes #3 and #4 show higher levels of sulfides than Tube #8.

DISCUSSION

Figures 1 and 2 present the as-received tube samples. Ring sections were taken from each tube; and dimensional measurements of OD, ID, wall thickness, and Rockwell B hardness were made in six, equally spaced positions around the perimeter of each ring. These data are presented in

Table II. Tube-wastage measurements, the difference between the maximum and minimum wall-thicknesses measured, are presented in Table III. The wastage is quite uniform except for Tubes #3 and #4 removed from the re-burning zone at elevation 586 feet. All other wastage measurements are trivial, about 5 mils (0.005"). The OD and ID dimensions are quite uniform, as would be expected. There are some anomalies in the Rockwell B hardnesses, see for example Tubes #1, #2, and #7. As will be shown later, these soft regions are associated with the electric-resistance weld.

Small dents were noted in five tubes, #1, #2, #3, #4, and #5; and the ring sections taken through the dents were photographed on the three that were most easily visible, see Figure 3. The dents are quite shallow and pose no problem to fluid flow through the tube.

The microstructures are shown in Figures 4-15. The microstructures are all normal ferrite and pearlite, and any differences noted between tubes reflect the final heat-treatment by the tubing manufacturer. There is no difference between the hot and cold sides and no indication of any thermal abuse. The microstructures in the regions of the unusually low Rockwell B hardness indicate the remnants of an electric-resistance weld (ERW), see for example Figure 5 from Tube #1 and Figure 14 from Tube #7. This ERW zone is a region of low carbon, and ferrite is softer than a ferrite and pearlite mixture.

The microstructures through the fireside surface, Figures 16-21, show the lack of corrosion noted in Tubes #1, #2, #6, and #7. Figures 16, 17, 20, and 21 show that the decarburized layer formed during final heat-treatment by the manufacturer of the boiler tubing is still intact. Tubes #5 and #8 contain refractory-retention studs, and photographs of those are presented in Figures 22 and 23. There are no thermal-fatigue cracks at the interface between the stud and the tube OD.

Only Tubes #3 and #4 contain any measurable wastage, see Table III. Cross sections through the wasted areas, Figures 18 and 19, show the wastage to be reasonably uniform, with no preferential grain-boundary attack.

Sulfur prints were made on the rings from Tubes #3, #4, and #8, see Figures 24-26. All are positive for metallic sulfides, proof of reducing conditions in the reburning zone. Tubes #3 and #4 (Figures 24 and 25) show higher levels of metallic sulfides than Tube #8 (Figure 26). The presence of sulfides to a greater degree on Tubes #3 and #4 may partially explain the slightly higher wastage. Sulfides are inherently less protective than oxides.

(To make a sulfur print, a piece of photographic print paper is dipped in a 2% sulfuric-acid solution, and the excess acid wiped off. The tube sample is rough-polished - a 120-grit belt sander is satisfactory - pressed onto the damp photographic paper for a few seconds and removed. The paper is fixed as usual for photographic paper. What remains is an image of the sulfide distribution on the tube. Sulfuric acid reacts with metallic sulfides to form hydrogen-sulfide gas, and the hydrogen-sulfide gas reacts with the silver salts on the photographic paper to form silver sulfide, which is dark brown or black.)

Finally, representative ID surfaces are shown in Figures 27-29. The inevitable iron-oxide deposit is thin and tightly bound to the tube surface, with only minimal pitting noted. The depths of the pits are less than 3 mils (0.003"). The ID surface is essentially smooth with no serious corrosion noted on any of the eight tubes. There is metallic copper evident, the small white specks in the ID scale, especially notable in Figures 27 and 28, indicative of corrosion or leaks in the pre-boiler circuits tubed with copper alloys, that is, the feedwater heaters or condenser.

In summary, these tubes are in excellent metallurgical condition. There is virtually no wastage, that is 5 mils

(0.005"), measured on Tubes #1, #2, #5, #6, #7, and #8. Tubes #3 and #4 had 25 and 15 mils (0.025" and 0.015") respectively. This suggests that there may be a problem in gas flow or mixing past the rear and east walls in the reburning zone at elevation 586 feet. Other wall-thickness measurements should be made in-place to determine the wastage pattern. Other than that small difference noted in the wastage pattern, all other features are essentially the same tube to tube.

TABLE II

DIMENSIONAL MEASUREMENTS

TUBE	POSITION	OD, IN.	ID, IN.	WALL, IN.	R_B HARDNESS
#1	12:00	2.985	2.650	0.165	65.5
	2:00	2.970	2.630	0.165	53
	4:00	2.975	2.645	0.170	62
	6:00			0.165	63
	8:00			0.170	63
	10:00			0.165	64
#2	12:00	2.985	2.650	0.165	63
	2:00	2.960	2.625	0.165	67
	4:00	2.960	2.620	0.165	63
	6:00			0.165	62.5
	8:00			0.170	54
	10:00			0.165	57
#3	12:00	2.965	2.565	0.190	66
	2:00	2.950	2.530	0.195	70
	4:00	2.930	2.510	0.215	71
	6:00			0.205	68
	8:00			0.205	69
	10:00			0.195	68

TABLE II
(continued)
DIMENSIONAL MEASUREMENTS

TUBE	POSITION	OD, IN.	ID, IN.	WALL, IN.	R_B HARDNESS
#4	12:00	2.970	2.585	0.190	61
	2:00	2.915	2.520	0.190	67
	4:00	2.970	2.570	0.205	62.5
	6:00			0.195	66.5
	8:00			0.195	67
	10:00			0.195	61
#5	12:00	2.960	2.545	0.205	68
	2:00	2.965	2.550	0.205	67
	4:00	2.930	2.525	0.200	67
	6:00			0.205	67
	8:00			0.205	68
	10:00			0.205	68
#6	12:00	2.965	2.570	0.195	58
	2:00	2.960	2.570	0.195	58
	4:00	2.970	2.570	0.200	58
	6:00			0.200	57
	8:00			0.195	55
	10:00			0.200	57

TABLE II
(concluded)
DIMENSIONAL MEASUREMENTS

TUBE	POSITION	OD, IN.	ID, IN.	WALL, IN.	R_B HARDNESS
#7	12:00	2.975	2.640	0.165	60.5
	2:00	2.965	2.635	0.165	58
	4:00	2.970	2.640	0.165	62
	6:00			0.170	62.5
	8:00			0.165	52.5
	10:00			0.165	46.5
#8	12:00	2.965	2.540	0.210	68
	2:00	2.960	2.540	0.210	66
	4:00	2.960	2.535	0.215	65.5
	6:00			0.215	68
	8:00			0.210	67.5
	10:00			0.210	68

TABLE III

WASTAGE

TUBE	WASTAGE, MILS*
#1	5
#2	5
#3	25
#4	15
#5	5
#6	5
#7	5
#8	5

*Maximum wall-thickness measured minus minimum wall-thickness measured.

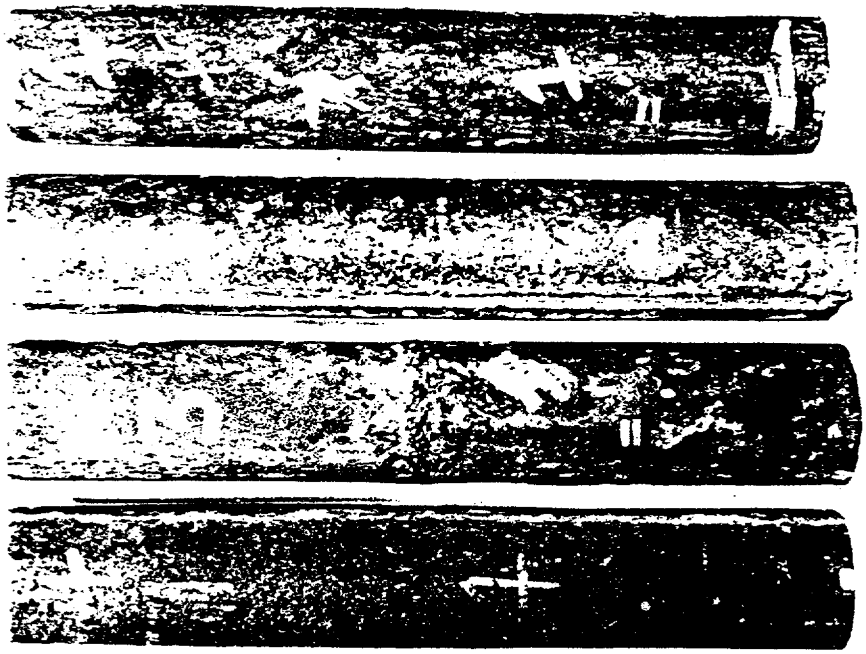

Figure 1. As-received tubes. 0.25x

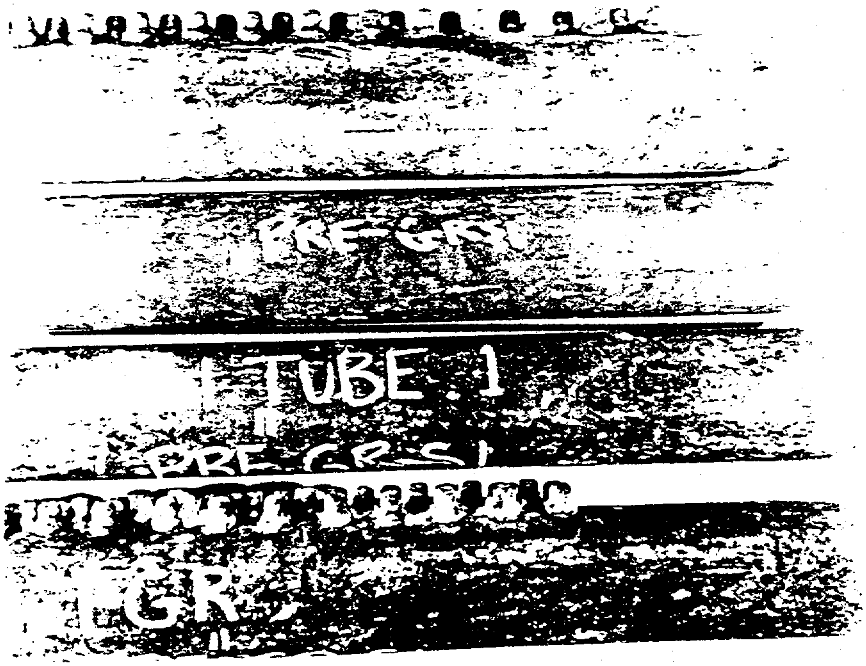

Figure 2. As-received tubes. 0.25x

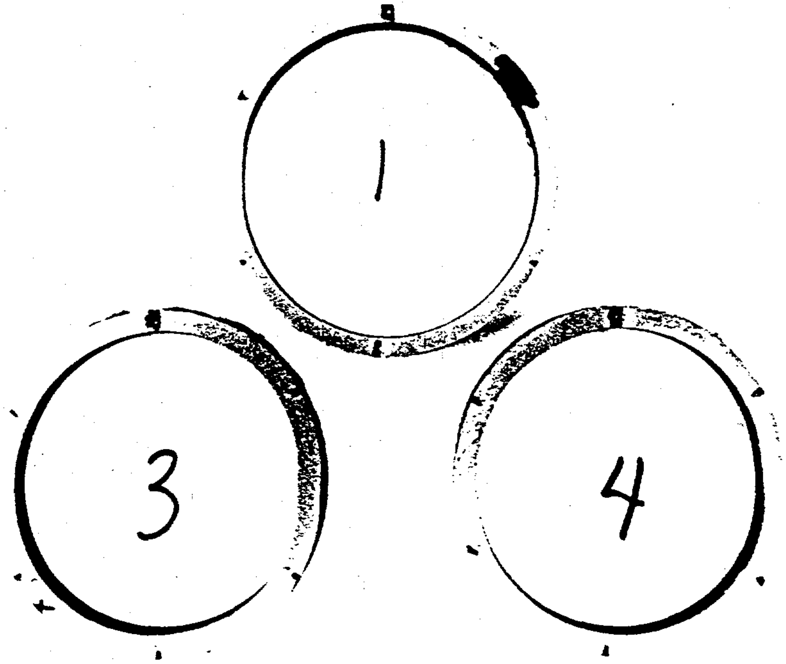

Figure 3. Rings through dents in Tubes #1, #3, and #4. Dents are quite small and are of no serious consequence. 0.6x

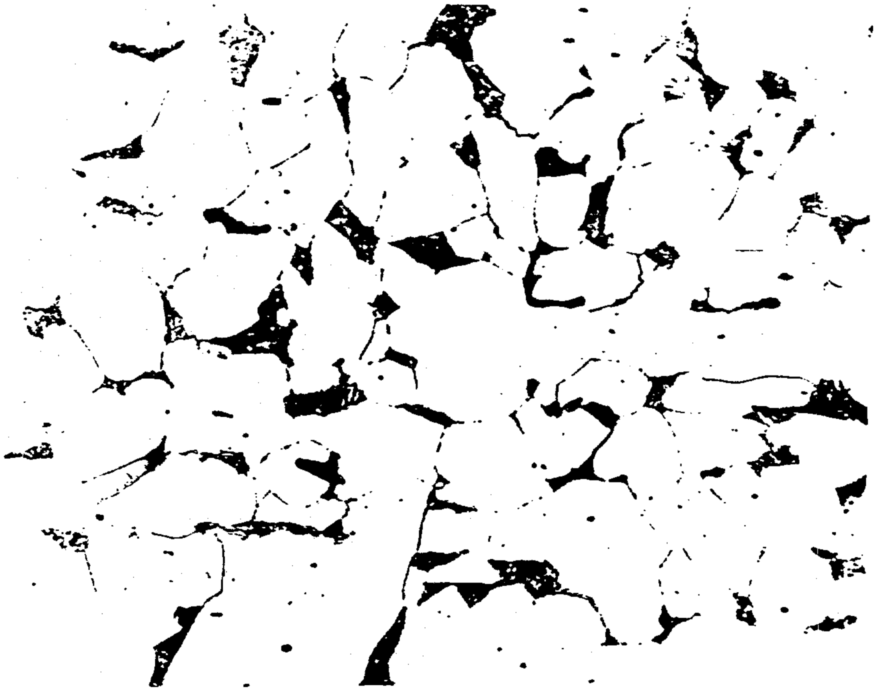

Figure 4. Tube #1, microstructure representative of whole tube. 500x, etched.

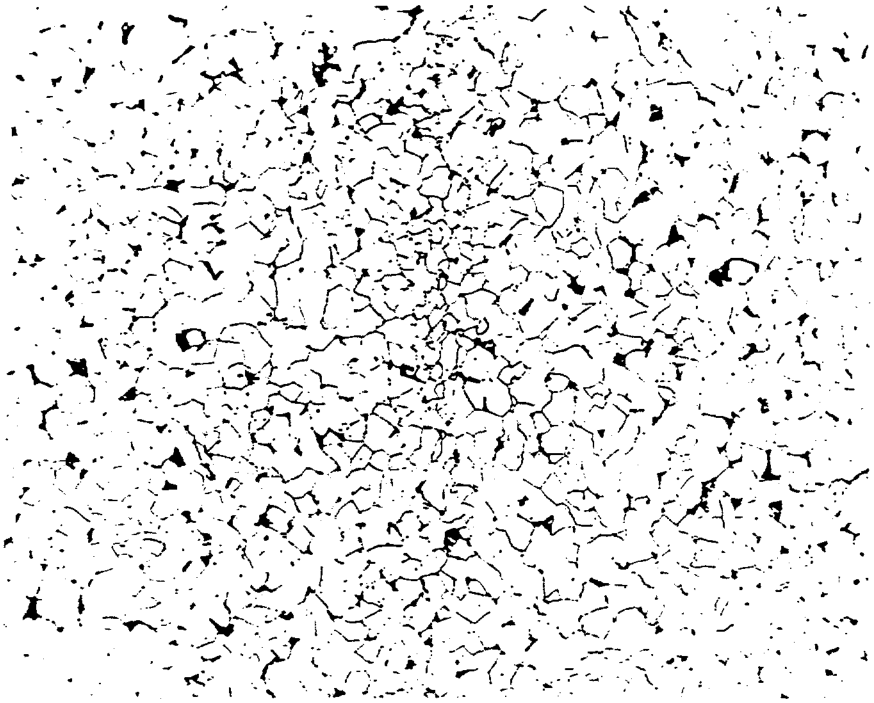

Figure 5. Tube #1 at ERW and low R_B hardness, see Table II. 100x, etched.

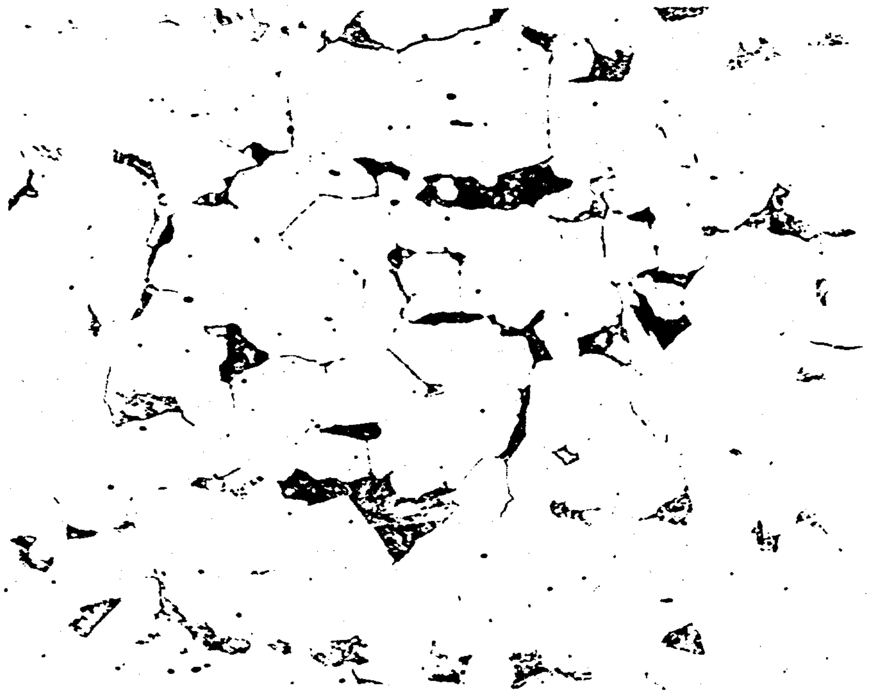

Figure 6. Tube #2 microstructure representative of whole tube. 500x, etched.

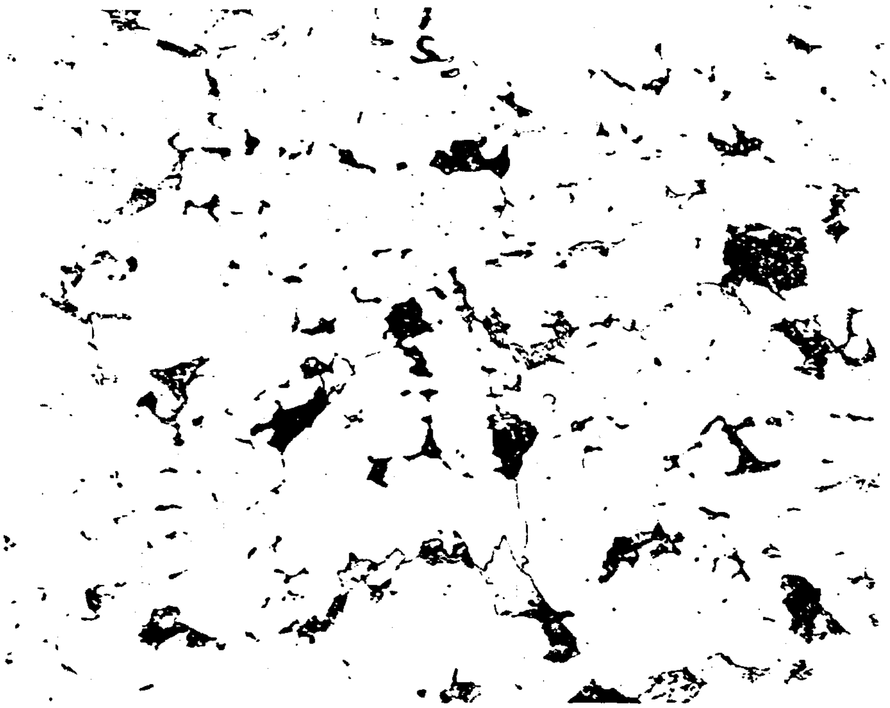

Figure 7. Tube #3 microstructure representative of "hot" side. 500x, etched.

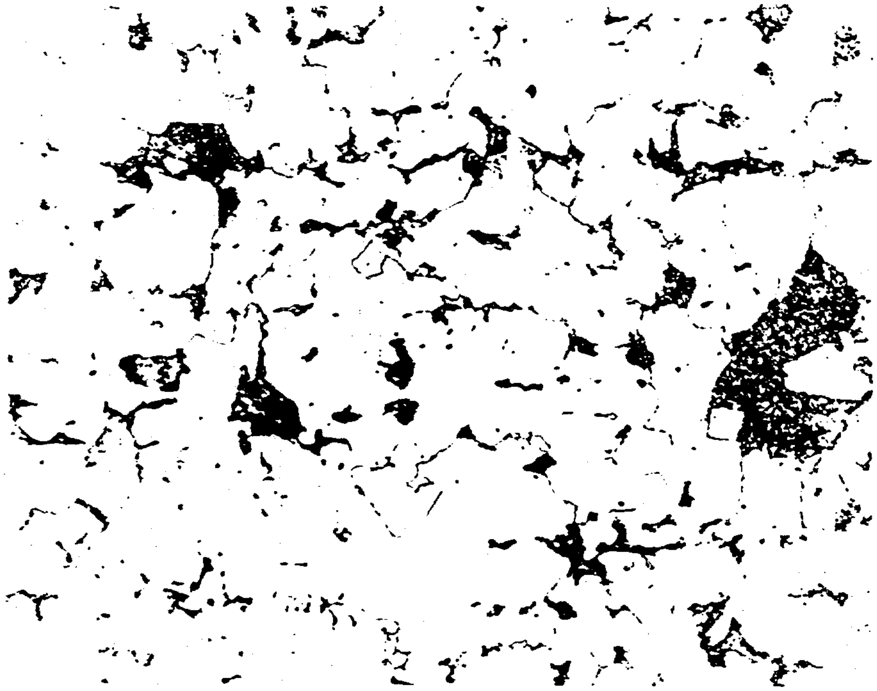

Figure 8. Tube #3 microstructure representative of "cold" side. 500x, etched.

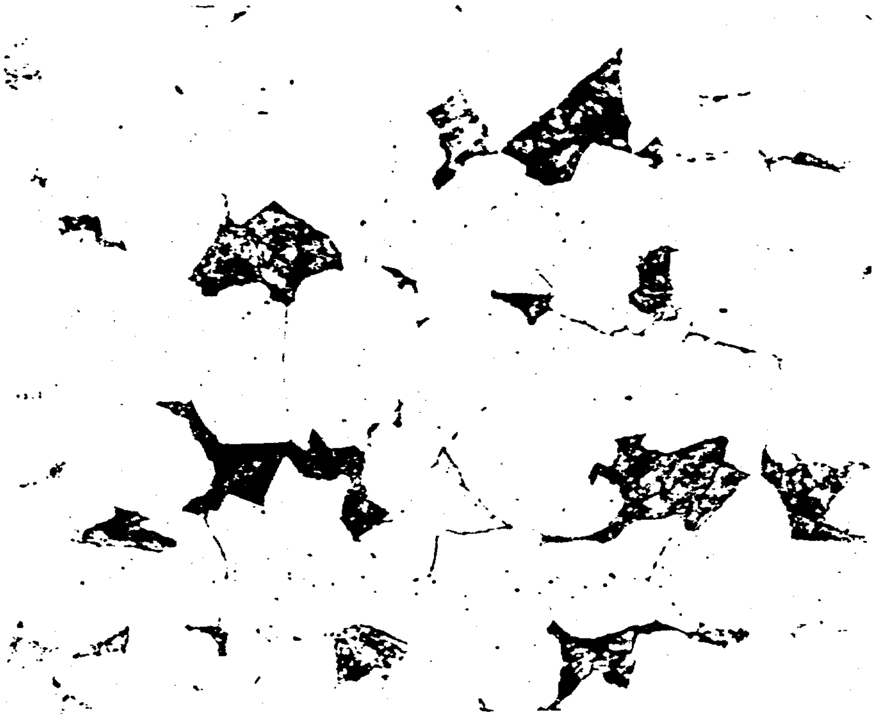

Figure 9. Tube #4 microstructure representative of whole tube. 500x, etched.

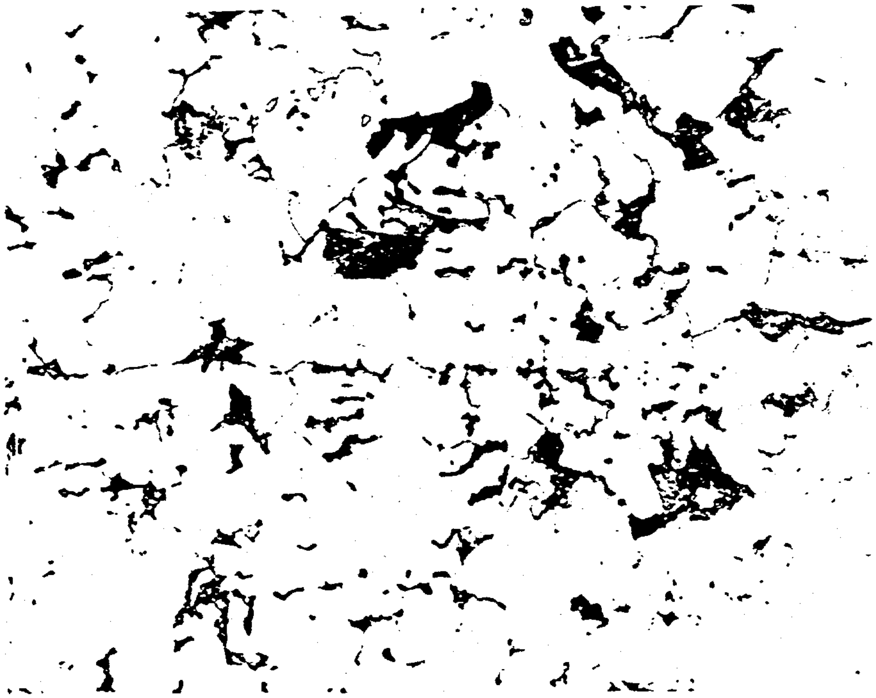

Figure 10. Tube #5 microstructure representative of studded side. 500x, etched.

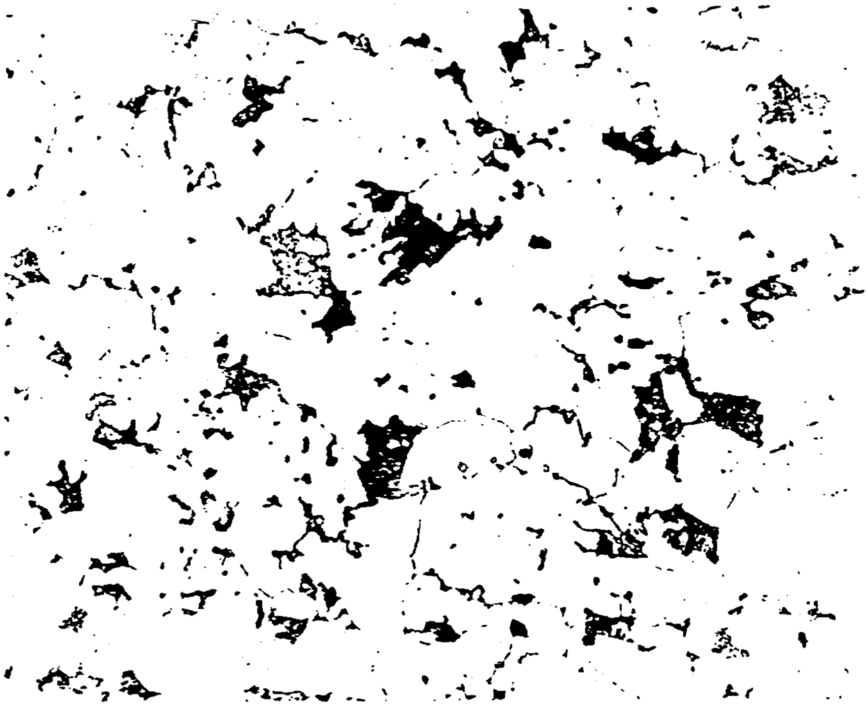

Figure 11. Tube #5 microstructure representative of "cold" side. 500x, etched.

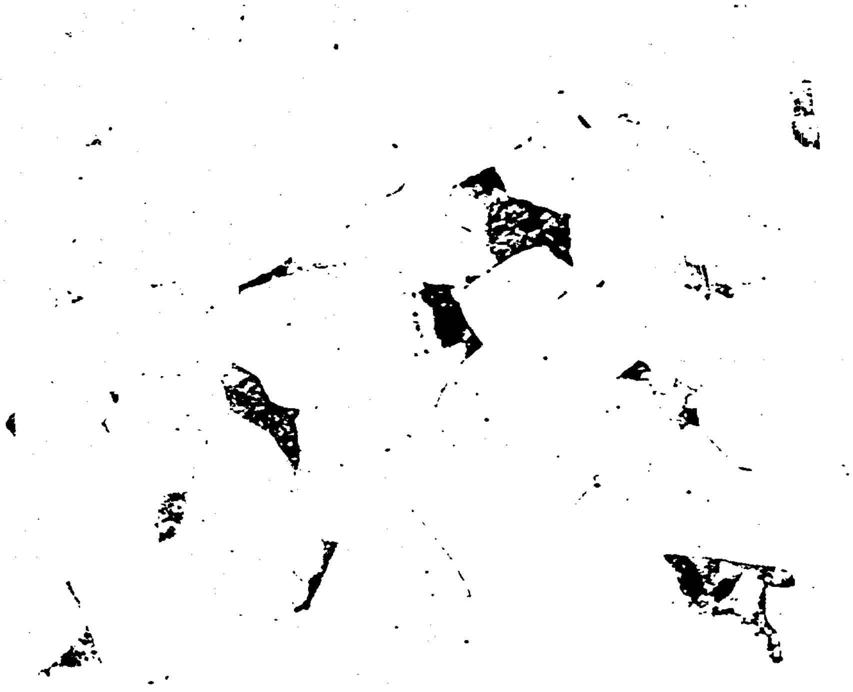

Figure 12. Tube #6 microstructure representative of whole tube. 500x, etched.

Figure 13. Tube #7 microstructure representative of whole tube. 500x, etched.

Figure 14. Tube #7 at ERW and low R_B hardness, see Table II. 500x, etched.

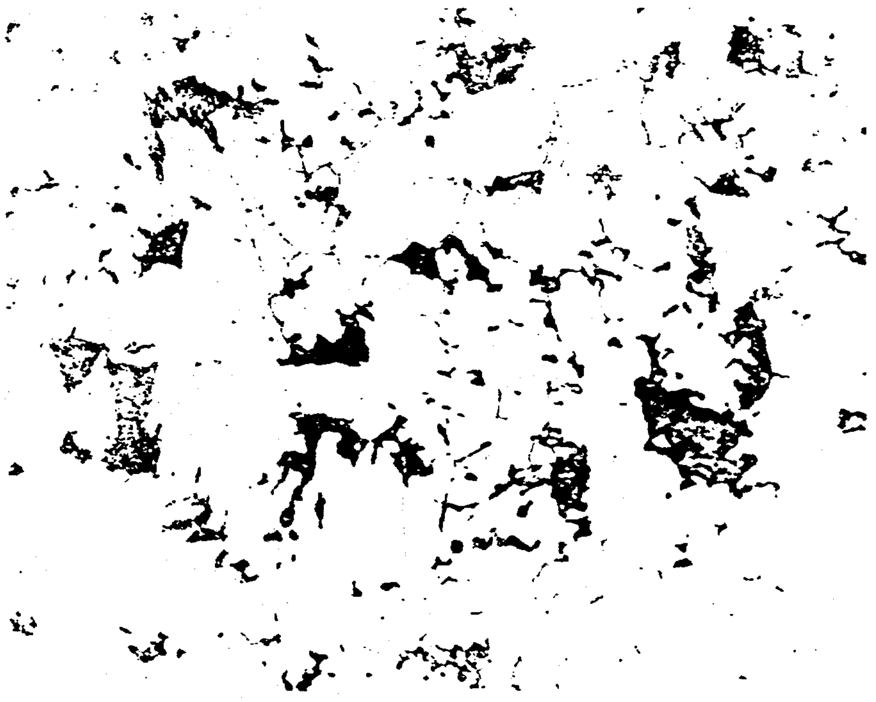

Figure 15. Tube #8 microstructure representative of whole tube. 500x, etched.

Microstructures are all normal ferrite and pearlite, differences reflect final heat-treatment by the tubing manufacturer. There is no difference between "hot" and "cold" sides and no indication of any thermal abuse.

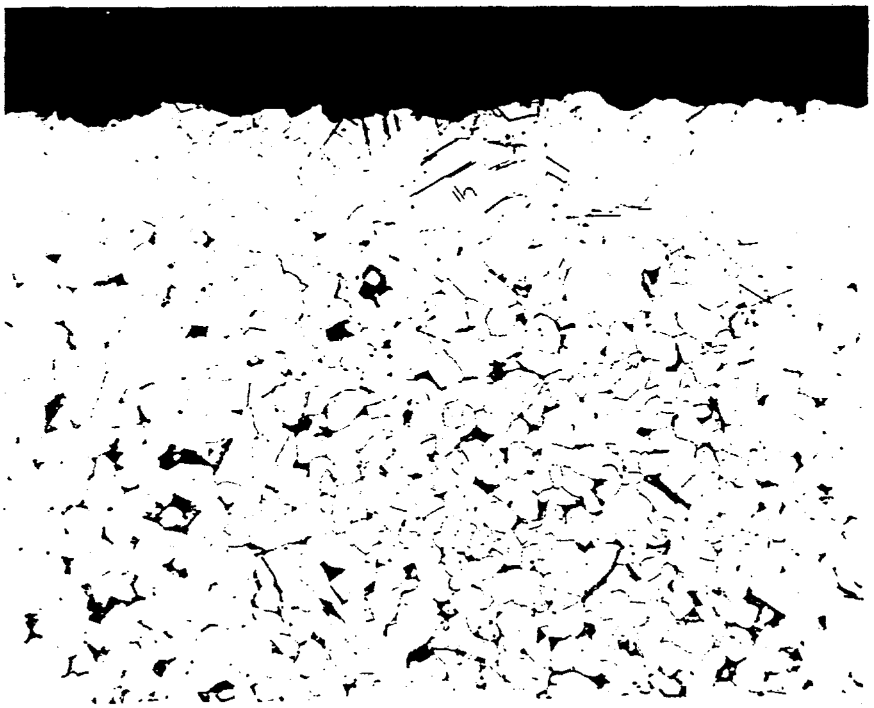

Figure 16. Tube #1 OD: no corrosion, decarburized layer intact. 100x, etched.

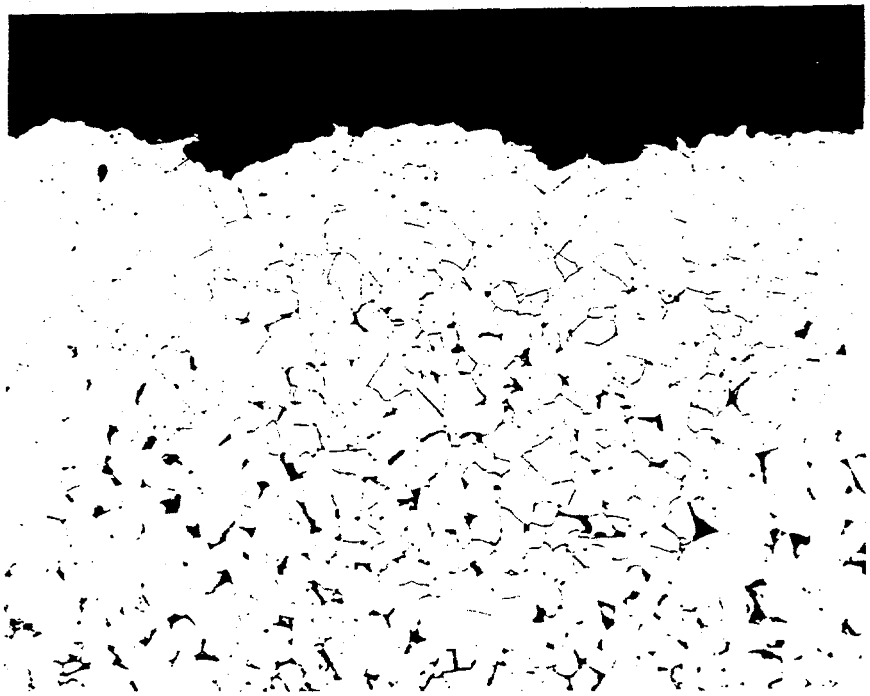

Figure 17. Tube #2 OD: no corrosion, decarburized layer intact. 100x, etched.

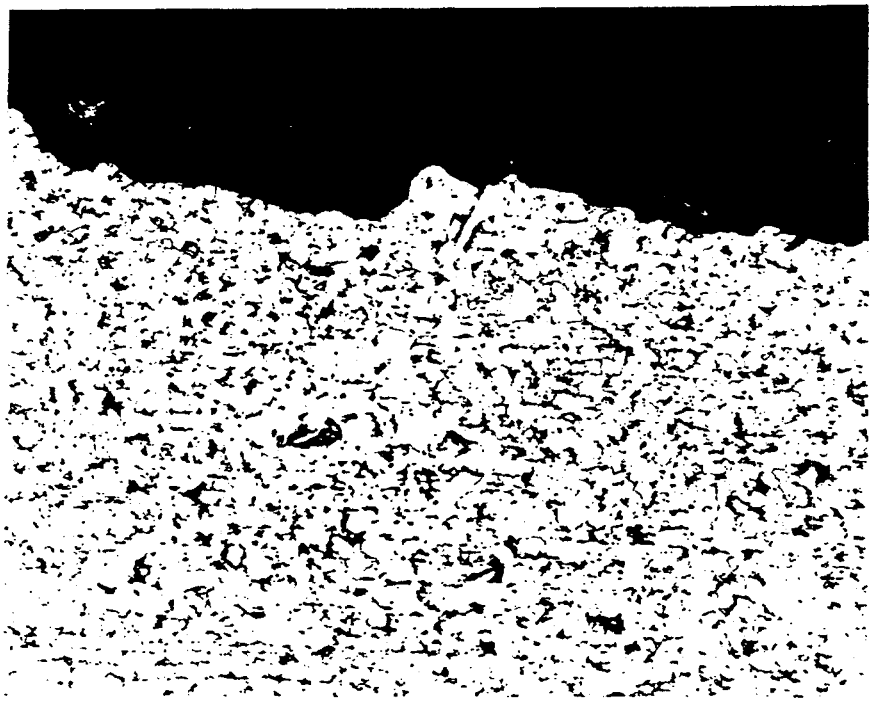

Figure 18. Tube #3 OD: corrosion is uniform, no grain-boundary attack. 100x, etched.

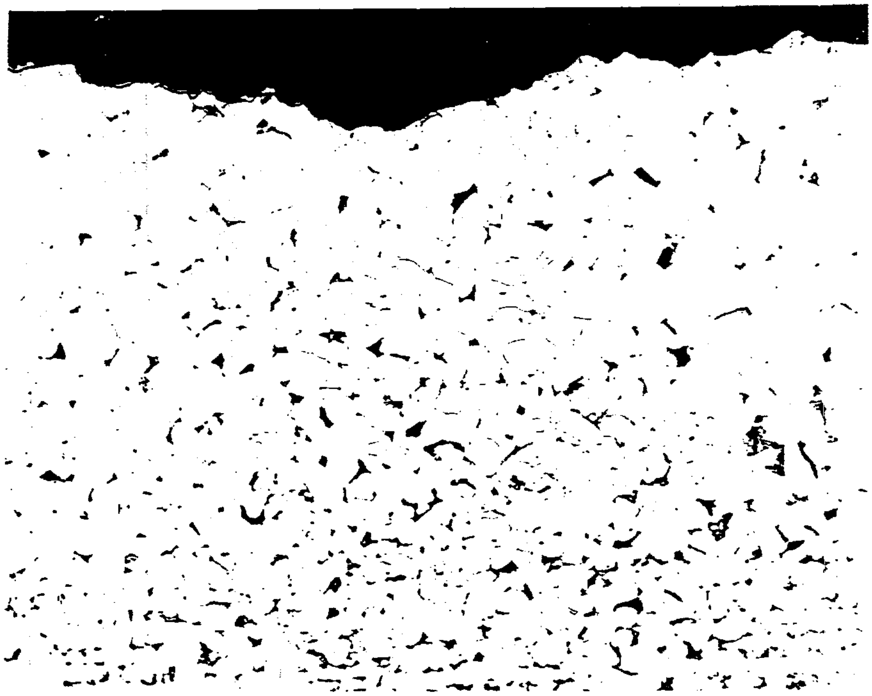

Figure 19. Tube #4 OD: corrosion is uniform. 100x, etched.

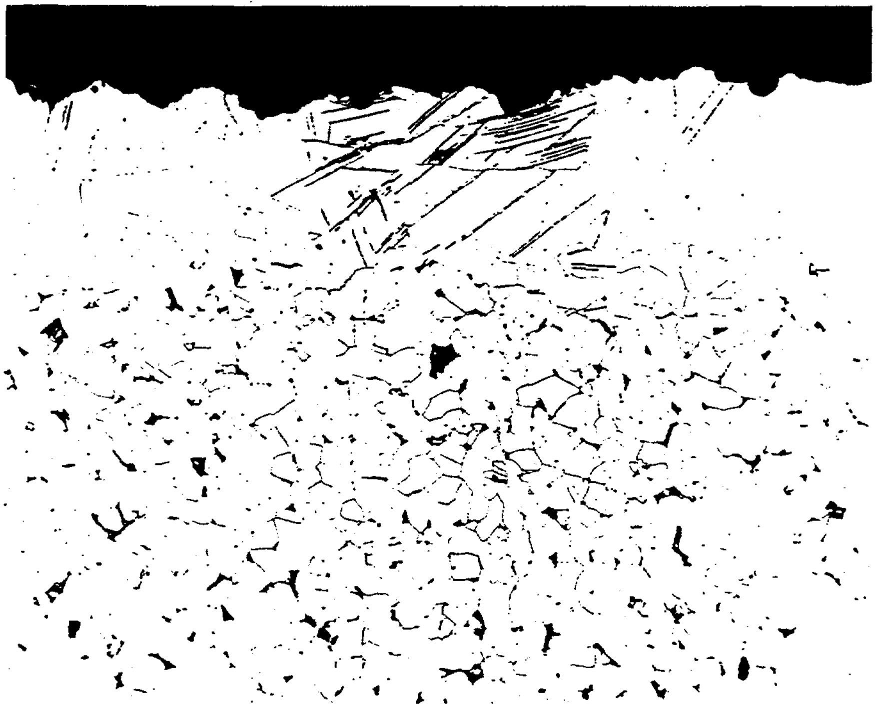

Figure 20. Tube #6 OD: no corrosion, note deformation twins in the ferrite in the decarburized layer. 100x, etched.

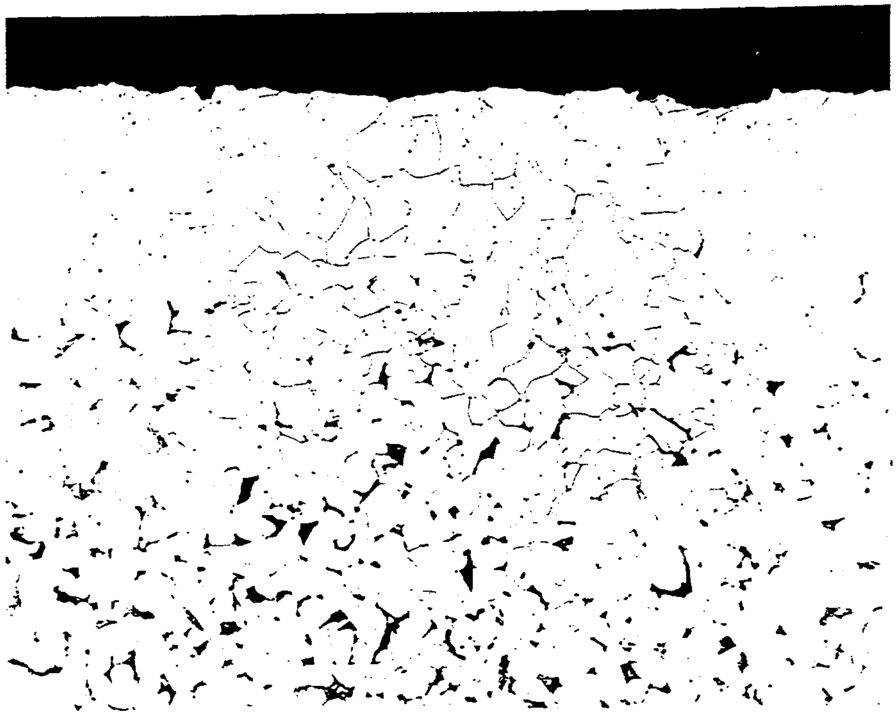

Figure 21. Tube #7 OD: no corrosion. 100x, etched.

Figure 22. Tube #5 OD at refractory-retention stud. 25x, etched.

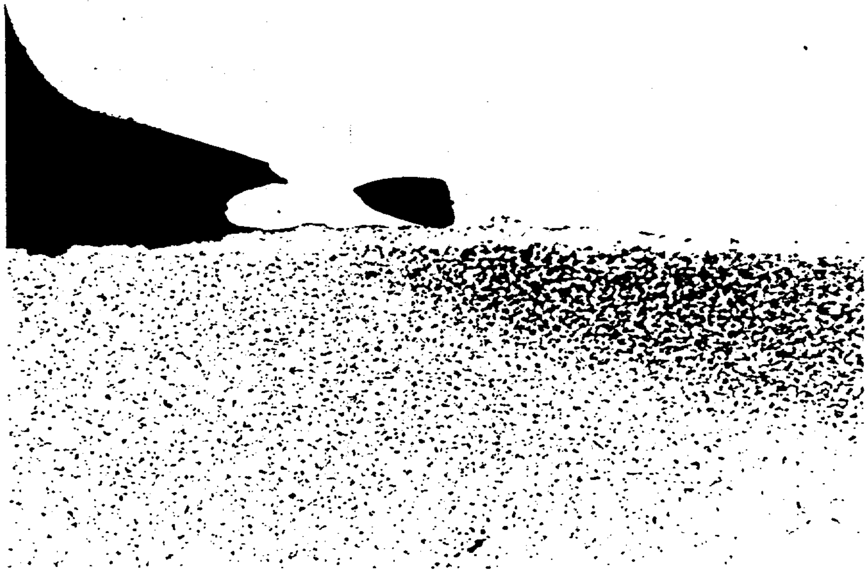

Figure 23. Tube #8 OD at refractory-retention stud. 25x, etched. No thermal-fatigue cracks noted on either tube.

Figure 24. Sulfur print, Tube #3.

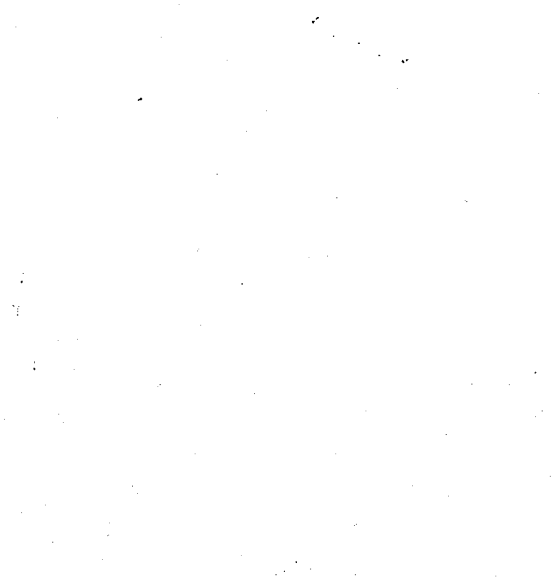

Figure 25. Sulfur print, Tube #4.

Figure 26. Sulfur print, Tube #8.

All are positive for metallic sulfides, but more sulfides are associated with Tubes #3 and #4 than with Tube #8. The boiler modifications lead to more carbon-monoxide formation in the reburning zone.

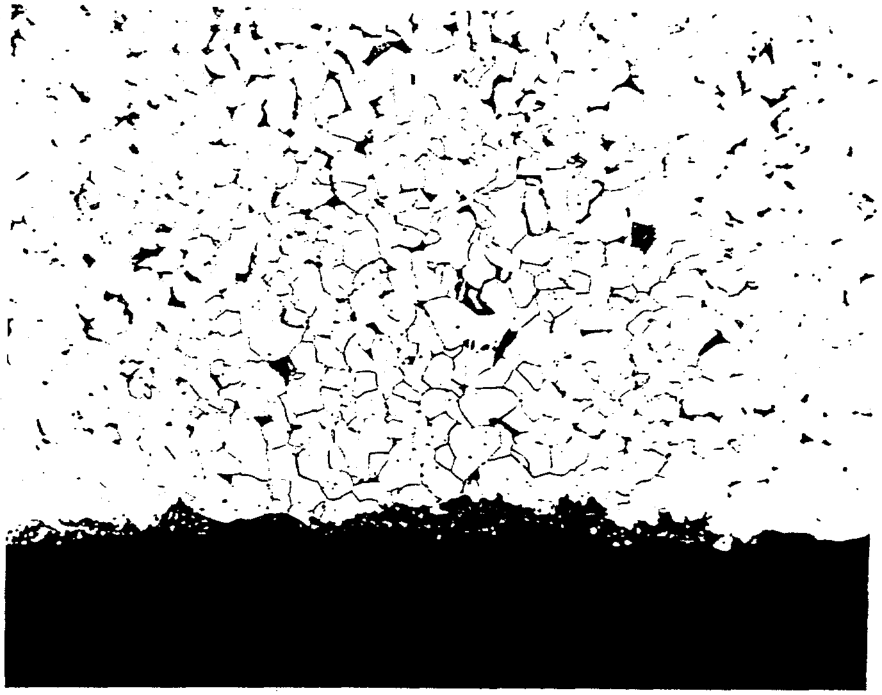

Figure 27. Tube #1 ID "hot" side. 100x, etched.

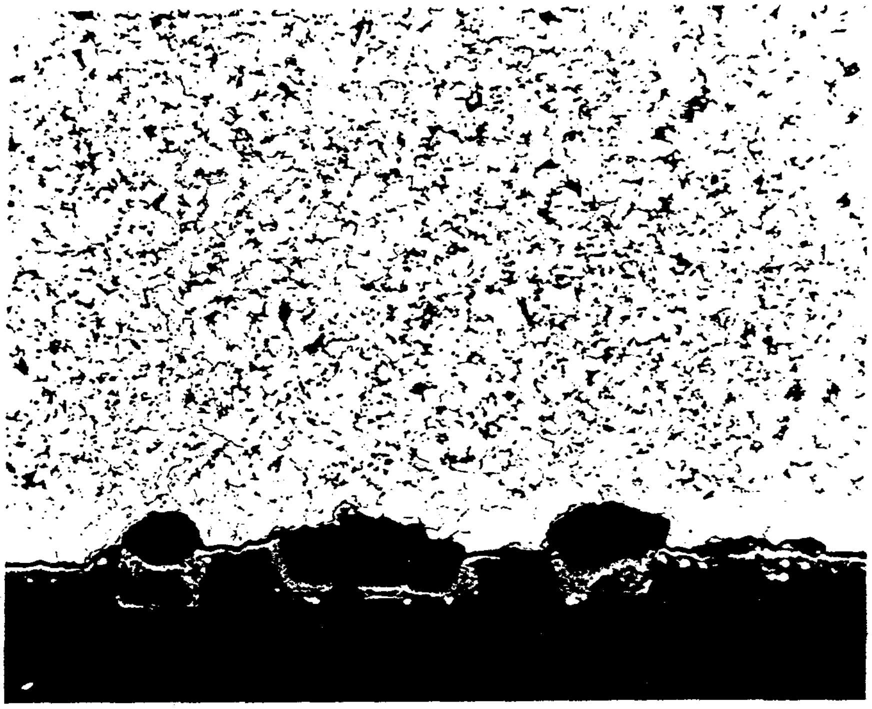

Figure 28. Tube #3 ID "hot" side. 100x, etched.

Figure 29. Tube #7 ID "hot" side. 100x, etched.

Figures 27-29 are representative ID surfaces. The pitting is slight, less than 0.003". The ID scale contains metallic copper, indicative of corrosion or leaks in the pre-boiler circuits.

1991 Ultrasonic Thickness Measurements
Conam Inspection, Inc.

There is only one copy of this colorized report. If you would like to review it please contact:

Donald E. Engelhardt
Project Management
Energy and Environmental Research Corporation
1345 North Main Street
P.O. Box 153
Orrville, Ohio 44667
Tel (216) 682-4007
Fax (216) 684-2110

1994 Ultrasonic Thickness Measurements
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Orrville, Ohio 44667
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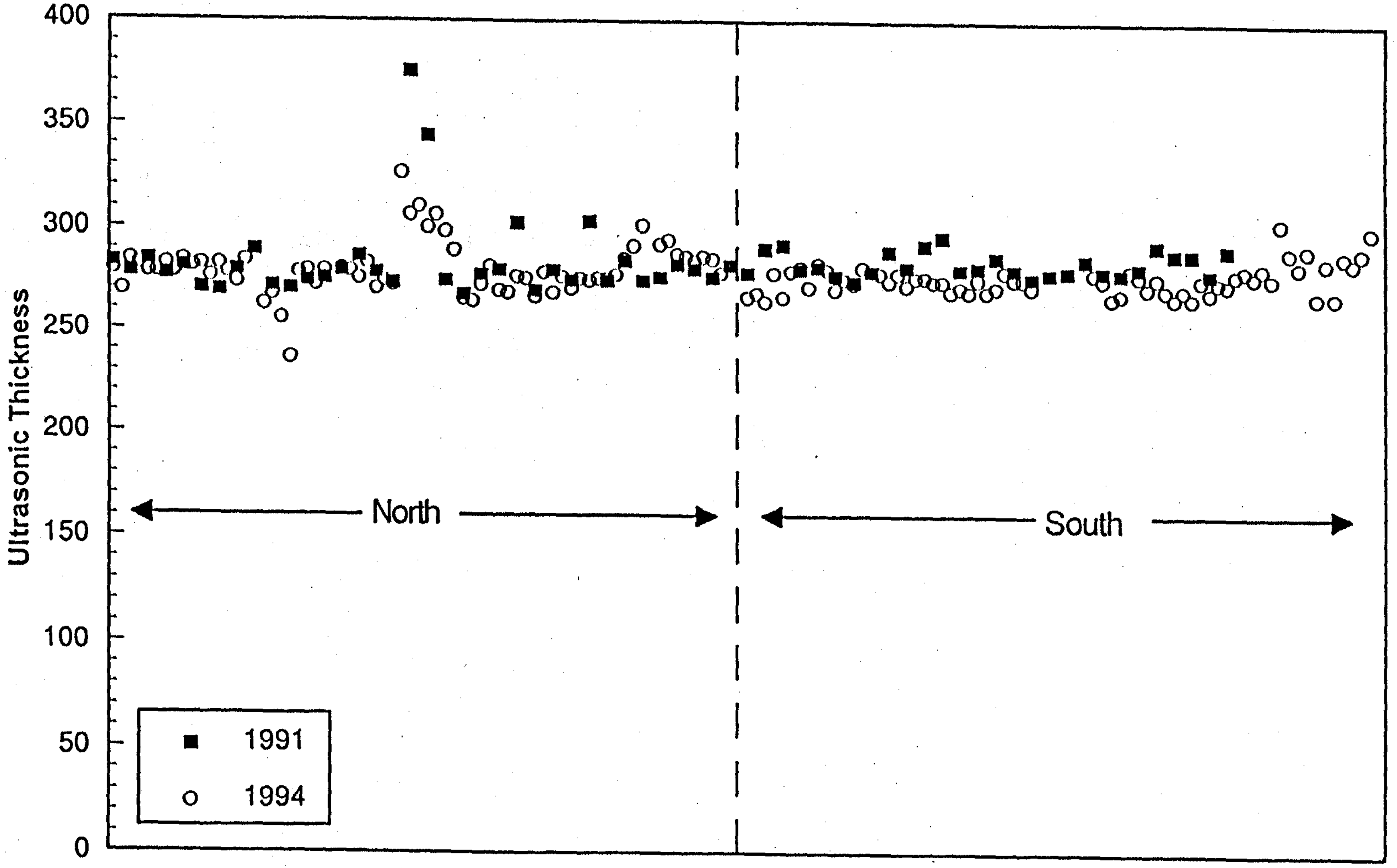
Fax (216) 684-2110

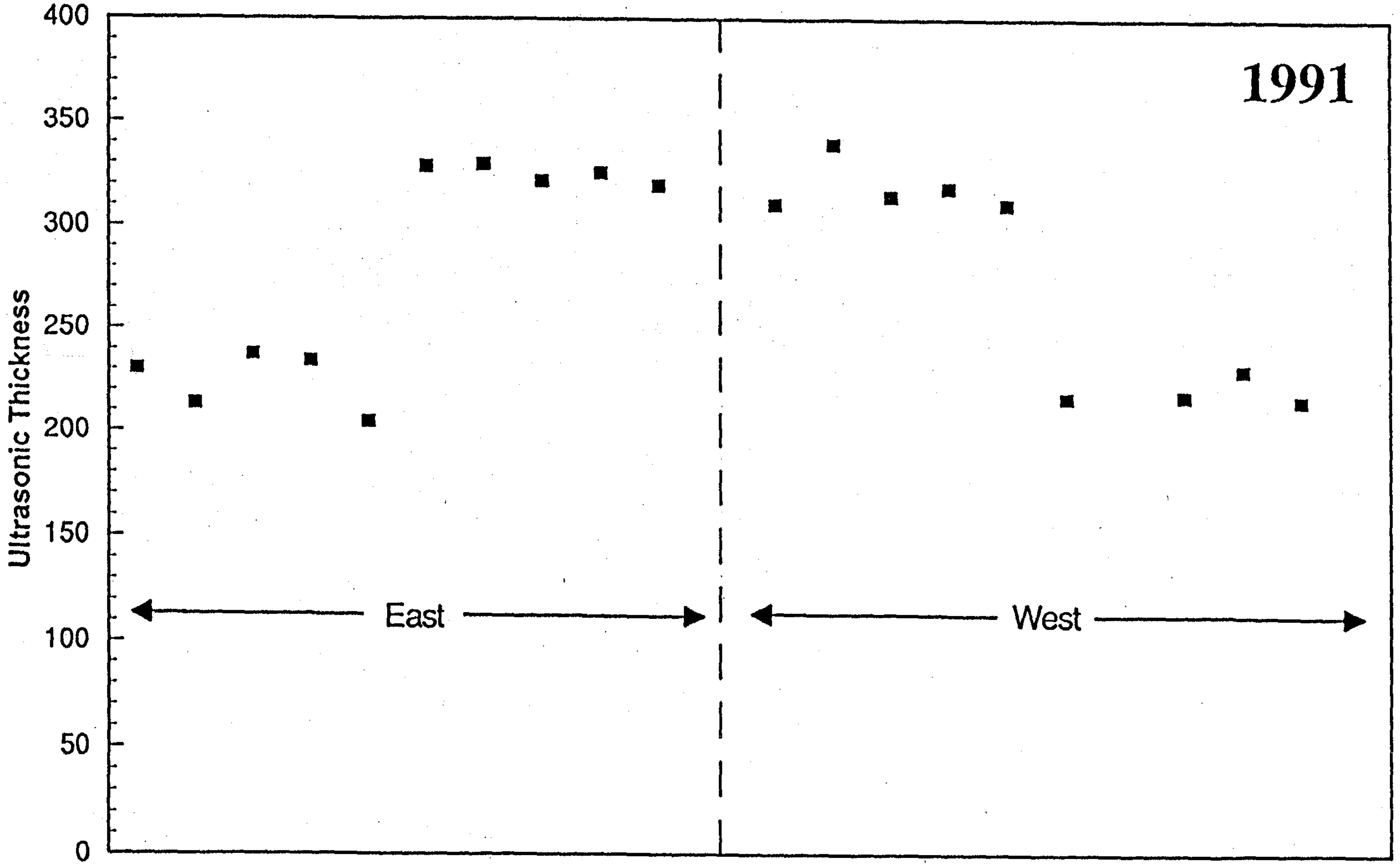
Lakeside Unit #7
Ultrasonic Thickness Results

Furnace Floor
Location 1, Elevation 560



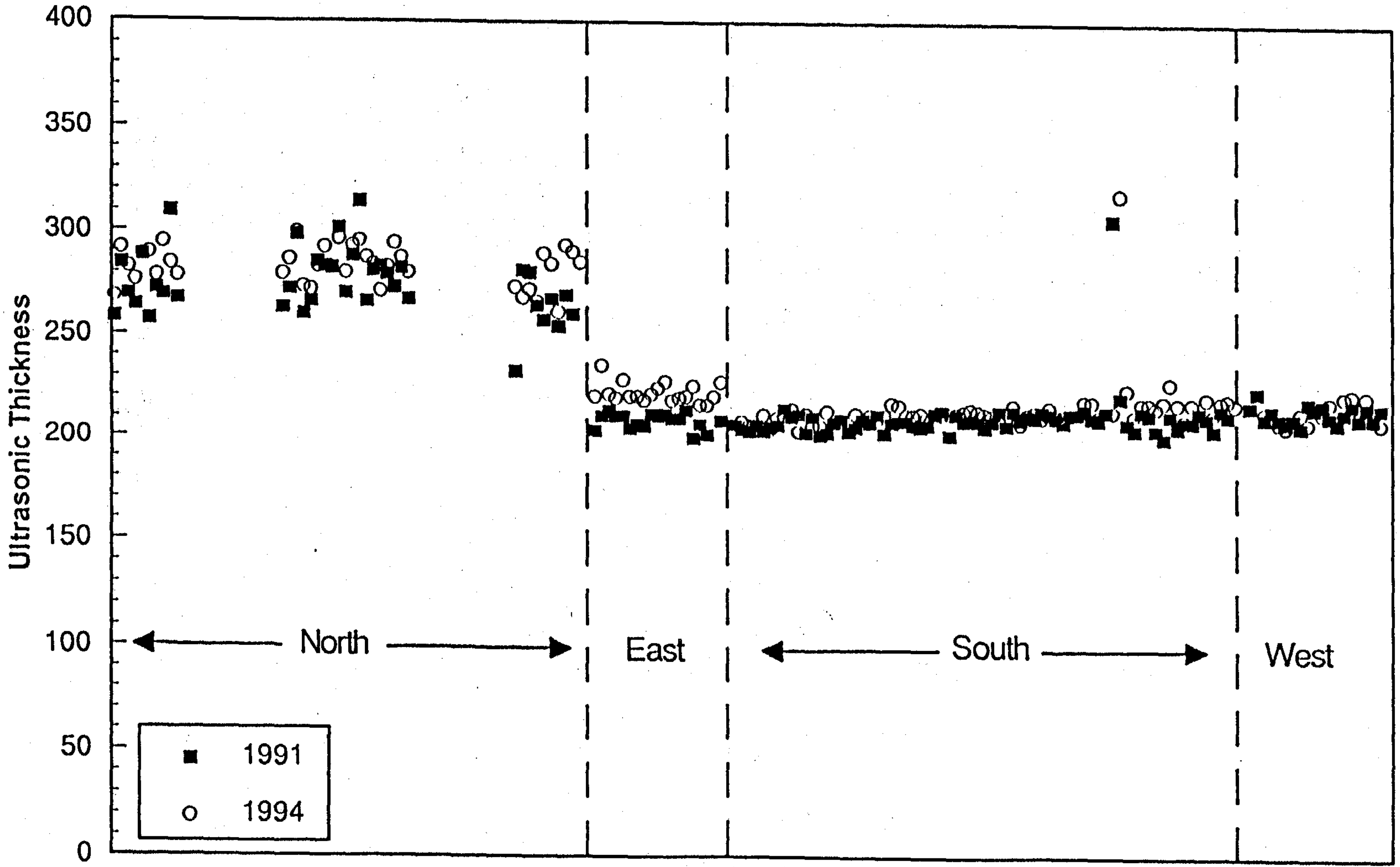
Lakeside Unit 7
Ultrasonic Thickness Results

Side Wall
Location 1, Elevation 560

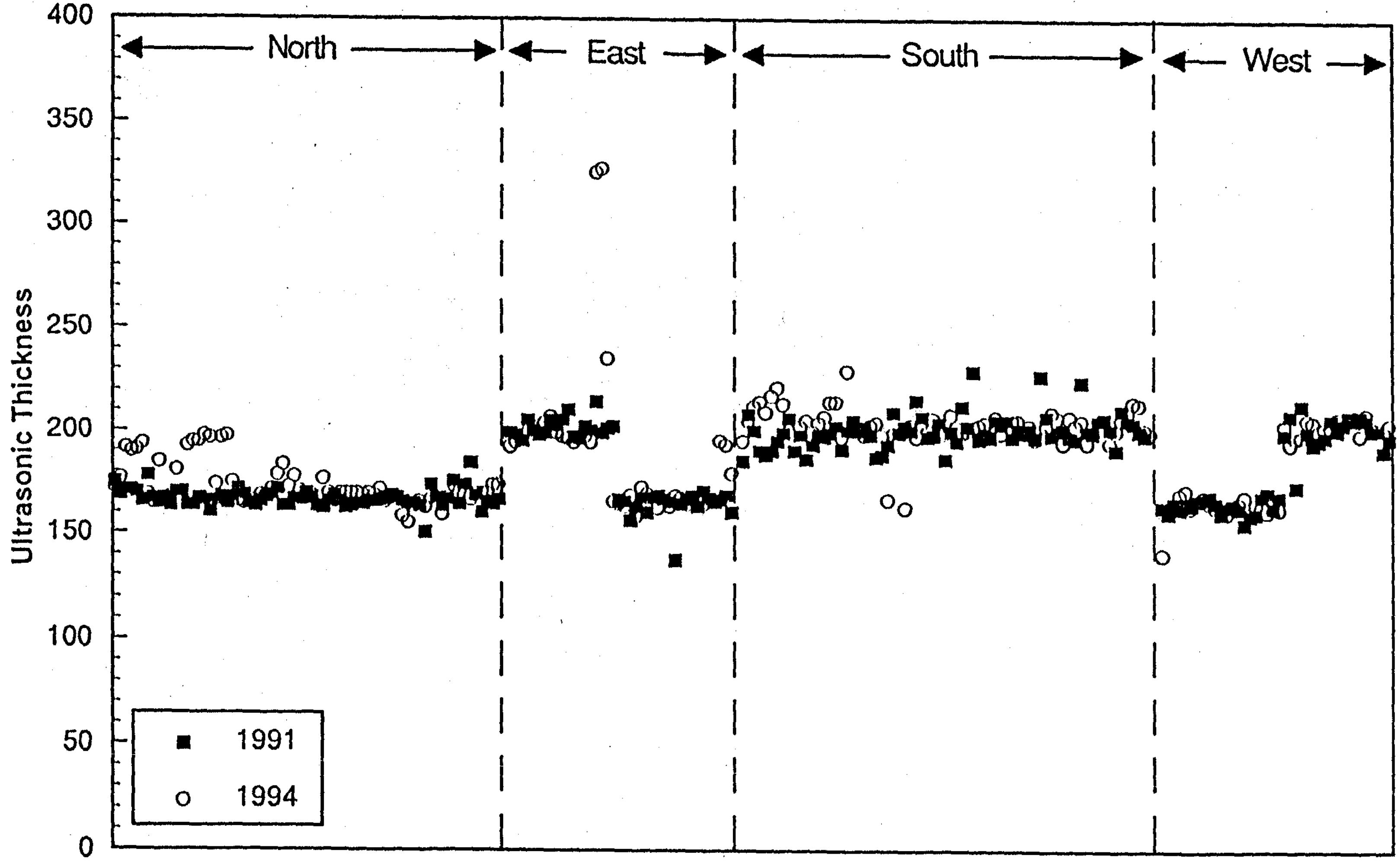


Lakeside Unit 7
Ultrasonic Thickness Results

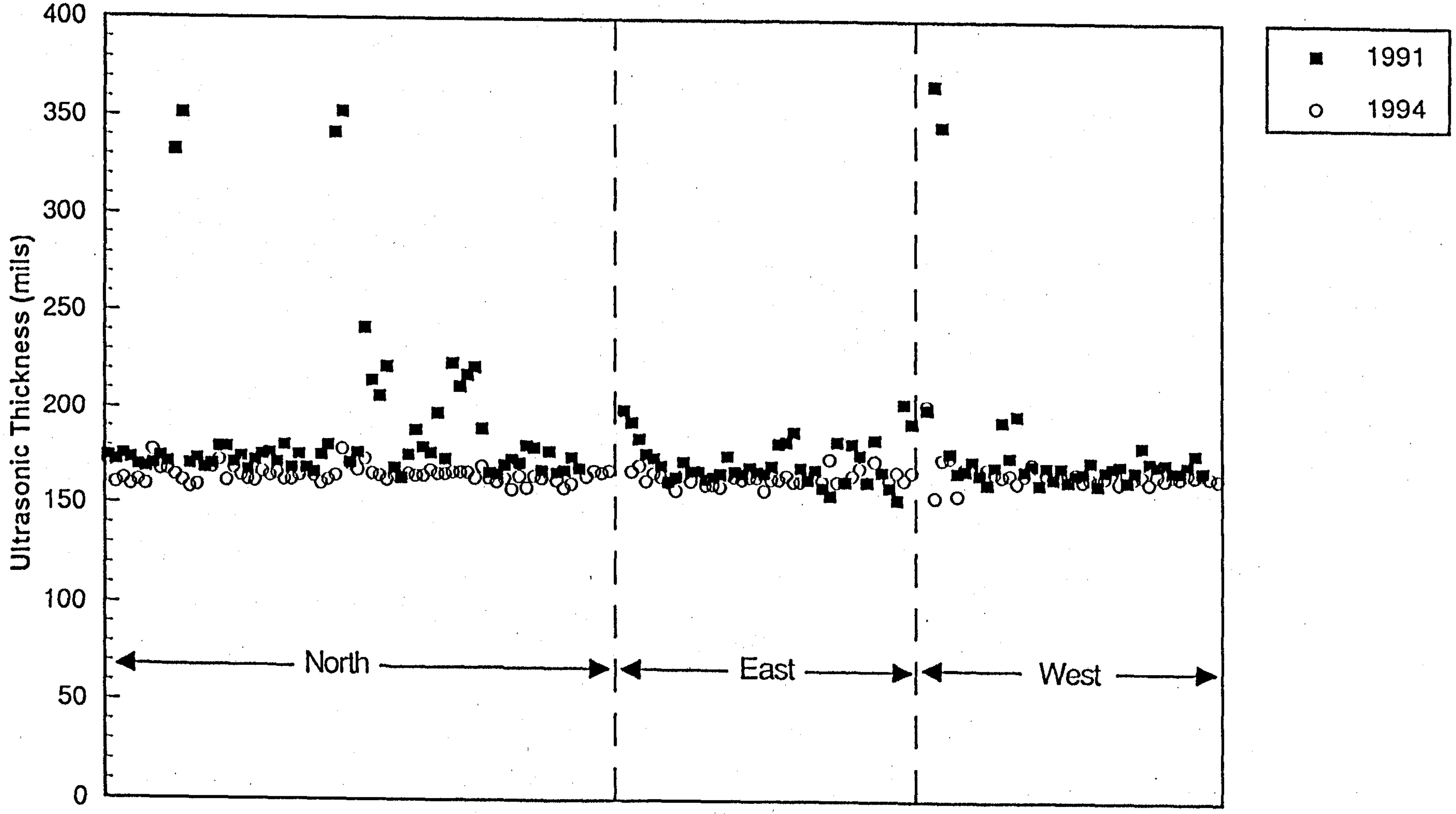
Location 2, Elevation 575



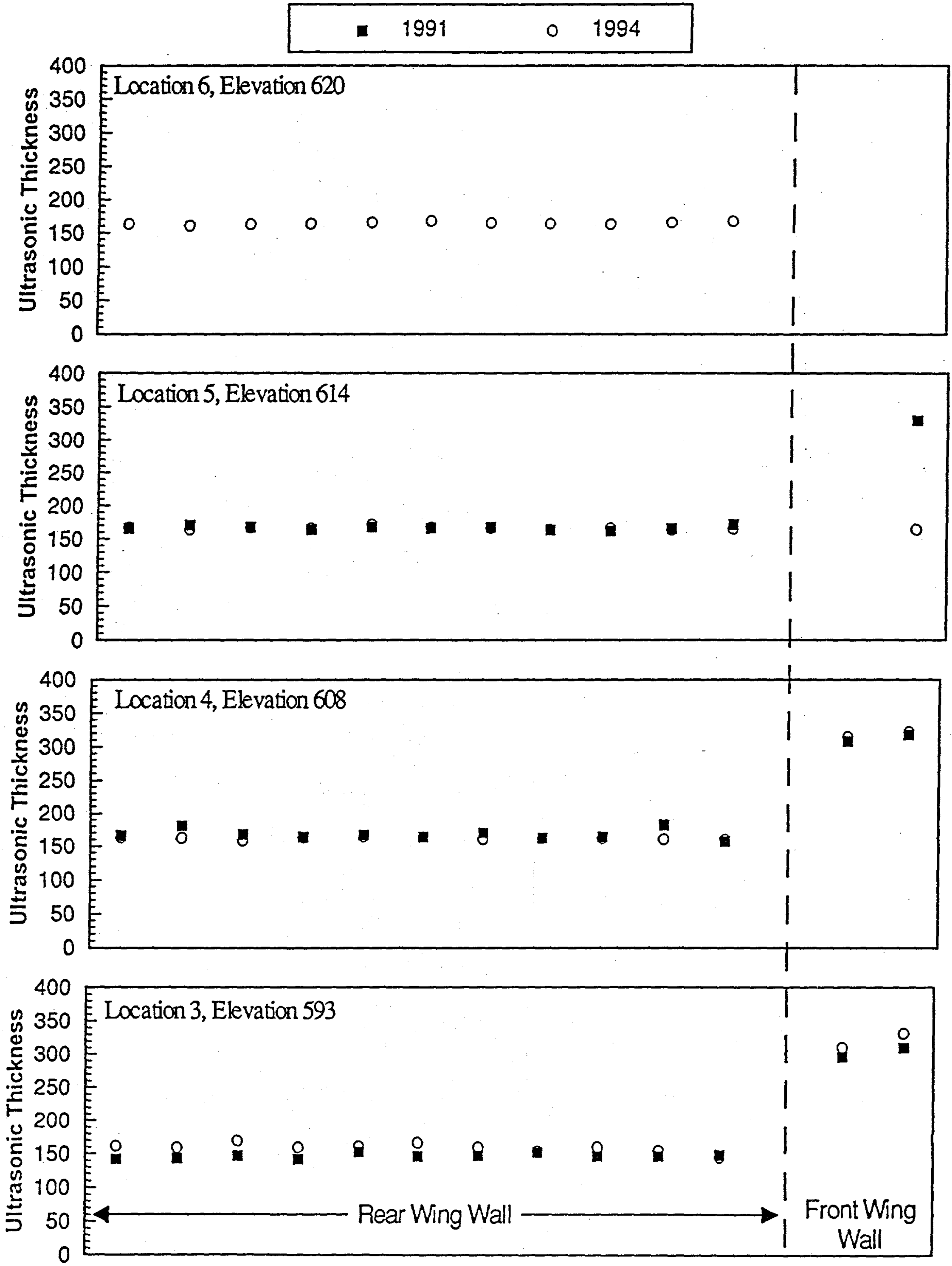
Lakeside Unit 7
Ultrasonic Thickness Results
Location 3, Elevation 593



Lakeside Unit 7
Ultrasonic Thickness Results
Furnace Water Wall
Location 4, Elevation 608



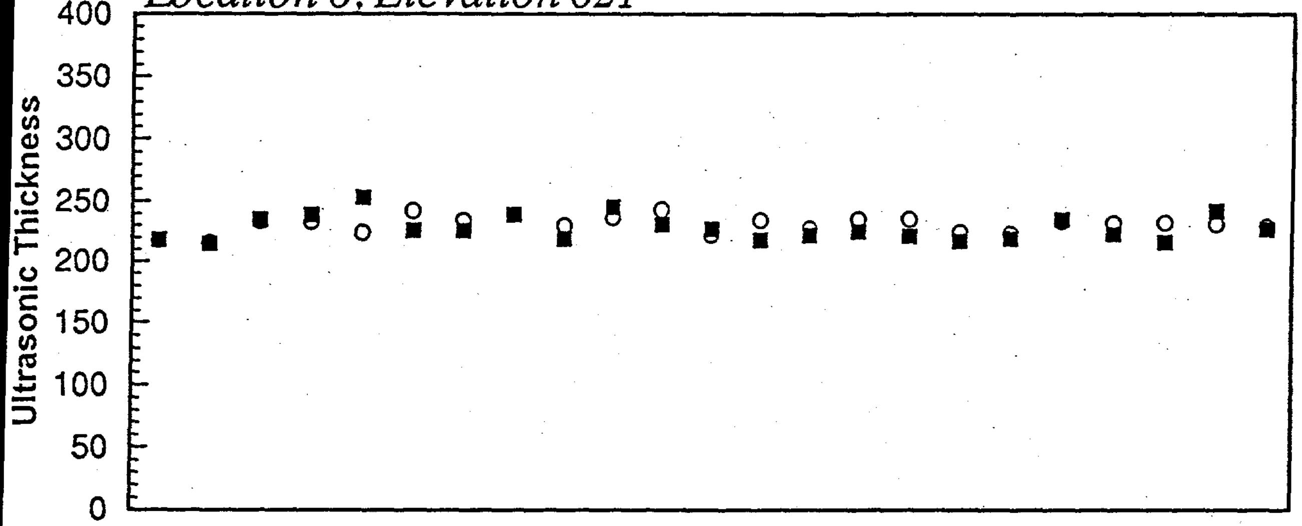
Lakeside Unit 7
Ultrasonic Thickness Resullts
Wing Wall



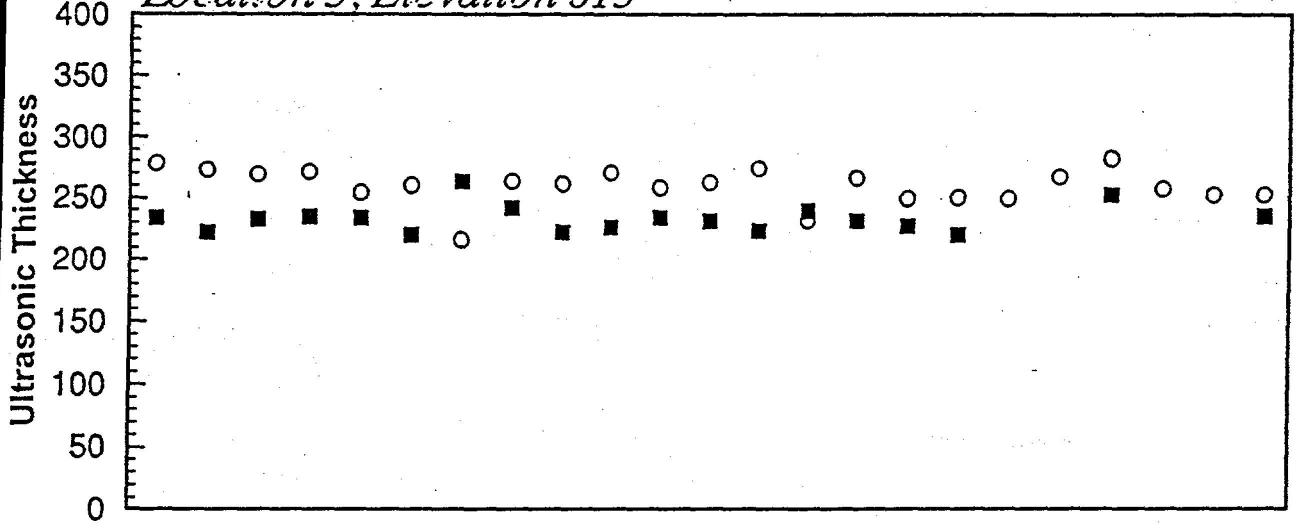
Lakeside Unit 7
Ultrasonic Thickness Results
First Row Secondary Superheater Tubes

■ 1991 ○ 1994

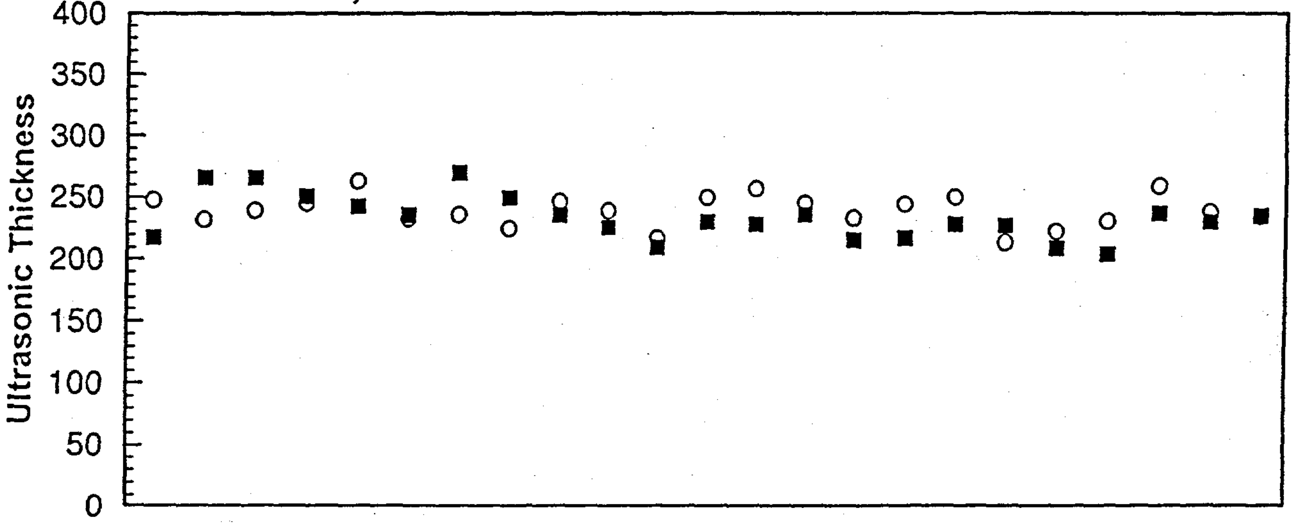
Location 6, Elevation 621



Location 5, Elevation 615



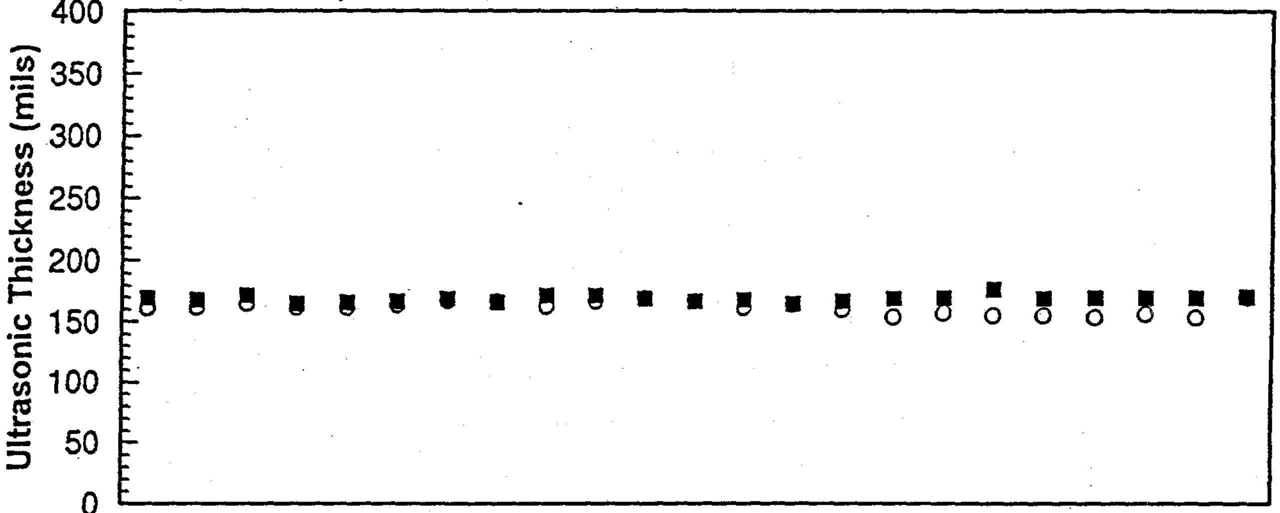
Location 4, Elevation 608



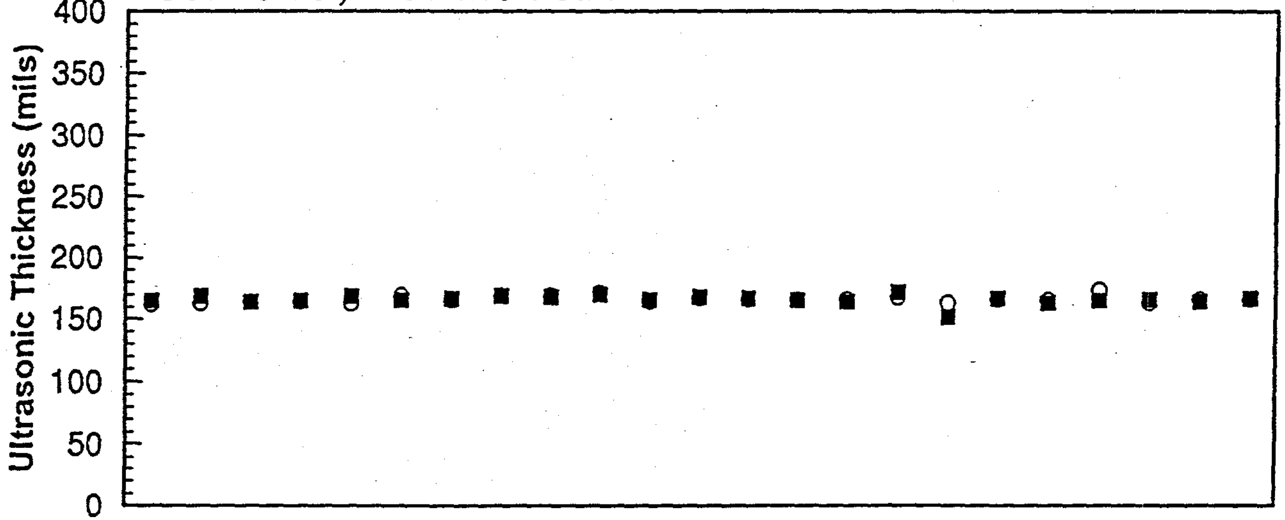
Lakeside Unit 7
Ultrasonic Thickness Results
Screen Tubes

■ 1991 ○ 1994

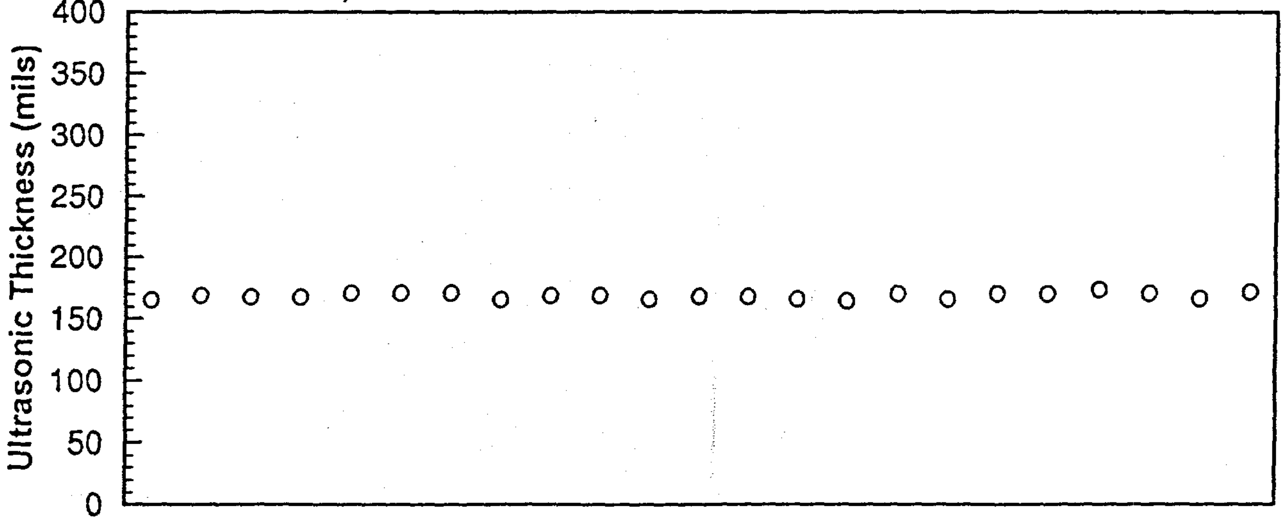
Location 6, Elevation 620



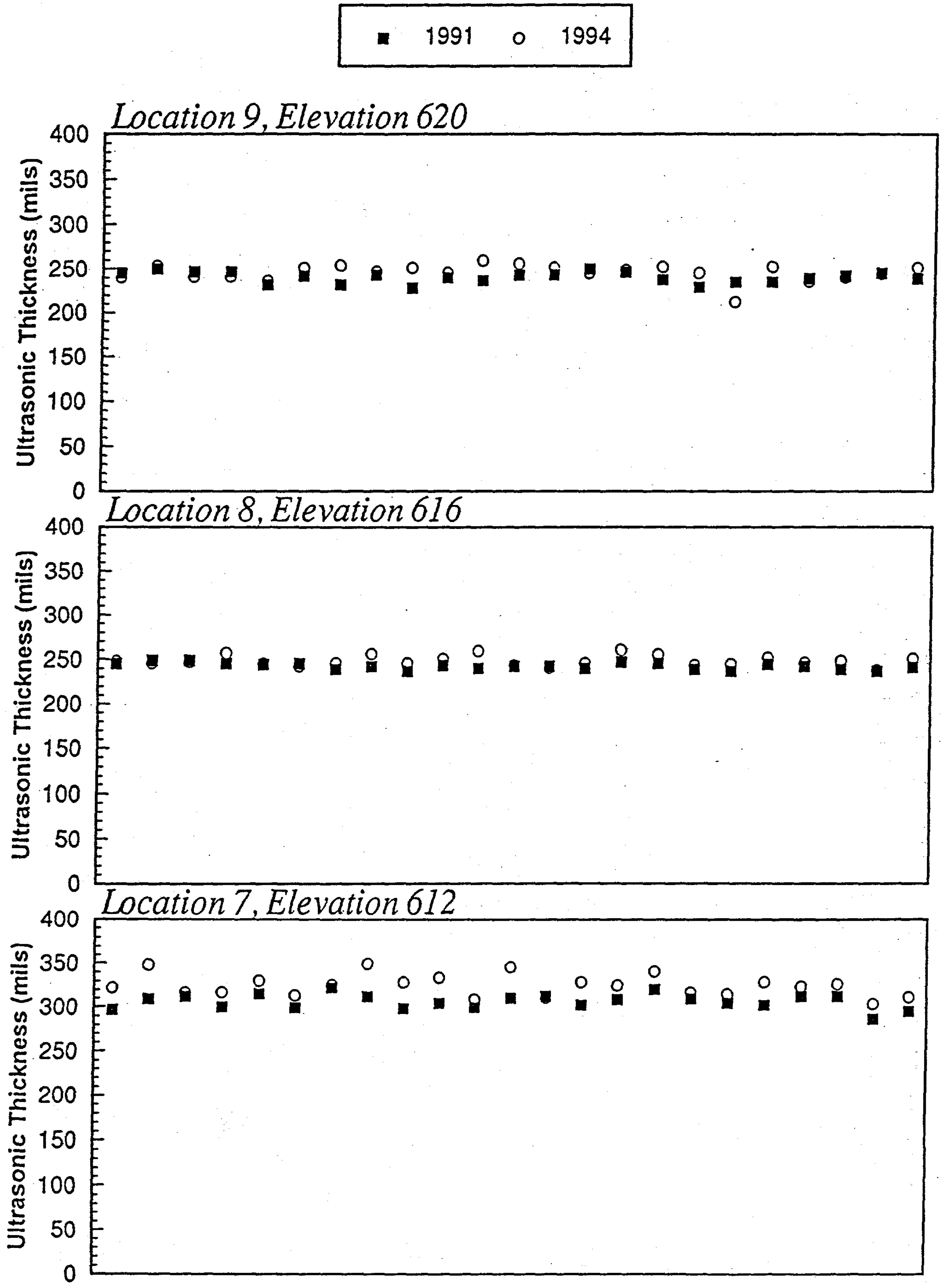
Location 5, Elevation 614



Location 4, Elevation 608



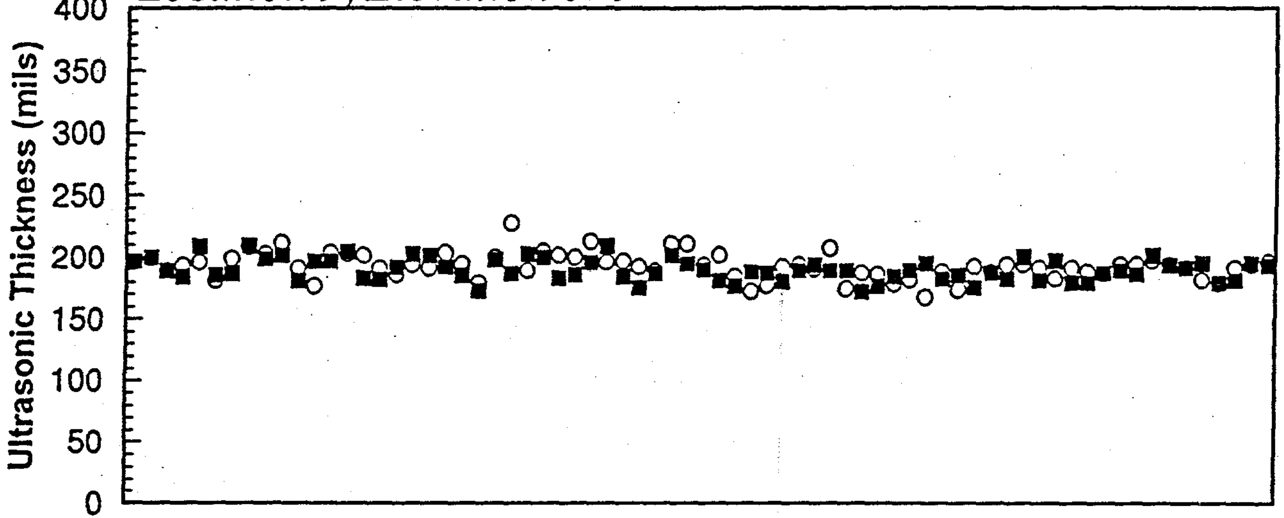
Lakeside Unit 7
Ultrasonic Thickness Results
Primary Superheater Inlet



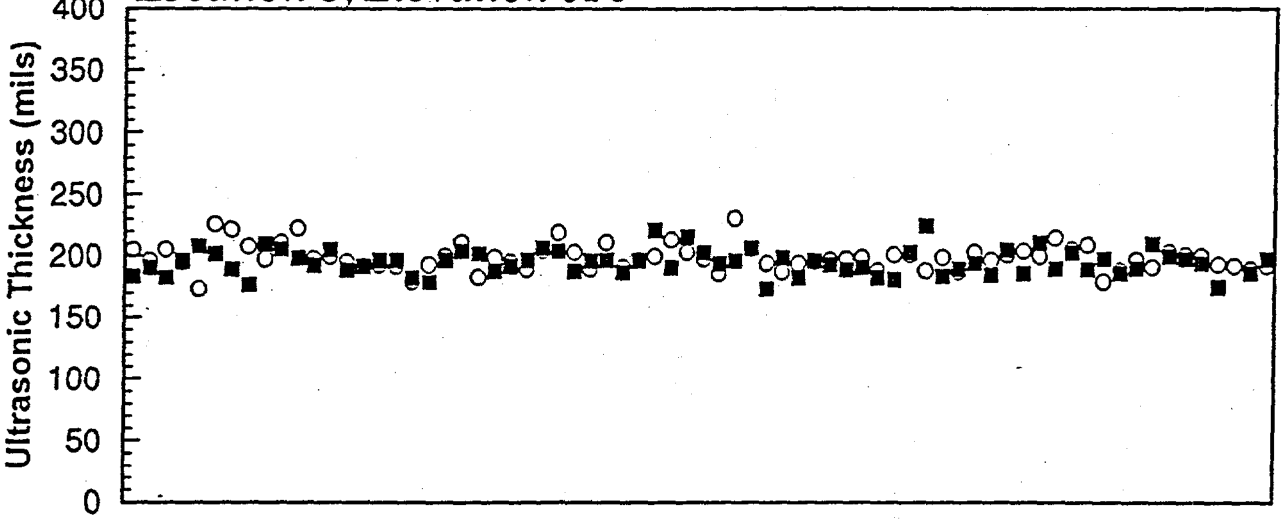
Lakeside Unit 7
Ultrasonic Thickness Results
Secondary Superheater Outlet

■ 1991 ○ 1994

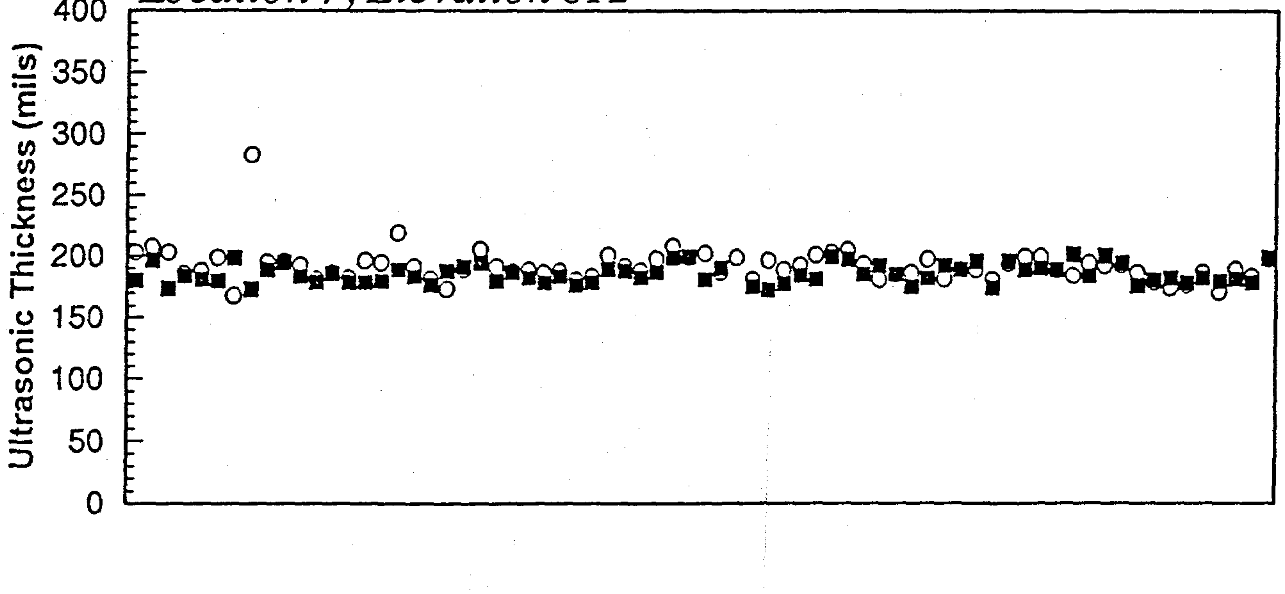
Location 9, Elevation 620



Location 8, Elevation 616



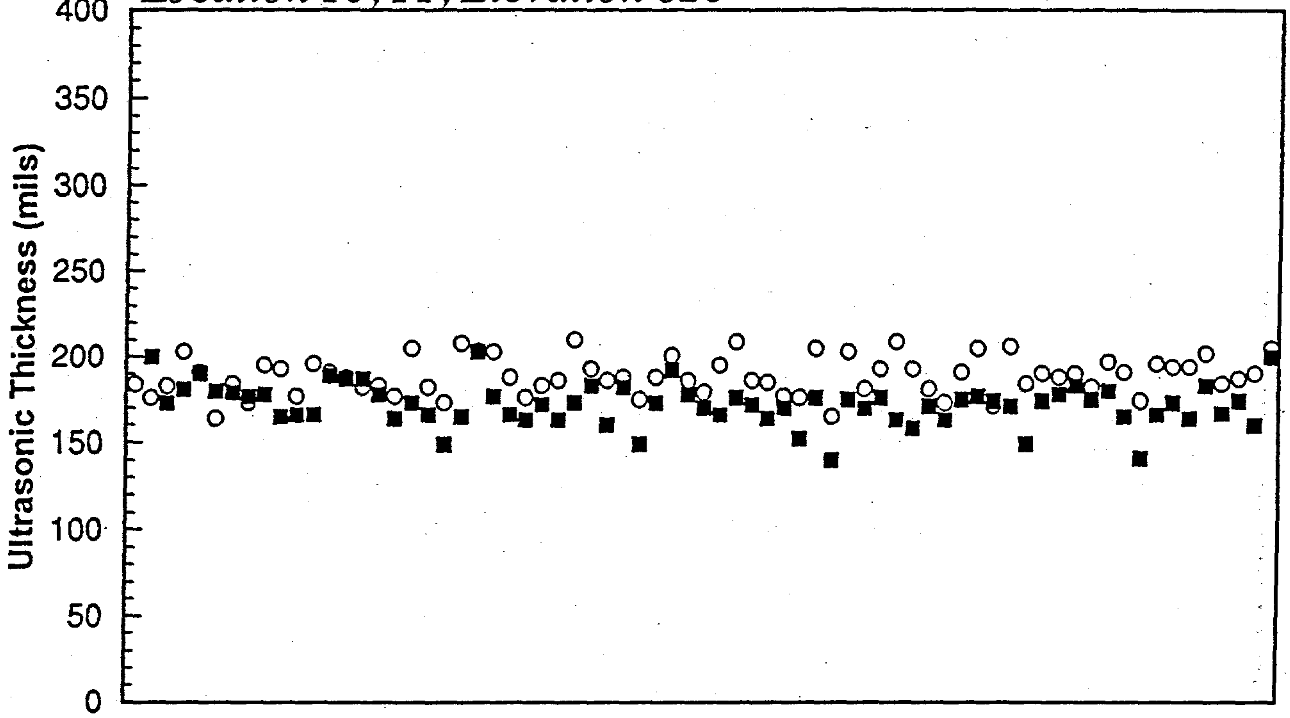
Location 7, Elevation 612



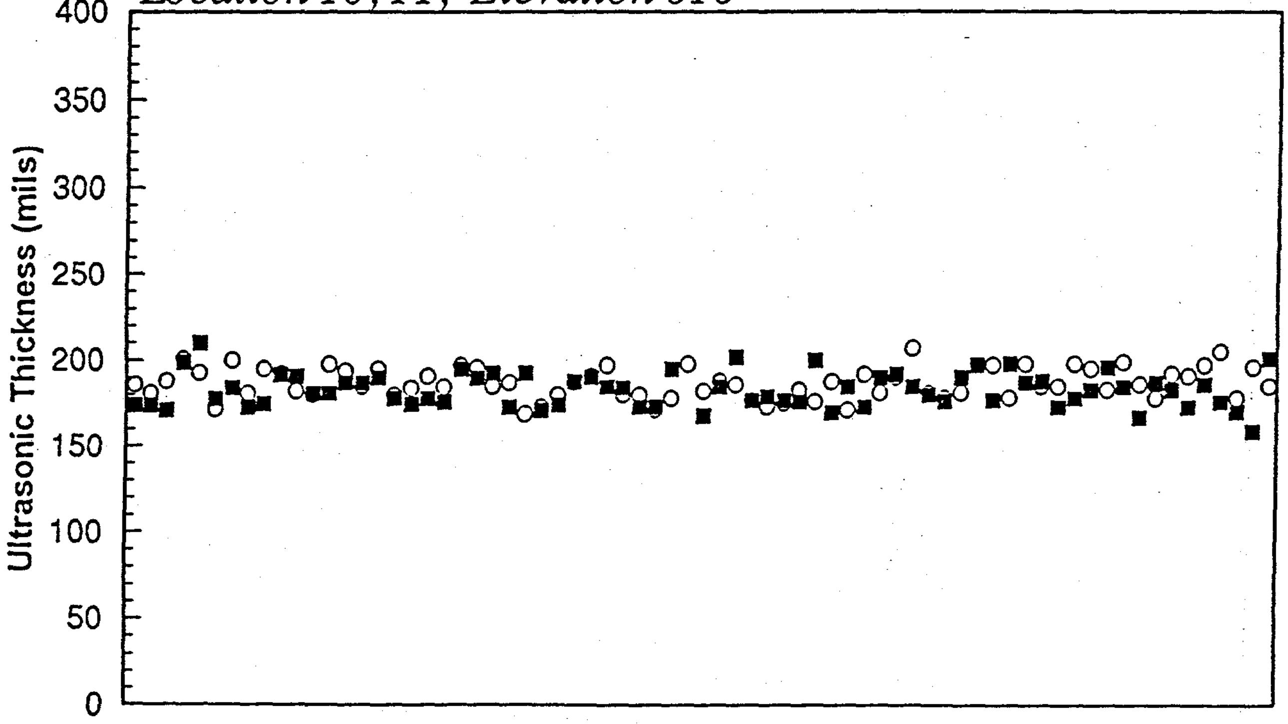
Lakeside Unit 7
Ultrasonic Thickness Results
Primary Superheater Outlet

■ 1991 ○ 1994

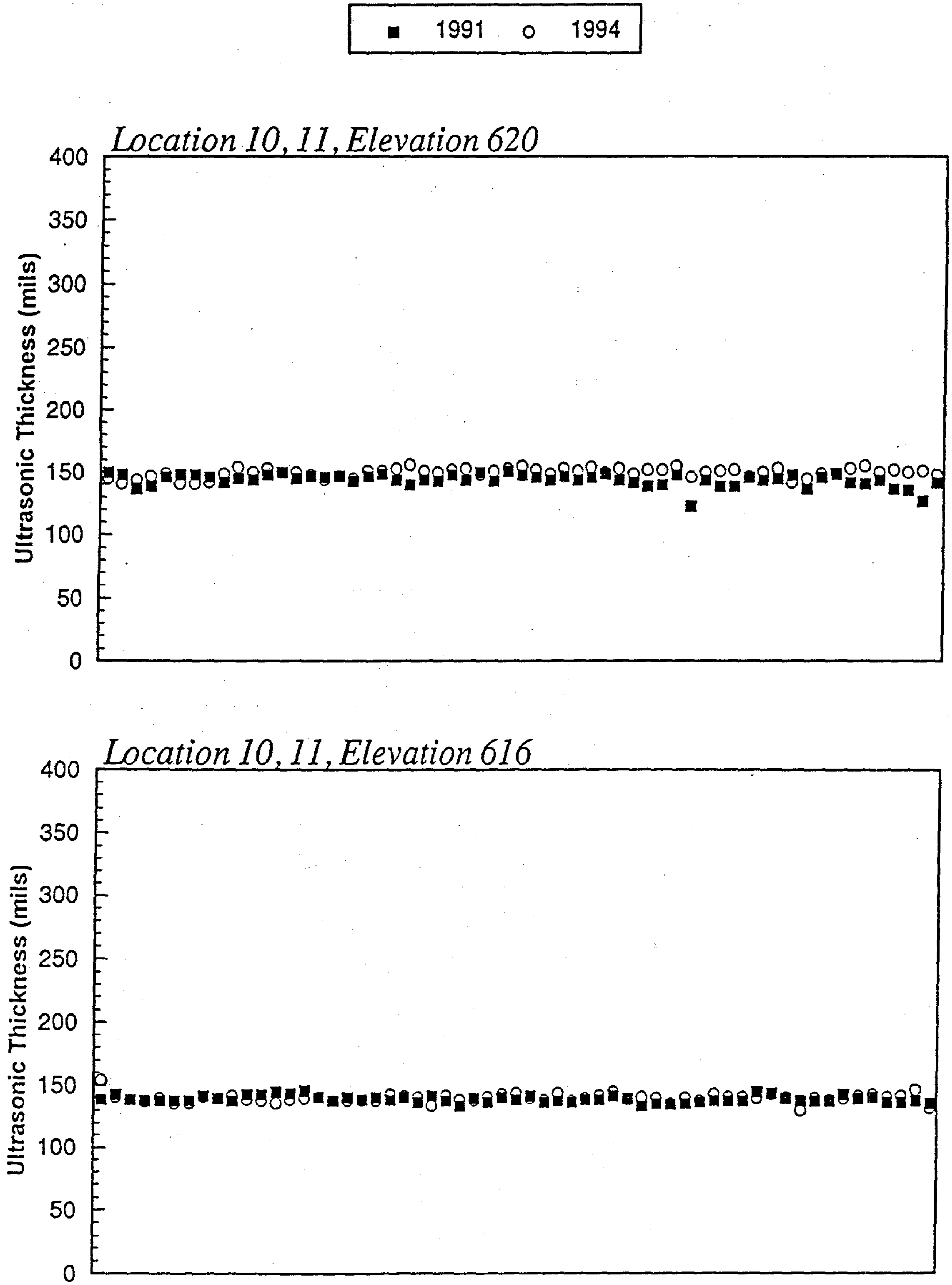
Location 10, 11, Elevation 620



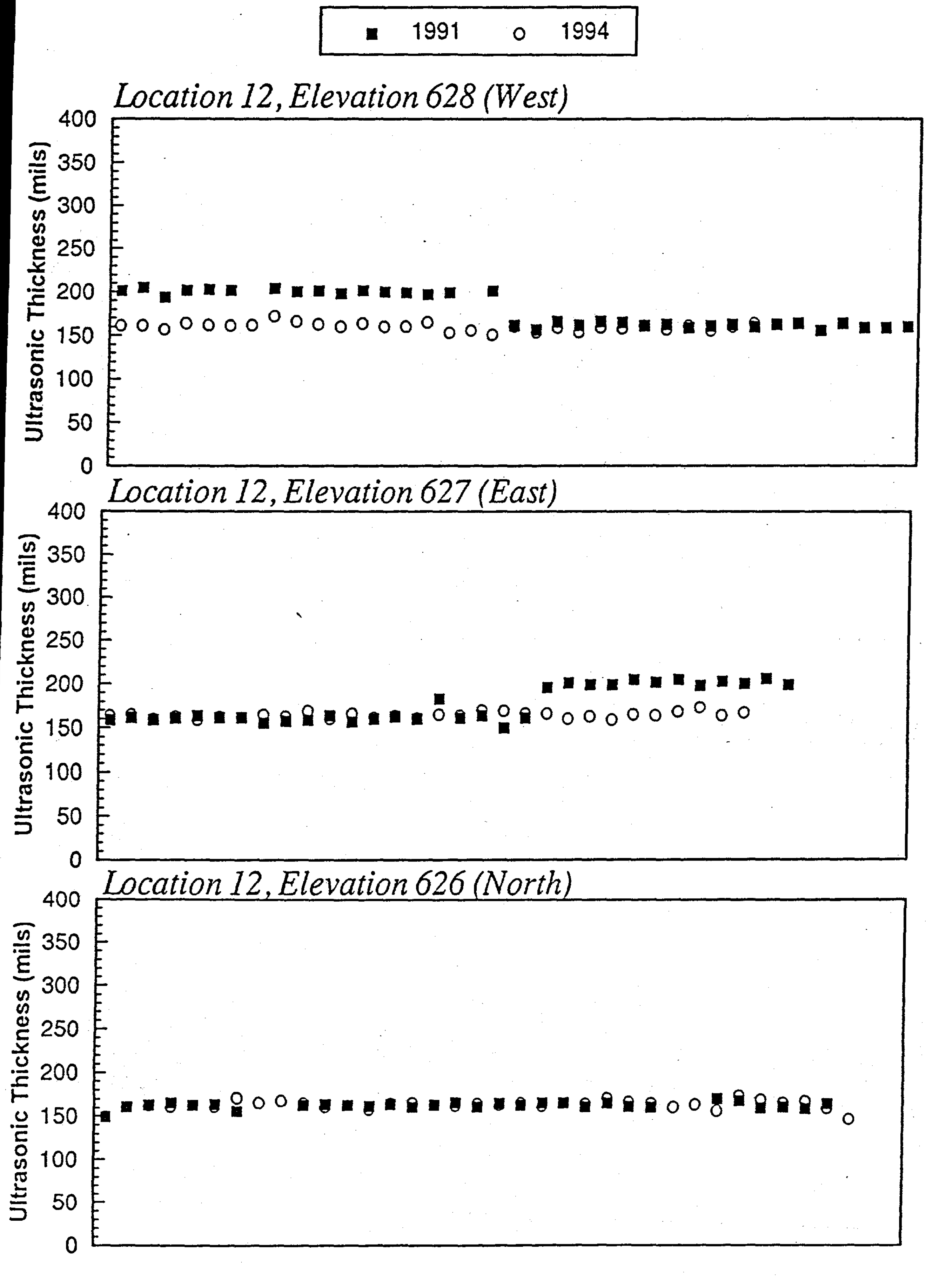
Location 10, 11, Elevation 616



Lakeside Unit 7
Ultrasonic Thickness Results
Generating Bank Inlet



Lakeside Unit 7
Ultrasonic Thickness Results
Furnace Water Walls

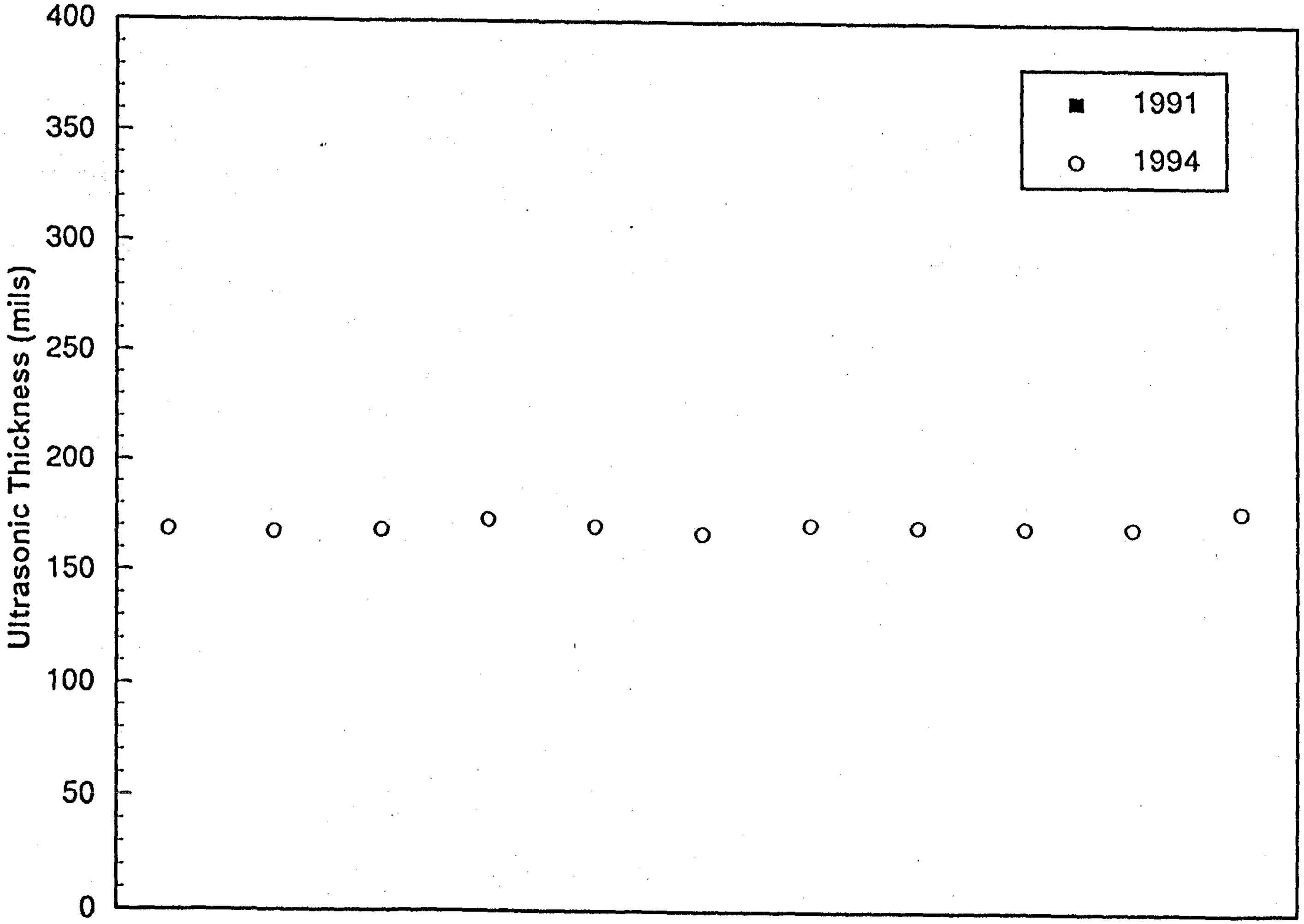


Location 12, Elevation 628 (West)

Location 12, Elevation 627 (East)

Location 12, Elevation 626 (North)

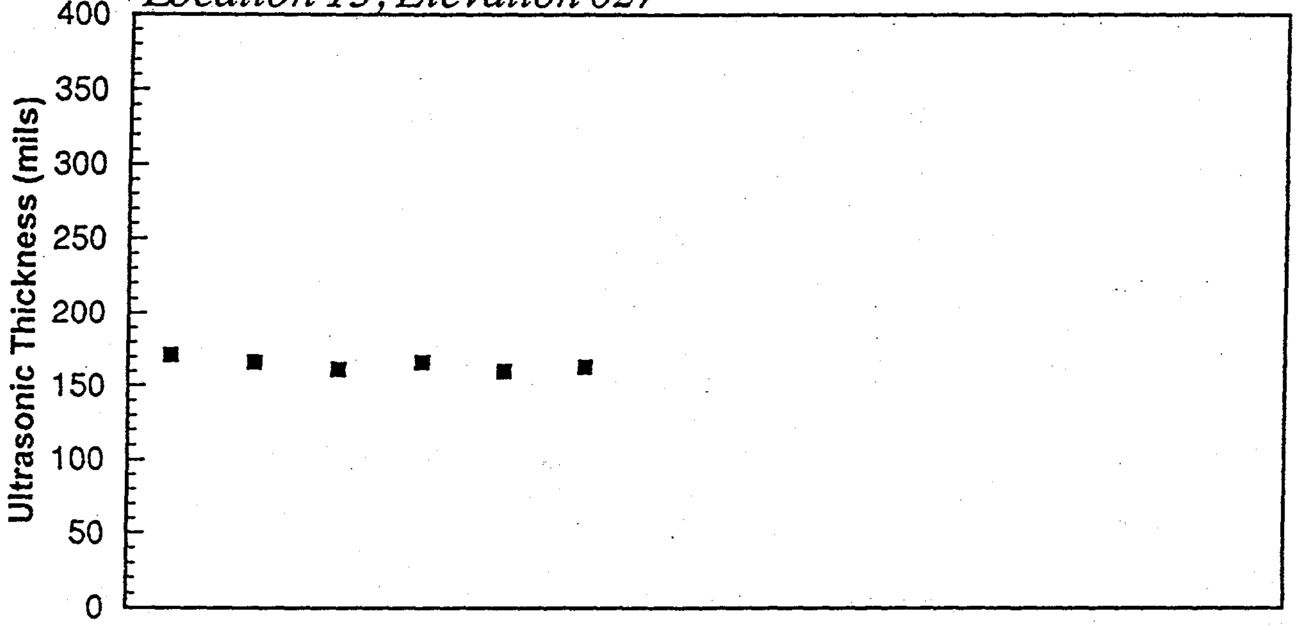
Lakeside Unit 7
Ultrasonic Thickness
Header Pipes North Side
Location 12, Elevation 628



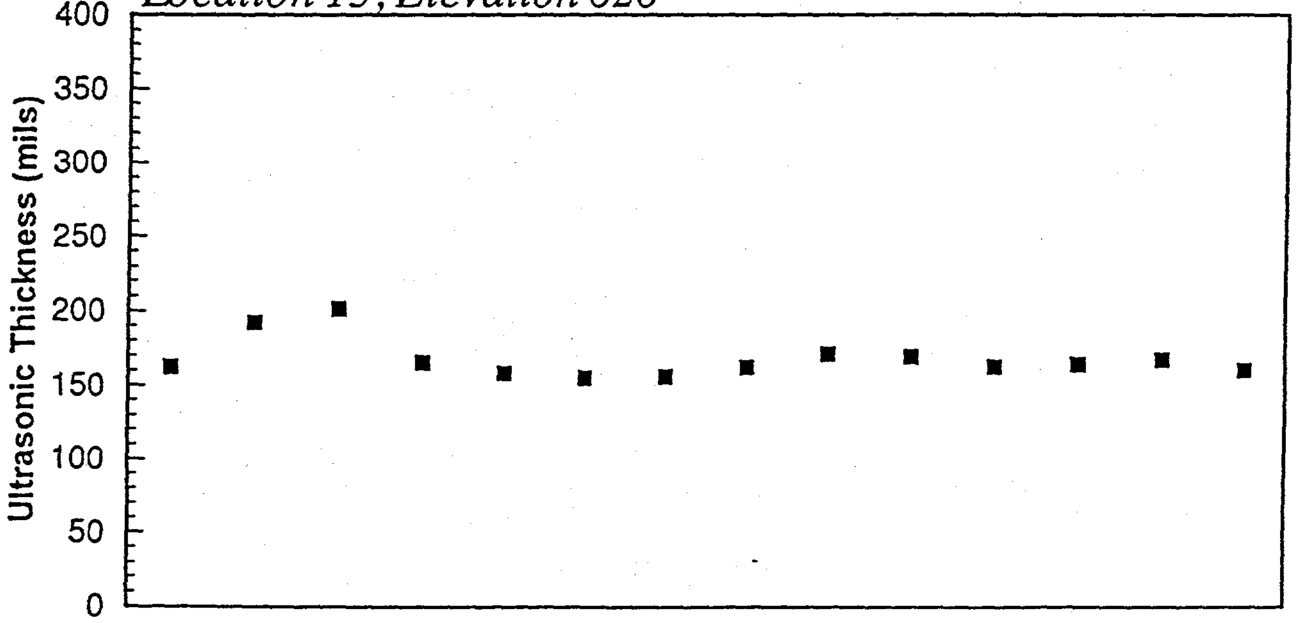
Lakeside Unit 7
Ultrasonic Thickness Results
Penthouse, Primary Superheater Inlet

■ 1991 ○ 1994

Location 13, Elevation 627

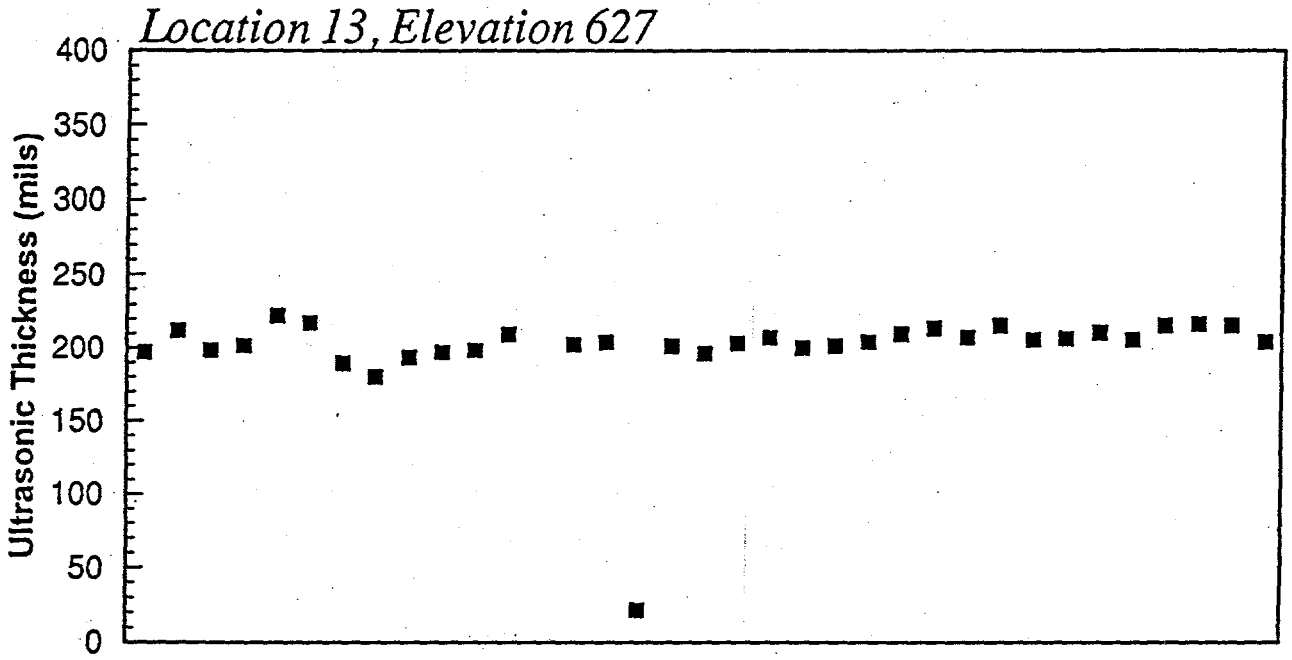


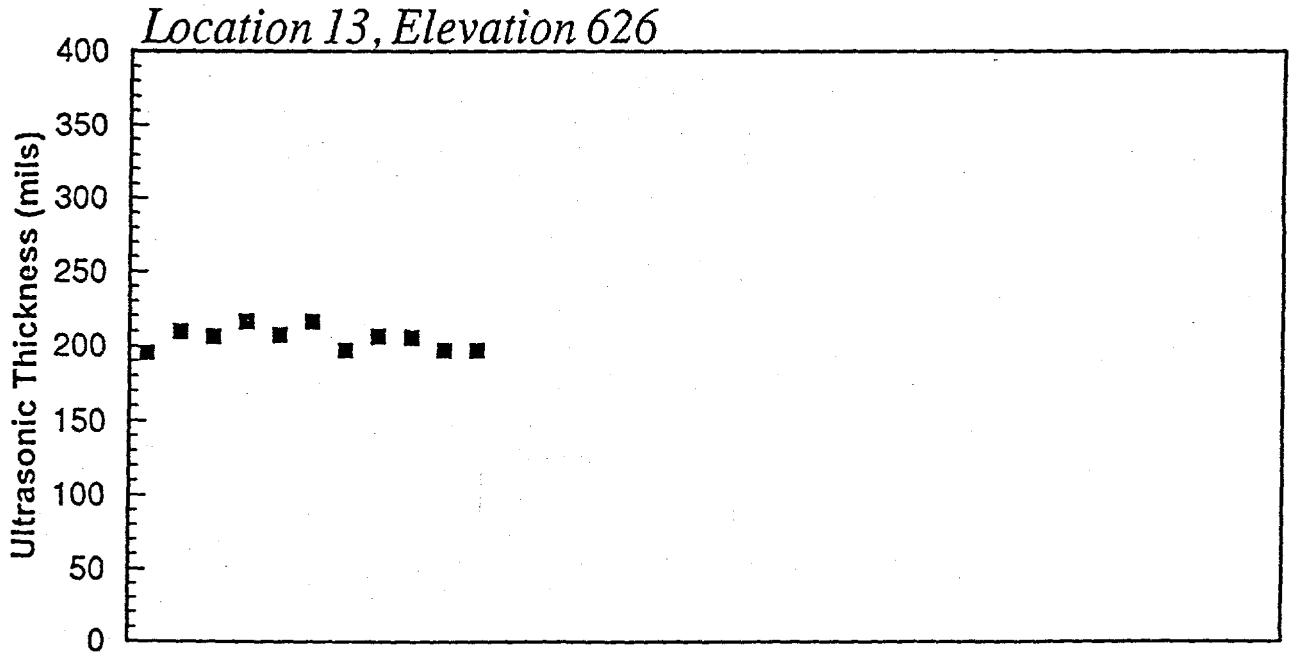
Location 13, Elevation 626



Lakeside Unit 7
Ultrasonic Thickness Results
Penthouse, Primary Superheater Outlet

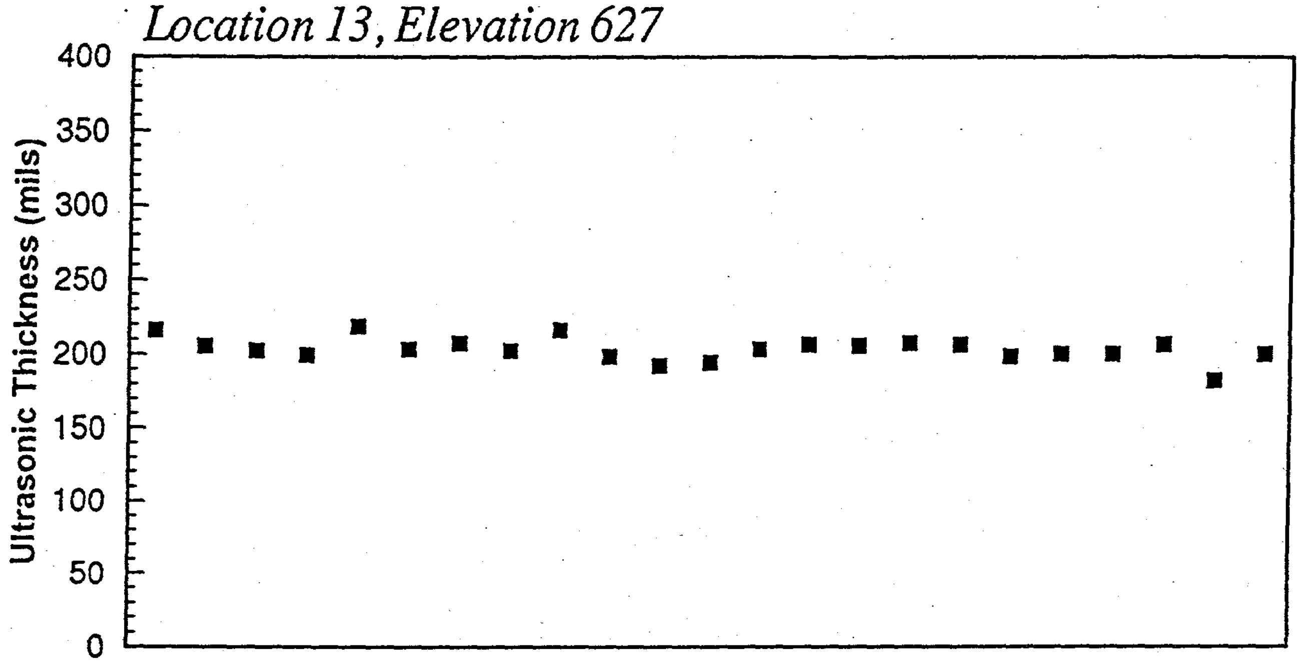
■ 1991 ○ 1994

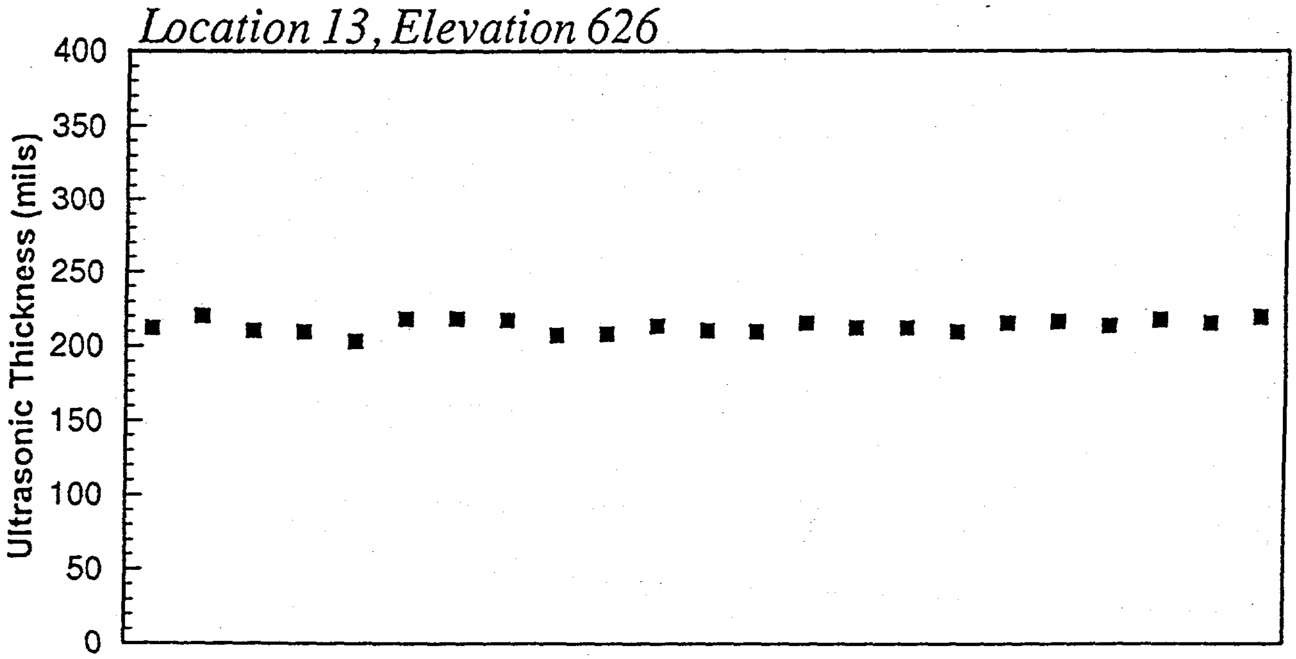

Location 13, Elevation 627


Location 13, Elevation 626

Lakeside Unit 7
Ultrasonic Thickness Results
Penthouse, Secondary Superheater Inlet

■ 1991 ○ 1994


Location 13, Elevation 627

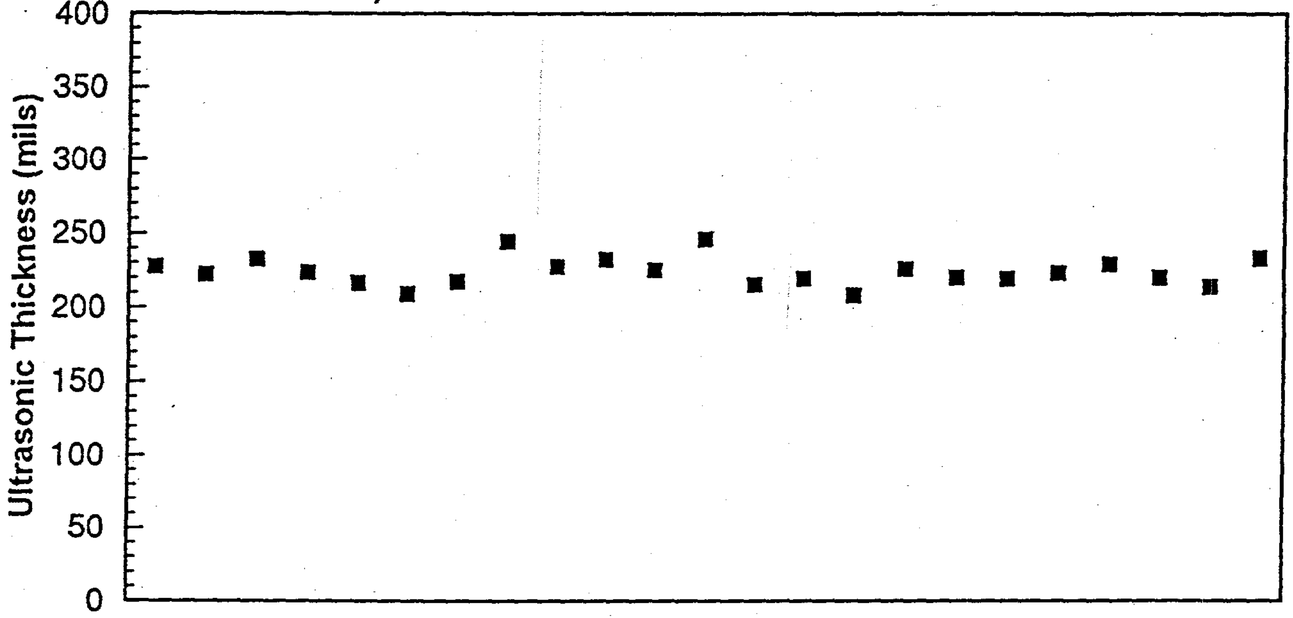

Location 13, Elevation 626

Lakeside Unit 7
Ultrasonic Thickness Results

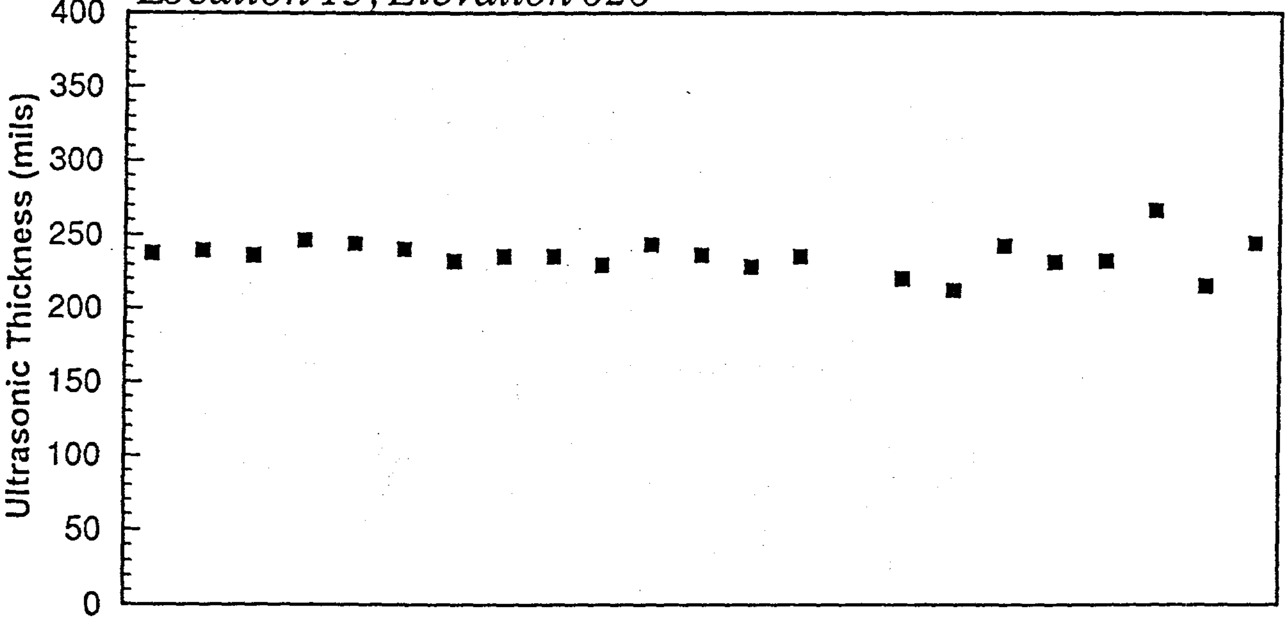
Penthouse, Secondary Superheater Outlet

■ 1991 ○ 1994

Location 13, Elevation 627



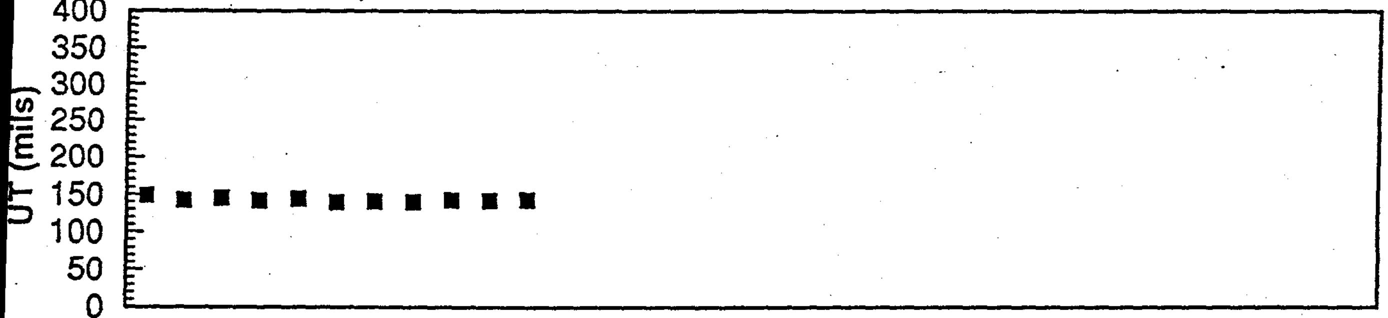
Location 13, Elevation 626



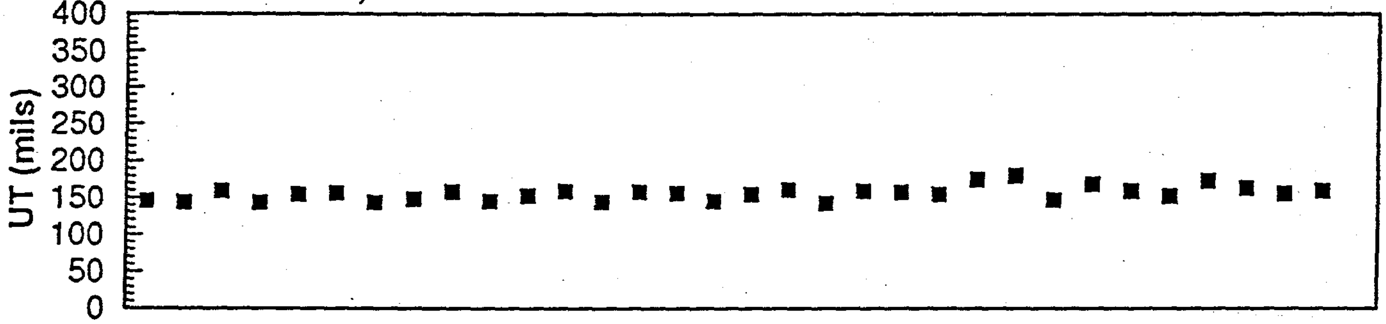
Lakeside Unit 7
Ultrasonic Thickness Results
Penthouse, Rear Wing Wall

■ 1991 ○ 1994

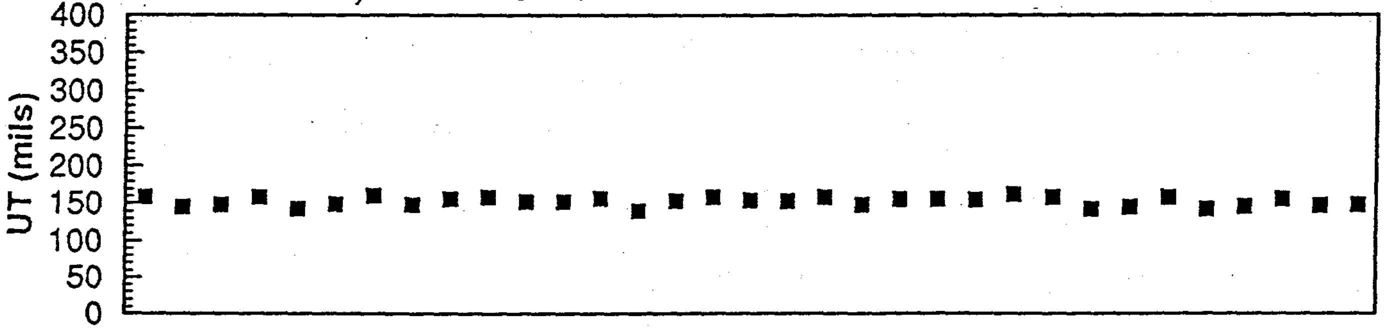
Location 13, Elevation 629



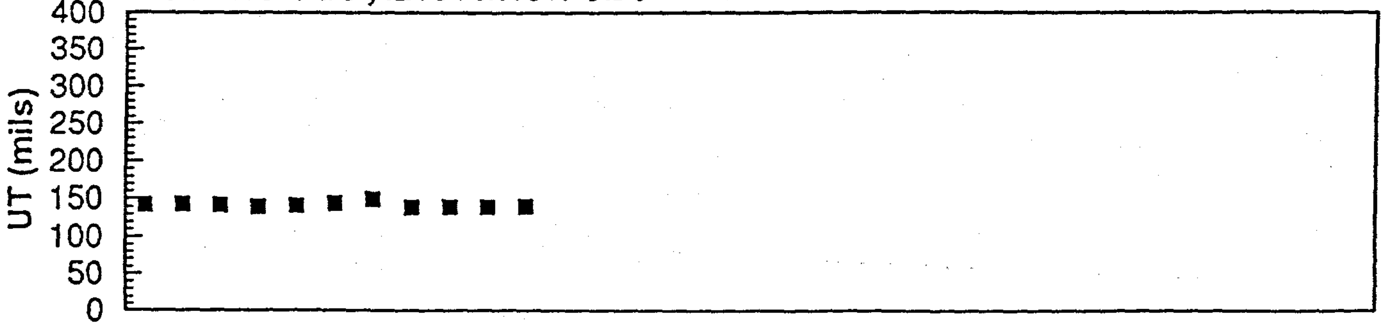
Location 13, Elevation 628



Location 13, Elevation 627



Location 13, Elevation 626



FIELD INSPECTION REPORT

CITY WATER LIGHT AND POWER
LAKESIDE STATION
SPRINFIELD, ILLINOIS

SIZE: 21-VCX
SERIAL NO. 3452
OUR FILE: LAP-1771

THE AIR PREHEATER SOOT BLOWER WAS ADJUSTED AND INSPECTED, PLEASE NOTE THE FOLLOWING COMMENTS:

THE SOOT BLOWER NOZZLE AND LANCE WERE INSPECTED AND FOUND TO BE IN OPERABLE CONDITION, ONLY A SLIGHT AMOUNT OF NOZZLE EROSION WAS DETECTED.

THE LANCE SWEEP WAS ADJUSTED AND TESTED ELECTRICALLY, THE LIMITS WERE ADJUSTED. A GREAT DEAL OF WEAR WAS DETECTED IN THE MECHANICAL LINKAGE.

THE SOOT BLOWER DRIVE SYSTEM WAS FOUND IN GOOD CONDITION, THE SPEED REDUCER AND GEAR DRIVE WERE OPENED, CLEANED, INSPECTED, AND WERE RELUBED.

THE MOUNTING BRACKET WAS INSPECTED, THE BOLTS WERE TORQUED AND THE DOWEL PINS WERE SECURED.

THE AIR PREHEATER COLD END RADIAL SEALS HAVE EROSION AREAS AND ARE THIN.

BASED ON THE INSPECTION THE FOLLOWING IS RECOMMENED:

1. REPLACE THE FOLLOWING:
    - A. COLD END RADIAL SEALS, HOLDING STRIPS AND FASTERNERS.
    - B. MECHANICAL SOOT BLOWER LINKAGE ARM AND BUSHINGS.
    - C. LINKAGE ARM PIN AND THE ECCENTRIC CRANK PIN.
    - D. CLEANING MEDIUM SWIVEL DEVICE.

2. DUE TO THE INCREASED ACTIVITY EXPECTED FROM THIS SOOT BLOWER IT IS RECOMMENDED TO HAVE THE FOLLOWING PARTS IN STOCK:
    1. NOZZLE AND LANCE ASSEMBLY.
    2. DRIVE SPEED REDUCER AND GEAR.
    3. ELECTRIC MOTOR AND COUPLING.
    4. SWIVEL JOINT.

THANK YOU FOR YOUR COOPERATION DURING THIS INSPECTION.

NOTE: ABB APCo AFTERMARKET SALES WILL QUOTE THE RECOMMENDED PARTS AND SPARE PARTS FOR YOUR CONSIDERATION.

FIELD INSPECTION REPORT

CITY WATER LIGHT AND POWER
LAKESIDE STATION
SPRINFIELD, ILLINOIS

SIZE: 21-VCX
SERIAL NO. 3452
OUR FILE: LAP-1771

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THE MOUNTING BRACKET WAS INSPECTED, THE BOLTS WERE TORQUED AND THE DOWEL PINS WERE SECURED.

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1. REPLACE THE FOLLOWING:
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   - B. MECHANICAL SOOT BLOWER LINKAGE ARM AND BUSHINGS.
   - C. LINKAGE ARM PIN AND THE ECCENTRIC CRANK PIN.
   - D. CLEANING MEDIUM SWIVEL DEVICE.
2. DUE TO THE INCREASED ACTIVITY EXPECTED FROM THIS SOOT BLOWER IT IS RECOMMENDED TO HAVE THE FOLLOWING PARTS IN STOCK:
   1. NOZZLE AND LANCE ASSEMBLY.
   2. DRIVE SPEED REDUCER AND GEAR.
   3. ELECTRIC MOTOR AND COUPLING.
   4. SWIVEL JOINT.

THANK YOU FOR YOUR COOPERATION DURING THIS INSPECTION.

NOTE: ABB APCO AFTERMARKET SALES WILL QUOTE THE RECOMMENDED PARTS AND SPARE PARTS FOR YOUR CONSIDERATION.

ABB AIR PREHEATER

TECHNICAL SERVICES REPORT

CUSTOMER: City Water Light & Power **REPORT DATE:** 11-07-94

STATION: Lakeside Plant **VISIT DATE:** 10-27-94

LOCATION: Springfield, IL **FUEL:** Coal

CONTRACT: LAP 1771 **UNIT NO.:** 7 **SER. NO.:** 3452 **SIZE:** 1-21-VCX-54

CUSTOMER PERSONNEL: Brian Fitzgerald

PHONE NO.: 217-786-4035

TYPE OF TRIP: ___SALES/ENG ___EREC/START UP ___REPAIR _X_INS
___COURTESY ___WTR-1 _X_WTR-5 ___WARRANTY

ACTION REQUIRED: ___YES _X_NO

QUOTATION: ___YES _X_NO

ACTION DEPT: ___TECH SRV ___ENGINEERING ___AFTERMKT SALES

TO: R. B. RHODES

FROM: BRUCE E. COREY
CHICAGO
800 323-7455
(816) 792-5252

CC: WELLSVILLE CENTRAL FILE
JEFF ANDERTON, G.C. GOETSCHIUS,
T.J. McNULTY, KENT RITTER,
GILKEY/MERGER/MATTISON/GORSKI
W.D. BLACKBURN, H.E. FINNEMORE,
J.H. EMERSON, R.J. McGUIRL, C.C. MURPHY

NEXT PLANNED OUTAGE DATE: DURATION:

ACTION ITEM(S):

The purpose of this inspection was to determine the current condition of heating element, seals, and rotor of this installation. Over the past several years, Energy & Environmental Research has been performing sorbent injection testing on Unit #7- B & W cyclone boiler under sponsorship of the Department of Energy. City Water Light & Power requested this inspection to determine if the testing has resulted in any deterioration of Air Preheater components.

FIELD INSPECTION NOTES

Basketed Heating Element - 42" DL/12" NF-6

The cold end heating element was clean throughout the area covered by the sootblower. There was no indication of any deposit except in the area inboard not covered by sootblower traverse. Several cold end "B" baskets were removed to check the top of the hot end baskets. No evidence of fouling or mechanical degradation was observed. Inspection of the hot end element from the air outlet duct revealed deposits characteristic of incomplete washing present in the inboard 8 inches of several "A" baskets. Also observed were element sheets in four "A" baskets which had been driven downward over the basket spider bars. Only one of two element pairs was affected at approximately a 6" radius outward of the post. This type of damage is the result of excessive sootblower dwell time at the inboard extent of its travel.

Rotor Seals

Radial seals, circumferential seals, and rotor post seals were found in commercially sound condition. Seal clearances are within acceptable tolerances, with the exception of the cold end circumferential seals. Excessive clearance of these seals is not from wear, it is the result of support angle setting. Observed clearances could be reduced by ¼".

Rotor and Structure

Weld repairs to diaphrams, which were performed in 1985, are failing. Fractures are evident in post to diaphram welds, shell to diaphram welds, or diaphram material adjacent to these welds. The cold end has the most severe damage. Hot end post fractures are just beginning to reoccur. The following fractures were noted at the cold end.

Diaphram #6 - post to diaphram weld
Diaphram #7 - post to diaphram weld double diaphram
Diaphram #10 - post and shell weld
Diaphram #12 - adjacent to shell and parallel to repair
Diaphram #2 - adjacent to shell trailing double diaphram
Diaphram #4 - adjacent to shell
Diaphram #5 - adjacent to shell

Installation of partial cold end diaphrams and inserts has been our long term recommendation for permanent repair. As a minimum, additional diaphram support should be installed to slow the propagation of weldment and diaphram cracks. Two hot end basket support bars are not completely welded to the adjacent diaphram.

Erosion of the cold end center section by the sootblowing medium was observed at the point of inner most sootblower nozzle ~~trouble~~. Welding a wear plate over this area will minimize future erosion.
TRAVEL

TALKED WITH BRUCE COREY 1/12 11:00 AM

CYLP TOOK CHEAPEST OPTION ON REPAIR IN 1985. PROBLEMS DISCOVERED NOW ARE NOT UNEXPECTED
CR-SI CERTAINLY NOT ROOT CAUSE.

HIGHER GAS TEMPS (WITH SI) AND HIGH DIFFERENTIAL PRESSURES COULD HAVE ACCELERATED THIS SITUATION - WAG AS TO HOW MUCH.

AirPol INC.
30 Henry Street, Teterboro, NJ 07608 · (201) 288-7070 · Fax (201) 288-6441

air
pol

April 16, 1992

Energy & Environmental Research Corporation
P. O. Box 153
1345 North Main Street
Orrville, OH 44667

Attention: Mr. D. Englehardt

Reference: Your P. O. 47883
Inspection of FLS Precipitator
City Water, Light & Power Co.
Lakeside Station, Springfield, Il.

Gentlemen:

On November 12 & 13, 1991 the referenced precipitators were inspected with the following results:

1. First field
    - A. Found piece of flat bar broken off discharge rapper at the second elevation. Flat bar needed to stop swinging of rapper hammer.
    - B. Rapper drive chains are too loose. Remove links.
    - C. Rapper drive chains at the drives need links removed and guide roller adjusted for discharge and collecting system drive chains.
    - D. Inlet screens need to be rapped prior to start up.

2. Second field.
    - A. Discharge chains need adjustment with links taken out of all fields.
    - B. Collecting rapper needs to be run more frequently to remove build-up on plates.

3. Third field.
    - A. Rapper chains need links removed.

4. Fourth field.
    - A. Discharge rapper chains need adjustment and links removed. Guide roller needs adjustment.

5. All 8 collecting and discharge drives need links removed at the drive box.

6. Checked all 32 support insulators. All ok with no cracks.

Overall, the precipitator is in very good condition, requiring primarily adjustment to the rapper drive chains.

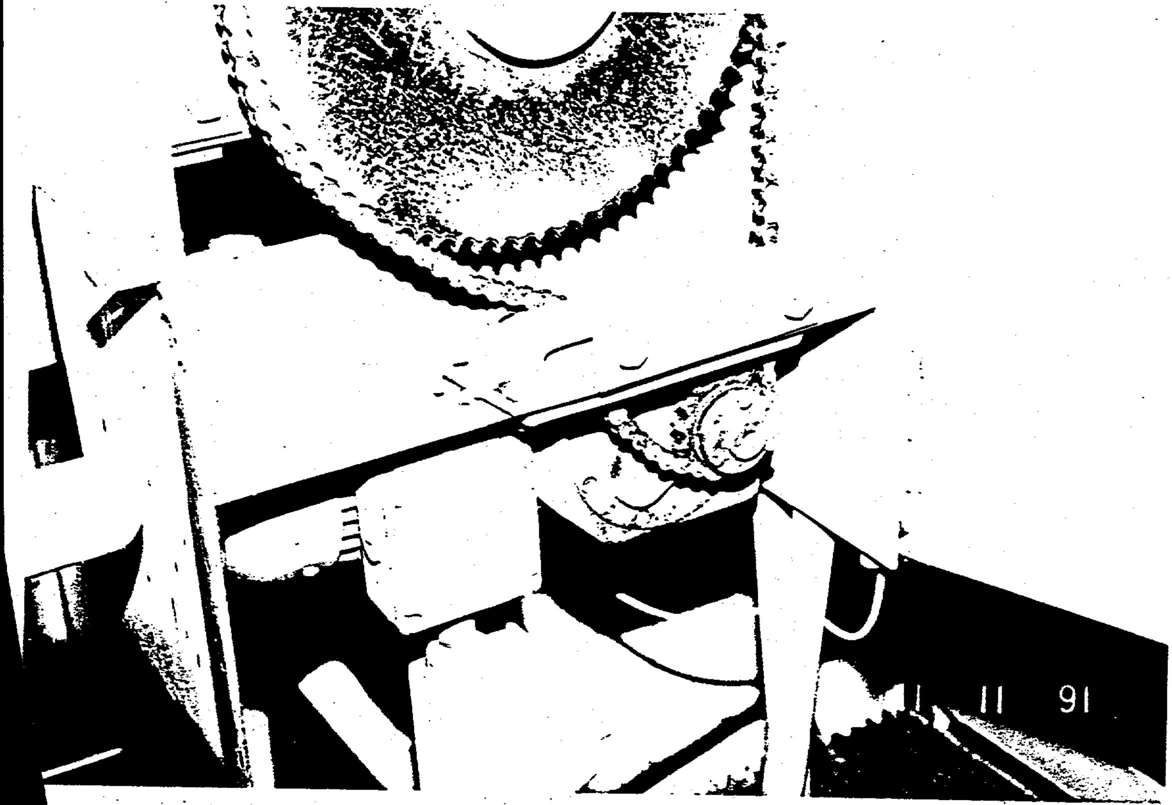
Photo's will follow.

Very truly yours,

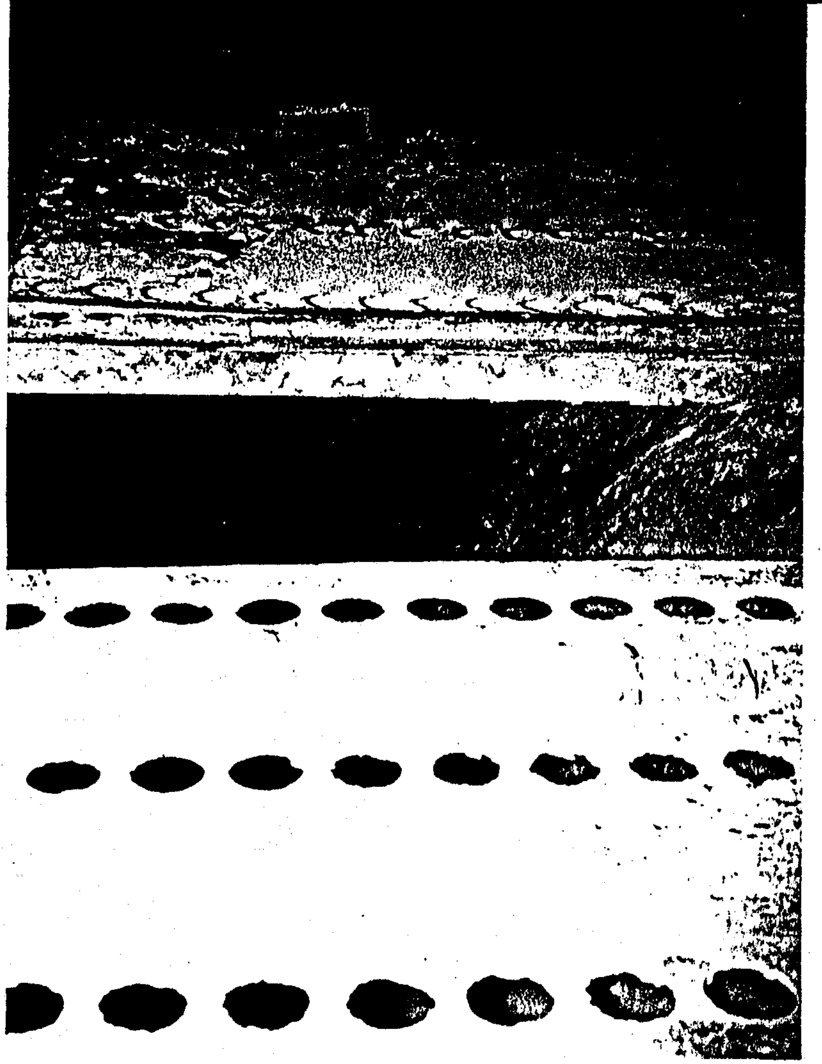
Donald Achenbach

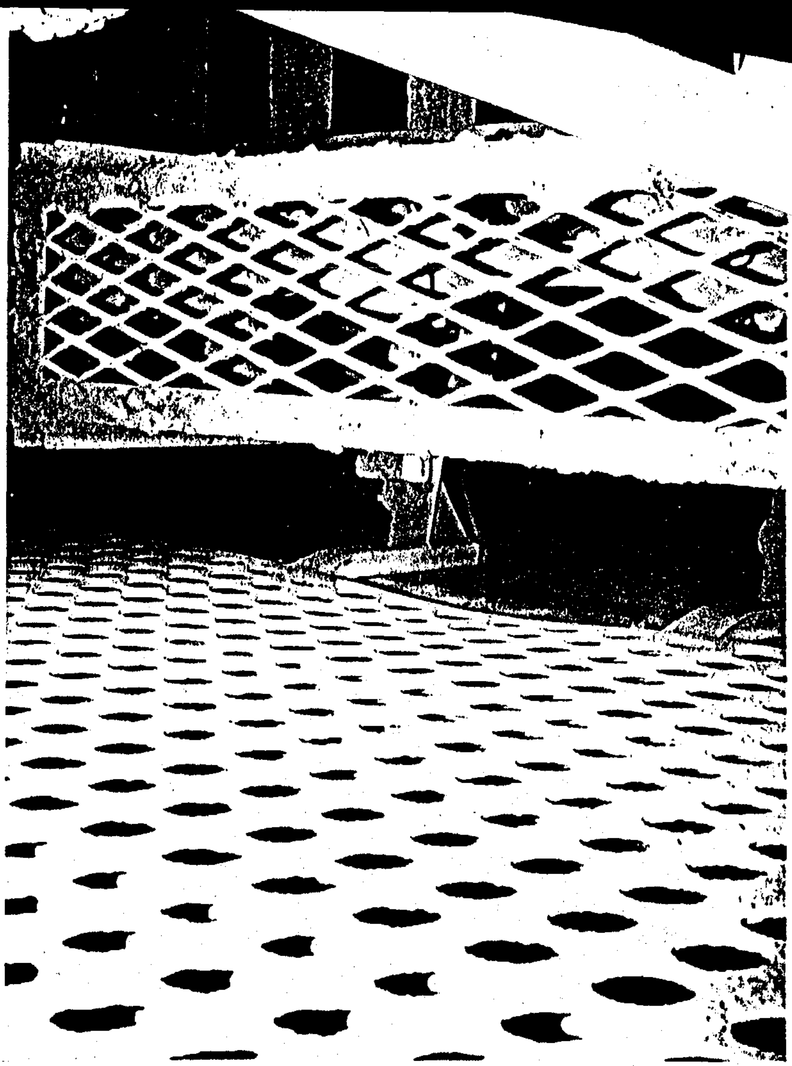
Donald A. Achenbach
General Sales Manager-Power

Flat Bar broken off Rapping Shaft



External Drive Chain on Rapping System
Needs Link removed and Idler adjusted



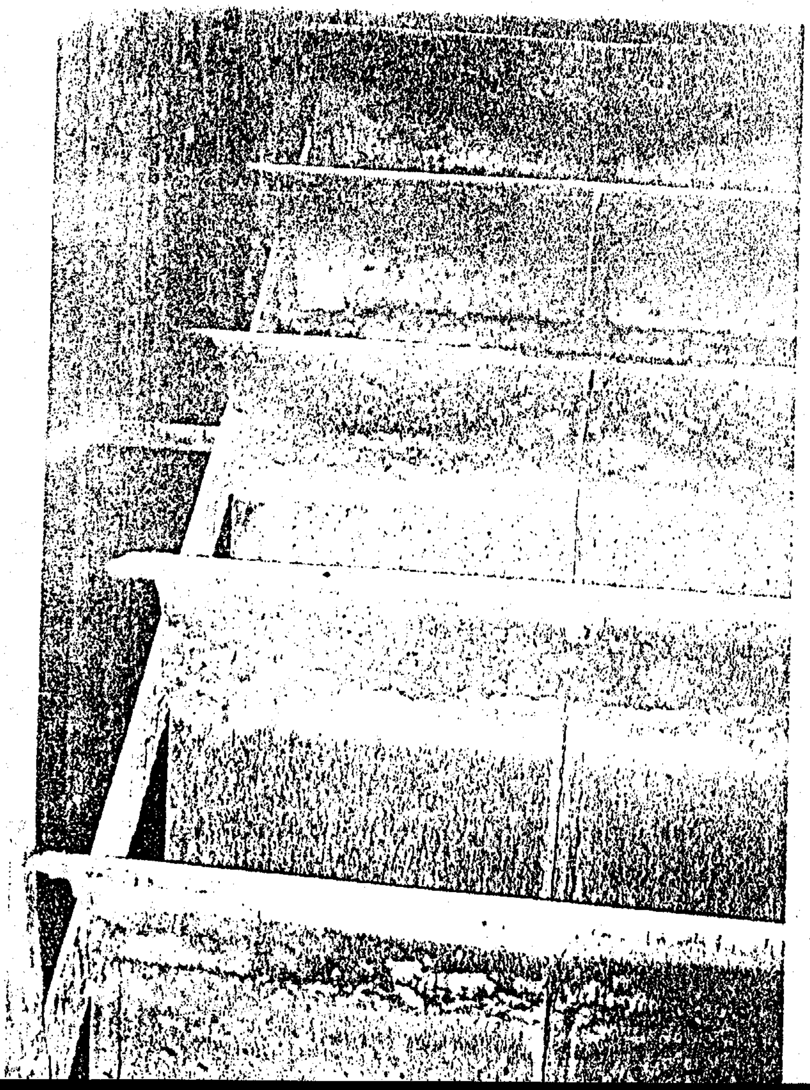


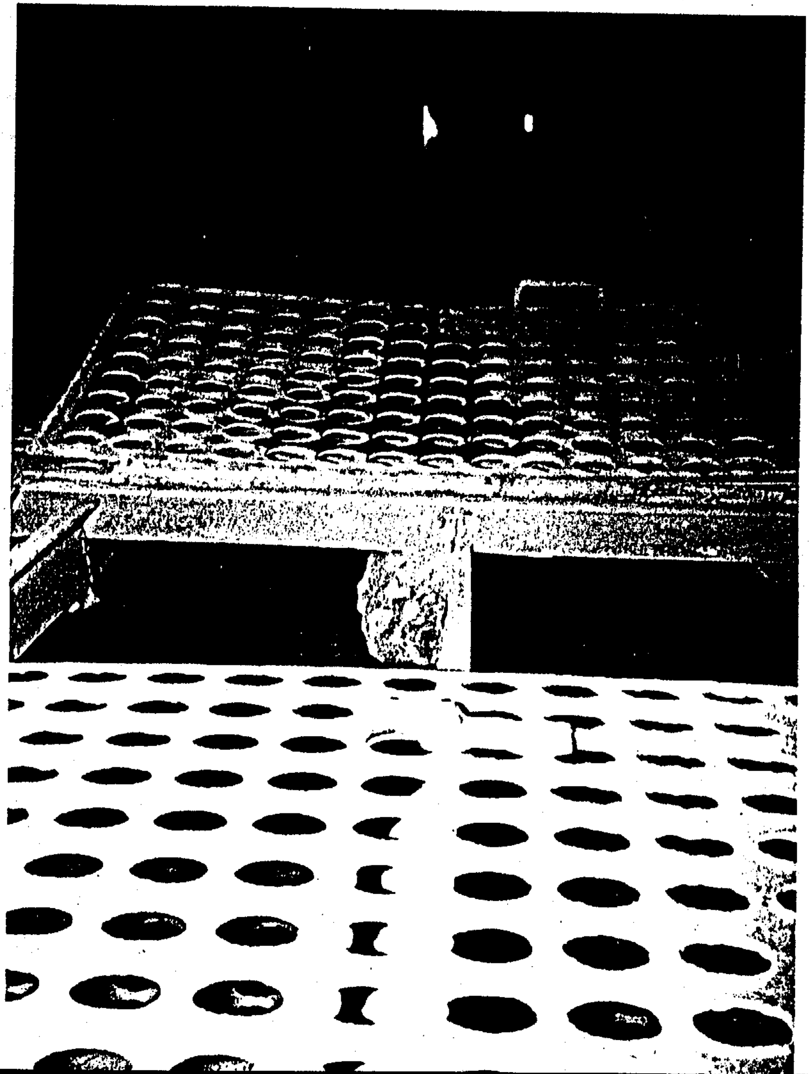
Internal Drive Chain on Rapping System

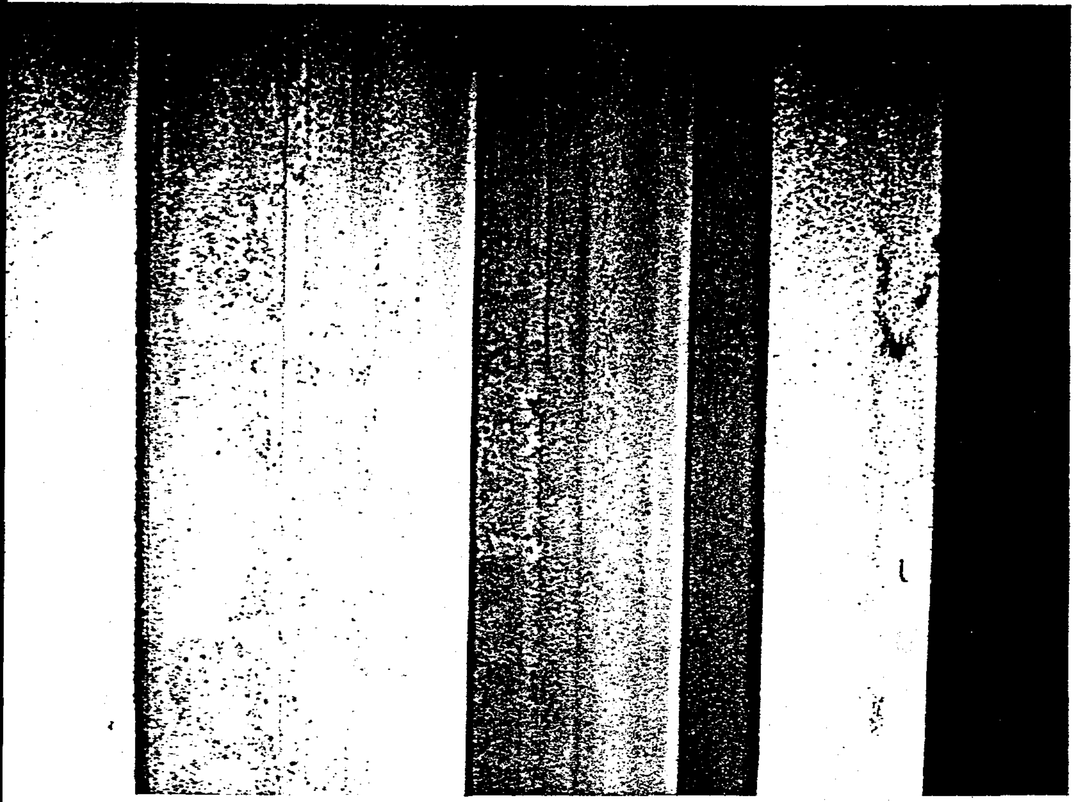
Link needs to be removed, and Guide Roller adjusted

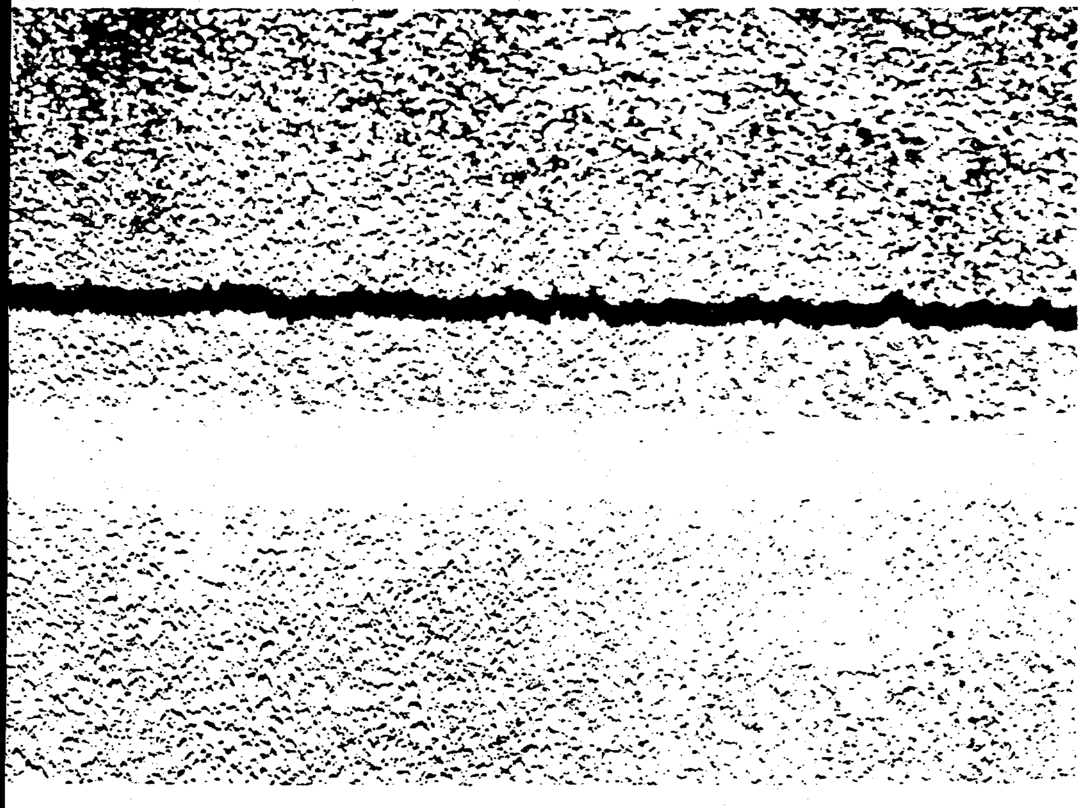
Internal Drive Chain on Rapping System

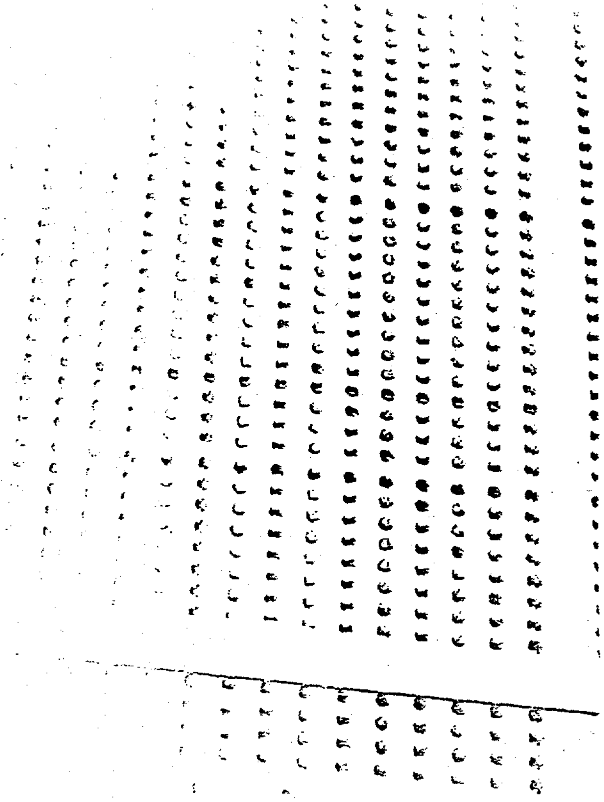
Link Needs to be removed, and Guide Roller adjusted

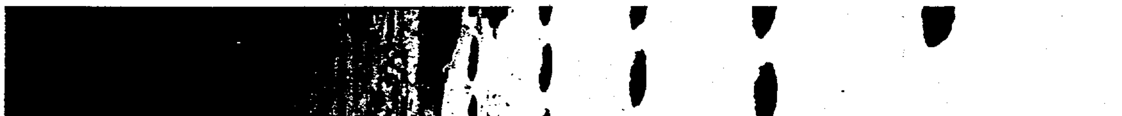












R POLLUTION CONTROL SPECIALISTS **EPSCON - FLS, INC.**

November 8, 1994

Energy & Environmental Research Corporation
1345 N. Main Street
P.O. Box 153
Orrville, Ohio 44667

Attn: Mr. Donald A. Engelhardt
Project Manager

Ref: Precipitator Inspection - City Water Light & Power
Springfield, Illinois
EER Authorizing P.O. No. 70897-8659
EPSCON-FLS, Inc. Contract Reference No. N-0258W

Gentlemen:

As directed by your purchase order, a representative of EPSCON-FLS inspected the Lakeside Unit #7 & #8 Precipitator, on October 28, 1994.

As I understand it, the main purpose of the inspection was to compare the present condition of this precipitator to the condition found during the 1991 inspection of this same precipitator. Sorbent injection as been utilized during this interim period. Fortunately, we were able to assign Mr. Billy Boswell to make this inspection. Mr. Boswell made the initial 1991 inspection as an employee of AirPol, Inc.

Two (2) unedited copies of Mr. Boswell's report to me are attached along with two (2) sets of photographs. In addition to the written report, I have talked with Mr. Boswell by phone concerning his observation. It is obvious from his report and the photographs, that the precipitator rapping systems are not functioning properly and in at least one case, not functioning at all. This would of course influence the amount of precipitated material still found on the collecting electrode surfaces. Curiously, the discharge electrodes proper, do not seem to be excessively built up. The inlet gas distribution screens were clean yet the outlet screens were build up substantially and partially plugged. This would suggest a change in the dust and/or gas characteristics since the 1991 observations.

At any rate, the precipitator rapping systems should be restored to their original capability by replacing worn parts, broken chains, worn bearings and shafts, etc.

WILLIAMSBURG COMMERCE CENTRE
460 McLAWS CIRCLE SUITE 220 • WILLIAMSBURG VA 23185 • (804) 253-1712 • TELEFAX (804) 220-9240

EPSCON-FLS, Inc. would be happy to work with you and or the power company directly, should you require our assistance. Please review these comments and Mr. Boswell's report and call me if we can be of future service.

Very truly yours

Walter W. West

Walter W. West
President

enclosures

WWW/sfh

Nov. 2, 1994

Epscon/FLS
Mr. Walter West
Subj: Precipitator Inspection CWLP Springfield, Ill.
Lakeside Unit 7&8

Here is a summary of my inspection of the precipitator at Lakeside 7&8 on Oct. 28th 1994. Upon arrival at the site I met with EER representatives Mr. Sid Sunberg and Site Manager: Mr. Elliott Mecchia.

1. My first discovery was that that the unit had a large amount of dust in side It's conceivable to think that the rapping system is not working properly or is not working frequently enough . In "1991 I inspected this same precipitator and found it to be clean of this problem. I must say that it is quite the opposite this time. In my latest inspection, I found the dust more abrasive than the inspection of "1991" at this time I cannot give you a answer to what the problem may be.

2. In regards to the Inlet screens, I found them to be very clean.

3. The 1st field collecting plates were found to have high levels of dust. This is a result of the rapping system not being set correctly. The rappers need to run more frequently.

4. I found the the discharge rapping shafts to be worn beyond usefulness and I would suggest replacement of all. The hammers have turned on the shaft and need to be reset to correct orientation. As some of the hammers hit at the same time. Also the drives for the the rapping need new chains and need to be adjusted properly. The sprocket is slightly worn, but can be used.

5. The collecting rapping drives need new chains along with correct adjustment. Shafts are in need of work. Due to the large amount of dust, I could not check shafts for heavy wear. These shafts need to be checked after rappers have ran for 24 hrs.

NOV 1994
RECEIVED

6.I found the 2nd field to have the heaviest amount of dust on the collecting plates. The field on the left facing the outlet, The rapping system had not been

running due to the chain being broken on the drive. **See " Photos " .** Another problem that has happened is collecting drive is locked up and I could not free the shaft with the help of a 24" pipe wrench. The plates on the right field had high amounts of dust on them. This field needs more rapping.

7. Discharge rapping shafts are very bad on this field . **See " Photos "**. Also the bearings need to be turned 180 degrees. For the most part the chains need to be replaced and set, also hammers need to be set to correct orientation.

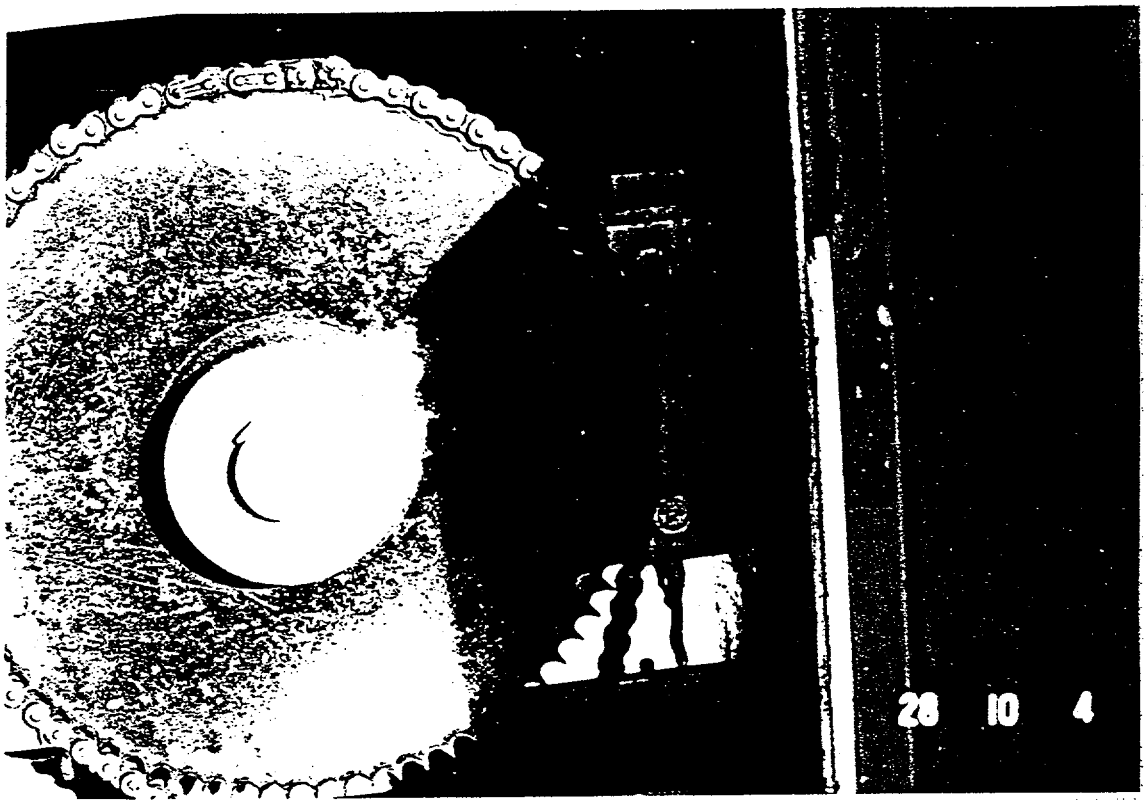
8. The 3rd and 4th fields are almost identical to the 1st field.

9. The outlet screens are 50% plugged with dust. Large amounts of dust are lying in the outlet nozzle. This needs to be removed as it restricts air flow through the nozzle. In the 1991 inspection I noted that these screens were as clean as the Inlet screens on this Inspection. It is possible to install a rapping system on the screens.

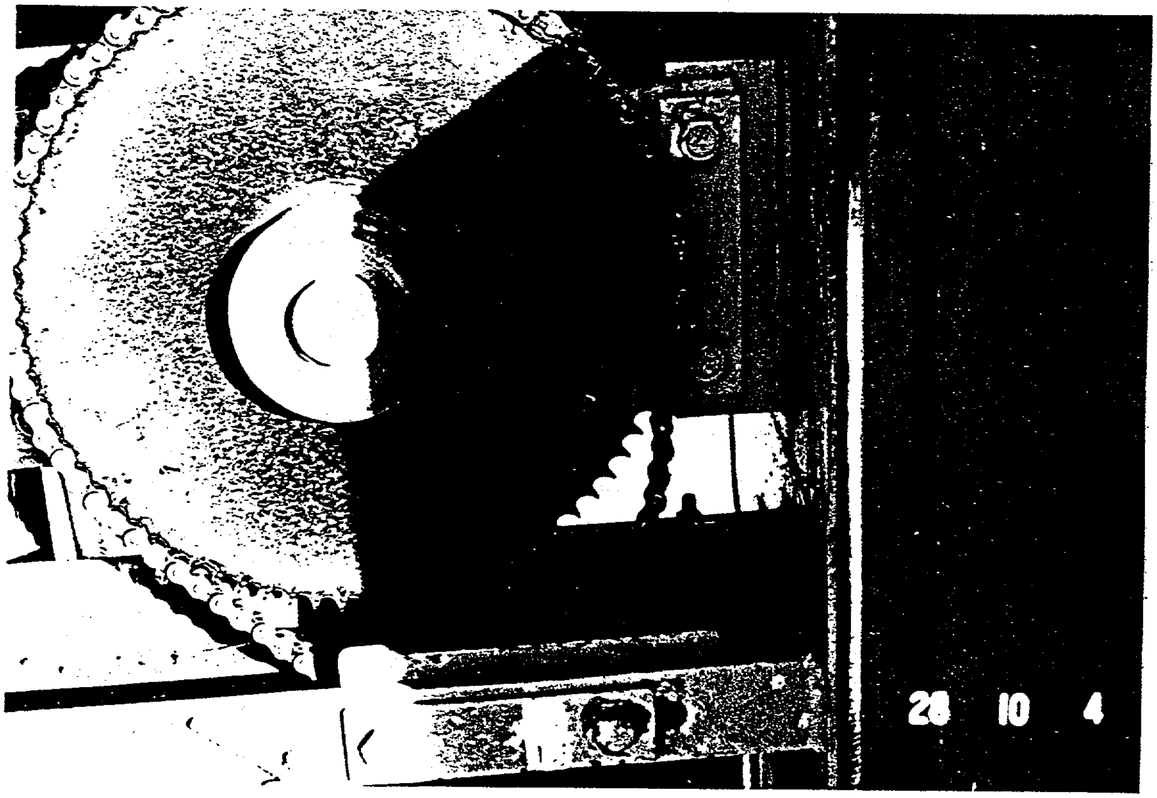
10. I also checked 8 insulator compartments on the roof and found no cracks or chips. I was asked by CWLP to give them a copy of my report and discoveries I had made and problems that I had noted. I also sat down with EER representatives and discussed what I had found during my inspection. I was asked by EER not to give CWLP a report but let it come from them. I said a report with photos would be sent to EER from Epscon/ FLS office in Williamsburg, Va. I was asked by CWLP if Epscon/FLS did repair work provide Technical Supervision. I gave them Epscon/FLS office number and your name Mr. West.

" Best Regards "

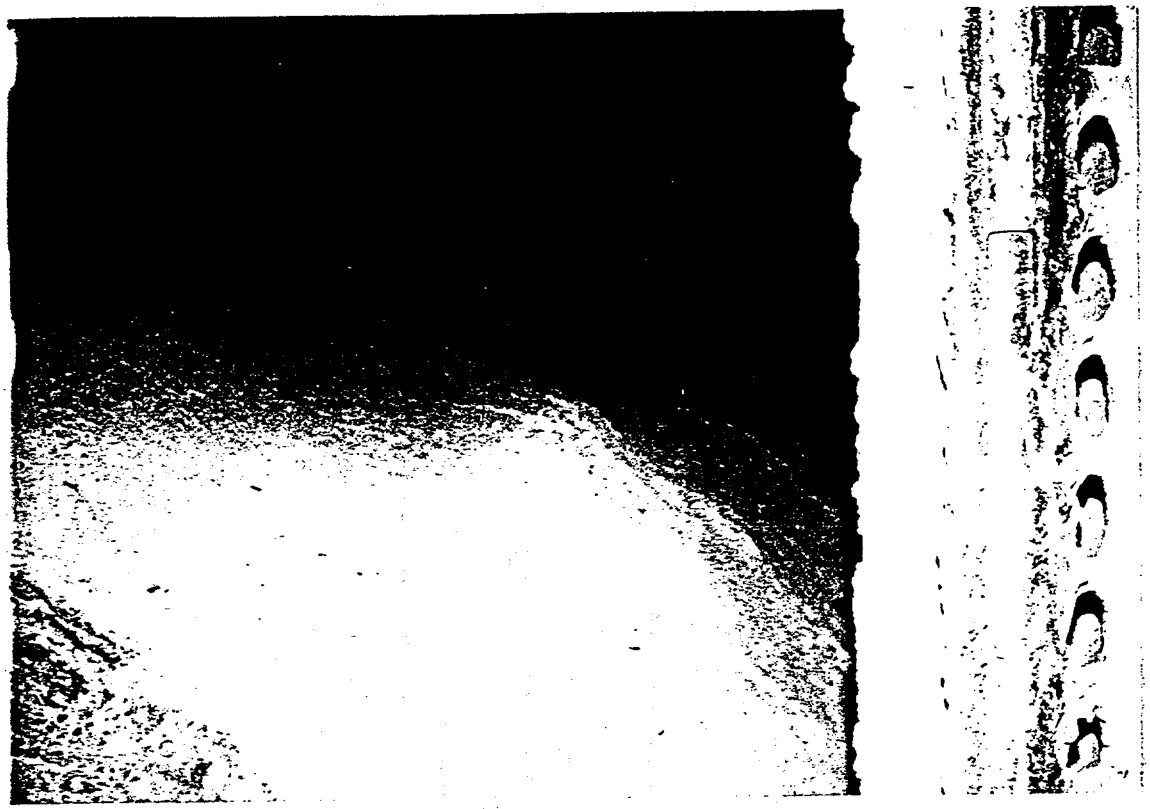
Billy R. Boswell Sr.



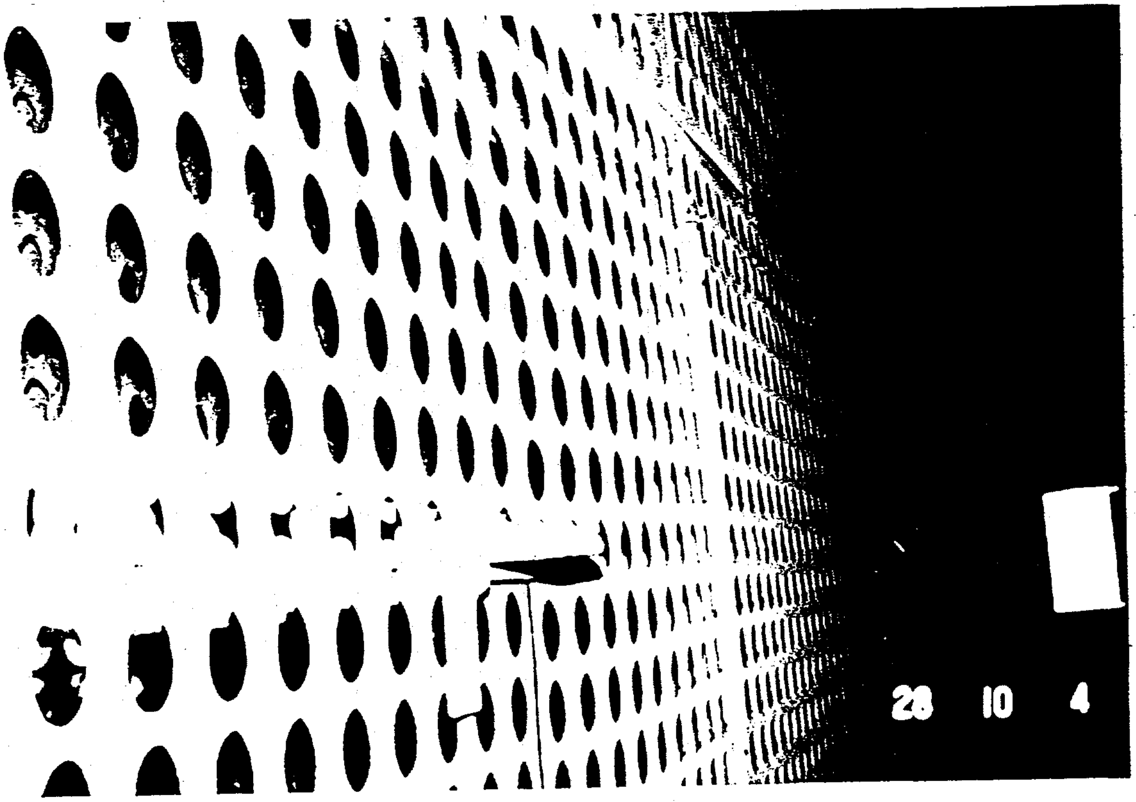
External Drive Chain on Rapper System



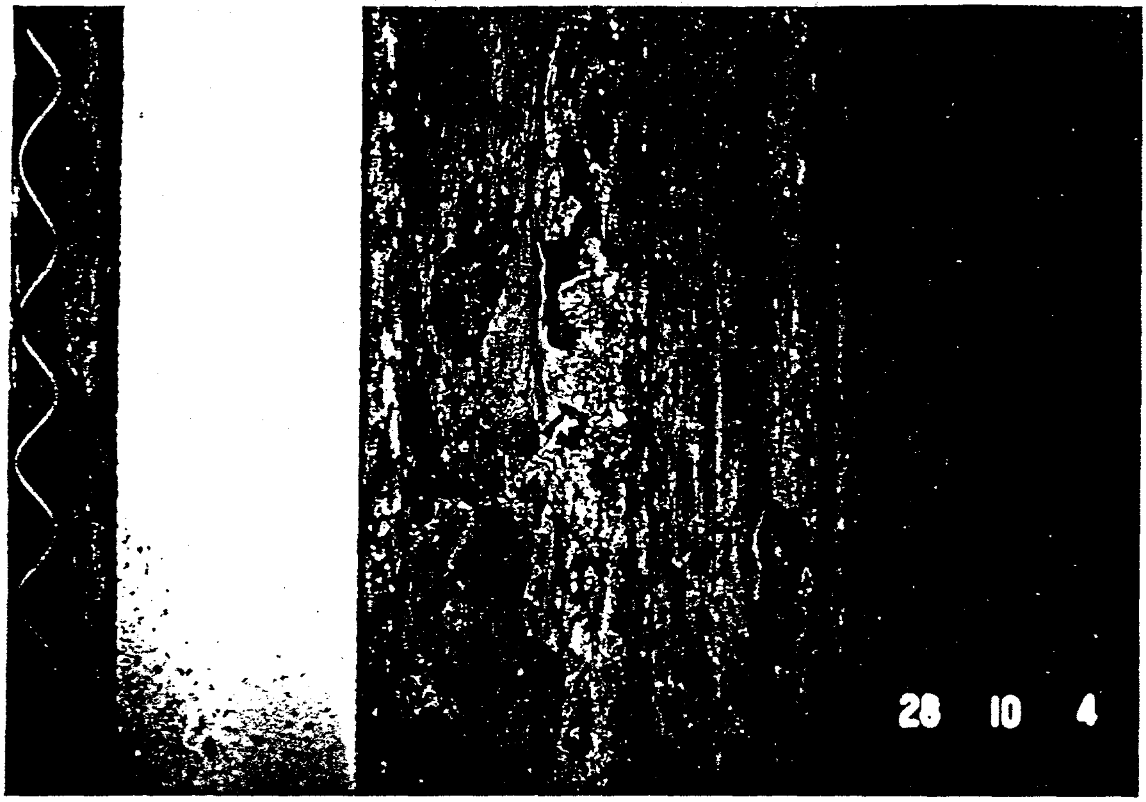
External Drive Chain on Rapper System



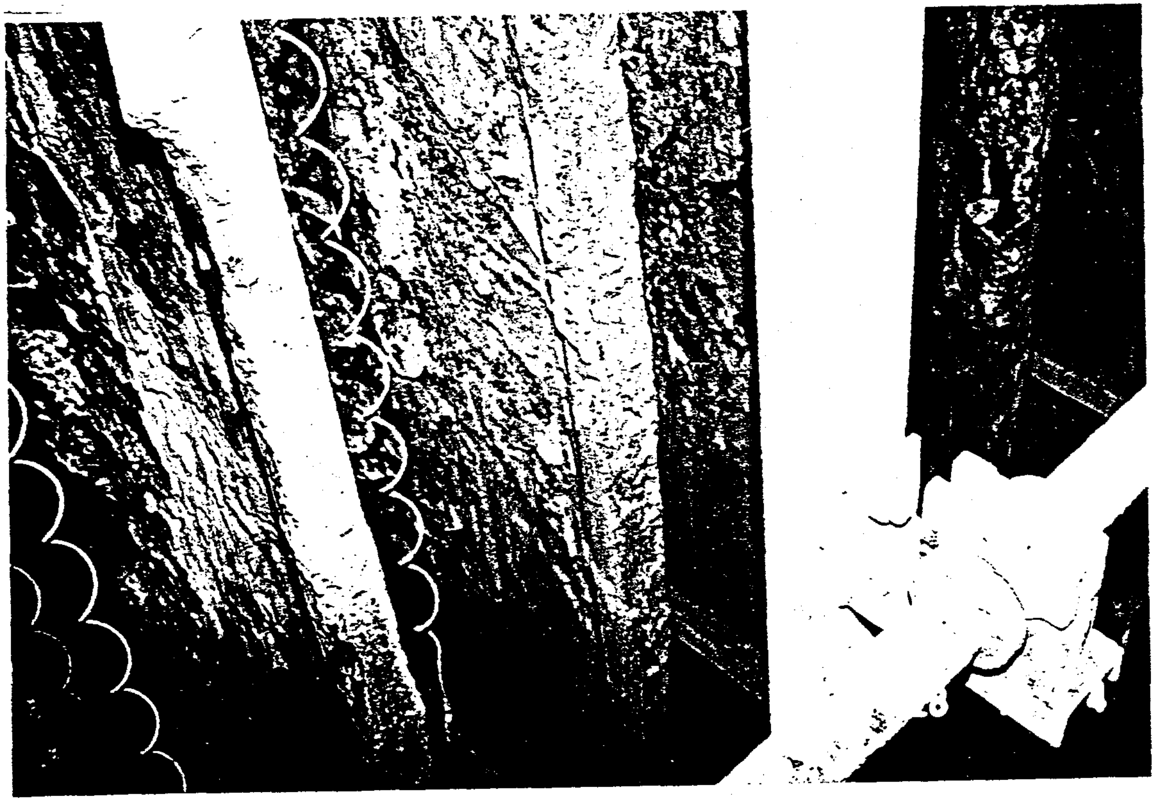
Dust Accumulation - Outlet Nozzle



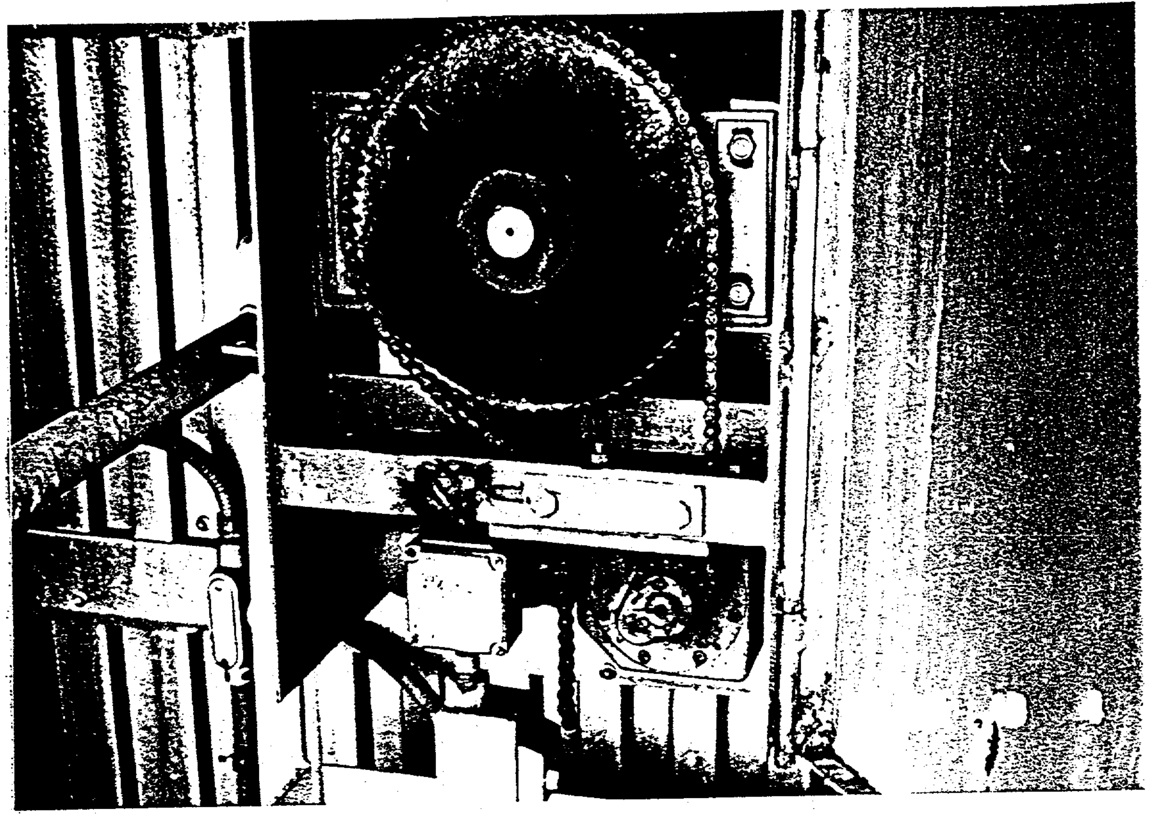
Inlet Screen



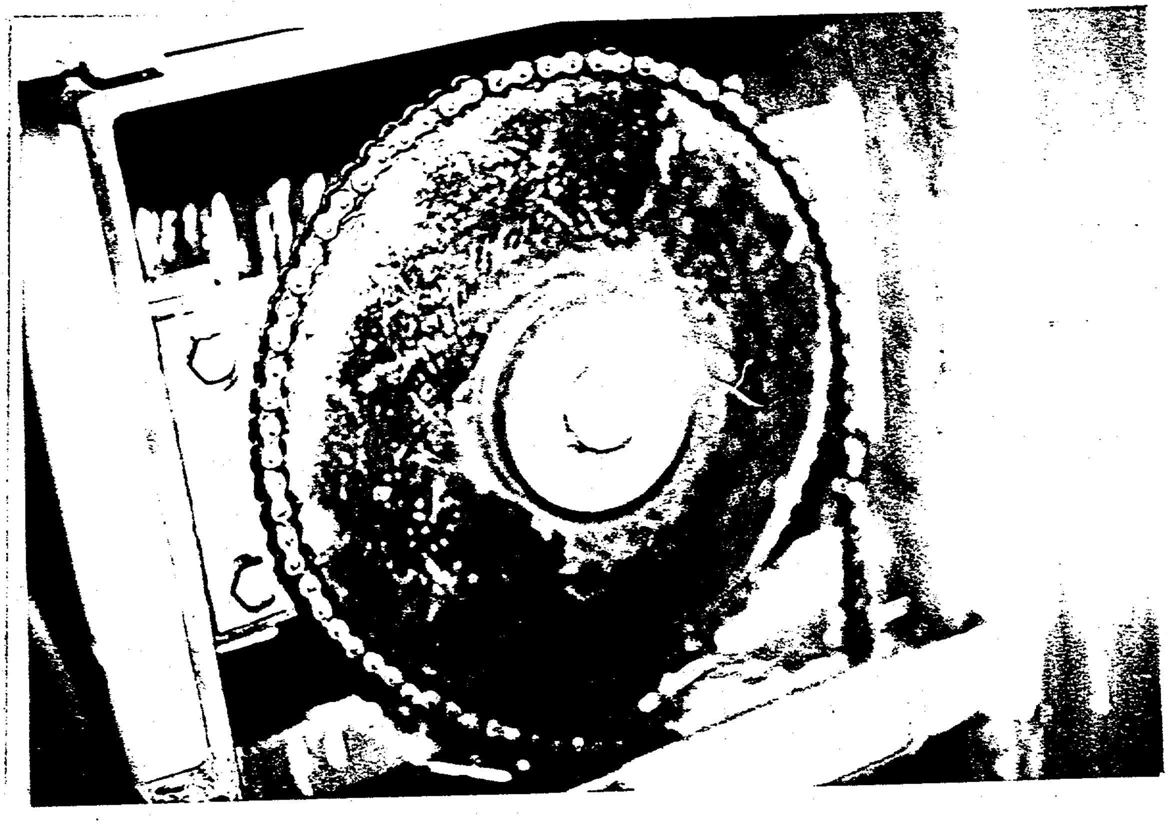
Dust Build-up on Collecting Plate



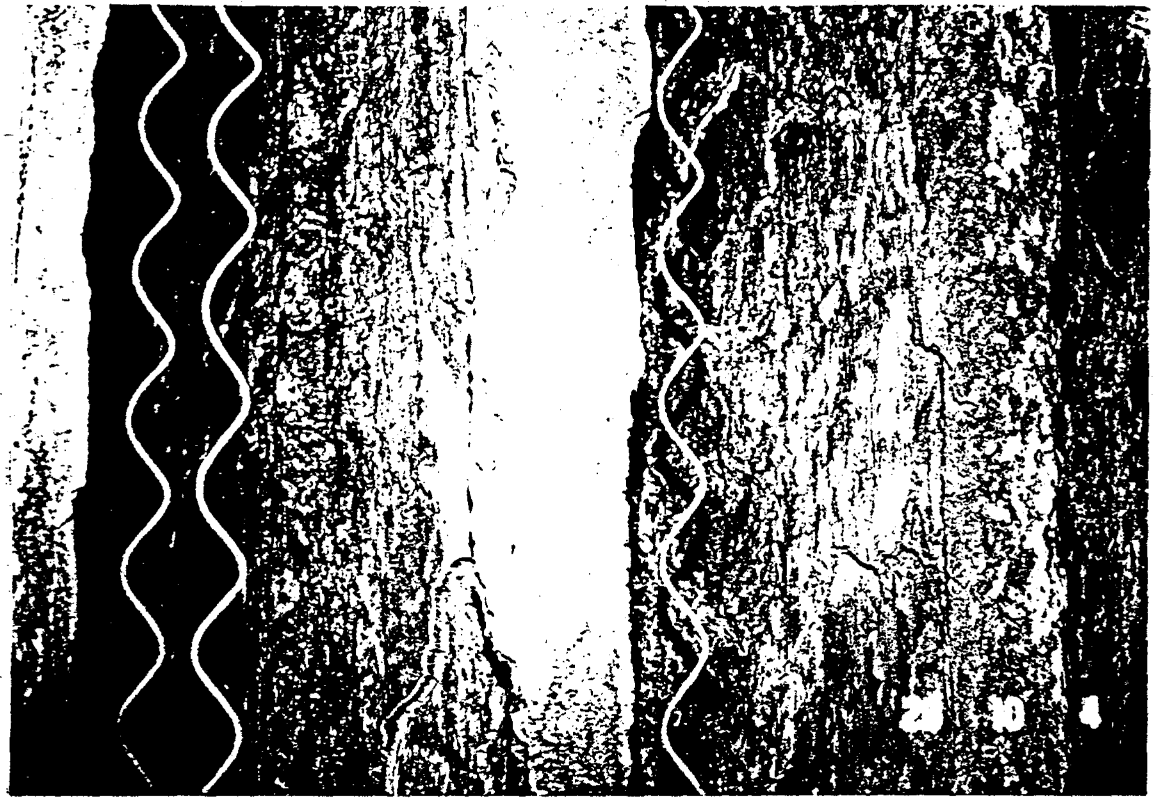
Dust Build-up on Collecting Plates



Broken External Drive Chain on Rapper System



External Drive Chain on Rapper System



Dust Build-up on Collecting Plates

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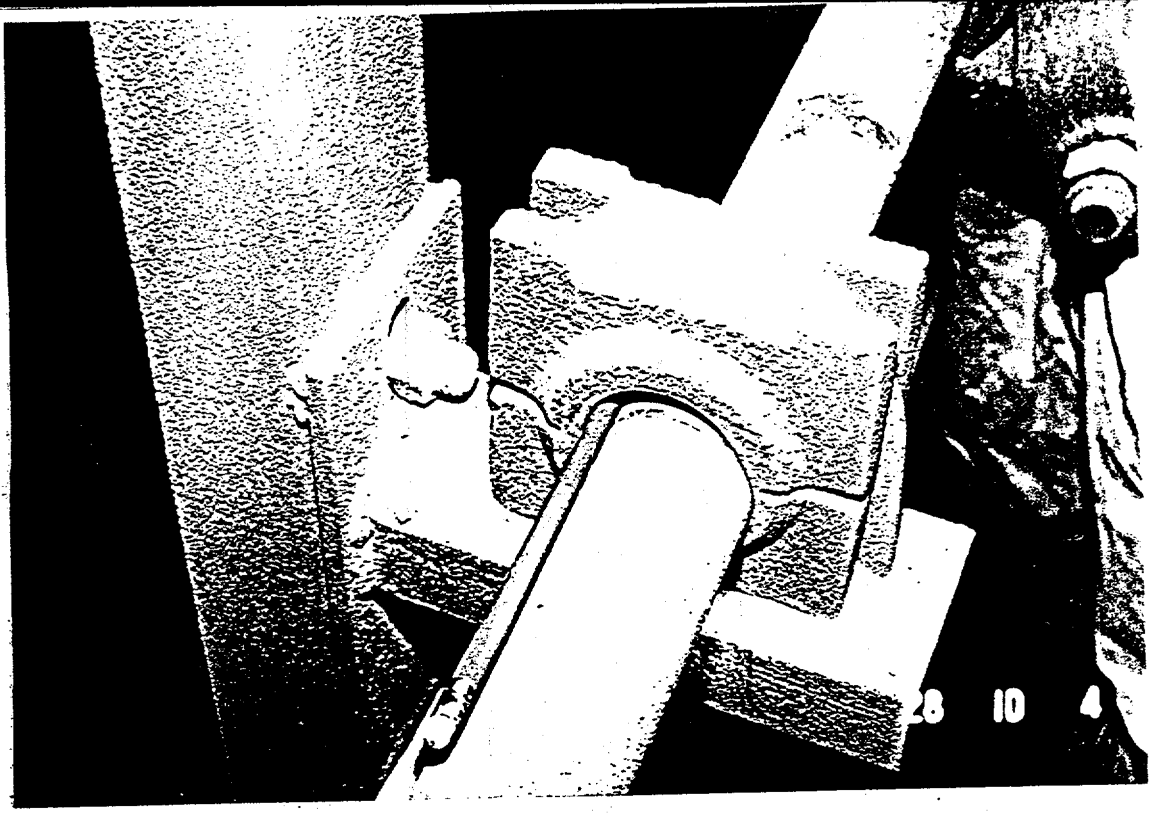
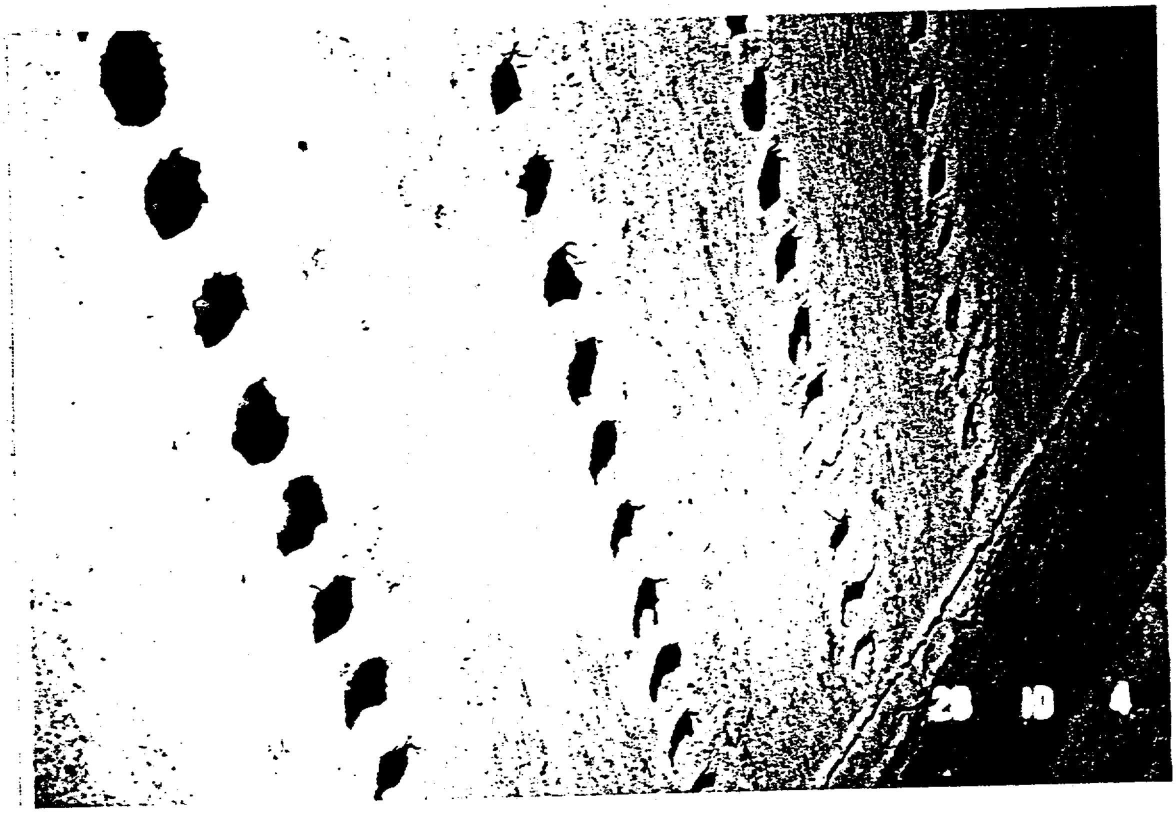
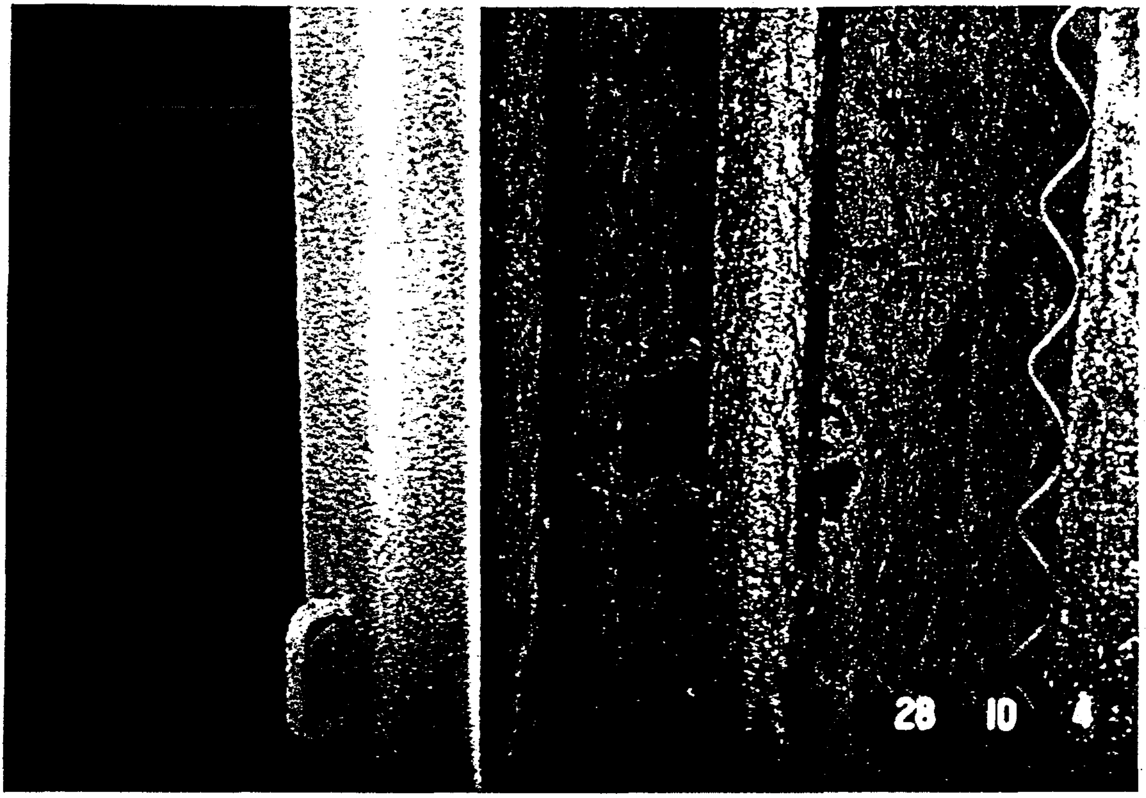


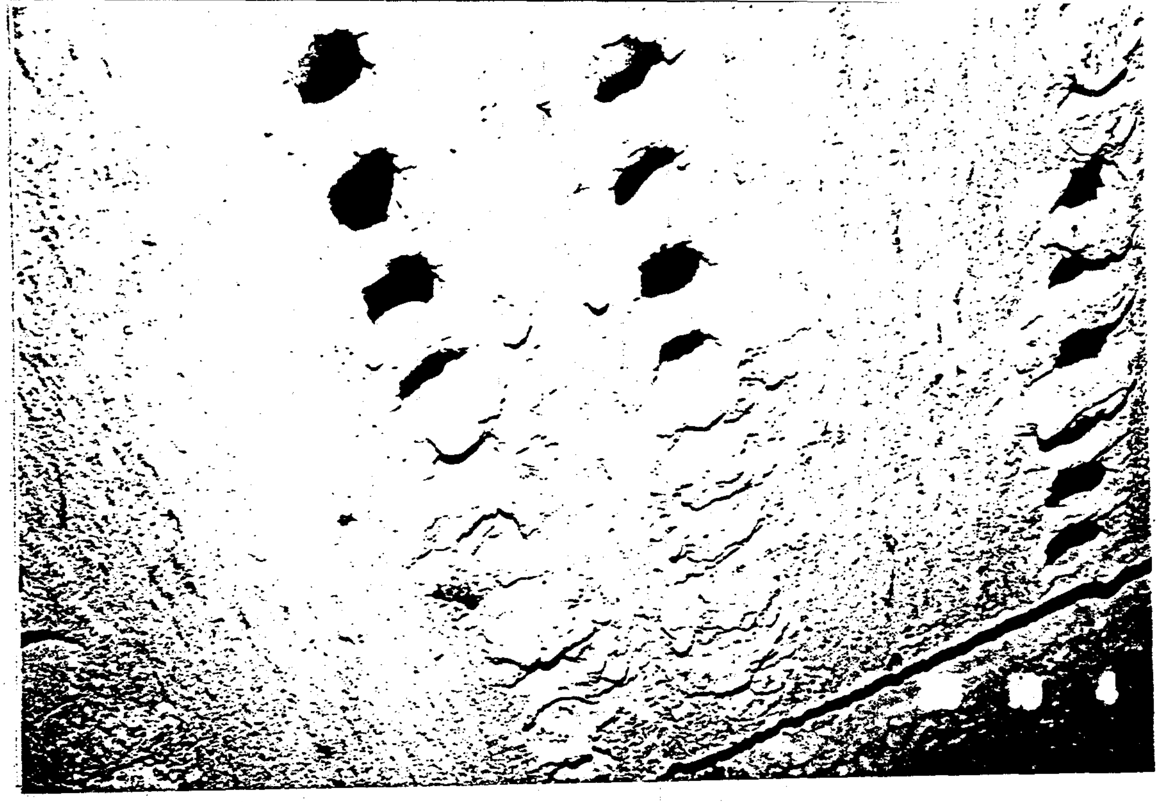
Internal Rapper Drive Shaft Bearing Wear



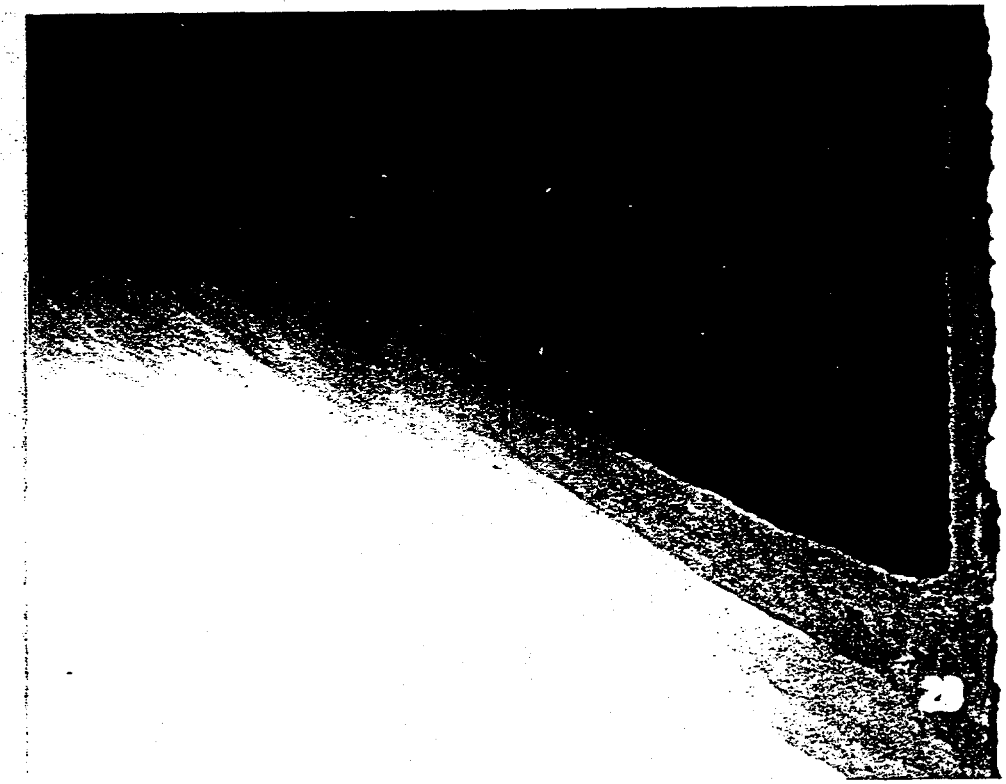
Outlet Screen - Dust Build-up



Dust Build-up on Collecting Plates



Outlet Screen Pluggage



Dust Accumulation - Outlet Nozzle

~~[illegible]~~ / EPM / File

12.2200,
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CITY WATER LIGHT AND POWER
SPRINGFIELD, ILL.

OFFICE OF PUBLIC UTILITIES
CITY OF SPRINGFIELD, ILLINOIS

LAKESIDE AND DALLMAN GENERATING STATIONS

December 30, 1994

Mr. Don Engelhardt
Energy and Environmental Research Corporation
PO Box 153
Orrville, Ohio 44667

Subject: Lakeside Precipitator Inspection

Mr. Engelhardt:

Attached you will find the Minutes of the Meeting for the Lakeside Precipitator Inspection, I thought you might be interested in them.

Sincerely,

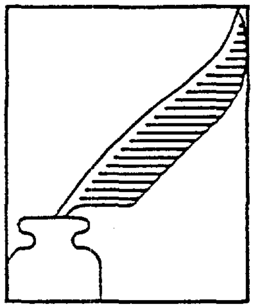
TJB

Tom Booker

TB/bsj

3100 STEVENSON DRIVE • SPRINGFIELD, ILLINOIS 62703 • (217) 786-3957 • FAX (217) 786-3966

MINUTES OF MEETING



WRITTEN BY: Michael Hohenstein MH

MEETING OF: December 15, 1994

PLACE: Conf Room 311

ATTENDEES:
Tom Booker
Roger Cullers
Dennis Esselman
Nick Murphy
Dave Tebrugge
Bob Walbert

RECEIVED
DEC 28 1994

PURPOSE: To discuss and review the Epscon-FLS Lakeside precipitator inspection report.

SUMMARY OF DISCUSSIONS, DECISIONS, AND COMMITMENTS: Due to alarming discoveries outlined in the report not being consistent with feedback received from the Maintenance personnel who assisted with the inspection, this meeting was held to identify corrective action required. After an indepth review and discussion of Mr. Boswell's report, the following was agreed to (please note the below listed numbers parallel the item numbers in the attached Epscon-FLS report):

1. We do not believe there is a problem at this time. The possibility exists the unit was operated at or below acid dew point which contributed to the heavy dust build-up.

2. No problem identified.

3. We believe the rapping system is set correctly and the reason for the high dust build-up was due to the drive chain being broken at the master link. The chain has since been repaired and operated satisfactorily.

4. In our opinion and from information obtained from the FLS instruction manual, the discharge rapping shafts are not worn beyond their usefulness nor do they need to be replaced. In addition, the hammers have not rotated on the shaft but are in the same keyed position from original start-up which we believe is still sufficient. The drive chain did have wear and was subsequently replaced. We are also starting to see some wear on the rapper shaft bearings which, per FLS drawing #7.700476, should be rotated top to bottom after wearing 1" minimum.

5. The discharge rapper shafts appear satisfactory. However, the bearing clearances need measured for wear. The drive chains appear to only need adjustment for proper tension, not replacement.

6. This field did have the heaviest amount of ash build-up due to a broken drive chain. The chain has since been replaced and is operating satisfactorily. The drive was not locked up as suggested but obviously it has too much mass to operate with only a 24" pipe wrench attached.

7. On the discharge rapper shafts, we do not agree that the shafts are in bad shape nor do we agree the hammers need to be re-set to a different orientation. However, we do agree that the bearings need to be measured and possibly rotated 180° and the chains need to be replaced or at the minimum set to correct tension. Here again, the hammers are keyed to the same specifications as original start-up and have not moved.

8. No problem found with the exception of heavy dust build-up.

9. We do not believe a rapping system on the screens is warranted. One possible explanation as to this build-up is the same as item #1 and that is the possibility the precipitator was in operation at or below acid dew point such as low load operation with only one unit on.

10. No problems found.

Areas Requiring Follow-up

Based on the above, the following will be performed as manpower and unit availability permit:

1. Check drive shaft bearings wear on all shafts for a possible rotation of bearings 180° or at worst case partial bearing replacement.

2. Inspect internal drive chain tension per FLS procedures and adjust as necessary.
3. Complete hopper throat heater wiring modifications.
4. Revise P.M. Program for rapper drive gear box lubricants.
5. Perform complete inspection on Units #31 and #32 precipitator rapper systems similar to the Lakeside inspection.
6. Nick Murphy is to review current inventory of drive chains and shaft bearings and order the necessary amount to get both Units #31 and #32 and Lakeside precipitator rapping systems to a reliable operating condition.

Overall, we believe the Epscon-FLS precipitator inspection report to be of poor professional quality and mis-leading and do not recommend Epscon or at least Mr. Boswell for future precipitator inspections. The writer of these minutes would like to take the opportunity to thank Mr. Bob Walbert and Mr. Dave Tebrugge for their input and extra effort put forth during the precipitator inspection and in obtaining and bringing to the meeting highlighted OEM inspection procedures on the rapper drive system.

There being no further business to discuss, the meeting was adjourned.

MH:ee

Attachments: Epscon-FLS inspection report
OEM inspection and adjustment procedures

cy: Tom Bee
File

Nov. 2, 1994

Epscon/FLS
Mr. Walter West
Subj: Precipitator Inspection CWLP Springfield, Ill.
Lakeside Unit 7&8

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" Best Regards "

Billy R. Boswell Sr.

RAPPER SHAFT BEARINGS (Figure 11)

The precipitator's high voltage discharge system as well as the grounded collecting plate system is equipped with rapper systems consisting of tumbling hammers mounted on slowly rotating rapper shafts. For both systems, the rapper shafts are resting in slide bearings.

These slide bearings are made from cast iron. They must not be lubricated and do not require any maintenance except for observation of wear.

In time, and depending on operating conditions, these bearings will be worn especially in the precipitator inlet field where the dust concentration is the greatest.

The wear in the bottom of the bearing must not exceed 5/16". This can be ascertained by measuring the distance between the underside of the shaft and the underside of the bearing (see figure X). The dimension (b) must not be less than approx. 1".

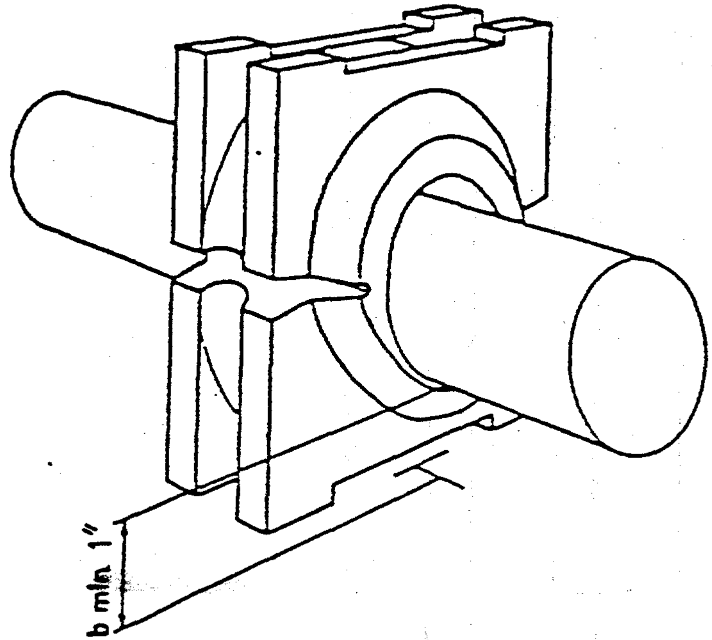
As (b) becomes less than 1", the symetrical bearing can be turned 180° around the shaft and attached again (figure Y). In this new position, the bearing can be used until the (b) dimensionagain becomes less than approx. 1".

It should be mentioned here that the very large clearance between the top of the shaft and the top part of the bearing has no importance for the function of the bearing.

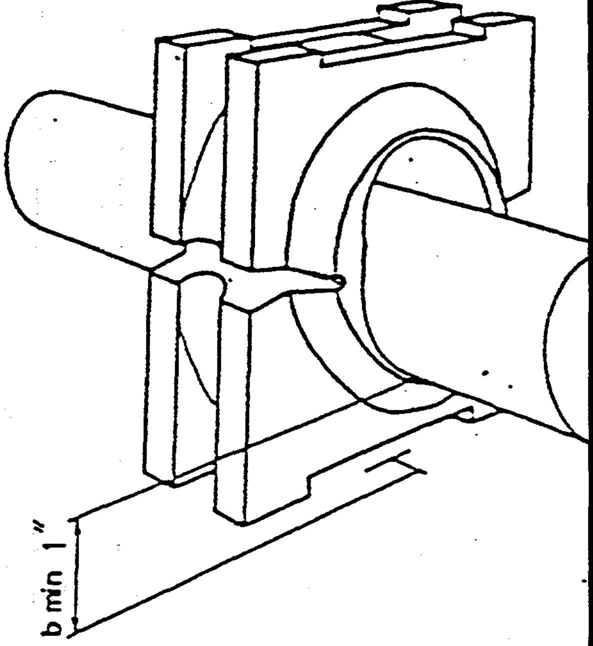
When the (b) dimension for the second time has become less than 1", it is necessary to replace the worn bearing with a special bearing including a bushing to be mounted on the rapper shaft to compensate for the wear which by now also has become too large on the shaft (figure Z).

Figure 11

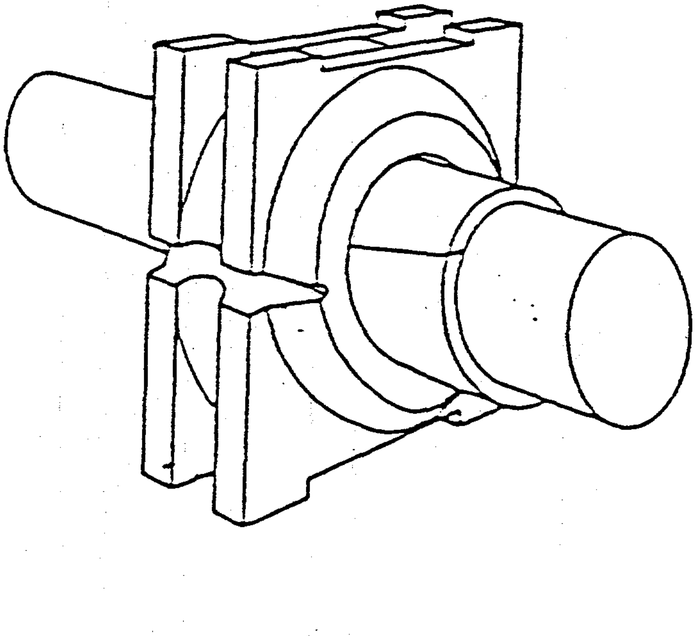
X



Y



Z



INSIDE RAPPER CHAIN DRIVE (Figure 10)

The inside chain drive connects the rapper shaft of the discharge system (A) on which the tumbling hammers are mounted to the intermediate shaft (B) which has connection to the rapper drive (D) through the insulator shaft (C).

The inside chain should be kept tight by the adjustable chain tightner (E). As the chain wheels become worn, adjustments of the chain tightner is necessary.

The chain tightener should be adjusted when the distance (a) is less than 1/8".

The chain should be replaced when the chain links are worn half way through. The chain can be replaced by removing the locking plate (F), which is welded to one of the links.

The individual chain links can be disassembled when the chain links are put in position (d).

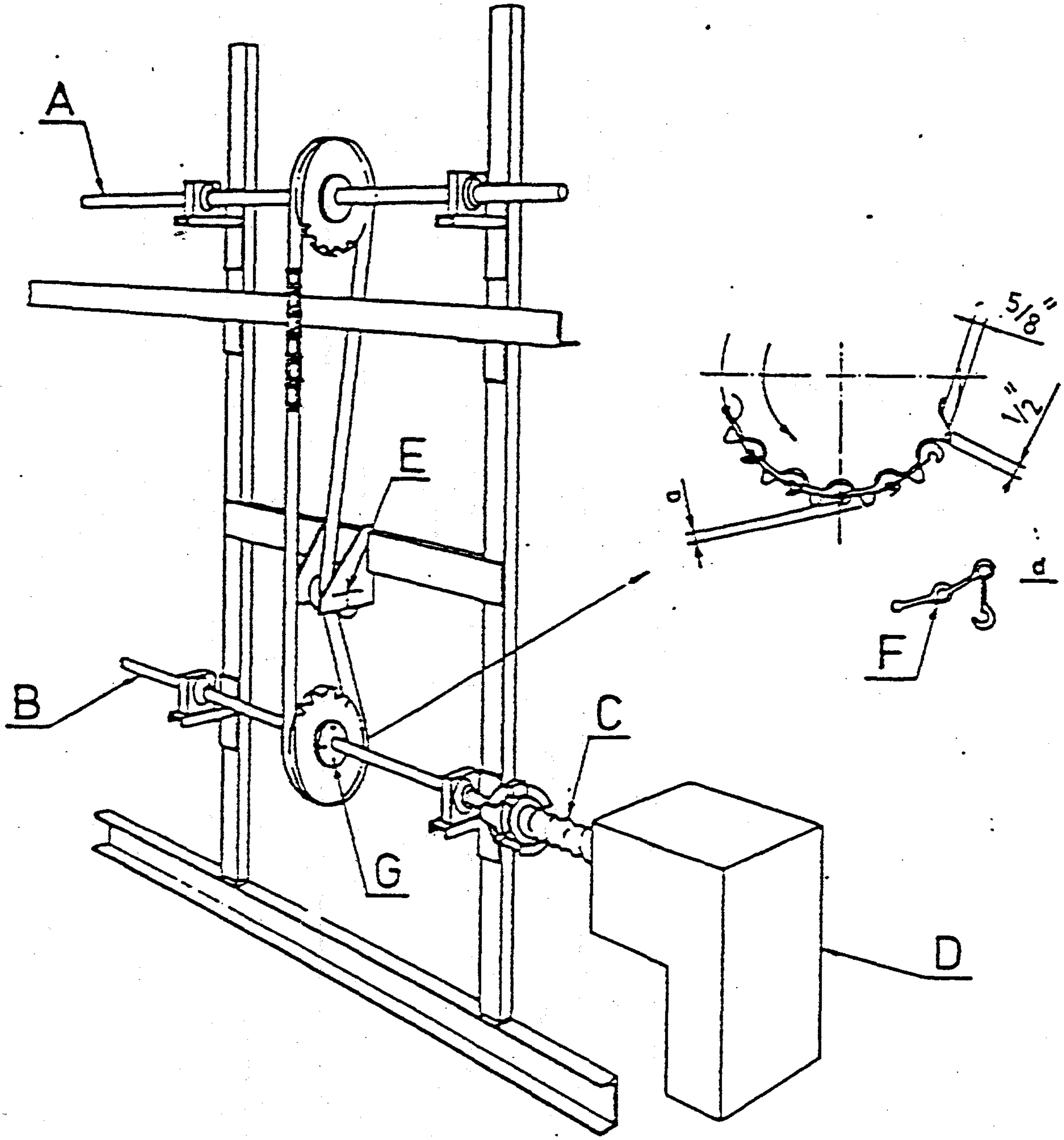
The chain wheels are split and can be replaced by removing the bolts (G).

The chain wheels should be replaced when the thickness of the teeth at the pitch line is less than 1/2".

Figure 16

F. L. SMIDTH 7.700476

E.25



IR POLLUTION CONTROL SPECIALISTS **EPSCON - FLS, INC.**

January 19, 1995

City Water, Light and Power
3100 Stevenson Drive
Springfield, Illinois 62757

Attn: Mr. Michael Hohenstein

Ref: EPSCON-FLS Lakeside Precipitator Inspection Report

Dear Mr. Hohenstein:

Late last year, E.E.R.C. engaged EPSCON-FLS to inspect the Lakeside FLS precipitator. The inspection was conducted by Mr. Billy Boswell on October 28, 1994. Unfortunately, Mr. Boswells report was not well received by your company, as evidenced by the "Minutes of Meeting" dated December 15, 1994, a copy of which was forwarded to us by Mr. Elliot Mecchia for our review.

My purpose in writing to you at this time is to perhaps clarify the intent of some of Mr. Boswells comments and to correct a misunderstanding regarding the "Rapper Hammer to Shaft" attachment. The last thing I want to do is get into a dispute with your maintenance department.

Perhaps the best way to offer my comments is to follow the numerical references used in Boswell's report and your "Minutes of Meeting" response:

1. Mr. Boswell's commented that the unit in general is dirtier than he has seen it in the past. From the photographs, this is a statement of fact. We are not making a judgement as to why the unit has more buildup, but are suggesting that since is does, the functioning of the rapping systems should be explored. It very well may be advisable to re-program the rappers (particularly the inlet field) to operate on a more frequent "run" cycle and / or adjust the "on" time to permit more than one rap per hammer per cycle.

2. As agreed, no problem noted.

3. There seems to be some confusion on this point. Mr. Boswell reported the 2nd Field C.E. drive chain was broken, not the 1st Field. If in fact the 1st Field chain was also broken and has now been repaired, please observe the level of dust build up. If it is still excessive, we suggest the rapping cycles be changed as discussed in Item 1 above.

4. Mr. Boswell insists some of the hammers <u>have</u> slipped or rotated on their shafts. A review of the"F" PPTR drawings in our possession clearly show that the individual hammer assemblies are <u>not</u> keyed to their respective drive shafts.

WILLIAMSBURG COMMERCE CENTRE
460 McLAWS CIRCLE SUITE 220 • WILLIAMSBURG VA 23185 • (804) 253-1712 • TELEFAX (804) 220-9240

The "U" bolts are supposed to keep the clamp assembly tight against the shaft. However, if they loosen up they can move about the shaft. There is a small piece of key stock welded to the shaft between the "U" bolts to keep the hammers from moving laterally, but it is not intended to keep the hammers "timed" on the shaft. It is true that if the "U" bolts loosen , the hammer will rotate until its mounting plate contacts the small key stock. However, if the key stock breaks off, the hammer assembly will continue to rotate. Mr. Boswell claims some of the key stock welds have failed and are missing.

With respect to the condition of the shafts, Mr. Boswell was concerned with both the wear on the shafts and the wear on the bearings. In this opinion, the combination of wear was excessive. His comment regarding the replacement of shafts was not fully explained. While it is true FLS can provide a special bearing and a sleeve to cover the worn portion of the shaft, this is a very expensive (Material and labor) method of correcting the problem. Field experience has established that it is less expensive and quicker to simply furnish 2" O.D. cold rolled steel shafting as replacements, along with new or rotated bearings. Whether, the present shafts have reached that wear point is, I guess, a matter of opinion.

5. Mr. Boswells note #5 was referring to collecting plate rapper drives, not discharge rapper drives. At any rate it has been Mr. Boswell's experience that even though a chain has not broken it can be worn to the point that the chain can "slip" on the gear teeth, even when it is tensioned properly. Perhaps, Mr. Boswell thought the chain had worn to that degree.

6. The basic problem was the broken chain which is not in dispute. Whether or not the shaft can be turned with a 24" pipe wrench is of no importance. When new, you can easily turn this shaft with a pipe wrench, provided all the hammers are indexed properly. Since the drive chain was broken, no doubt fly ash may have bound up the bearings. Obviously, once the chain was repaired, the drive unit had sufficient torque to free and rotate the system.

7. Here again, perhaps the condition of the shafts is a matter of opinion. Same comment as in Item #4 with respect to hammers being secured to shafts. They are not directly keyed to shafts.

8. No comments necessary.

9. Regarding dust build up on outlet screens, that is not a good situation and negatively influences gas distribution in the final field of the PPTR. From a practical performance point of view, it may not matter, assuming you are not experiencing opacity or compliance problems.

Mr. Boswell's report did not say you should install a rapping system in this area but merely stated it was possible to do so. Perhaps a more important aspect of his #9 comment has to do with the ash build up behind the outlet screen in the nozzle. From a corrosion point of view it is not a good condition. The ash accumulation is probably a result of lower gas flows to the PPTR thus reducing internal gas velocity and dust fallout results. Unfortunately, when gas flows are again increase velocity increases and dust re-entrainment may occur. If you have no concerns regarding these comments, then nothing need be done.

10. No comments necessary.

Summary:

I am sorry you consider Mr. Boswell's report mis-leading. The report no doubt could have been more detailed in its explanation of observations. I understand Mr. Boswell also had discussions with some of the station personnel following his inspection, which I assumed supplemented the written report. In any event, I believe the report to be essentially correct.

EPSCON-FLS is in the process of assuming an expanded role as the U.S, FLS licensee. As such, we want to serve you properly with respect to technical services and or O.E.M. parts.

Please afford us that opportunity in the future.

Very truly yours

Walter W. West

Mr. Walter W. West
President

cc: Mr. Tom Booker - C.W.L.P
Mr. Elliott Mecchia - E.E.R.C.

INTERNATIONAL CHIMNEY
CORPORATION
ENGINEERS — CONTRACTORS
55 S·LONG ST·BOX·260·BUFFALO·N·Y·14221-0260
(716) 634-3967

DETROIT
CLEVELAND
INDIANAPOLIS
CHICAGO
ATLANTA

December 16, 1991
Our File #CE-24953-C

Energy & Environmental Research Corporation
1645 North Main Street
Orville, Ohio 44668

Attention: Mr. Don Engelhardt
Project Manager

Subject: Your P.O. #47882
Internal & External Inspection
Unit No. 7 & 8 Chimney
City Utilities of Springfield, Illinois

Gentlemen:

In accordance with the above purchase order number, we have completed the internal and external inspection of the subject chimney and are submitting our inspection report including findings, photographs, recommendation for repairs as well as the ultrasonic thickness test readings of the steel lining.

We feel that our report is clear in all details, however, should there be any questions please do not hesitate to contact the writer at our Midwest General Office (815)727-0966.

Respectfully submitted,

INTERNATIONAL CHIMNEY CORP.

By Dennis M. Sweeney
Dennis M. Sweeney
Project Manager

dat
Encls.

CITY UTILITIES OF SPRINGFIELD
LAKESIDE STATION
UNIT NO. 7 & 8 CHIMNEY INSPECTION

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CITY UTILITIES OF SPRINGFIELD
LAKESIDE STATION
UNIT NO. 7 & 8 CHIMNEY INSPECTION

SECTION I. - DESCRIPTION OF CHIMNEY

The subject chimney is 299' in height, constructed of reinforced concrete with an independent steel lining. The top I.D. of the lining is 13'.

The exterior of the chimney is equipped with a full height scaling ladder which interconnects the monitoring platform located at the midpoint of the chimney to the full circumference platform located approximately 9' below the top of the chimney.

The breeching opening enters from the south quadrant approximately 30' above base.

Access to the interior of the lining is from the manway access in the breeching ductwork.

The exterior of the chimney is also equipped with an obstruction lighting system consisting of four beacon lights located at the top and two sets of obstruction lights located at the mid platform.

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UNIT NO. 7 & 8 CHIMNEY INSPECTION

SECTION II. - INSPECTION PROCEDURES

EXTERIOR:

The exterior of the chimney was inspected utilizing the existing ladder system and platforms which enabled our inspector to make a close, visual inspection of the concrete column as well as all appurtenances. The remainder of the chimney exterior was inspected utilizing terrain telescope and telephoto camera equipment.

INTERIOR:

Our inspector was lowered from the top of the chimney lining, down through the base. Ultrasonic thickness readings were taken of the lining on 10' centers for the full height.

ANNULAR SPACE:

Access to the annular space was available only at the monitoring ports located at the midpoint of the chimney. Our inspector viewed what was readily accessible and a couple of photographs are attached.

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UNIT NO. 7 & 8 CHIMNEY INSPECTION

SECTION III. - INSPECTION FINDINGS

CONCRETE COLUMN:

Overall, the concrete column was found to be in a solid and sound condition. Two stress relief cracks were noted, the cracks are located on the north and south quadrants starting at the mid platform and extend to the top of the chimney. The cracks are approximately 1/16" to 1/8" in width and appear to be causing no detrimental harm to the structural integrity of the column.

The coating on the exterior column from the mid platform to the top was found to be tightly bonded to the concrete surface, however the coating has faded and discolored at this time.

LADDER SYSTEM:

The ladder system was found to be safe and sound upon inspection, however, it was noted that both the ladder and safety notch rail are pitted and rusting freely, in particular, throughout the top 1/3 of the chimneys height.

PLATFORMS:

Both the monitoring platform and the top full circumference platform were found to be intact and in safe condition. It was noted that the grating on the monitoring platform apparently has been damaged in the past and at this time is warping, leaving the grating distorted. No. 11 photo on the exterior photographs shows this condition.

The top platform as stated, was found to be solid and sound, however, it was noted that all support steel and handrails are rusting freely.

OBSTRUCTION LIGHTING SYSTEM:

All lights were found to be functioning at the time of our inspection.

LIGHTNING PROTECTION SYSTEM:

The lightning protection system was found to be intact at the time of our inspection, however, it was noted that the six points (air terminals) located at the top of the chimney were found to be deteriorating with the lead coating being worn away and the rods themselves becoming thin.

The remainder of the lightning protection system was found to be intact, however, two anchors on the encircling cable and downlead were found to be broken.

CHIMNEY CAP:

The chimney cap was found to be intact, however, it was noted that the weld seam connecting the skirt which comes over the exterior of the chimney column and attaches to the slope of the rainhood, was found to be in a badly deteriorated condition with approximately 80% of this weld being worn away at this time.

CHIMNEY LINING:

Overall, the lining was found to be in solid and sound condition. No buckling, bulging or split welded seams were noted. Ultrasonic thickness readings were taken with the results being shown and attached herein.

BREECHING:

The breeching connection, expansion joint and rain seals were all found to be intact and in good condition. It was noted that minor leaking on the floor of the breeching at the entrance of the chimney has occurred.

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SECTION IV. - PHOTOGRAPHS

A total of (41) color photographs which depict the findings as stated in SECTION III. of this report are attached.

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EXTERIOR PHOTOGRAPHS

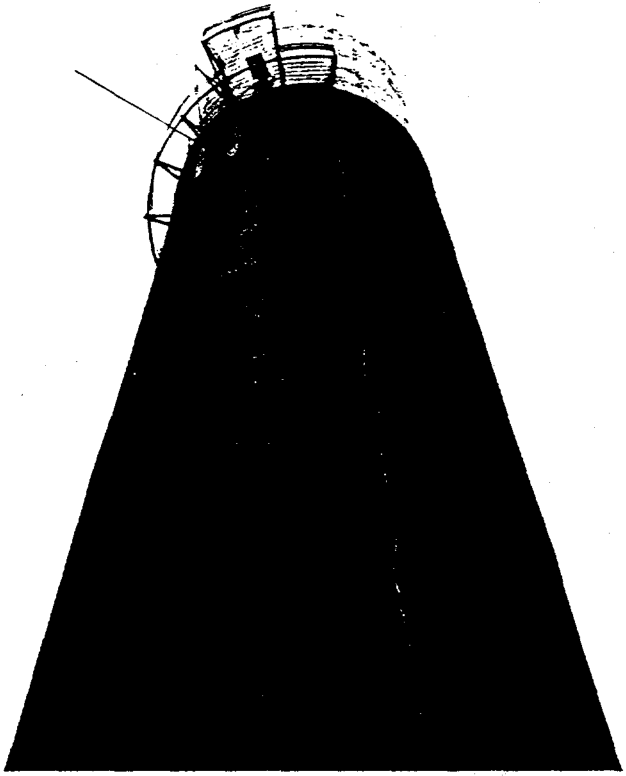

Photo #1 - Overall view of Unit No. 7 & 8 Chimney.

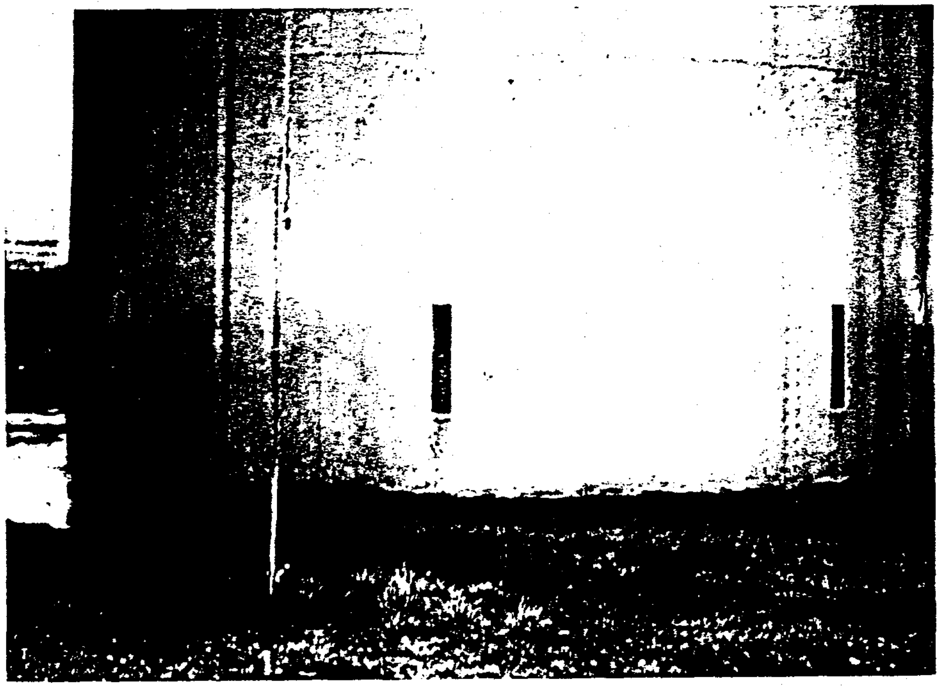

Photo #2 - View of chimney base. No cracking or deterioration noted.

CITY UTILITIES OF SPRINGFIELD
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UNIT NO. 7 & 8 CHIMNEY INSPECTION

EXTERIOR PHOTOGRAPHS

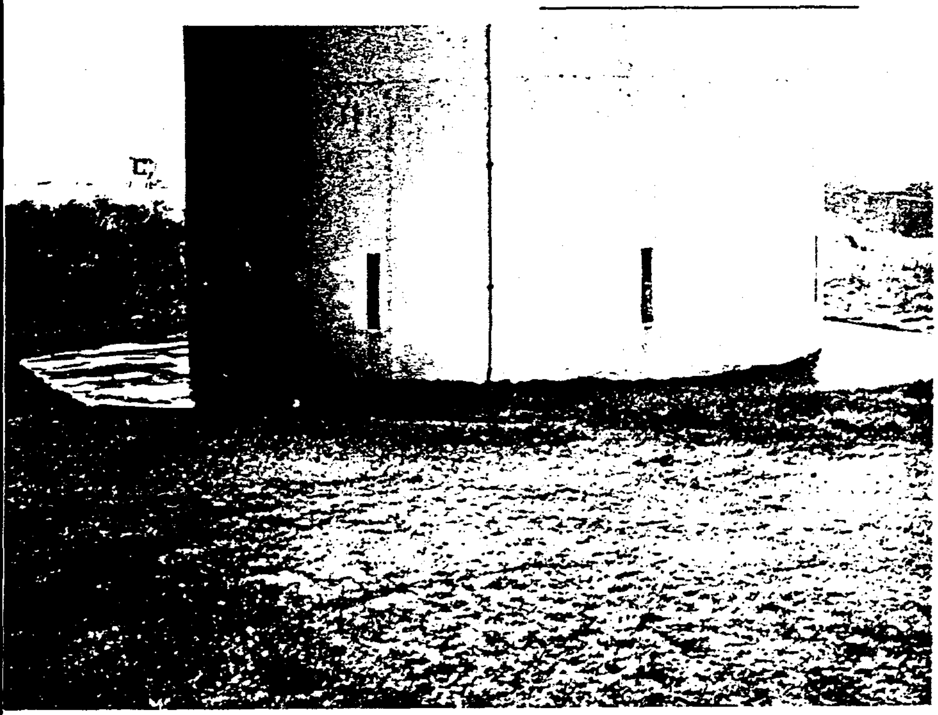

Photo #3 - View of chimney base. No cracking or deterioration noted.

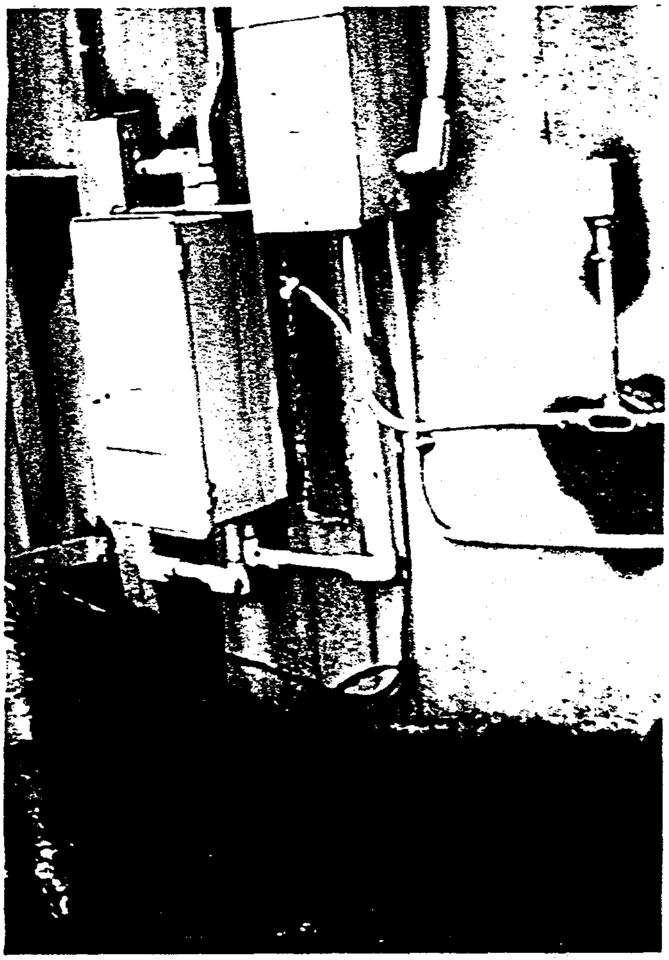

Photo #4 - The ground connection to the control panels is disconnected.

CITY UTILITIES OF SPRINGFIELD
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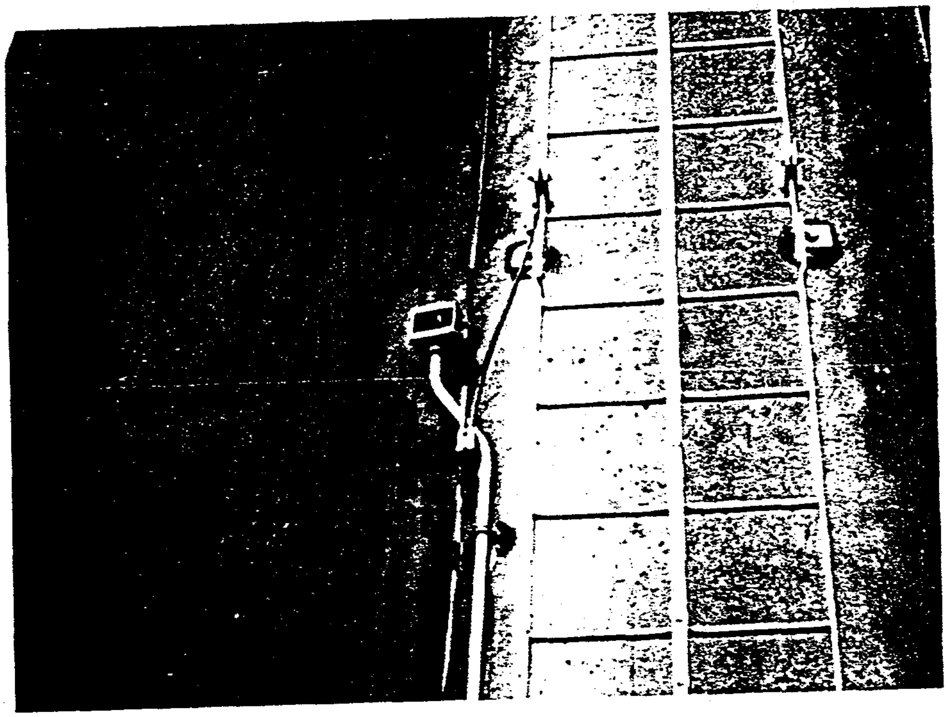

Photo #5 - Electrical box cover missing 25' elevation.

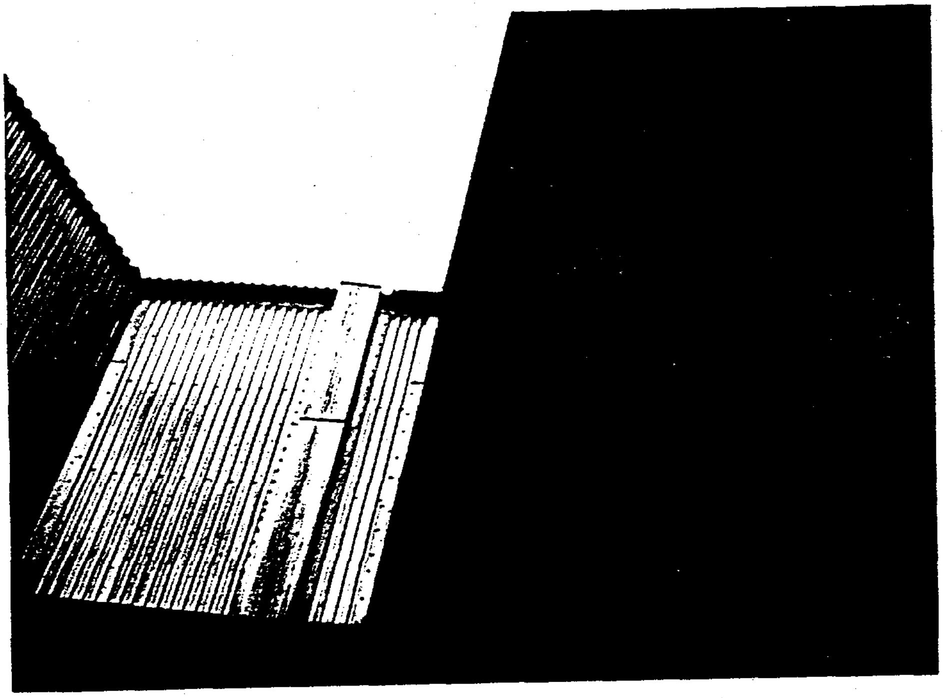

Photo #6 - Breeching ductwork is intact. Connection to lightning protection system is intact.

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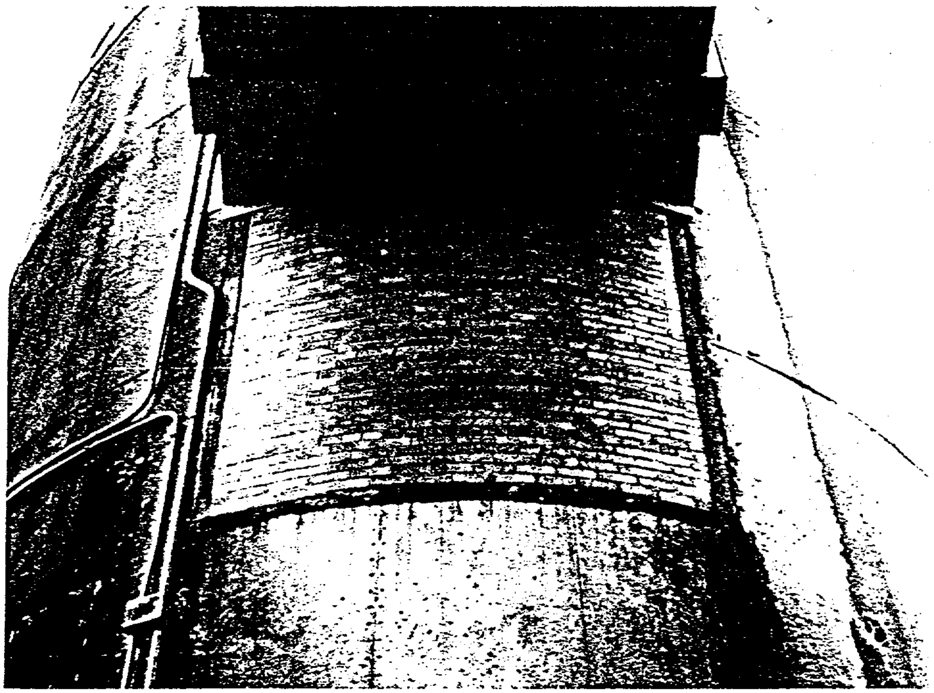

Photo #7 - View looking at breeching ductwork from below. Minor rusting, leakage noted.

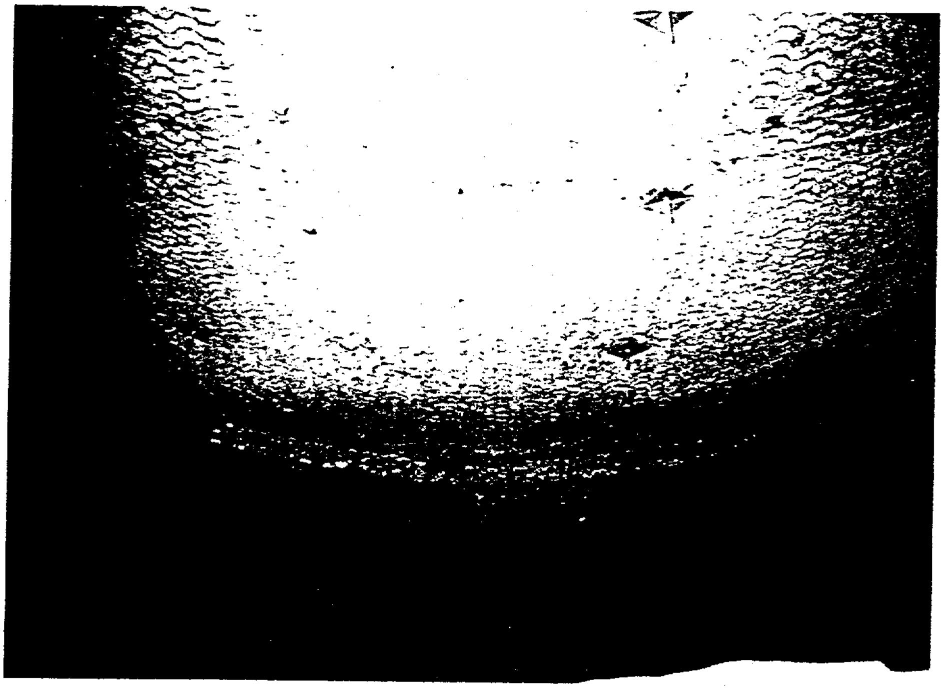

Photo #8 - View of chimney lining insulation at monitoring platform. Minor deterioration.

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EXTERIOR PHOTOGRAPHS

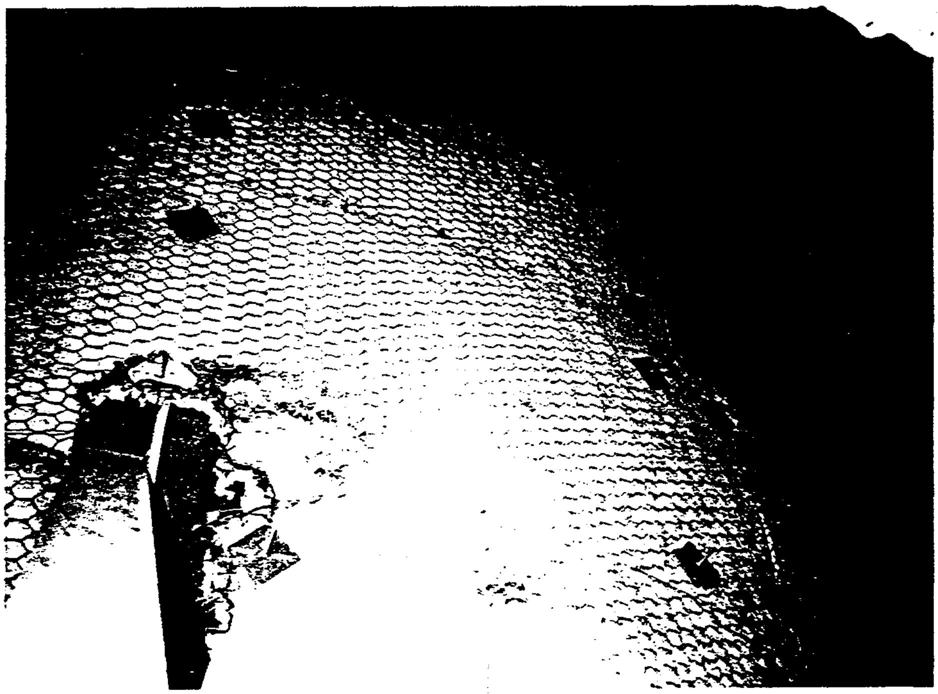

Photo #9 - View of chimney lining insulation at monitoring platform. Minor deterioration.

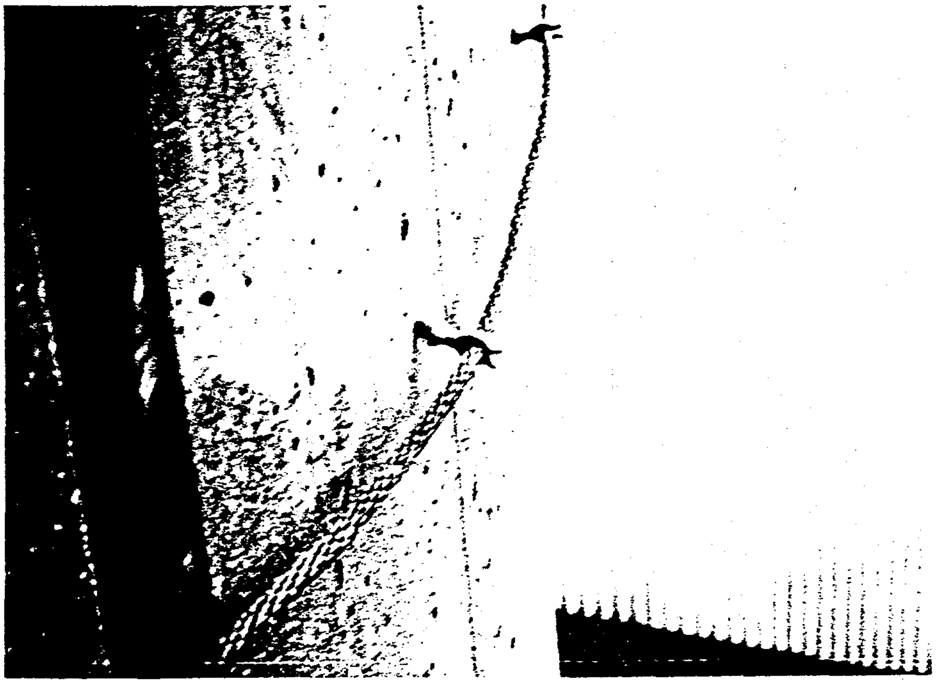

Photo #10 - Broken anchor on mid-encircling cable, north quadrant.

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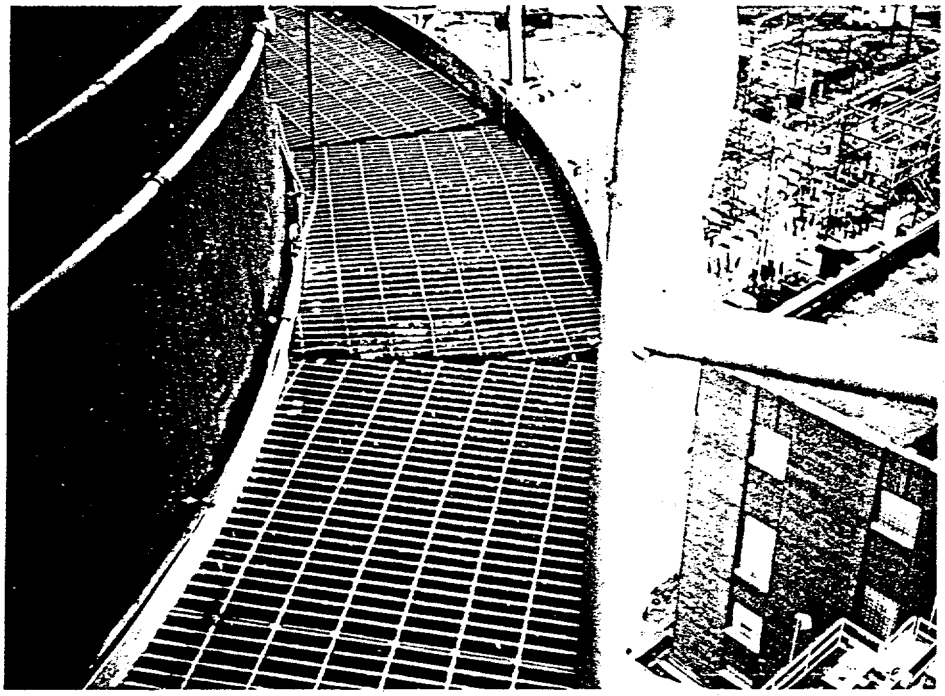

Photo #11 - Typical condition of monitoring platform. Note damaged grating.

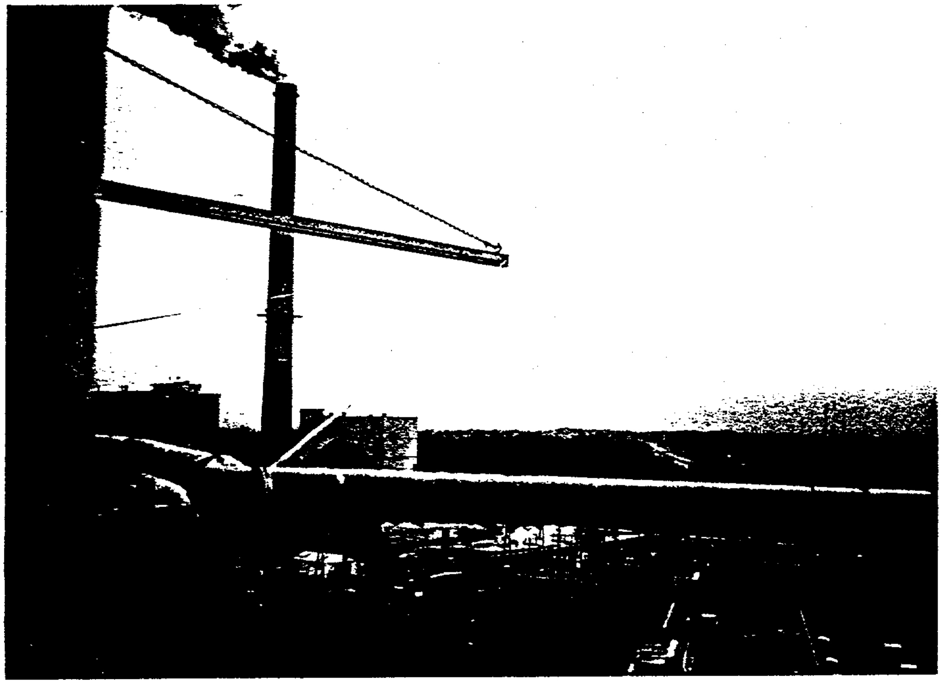

Photo #12 - Monorail for monitoring equipment.

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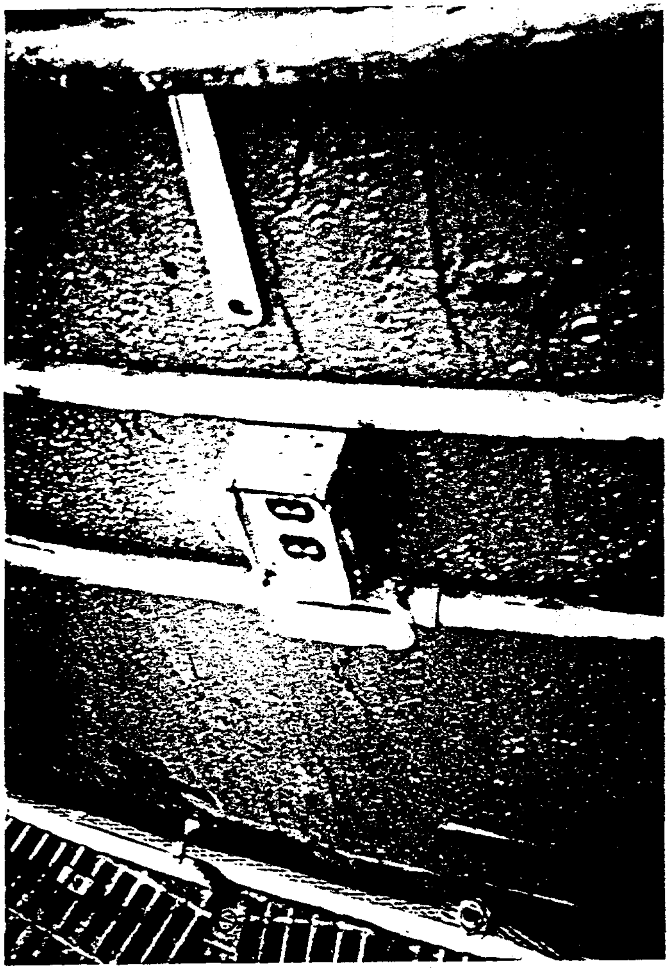

Photo #13 - Electrical outlet at monitoring platform. Note no cover on box.

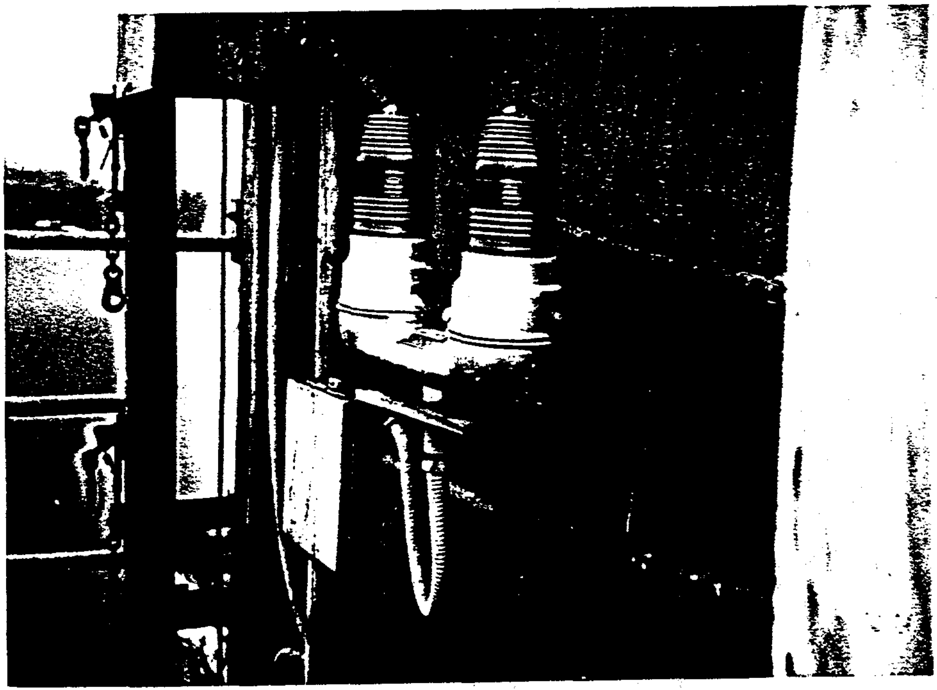

Photo #14 - Obstruction lights on monitoring platform are in operation.

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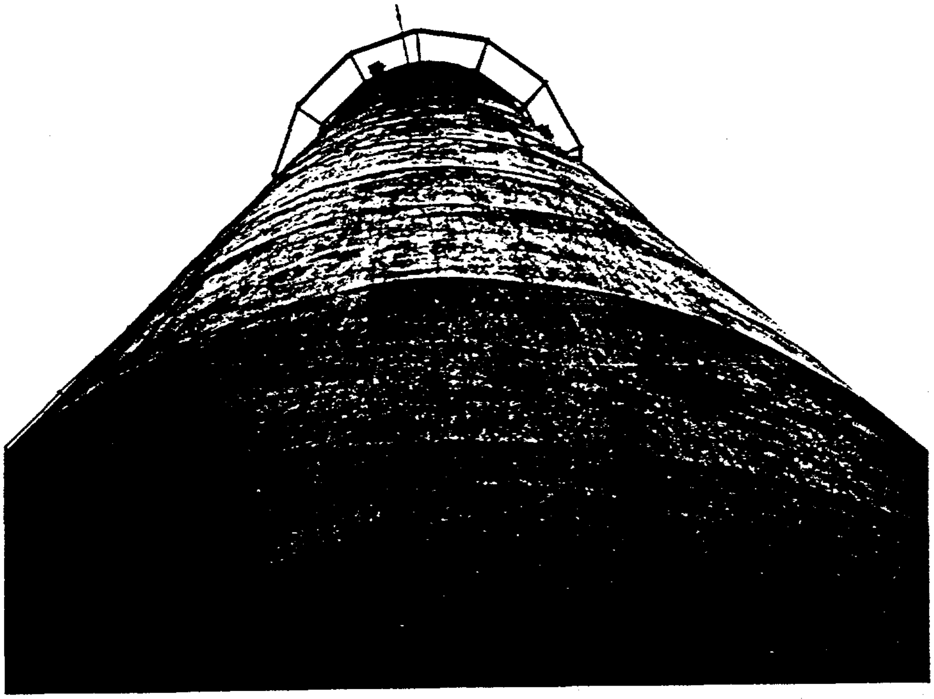

Photo #15 - View looking up from monitoring platform. Minor stress cracking was noted. Coating is tightly binded to the surface.

Photo #16 - Typical condition of concrete column on north quadrant above monitoring platform. Stress crack runs to the top of the chimney.

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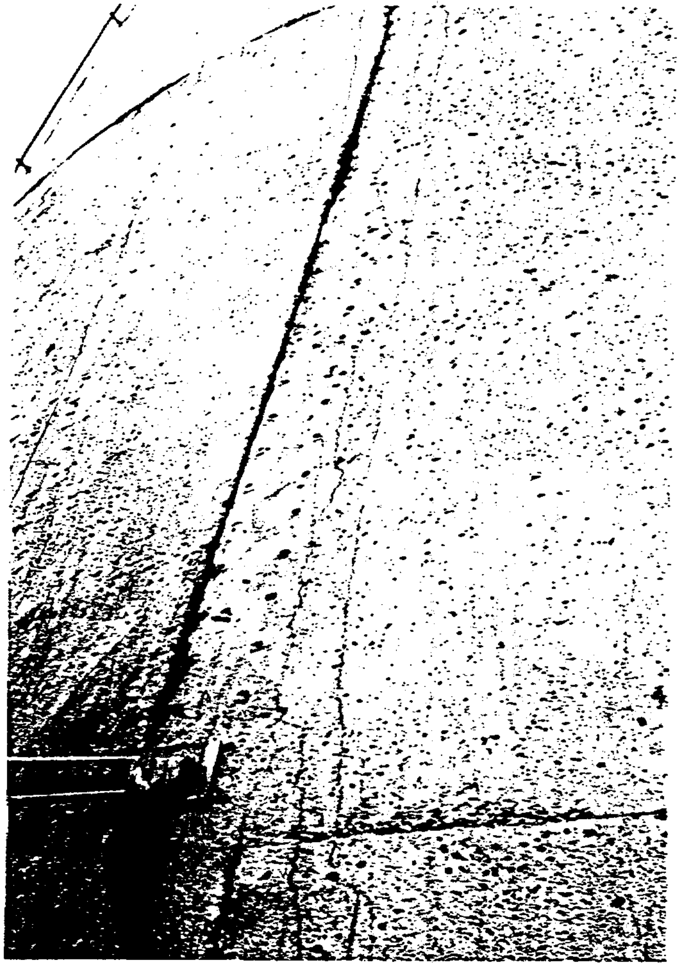

Photo #17 - Typical condition of concrete column on south quadrant above monitoring platform. Stress crack runs to the top of the chimney.

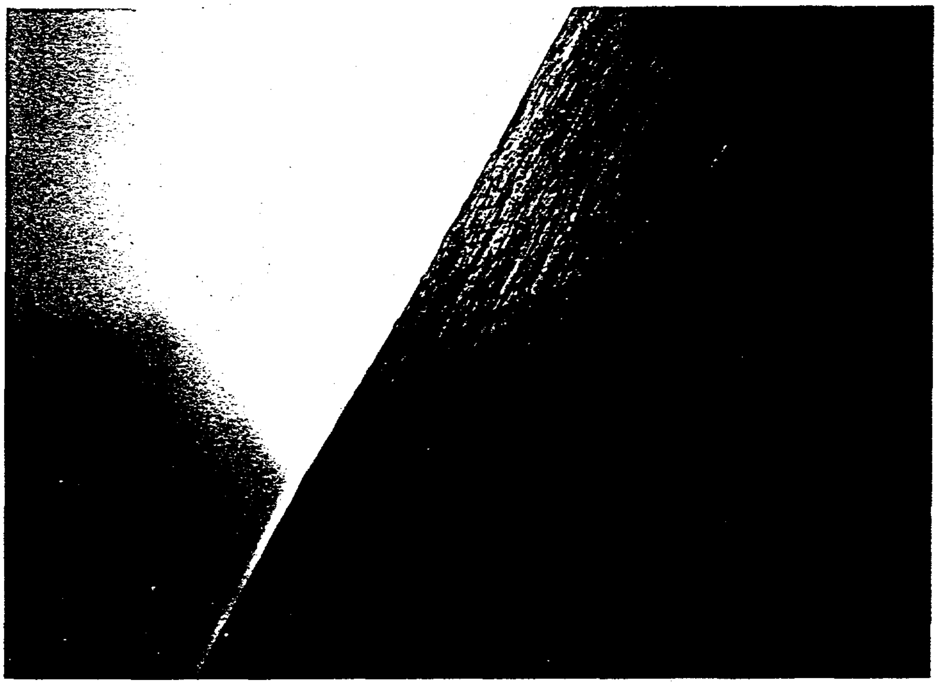

Photo #18 - The construction joints throughout the top of the chimney show no signs of cracking.

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Photo #19 - Minor cracking noted in patch which was installed to repair spalled surface.

Photo #20 - View of ladder and safety notch rail rusting freely.

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Photo #21 - View of ladder and safety notch rail rusting freely.

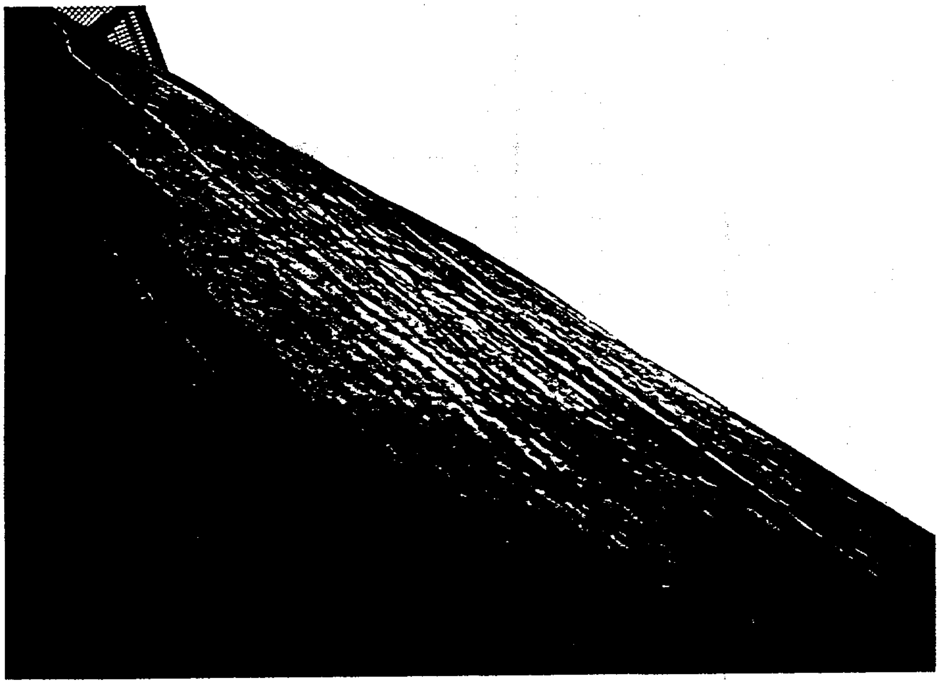

Photo #22 - The conduit throughout the top half of the chimney is rusting freely.

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Photo #23 - The top encircling cable of the lightning protection system was found intact.

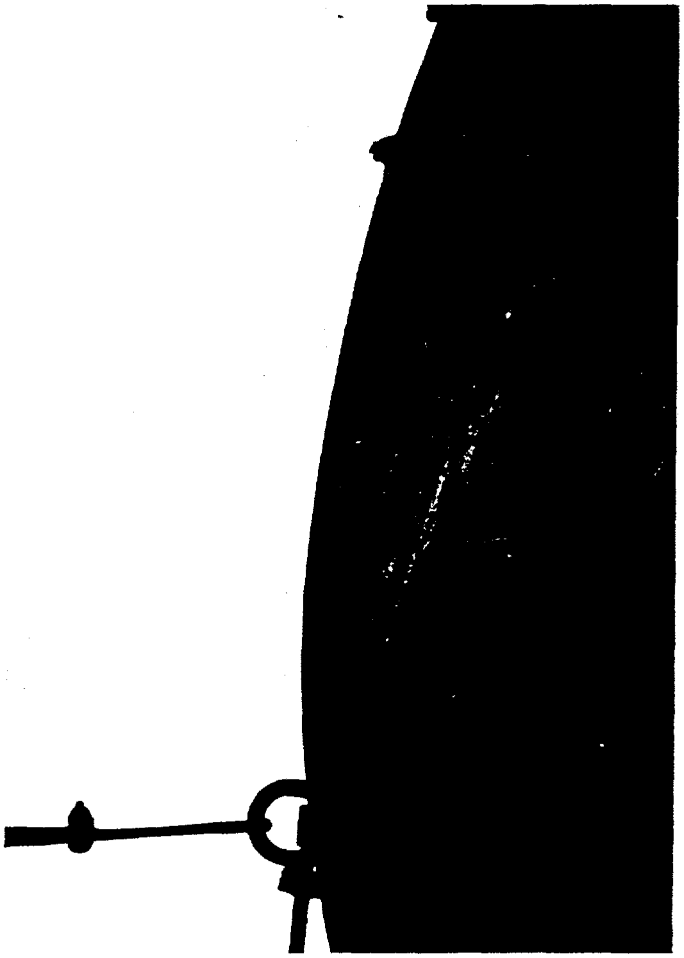

Photo #24 - The top encircling cable of the lightning protection system was found intact.

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Photo #25 - The handrails and support steel of the top platform is stained and rusting freely.

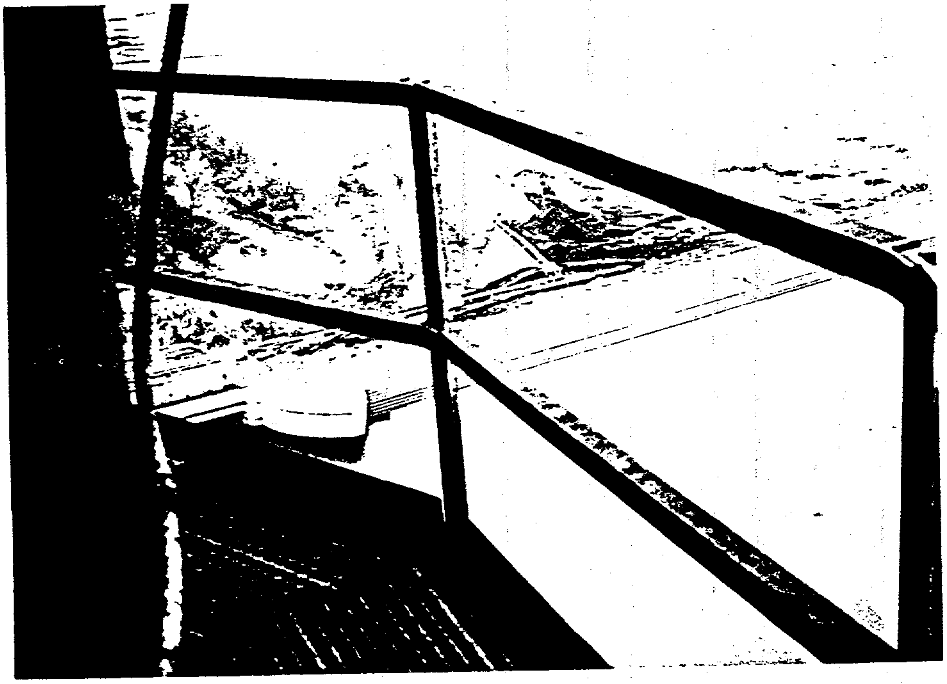

Photo #26 - The handrails and support steel of the top latform is stained and rusting freely.

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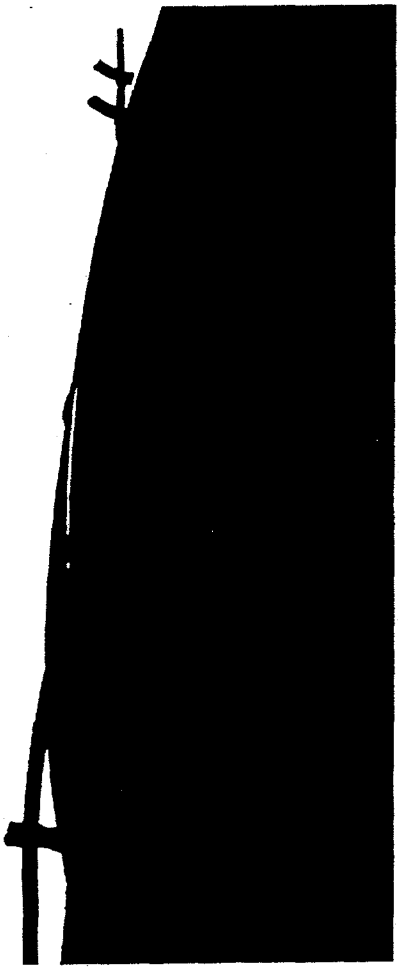

Photo #27 - View looking up at the skirt of the rainhood. The weld seam is split with 80% of the weld being deteriorated.

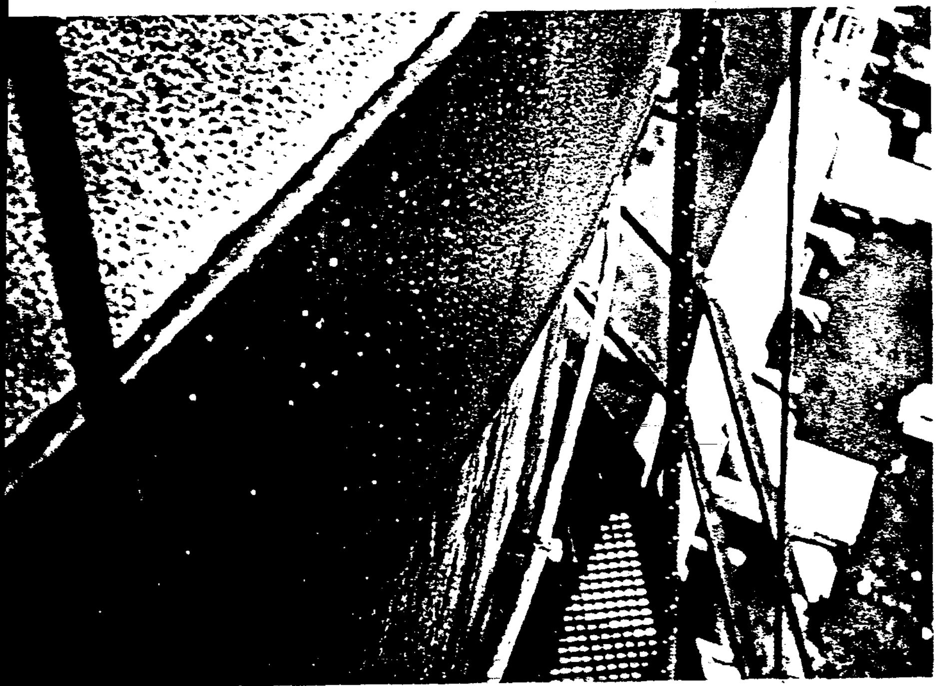

Photo #28 - View of the deteriorated weld at the connection of the skirt to the hood.

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Photo #29 - View of the deteriorated weld at the connection of the skirt to the hood.

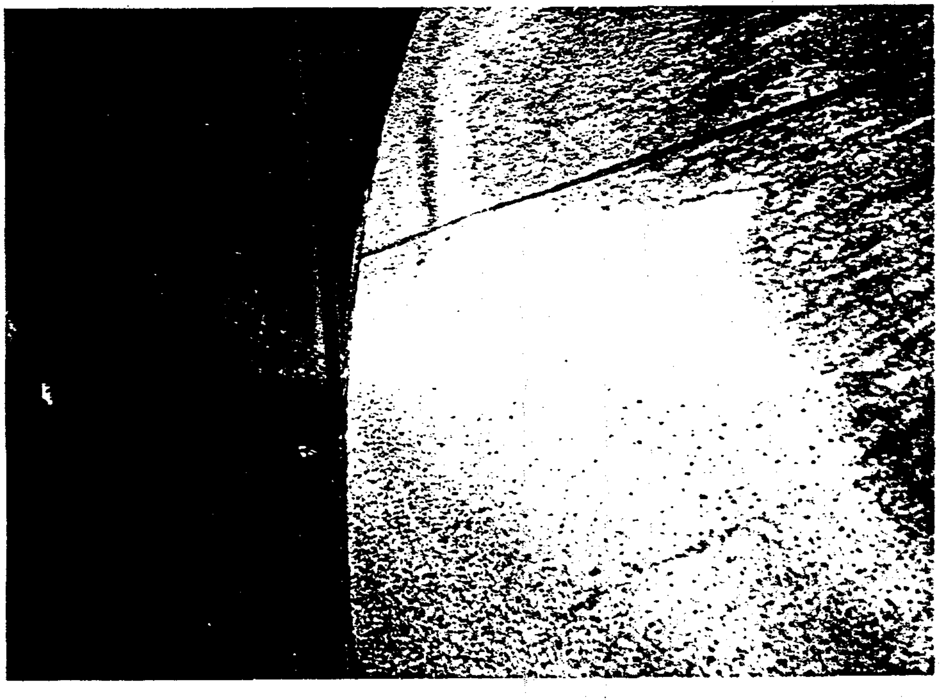

Photo #30 - View of the deteriorated weld at the connection of the skirt to the hood.

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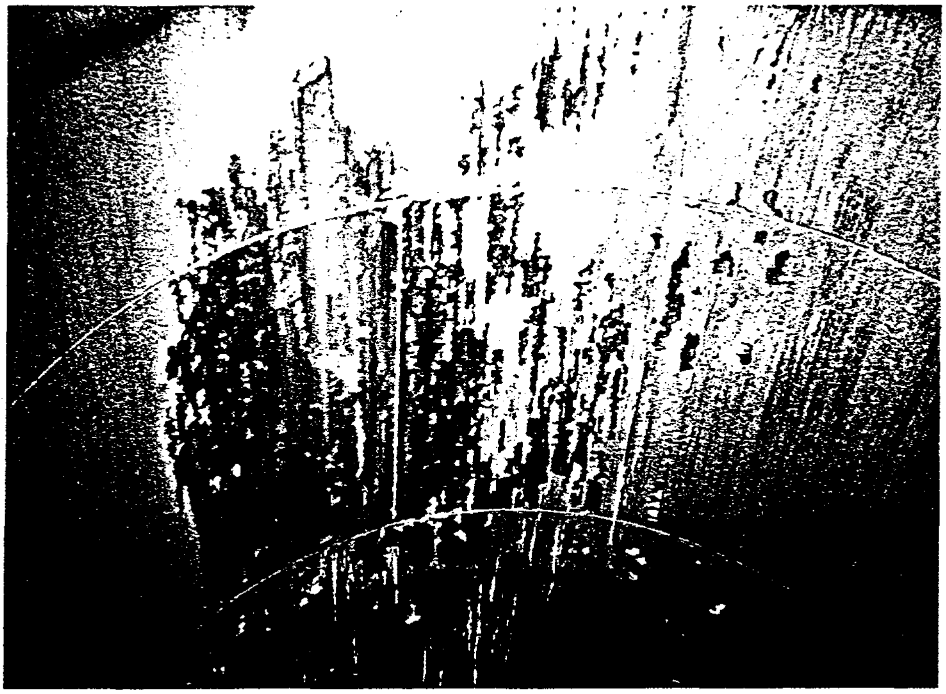

Photo #1 - Typical condition of lining top 50'. All welds solid and sound, light fly ash coating.

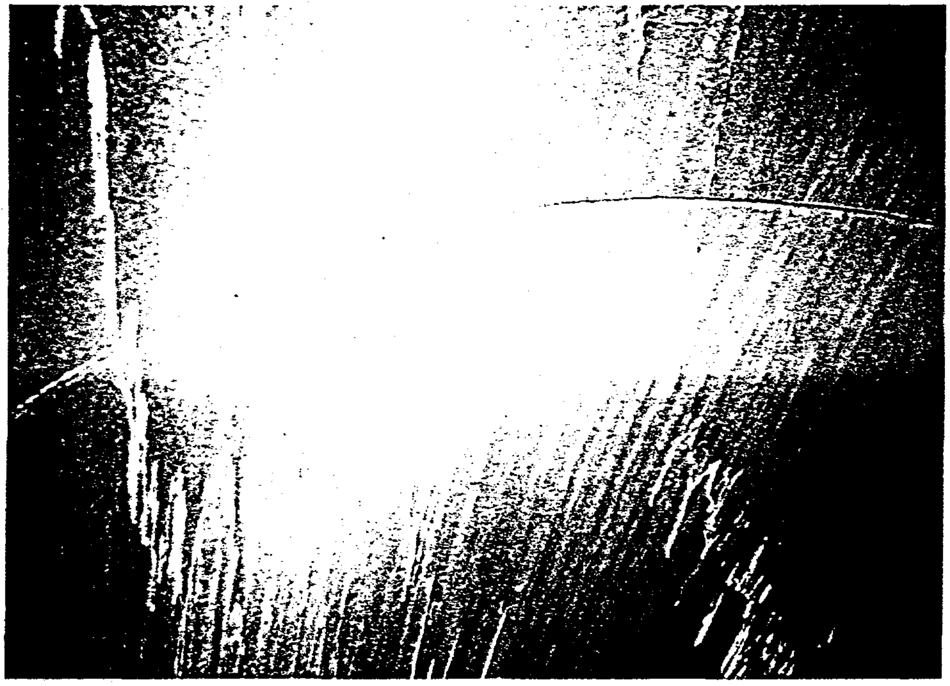

Photo #2 - 75' below top. Light fly ash coating, weld seams solid and sound.

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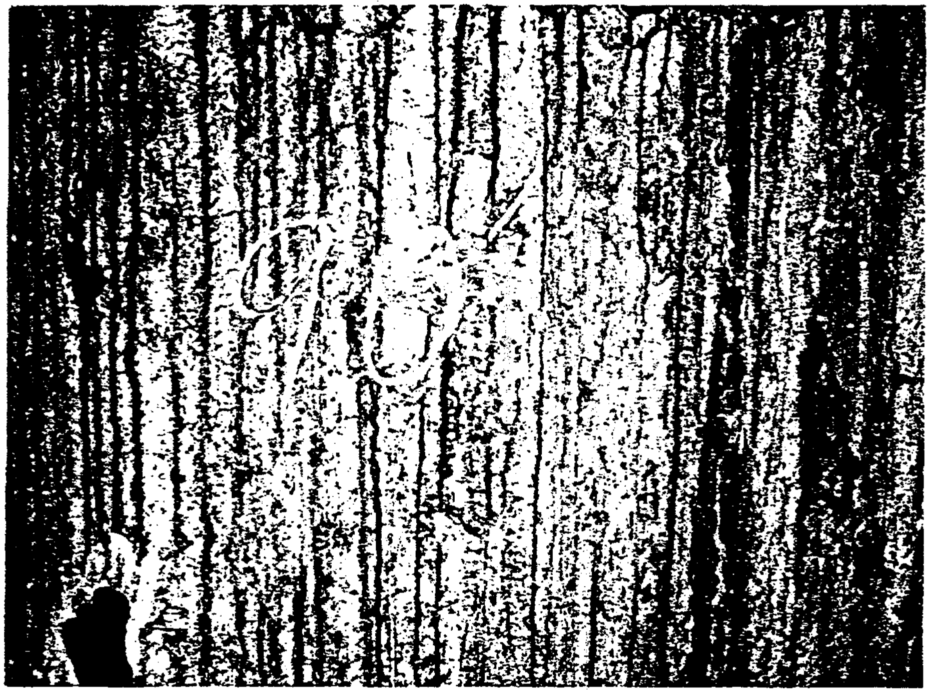

Photo #3 - 90' below top. Light fly ash coating, weld seams solid and sound.

Photo #4 - 100' below top. Light fly ash coating, weld seams solid and sound.

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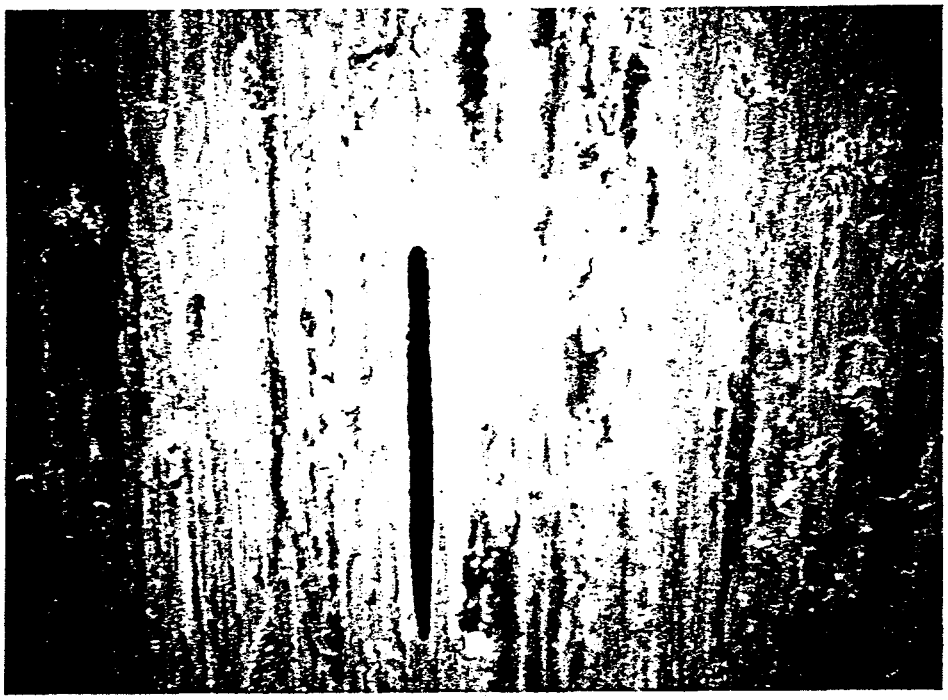

Photo #5 - 150' below top. Fly ash approximately 1/2" thick throughout this area.

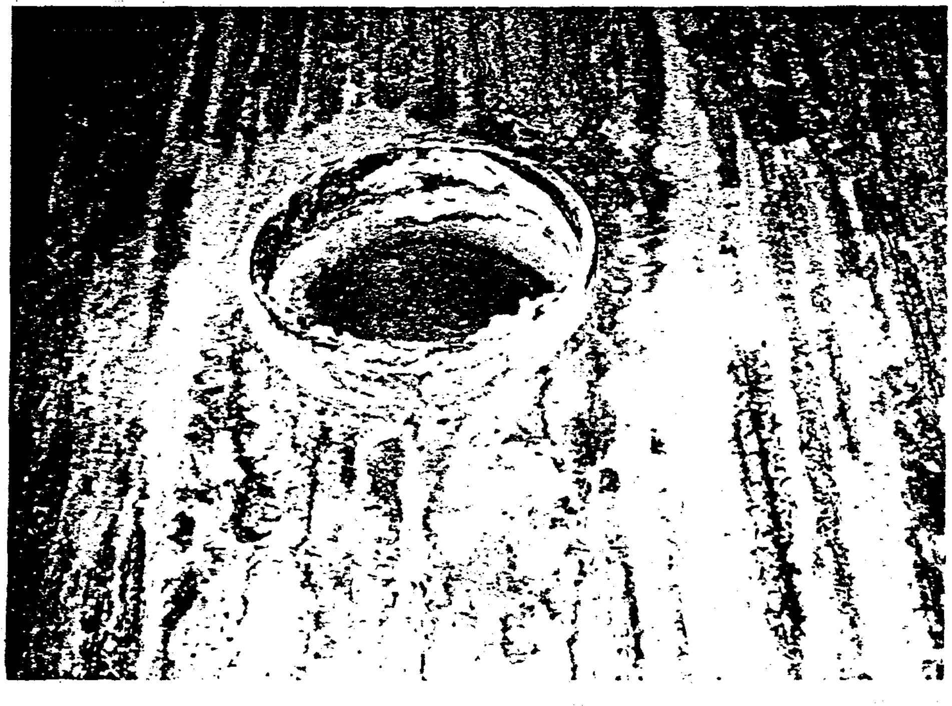

Photo #6 - The monitoring ports were found to be intact and free of debris.

CITY UTILITIES OF SPRINGFIELD
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INTERIOR PHOTOGRAPHS

Photo #7 - 170' below top. Fly ash approximately 1/2" thick, steel lining is solid and sound.

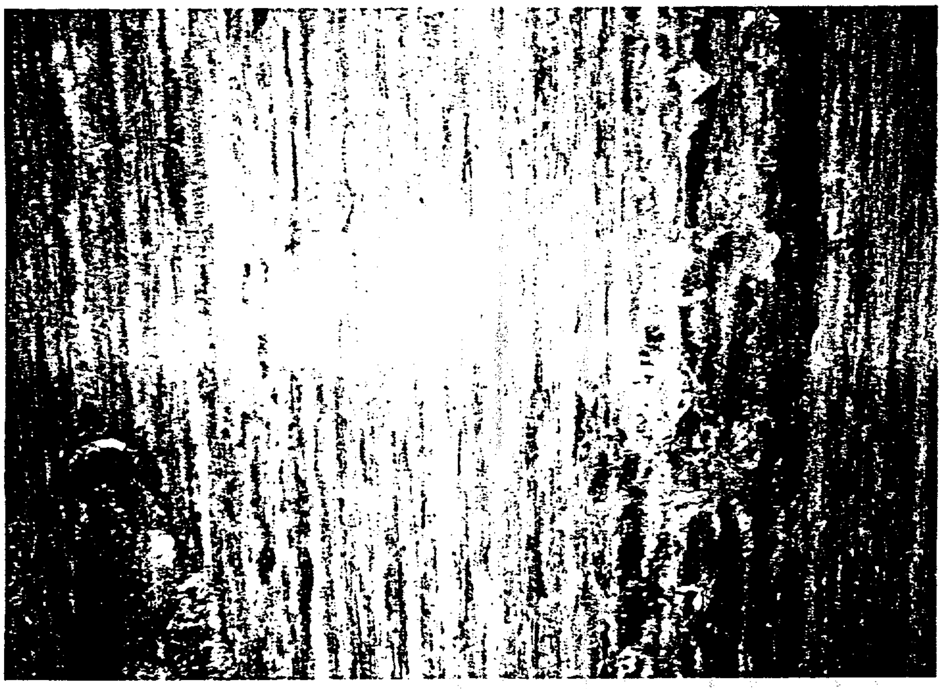

Photo #8 - 200' below top. Fly ash approximately 1/2" thick, steel lining is solid and sound.

CITY UTILITIES OF SPRINGFIELD
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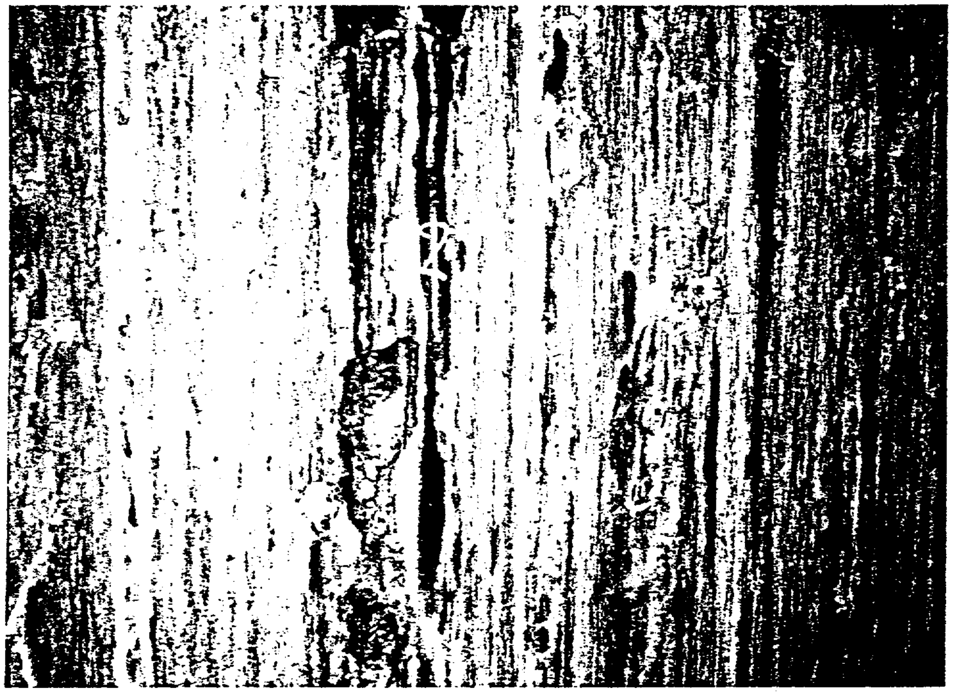

Photo #9 - 225' below top. Fly ash approximately 1/2" thick, minor scaling noted.

Photo #10 - 250' below top. Fly ash approximately 1/2" thick, minor scaling noted.

CITY UTILITIES OF SPRINGFIELD
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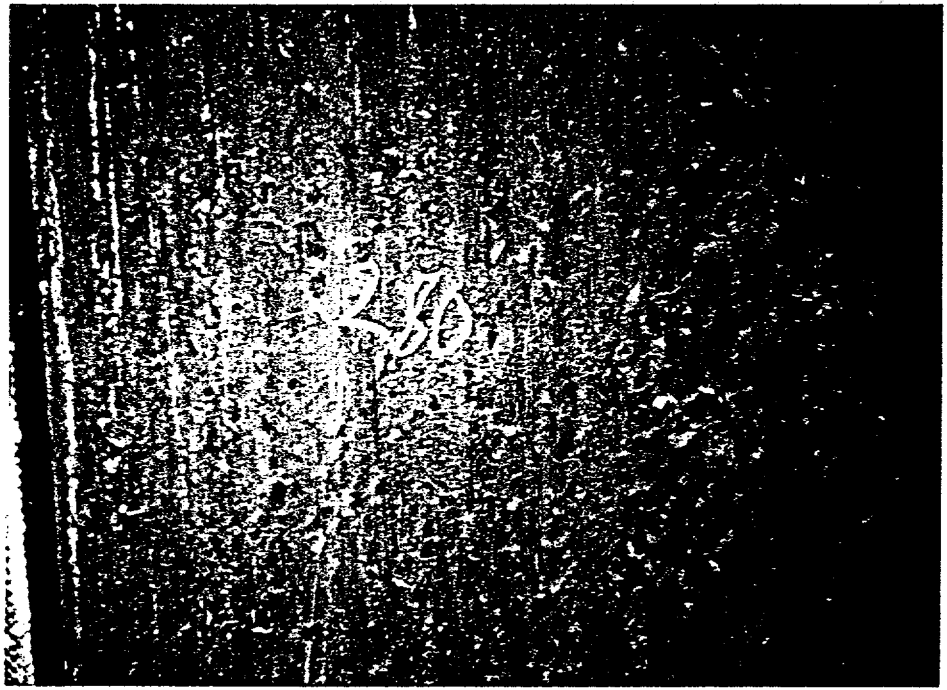

Photo #11 - 280' below top. Fly ash approximately 1/2" thick, minor scaling noted.

UTILITIES OF SPRINGFIELD
NO. 7 & 8 CHIMNEY

INTERNATIONAL CHIMNEY CORPORATION

DECEMBER 16, 1991
OUR FILE #CE-24953-C

ULTRASONIC THICKNESS TEST

From Top To Bottom	Original Thickness	PRESENT THICKNESS				
		NORTH				
300'		.215				
290'		.217				
280'		.215				
270'		.224				
260'		.223				
250'		.225				
240'		.230				
230'		.222				
220'		.225				
210'		.228				
200'		.234				
190'		.223				
180'		.229				
170'		.237				
160'		.232				
150'		.236				
140'		.240				
130'		.224				
120'		.228				
110'		.224				
100'		.236				
90'		.239				
80'		.232				
70'		.235				
60'		.246				
50'		.248				
40'						
30'	FALSE BOTTOM					
20'						
10'						

CITY UTILITIES OF SPRINGFIELD
LAKESIDE STATION
UNIT NO. 7 & 8 CHIMNEY INSPECTION

SECTION VI. - RECOMMENDATION FOR REPAIRS

Upon discovering the condition of the chimney cap, International Chimney Corporation informed both your personnel and plant personnel of this condition and was told that the repairs would be completed to the deteriorated weld by plant personnel. Therefore, at this time, we foresee no immediate repairs required to the subject chimney.

Consideration should be given to installing a new coating throughout the top of the chimney column including both platforms and the ladder system. A mastic type Tuffide coating should be used on the concrete column, thereby, sealing any stress relief cracks as noted and extending the lifetime of the chimney column itself.

The air terminals at the top of the chimney column were found to be in a deteriorated condition and consideration should be given to removing or replacing these air terminals.

CONCLUSION:

At this time, we are pleased to report that the subject chimney is in good, operating condition.

INTERNATIONAL CHIMNEY
CORPORATION
ENGINEERS — CONTRACTORS
55 S·LONG ST·BOX·260·BUFFALO·N·Y·14221-0260
(716) 634-3967

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City Utilities of Springfield
Lakeside Station
Unit #7 & #8 Chimney Inspection

Original Report

INTERNATIONAL CHIMNEY CORPORATION
Engineers - Contractors
Mid-West General Office
P.O. Box 0577
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Serving The Industry For Over 60 Years

INTERNATIONAL CHIMNEY
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ATLANTA

November 28, 1994
Our File #CE-27354-C

Energy and Environmental Research Corp.
1345 North Main Street
P.O. Box 153
Orrville, OH 44667

Attention: Mr. Don Engelhardt
Project Manager

Subject: Your Purchase Order No. 70899
Internal and External Inspection
Lakeside Station - Unit #7 & #8 Chimney
City Utilities of Springfield, Illinois

Gentlemen:

In accordance with the above purchase order number, we have completed the internal and external inspection of the subject chimney and are submitting, herewith, our inspection report including findings, photographs, ultrasonic thickness test readings and recommendation for repairs.

We feel that our report is clear in all details, however, should there be any questions, please do not hesitate to contact the writer at our Midwest General Office at (815) 727-0966.

Respectfully Submitted,

INTERNATIONAL CHIMNEY CORP.

By
Dennis M. Sweeney
Project Manager

mmc
encls

November 28, 1994

INTERNATIONAL CHIMNEY CORPORATION

Our File #CE-27354-C

City Utilities of Springfield
Lakeside Station
Unit #7 & #8 Chimney Inspection

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City Utilities of Springfield
Lakeside Station
Unit #7 & #8 Chimney Inspection

Section I. Description of Chimney

The subject chimney is 299' in height, constructed of reinforced concrete with an independent steel lining. The top I.D. of the lining is 13'.

The exterior of the chimney is equipped with a full height scaling ladder which interconnects the monitoring platform located at the midpoint of the chimney to the full circumference platform approximately 9' below the top of the chimney.

The breeching opening enters from the south quadrant approximately 30' above the base.

Access to the interior of the lining is from the manway access in the breeching ductwork.

The exterior of the chimney is also equipped with an obstruction lighting system consisting of four beacon lights located at the top and two sets of obstruction lights located at the mid platform.

Section II. Inspection Procedures

Exterior:

The exterior of the chimney was inspected utilizing the existing ladder system and platforms which enabled our inspector to make a close, visual inspection of the concrete column as well as all appurtenances. The remainder of the chimney exterior was inspected utilizing terrain and telephoto camera equipment.

Interior:

Our inspector was lowered from the top of the chimney lining, down through to the base. Ultrasonic thickness readings were taken of the lining on 10' centers for the full height.

Annular Space:

Access to the annular space was available only at the monitoring ports located at the midpoint of the chimney. Our inspector viewed what was readily accessible.

Section III. Inspection Findings

Concrete Column:

Overall, the concrete column was found to be in solid and sound condition with the existing stress relief cracks which were noted in our report of December 1991 showing no signs of increase in either width or length.

The coating on the exterior column was found to be intact, however, this coating is faded, stained and discoloring.

Ladder System:

The ladder system was found to be safe and sound upon inspection, however, it was noted that both the ladder and safety notch rail are pitted and rusting freely. This condition was highly evident throughout the top one third of the chimney column.

One anchor bolt on the bottom standoff of the ladder was found to be missing.

Platforms:

The monitoring platform located at the approximately 150' elevation as well as the uppermost full circumference platform were both found to be intact and in safe and sound condition.

The monitoring platform grating was found to be rusting freely, however, all structural supports and hand rails were solid and sound.

The uppermost platform grating is of fiberglass construction and was found to be solid and sound. Again, the steelwork is stained and rusting freely.

Obstruction Lighting System:

All lights were found to be functioning at the time of our inspection.

Lightning Protection System:

The lightning protection system was found to be intact at the time of our inspection with all air terminals, jumper cables, downleads and encircling cables being intact. It was noted that a total of nine encircling cable anchors are broken at this time.

Chimney Cap:

The chimney cap was found to be intact with all weld seams being solid and full. No cracking of weld seams or any of the rainhood connections was noted.

Chimney Lining:

The lining was found to be in solid and sound condition with no buckling, bulging or splitting of welded seams being noted. Ultrasonic thickness readings were taken showing no signs of increased deterioration throughout the full height of the lining. These readings are shown under Section V. of this report.

Breeching Ductwork:

The breeching ductwork at its connection to the concrete column was found to be tightly sealed and it appears that all insulation and expanded metal are intact.

All steelwork including turning vanes, support rods and bolted connections were found to be intact in the interior of the breeching ductwork.

Section IV. Photographs

A total of forty-four color photographs depicting our findings are attached, herewith.

November 28, 1994

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Our File #CE-27354-C

City Utilities of Springfield
Lakeside Station
Unit #7 & #8 Chimney Inspection

Exterior Photographs

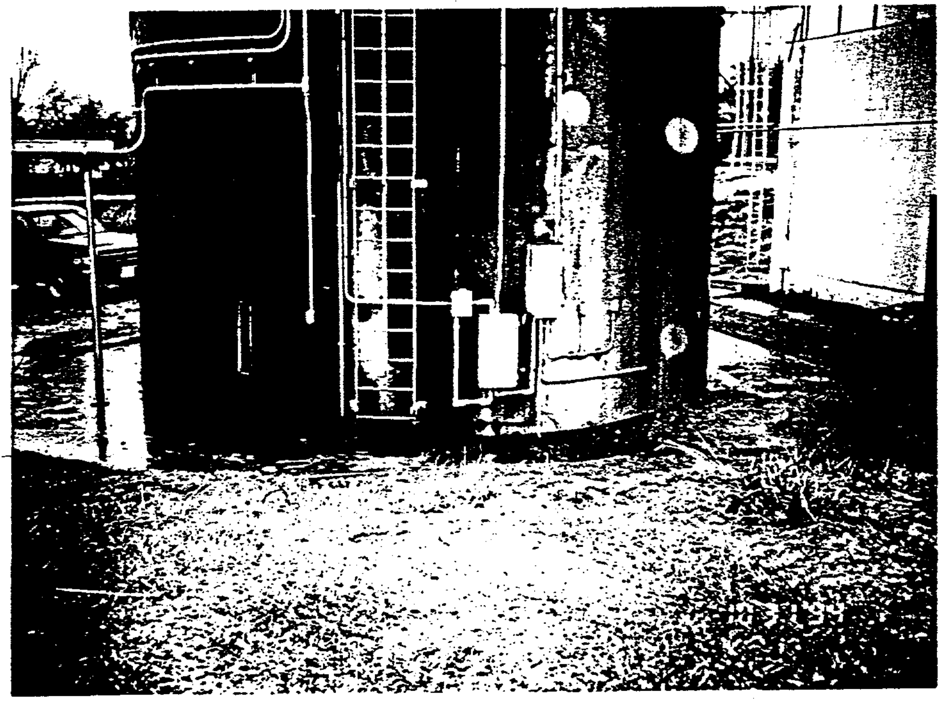

Photo #1 - View of base of chimney, north quadrant.

Photo #2 - The ground connection of the lightning protection system was found to be intact. Note the one bolt missing on the ladder standoff.

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Exterior Photographs

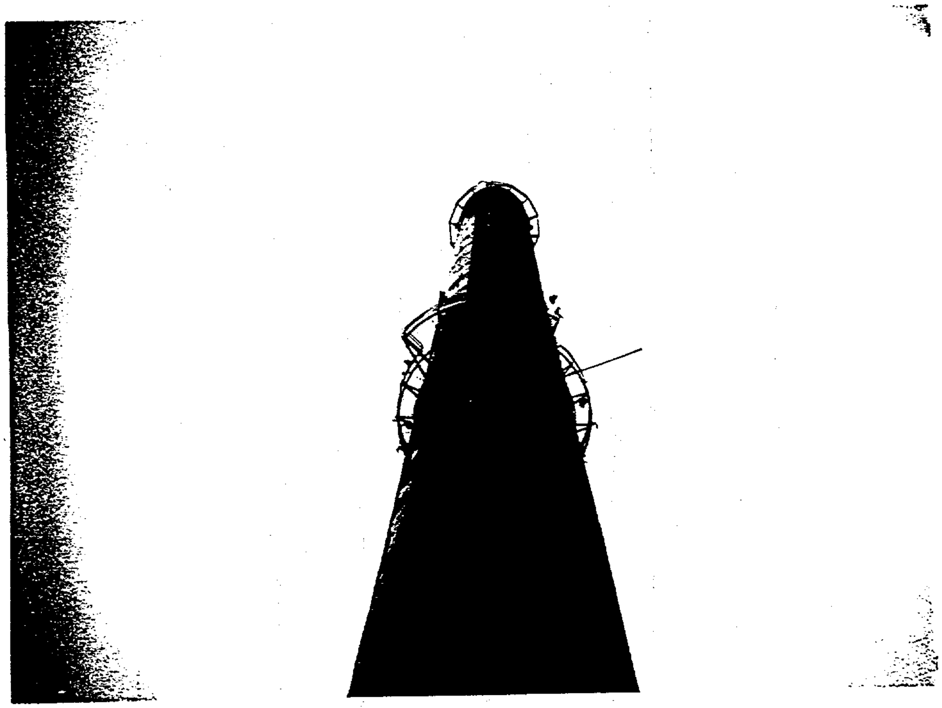

Photo #3 - View of chimney from grade elevation looking to the top.

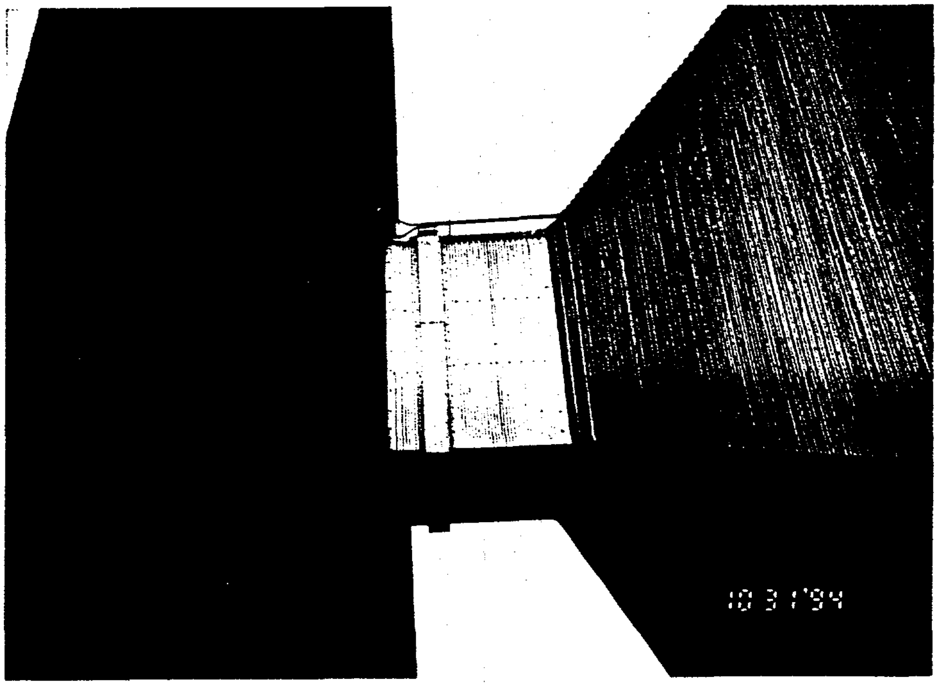

Photo #4 - Breeching ductwork connection to chimney.

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Exterior Photographs

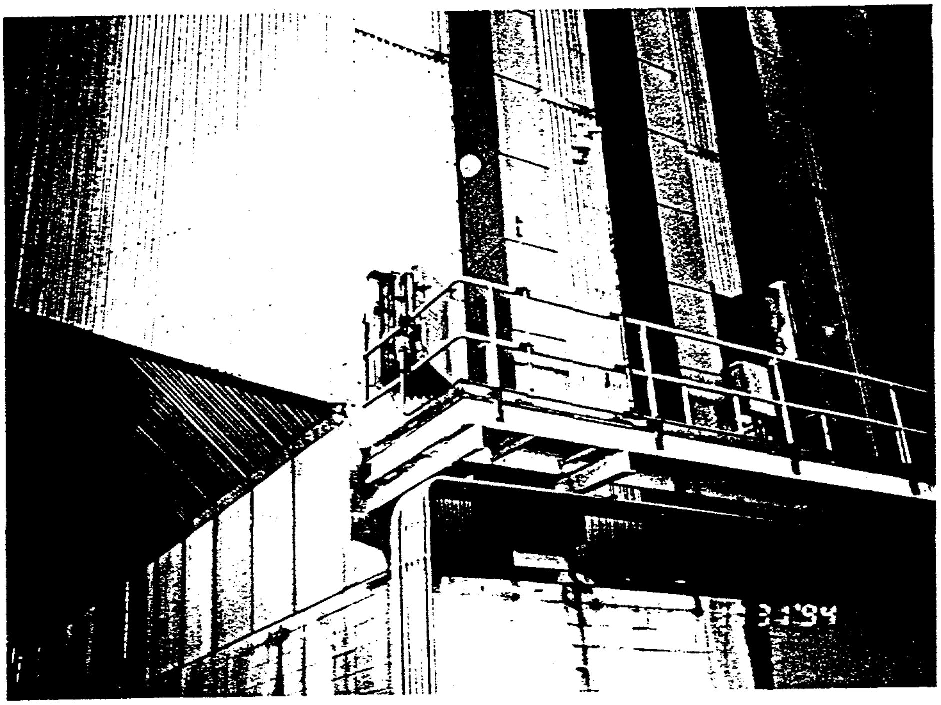

Photo #5 - View of access door in ductwork. This door allows access into the base of the chimney lining.

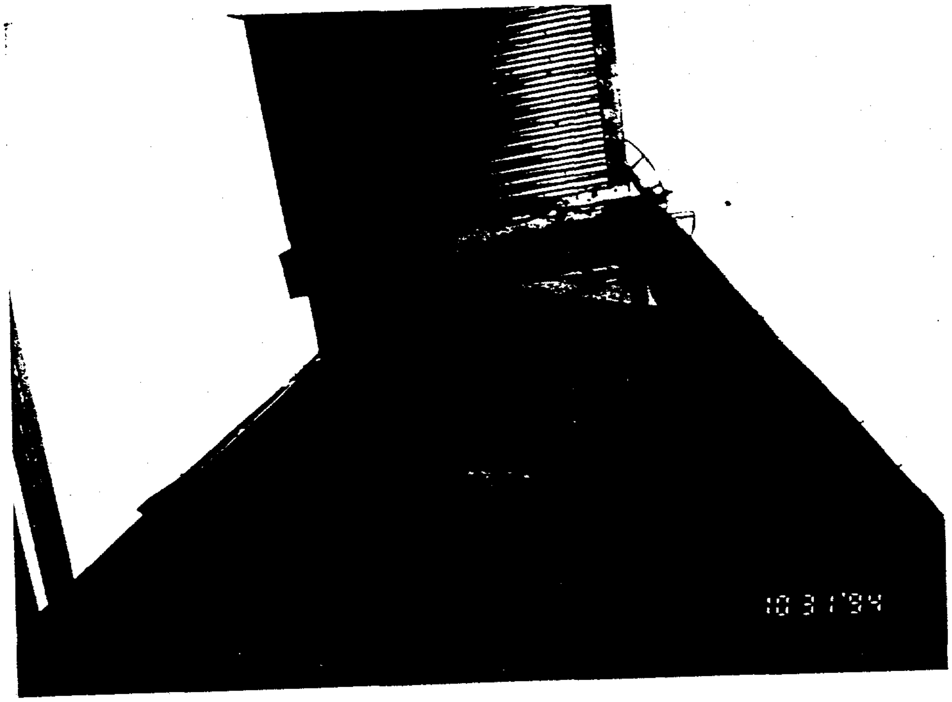

Photo #6 - View looking up at the bottom of the breeching ductwork. The seal appears to be tight.

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Exterior Photographs

Photo #7 - Access doo into base of chimney below false bottom.

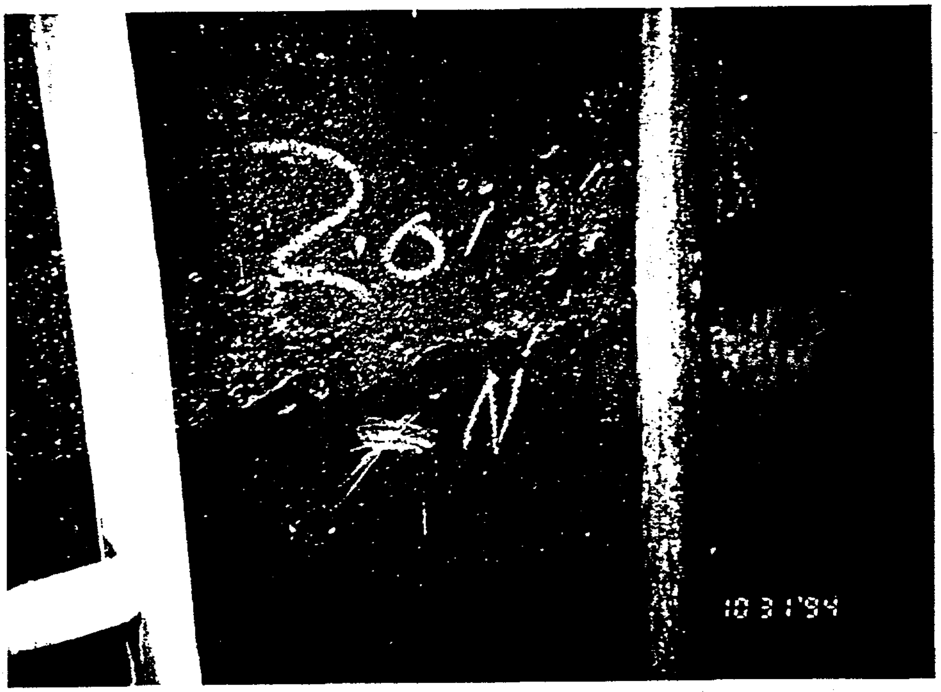

Photo #8 - Typical condition of concrete column 20' above base. The concrete is solid and sound.

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Exterior Photographs

Photo #9 - Typical condition of concrete column 48′ above base. The concrete is solid and sound.

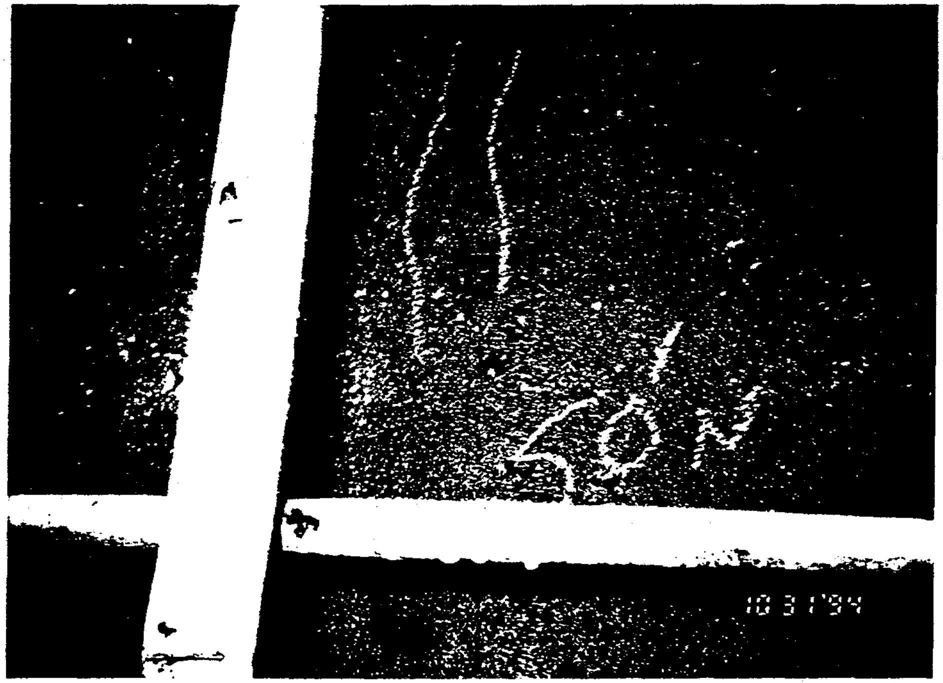

Photo #10 - View of crack in concrete column on north quadrant at elevation 50′ behind the ladder. The crack is hairline and continues on.

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Exterior Photographs

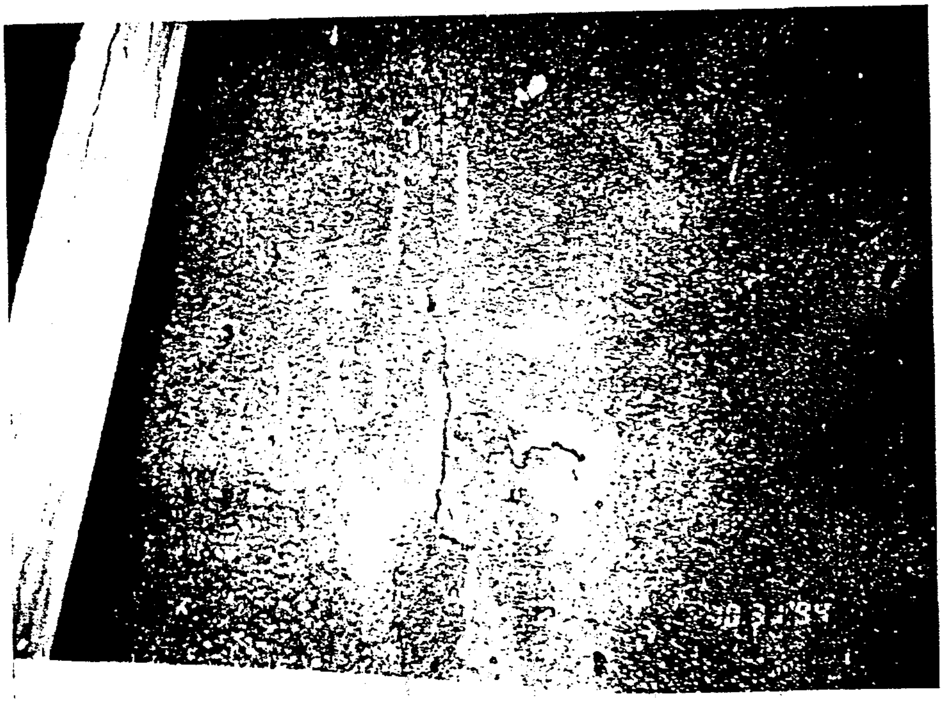

Photo #11 - View of crack in concrete column on north quadrant at elevation 80' behind the ladder. The crack is hairline and ends at elevation 102'.

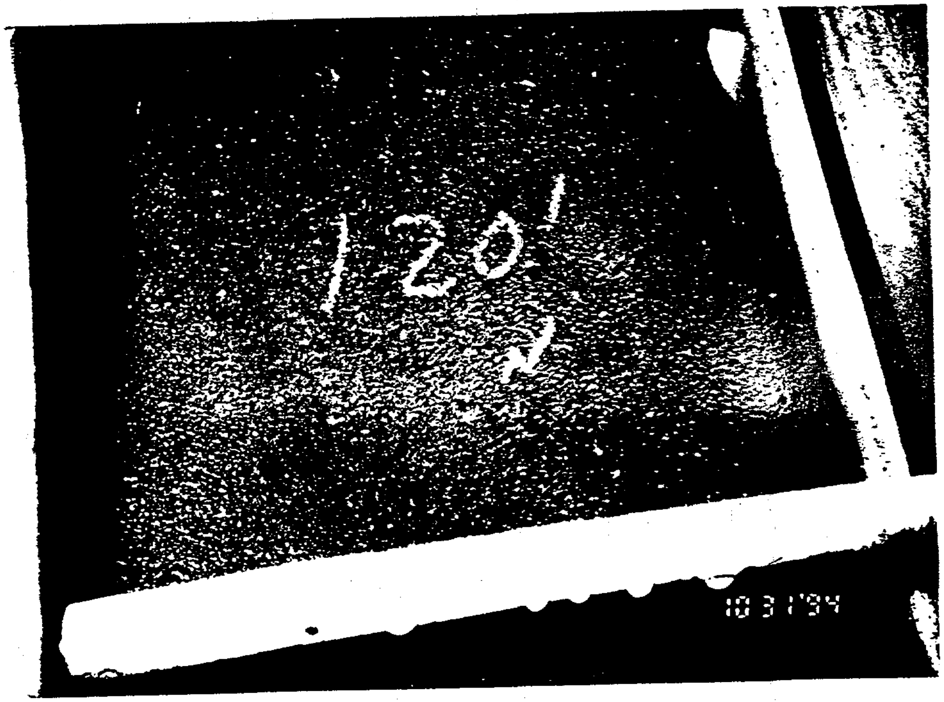

Photo #12 - 120' elevation, north quadrant, the concrete is solid and sound.

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Exterior Photographs

Photo #13 - The platform at elevation 150' is solid and sound. Minor rusting of the grating was noted. Nine encircling cable anchors are broken.

Photo #14 - View of test port, all seals were found to be intact.

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Exterior Photographs

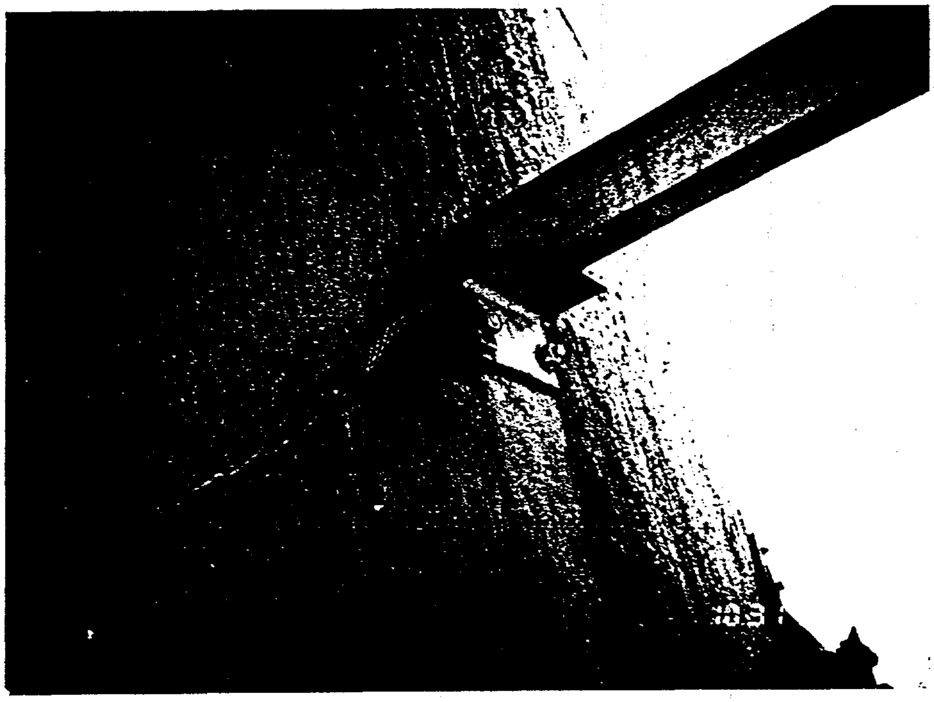

Photo #15 - View of monorail connection to concrete column at monitoring platform. All connections are intact.

Photo #16 - Typical condition of column at elevation 175', the concrete and coating are intact.

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Exterior Photographs

Photo #17 - Typical condition of column at elevation 200', the coating is heavily stained.

Photo #18 - View looking up ladder system from elevation 220'. The ladder is solid and sound. Minor rusting and staining were noted.

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Exterior Photographs

Photo #19 - Close up view of the ladder at elevation 250'. Note the staining and peeling of the coating.

Photo #20 - View of platform at top of chimney. The platform is in safe and sound condition.

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Exterior Photographs

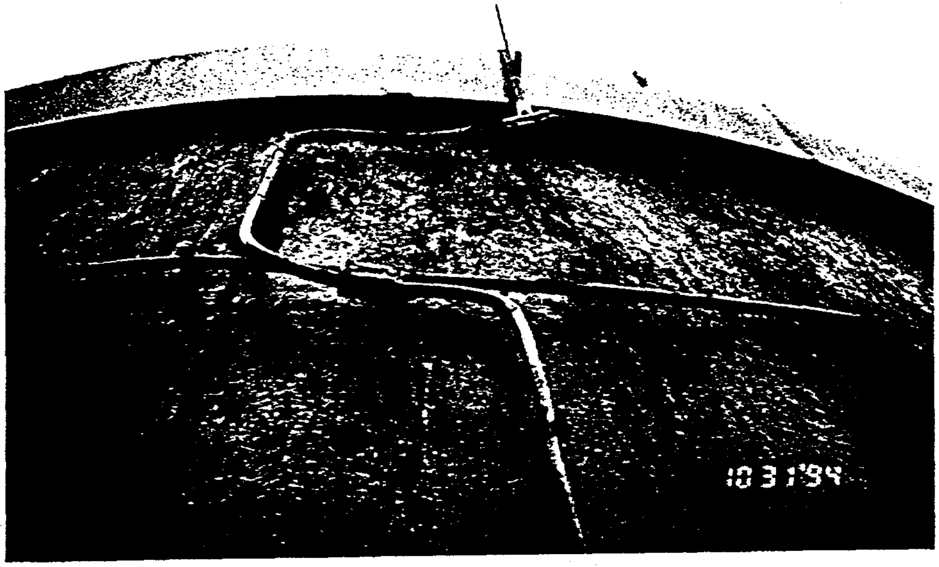

Photo #21 - Coating is heavily stained at top of chimney. All air terminals and connections are intact.

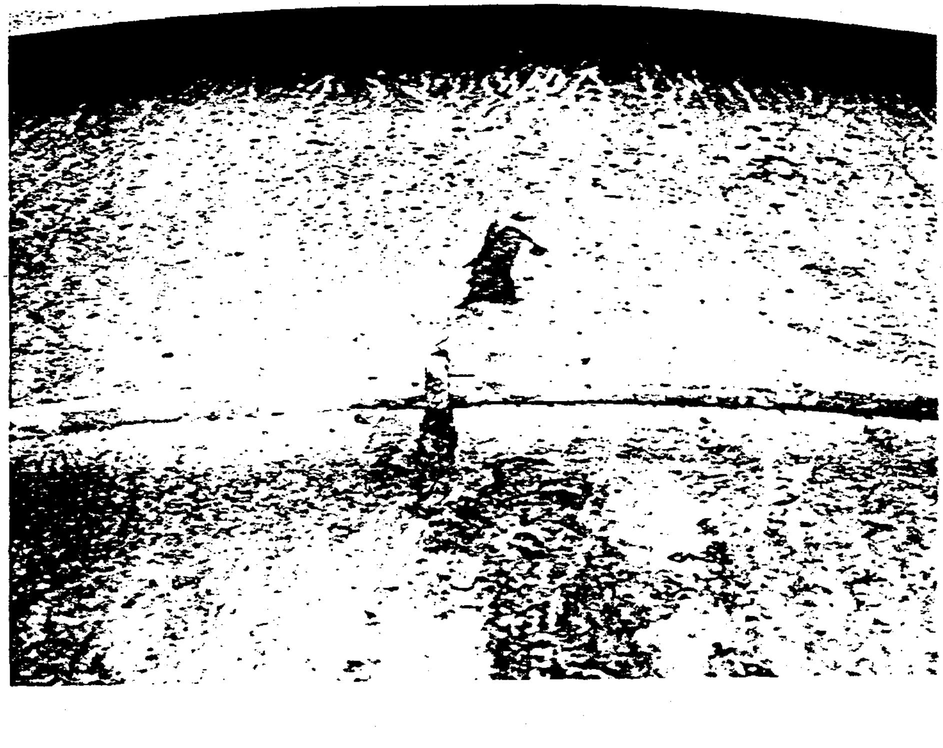

Photo #22 - Minor peeling of coating at the top of the column was noted.

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Exterior Photographs

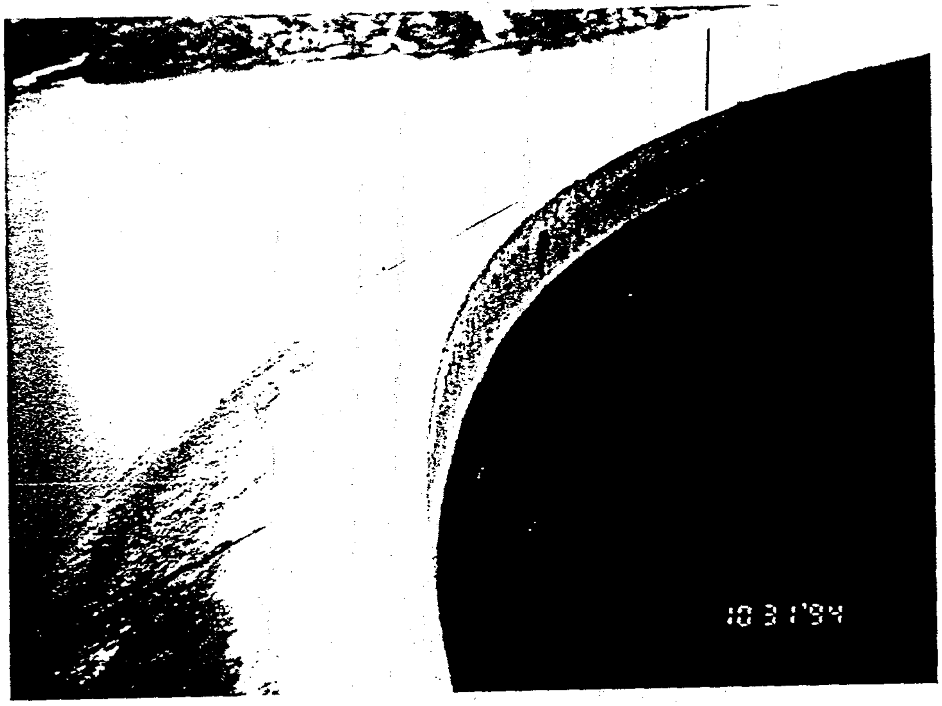

Photo #23 - Typical condition of rainhood at the top of the chimney. The rainhood is solid and sound.

Photo #24 - Typical condition of rainhood at the top of the chimney. The rainhoo is solid and sound.

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Interior Photographs

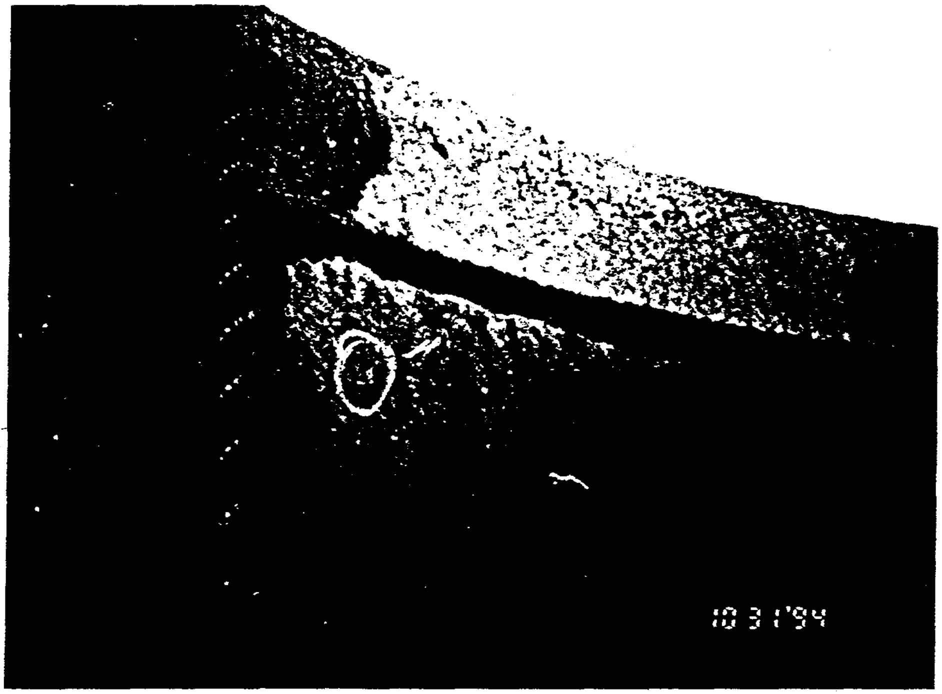

Photo #1 - Typical condition of lining steelwork at top of chimney. All welds are solid and sound.

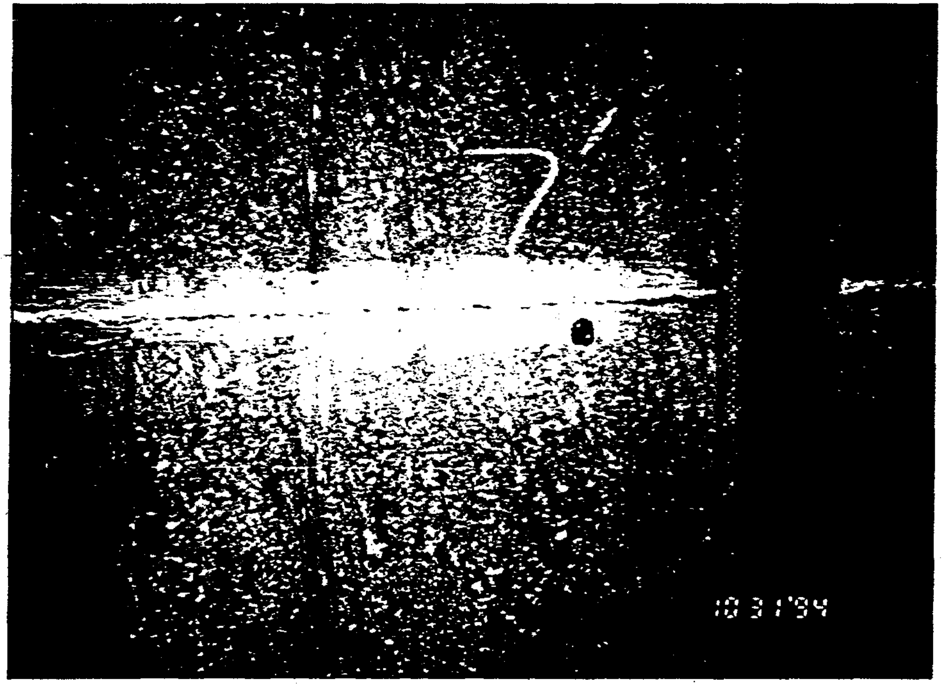

Photo #2 - Typical condition of lining steelwork at 7' below top.

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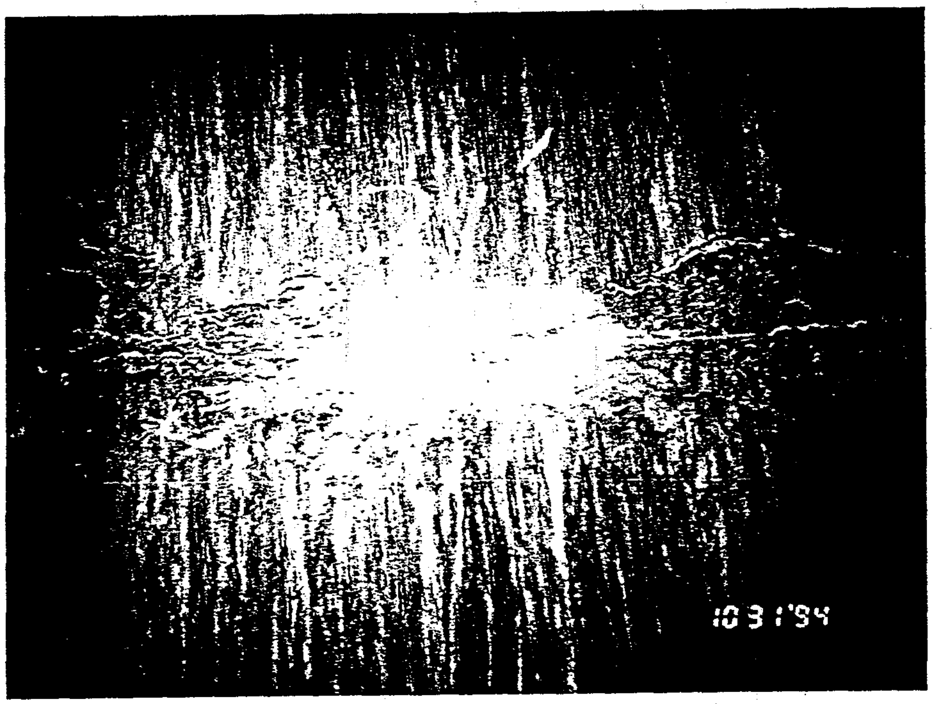

Photo #3 - Typical condition of lining steelwork 21' below top.

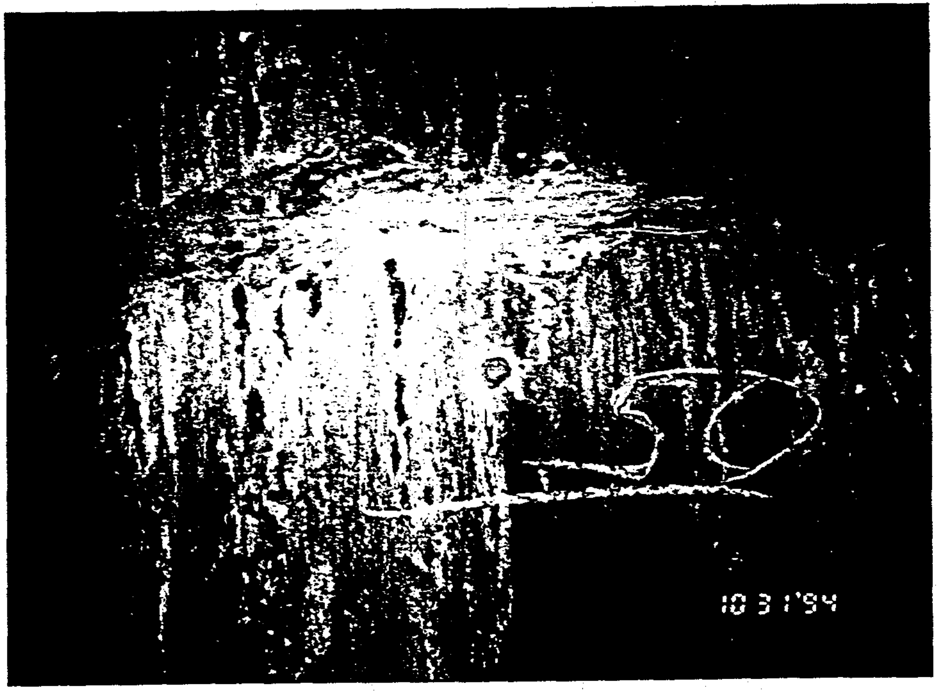

Photo #4 - Typical condition of lining steelwork at 50' below top.

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Interior Photographs

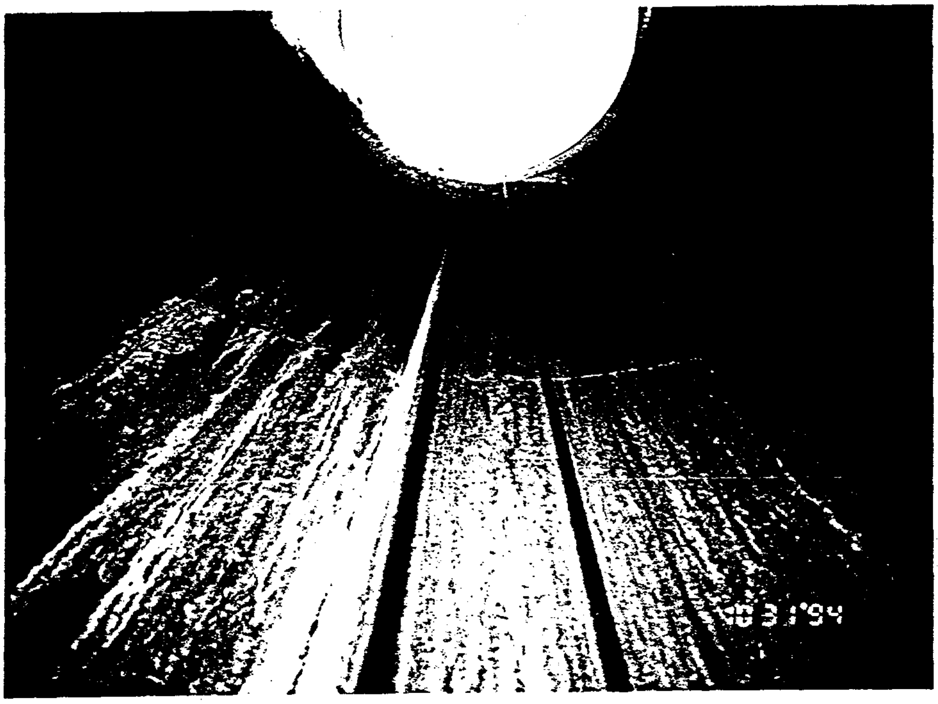

Photo #5 - View looking up to top of chimney from 50' below top. No buckling or bulging of steelwork was noted.

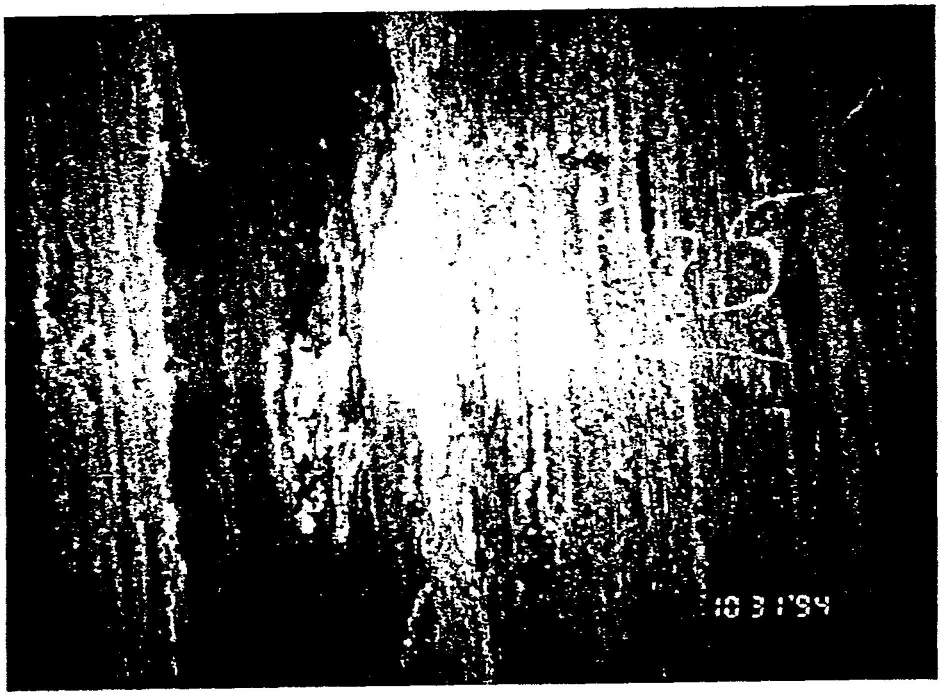

Photo #6 - 75' below top, light fly ash coating was noted.

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Interior Photographs

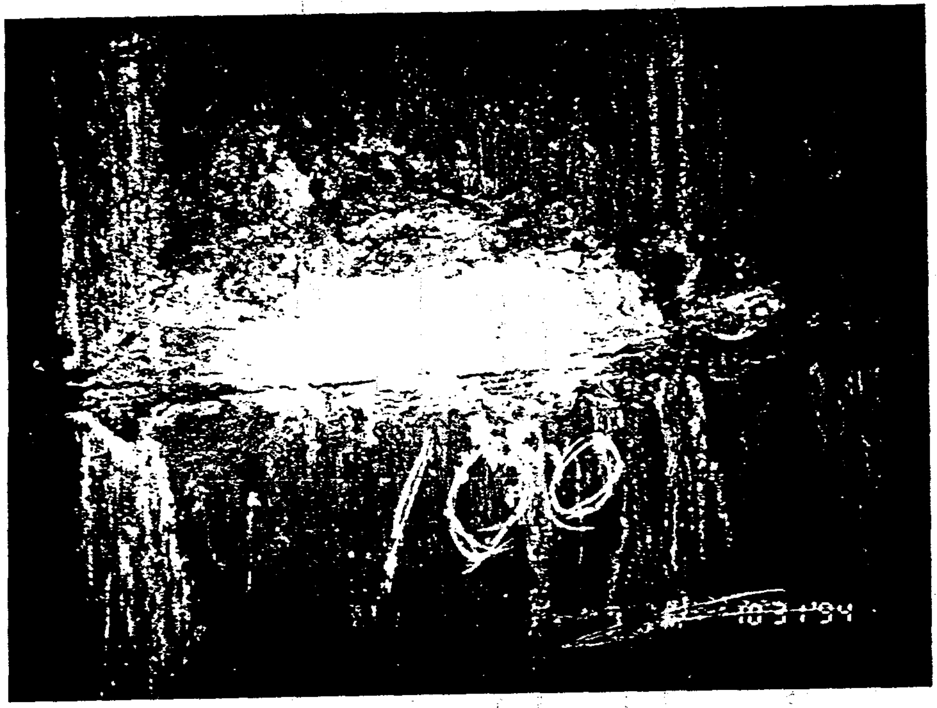

Photo #7 - 100' below
top, the welded seam i
intact and a light fly
ash coating was noted.

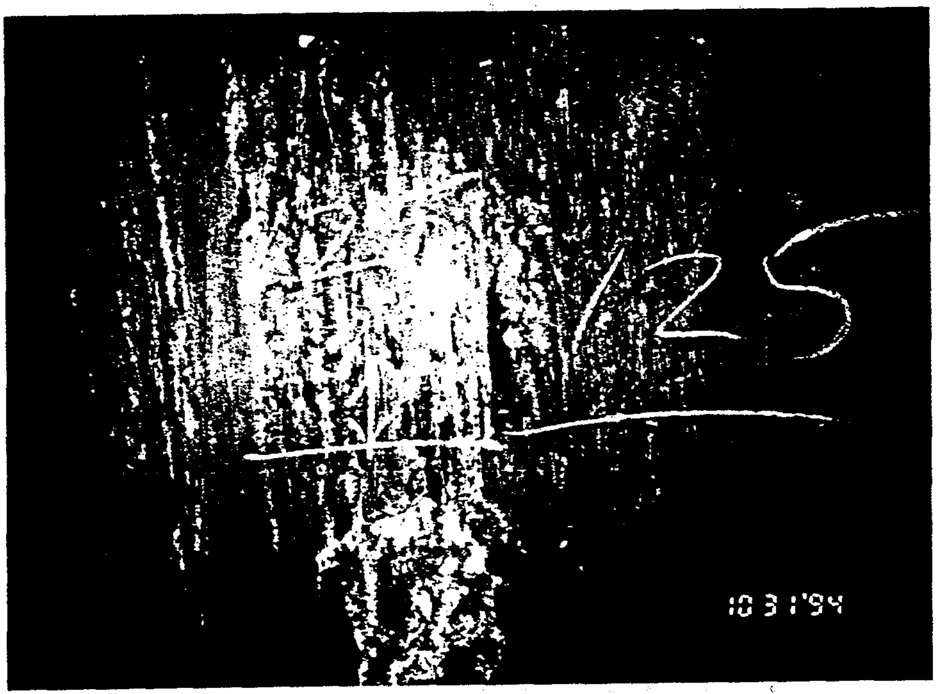

Photo #8 - 125' below
top, the welded seam i
intact and a light fly
ash coating was noted.

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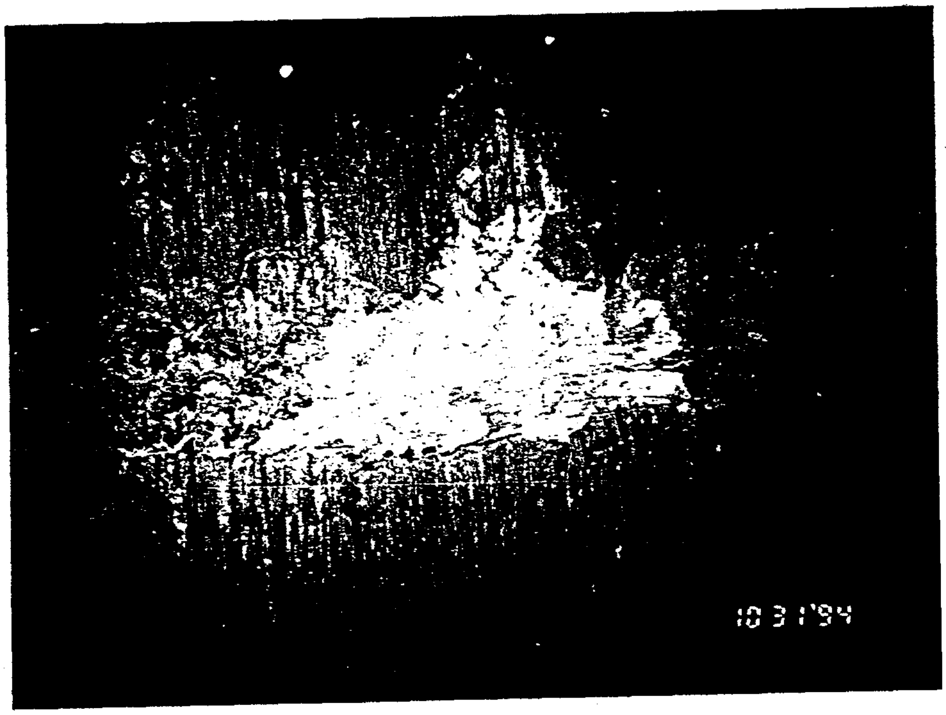

Photo #9 - 150' below top, the welded seam is intact and a light fly ash coating was noted.

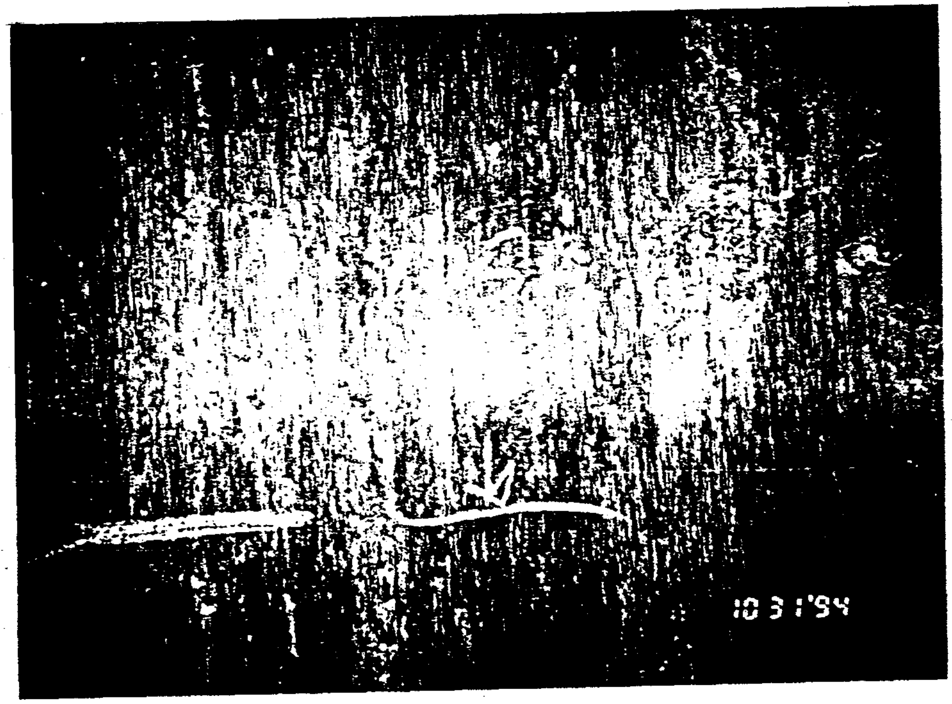

Photo #10 - 175' below top, the welded seam is intact and the fly ash is approximately 1/2" thick.

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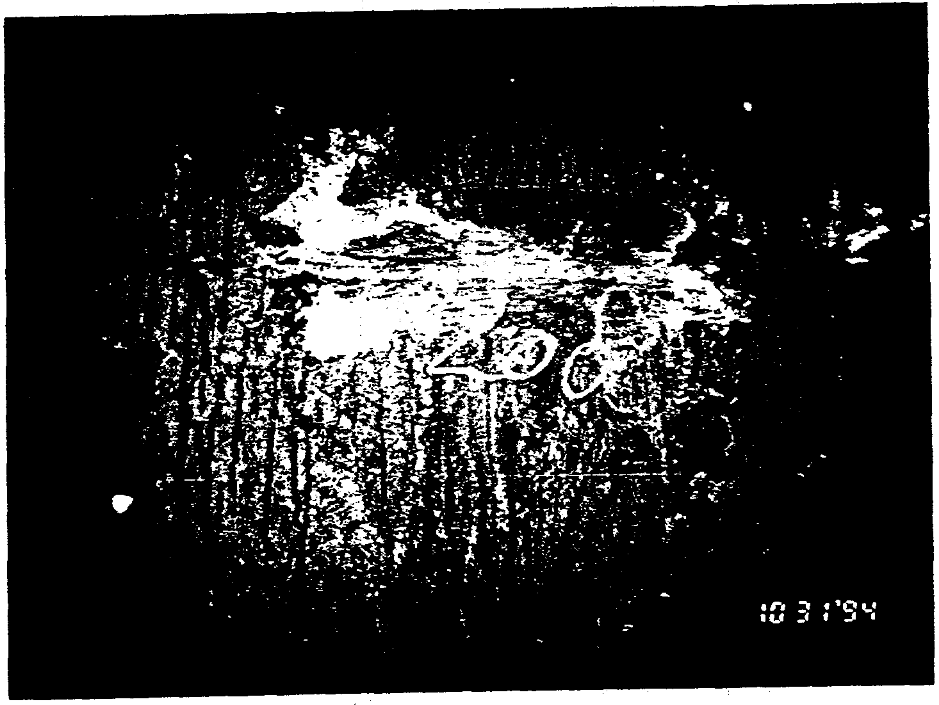

Photo #11 - 200' below top, the welded seam i intact and the fly ash is approximately 1/2" thick.

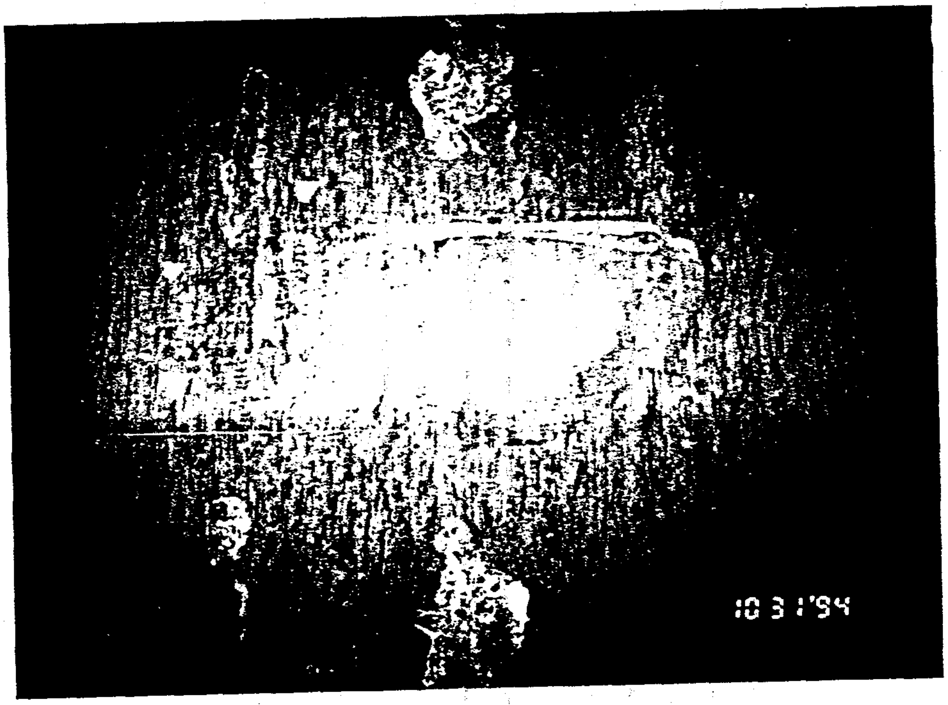

Photo #12 - 225' belo top, the fly ash is approximately 1/2" thick and minor scali was noted.

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Interior Photographs

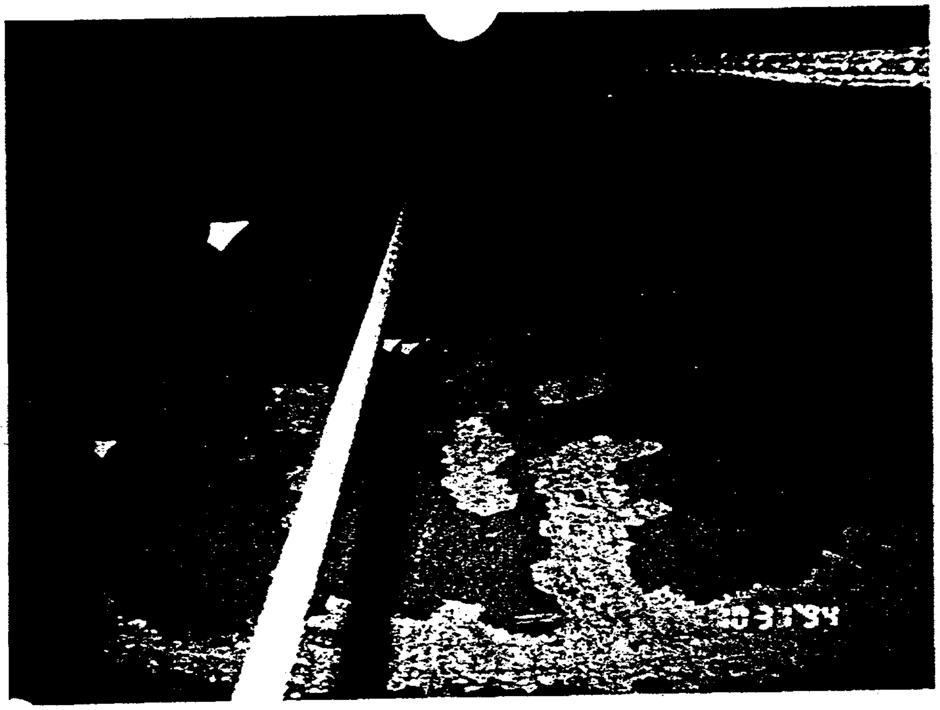

Photo #13 - View looking up from 225' below the top.

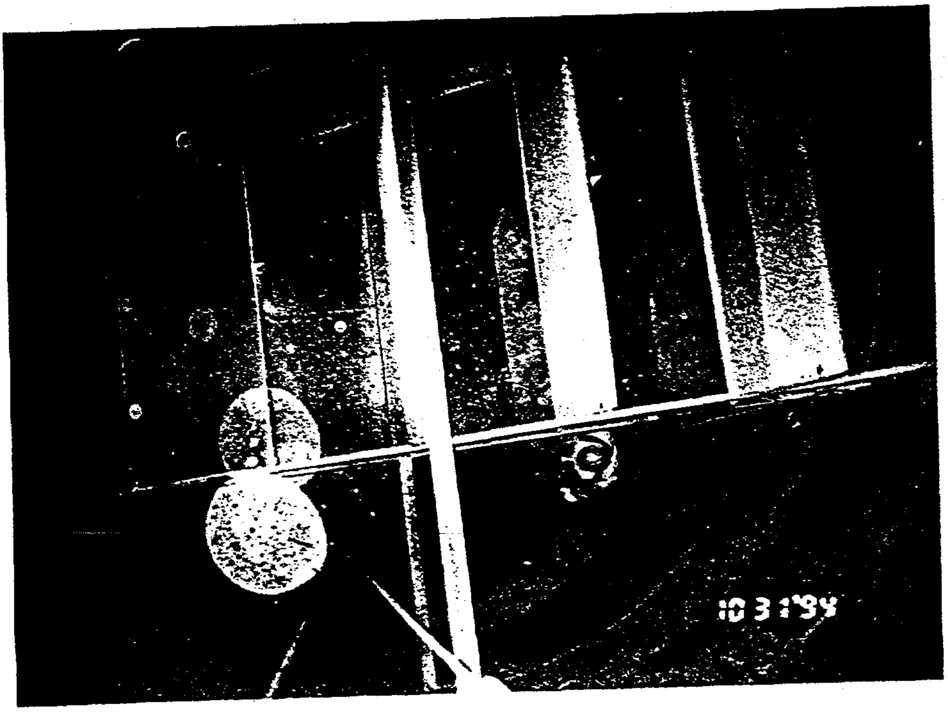

Photo #14 - View looking down into base of chimney lining. All turning vanes are intact.

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Interior Photographs

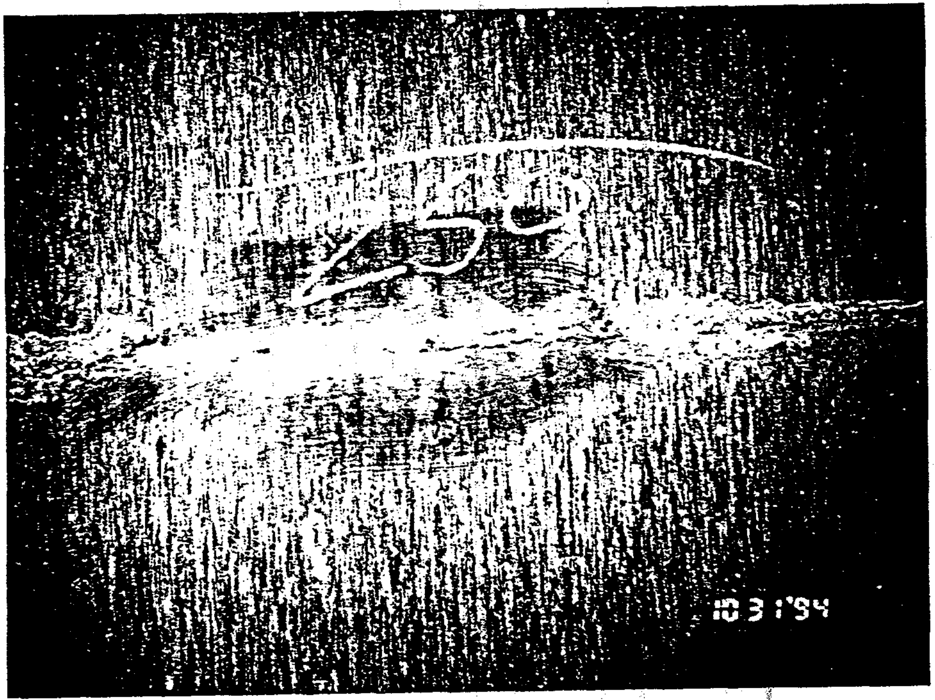

Photo #15 - 250' below the top, the welded seam is intact and a light fly ash coating was noted.

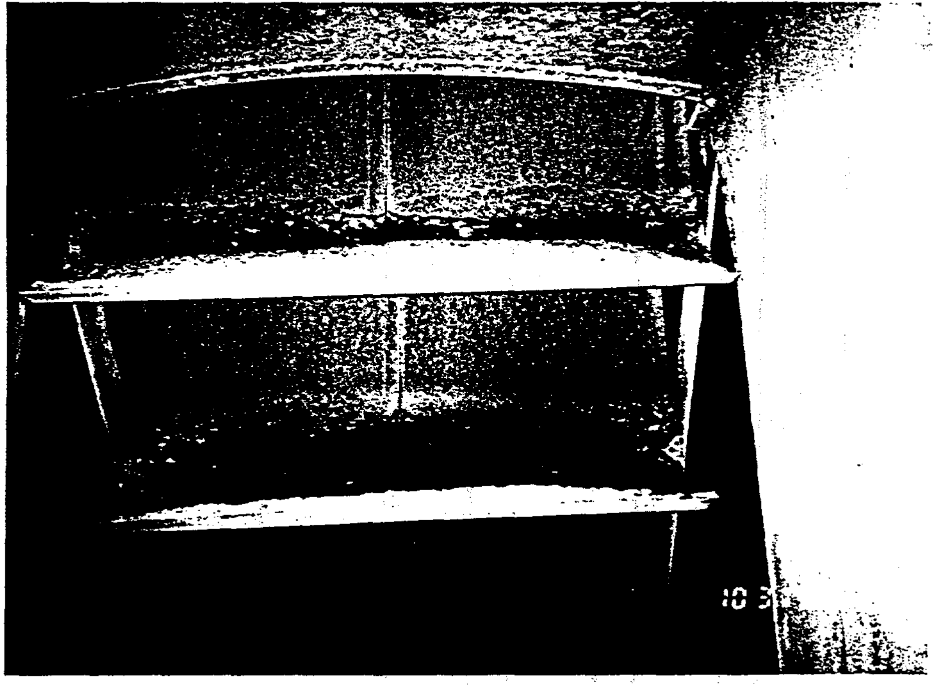

Photo #16 - View of turning vanes in base of lining.

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Interior Photographs

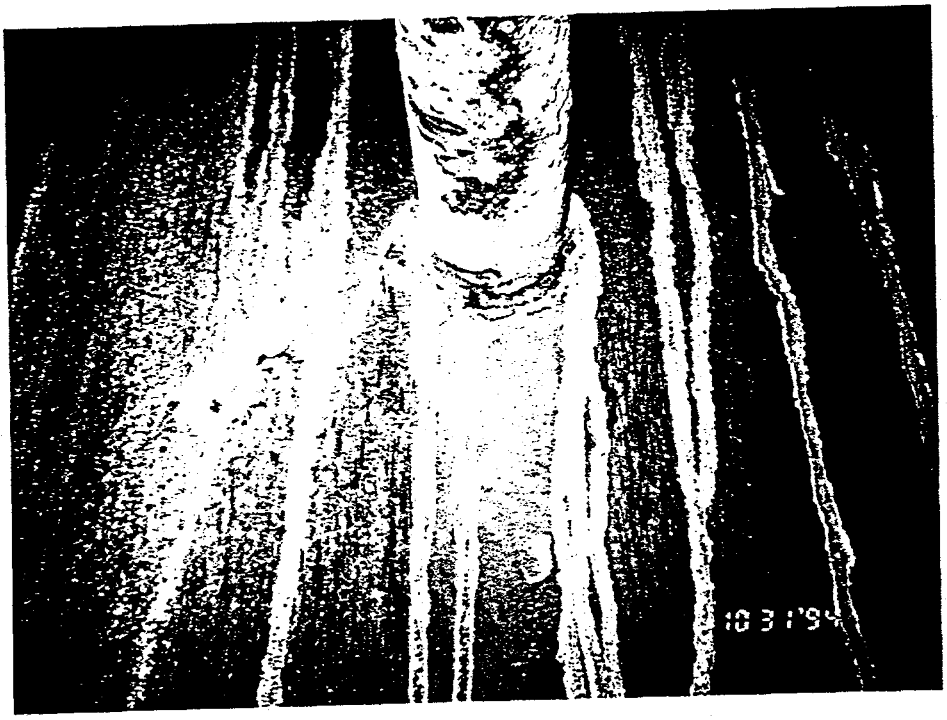

Photo #17 - Close view of welded connections of turning vanes. All welds are intact.

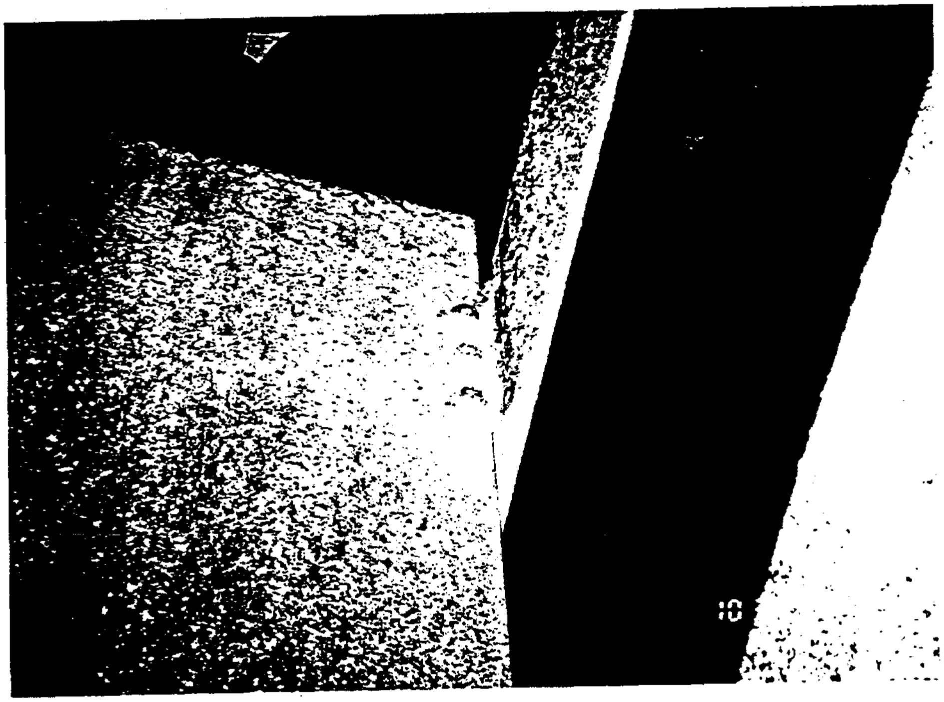

Photo #18 - Close view of bolted connections of turning vanes. All bolted connections are intact.

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Interior Photographs

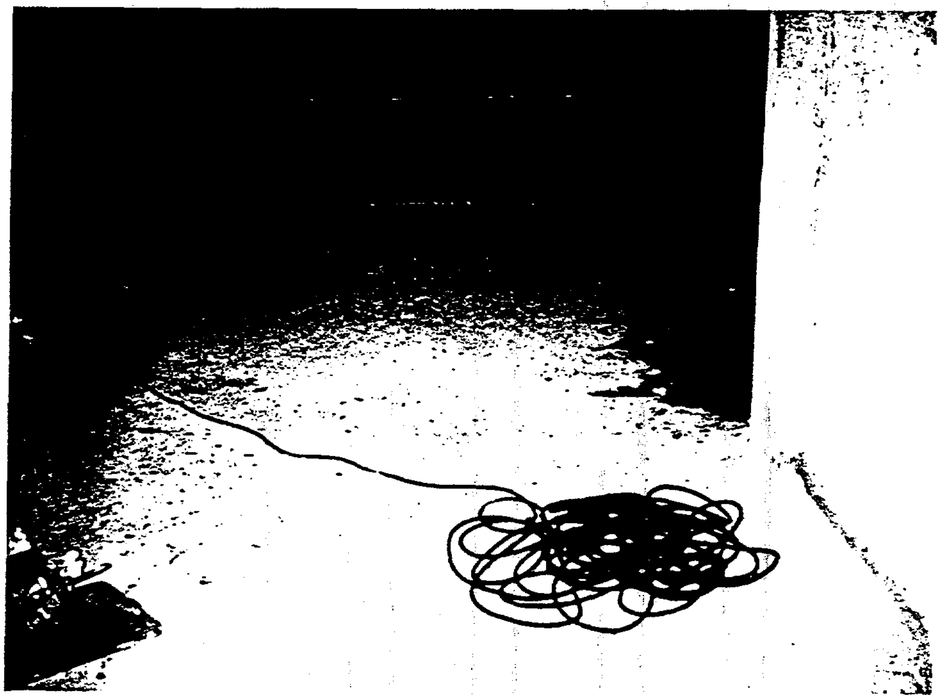

Photo #19 - Only mino fly ash buildup was noted at the base of the lining.

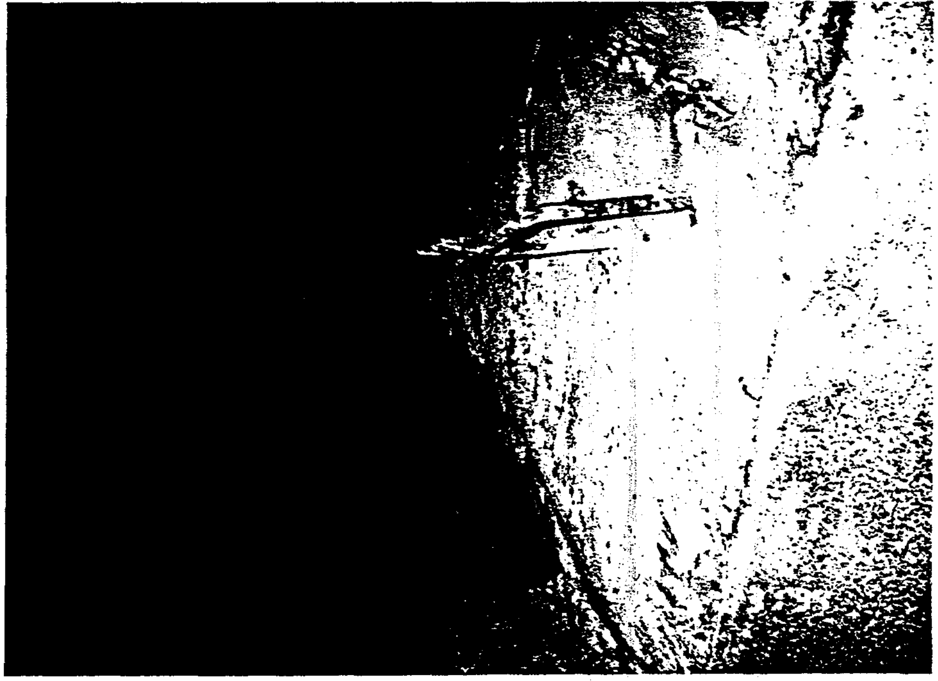

Photo #20 - The hand brackets in ductwork are intact.

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Section V. Ultrasonic Thickness Test Results

Ultrasonic thickness test readings of the liner were taken on 10′ intervals from the top down.

ELEVATION	READING
300′	0.212
290′	0.225
280′	0.214
270′	0.222
260′	0.222
250′	0.219
240′	0.224
230′	0.215
220′	0.225
210′	0.231
200′	0.230
190′	0.220
180′	0.225
170′	0.231
160′	0.232
150′	0.234
140′	0.245
130′	0.238
120′	0.234
110′	0.231
100′	0.235
90′	0.240
80′	0.240
70′	0.241
60′	0.245
50′	0.245

APPENDIX 2

EMISSIONS, OPERATING CONDITIONS, AND THERMAL PERFORMANCE DATA

TABLE A-1. GAS REBURNING EMISSIONS SUMMARY

Test I. D.	Test Date	Test Duration (hr:min)	Gross Power (MWe)	Gas Heat (%)	Coal SR	Reb SR	Burn-out SR	Exit SR	OFA (%)	CEMS O2 (%, dry)	Plant O2 (%, wet)	COc (ppm)	CO2c (%)	NOxc (ppm)	NOx (lb/MBtu)	NOx Reduc. (%)	SO2c (ppm)	SO2 (lb/MBtu)	HCc (ppm)
GR-5B	7/28/93	0:54	33	23.4	1.17	0.89	1.24	1.25	28	3.57	2.93	174	14.3	265	0.352	63.26	2426	4.509	1.6
GR-5C	7/28/93	0:25	33	23.4	1.14	0.87	1.23	1.24	29	3.50	2.82	229	14.3	264	0.350	63.51	2409	4.476	1.8
GR-5A	7/29/93	0:50	35	23.2	1.15	0.88	1.22	1.23	28	3.48	2.91	87	14.4	288	0.383	61.20	2512	4.669	0.9
GR-4A	7/29/93	0:13	35	21.8	1.14	0.90	1.23	1.23	27	3.59	3.08	54	14.4	302	0.401	59.34	2544	4.733	1.8
GR-3A	7/30/93	0:49	34	19.5	1.14	0.92	1.21	1.22	25	3.27	2.68	83	14.6	303	0.403	58.61	2624	4.874	4.6
GR-2A	7/30/93	0:50	34	16.1	1.15	0.96	1.23	1.24	22	3.26	2.69	27	14.7	351	0.469	52.30	2726	5.106	2.2
GR-5D	7/30/93	0:51	35	23.1	1.15	0.87	1.22	1.23	28	3.52	2.91	82	14.4	322	0.429	56.50	2535	4.713	0.9
GR-5E	7/30/93	0:54	34	22.8	1.15	0.87	1.22	1.23	28	3.46	2.75	141	14.4	321	0.426	56.70	2515	4.676	0.9
GR-5F	7/30/93	0:50	34	22.6	1.12	0.86	1.20	1.21	29	3.51	2.60	432	14.3	323	0.429	56.04	2506	4.661	15.7
GR-5G	7/30/93	0:55	35	22.8	1.08	0.85	1.17	1.17	28	3.46	2.78	92	14.3	289	0.384	61.11	2501	4.651	0.6
GR-15B	8/2/93	0:50	26	22.6	1.14	0.89	1.22	1.23	27	4.00	3.45	28	14.4	309	0.411	52.79	2525	4.703	0.6
GR-15A	8/2/93	0:50	26	22.6	1.12	0.87	1.20	1.21	27	3.66	3.21	34	14.5	285	0.379	56.54	2518	4.682	0.1
GR-15C	8/2/93	0:50	26	22.5	1.18	0.92	1.25	1.26	26	4.17	3.65	7	14.5	314	0.418	52.22	2497	4.646	0.0
GR-14A	8/2/93	0:50	26	25.0	1.15	0.87	1.20	1.21	27	3.65	3.21	41	14.4	277	0.368	58.05	2420	4.488	0.1
GR-13A	8/2/93	0:50	26	20.5	1.15	0.92	1.25	1.26	26	4.08	3.59	7	14.5	316	0.422	51.69	2517	4.691	0.0
GR-12A	8/2/93	0:50	26	19.6	1.11	0.92	1.24	1.23	26	4.17	3.63	6	14.6	334	0.445	48.88	2562	4.780	0.0
GR-11A	8/2/93	0:50	26	16.5	1.11	0.94	1.21	1.21	22	3.95	3.34	6	14.7	374	0.501	42.52	2644	4.951	0.0
GR-25A	8/11/93	0:53	19	23.9	1.14	0.89	1.25	1.25	29	3.84	3.01	134	14.1	204	0.271	65.35	2372	4.404	3.5
GR-25B	8/11/93	0:50	19	23.9	1.17	0.91	1.28	1.27	28	3.96	3.16	85	14.1	215	0.285	63.46	2343	4.350	1.1
GR-25C	8/11/93	0:50	20	24.0	1.19	0.93	1.26	1.26	26	3.65	2.93	104	14.1	217	0.289	63.17	2347	4.358	2.1
GR-24A	8/11/93	0:50	19	22.2	1.16	0.92	1.26	1.26	26	3.62	2.99	70	14.1	223	0.296	62.10	2401	4.467	0.9
GR-22A	8/11/93	0:29	19	17.0	1.17	1.00	1.27	1.27	22	3.69	3.13	21	14.3	269	0.358	53.96	2542	4.761	0.0
GR-15D	8/12/93	0:50	27	23.2	1.14	0.89	1.23	1.24	28	3.13	2.36	486	14.3	243	0.322	63.24	2458	4.571	18.7
GR-15E	8/12/93	0:50	27	23.1	1.14	0.89	1.24	1.24	28	3.08	2.36	451	14.3	225	0.299	65.94	2452	4.559	19.0
GR-15F	8/12/93	0:57	27	23.3	1.14	0.89	1.24	1.24	28	2.92	2.26	496	14.3	196	0.261	70.26	2454	4.558	27.1
GR-5A2	8/13/93	0:50	33	24.6	1.09	0.84	1.24	1.24	32	3.95	3.06	253	14.3	308	0.408	57.90	2417	4.486	7.5
GR-8A	8/13/93	0:50	34	24.8	1.15	0.88	1.25	1.25	30	3.98	3.11	154	14.3	325	0.431	55.73	2390	4.434	3.8
GR-5H	8/13/93	0:50	33	24.9	1.15	0.88	1.31	1.30	33	4.62	3.72	105	14.3	351	0.465	51.82	2366	4.390	1.8
GR-5I	8/13/93	0:52	32	24.9	1.15	0.88	1.34	1.33	34	5.02	4.09	44	14.2	368	0.488	48.71	2383	4.420	0.6
GR-15G	8/17/93	0:42	25	21.4	1.13	0.91	1.20	1.20	25	3.54	2.88	31	14.4	280	0.373	56.57	2398	4.466	1.9
GR-15G2	8/17/93	0:51	25	23.6	1.15	0.90	1.21	1.21	26	3.76	3.12	12	14.3	290	0.385	55.11	2316	4.305	0.8
GR-15H	8/17/93	0:50	25	23.5	1.15	0.90	1.30	1.29	30	4.79	3.89	12	14.2	326	0.433	49.40	2290	4.254	0.7
GR-15I	8/17/93	0:50	25	23.5	1.15	0.91	1.34	1.34	33	5.36	4.30	16	14.1	334	0.444	48.37	2283	4.241	0.7
GR-8B	8/18/93	0:53	33	24.8	1.14	0.88	1.24	1.24	29	3.84	3.12	49	14.3	311	0.412	57.08	2324	4.311	0.0
GR-5I	8/18/93	0:56	33	24.8	1.15	0.88	1.33	1.32	33	4.79	3.92	14	14.2	346	0.459	52.15	2317	4.299	0.0
GR-25D	8/19/93	0:46	19	22.2	1.14	0.90	1.27	1.27	29	4.96	4.00	12	14.2	310	0.412	46.92	2360	4.393	0.0
GR-25E	8/19/93	1:00	19	22.2	1.13	0.91	1.27	1.27	29	4.92	4.10	9	14.2	303	0.404	48.01	2347	4.368	0.0
GR-25E2	8/19/93	0:52	19	21.9	0.95	0.76	1.11	1.12	32	3.51	2.96	233	14.2	191	0.254	67.37	2368	4.408	0.0
GR-25F	8/19/93	0:58	19	22.0	0.96	0.77	1.13	1.12	32	3.55	2.98	276	14.2	171	0.227	70.81	2351	4.376	0.0
GR-25G	8/20/93	0:31	19	22.7	1.08	0.86	1.15	1.15	25	3.85	3.12	75	14.4	233	0.310	60.26	2394	4.452	0.0
GR-25G2	8/20/93	0:46	19	25.5	1.08	0.83	1.12	1.12	26	3.55	2.83	225	14.3	222	0.293	62.29	2304	4.272	0.0
GR-25H	8/20/93	0:53	19	25.6	1.08	0.83	1.25	1.24	33	5.05	4.15	19	14.2	275	0.365	53.25	2282	4.230	0.0
GR-25I	8/20/93	0:51	19	25.7	1.08	0.83	1.20	1.19	31	4.49	3.72	23	14.2	252	0.334	57.11	2273	4.213	0.0
GR-25F2	8/20/93	0:48	19	25.9	1.08	0.83	1.20	1.19	31	4.54	3.74	54	14.2	248	0.329	57.67	2261	4.190	0.0
GR-25E3	8/20/93	0:57	19	25.8	1.08	0.82	1.19	1.19	31	4.40	3.60	77	14.2	260	0.345	55.66	2256	4.182	0.0
GR-25D2	8/20/93	0:57	19	25.3	1.08	0.82	1.19	1.19	31	4.24	3.23	203	14.2	264	0.349	55.10	2274	4.206	0.0

Notes: Subscript c denotes correction to 3% O2

NOx reduction from correlated baseline: NOx = 0.522 + 0.0134*(load)

TABLE A-1. GAS REBURNING EMISSIONS SUMMARY (CONTINUED)

Test I. D.	Test Date	Test Duration (hr:min)	Gross Power (MWe)	Gas Heat (%)	Coal SR	Reb SR	Burn-out SR	Exit SR	OFA (%)	CEMS O2 (%, dry)	Plant O2 (%, wet)	COc (ppm)	CO2c (%)	NOxc (ppm)	NOx (lb/MBtu)	NOx Reduc. (%)	SO2c (ppm)	SO2 (lb/MBtu)	HCc (ppm)
GR-14A2	8/23/93	0:50	24	24.4	1.06	0.82	1.21	1.21	32	3.98	3.28	326	14.3	228	0.303	64.12	2394	4.443	0.0
GR-15A2	8/23/93	0:58	24	23.2	1.05	0.82	1.22	1.22	32	3.97	3.27	390	14.3	234	0.311	63.25	2412	4.483	0.0
GR-5E2	8/23/93	0:50	31	25.2	1.13	0.86	1.24	1.23	30	3.63	3.08	117	14.2	276	0.366	61.12	2271	4.211	0.0
GR-14A2	8/31/93	0:55	24	25.0	1.14	0.88	1.28	1.28	32	3.77	2.71	353	14.4	269	0.357	57.72	2496	4.628	19.6
GR-15F2	8/31/93	0:50	24	24.1	1.15	0.89	1.27	1.27	30	3.49	2.61	255	14.4	248	0.329	61.01	2518	4.675	8.5
GR-15E2	8/31/93	0:50	24	24.0	1.15	0.89	1.27	1.27	30	3.55	2.49	434	14.4	278	0.370	56.11	2514	4.668	30.8
GR-19A	8/31/93	0:50	24	24.1	1.15	0.89	1.32	1.32	32	4.10	3.13	186	14.4	282	0.375	55.52	2508	4.656	8.6
GR-25H2	9/1/93	0:50	19	25.7	1.15	0.89	1.37	1.36	35	4.89	3.91	91	14.1	213	0.282	63.81	2397	4.442	3.5
GR-1A	9/2/93	1:00	35	11.6	1.15	1.03	1.27	1.27	19	2.63	2.39	79	14.9	392	0.528	46.59	2767	5.210	0.0
GR-5G2	9/2/93	0:35	34	25.0	1.16	0.89	1.22	1.22	27	2.23	1.85	477	14.1	228	0.302	68.92	2438	4.538	0.0
GR-5C2	9/2/93	0:52	33	25.4	1.25	0.95	1.32	1.31	28	3.57	3.16	30	14.2	302	0.400	58.61	2390	4.432	0.0
GR-5D2	9/2/93	0:50	33	25.3	1.25	0.95	1.31	1.31	28	3.58	3.13	28	14.2	322	0.427	55.77	2387	4.426	0.0
GR-25A	9/3/93	0:50	20	23.6	1.20	0.95	1.33	1.32	29	4.23	3.97	33	14.3	250	0.332	57.71	2503	4.650	0.0
GR-25B2	9/3/93	0:50	19	25.5	1.28	0.98	1.35	1.34	27	3.90	3.75	62	14.3	249	0.329	57.34	2435	4.512	0.0
GR-25I2	9/7/93	0:55	19	25.8	1.15	0.88	1.35	1.34	34	4.64	3.75	204	14.3	201	0.266	65.96	2524	4.677	0.0
GR-25J	9/7/93	0:53	19	25.6	1.15	0.89	1.42	1.41	37	5.46	4.47	68	14.3	232	0.308	60.71	2498	4.631	0.0
GR-H2	9/7/93	0:46	20	25.6	1.15	0.88	1.29	1.29	32	3.88	3.05	495	14.3	174	0.231	70.58	2480	4.597	0.0
GR-27B	9/8/93	0:48	19	22.9	1.11	0.88	1.30	1.30	32	4.15	3.05	529	14.4	171	0.227	70.80	2556	4.753	0.0
GR-27C	9/8/93	0:50	19	23.0	1.10	0.88	1.35	1.35	35	4.73	3.64	515	14.3	185	0.246	68.26	2520	4.684	0.0
GR-27D	9/8/93	0:50	19	22.9	1.10	0.89	1.40	1.39	37	5.35	4.23	219	14.2	208	0.276	64.47	2529	4.700	0.0
GR-27E	9/8/93	0:50	19	23.0	1.11	0.89	1.47	1.45	39	6.02	4.82	67	14.2	238	0.316	59.38	2540	4.722	0.0
GR-28A	9/8/93	0:50	19	19.7	1.11	0.92	1.40	1.39	34	5.26	4.17	107	14.4	223	0.298	61.67	2644	4.932	0.0
GR-28B	9/8/93	0:50	19	18.0	1.11	0.94	1.38	1.37	32	4.97	3.97	168	14.5	227	0.304	61.05	2699	5.045	0.0
GR-18A	9/30/93	0:50	23	26.0	1.09	0.84	1.43	1.41	41	5.66	4.60	92	13.8	223	0.295	64.69	2390	4.429	0.0
GR	10/25/93	2:18	25	18.5	1.14	0.95	1.29	1.30	27	3.87	2.77	358	14.1	269	0.360	57.80	2560	4.783	0.0
GR 113B	10/26/93	2:05	24	24.6	1.15	0.89	1.31	1.31	32	4.53	3.49	198	14.2	235	0.312	63.32	2333	4.330	0.0
GR 113A	10/26/93	1:05	25	24.6	1.10	0.86	1.30	1.30	34	4.50	3.38	454	14.3	210	0.279	67.21	2310	4.287	0.0
GR113C	10/26/93	0:30	25	25.0	1.18	0.91	1.30	1.30	30	4.16	3.25	221	14.2	232	0.308	63.81	2293	4.254	0.0
GR 111A	10/26/93	0:50	25	26.0	1.14	0.86	1.25	1.25	31	3.76	2.70	520	14.2	200	0.265	68.87	2272	4.210	0.0
GR 111B	10/26/93	0:50	25	20.1	1.15	0.94	1.26	1.26	26	3.53	2.67	418	14.5	224	0.298	64.97	2407	4.489	0.0
GR 101B	10/27/93	0:50	34	24.7	1.15	0.89	1.29	1.29	32	4.28	3.32	136	14.4	333	0.441	54.57	2397	4.449	0.0
GR 101C	10/27/93	0:50	34	24.9	1.18	0.91	1.30	1.29	30	4.21	3.39	46	14.4	333	0.442	54.53	2372	4.400	0.0
GR 101D	10/27/93	0:50	34	24.9	1.20	0.92	1.30	1.30	29	4.28	3.37	27	14.4	334	0.443	54.35	2332	4.327	0.0
GR 101A	10/27/93	0:50	34	24.7	1.10	0.85	1.30	1.29	34	4.52	3.30	283	14.3	292	0.387	60.15	2322	4.309	0.0
GR 104A	10/27/93	0:30	34	24.9	1.18	0.91	1.30	1.30	30	4.36	3.34	29	14.3	325	0.431	55.65	2298	4.262	0.0
GR 104B	10/27/93	0:29	34	24.9	1.18	0.90	1.30	1.30	30	4.38	3.34	42	14.3	335	0.444	54.24	2294	4.256	0.0
GR 104C	10/27/93	0:30	34	24.9	1.18	0.90	1.29	1.30	30	4.39	3.35	51	14.2	349	0.462	52.39	2301	4.268	0.0
GR 102A	10/28/93	0:50	33	23.7	1.18	0.92	1.30	1.30	30	4.31	3.33	74	14.3	341	0.453	52.90	2415	4.487	0.0
GR 102B	10/28/93	0:50	33	20.1	1.17	0.96	1.29	1.29	26	4.01	3.14	45	14.4	355	0.473	50.88	2485	4.633	0.0
GR 102C	10/28/93	0:50	33	15.1	1.17	1.01	1.29	1.28	21	3.81	3.06	18	14.6	405	0.544	43.57	2628	4.928	0.0
GR 103A	10/28/93	0:50	33	25.6	1.17	0.89	1.25	1.25	28	3.71	2.73	323	14.1	289	0.384	60.12	2365	4.383	0.0
GR 103B	10/28/93	0:50	33	25.7	1.17	0.90	1.34	1.34	33	4.87	3.84	25	14.0	343	0.454	52.85	2368	4.388	0.0

Notes: Subscript c denotes correction to 3% O2

NOx reduction from correlated baseline: NOx = 0.522 + 0.0134*(load)

TABLE A-1. GAS REBURNING EMISSIONS SUMMARY (CONTINUED)

Test I. D.	Test Date	Test Duration (hr:min)	Gross Power (MWe)	Gas Heat (%)	Coal SR	Reb SR	Burn-out SR	Exit SR	OFA (%)	CEMS O2 (%, dry)	Plant O2 (%, wet)	COc (ppm)	CO2c (%)	NOxc (ppm)	NOx (lb/MBtu)	NOx Reduc. (%)	SO2c (ppm)	SO2 (lb/MBtu)	HCc (ppm)
GR 112A2	10/29/93	0:30	24	21.4	1.18	0.95	1.29	1.29	26	3.81	2.99	383	14.5	234	0.311	63.05	2471	4.601	0.0
GR 112A	10/29/93	0:25	24	24.1	1.18	0.92	1.30	1.30	29	4.09	3.15	297	14.3	232	0.308	63.41	2399	4.454	0.0
GR 112B	10/29/93	0:30	24	20.4	1.18	0.96	1.30	1.30	26	3.89	3.05	175	14.5	250	0.334	60.34	2489	4.640	0.0
GR 112C	10/29/93	0:30	24	14.9	1.18	1.03	1.30	1.30	21	3.80	3.05	58	14.8	310	0.415	50.68	2637	4.946	0.0
GR-106A	11/10/93	0:15	32	25.0	1.09	0.83	1.20	1.20	31	3.15	1.92	502	14.3	227	0.302	68.12	2386	4.425	0.0
GR-106B	11/10/93	0:30	32	25.0	1.09	0.83	1.25	1.25	33	3.78	2.53	520	14.3	242	0.320	66.32	2371	4.399	0.0
GR-107C	11/10/93	0:30	32	25.1	1.09	0.83	1.24	1.25	34	3.79	2.48	521	14.3	284	0.376	60.39	2351	4.359	0.0
GR--107B	11/10/93	0:30	32	25.1	1.09	0.83	1.24	1.25	33	3.71	2.55	518	14.2	255	0.338	64.38	2345	4.350	0.0
GR-106C	11/10/93	0:30	32	25.3	1.09	0.83	1.29	1.29	35	4.32	3.08	537	14.3	249	0.330	65.19	2340	4.339	0.0
GR-108A	11/10/93	0:10	32	23.6	1.15	0.90	1.30	1.29	31	4.17	3.16	170	14.4	278	0.370	60.95	2380	4.420	0.0
GR-106B	11/10/93	0:30	32	25.0	1.09	0.83	1.25	1.25	33	3.78	2.53	520	14.3	242	0.320	66.32	2371	4.399	0.0
GR-107C	11/10/93	0:30	32	25.1	1.09	0.83	1.24	1.25	34	3.79	2.48	521	14.3	284	0.376	60.39	2351	4.359	0.0
GR--107B	11/10/93	0:30	32	25.1	1.09	0.83	1.24	1.25	33	3.71	2.55	518	14.2	255	0.338	64.38	2345	4.350	0.0
GR-106C	11/10/93	0:30	32	25.3	1.09	0.83	1.29	1.29	35	4.32	3.08	537	14.3	249	0.330	65.19	2340	4.339	0.0
GR	11/15/93	0:41	26	23.0	1.15	0.91	1.30	1.33	30	5.10	3.45	195	14.3	222	0.295	65.83	2414	4.489	0.0
GR	11/16/93	0:16	23	22.0	1.15	0.92	1.30	1.32	29	4.35	3.26	250	14.3	230	0.306	63.27	2337	4.366	0.0
GR 114 A	11/17/93	0:20	23	23.0	1.15	0.91	1.29	1.35	30	4.94	3.86	50	14.4	226	0.301	63.79	2350	4.368	0.0
GR 114 B	11/17/93	0:00	23	23.2	1.14	0.90	1.29	1.35	30	4.92	3.79	50	14.4	225	0.299	64.05	2370	4.404	0.0
GR 114 C	11/17/93	0:20	23	23.1	1.14	0.90	1.28	1.34	30	4.90	3.70	46	14.3	246	0.327	60.68	2377	4.418	0.0
GR	11/23/93	5:22	23	22.2	1.14	0.91	1.30	1.29	30	4.13	3.36	223	14.3	228	0.304	63.44	2432	4.526	0.0
GR	2/16/94	1:38	26	21.4	1.15	0.93	1.29	1.30	28	4.51	3.45	228	14.3	307	0.412	52.96	2440	4.548	0.0
GR	2/17/94	4:51	26	22.2	1.14	0.91	1.26	1.30	28	5.14	3.84	83	14.1	285	0.380	56.61	2360	4.389	0.0
GR	2/18/94	2:04	28	21.2	1.14	0.92	1.24	1.29	26	4.51	3.55	108	14.3	281	0.377	57.78	2418	4.508	0.0
GR	3/28/94	0:37	30	22.2	1.16	0.92	1.26	1.29	27	4.13	3.22	134	14.5	273	0.364	60.39	2462	4.582	0.0
GR	4/6/94	1:00	31	20.1	1.16	0.95	1.25	1.29	24	4.14	3.29	116	14.4	284	0.385	59.01	2513	4.698	0.0
GR-25-25	4/8/94	1:47	25	23.8	1.15	0.90	1.28	1.35	30	5.06	3.55	163	14.2	188	0.249	70.98	1882	3.478	0.0
GR-25-25	4/8/94	2:09	25	23.1	1.16	0.92	1.30	1.34	29	4.45	3.44	300	13.9	209	0.278	67.56	2405	4.469	0.0
GR-25-30	4/8/94	2:46	29	14.3	1.18	1.03	1.32	1.37	23	4.95	3.87	190	14.7	384	0.518	42.99	2690	5.063	0.0
GR-23-25	4/9/94	0:47	20	22.1	1.20	0.97	1.44	1.49	33	6.41	5.05	38	14.1	247	0.328	58.81	2422	4.510	0.0
GR-23-23	4/9/94	5:12	24	23.1	1.17	0.93	1.34	1.40	30	5.26	4.11	57	14.2	225	0.299	64.41	2394	4.451	0.0
GR-23-29	4/9/94	7:29	29	23.4	1.15	0.90	1.31	1.36	31	4.76	3.80	142	14.1	225	0.299	67.02	2342	4.350	0.0
GR-23-30	4/11/94	11:50	30	23.0	1.15	0.91	1.28	1.33	29	4.29	3.51	100	14.2	231	0.308	66.79	2332	4.335	0.0
GR-23-26	4/11/94	0:31	26	23.7	1.15	0.91	1.31	1.37	31	5.21	4.12	23	14.1	219	0.292	66.63	2372	4.407	0.0
GR-23-25	4/12/94	7:45	26	23.6	1.15	0.90	1.31	1.36	31	4.93	4.02	57	14.0	217	0.288	67.08	2332	4.332	0.0
GR-23-30	4/12/94	6:14	30	21.4	1.15	0.93	1.27	1.32	27	4.43	3.54	116	14.2	287	0.383	58.76	2435	4.535	0.0
GR	4/14/94	118:26	27	22.6	1.15	0.92	1.26	1.32	27	4.34	3.45	79	14.0	239	0.318	63.80	2180	4.054	0.0
GR-23-24	4/20/94	0:35	25	23.4	1.15	0.91	1.27	1.33	28	4.52	3.59	28	14.1	233	0.309	63.73	2390	4.443	0.0
GR-23-30	4/21/94	5:51	30	23.6	1.15	0.90	1.28	1.33	29	4.41	3.64	136	14.1	266	0.353	61.98	2238	4.158	0.0
GR	5/17/94	8:33	25	22.5	1.14	0.91	1.25	1.29	27	4.09	3.07	258	14.3	220	0.292	65.83	1885	3.465	0.0
GR	5/18/94	10:03	25	22.7	1.15	0.92	1.28	1.31	29	4.60	3.63	112	14.3	230	0.307	64.41	2464	4.582	0.0

Notes: Subscript c denotes correction to 3% O_2

NOx reduction from correlated baseline: NOx = 0.522 + 0.0134*(load)

TABLE A-2. GAS REBURNING OPERATING CONDITIONS

Test I. D.	Test Date	Gross Power (MWe)	Gas Heat (%)	Coal Flow (lb/hr)	Reb Gas (scfm)	FGR (scfm)	Cyclone Air (lb/hr)	OFA Flow (scfm)	Opac (%)	Steam Load (lb/hr)	SSH Steam (F)	SSH Steam (psig)	PSH Steam (F)	Blr Drum (psig)	BlrBnk G I (F)	BlrBnk G O (F)	AirHtr G O (F)
GR-5B	7/28/93	33	23.4	28,556	1,616	5,976	264,388	23,055	2	300,721	897	881	837	942	893	667	339
GR-5C	7/28/93	33	23.4	28,765	1,619	5,981	258,776	23,784	2	300,936	895	881	837	942	903	674	341
GR-5A	7/29/93	35	23.2	29,467	1,615	5,966	266,670	22,922	3	305,477	898	876	837	940	909	674	340
GR-4A	7/29/93	35	21.8	30,006	1,493	5,894	270,476	22,053	3	305,810	895	876	842	940	918	678	343
GR-3A	7/30/93	34	19.5	30,034	1,335	5,977	270,992	19,958	3	298,822	896	874	831	934	892	665	338
GR-2A	7/30/93	34	16.1	31,895	1,125	5,953	288,118	17,825	3	306,850	894	876	828	940	903	676	339
GR-5D	7/30/93	35	23.1	29,680	1,623	5,086	267,869	23,472	3	307,869	893	876	829	939	923	682	343
GR-5E	7/30/93	34	22.8	30,005	1,624	4,037	270,806	23,492	3	307,736	895	876	825	939	916	681	346
GR-5F	7/30/93	34	22.6	29,696	1,623	3,096	267,856	23,570	3	307,935	894	876	821	939	894	667	340
GR-5G	7/30/93	35	22.8	29,950	1,624	5,902	270,247	23,550	4	311,521	895	876	828	941	911	675	340
GR-15B	8/2/93	26	22.6	24,588	1,241	4,972	221,399	17,954	3	241,513	898	876	819	912	883	659	327
GR-15A	8/2/93	26	22.6	24,630	1,244	4,930	217,098	17,975	3	242,928	895	876	816	912	891	662	329
GR-15C	8/2/93	26	22.5	24,482	1,248	4,885	227,490	17,979	3	242,814	893	876	817	912	906	668	332
GR-14A	8/2/93	26	25.0	23,992	1,385	4,967	218,330	17,975	3	244,307	896	876	819	912	912	670	333
GR-13A	8/2/93	26	20.5	24,875	1,139	4,978	226,562	17,977	3	243,435	893	877	815	912	913	673	333
GR-12A	8/2/93	26	19.6	24,930	1,086	4,998	227,180	17,985	3	242,134	895	876	817	911	919	677	335
GR-11A	8/2/93	26	16.5	25,749	919	4,977	235,043	15,164	3	241,438	896	876	812	910	927	678	336
GR-25A	8/11/93	19	23.9	18,669	1,010	4,946	167,957	15,572	4	179,852	895	881	784	894	823	620	311
GR-25B	8/11/93	19	23.9	18,610	1,010	4,935	171,507	15,563	4	180,033	894	881	786	895	833	622	313
GR-25C	8/11/93	20	24.0	18,543	1,011	4,933	174,203	14,160	4	180,863	896	881	787	895	840	622	314
GR-24A	8/11/93	19	22.2	18,860	932	4,922	172,575	14,120	4	180,294	895	881	786	895	838	622	314
GR-22A	8/11/93	19	17.0	19,636	700	4,864	182,606	11,962	4	177,000	896	879	786	893	842	622	315
GR-15D	8/12/93	27	23.2	24,740	1,287	3,045	222,974	19,397	4	241,487	897	881	788	912	920	664	334
GR-15E	8/12/93	27	23.1	24,838	1,287	3,975	223,657	19,413	4	242,216	895	881	792	913	931	668	336
GR-15F	8/12/93	27	23.3	24,566	1,289	5,996	221,259	19,440	4	242,256	896	881	796	914	922	672	337
GR-5A2	8/13/93	33	24.6	28,771	1,618	5,978	246,585	26,780	4	294,765	894	881	828	937	910	671	339
GR-8A	8/13/93	34	24.8	28,569	1,630	5,948	258,248	24,881	4	295,814	896	881	836	939	919	678	342
GR-5H	8/13/93	33	24.9	28,499	1,635	5,869	257,340	28,391	4	295,450	892	881	834	938	927	681	344
GR-5I	8/13/93	32	24.9	28,582	1,636	5,871	257,947	30,168	5	295,619	893	881	836	937	937	687	347
GR-15G	8/17/93	25	21.4	24,419	1,150	5,066	217,422	16,152	0	233,504	898	881	824	914	868	642	329
GR-15G2	8/17/93	25	23.6	23,964	1,275	5,036	216,811	17,397	0	233,426	895	881	821	913	876	645	331
GR-15H	8/17/93	25	23.5	24,088	1,278	4,968	218,830	21,734	0	233,833	892	881	821	913	880	649	332
GR-15I	8/17/93	25	23.5	24,213	1,279	5,016	219,827	24,257	0	234,261	893	881	822	913	893	653	333
GR-8B	8/18/93	33	24.8	29,316	1,668	5,992	263,491	24,991	3	299,698	897	892	844	952	902	673	345
GR-5I	8/18/93	33	24.8	29,386	1,669	5,990	265,243	30,181	3	301,041	891	891	844	952	924	682	348
GR-25D	8/19/93	19	22.2	19,189	943	3,104	171,652	15,736	5	178,273	896	892	803	906	815	616	314
GR-25E	8/19/93	19	22.2	19,174	943	4,018	171,473	15,726	3	178,937	894	892	804	906	818	619	315
GR-25E2	8/19/93	19	21.9	19,848	956	4,073	148,830	15,703	3	179,425	899	891	789	905	820	615	317
GR-25F	8/19/93	19	22.0	19,651	958	5,959	148,172	15,717	3	179,305	895	892	792	905	816	618	318
GR-25G	8/20/93	19	22.7	19,482	986	5,113	166,057	12,896	4	181,339	895	891	801	907	817	615	314
GR-25G2	8/20/93	19	25.5	18,821	1,109	5,130	160,305	12,924	4	179,989	896	891	805	906	818	616	315
GR-25H	8/20/93	19	25.6	18,870	1,121	5,109	160,673	18,484	4	181,978	890	892	804	906	830	621	316
GR-25I	8/20/93	19	25.7	18,759	1,116	5,109	159,763	16,264	4	180,455	895	892	806	906	829	621	316
GR-25F2	8/20/93	19	25.9	18,513	1,116	5,974	157,578	16,271	4	178,707	895	892	808	906	828	621	317
GR-25E3	8/20/93	19	25.8	18,655	1,116	4,065	158,914	16,257	4	179,454	894	892	802	906	831	619	317
GR-25D2	8/20/93	19	25.3	19,196	1,116	3,023	163,546	16,255	4	178,948	895	892	803	906	807	613	321

TABLE A-2. GAS REBURNING OPERATING CONDITIONS (CONTINUED)

Test I. D.	Test Date	Gross Power (MWe)	Gas Heat (%)	Coal Flow (lb/hr)	Reb Gas (scfm)	FGR (scfm)	Cyclone Air (lb/hr)	OFA Flow (scfm)	Opac (%)	Steam Load (lb/hr)	SSH Steam (F)	SSH Steam (psig)	PSH Steam (F)	Blr Drum (psig)	BlrBnk G I (F)	BlrBnk G O (F)	AirHtr G O (F)
GR-14A2	8/23/93	24	24.4	22,457	1,251	5,007	187,748	20,137	3	225,288	893	881	798	909	865	646	321
GR-15A2	8/23/93	24	23.2	22,949	1,195	4,987	189,319	20,652	5	226,924	892	881	796	909	877	651	324
GR-5E2	8/23/93	31	25.2	27,897	1,624	5,961	247,582	24,499	3	292,340	895	881	826	936	968	704	352
GR-14A2	8/31/93	24	25.0	21,438	1,232	5,093	193,208	20,194	5	224,548	895	881	793	907	881	652	323
GR-15F2	8/31/93	24	24.1	21,506	1,176	5,985	194,356	18,974	5	223,314	897	881	795	907	885	656	324
GR-15E2	8/31/93	24	24.0	21,615	1,176	4,034	195,212	18,966	5	223,294	895	881	791	906	895	656	324
GR-19A	8/31/93	24	24.1	21,497	1,177	5,998	194,059	21,234	5	223,020	894	881	795	906	904	662	327
GR-25H2	9/1/93	19	25.7	17,511	1,047	5,994	158,683	20,090	4	182,160	890	881	774	893	823	623	304
GR-1A	9/2/93	35	11.6	33,428	756	5,968	302,290	15,855	4	314,036	896	881	824	945	940	695	342
GR-5G2	9/2/93	34	25.0	28,342	1,596	5,974	261,032	22,499	4	301,426	900	879	820	938	934	692	347
GR-5C2	9/2/93	33	25.4	27,712	1,624	5,998	272,739	23,711	6	300,258	894	881	837	941	912	680	334
GR-5D2	9/2/93	33	25.3	27,833	1,629	5,020	273,941	23,699	4	299,993	896	881	835	940	923	683	335
GR-25A	9/3/93	20	23.6	18,819	1,000	5,086	178,010	16,496	5	185,007	898	881	798	896	800	612	300
GR-25B2	9/3/93	19	25.5	16,987	1,001	5,132	171,206	14,510	7	176,190	895	881	797	893	786	610	300
GR-25I2	9/7/93	19	25.8	17,668	1,058	5,909	160,039	19,378	4	181,161	894	881	775	893	824	620	300
GR-25J	9/7/93	19	25.6	17,876	1,059	5,876	161,806	22,328	4	182,608	894	881	777	893	831	622	300
GR-H2	9/7/93	20	25.6	17,813	1,060	5,937	161,521	17,127	4	182,348	901	881	781	894	827	620	300
GR-27B	9/8/93	19	22.9	17,898	914	5,941	156,261	17,029	5	177,252	894	881	775	892	797	608	300
GR-27C	9/8/93	19	23.0	17,783	916	5,898	154,833	19,040	5	176,889	894	881	774	891	801	608	300
GR-27D	9/8/93	19	22.9	17,920	917	5,950	156,072	20,798	5	177,507	894	881	775	892	804	611	300
GR-27E	9/8/93	19	23.0	17,768	918	5,989	155,062	23,285	5	177,042	894	881	775	891	806	613	300
GR-28A	9/8/93	19	19.7	18,484	783	5,993	161,291	19,374	6	176,843	899	881	774	891	805	612	300
GR-28B	9/8/93	19	18.0	18,905	716	5,993	164,866	17,954	5	177,719	897	881	772	891	800	611	300
GR-18A	9/30/93	23	26.0	20,639	1,249	5,936	177,784	28,454	6	212,078	892	881	785	901	857	639	311
GR	10/25/93	25	18.5	23,357	916	5,439	210,495	17,278	5	225,010	886	883	776	907	881	653	316
GR 113B	10/26/93	24	24.6	21,776	1,223	5,930	196,651	21,400	6	223,017	886	883	802	910	851	640	313
GR 113A	10/26/93	25	24.6	21,779	1,228	5,904	189,240	22,749	6	223,303	885	883	796	909	868	646	316
GR113C	10/26/93	25	25.0	21,370	1,229	5,930	198,640	19,676	6	223,204	890	883	803	909	878	651	318
GR 111A	10/26/93	25	26.0	21,476	1,299	5,979	192,523	19,682	6	223,879	886	883	801	910	884	654	319
GR 111B	10/26/93	25	20.1	22,662	980	5,936	204,722	16,182	6	223,758	886	883	799	910	886	656	320
GR 101B	10/27/93	34	24.7	28,829	1,631	5,980	261,016	27,347	7	304,190	885	883	826	942	938	690	338
GR 101C	10/27/93	34	24.9	28,714	1,641	5,993	267,454	26,006	7	303,856	885	883	831	943	947	697	341
GR 101D	10/27/93	34	24.9	28,670	1,641	5,976	271,480	25,164	7	303,810	886	884	831	943	960	704	344
GR 101A	10/27/93	34	24.7	28,933	1,636	5,990	251,137	29,998	7	304,051	884	883	819	940	969	702	345
GR 104A	10/27/93	34	24.9	28,649	1,641	4,973	266,876	26,368	7	303,978	887	884	822	941	970	702	344
GR 104B	10/27/93	34	24.9	28,652	1,642	3,998	266,778	26,345	7	303,989	885	884	822	940	973	703	345
GR 104C	10/27/93	34	24.9	28,699	1,642	2,988	267,328	26,320	7	303,828	885	883	819	940	967	702	344
GR 102A	10/28/93	33	23.7	29,008	1,551	6,000	268,729	25,590	7	297,422	889	884	842	944	889	668	336
GR 102B	10/28/93	33	20.1	29,908	1,293	5,977	276,516	22,110	7	297,820	886	883	842	944	901	670	330
GR 102C	10/28/93	33	15.1	31,673	974	5,989	293,310	17,716	7	298,520	885	883	839	942	904	675	332
GR 103A	10/28/93	33	25.6	28,266	1,676	5,961	261,592	23,614	7	297,971	886	883	840	943	923	681	335
GR 103B	10/28/93	33	25.7	28,288	1,686	5,961	261,797	29,799	7	298,709	880	883	837	942	937	690	339

TABLE A-2. GAS REBURNING OPERATING CONDITIONS (CONTINUED)

Test I. D.	Test Date	Gross Power (MWe)	Gas Heat (%)	Coal Flow (lb/hr)	Reb Gas (scfm)	FGR (scfm)	Cyclone Air (lb/hr)	OFA Flow (scfm)	Opac (%)	Steam Load (lb/hr)	SSH Steam (F)	SSH Steam (psig)	PSH Steam (F)	Blr Drum (psig)	BlrBnk G I (F)	BlrBnk G O (F)	AirHtr G O (F)
GR 112A2	10/29/93	24	21.4	21,817	1,024	6,000	202,661	16,626	7	216,817	888	884	796	907	933	683	326
GR 112A	10/29/93	24	24.1	21,206	1,160	6,000	196,936	18,697	7	216,731	885	884	795	907	939	685	328
GR 112B	10/29/93	24	20.4	21,904	967	6,000	203,333	16,574	7	216,516	887	884	795	907	938	685	328
GR 112C	10/29/93	24	14.9	23,365	704	5,935	216,978	13,342	7	216,801	886	884	793	907	937	686	328
GR-106A	11/10/93	32	25.0	28,979	1,667	5,999	248,531	25,088	7	171,613	885	871	786	881	793	624	334
GR-106B	11/10/93	32	25.0	28,949	1,668	5,964	247,973	28,122	7	210,074	898	880	822	904	858	671	347
GR-107C	11/10/93	32	25.1	28,799	1,669	3,106	246,710	28,155	6	298,208	886	881	817	937	918	738	391
GR--107B	11/10/93	32	25.1	28,883	1,670	3,998	247,392	28,123	7	171,161	885	871	789	882	794	628	340
GR-106C	11/10/93	32	25.3	28,782	1,678	5,970	247,290	30,729	7	282,563	897	881	836	933	930	725	381
GR-108A	11/10/93	32	23.6	29,279	1,562	5,919	264,485	26,844	7	210,776	885	871	805	894	855	674	365
GR-106B	11/10/93	32	25.0	28,949	1,668	5,964	247,973	28,122	7	209,207	885	871	799	893	841	654	353
GR-107C	11/10/93	32	25.1	28,799	1,669	3,106	246,710	28,155	5	296,138	886	881	816	938	915	731	390
GR--107B	11/10/93	32	25.1	28,883	1,670	3,998	247,392	28,123	4	295,850	885	881	816	938	919	735	395
GR-106C	11/10/93	32	25.3	28,782	1,678	5,970	247,290	30,729	7	209,940	886	871	807	894	853	667	364
GR	11/15/93	26	23.0	22,150	1,141	5,864	200,722	19,596	6	179,492	868	891	741	900	841	667	356
GR	11/16/93	23	22.0	22,749	1,107	5,989	205,529	19,446	0			898	695	903			
GR 114 A	11/17/93	23	23.0	22,212	1,144	5,004	200,801	19,401	5	302,556	893	889	808	945	909	709	369
GR 114 B	11/17/93	23	23.2	22,080	1,148	4,050	199,220	19,423	7	205,913	896	881	817	903	840	657	344
GR 114 C	11/17/93	23	23.1	22,186	1,148	2,936	200,032	19,412	5	300,675	891	891	814	946	919	750	395
GR	11/23/93	23	22.2	22,621	1,113	5,915	203,367	19,536	7	206,601	896	881	814	903	858	677	360
GR	2/16/94	26	21.4	27,369	1,291	5,963	247,913	22,281	7	207,190	887	871	800	893	860	672	361
GR	2/17/94	26	22.2	25,707	1,270	5,948	231,845	20,229	6	178,030	899	881	780	892	808	651	350
GR	2/18/94	28	21.2	26,969	1,248	5,967	242,787	19,020	6	295,749	901	881	801	932	940	766	414
GR	3/28/94	30	22.2	28,662	1,409	5,618	262,048	21,567	4	268,092	894	881	847	929	886	656	327
GR	4/6/94	31	20.1	28,237	1,243	6,000	258,115	18,989	4	260,989	895	882	839	925	868	651	321
GR-25-25	4/8/94	25	23.8	21,416	1,151	5,975	194,308	18,721	4	204,949	891	881	816	903	832	647	339
GR-25-25	4/8/94	25	23.1	21,685	1,123	5,894	198,948	18,786	3	205,653	890	881	816	903	828	626	314
GR-25-30	4/8/94	29	14.3	27,514	837	5,859	253,780	18,490	3	240,654	898	882	827	916	880	655	327
GR-23-25	4/9/94	20	22.1	18,467	901	5,993	173,542	19,481	3	169,545	903	880	797	891	822	626	312
GR-23-23	4/9/94	24	23.1	20,538	1,063	5,989	189,944	18,816	3	194,220	892	881	808	898	859	641	320
GR-23-29	4/9/94	29	23.4	25,045	1,321	5,901	226,113	23,310	3	241,190	891	882	829	916	898	660	333
GR-23-30	4/11/94	30	23.0	26,796	1,377	5,949	242,747	22,657	4	255,784	891	881	834	922	928	681	339
GR-23-26	4/11/94	26	23.7	22,757	1,216	6,000	206,133	21,209	4	214,139	903	881	828	906	848	642	319
GR-23-25	4/12/94	26	23.6	22,993	1,224	5,987	207,817	21,204	12	216,329	891	881	824	907	858	647	323
GR-23-30	4/12/94	30	21.4	27,609	1,307	5,691	250,383	21,278	1	255,629	890	881	834	922	898	669	335
GR	4/14/94	27	22.6	23,164	1,168	5,980	210,220	17,936	3	225,574	892	881	814	910	875	650	328
GR-23-24	4/20/94	25	23.4	21,087	1,113	5,972	191,634	17,211	5	209,014	893	881	788	901	881	652	327
GR-23-30	4/21/94	30	23.6	25,834	1,380	5,987	234,455	22,278	5	265,300	891	881	823	923	877	652	327
GR	5/17/94	25	22.5	22,533	1,127	5,840	203,314	17,476	4	216,029	888	879	828	904	823	628	320
GR	5/18/94	25	22.7	22,033	1,112	5,808	199,626	18,307	4	220,273	889	880	823	906	892	654	321

TABLE A-3. GAS REBURNING THERMAL IMPACTS

Test I. D.	Test Date	Gross Power (MWe)	Gas Heat (%)	TotStm H A (MBtu/hr)	Furn H A (MBtu/hr)	SSH H A (MBtu/hr)	PSH H A (MBtu/hr)	GenBnk H A (MBtu/hr)	Attmp H A (MBtu/hr)	AirHrt H A (MBtu/hr)	Furn H A Ratio	SSH H A Ratio	PSH H A Ratio	GenBnk H A Ratio	DrmAtt H A Ratio	AirHtr H A Ratio	Boiler Effic. (%)
GR-5B	7/28/93	33	23.4	342.6	203.7	40.1	71.8	27.0	28.8	38.8	0.96	1.06	1.06	0.98	1.33	1.02	84.59
GR-5C	7/28/93	33	23.4	342.5	203.3	39.8	72.0	27.3	29.2	38.7	0.96	1.06	1.07	0.99	1.35	1.02	84.56
GR-5A	7/29/93	35	23.2	345.4	203.9	40.6	72.6	28.3	29.2	39.8	0.95	1.07	1.06	1.01	1.33	1.03	84.58
GR-4A	7/29/93	35	21.8	345.4	202.9	40.1	73.5	28.8	30.2	40.0	0.95	1.05	1.08	1.02	1.37	1.04	84.49
GR-3A	7/30/93	34	19.5	339.4	202.2	41.2	69.5	26.6	29.0	38.5	0.96	1.11	1.04	0.97	1.37	1.03	84.80
GR-2A	7/30/93	34	16.1	346.1	207.4	40.1	71.2	27.3	27.8	39.7	0.97	1.05	1.04	0.97	1.25	1.02	84.91
GR-5D	7/30/93	35	23.1	347.6	207.9	39.0	71.7	29.0	26.9	40.5	0.97	1.01	1.04	1.02	1.20	1.04	84.52
GR-5E	7/30/93	34	22.8	350.6	211.1	39.7	71.5	28.2	26.6	40.8	0.97	1.02	1.03	0.99	1.17	1.05	84.51
GR-5F	7/30/93	34	22.6	348.8	211.5	39.9	70.5	26.8	26.1	39.9	0.98	1.03	1.02	0.94	1.16	1.03	84.73
GR-5G	7/30/93	35	22.8	350.9	209.7	39.9	72.3	28.9	27.3	40.3	0.97	1.02	1.04	1.01	1.20	1.02	84.63
GR-15B	8/2/93	26	22.6	277.3	169.7	31.0	54.5	22.1	19.7	32.2	0.95	1.10	1.06	1.09	1.46	1.09	84.59
GR-15A	8/2/93	26	22.6	278.0	170.6	31.0	54.2	22.2	19.5	31.8	0.95	1.09	1.05	1.09	1.43	1.07	84.63
GR-15C	8/2/93	26	22.5	277.9	169.4	30.2	54.4	23.8	19.1	33.1	0.95	1.06	1.05	1.16	1.40	1.11	84.42
GR-14A	8/2/93	26	25.0	280.1	170.4	31.0	55.1	23.6	19.6	32.1	0.95	1.08	1.06	1.14	1.41	1.07	84.45
GR-13A	8/2/93	26	20.5	278.5	170.2	29.9	54.4	24.0	18.7	33.1	0.95	1.05	1.05	1.17	1.36	1.11	84.45
GR-12A	8/2/93	26	19.6	277.2	168.9	29.8	54.3	24.3	18.5	33.2	0.95	1.05	1.06	1.19	1.37	1.12	84.42
GR-11A	8/2/93	26	16.5	277.1	169.8	29.2	53.5	24.6	17.0	32.8	0.95	1.03	1.04	1.21	1.26	1.11	84.61
GR-25A	8/11/93	19	23.9	225.5	0.0	21.2	39.1	0.0	8.6	0.0	0.00	1.03	1.02	0.00	1.23	0.00	84.62
GR-25B	8/11/93	19	23.9	226.5	0.0	21.2	39.6	0.0	8.7	0.0	0.00	1.02	1.03	0.00	1.23	0.00	84.50
GR-25C	8/11/93	20	24.0	223.3	0.0	21.1	39.2	0.0	8.8	0.0	0.00	1.03	1.03	0.00	1.30	0.00	84.54
GR-24A	8/11/93	19	22.2	218.7	0.0	20.6	38.3	0.0	8.4	0.0	0.00	1.03	1.03	0.00	1.33	0.00	84.60
GR-22A	8/11/93	19	17.0	216.6	0.0	20.2	37.8	0.0	8.1	0.0	0.00	1.03	1.04	0.00	1.35	0.00	84.58
GR-15D	8/12/93	27	23.2	280.7	0.0	28.0	50.6	0.0	12.1	0.0	0.00	0.98	0.97	0.00	0.87	0.00	84.39
GR-15E	8/12/93	27	23.1	281.1	0.0	28.4	51.3	0.0	13.2	0.0	0.00	0.98	0.98	0.00	0.94	0.00	84.34
GR-15F	8/12/93	27	23.3	281.8	0.0	29.1	52.1	0.0	14.4	0.0	0.00	1.01	0.99	0.00	1.03	0.00	84.31
GR-5A2	8/13/93	33	24.6	337.5	0.0	37.5	69.1	0.0	25.5	0.0	0.00	1.02	1.04	0.00	1.21	0.00	84.30
GR-8A	8/13/93	34	24.8	338.3	0.0	39.0	70.8	0.0	28.2	0.0	0.00	1.05	1.07	0.00	1.33	0.00	84.16
GR-5H	8/13/93	33	24.9	337.9	0.0	38.2	70.5	0.0	27.6	0.0	0.00	1.03	1.06	0.00	1.31	0.00	83.87
GR-5I	8/13/93	32	24.9	338.0	0.0	36.6	70.7	0.0	26.2	0.0	0.00	0.99	1.06	0.00	1.24	0.00	83.65
GR-15G	8/17/93	25	21.4	275.2	0.0	31.3	54.6	0.0	20.6	0.0	0.00	1.12	1.08	0.00	1.57	0.00	84.65
GR-15G2	8/17/93	25	23.6	276.0	0.0	30.3	54.3	0.0	19.7	0.0	0.00	1.08	1.07	0.00	1.48	0.00	84.49
GR-15H	8/17/93	25	23.5	275.6	0.0	29.2	54.4	0.0	19.0	0.0	0.00	1.04	1.07	0.00	1.43	0.00	84.11
GR-15I	8/17/93	25	23.5	275.9	0.0	28.6	54.6	0.0	18.4	0.0	0.00	1.02	1.07	0.00	1.38	0.00	83.89
GR-8B	8/18/93	33	24.8	345.3	0.0	41.3	73.7	0.0	31.4	0.0	0.00	1.09	1.08	0.00	1.43	0.00	84.15
GR-5I	8/18/93	33	24.8	346.3	0.0	39.7	74.1	0.0	30.9	0.0	0.00	1.04	1.08	0.00	1.39	0.00	83.69
GR-25D	8/19/93	19	22.2	219.5	0.0	21.2	40.2	0.0	10.8	0.0	0.00	1.06	1.08	0.00	1.72	0.00	84.49
GR-25E	8/19/93	19	22.2	220.0	0.0	20.6	40.5	0.0	10.7	0.0	0.00	1.03	1.09	0.00	1.67	0.00	84.44
GR-25E2	8/19/93	19	21.9	221.6	0.0	20.8	39.0	0.0	8.5	0.0	0.00	1.03	1.04	0.00	1.30	0.00	85.02
GR-25F	8/19/93	19	22.0	221.1	0.0	21.1	39.2	0.0	9.4	0.0	0.00	1.04	1.05	0.00	1.45	0.00	84.96
GR-25G	8/20/93	19	22.7	222.1	0.0	21.2	40.5	0.0	10.6	0.0	0.00	1.04	1.07	0.00	1.59	0.00	84.94
GR-25G2	8/20/93	19	25.5	221.1	0.0	21.5	40.8	0.0	11.3	0.0	0.00	1.07	1.09	0.00	1.73	0.00	84.94
GR-25H	8/20/93	19	25.6	222.1	0.0	20.8	41.1	0.0	11.1	0.0	0.00	1.02	1.08	0.00	1.66	0.00	84.42
GR-25I	8/20/93	19	25.7	221.3	0.0	21.2	40.9	0.0	11.1	0.0	0.00	1.05	1.09	0.00	1.69	0.00	84.60
GR-25F2	8/20/93	19	25.9	219.1	0.0	21.0	40.7	0.0	11.4	0.0	0.00	1.06	1.10	0.00	1.80	0.00	84.57
GR-25E3	8/20/93	19	25.8	220.4	0.0	21.2	40.4	0.0	10.9	0.0	0.00	1.05	1.08	0.00	1.69	0.00	84.59
GR-25D2	8/20/93	19	25.3	227.1	24.9	22.8	41.4	2.5	12.1	2.8	0.17	1.08	1.07	0.18	1.68	0.13	84.52

Note: H A Ratio relative to baseline case

TABLE A-3. GAS REBURNING THERMAL IMPACTS (CONTINUED)

Test I. D.	Test Date	Gross Power (MWe)	Gas Heat (%)	TotStm H A (MBtu/hr)	Furn H A (MBtu/hr)	SSH H A (MBtu/hr)	PSH H A (MBtu/hr)	GenBnk H A (MBtu/hr)	Attmp H A (MBtu/hr)	AirHrt H A (MBtu/hr)	Furn H A Ratio	SSH H A Ratio	PSH H A Ratio	GenBnk H A Ratio	DrmAtt H A Ratio	AirHtr H A Ratio	Boiler Effic. (%)
GR-14A2	8/23/93	24	24.4	265.9	168.7	28.2	49.1	19.9	15.1	29.2	0.98	1.06	1.01	1.05	1.25	1.06	84.68
GR-15A2	8/23/93	24	23.2	268.6	170.6	27.9	49.3	20.8	14.5	29.6	0.98	1.04	1.00	1.08	1.17	1.07	84.61
GR-5E2	8/23/93	31	25.2	339.4	200.8	38.8	69.0	30.9	26.1	39.2	0.95	1.04	1.04	1.13	1.23	1.07	83.97
GR-14A2	8/31/93	24	25.0	256.9	163.7	25.5	46.7	21.1	11.9	30.1	0.97	1.00	1.01	1.17	1.08	1.10	84.39
GR-15F2	8/31/93	24	24.1	256.2	162.6	25.7	46.7	21.1	12.1	29.8	0.97	1.02	1.01	1.18	1.11	1.10	84.42
GR-15E2	8/31/93	24	24.0	255.9	162.8	25.4	46.2	21.5	11.5	29.9	0.97	1.01	1.00	1.20	1.06	1.10	84.43
GR-19A	8/31/93	24	24.1	255.4	160.9	24.9	46.7	22.9	11.8	31.1	0.96	0.99	1.01	1.28	1.09	1.15	84.16
GR-25H2	9/1/93	19	25.7	214.9	144.3	17.9	36.3	16.3	5.1	26.1	0.98	0.92	1.00	1.21	0.87	1.22	84.36
GR-1A	9/2/93	35	11.6	350.4	209.6	39.6	71.5	29.8	26.0	41.7	0.97	1.02	1.03	1.04	1.14	1.05	84.63
GR-5G2	9/2/93	34	25.0	345.4	206.6	40.9	69.2	28.8	26.0	40.5	0.97	1.08	1.02	1.03	1.18	1.06	84.24
GR-5C2	9/2/93	33	25.4	337.2	199.3	38.8	70.8	28.3	28.4	41.7	0.95	1.05	1.07	1.04	1.35	1.10	84.12
GR-5D2	9/2/93	33	25.3	337.0	199.3	38.2	70.5	29.1	27.2	41.9	0.95	1.03	1.06	1.07	1.29	1.11	84.08
GR-25A	9/3/93	20	23.6	217.4	141.4	21.3	39.4	15.3	10.2	26.4	0.96	1.08	1.07	1.12	1.67	1.21	84.66
GR-25B2	9/3/93	19	25.5	210.0	137.9	20.0	37.8	14.3	9.5	24.7	0.96	1.07	1.08	1.11	1.81	1.20	84.51
GR-25I2	9/7/93	19	25.8	222.9	149.5	19.0	37.7	16.6	5.5	26.5	1.00	0.93	1.00	1.17	0.83	1.24	84.53
GR-25J	9/7/93	19	25.6	225.1	150.3	18.6	38.3	17.8	5.2	28.0	0.99	0.90	1.00	1.23	0.75	1.31	84.27
GR-H2	9/7/93	20	25.6	219.2	145.7	19.5	37.6	16.4	6.1	25.5	0.98	0.98	1.02	1.19	0.98	1.19	84.76
GR-27B	9/8/93	19	22.9	210.2	142.0	18.1	35.5	14.6	5.4	24.6	0.98	0.96	1.01	1.13	1.02	1.19	84.79
GR-27C	9/8/93	19	23.0	210.1	142.2	17.3	35.4	15.2	4.5	25.4	0.99	0.92	1.01	1.18	0.85	1.23	84.60
GR-27D	9/8/93	19	22.9	210.8	142.3	17.1	35.7	15.7	4.4	26.3	0.99	0.91	1.01	1.21	0.82	1.27	84.43
GR-27E	9/8/93	19	23.0	210.6	142.5	16.3	35.6	16.2	3.6	27.4	0.99	0.86	1.01	1.25	0.67	1.32	84.18
GR-28A	9/8/93	19	19.7	210.9	142.6	17.1	35.5	15.7	3.8	26.2	0.99	0.91	1.01	1.22	0.71	1.27	84.52
GR-28B	9/8/93	19	18.0	211.6	143.6	17.4	35.4	15.2	4.0	25.9	0.99	0.92	1.00	1.17	0.74	1.24	84.66
GR-18A	9/30/93	23	26.0	233.1	150.4	19.9	41.3	21.5	7.1	32.7	0.96	0.90	1.01	1.38	0.86	1.28	84.07
GR	10/25/93	25	18.5	277.9	182.1	26.1	48.2	21.5	10.1	31.5	1.02	0.92	0.94	1.06	0.75	1.15	84.75
GR 113B	10/26/93	24	24.6	266.4	169.5	26.8	49.8	20.2	15.2	31.4	0.98	1.00	1.02	1.05	1.24	1.16	84.51
GR 113A	10/26/93	25	24.6	263.5	168.3	25.5	48.5	21.1	13.3	31.4	0.98	0.97	1.01	1.12	1.11	1.16	84.47
GR113C	10/26/93	25	25.0	263.9	166.1	27.0	49.5	21.3	15.1	31.0	0.97	1.02	1.03	1.13	1.27	1.14	84.41
GR 111A	10/26/93	25	26.0	264.0	166.3	27.0	49.4	21.3	15.3	30.4	0.97	1.02	1.02	1.13	1.28	1.12	84.55
GR 111B	10/26/93	25	20.1	263.7	166.5	27.2	48.9	21.1	15.2	30.1	0.97	1.03	1.02	1.11	1.27	1.10	84.69
GR 101B	10/27/93	34	24.7	345.4	205.4	38.5	70.9	30.7	27.3	43.0	0.96	1.00	1.03	1.09	1.23	1.12	84.13
GR 101C	10/27/93	34	24.9	344.9	203.6	38.7	71.6	30.9	28.4	43.3	0.95	1.01	1.05	1.10	1.28	1.13	84.01
GR 101D	10/27/93	34	24.9	344.8	202.7	38.4	71.8	31.9	28.1	43.5	0.95	1.00	1.05	1.14	1.27	1.13	83.93
GR 101A	10/27/93	34	24.7	345.0	206.4	35.5	69.6	33.4	23.3	43.6	0.96	0.93	1.01	1.18	1.05	1.14	83.95
GR 104A	10/27/93	34	24.9	345.4	205.6	36.6	70.1	33.0	24.4	43.5	0.96	0.96	1.02	1.17	1.10	1.14	83.92
GR 104B	10/27/93	34	24.9	344.9	206.1	35.8	70.0	33.0	23.9	43.5	0.96	0.94	1.02	1.17	1.08	1.13	83.92
GR 104C	10/27/93	34	24.9	344.5	208.0	35.2	69.3	32.0	22.6	43.6	0.97	0.92	1.01	1.14	1.02	1.14	83.93
GR 102A	10/28/93	33	23.7	354.6	208.3	43.6	75.4	27.3	34.4	42.6	0.95	1.11	1.07	0.94	1.49	1.14	84.17
GR 102B	10/28/93	33	20.1	351.1	206.2	42.2	74.9	27.8	33.7	41.4	0.95	1.08	1.07	0.97	1.48	1.10	84.49
GR 102C	10/28/93	33	15.1	350.3	207.3	41.3	74.2	27.5	32.4	41.3	0.96	1.06	1.06	0.96	1.42	1.10	84.65
GR 103A	10/28/93	33	25.6	350.5	205.8	41.3	74.5	28.9	32.4	40.9	0.95	1.06	1.07	1.01	1.43	1.09	84.37
GR 103B	10/28/93	33	25.7	350.6	205.9	39.3	74.1	31.3	30.9	44.2	0.95	1.01	1.06	1.09	1.35	1.17	83.86

Note: H A Ratio relative to baseline case

TABLE A-3. GAS REBURNING THERMAL IMPACTS (CONTINUED)

Test I. D.	Test Date	Gross Power (MWe)	Gas Heat (%)	TotStm H A (MBtu/hr)	Furn H A (MBtu/hr)	SSH H A (MBtu/hr)	PSH H A (MBtu/hr)	GenBnk H A (MBtu/hr)	Attmp H A (MBtu/hr)	AirHrt H A (MBtu/hr)	Furn H A Ratio	SSH H A Ratio	PSH H A Ratio	GenBnk H A Ratio	DrmAtt H A Ratio	AirHtr H A Ratio	Boiler Effic. (%)
GR 112A2	10/29/93	24	21.4	256.5	160.7	25.6	47.2	23.0	13.5	31.2	0.96	1.01	1.02	1.27	1.22	1.19	84.37
GR 112A	10/29/93	24	24.1	256.4	160.3	25.5	47.0	23.6	13.5	31.6	0.95	1.00	1.01	1.30	1.22	1.20	84.19
GR 112B	10/29/93	24	20.4	256.3	160.2	25.9	46.9	23.3	13.6	31.2	0.95	1.02	1.01	1.29	1.23	1.19	84.30
GR 112C	10/29/93	24	14.9	256.1	160.5	25.9	46.6	23.1	13.5	31.2	0.96	1.02	1.01	1.28	1.23	1.19	84.50
GR-106A	11/10/93	32	25.0	232.0	159.8	20.6	38.9	12.6	9.5	26.6	1.07	1.01	1.03	0.90	1.42	1.33	84.42
GR-106B	11/10/93	32	25.0	289.8	186.6	30.0	54.1	19.1	19.2	31.2	1.06	1.08	1.07	0.96	1.46	1.23	83.46
GR-107C	11/10/93	32	25.1	350.8	217.5	39.5	70.1	23.7	26.5	45.3	1.00	1.02	1.01	0.83	1.16	1.21	82.32
GR--107B	11/10/93	32	25.1	233.3	161.0	20.3	39.4	12.6	9.4	26.8	1.07	0.99	1.04	0.89	1.38	1.34	84.14
GR-106C	11/10/93	32	25.3	356.5	219.0	41.0	70.7	25.8	29.9	41.8	1.04	1.11	1.07	0.95	1.42	1.18	83.06
GR-108A	11/10/93	32	23.6	289.3	191.8	28.7	51.9	16.8	17.3	33.1	1.08	1.03	1.02	0.84	1.30	1.30	83.72
GR-106B	11/10/93	32	25.0	287.9	192.2	28.6	50.8	16.4	16.4	32.1	1.09	1.03	1.01	0.82	1.25	1.27	84.25
GR-107C	11/10/93	32	25.1	348.5	216.1	40.4	69.4	22.7	27.2	41.3	1.00	1.05	1.01	0.80	1.21	1.11	82.93
GR--107B	11/10/93	32	25.1	347.8	214.9	40.9	69.4	22.6	28.0	41.2	1.00	1.06	1.01	0.80	1.25	1.11	82.74
GR-106C	11/10/93	32	25.3	288.9	190.4	29.4	52.0	17.0	18.2	32.6	1.08	1.06	1.03	0.85	1.38	1.29	83.87
GR	11/15/93	26	23.0	215.8	152.5	17.0	33.0	13.4	2.7	26.7	1.03	0.86	0.89	0.98	0.43	1.27	83.61
GR	11/16/93	23	22.0	279.6	180.1	28.6	51.6	19.2	17.7	31.1	1.05	1.08	1.07	1.02	1.47	1.23	83.29
GR 114 A	11/17/93	23	23.0	366.9	232.3	39.5	71.0	24.1	22.7	43.9	1.04	0.97	0.97	0.80	0.93	1.15	84.08
GR 114 B	11/17/93	23	23.2	272.7	177.0	27.7	50.3	17.7	17.2	28.0	1.05	1.08	1.07	0.97	1.53	1.13	83.69
GR 114 C	11/17/93	23	23.1	348.9	221.4	38.0	69.0	20.6	23.4	45.1	1.03	0.98	1.00	0.73	1.04	1.19	83.38
GR	11/23/93	23	22.2	272.9	177.1	27.2	49.9	18.8	16.3	31.2	1.05	1.06	1.06	1.03	1.44	1.26	82.82
GR	2/16/94	26	21.4	272.1	179.9	27.3	48.1	16.9	15.7	32.2	1.06	1.06	1.03	0.92	1.39	1.29	83.88
GR	2/17/94	26	22.2	223.6	153.8	19.9	38.2	11.7	6.4	26.8	1.03	0.97	1.01	0.83	0.96	1.29	83.97
GR	2/18/94	28	21.2	339.5	219.2	35.4	64.4	20.5	17.3	44.3	1.04	0.96	0.97	0.75	0.82	1.19	82.97
GR	3/28/94	30	22.2	329.6	198.6	36.7	67.0	27.3	28.7	36.0	1.01	1.09	1.11	1.12	1.59	1.08	84.41
GR	4/6/94	31	20.1	323.5	200.5	33.9	64.2	24.9	24.7	34.3	1.03	1.04	1.09	1.05	1.43	1.06	84.64
GR-25-25	4/8/94	25	23.8	260.8	169.0	26.1	48.0	17.6	16.6	26.6	1.03	1.08	1.08	1.03	1.65	1.08	83.64
GR-25-25	4/8/94	25	23.1	271.5	175.9	26.4	50.0	19.2	16.6	26.4	1.04	1.03	1.07	1.05	1.49	1.07	84.36
GR-25-30	4/8/94	29	14.3	306.0	191.9	29.8	58.7	25.5	19.3	33.1	1.04	0.98	1.08	1.17	1.25	1.12	84.15
GR-23-25	4/9/94	20	22.1	234.3	158.8	17.8	40.2	17.4	6.0	24.3	1.06	0.88	1.06	1.23	0.89	1.24	83.61
GR-23-23	4/9/94	24	23.1	260.2	170.1	23.0	46.6	20.5	12.3	26.4	1.04	0.96	1.06	1.21	1.25	1.14	83.92
GR-23-29	4/9/94	29	23.4	309.8	192.9	30.8	59.7	26.4	21.1	32.9	1.03	1.00	1.07	1.19	1.34	1.11	83.86
GR-23-30	4/11/94	30	23.0	325.9	199.2	34.1	63.8	28.7	24.7	35.9	1.02	1.04	1.08	1.20	1.41	1.13	83.90
GR-23-26	4/11/94	26	23.7	269.6	171.1	26.3	51.1	21.1	16.4	29.0	1.02	1.04	1.11	1.17	1.51	1.12	84.09
GR-23-25	4/12/94	26	23.6	272.1	172.5	26.6	51.4	21.7	17.6	29.5	1.02	1.03	1.09	1.18	1.55	1.13	84.02
GR-23-30	4/12/94	30	21.4	314.4	193.1	33.0	61.7	26.5	24.0	35.2	1.02	1.05	1.08	1.16	1.47	1.11	84.11
GR	4/14/94	27	22.6	274.0	171.0	27.1	52.2	22.7	17.0	29.0	0.99	1.01	1.06	1.19	1.33	1.05	84.10
GR-23-24	4/20/94	25	23.4	261.2	169.5	23.8	46.5	21.4	9.7	26.4	1.00	0.92	0.99	1.16	0.85	1.05	84.04
GR-23-30	4/21/94	30	23.6	305.5	187.7	31.2	61.3	25.3	20.1	33.3	0.97	0.96	1.05	1.07	1.17	1.01	84.21
GR	5/17/94	25	22.5	278.3	173.8	30.6	55.2	18.6	22.0	26.8	0.98	1.09	1.09	0.92	1.65	1.03	84.46
GR	5/18/94	25	22.7	268.9	165.4	28.2	52.9	22.5	19.2	28.0	0.96	1.05	1.08	1.18	1.56	1.05	84.35

Note: H A Ratio relative to baseline case

TABLE A-4. SORBENT INJECTION EMISSIONS SUMMARY

Test I. D.	Test Date	Test Duration (hr:min)	Gross Power (MWe)	Ca/S Molar Ratio	Coal SR	Reb SR	Burn-out SR	Exit SR	OFA (%)	CEMS O2 (%, dry)	Plant O2 (%, wet)	COc (ppm)	CO2c (%)	NOxc (ppm)	NOx (lb/MBtu)	SO2c (ppm)	SO2 (lb/MBtu)	SO2 Reduc. (%)	Ca Utiliz. (%)
SI-15	9/10/93	1:00	20	1.23	1.15	1.15	1.27	1.34	10	5.84	4.61	13	15.4	588	0.802	2,470	4.705	20.26	16.51
SI-17	9/10/93	1:00	20	2.34	1.15	1.15	1.27	1.34	9	5.61	4.33	12	15.4	603	0.822	2,083	3.972	32.67	13.97
SI-19	9/10/93	0:57	20	3.46	1.15	1.15	1.27	1.34	9	5.36	4.14	13	15.1	589	0.803	1,761	3.357	43.11	12.45
SI-2	9/13/93	0:08	33	2.05	1.16	1.16	1.24	1.31	6	3.99	2.96	13	15.3	704	0.960	1,967	3.767	36.15	17.64
SI-8	9/13/93	0:54	33	2.01	1.16	1.16	1.24	1.30	7	3.95	2.92	13	15.3	669	0.913	1,129	2.147	63.60	31.67
SI-2A	9/14/93	1:01	33	2.09	1.16	1.16	1.23	1.31	6	4.46	3.33	9	15.4	732	0.998	1,732	3.304	44.01	21.07
SI-8A	9/14/93	2:00	33	2.16	1.15	1.15	1.23	1.29	6	4.16	3.05	9	15.5	746	1.017	1,551	2.958	49.87	23.09
SI-14	9/17/93	1:00	20	1.95	1.15	1.15	1.27	1.40	9	6.01	4.34	17	15.2	590	0.804	2,193	4.181	29.14	14.98
SI-16	9/17/93	1:00	20	1.87	1.15	1.15	1.27	1.36	9	5.54	4.49	10	15.2	569	0.775	2,151	4.102	30.47	16.27
SI-26	9/20/93	1:00	24	1.93	1.15	1.15	1.26	1.35	8	5.01	3.89	14	15.4	586	0.797	2,126	4.043	31.48	16.31
SI-27	9/20/93	1:00	24	1.94	1.15	1.15	1.26	1.32	8	4.71	3.69	12	15.5	591	0.805	2,138	4.074	30.95	15.95
SI-2B	9/22/93	1:00	33	2.27	1.14	1.14	1.22	1.30	7	3.96	3.19	16	15.3	681	0.929	1,716	3.276	44.48	19.61
SI-8B	9/22/93	0:57	33	2.15	1.15	1.15	1.23	1.28	7	3.68	3.01	13	15.2	697	0.950	1,693	3.229	45.27	21.03
SI-11B	9/22/93	1:00	34	2.15	1.15	1.15	1.23	1.26	7	3.31	2.79	13	15.2	689	0.939	1,761	3.357	43.10	20.08
SI-3	9/23/93	1:00	33	1.10	1.15	1.15	1.23	1.30	7	4.24	3.45	10	15.4	744	1.014	2,096	3.996	32.28	29.29
SI-6	9/23/93	1:00	33	2.10	1.15	1.15	1.23	1.29	6	4.04	3.20	12	15.4	750	1.022	1,553	2.965	49.75	23.66
SI-10	9/23/93	1:00	33	2.87	1.15	1.15	1.23	1.29	6	4.02	3.06	14	15.3	790	1.077	1,186	2.267	61.57	21.43
SI-27	11/2/93	0:57	23	1.75	1.14	1.14	1.25	1.29	8	4.96	4.04	10	15.2	624	0.851	2,057	3.923	33.51	19.19
SI-28	11/2/93	0:55	23	1.74	1.14	1.14	1.25	1.30	8	5.07	4.04	8	15.2	619	0.843	1,976	3.762	36.24	20.78
SI-29	11/2/93	0:57	23	1.77	1.14	1.14	1.25	1.31	8	5.25	4.10	7	15.3	649	0.885	1,907	3.644	38.24	21.58
SI-30	11/2/93	0:57	23	1.72	1.14	1.14	1.24	1.34	8	5.52	4.23	11	15.2	652	0.889	1,858	3.547	39.88	23.14
SI-16	11/3/93	0:30	19	1.64	1.14	1.14	1.27	1.33	10	5.56	4.51	11	15.1	622	0.848	2,173	4.139	29.84	18.17
SI-17	11/3/93	0:30	19	1.71	1.14	1.14	1.27	1.36	10	5.84	4.59	13	15.1	633	0.863	2,106	4.016	31.94	18.69
SI-18	11/3/93	0:35	19	1.56	1.14	1.14	1.27	1.38	10	6.26	4.79	12	14.9	613	0.835	2,114	4.030	31.70	20.26
SI-23	11/3/93	0:30	23	1.14	1.15	1.15	1.26	1.32	9	5.32	4.25	7	15.2	689	0.940	2,171	4.133	29.95	26.37
SI-24	11/3/93	0:35	23	2.24	1.15	1.15	1.26	1.33	9	5.21	4.17	11	15.1	664	0.903	1,622	3.108	47.32	21.15
SI-23-25	6/2/94	3:17	25	1.67	1.14	1.15	1.20	1.23	4	5.13	3.77	39	15.3	661	0.901	2,112	4.034	31.64	18.96
SI-25	6/3/94	6:12	26	1.79	1.15	1.15	1.19	1.23	4	5.18	3.71	39	15.2	640	0.872	1,858	3.541	39.98	22.33
SI-31	6/3/94	5:41	31	1.58	1.15	1.15	1.19	1.22	4	4.44	3.12	27	15.3	678	0.924	1,841	3.428	41.89	26.51

Notes: Subscript c denotes correction to 3% O2
SO2 reduction from 5.9 lb/MBtu baseline

TABLE A-5. SORBENT INJECTION OPERATING DATA.

Test I. D.	Test Date	Ca/S Molar Ratio	Sorb Flow (lb/hr)	Srb Inj AirFlow (scfm)	Coal Flow (lb/hr)	Cyclone Air (lb/hr)	OFA Flow (scfm)	Opac (%)	Steam Load (lb/hr)	SSH Steam (F)	SSH Steam (psig)	PSH Steam (F)	Blr Drum (psig)	BlrBnk G I (F)	BlrBnk G O (F)	AirHtr G O (F)
SI-15	9/10/93	1.23	1,848	2,425	23,075	209,292	4,984	6	180,514	879	881	750	891	833	651	329
SI-17	9/10/93	2.34	3,548	2,387	23,819	216,516	5,010	6	178,030	899	881	780	892	808	651	350
SI-19	9/10/93	3.46	5,290	2,365	23,761	215,667	4,989	6	178,081	897	881	768	892	841	666	357
SI-2	9/13/93	2.05	5,163	4,506	38,813	354,648	5,403	5	302,556	893	889	808	945	909	709	369
SI-8	9/13/93	2.01	4,972	3,482	38,405	351,112	5,482	4	302,349	891	891	798	944	924	746	400
SI-2A	9/14/93	2.09	5,233	4,528	39,144	356,255	5,381	5	300,675	891	891	814	946	919	750	395
SI-8A	9/14/93	2.16	5,357	3,787	38,811	352,896	5,276	5	301,309	893	891	797	944	946	760	411
SI-14	9/17/93	1.95	2,935	4,952	23,604	213,994	4,815	6	179,492	868	891	741	900	841	667	356
SI-16	9/17/93	1.87	2,851	3,516	23,726	215,322	4,873	5	177,421	892	891	774	902	805	641	354
SI-26	9/20/93	1.93	3,575	4,391	28,711	260,417	5,337	5	218,224	891	881	774	903	826	656	355
SI-27	9/20/93	1.94	3,575	3,039	28,616	259,585	5,340	5	218,697	892	881	778	904	825	661	365
SI-2B	9/22/93	2.27	5,485	4,479	37,603	339,292	5,316	6	295,194	900	881	795	930	924	727	384
SI-8B	9/22/93	2.15	5,241	3,136	37,676	340,233	5,345	5	295,652	901	881	798	931	917	735	395
SI-11B	9/22/93	2.15	5,204	1,813	37,535	339,057	5,318	5	295,505	901	881	802	932	909	728	387
SI-3	9/23/93	1.10	2,816	3,588	37,916	344,836	5,384	6	295,721	900	881	807	932	891	699	369
SI-6	9/23/93	2.10	5,431	3,465	38,181	347,150	5,314	6	296,183	901	881	801	932	925	740	397
SI-10	9/23/93	2.87	7,457	3,383	38,096	346,571	5,333	6	295,749	901	881	801	932	940	766	414
SI-27	11/2/93	1.75	3,427	1,655	29,067	261,868	5,376	7	209,207	885	871	799	893	841	654	353
SI-28	11/2/93	1.74	3,517	2,444	29,079	261,670	5,315	7	208,851	887	871	803	893	840	659	356
SI-29	11/2/93	1.77	3,582	3,196	29,484	265,503	5,361	7	209,940	886	871	807	894	853	667	364
SI-30	11/2/93	1.72	3,500	4,526	29,554	266,124	5,317	7	210,776	885	871	805	894	855	674	365
SI-16	11/3/93	1.64	2,745	2,022	24,312	218,742	5,498	7	171,613	885	871	786	881	793	624	334
SI-17	11/3/93	1.71	2,836	3,168	24,203	218,220	5,510	7	171,161	885	871	789	882	794	628	340
SI-18	11/3/93	1.56	2,635	4,463	24,491	220,574	5,514	7	170,736	886	871	787	882	795	633	343
SI-23	11/3/93	1.14	2,201	2,825	28,323	255,812	5,536	7	206,769	887	871	795	892	833	653	345
SI-24	11/3/93	2.24	4,632	3,143	28,771	259,732	5,547	7	207,190	887	871	800	893	860	672	361
SI-23-25	6/2/94	1.67	3,498	1,593	30,726	277,040	2,703	4	204,642	888	881	832	903	860	652	359
SI-25	6/3/94	1.79	3,785	1,532	30,934	279,216	2,690	4	206,013	888	881	836	904	867	661	366
SI-31	6/3/94	1.58	3,997	1,440	36,927	333,626	3,051	4	252,332	889	880	849	922	914	693	380

TABLE A-6. SORBENT INJECTION HEAT TRANSFER DATA.

Test I. D.	Test Date	Gross Power (MWe)	Ca/S Molar Ratio	TotStm H A (MBtu/hr)	Furn H A (MBtu/hr)	SSH H A (MBtu/hr)	PSH H A (MBtu/hr)	GenBnk H A (MBtu/hr)	Attmp H A (MBtu/hr)	AirHrt H A (MBtu/hr)	Furn H A Ratio	SSH H A Ratio	PSH H A Ratio	GenBnk H A Ratio	DrmAtt H A Ratio	AirHtr H A Ratio	Boiler Effic. (%)
SI-15	9/10/93	20	1.23	214.3	150.9	16.6	33.7	13.2	2.3	25.7	1.03	0.85	0.93	0.98	0.38	1.21	84.52
SI-17	9/10/93	20	2.34	223.6	153.8	19.9	38.2	11.7	6.4	26.8	1.03	0.97	1.01	0.83	0.96	1.29	83.97
SI-19	9/10/93	20	3.46	220.4	151.1	19.8	36.5	13.0	5.4	26.7	1.02	0.99	0.98	0.95	0.82	1.28	83.84
SI-2	9/13/93	33	2.05	366.9	232.3	39.5	71.0	24.1	22.7	43.9	1.04	0.97	0.97	0.80	0.93	1.15	84.08
SI-8	9/13/93	33	2.01	363.8	236.4	37.6	68.7	21.1	19.3	44.4	1.06	0.93	0.95	0.71	0.80	1.16	83.32
SI-2A	9/14/93	33	2.09	348.9	221.4	38.0	69.0	20.6	23.4	45.1	1.03	0.98	1.00	0.73	1.04	1.19	83.38
SI-8A	9/14/93	33	2.16	346.3	221.5	37.3	65.3	22.2	19.5	45.0	1.03	0.98	0.95	0.79	0.88	1.18	83.05
SI-14	9/17/93	20	1.95	215.8	152.5	17.0	33.0	13.4	2.7	26.7	1.03	0.86	0.89	0.98	0.43	1.27	83.61
SI-16	9/17/93	20	1.87	219.8	151.0	19.5	37.0	12.3	6.3	26.0	1.02	0.97	0.99	0.89	0.97	1.25	83.76
SI-26	9/20/93	24	1.93	262.2	178.4	23.4	45.0	15.4	7.6	31.6	1.05	0.90	0.95	0.83	0.66	1.20	84.00
SI-27	9/20/93	24	1.94	260.4	176.6	24.1	45.1	14.5	8.7	31.4	1.04	0.94	0.96	0.79	0.76	1.19	83.88
SI-2B	9/22/93	33	2.27	351.2	228.1	34.9	65.2	22.9	15.2	42.7	1.06	0.91	0.95	0.81	0.68	1.15	83.72
SI-8B	9/22/93	33	2.15	352.0	228.5	36.6	66.0	20.9	17.2	43.2	1.06	0.95	0.95	0.74	0.76	1.16	83.51
SI-11B	9/22/93	34	2.15	351.6	227.9	36.7	66.7	20.3	18.2	42.8	1.06	0.95	0.97	0.72	0.81	1.15	83.83
SI-3	9/23/93	33	1.10	339.7	216.5	35.4	65.5	22.3	18.5	42.4	1.03	0.96	0.99	0.82	0.88	1.14	84.09
SI-6	9/23/93	33	2.10	339.8	217.8	35.8	64.4	21.6	17.7	43.9	1.04	0.97	0.97	0.80	0.84	1.18	83.39
SI-10	9/23/93	33	2.87	339.5	219.2	35.4	64.4	20.5	17.3	44.3	1.04	0.96	0.97	0.75	0.82	1.19	82.97
SI-27	11/2/93	23	1.75	287.9	192.2	28.6	50.8	16.4	16.4	32.1	1.09	1.03	1.01	0.82	1.25	1.27	84.25
SI-28	11/2/93	23	1.74	289.3	192.6	29.2	51.5	16.0	17.2	32.0	1.09	1.05	1.02	0.80	1.31	1.27	84.13
SI-29	11/2/93	23	1.77	288.9	190.4	29.4	52.0	17.0	18.2	32.6	1.08	1.06	1.03	0.85	1.38	1.29	83.87
SI-30	11/2/93	23	1.72	289.3	191.8	28.7	51.9	16.8	17.3	33.1	1.08	1.03	1.02	0.84	1.30	1.30	83.72
SI-16	11/3/93	19	1.64	232.0	159.8	20.6	38.9	12.6	9.5	26.6	1.07	1.01	1.03	0.90	1.42	1.33	84.42
SI-17	11/3/93	19	1.71	233.3	161.0	20.3	39.4	12.6	9.4	26.8	1.07	0.99	1.04	0.89	1.38	1.34	84.14
SI-18	11/3/93	19	1.56	232.4	160.0	20.7	39.1	12.7	9.5	27.1	1.07	1.01	1.03	0.90	1.42	1.37	83.92
SI-23	11/3/93	23	1.14	269.3	180.4	26.2	46.9	15.8	14.1	31.4	1.07	1.03	1.01	0.88	1.27	1.26	84.33
SI-24	11/3/93	23	2.24	272.1	179.9	27.3	48.1	16.9	15.7	32.2	1.06	1.06	1.03	0.92	1.39	1.29	83.88
SI-23-25	6/2/94	25	1.67	284.8	183.4	30.1	52.6	18.7	22.5	29.0	1.08	1.17	1.11	1.02	1.93	1.18	84.34
SI-25	6/3/94	26	1.79	287.2	184.3	30.7	53.5	18.7	23.6	29.7	1.08	1.17	1.12	1.01	1.94	1.20	84.19
SI-31	6/3/94	31	1.58	343.9	214.4	38.6	66.9	24.1	31.9	37.2	1.09	1.16	1.12	0.99	1.79	1.19	84.07

Note: H A Ratio relative to baseline case

TABLE A-7. GAS REBURNING-SORBENT INJECTION EMISSIONS SUMMARY

Test I. D.	Test Date	Test Duration (hr:min)	Gross Power (MWe)	Gas Heat (%)	Ca/S Molar Ratio	Coal SR	Reb SR	Burn-out SR	Exit SR	OFA (%)	CEMS O2 (%, dry)	Plant O2 (%, wet)	COc (ppm)	CO2c (%)	NOxc (ppm)	NOx (lb/MBtu)	NOx Reduc. (%)	SO2c (ppm)	SO2 (lb/MBtu)	Totl-SO2 Reduc. (%)	Sorb-SO2 Reduc. (%)	Ca Utiliz. (%)
GRSI-11A	9/30/93	1:00	27	24.7	2.25	1.15	0.88	1.20	1.26	27	3.28	2.23	370	13.9	224	0.298	66.26	1,191	2.211	62.52	50.24	22.37
GRSI-11B	10/1/93	0:40	24	22.4	2.13	1.14	0.91	1.31	1.37	30	4.56	3.41	71	14.1	233	0.311	63.07	1,546	2.878	51.22	37.16	17.47
GRSI-1A	10/5/93	1:00	33	22.0	1.77	1.15	0.91	1.24	1.29	26	3.52	2.56	187	14.3	280	0.372	61.29	1,440	2.676	54.65	41.87	23.59
GRSI-1B	10/5/93	1:00	33	22.2	1.63	1.15	0.92	1.31	1.36	30	4.42	3.41	49	14.2	304	0.405	57.97	1,350	2.510	57.46	45.34	27.88
GRSI-1C	10/5/93	0:59	33	22.3	1.68	1.16	0.92	1.35	1.39	32	4.76	3.63	35	14.2	327	0.435	54.80	1,358	2.527	57.17	44.91	26.75
GRSI-13A	10/6/93	1:00	23	26.2	1.90	1.14	0.86	1.25	1.32	31	4.02	2.71	352	14.1	171	0.227	72.78	1,425	2.636	55.33	39.49	20.80
GRSI-13B	10/6/93	1:02	24	20.4	1.90	1.14	0.92	1.24	1.31	25	3.78	2.52	194	14.4	210	0.280	66.71	1,474	2.742	53.52	41.59	21.86
GRSI-13C	10/6/93	1:00	24	17.5	2.00	1.14	0.96	1.23	1.30	22	3.64	2.44	177	14.5	228	0.304	64.10	1,400	2.625	55.51	46.07	22.99
GRSI-13D	10/6/93	1:00	24	14.9	1.91	1.16	1.00	1.25	1.32	20	3.43	2.46	66	14.6	273	0.365	56.91	1,470	2.774	52.98	44.76	23.41
GRSI-11A2	10/6/93	1:00	24	26.2	1.97	1.16	0.93	1.26	1.33	27	3.78	2.75	117	14.2	220	0.293	65.40	1,269	2.367	59.89	45.66	23.20
GRSI-3D	10/7/93	1:02	34	14.2	1.87	1.16	1.01	1.26	1.31	20	3.40	2.60	52	14.6	366	0.492	49.36	1,530	2.877	51.24	43.19	23.16
GRSI-3C	10/7/93	1:02	33	18.6	1.75	1.15	0.95	1.26	1.31	24	3.36	2.47	173	14.4	283	0.377	61.12	1,388	2.592	56.07	46.02	26.33
GRSI-3B	10/7/93	1:00	33	20.7	1.75	1.15	0.93	1.26	1.31	26	3.37	2.48	141	14.3	267	0.356	63.26	1,280	2.382	59.62	49.09	27.99
GRSI-3A	10/7/93	1:00	33	25.6	1.90	1.15	0.87	1.25	1.30	30	3.37	2.40	346	14.0	238	0.315	67.35	1,125	2.091	64.55	52.38	27.58
GRSI-12A	10/11/93	1:00	24	21.8	1.82	1.10	0.88	1.31	1.38	33	4.78	3.52	193	14.0	219	0.292	65.62	1,618	3.011	48.96	34.75	19.05
GRSI-12B	10/11/93	1:00	24	22.2	1.90	1.20	0.95	1.31	1.38	27	4.43	3.28	68	14.1	256	0.341	59.86	1,415	2.631	55.40	42.70	22.50
GRSI-15A	10/11/93	1:00	24	22.2	1.10	1.14	0.91	1.24	1.30	27	3.66	2.65	295	14.1	193	0.257	69.59	1,640	3.047	48.36	33.67	30.47
GRSI-15B	10/11/93	1:00	24	22.2	1.80	1.14	0.90	1.24	1.30	27	3.34	2.41	446	14.1	179	0.238	71.98	1,342	2.499	57.64	45.52	25.29
GRSI-15C	10/11/93	0:31	24	22.4	2.70	1.14	0.90	1.23	1.29	27	3.33	2.40	441	14.1	182	0.243	71.38	1,231	2.301	60.99	49.74	18.40
GRSI-101B	11/2/93	1:00	32	23.4	1.49	1.14	0.89	1.25	1.30	28	4.05	3.13	108	14.3	289	0.384	59.32	1,480	2.750	53.39	39.17	26.33
GRSI-101B	11/11/93	1:00	31	23.3	1.72	1.15	0.90	1.25	1.29	28	3.96	2.81	164	14.3	267	0.356	62.15	1,391	2.584	56.20	42.89	24.99
GRSI-101C	11/11/93	1:00	31	23.0	1.74	1.17	0.92	1.24	1.29	26	4.01	2.79	158	14.2	298	0.396	57.91	1,234	2.290	61.19	49.57	28.47
GRSI-101A	11/11/93	1:00	31	22.9	1.75	1.12	0.88	1.26	1.30	30	4.13	3.03	75	14.2	272	0.362	61.55	1,332	2.472	58.10	45.65	26.15
GRSI-201B	11/12/93	1:00	23	23.3	2.06	1.15	0.90	1.25	1.32	28	4.05	2.90	252	14.2	200	0.265	67.96	1,302	2.426	58.88	46.42	22.53
GRSI-202A	11/12/93	1:05	23	23.0	2.09	1.15	0.91	1.30	1.36	30	5.66	3.27	110	13.8	242	0.321	61.04	1,030	1.916	67.52	57.80	27.66
GRSI-201A	11/12/93	1:10	23	23.1	2.12	1.12	0.88	1.26	1.33	30	4.77	3.01	256	14.1	195	0.259	68.61	1,148	2.124	63.99	53.16	25.13
GRSI-202B	11/12/93	1:00	23	23.3	2.12	1.15	0.91	1.35	1.41	33	6.47	3.77	56	13.7	271	0.360	56.46	1,184	2.198	62.74	51.45	24.23
GRSI-201C	11/12/93	1:00	23	23.2	2.14	1.17	0.92	1.24	1.31	25	3.75	2.57	256	14.2	212	0.281	65.93	1,092	2.038	65.46	55.01	25.65
GRSI	11/15/93	3:15	26	22.2	1.67	1.15	0.92	1.30	1.36	29	5.72	3.51	56	14.1	259	0.343	60.31	1,365	2.528	57.15	44.95	26.84
GRSI	11/16/93	4:53	23	22.2	1.97	1.15	0.92	1.29	1.35	29	5.16	3.42	83	14.0	233	0.310	62.69	1,147	2.137	63.77	53.45	27.12
GRSI	11/17/93	1:00	23	22.1	1.74	1.15	0.92	1.29	1.34	29	4.66	3.41	66	14.3	244	0.325	60.87	1,414	2.638	55.29	42.64	24.54
GRSI	2/16/94	2:08	29	21.5	1.33	1.14	0.92	1.28	1.33	28	4.65	3.74	85	14.2	302	0.402	55.58	1,529	2.852	51.67	38.43	28.85
GRSI	2/18/94	3:09	27	20.0	1.38	1.14	0.93	1.24	1.30	25	4.93	3.28	99	14.2	277	0.369	58.52	1,448	2.700	54.23	42.77	31.01
GRSI	3/28/94	0:34	30	21.7	1.21	1.15	0.92	1.26	1.32	27	4.89	3.57	83	14.3	312	0.414	54.87	1,703	3.169	46.29	31.38	25.97
GRSI	3/29/94	7:03	28	22.4	1.69	1.14	0.91	1.24	1.30	27	4.49	3.32	150	14.2	282	0.375	58.10	1,181	2.201	62.70	51.92	30.67
GRSI	3/30/94	6:34	31	22.2	1.78	1.13	0.90	1.24	1.30	27	4.65	3.32	129	14.2	286	0.380	59.39	1,136	2.113	64.19	53.96	30.37
GRSI	3/31/94	6:26	32	22.6	1.66	1.13	0.90	1.25	1.31	28	4.33	3.31	199	14.2	252	0.337	64.51	1,250	2.336	60.41	48.82	29.50

Notes: Subscript c denotes correction to 3% O2

NOx reduction from correlated baseline: NOx = 0.522 + 0.0134*(load)

SO2 reduction from 5.9 lb/MBtu baseline

TABLE A-7. GAS REBURNING-SORBENT INJECTION EMISSIONS SUMMARY (CONTINUED)

Test I. D.	Test Date	Test Duration (hr:min)	Gross Power (MWe)	Gas Heat (%)	Ca/S Molar Ratio	Coal SR	Reb SR	Burn-out SR	Exit SR	OFA (%)	CEMS O2 (%, dry)	Plant O2 (%, wet)	COc (ppm)	CO2c (%)	NOxc (ppm)	NOx (lb/MBtu)	NOx Reduc. (%)	SO2c (ppm)	SO2 (lb/MBtu)	Totl-SO2 Reduc. (%)	Sorb-SO2 Reduc. (%)	Ca Utiliz. (%)
GRSI	4/4/94	0:36	30	23.3	1.79	1.15	0.91	1.27	1.33	29	4.23	3.13	284	14.1	214	0.285	69.26	1,300	2.415	59.07	46.63	26.11
GR-SI	4/6/94	38:00	29	22.4	1.67	1.15	0.92	1.28	1.33	28	4.58	3.19	171	14.2	234	0.311	65.70	1,257	2.338	60.37	48.93	29.30
GRSI-23-24	5/13/94	14:17	24	21.8	1.86	1.15	0.93	1.28	1.33	28	4.20	3.16	143	14.1	208	0.277	67.43	1,249	2.315	60.77	49.80	26.73
GRSI-19-28	5/13/94	1:56	28	19.5	1.65	1.16	0.96	1.26	1.31	24	3.77	2.59	203	14.1	243	0.325	63.77	1,269	2.372	59.79	50.07	30.34
GRSI-22-28	5/13/94	4:55	28	21.8	1.77	1.19	0.95	1.33	1.37	28	4.35	3.20	206	13.9	270	0.364	59.33	1,192	2.211	62.53	52.08	29.45
GRSI	5/14/94	63:40	29	21.6	1.75	1.15	0.92	1.29	1.32	28	4.13	3.03	218	14.1	243	0.325	64.31	1,162	2.180	63.05	52.87	30.21
GRSI-23-33	6/2/94	0:40	33	22.1	1.64	1.15	0.91	1.24	1.27	27	3.82	2.30	375	14.6	270	0.359	62.92	1,487	2.766	53.11	39.78	24.21
GRSI-23-31	6/2/94	7:40	31	22.7	1.81	1.15	0.91	1.27	1.29	29	4.47	2.79	292	14.5	256	0.340	63.93	1,308	2.429	58.82	46.72	25.79

Notes: Subscript c denotes correction to 3% O2

NOx reduction from correlated baseline: NOx = 0.522 + 0.0134*(load)

SO2 reduction from 5.9 lb/MBtu baseline

TABLE A-8. GAS REBURING-SORBENT INJECTION OPERATING DATA

Test I. D.	Test Date	Coal Flow (lb/hr)	Gas Heat (%)	Ca/S Molar Ratio	Reb Gas (scfm)	FGR (scfm)	Cyclone Air (lb/hr)	OFA Flow (scfm)	Sorb Flow (lb/hr)	Srb Inj AirFlow (scfm)	Opac (%)	Steam Load (lb/hr)	SSH Steam (F)	SSH Steam (psig)	PSH Steam (F)	Blr Drum (psig)	BlrBnk G I (F)	BlrBnk G O (F)	AirHtr G O (F)
GRSI-11A	9/30/93	24,484	24.7	2.25	1,382	4,817	221,388	18,229	3,700	3,566	6	244,322	897	881	812	916	891	706	371
GRSI-11B	10/1/93	22,576	22.4	2.13	1,125	5,042	203,246	20,310	3,365	3,779	5	216,351	896	881	793	904	844	666	346
GRSI-1A	10/5/93	29,538	22.0	1.77	1,436	5,829	268,366	21,430	3,591	3,769	6	297,705	889	880	809	936	915	727	378
GRSI-1B	10/5/93	29,549	22.2	1.63	1,449	5,913	268,614	26,181	3,273	3,763	7	298,531	881	881	809	937	916	737	390
GRSI-1C	10/5/93	29,460	22.3	1.68	1,452	5,947	267,936	28,227	3,415	3,763	6	298,208	886	881	817	937	918	738	391
GRSI-13A	10/6/93	20,569	26.2	1.90	1,257	5,016	184,642	19,022	2,757	3,604	6	212,547	886	881	790	904	828	656	345
GRSI-13B	10/6/93	22,330	20.4	1.90	989	4,964	200,262	15,488	2,981	3,580	5	215,810	887	881	788	904	833	668	359
GRSI-13C	10/6/93	23,422	17.5	2.00	857	4,877	210,448	13,811	3,281	3,562	5	220,344	885	881	788	906	843	680	369
GRSI-13D	10/6/93	24,100	14.9	1.91	726	4,764	219,418	12,354	3,207	3,557	5	220,924	886	881	789	906	839	681	369
GRSI-11A2	10/6/93	22,693	26.2	1.97	1,070	5,028	206,500	17,083	3,178	3,532	4	220,913	887	881	805	908	845	685	377
GRSI-3D	10/7/93	32,157	14.2	1.87	915	5,757	292,902	16,430	4,003	3,634	5	296,651	886	881	808	936	909	729	382
GRSI-3C	10/7/93	30,254	16.6	1.75	1,192	5,997	274,831	19,939	3,614	3,694	5	296,138	886	881	816	938	915	731	390
GRSI-3B	10/7/93	29,469	20.7	1.75	1,324	6,000	267,894	21,413	3,647	3,693	4	295,850	885	881	816	938	919	735	395
GRSI-3A	10/7/93	27,955	25.6	1.90	1,655	5,959	253,809	24,639	3,653	3,692	4	295,541	885	881	816	938	926	737	398
GRSI-12A	10/11/93	22,896	21.8	1.82	1,099	4,571	199,167	22,077	2,885	3,651	6	221,265	885	881	779	904	826	654	338
GRSI-12B	10/11/93	22,435	22.2	1.90	1,102	5,001	211,388	17,830	2,940	3,888	6	221,546	886	881	792	906	843	668	349
GRSI-15A	10/11/93	22,413	22.2	1.10	1,101	5,990	201,005	16,789	1,654	3,529	6	219,481	887	881	792	905	824	651	346
GRSI-15B	10/11/93	22,362	22.2	1.80	1,102	5,989	200,320	16,754	2,751	3,659	6	220,973	886	881	795	906	834	660	349
GRSI-15C	10/11/93	22,467	22.4	2.70	1,118	5,947	201,568	16,647	4,133	3,517	6	221,062	886	881	795	906	852	678	358
GRSI-101B	11/2/93	30,110	23.4	1.49	1,583	5,955	271,131	24,423	3,082	3,603	7	286,355	887	871	828	925	942	734	370
GRSI-101B	11/11/93	29,724	23.3	1.72	1,557	5,886	269,000	23,534	3,548	3,726	6	221,265	885	881	779	904	826	654	338
GRSI-101C	11/11/93	30,246	23.0	1.74	1,559	5,950	278,473	22,205	3,590	3,704	5	296,651	886	881	808	936	909	729	382
GRSI-101A	11/11/93	30,428	22.9	1.75	1,557	5,933	269,243	25,734	3,620	3,699	5	177,421	892	891	774	902	805	641	354
GRSI-201B	11/12/93	22,142	23.3	2.06	1,158	5,768	200,486	17,751	3,169	3,778	6	212,547	886	881	790	904	828	656	345
GRSI-202A	11/12/93	22,441	23.0	2.09	1,158	5,857	202,861	19,882	3,222	3,780	4	295,541	885	881	816	938	926	737	398
GRSI-201A	11/12/93	22,344	23.1	2.12	1,158	5,924	196,739	19,327	3,250	3,797	5	215,810	887	881	788	904	833	668	359
GRSI-202B	11/12/93	22,598	23.3	2.12	1,158	5,870	204,429	22,729	3,310	3,770	5	220,924	886	881	789	906	839	681	369
GRSI-201C	11/12/93	22,207	23.2	2.14	1,158	5,931	205,754	15,938	3,259	3,795	5	218,224	891	881	774	903	826	656	355
GRSI	11/15/93	23,350	22.2	1.67	1,146	5,972	211,012	20,085	2,681	3,568	4	220,913	887	881	805	908	845	685	377
GRSI	11/16/93	23,409	22.2	1.97	1,149	5,966	211,201	19,779	3,136	3,753	5	220,344	885	881	788	906	843	680	369
GRSI	11/17/93	23,589	22.1	1.74	1,150	5,976	213,068	19,514	2,804	3,669	6	296,183	901	881	801	932	925	740	397
GRSI	2/16/94	28,269	21.5	1.33	1,333	5,882	254,629	22,886	2,638	3,435	6	244,322	897	881	812	916	891	706	371
GRSI	2/18/94	28,027	20.0	1.38	1,210	5,970	251,407	18,778	2,653	4,627	6	178,081	897	881	768	892	841	666	357
GRSI	3/28/94	29,673	21.7	1.21	1,420	5,637	269,852	22,479	2,469	4,514	4	268,219	890	880	839	928	897	681	345
GRSI	3/29/94	28,019	22.4	1.69	1,394	5,954	252,265	21,059	3,425	4,502	4	252,722	892	881	835	922	900	701	366
GRSI	3/30/94	28,896	22.2	1.78	1,422	5,858	257,232	21,949	3,514	4,521	4	259,411	892	881	832	924	904	705	368
GRSI	3/31/94	29,216	22.6	1.66	1,480	5,943	261,282	23,428	3,327	4,225	4	268,424	891	880	831	927	910	712	372

TABLE A-8. GAS REBURING-SORBENT INJECTION OPERATING DATA (CONTINUED)

Test I. D.	Test Date	Coal Flow (lb/hr)	Gas Heat (%)	Ca/S Molar Ratio	Reb Gas (scfm)	FGR (scfm)	Cyclone Air (lb/hr)	OFA Flow (scfm)	Sorb Flow (lb/hr)	Srb Inj AirFlow (scfm)	Opac (%)	Steam Load (lb/hr)	SSH Steam (F)	SSH Steam (psig)	PSH Steam (F)	Blr Drum (psig)	BlrBnk G I (F)	BlrBnk G O (F)	AirHtr G O (F)
GRSI	4/4/94	26,151	23.3	1.79	1,372	5,818	237,819	21,982	3,196	4,123	3	252,529	892	881	824	920	920	715	361
GR-SI	4/6/94	26,261	22.4	1.67	1,306	5,955	238,401	21,290	2,970	3,633	4	239,332	891	881	827	917	888	698	370
GRSI-23-24	5/13/94	22,152	21.8	1.86	1,067	5,985	201,531	17,583	2,839	3,041	4	209,729	891	881	812	904	863	682	372
GRSI-19-28	5/13/94	25,932	19.5	1.65	1,078	5,943	237,351	17,132	2,844	2,885	3	246,375	892	879	829	917	902	709	391
GRSI-22-28	5/13/94	25,142	21.8	1.77	1,209	5,918	235,782	21,130	3,052	2,820	3	244,993	888	881	820	916	898	711	384
GRSI	5/14/94	26,735	21.6	1.75	1,271	5,930	241,970	21,795	3,175	2,466	4	255,107	888	882	821	921	896	702	374
GRSI-23-33	6/2/94	30,964	22.1	1.64	1,520	6,000	281,581	23,088	3,487	1,902	5	273,433	896	881	853	932	959	725	374
GRSI-23-31	6/2/94	29,305	22.7	1.81	1,485	5,980	265,484	24,279	3,647	1,652	4	257,962	889	881	862	927	941	730	382

TABLE A-9. GAS REBURNING-SORBENT INJECTION THERMAL IMPACTS

Test I. D.	Test Date	Gross Power (MWe)	Gas Heat (%)	Ca/S Molar Ratio	TotStm H A (MBtu/hr)	Furn H A (MBtu/hr)	SSH H A (MBtu/hr)	PSH H A (MBtu/hr)	GenBnk H A (MBtu/hr)	Attmp H A (MBtu/hr)	AirHrt H A (MBtu/hr)	Furn H A Ratio	SSH H A Ratio	PSH H A Ratio	GenBnk H A Ratio	DrmAtt H A Ratio	AirHtr H A Ratio	Boiler Effic. (%)
GRSI-11A	9/30/93	27	24.7	2.25	261.3	161.3	30.5	50.4	19.0	18.9	34.3	0.94	1.16	1.06	1.02	1.61	1.14	83.35
GRSI-11B	10/1/93	24	22.4	2.13	241.4	155.6	24.4	43.8	17.6	11.7	32.2	0.97	1.05	1.02	1.08	1.27	1.23	83.48
GRSI-1A	10/5/93	33	22.0	1.77	349.5	217.9	40.3	68.1	23.2	25.2	41.8	1.01	1.04	0.98	0.82	1.12	1.12	83.25
GRSI-1B	10/5/93	33	22.2	1.63	349.2	218.3	39.4	68.5	23.0	25.8	44.4	1.01	1.02	0.99	0.81	1.14	1.18	82.54
GRSI-1C	10/5/93	33	22.3	1.68	350.8	217.5	39.5	70.1	23.7	26.5	45.3	1.00	1.02	1.01	0.83	1.16	1.21	82.32
GRSI-13A	10/6/93	23	26.2	1.90	264.2	173.8	27.0	47.6	15.8	13.9	29.3	1.01	1.03	0.99	0.84	1.18	1.14	83.60
GRSI-13B	10/6/93	24	20.4	1.90	264.6	174.6	27.6	47.3	15.2	14.0	29.2	1.02	1.04	0.98	0.81	1.17	1.12	83.50
GRSI-13C	10/6/93	24	17.5	2.00	268.6	177.1	28.1	48.2	15.1	14.6	29.4	1.02	1.04	0.98	0.78	1.17	1.10	83.38
GRSI-13D	10/6/93	24	14.9	1.91	270.5	178.7	28.4	48.6	14.7	14.7	29.9	1.02	1.04	0.98	0.76	1.16	1.12	83.42
GRSI-11A2	10/6/93	24	26.2	1.97	272.8	175.7	30.5	51.4	15.3	18.9	30.6	1.00	1.11	1.03	0.78	1.47	1.14	82.91
GRSI-3D	10/7/93	34	14.2	1.87	349.5	219.5	39.5	68.2	22.3	24.9	41.8	1.02	1.02	0.98	0.78	1.10	1.12	83.32
GRSI-3C	10/7/93	33	18.6	1.75	348.5	216.1	40.4	69.4	22.7	27.2	41.3	1.00	1.05	1.01	0.80	1.21	1.11	82.93
GRSI-3B	10/7/93	33	20.7	1.75	347.8	214.9	40.9	69.4	22.6	28.0	41.2	1.00	1.06	1.01	0.80	1.25	1.11	82.74
GRSI-3A	10/7/93	33	25.6	1.90	347.2	213.6	41.1	69.1	23.2	28.2	41.1	0.99	1.07	1.01	0.82	1.26	1.11	82.56
GRSI-12A	10/11/93	24	21.8	1.82	270.0	180.9	24.9	47.1	17.1	10.0	33.0	1.04	0.92	0.95	0.88	0.79	1.23	83.69
GRSI-12B	10/11/93	24	22.2	1.90	270.6	177.2	27.1	49.1	17.2	13.9	32.4	1.01	1.00	0.99	0.88	1.10	1.21	83.39
GRSI-15A	10/11/93	24	22.2	1.10	268.4	176.2	27.2	48.6	16.4	13.9	30.2	1.02	1.01	0.99	0.85	1.12	1.13	83.81
GRSI-15B	10/11/93	24	22.2	1.80	271.4	177.2	28.0	49.7	16.5	15.1	30.2	1.01	1.02	1.00	0.84	1.19	1.13	83.75
GRSI-15C	10/11/93	24	22.4	2.70	269.4	175.8	27.8	49.3	16.6	15.0	30.6	1.01	1.03	1.00	0.86	1.20	1.14	83.55
GRSI-101B	11/2/93	32	23.4	1.49	369.6	228.5	42.2	72.1	26.7	31.0	45.4	1.05	1.09	1.04	0.93	1.36	1.26	83.31
GRSI-101B	11/11/93	31	23.3	1.72	270.0	180.9	24.9	47.1	17.1	10.0	33.0	1.04	0.92	0.95	0.88	0.79	1.23	83.69
GRSI-101C	11/11/93	31	23.0	1.74	349.5	219.5	39.5	68.2	22.3	24.9	41.8	1.02	1.02	0.98	0.78	1.10	1.12	83.32
GRSI-101A	11/11/93	31	22.9	1.75	219.8	151.0	19.5	37.0	12.3	6.3	26.0	1.02	0.97	0.99	0.89	0.97	1.25	83.76
GRSI-201B	11/12/93	23	23.3	2.06	264.2	173.8	27.0	47.6	15.8	13.9	29.3	1.01	1.03	0.99	0.84	1.18	1.14	83.60
GRSI-202A	11/12/93	23	23.0	2.09	347.2	213.6	41.1	69.1	23.2	28.2	41.1	0.99	1.07	1.01	0.82	1.26	1.11	82.56
GRSI-201A	11/12/93	23	23.1	2.12	264.6	174.6	27.6	47.3	15.2	14.0	29.2	1.02	1.04	0.98	0.81	1.17	1.12	83.50
GRSI-202B	11/12/93	23	23.3	2.12	270.5	178.7	28.4	48.6	14.7	14.7	29.9	1.02	1.04	0.98	0.76	1.16	1.12	83.42
GRSI-201C	11/12/93	23	23.2	2.14	262.2	178.4	23.4	45.0	15.4	7.6	31.6	1.05	0.90	0.95	0.83	0.66	1.20	84.00
GRSI	11/15/93	26	22.2	1.67	272.8	175.7	30.5	51.4	15.3	18.9	30.6	1.00	1.11	1.03	0.78	1.47	1.14	82.91
GRSI	11/16/93	23	22.2	1.97	268.6	177.1	28.1	48.2	15.1	14.6	29.4	1.02	1.04	0.98	0.78	1.17	1.10	83.38
GRSI	11/17/93	23	22.1	1.74	339.8	217.8	35.8	64.4	21.6	17.7	43.9	1.04	0.97	0.97	0.80	0.84	1.18	83.39
GRSI	2/16/94	29	21.5	1.33	261.3	161.3	30.5	50.4	19.0	18.9	34.3	0.94	1.16	1.06	1.02	1.61	1.14	83.35
GRSI	2/18/94	27	20.0	1.38	220.4	151.1	19.8	36.5	13.0	5.4	26.7	1.02	0.99	0.98	0.95	0.82	1.28	83.84
GRSI	3/28/94	30	21.7	1.21	335.2	203.6	37.7	67.0	26.9	29.1	38.7	1.02	1.10	1.08	1.07	1.55	1.16	83.83
GRSI	3/29/94	28	22.4	1.69	321.9	198.5	36.7	63.3	23.5	27.5	37.6	1.03	1.13	1.08	1.00	1.61	1.20	83.33
GRSI	3/30/94	31	22.2	1.78	329.4	204.7	36.3	64.4	24.0	26.4	38.6	1.04	1.09	1.07	0.99	1.46	1.20	83.33
GRSI	3/31/94	32	22.6	1.66	339.2	209.5	38.8	66.4	24.5	28.4	40.1	1.04	1.12	1.06	0.96	1.48	1.20	83.19

Note: H A Ratio relative to baseline case

TABLE A-9. GAS REBURNING-SORBENT INJECTION THERMAL IMPACTS (CONTINUED)

Test I. D.	Test Date	Gross Power (MWe)	Gas Heat (%)	Ca/S Molar Ratio	TotStm H A (MBtu/hr)	Furn H A (MBtu/hr)	SSH H A (MBtu/hr)	PSH H A (MBtu/hr)	GenBnk H A (MBtu/hr)	Attmp H A (MBtu/hr)	AirHrt H A (MBtu/hr)	Furn H A Ratio	SSH H A Ratio	PSH H A Ratio	GenBnk H A Ratio	DrmAtt H A Ratio	AirHtr H A Ratio	Boiler Effic. (%)
GRSI	4/4/94	30	23.3	1.79	315.8	199.2	32.8	60.4	23.5	22.0	37.1	1.04	1.03	1.06	1.02	1.33	1.19	83.31
GR-SI	4/6/94	29	22.4	1.67	308.0	192.0	34.4	59.2	21.5	24.7	35.1	1.03	1.13	1.07	0.98	1.60	1.20	83.10
GRSI-23-24	5/13/94	24	21.8	1.86	257.1	162.7	28.1	49.0	17.3	17.6	27.5	0.97	1.11	1.06	0.97	1.60	1.09	82.94
GRSI-19-28	5/13/94	28	19.5	1.65	294.0	177.9	36.2	59.5	20.4	26.5	31.7	0.95	1.18	1.07	0.92	1.70	1.05	82.79
GRSI-22-28	5/13/94	28	21.8	1.77	293.3	181.0	33.5	58.0	20.7	23.0	34.3	0.97	1.10	1.05	0.94	1.48	1.14	82.59
GRSI	5/14/94	29	21.6	1.75	305.0	188.0	34.0	61.0	22.0	23.0	36.0	0.98	1.07	1.05	0.94	1.40	1.12	83.10
GRSI-23-33	6/2/94	33	22.1	1.64	372.0	225.4	43.6	73.3	29.7	35.7	43.8	1.08	1.19	1.11	1.10	1.71	1.28	83.39
GRSI-23-31	6/2/94	31	22.7	1.81	349.1	211.4	41.4	70.4	26.0	36.9	41.5	1.06	1.22	1.15	1.05	1.94	1.30	83.02

Note: H A Ratio relative to baseline case

APPENDIX 3

COAL, FLY ASH, AND SORBENT ANALYSES

TABLE B-1. COAL ANALYSES

Date	Sampling Location: Feeder	Moisture (%)	Volatile Matter (%)	Fixed Carbon (%)	Ash (%)	C (%)	H (%)	N (%)	S (%)	O (%)	HHV (Btu/lb)	SO2 Theoretical (lb/MBtu)	Stoichiometric Air (lb/lb coal)
5/14/93	East	17.13	32.77	40.43	9.67	57.16	3.99	1.15	2.99	7.91	10,272	5.82	7.75
5/14/93	West	17.94	33.23	39.04	9.79	56.51	3.91	1.12	3.11	7.62	10,216	6.09	7.66
7/13/93	West	19.56	32.22	38.41	9.81	55.14	3.72	1.14	2.95	7.68	9,990	5.91	7.43
7/13/93	East	21.58	30.36	38.04	10.02	53.29	3.62	1.04	2.86	7.59	9,661	5.92	7.18
7/20/93	East	20.16	31.82	37.89	10.13	55.05	3.72	1.05	2.95	6.94	9,885	5.97	7.45
7/20/93	West	24.30	29.79	36.36	9.55	51.65	3.54	0.98	2.81	7.17	9,379	5.99	6.98
9/2/93	East	18.18	33.04	39.31	9.47	57.19	4.21	1.11	3.07	6.77	10,233	6.00	7.88
9/2/93	West	17.66	32.47	40.03	9.84	56.49	4.00	1.10	3.09	7.82	10,221	6.05	7.68
9/3/93	East	19.84	32.39	38.36	9.41	55.24	4.02	1.05	3.11	7.33	9,980	6.23	7.57
9/3/93	West	20.62	32.99	37.11	9.28	54.53	3.79	1.05	3.08	7.65	9,934	6.20	7.39
10/1/93	West	18.17	32.81	39.27	9.75	56.95	3.93	1.10	3.15	6.95	10,279	6.13	7.75
10/1/93	East	17.93	32.91	39.53	9.63	56.42	3.89	1.07	3.18	7.88	10,308	6.17	7.64
4/16/94	East	18.23	35.87	36.36	9.54	56.62	3.89	1.14	3.01	7.57	10,317	5.84	7.67
4/16/94	West	17.99	33.18	39.34	9.49	58.26	4.13	1.12	3.12	5.89	10,397	6.00	8.02
Average		19.24	32.56	38.53	9.67	55.75	3.88	1.09	3.03	7.34	10,077	6.02	7.58
Maximum		24.30	35.87	40.43	10.13	58.26	4.21	1.15	3.18	7.91	10,397	6.23	8.02
Minimum		17.13	29.79	36.36	9.28	51.65	3.54	0.98	2.81	5.89	9,379	5.82	6.98
St. Dev.		1.95	1.40	1.27	0.24	1.75	0.19	0.05	0.11	0.56	290	0.13	0.27

TABLE B-2. COAL ASH CHARACTERISTICS

Date	Sampling Location: Feeder	SiO_2 (%)	Al_2O_3 (%)	TiO_2 (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)	K_2O (%)	Na_2O (%)	SO_3 (%)	P_2O_5 (%)	SrO (%)	BaO (%)	MnO (%)	Undet. (%)	Silica Value	Base: Acid Ratio	Ash Fusion Temperature * (°F)	Fouling Index
5/14/93	East	53.19	13.80	0.71	17.47	4.84	0.72	1.49	2.11	4.83	0.19	0.03	0.08	0.11	0.43	69.78	0.39	2,418	0.82
5/14/93	West	51.98	13.99	0.74	18.03	6.28	1.01	1.50	1.62	4.22	0.17	0.03	0.02	0.17	0.24	67.24	0.43	2,380	0.70
9/2/93	East	54.38	13.92	0.97	16.53	4.35	0.63	1.56	0.89	3.95	0.10	0.04	0.00	0.09	2.59	71.66	0.35	2,483	0.31
9/2/93	West	54.82	13.53	0.79	17.13	4.76	0.62	1.55	0.82	4.26	0.18	0.03	0.00	0.10	1.41	70.89	0.36	2,463	0.30
9/3/93	East	52.25	13.65	0.75	17.61	5.61	0.84	1.51	1.75	4.86	0.16	0.06	0.14	0.10	0.71	68.47	0.41	2,398	0.72
9/3/93	West	53.44	13.57	0.94	17.71	4.66	0.58	1.52	1.02	3.50	0.11	0.04	0.00	0.10	2.81	69.96	0.38	2,442	0.39
10/1/93	West	54.74	14.17	0.78	18.88	4.09	0.56	1.57	1.26	3.13	0.11	0.02	0.00	0.10	0.59	69.94	0.38	2,438	0.48
10/1/93	East	55.56	14.24	0.79	18.73	4.29	0.59	1.58	1.15	2.84	0.10	0.02	0.00	0.11	0.00	70.18	0.37	2,445	0.43
Average		53.80	13.86	0.81	17.76	4.86	0.69	1.54	1.33	3.95	0.14	0.03	0.03	0.11	1.10	69.77	0.38	2,433	0.52
Maximum		55.56	14.24	0.97	18.88	6.28	1.01	1.58	2.11	4.86	0.19	0.06	0.14	0.17	2.81	71.66	0.43	2,483	0.82
Minimum		51.98	13.53	0.71	16.53	4.09	0.56	1.49	0.82	2.84	0.10	0.02	0.00	0.09	0.00	67.24	0.35	2,380	0.30
St. Dev		1.29	0.27	0.09	0.78	0.74	0.16	0.03	0.46	0.74	0.04	0.01	0.05	0.03	1.07	1.37	0.03	34	0.20

* Note: T250 Temperature

TABLE B-3. ANALYSES OF LINWOOD HYDRATED LIME

Shipment Date	Trialer #	Ca(OH)2 (%, weight)	Free H2O (%, weight)
4/18/93	220	91.0	1.2
4/18/93	211	92.3	1.1
4/18/93	234	90.5	1.3
4/18/93	234	91.7	1.1
4/18/93	221	91.3	1.1
5/14/93	219	94.2	0.6
5/14/93	275	93.6	0.6
5/26/93		93.1	0.7
9/14/93	274	94.4	0.8
9/14/93	221	94.1	0.8
9/24/93	256	92.4	1.0
9/24/93	253	92.9	0.5
9/24/93	274	92.8	0.6
9/24/93	221	92.4	0.9
10/8/93	274	94.6	0.3
10/8/94	253	94.7	0.3
10/8/93	211	93.9	0.4
10/8/93	222	94.0	0.6
Average		**93.0**	**0.8**

APPENDIX 4

NOVACON SORBENT TEST REPORT

NovaCon Sorbent Testing
at Lakeside Station Unit 7
City Water, Light & Power - Springfield, Illinois

Test Report

Prepared by:
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1345 N. Main Street
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November 18, 1994

1.0 INTRODUCTION

Testing of sorbents provided by NovaCon Energy Systems, Inc. of Bedford, New York, was conducted at Lakeside Station Unit 7 as part of the Gas Reburning-Sorbent Injection (GR-SI) demonstration. The GR-SI demonstration is a Clean Coal Technology Program (Round 1) sponsored by the U.S. DOE, Gas Research Institute (GRI), Illinois State Department of Energy and Natural Resources (ENR), and the host utility. The work has been carried out by Energy and Environmental Research Corporation (EER). The NovaCon Sorbent Test was co-funded by the Illinois Clean Coal Institute and followed long-term GR-SI testing with Linwood hydrated lime sorbent.

Two types of sorbents referenced as Dolomitic and Calcitic were tested from October 17 to 19, 1994. The Dolomitic sorbent was denoted "90-325," because it has a specified fineness of 90% passing 325 mesh U.S. Standard Sieve, and has a makeup of approximately 55% $CaCO_3$, corresponding to a calcium content of 22%. The Calcitic sorbent is denoted "80-200," with a specified 80% passing 200 mesh U.S. Standard Sieve, and has a makeup of 93% $CaCO_3$, corresponding to 37% calcium content.

These sorbents have an approximate settled density of 90 lb/ft^3. This is three times that of the Linwood calcitic hydrate which has been the baseline sorbent at Lakeside. The difference in bulk density required adjustment to the sorbent feed and air transport systems. Sorbent Injection tests were preceded by a coal only baseline test, from which SO_2 reductions were calculated.

Both Dolomite and Calcite sobents were evaluated by EER in a Boiler Simulation Furnace (BSF), at EER's Santa Ana, California test facility, prior to the full scale evaluation. These tests focused on optimizing SO_2 reduction/calcium utilization and on characterization of fly ash/spent sorbent mixture. SO_2 reductions/calcium utilizations were compared to results obtained with Linwood hydrate. These tests indicated that SO_2 capture depended significantly on the particle size (grind), with fine grinds yielding the best results, and on injection temperature. The optimum injection temperatures for NovaCon sorbents were higher than that of Linwood hydrated lime. This indicated that NovaCon sorbents may perform well in boilers which have relatively high furnace temperature, such as cyclone fired units. A Toxicity Characteristic Leaching Procedure (TCLP) test indicated that the fly ash/spent sorbent mixture, obtained with Dolomite, is not hazardous.

2.0 TEST RESULTS

Results of NovaCon Sorbent testing at Lakeside Unit 7 are summarized in Table 1 and are compared with Linwood hydrate results in Figures 1 and 2. Due to the availability of materials, the sorbents were evaluated with short (typically less than 1 hour data points) parametric tests. The calcium to sulfur molar ratios ranged from 0.90 to 2.52 at full load, but reached 4.06 at reduced load of 22 MW_e. The mass loading of Calcitic sorbent was lower than that of Dolomitic sorbent, due to its higher calcium content. SO_2 reductions for Dolomite 90-325 ranged from 12% (Ca/S of 0.90) to 27% (Ca/S of 1.82). Calcium utilization ranged from 10% at high sorbent addition rates (Ca/S of 1.96 to 2.52), to 15% at low sorbent addition rates (Ca/S below 1.6). SO_2 reduction with the Calcitic sorbent at full load ranged from 17 to 18% (Ca/S of 1.35 to 1.68) to 24% (Ca/S of 2.45). The calcium utilization was in the 10 to 13% range. Testing of Calcite at a reduced load of 22 MW_e indicated reduced performance. At low load, injection of Calcitic sorbent at Ca/S molar ratios of 3.47 to 4.06 resulted in SO_2 reductions of 16 to 18% and calcium utilization of 5%. All SO_2 reductions were calculated from the 5.507 lb/MBtu baseline.

The performance of both the NovaCon sorbents, 90-325 and Calcitic, was significantly below that achieved in earlier BSF experimental testing, and also below that expected for the Lakeside Unit. BSF test data are summarized in Figures 3 and 4, which show SO_2 removal rates as a function of Ca/S and injection temperature respectively. Such data has been used successfully in the past, in the extrapolation, interpolation and evaluation of sorbent performance in a variety of applications.

The data in Figure 3 suggest that the Dolomitic 90-325 sorbent performs similarly to the Linwood calcitic hydrate, which has been the baseline sorbent at Lakeside to date, while the Calcitic sorbent yields SO_2 removal rates at about 63% of the level of Linwood. The data in

TABLE 1. SUMMARY OF NOVACON SORBENT PERFORMANCE AT LAKESIDE STATION UNIT 7

Test I.D.	Test Date	Sorbent	Gross Load (MWe)	SO2 Emissions (lb/MBtu)	Sorbent Flow (lb/hr)	Ca/S Molar Ratio	Sorbent Injection Air (scfm)	SO2 Reduction * (%)	Calcium Utilization (%)
SI	10/18/94	Dolomite	33.2	4.081	14,341	2.52	4,019	25.89	10.28
SI	10/18/94	Dolomite	32.6	4.345	10,944	1.96	4,053	21.10	10.77
SI	10/18/94	Dolomite	32.7	4.172	8,827	1.57	4,117	24.24	15.44
Test #1	10/19/94	Dolomite	32.8	4.799	5,186	0.90	4,252	12.86	14.28
Test #2	10/19/94	Dolomite	33.3	4.819	5,225	0.90	2,991	12.49	13.88
Test #3	10/19/94	Dolomite	32.8	4.754	5,252	0.91	4,987	13.67	15.03
Test #4	10/19/94	Dolomite	32.8	4.043	10,529	1.82	4,290	26.58	14.61
Test #5	10/19/94	Dolomite	32.9	4.179	9,032	1.56	4,366	24.11	15.46
Test #6	10/19/94	Calcite	33.0	4.182	8,441	2.45	4,352	24.06	9.82
Test #7	10/19/94	Calcite	33.2	4.524	4,683	1.35	4,502	17.85	13.22
Test #8	10/19/94	Calcite	31.6	4.594	5,410	1.68	4,515	16.58	9.87
Test #9	10/19/94	Calcite	22.6	4.618	8,364	3.47	4,433	16.14	4.65
Test #10	10/19/94	Calcite	22.2	4.499	9,896	4.06	4,405	18.30	4.51

* Note: SO2 Reductions Calculated From 5.507 lb/MBtu Baseline

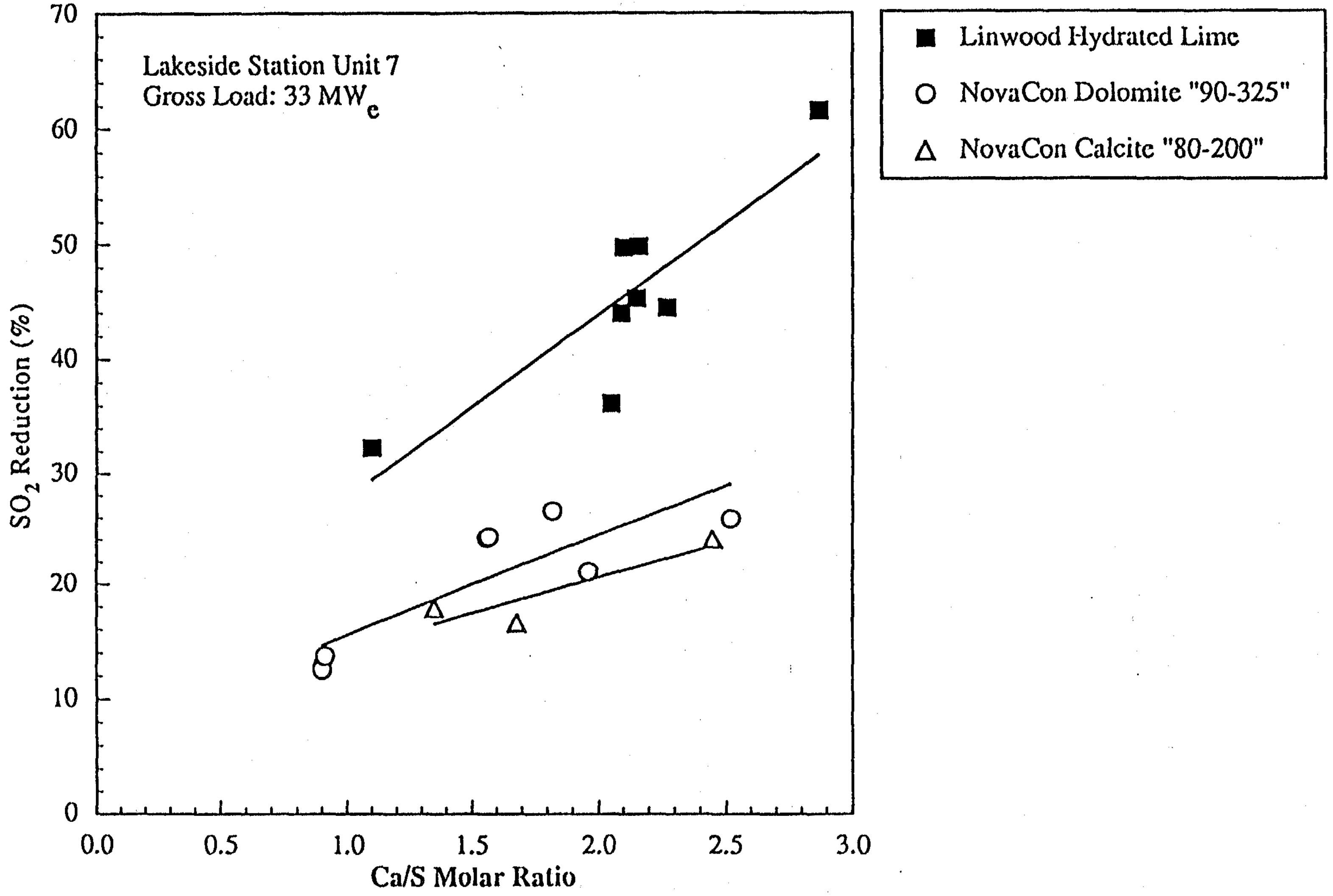


Figure 1. SO_2 reductions of NovaCon and Linwood Hydrated Lime sorbents.

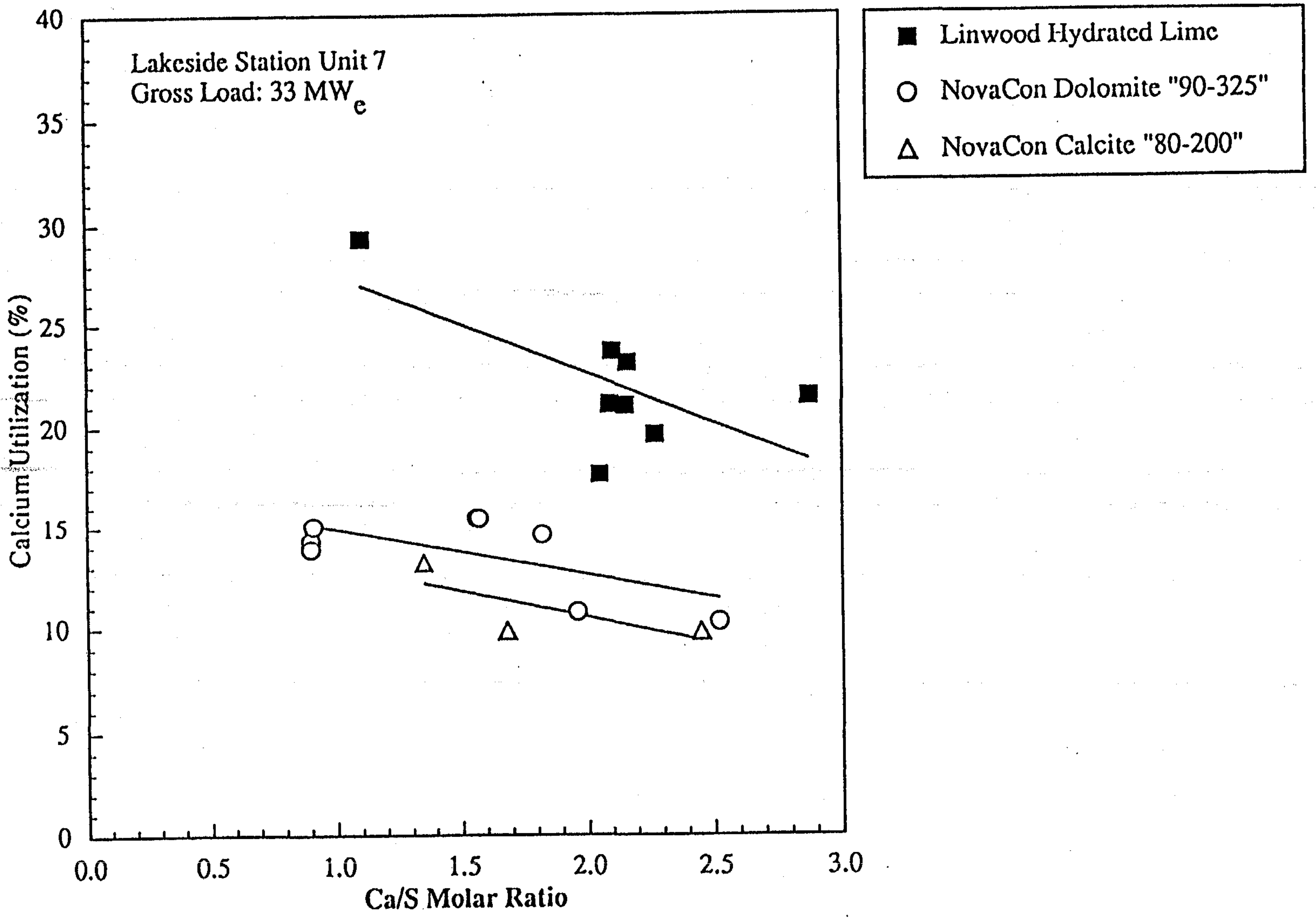
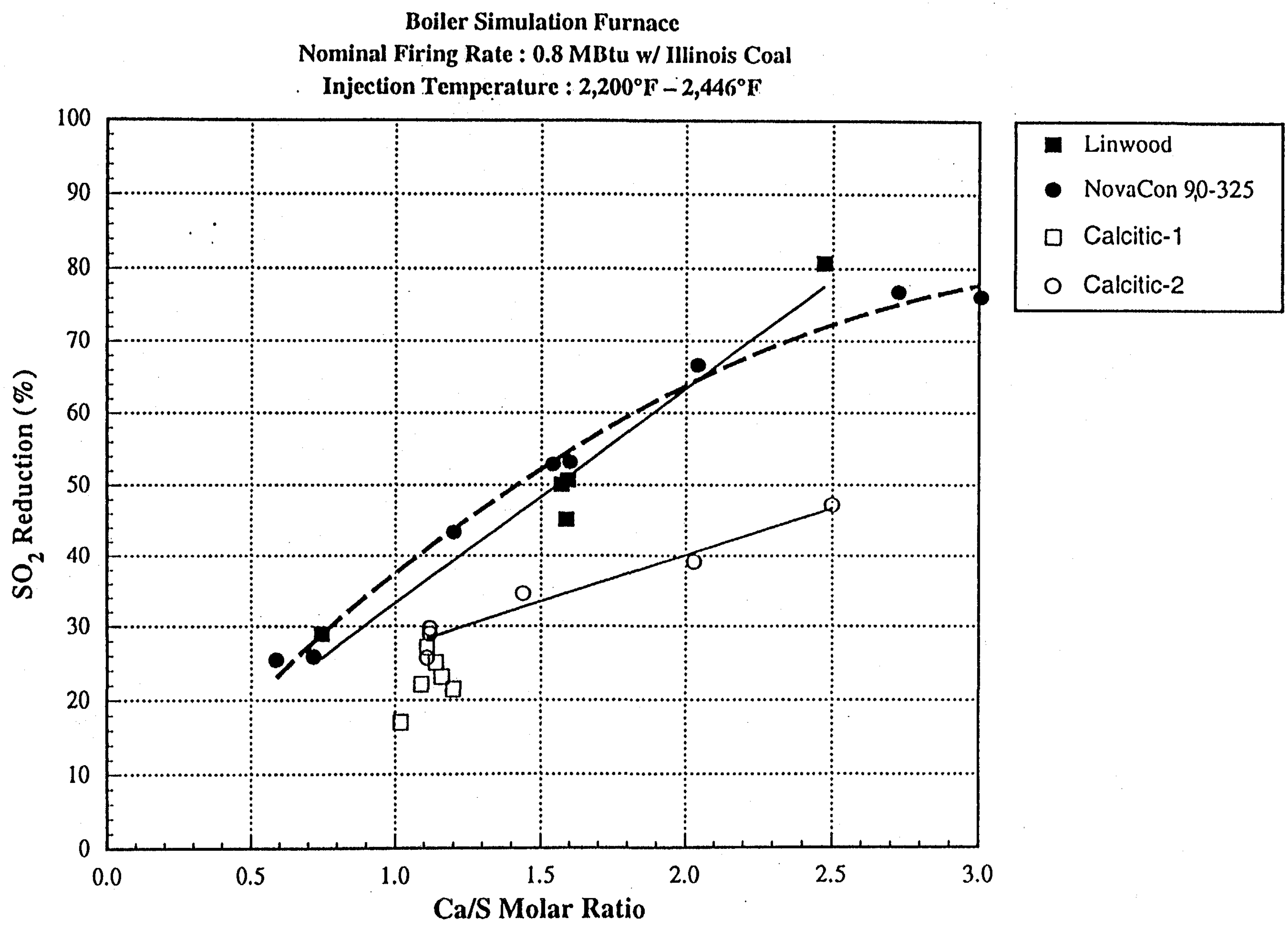


Figure 2. Calcium utilization of NovaCon and Linwood Hydrated Lime sorbents.



Boiler Simulation Furnace
Nominal Firing Rate : 0.8 MBtu w/ Illinois Coal
Injection Temperature : 2,200°F – 2,446°F

Figure 3. SO_2 reduction as a function of Ca/S molar ratio (BSF).

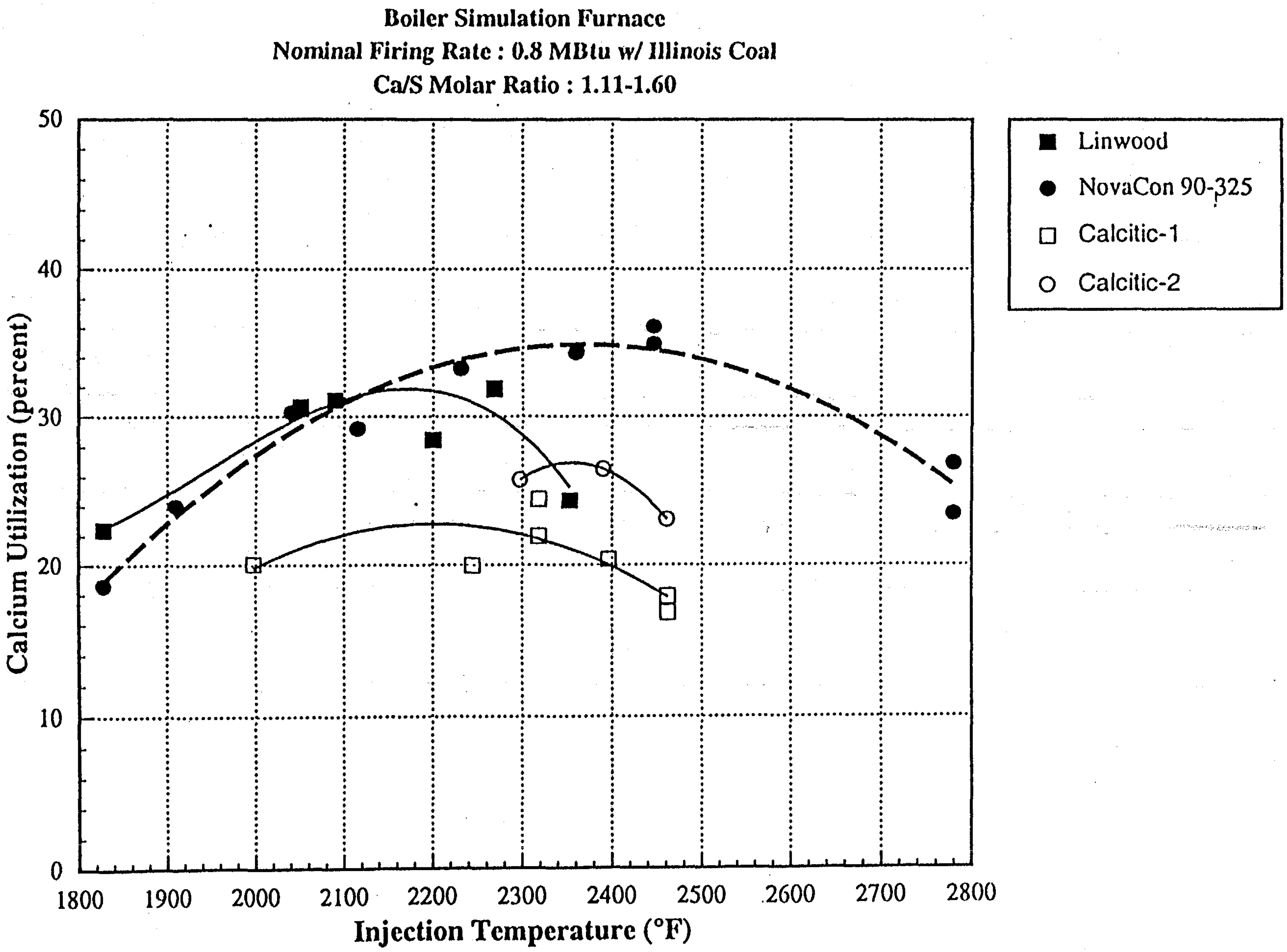


Figure 4. Injection temperature varation test (BSF).

Figure 4 indicate further that both NovaCon sorbents yield optimum performance at an injection temperature some 200°F higher than that for the Linwood hydrate (~2350°F compared to ~2150°F). The BSF data are not expected to translate directly to the Lakeside boiler, since absolute performance will be impacted by parameters such as injection temperature, quench rate and mixing. However, experience suggests that the relative behavior between sorbents should hold. On this basis, and using the data in Figure 3, when the Linwood sorbent achieves 40% SO_2 removal in the boiler the NovaCon sorbents would be expected to yield 40-44% and 30% SO_2 removal respectively. The boiler data in Figure 1 indicate SO_2 removal rates of ~25% and ~19% respectively, corresponding to about 60% of expected values.

The reason for the reduced level of performance of the NovaCon sorbents in the boiler is not immediately apparent from the data, although injection temperature, and temperature quench rate are parameters which can significantly impact sorbent behavior. In this regard it should be noted that the sorbent injection system at Lakeside has been designed to accommodate the properties of the Linwood calcitic hydrate. Mean gas temperatures at the boiler injection elevation are ~2200°F and ~2450°F, at the upper and lower elevations respectively. This is quite close to optimum for the Linwood sorbent at boiler conditions, and the measured performance (Figure 1) is consistent with the mean injection temperature of some 2300°F and a quench rate of ~1000°F/sec.

Both the NovaCon 90-325 and Calcitic sorbents have been shown to prefer somewhat higher injection temperatures, and performance should be expected to improve the injection at a lower elevation in the boiler (~2400 - 2500°F). However, injection temperature does not explain all sorbent behavior, since experience suggests that, to a first approximation, temperature and quench rate affect all sorbents equally, and consequently that the relative behavior between Linwood and NovaCon should translate from the BSF to the field. One explanation may be that the NovaCon sorbents are more sensitive to the higher quench rates which are typical of many field installations (and the Lakeside boiler in particular), though this would be inconsistent with prior experience. Another potential reason for the apparent reduced SO_2 removal performance could be that the sorbents tested at Lakeside are different from those tested earlier in the BSF. Particle size distribution can, for example, have a significant impact on the behavior of both

Dolomitic and Calcitic materials though there are other physical and chemical parameters which may not have been characterized. Some additional evaluation of sorbent samples obtained from the Lakeside tests might be beneficial in resolving any differences.

A Boiler Performance Monitoring System (BPMS) was used to monitor boiler characteristics. The BPMS data indicates that under sorbent injection there was reduced heat absorption by the secondary superheater, but increased heat absorption by the furnace, primary superheater and air heater. This change in heat absorption pattern is due to sorbent deposition. Reduced levels of steam attemperation were required. The unit has a drum type attemperator mounted in the upper steam drum. The secondary superheater outlet steam temperatures were maintained in the range of 887 to 894°F, which is the same as under baseline operation. Overall the changes in thermal performance were very minor. The duration of the tests was not sufficient to characterize the impacts on ESP performance and sootblowing cycles.