INTEGRATED DRY NO_x/SO_2 EMISSIONS CONTROL SYSTEM:

INTEGRATED SYSTEM TEST REPORT

(Test Period: February 7, 1994 to March 14, 1996)

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Draft: August 1996
Revised: February 1997

Final: April 1997

Patents Cleared by Chicago on MAY 23 1997

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ABSTRACT

The DOE sponsored Integrated Dry NO_x/SO_2 Emissions Control System Program, is a Clean Coal Technology III demonstration, being conducted by Public Service Company of Colorado. The test site is Arapahoe Generating Station Unit 4, a 100 MWe, down-fired utility boiler burning a low-sulfur Western coal. The project goal is to demonstrate up to 70 percent reductions in NO_x and SO_2 emissions through the integration of: (1) down-fired low-NO_x burners with overfire air; (2) Selective Non-Catalytic Reduction (SNCR) for additional NO_x removal; and (3) Dry Sorbent Injection (DSI) and duct humidification for SO_2 removal.

This report documents the final phase of the test program, in which the overall performance of the integrated system was evaluated. Previous testing has shown that the goal of 70 percent NO_x removal was easily achieved with the combination of low-NO_x burners, overfire air, and urea-based SNCR. Similarly, the ability of the sodium-based DSI system to achieve 70 percent SO_2 removal was also demonstrated previously.

The integrated tests demonstrated the synergistic benefit of operating the SNCR and sodium-based DSI systems concurrently. With the automatic control system set to limit the NH_3 emissions to less than 8 ppm, the NO_2 emissions from the sodium-based DSI system were reduced by nominally 50 percent compared to operation with the DSI system alone. Comparably, the combined operation reduced NH_3 emissions, as reflected by a higher urea *injection rate for a fixed NH_3 emission limit.*

With combined DSI and SNCR operation, an ammonia odor problem was encountered around the Unit 4 ash silo (this did not occur with the SNCR system operated alone at comparable NH_3 slip levels). This odor problem is attributed to the sodium changing the rate at which NH_3 is released from the ash when it is wetted for truck transport to the disposal site.

ACKNOWLEDGEMENTS

The authors would like to thank Mr. Jim Love, Arapahoe Plant Manager, and his maintenance and operating staff for the exceptional cooperation they have provided during this project. Special thanks are also deserved by Mr. Jerry L. Hebb of the Pittsburg DOE Federal Energy Technology Center (FETC) office, whose contribution is greatly appreciated. The advice and technical support provided by Mr. Jeff Stallings at Electric Power Research Institute (EPRI), has also been of great assistance throughout the project. Last, but definitely not least, is our appreciation to the many PSCo Engineering and Construction personnel and other contractors who have made the Integrated Dry NO_x/SO_2 Emissions Control System a success.

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LIST OF DEFINITIONS

ARIL	Advanced Retractable Injection Lance
B&W	Babcock & Wilcox
CEM	Continuous Emission Monitor
cfm	Cubic Feet per Minute
DCS	Distributed Control System
DOE	U. S. Department of Energy
DRB-XCL®	Dual Register Burner - Axially Controlled Low-NO_x
DSI	Dry Sorbent Injection
EPRI	Electric Power Research Institute
FEGT	Furnace Exit Gas Temperature
FERCo	Fossil Energy Research Corp.
FFDC	Fabric Filter Dust Collector
HVT	High Velocity Thermocouple
ID	Induced Draft (fan)
LCP	Local Control Panel
LNB	Low-NO_x Burner
MWe	MegaWatts (electrical)
MWg	MegaWatts (gross)
N/NO	Nitrogen-to-NO Ratio
OFA	OverFire Air
PLC	Programmable Logic Controller
ppm	Parts Per Million
ppmc	Parts Per Million Corrected to 3 percent O_2 level
ppm,d	Parts Per Million, Dry basis
ppm,w	Parts Per Million, Wet basis
PSCo	Public Service Company of Colorado
psig	Pounds per Square Inch Gauge
RATA	Relative Accuracy Test Audit
scfh	Standard Cubic Feet per Hour, measured at 1 atmosphere and 60°F
SNCR	Selective Non-Catalytic NO_x Reduction
2Na/S	Sodium-to-Sulfur Ratio

EXECUTIVE SUMMARY

This test report summarizes the technical activities and results for one phase of a Department of Energy sponsored Clean Coal Technology III demonstration of an Integrated Dry NO_x/SO_2 Emissions Control System for coal-fired boilers. The project is being conducted at Public Service Company of Colorado's Arapahoe Generating Station Unit 4 located in Denver, Colorado. The project goal is to demonstrate up to 70 percent reductions in NO_x and SO_2 emissions through the integration of existing and emerging technologies, including: (1) down-fired low-NO_x burners with overfire air; (2)Selective Non-Catalytic Reduction (SNCR) for additional NO_x removal; and (3) Dry Sorbent Injection (DSI) and duct humidification for SO_2 removal.

Due to the number of technologies being integrated, the test program has been divided into the following test activities:

- Baseline tests with the original combustion system
- Baseline tests with the original combustion system and SNCR
- Low-NOx Burner (LNB)/Overfire Air (OFA) tests
- LNB/OFA/SNCR tests
- LNB/OFA/Calcium-based DSI tests
- LNB/OFA/Sodium-based DSI tests
- LNB/OFA/ARIL Lance SNCR tests
- LNB/OFA/SNCR/DSI tests (integrated system testing)

This report documents the eighth (final) phase of the test program, in which the overall performance of the integrated system was evaluated. Previous testing has shown that the goal of 70 percent NO_x removal was easily achieved with the combination of low-NO_x burners, overfire air, and urea-based SNCR (Smith, et al., 1994a and 1996b). Similarly, the ability of the sodium-based DSI system to achieve 70 percent SO_2 removal was also demonstrated previously (Smith, et al., 1996a). The main focus of this final test phase was to investigate the "synergistic benefits" of operating the SNCR and DSI systems concurrently. In particular, the integrated system was expected to result in reduced NH_3 emissions from the SNCR process, as well as reduced NO_2 emissions from the sodium injection process.

Parametric testing provided indications that the NO_2 emissions were reduced with the integrated system. The time history of an integrated test where the DSI system was started approximately four hours before urea injection began (to allow the NO_2 emissions to stabilize), is shown in Figure ES-1. The results indicate that the NO_2 emissions were reduced with SNCR, but it is difficult to quantify the actual reduction level due to the short duration of the test. Overall, the NO_2 reductions measured during the parametric tests were variable, due to both the short duration of the parametric tests, and the effect of baghouse cleaning cycle on NO_2 emissions.

The parametric tests were also generally too short in duration to assess if the NH_3 emissions were reduced with the integrated system. This was a result of the time required for the NH_3 emissions to stabilize due to adsorption and desorption on the flyash in the baghouse. Figure ES-2 shows the time history of the only parametric test which indicated a significant reduction in NH_3 emissions (from nominally 16 to 10 ppm). Although this single parametric test provided an indication of the NH_3 emission reductions achievable with the integrated system, long-term load-following tests were required to accurately assess the benefits of the integrated system. Also note, for the test shown in Figure ES-2, the SNCR system was started three hours before the sodium was injected. As a result, there was no increase in NO_2 due to the sodium injection for this entire test.

Long-term load-following operation of the integrated system with the DSI controls set to maintain 75 percent SO_2 removal, and the SNCR controls set to limit the NH_3 emissions to 8 ppm, yielded average overall NO_x removals of nominally 40 percent. This was a 9 percent (net) increase over the sum of the NO_x removals measured during the separate application of the two control technologies. This increase indicated that the integrated system indeed resulted in a reduction in stack NH_3 emissions. The reduction allowed higher urea injection rates for a fixed NH_3 emission limit, and thus, increased SNCR NO_x removals.

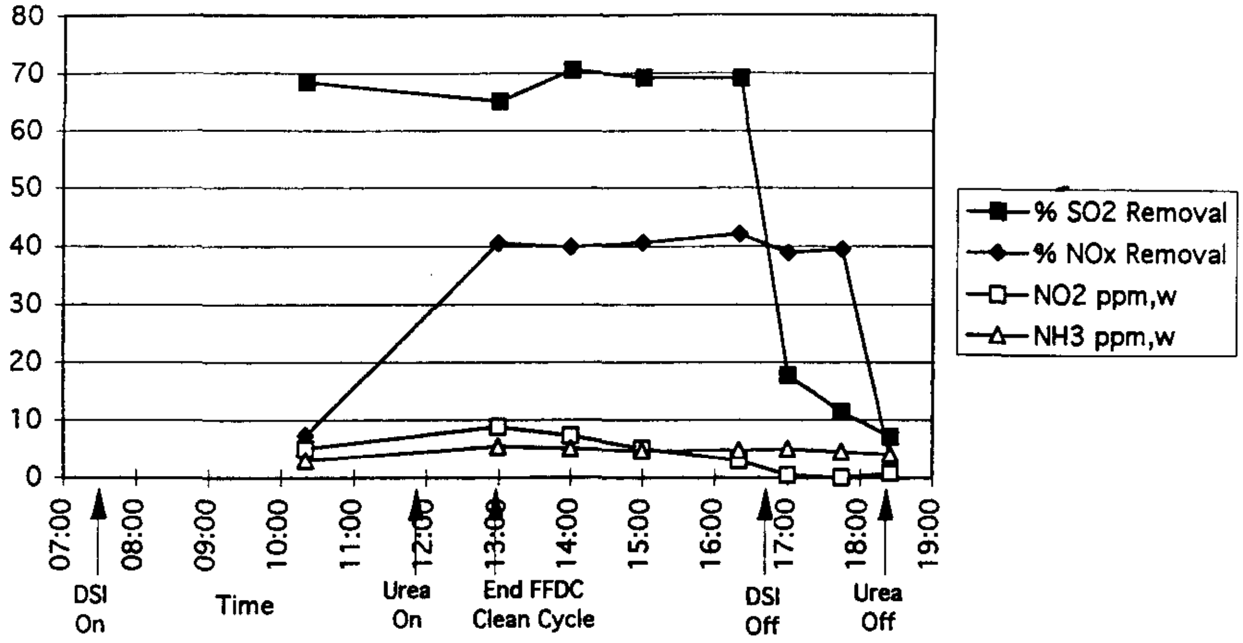


Figure ES-1. Time History of Integrated Test with Sodium Sesquicarbonate Injection (95 MWe, 2Na/S = 2.0, N/NO = 1.0)

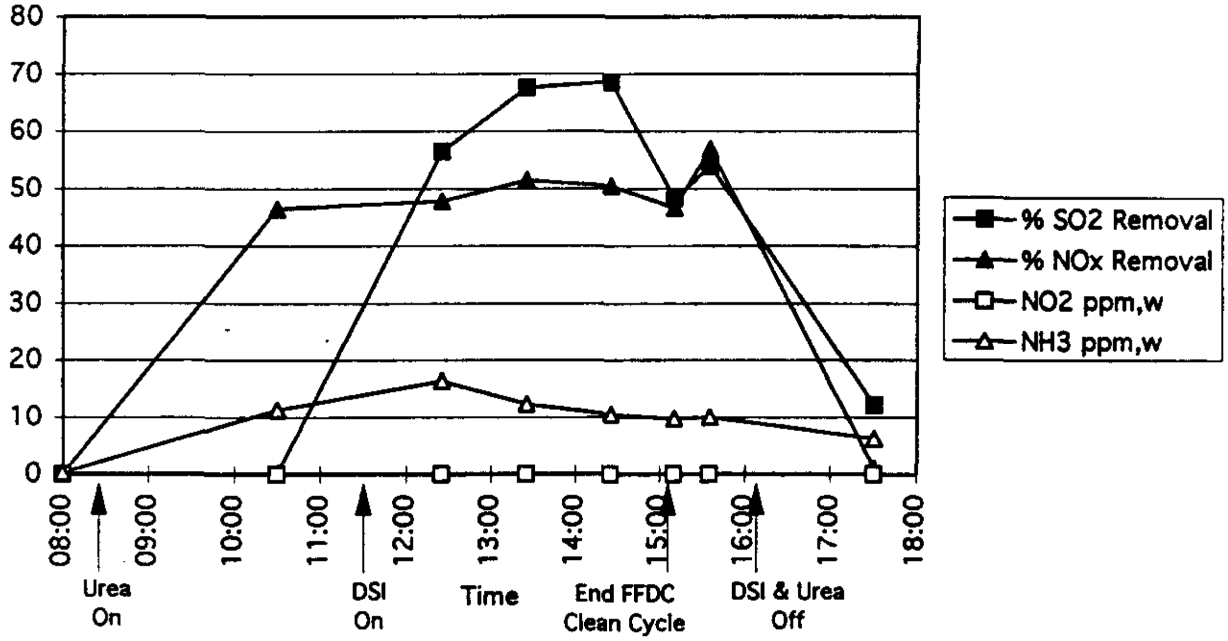


Figure ES-2. Time History of Integrated Test with Sodium Bicarbonate Injection (100 MWe, 2Na/S = 1.1, N/NO = 1.1)

The long-term testing also showed that the integrated system resulted in substantially reduced NO_2 emissions when compared to the DSI system alone. The average NO_2 emissions were reduced by nominally 50 percent when the integrated system was run with a stack NH_3 emission limit of 8 ppm. When the emission limit was 4.5 ppm, the reduction was on the order of 40 percent.

During the long-term integrated testing, a heavy NH_3 odor developed at the Unit 4 ash silo while mixing dust control water with the flyash. This was unexpected as previous testing with only the SNCR in operation had shown only a faint NH_3 odor even though flyash NH_3 concentrations of 100 to 200 ppm (by weight) occurred. The control point for the NH_3 trim setting was reduced from 8 to 4.5 in an attempt to reduce the odor. The flyash NH_3 concentration was reduced from nominally 550 to 150 ppm (by weight), but the heavy odor problem continued. After further investigation it was found that the addition of the sodium reagent in the waste stream caused a rapid pH change during the wetting process. This caused faster release of the NH_3 absorbed on the ash. While no major problems are created using only SNCR, the integration of sodium and urea injection did cause a concern. This concern was later addressed by switching to a dry disposal process that did not add water to the flyash.

In conclusion, the integrated tests demonstrated that the overall technical goals of the program (i.e., 70 percent NO_x removal and 70 percent SO_2 removal) could be achieved. Furthermore, the tests confirmed the synergistic benefits of reduced NH_3 and NO_2 emissions by integrating SNCR with sodium-based dry sorbent injection.

1.0 INTRODUCTION

This report presents the results from the final phase of the Public Service Company of Colorado (PSCo) and the Department of Energy (DOE) sponsored Integrated Dry NO_x/SO_2 Emissions Control System program. The DOE Clean Coal Technology III demonstration program is being conducted by Public Service Company of Colorado at PSCo's Arapahoe Generating Station Unit 4, located in Denver, Colorado. The intent of the demonstration program at Arapahoe Unit 4 is to achieve up to 70 percent reductions in NO_x and SO_2 emissions through the integration of existing and emerging technologies, while minimizing capital expenditures and limiting waste production to dry solids that are handled with conventional ash removal equipment. The technologies to be integrated are: (1) a down-fired low-NO_x burner system with overfire air; (2) Selective Non-Catalytic Reduction (SNCR) with urea and ammonia-based compounds for additional NO_x removal; and (3) dry sorbent injection (calcium- and sodium-based compounds) and duct humidification for SO_2 removal. Figure 1-1 shows a simplified schematic of the integrated system as implemented at Arapahoe Unit 4.

During the demonstration program, these emission control technologies are being optimized and integrated with the goal of achieving up to 70 percent reductions in NO_x and SO_2. It is anticipated that the integrated emissions control system will achieve these reductions at costs lower than other currently available technologies. It is also anticipated that these technologies will integrate synergistically. For example, an undesirable side effect of sodium-based sorbent injection for SO_2 control has been oxidation of NO to NO_2, resulting in plume colorization. Pilot-scale testing, sponsored by the Electric Power Research Institute (EPRI), has shown that the presence of NH_3 can reduce the NO_2 emissions from sodium-based dry sorbent injection. In the integrated system, the byproduct NH_3 emissions from the urea injection system will serve to minimize NO_2 formation.

Due to the number of technologies being integrated, the test program has been divided into the following test activities:

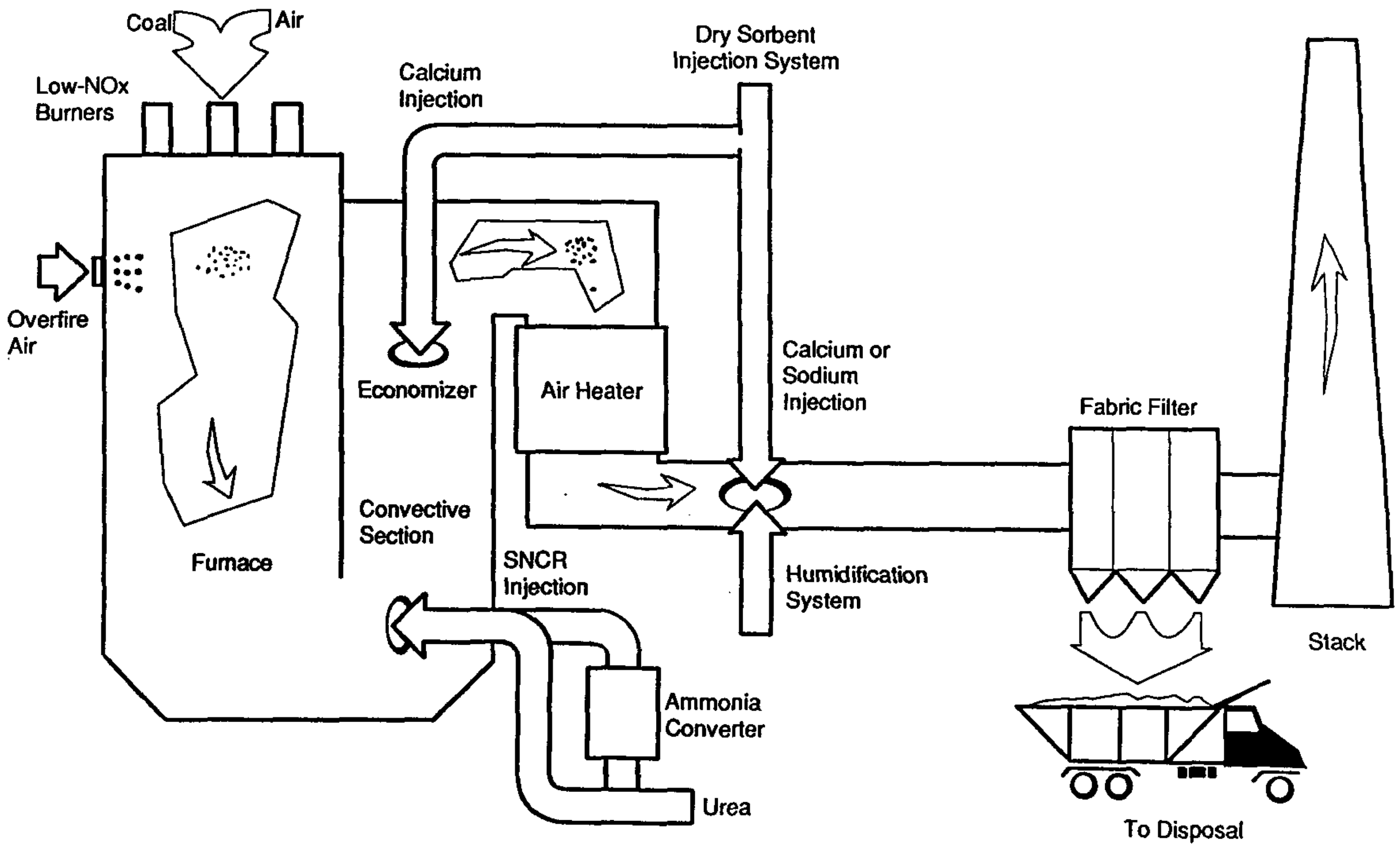


Figure 1-1. Arapahoe Unit 4 Integrated Dry NO_x/SO_2 Emissions Control System

- Baseline tests of the original combustion system. These results provide the basis for comparing the performance of the individual technologies as well as that of the integrated system. (completed, Shiomoto, et al., 1992)

- Baseline combustion system/SNCR tests. Performance of urea and aqueous ammonia injection with the original combustion system. (completed, Smith, et al., 1993)

- Low-NO_x burner (LNB)/overfire air (OFA) tests. (completed, Smith, et al., 1994a)

- LNB/OFA/SNCR tests. NO_x reduction potential of the combined low-NO_x combustion system and SNCR. (completed, Smith, et al., 1994b)

- LNB/OFA/calcium-based sorbent injection. Economizer injection and duct injection with humidification. (completed, Shiomoto, et al., 1994)

- LNB/OFA/sodium-based sorbent injection. SO_2 removal performance of sodium sesquicarbonate and sodium bicarbonate. (completed, Smith, et al., 1996a)

- LNB/SNCR ARIL lance tests. Improved performance of the SNCR system with the addition of the retractable injection lances (completed, Smith, et al., 1996b, to be issued as an EPRI report)

- Integrated Systems test. NO_x and SO_2 reduction potential of the integrated system using LNB/OFA/SNCR/dry sorbent injection using sodium-based reagents. Assess integrated system performance. (subject of this report)

In addition to investigation of NO_x and SO_2 emissions, the test program also investigated air toxics emissions. Air toxics emission levels were measured during the testing of the low-NO_x combustion system, and during the LNB/OFA/SNCR tests with urea. Air toxics emission levels were also measured during the calcium-injection tests, and additional tests were conducted during the sodium-injection tests to determine the potential air toxics removal of these two pollution control technologies. The air toxics test results will be documented in separate Environmental Monitoring Reports.

This report presents the results of the integrated system tests with sodium-based, dry-sorbent injection and urea-based SNCR. The majority of the testing was performed with sodium-sesquicarbonate injection downstream of the air heater. A limited number of sodium-bicarbonate tests were also run with injection both upstream and downstream of the air heater.

2.0 PROJECT DESCRIPTION

The following subsections will describe the key aspects of all the technologies being demonstrated as a part of the Integrated Dry NO_x/SO_2 Emissions Control System program. The project participants and their relative roles are also reviewed.

2.1 Process Description

The Integrated Dry NO_x/SO_2 Emissions Control System consists of five major control technologies that are combined to form an integrated system to control both NO_x and SO_2 emissions. NO_x reduction is accomplished through the use of low-NO_x burners, overfire air, and SNCR, while dry sorbent injection (using either calcium- or sodium-based reagents) is used to control SO_2 emissions. Flue gas humidification was also used to enhance the SO_2 removal capabilities of the calcium-based sorbents. Each of these technologies is discussed briefly below.

2.1.1 Low-NO_x Burners

NO_x formed during the combustion of fossil fuels consists primarily of NO_x formed from fuel-bound nitrogen, and thermal NO_x. NO_x formed from fuel-bound nitrogen results from the oxidation of nitrogen which is organically bonded to the fuel molecules. Thermal NO_x forms when nitrogen in the combustion air dissociates and oxidizes at flame temperatures. Thermal NO_x is of primary importance at temperatures in excess of 2800°F.

To reduce the NO_x emissions formed during the combustion process, Babcock & Wilcox (B&W) Dual Register Burner-Axially Controlled Low-NO_x (DRB-XCL®) burners were retrofit to the Arapahoe Unit 4 boiler. Most low-NO_x burners reduce the formation of NO_x through the use of air staging, which is accomplished by limiting the availability of air during the early stages of combustion. This lowers the peak flame temperature and results in a reduction in the formation of thermal NO_x. In addition, by reducing the oxygen availability in the initial combustion zone, the fuel-bound nitrogen is less likely to be converted to NO_x, but rather to N_2 and other stable nitrogen compounds.

The B&W DRB-XCL® burner achieves increased NO_x reduction effectiveness by incorporating fuel staging in addition to air staging. Fuel staging involves the introduction of fuel downstream of the flame under fuel-rich conditions. This results in the generation of hydrocarbon radicals which further reduce NO_x levels. The fuel staging is accomplished through the design of the coal nozzle/flame stabilization ring on the burner. Additionally, combustion air to each burner is accurately measured and regulated to provide a balanced fuel and air distribution for optimum NO_x reduction and combustion efficiency. Finally, the burner assembly is equipped with two sets of adjustable spin vanes which provide swirl for fuel/air mixing and flame stabilization.

2.1.2 Overfire Air

Low-NO_x burners and overfire air reduce the formation of NO_x by controlling the fuel/air mixing process. While low-NO_x burners control the mixing in the near-burner region, overfire air controls the mixing over a larger part of the furnace volume. By diverting part of the combustion air to a zone downstream of the burner, initial combustion takes place in a near stoichiometric or slightly fuel rich environment. The remaining air necessary to ensure complete combustion is introduced downstream of the primary combustion zone through a set of overfire air ports, sometimes referred to as NO_x ports. Conventional single-jet overfire air ports are not capable of providing adequate mixing across the entire furnace. The B&W dual-zone NO_x ports, however, incorporate a central zone which produces an air jet that penetrates across the furnace and a separate outer zone that diverts and disperses the air in the area of the furnace near the NO_x port. The central zone is provided with a manual air control disk for flow control, and the outer zone incorporates manually adjustable spin vanes for swirl control.

The combined use of the low-NO_x burners and overfire air ports was expected to reduce NO_x emissions by up to 50 percent.

2.1.3 Selective Non-Catalytic Reduction

NO_x reduction in utility boilers can also be accomplished by Selective Non-Catalytic Reduction (SNCR). This process involves the injection of either urea or ammonia (anhydrous or aqueous) into the combustion products where the flue gas temperature is in the range of 1600 to 2100°F. In this range, NH_2 is released from the injected chemical which then selectively reacts with NO in the presence of oxygen, forming primarily N_2 and H_2O. A SNCR system is capable of removing 40 to 50 percent of the NO from the flue gas stream.

Urea and ammonia each have their own optimum temperature and range within which NO_x reduction can occur. An example of such a temperature "window" is shown conceptually in Figure 2-1. At temperatures above the optimum, the injected chemical will react with O_2 forming additional NO_x, thereby reducing the NO_x removal efficiency. At temperatures below the optimum, the injected chemical does not react with NO, resulting in excessive NH_3 emissions (referred to as ammonia slip). Chemical additives can be injected with the urea to widen the optimum temperature range and minimize NH_3 emissions.

The SNCR chemical of primary interest for the present program is urea. The urea is generally injected into the boiler as a liquid solution through atomizers. The atomizing medium can be either air or steam, although air is used in the current installation. The urea and any additives are stored as a liquid and pumped through the injection atomizers. At Arapahoe Unit 4, a system has also been installed to catalytically convert the urea solution to ammonium compounds. The urea solution can be either injected directly into the furnace or processed through the catalytic system prior to injection.

2.1.4 Dry Sorbent Injection System

The dry sorbent injection (DSI) system consists of equipment for storing, conveying, pulverizing and injecting calcium- or sodium-based reagents into the flue gas stream between the air heater and the particulate removal equipment, or calcium-based reagents

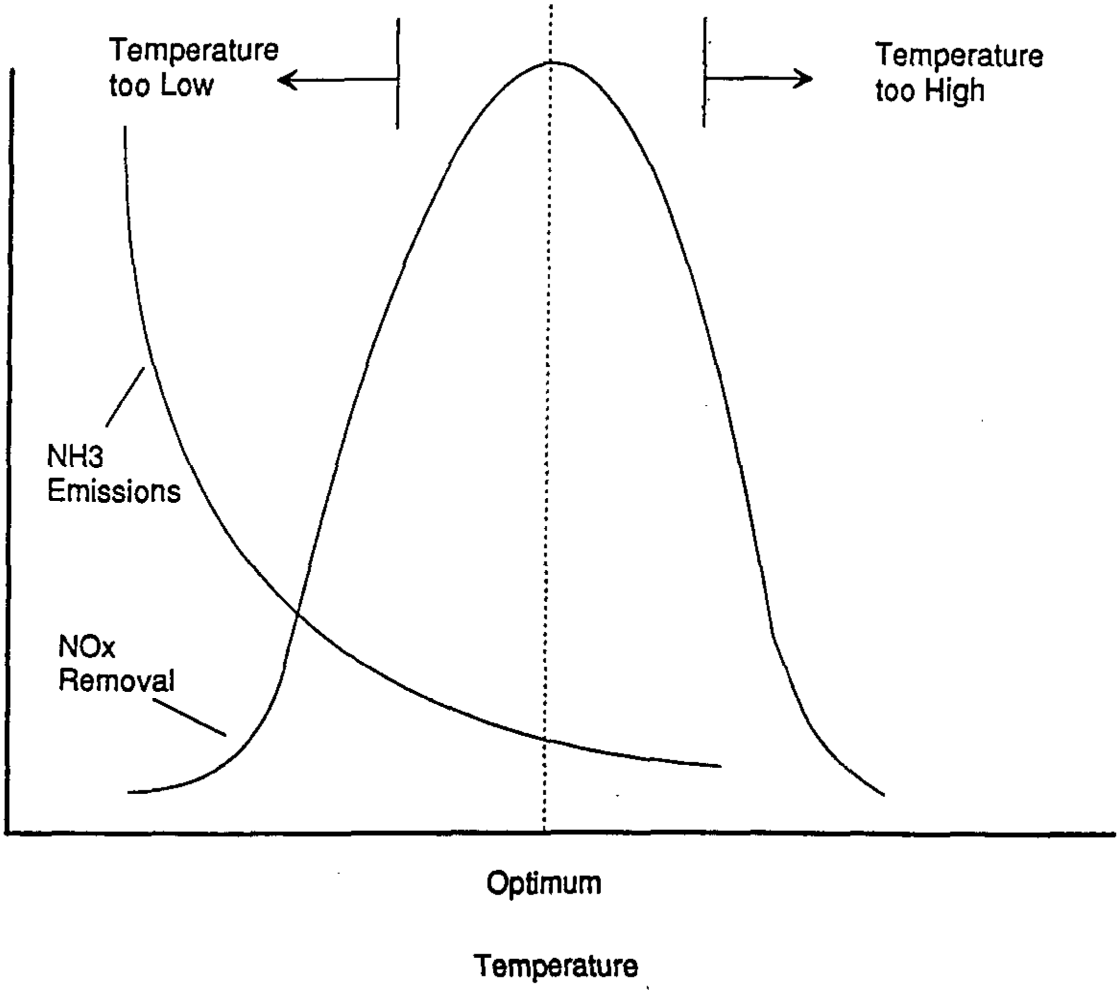


Figure 2-1. Conceptual Temperature Window for the SNCR Process

upstream of the economizer. The SO_2 formed during the combustion process reacts with *the sodium- or calcium-based reagents to form solid sulfites and sulfates. These reaction* products are collected in the particulate removal equipment together with the flyash and any unreacted reagent, and then removed for disposal. The system was expected to remove up to 70 percent of the SO_2 when using sodium-based products while maintaining high sorbent utilization.

Although sodium-based DSI systems reduce SO_2 emissions, NO_2 formation has been observed in some applications. NO_2 is a red/brown gas; therefore, a visible plume may form as NO_2 in flue gas exits the stack. Previous pilot-scale tests have shown that ammonia slip from urea injection reduces the formation of NO_2 while removing the ammonia which would otherwise exit the stack.

In certain areas of the country, it may be more economically advantageous to use calcium-based reagents, rather than sodium-based reagents, for SO_2 removal. SO_2 removal using calcium hydroxide ($Ca(OH)_2$) involves dry injection of the reagent into the furnace at a point where the flue gas temperature is approximately 1000°F. $Ca(OH)_2$ materials can also be injected into the flue gas ductwork downstream of the air heater, but at reduced SO_2 removal effectiveness.

2.1.5 Humidification

The effectiveness of calcium hydroxide in reducing SO_2 emissions when injected downstream of the air heater can be increased by flue gas humidification. Flue gas conditioning by humidification involves injecting water into the flue gas downstream of the air heater and upstream of any particulate removal equipment. The water is injected into the duct by dual-fluid atomizers which produce a fine spray that can be directed downstream and away from the duct walls. The subsequent evaporation causes the flue gas to cool, thereby decreasing its volumetric flowrate and increasing its relative and absolute humidity. It is important that the water be injected in such a way as to prevent it from wetting the duct walls and to ensure complete evaporation before the gas enters the particulate removal equipment or contacts the duct turning vanes. Since calcium hydroxide is not as reactive as the sodium-based reagents, the presence of water in the flue gas, which contains unreacted reagent, provides for additional SO_2 removal. Up to 50 percent SO_2 removal was expected when $Ca(OH)_2$ was used in conjunction with flue gas humidification.

2.2 Project Participants

PSCo is the project manager for the project, and is responsible for all aspects of project performance. PSCo has engineered the DSI system and the modifications to the flyash system, provided the host site, trained the operators, provided selected site construction services, start-up services and maintenance, and is assisting in the testing program.

EPRI provided technical assistance and advice on many of the technologies and also contributed to the project funding. B&W was responsible for engineering, procurement, fabrication, installation, and shop testing of the low-NO_x burners, overfire air ports, humidification equipment, and associated controls. They have also assisted in the testing program, and will provide for commercialization of the technology. NOELL, Inc. was responsible for the engineering, procurement and fabrication of the SNCR system. Fossil Energy Research Corp. is conducting the testing program. Western Research Institute is characterizing the waste materials and recommending disposal options. Colorado School of Mines conducted bench scale research on the mechanism and chemical kinetics of NO_2 formation with dry sorbent injection. Stone & Webster Engineering assisted PSCo with the engineering efforts. Cyprus Coal and Amax Coal are supplying the coal for the project, while Coastal Chemical, Inc. is providing the urea for the SNCR system.

3.0 HARDWARE DESCRIPTION

The hardware systems associated with each of the emission control technologies comprising the integrated system have been described in detail in previous reports (LNB/OFA: Smith, et al., 1994a; SNCR: Smith, et al., 1994b; DSI: Smith, et al., 1996a). The following subsections provide brief overviews of each system, as well as a description of the boiler and original combustion system.

3.1 Boiler and Original Combustion System Description

Arapahoe Unit 4 is the largest of four down-fired boilers located at the Arapahoe station and is rated at 100 MWe. The unit was built in the early 1950s and was designed to burn Colorado lignite or natural gas. Currently, the main fuel source for the station is a Colorado low-sulfur (0.4%) bituminous coal. Although the unit can be run at full load while firing natural gas, this fuel is only occasionally used to provide load when pulverizers or other equipment are out of service. An elevation view of the boiler is shown in Figure 3-1.

The original furnace configuration was a down-fired system employing 12 intertube burners located on the roof and arranged in a single row across the width of the furnace. A single division wall separates the furnace into east and west halves, each with six burners. Downstream of the burners, the flue gas flows down the furnace and then turns upward to flow through the convective sections on the boiler backpass. After reaching the burner level elevation, the gas passes through a horizontal duct and is then directed downward through a tubular air heater. After leaving the air heater, the flue gas passes through a reverse gas baghouse for particulate control. Induced draft fans are positioned downstream of the baghouse and deliver the flue gas into a common stack for Units 3 and 4.

The original intertube burners were not comparable to a more common wall-fired burner. Each burner consisted of a rectangular coal/primary air duct which was split into 20 separate nozzles arranged in a four by five rectangle that injected the coal/air mixture

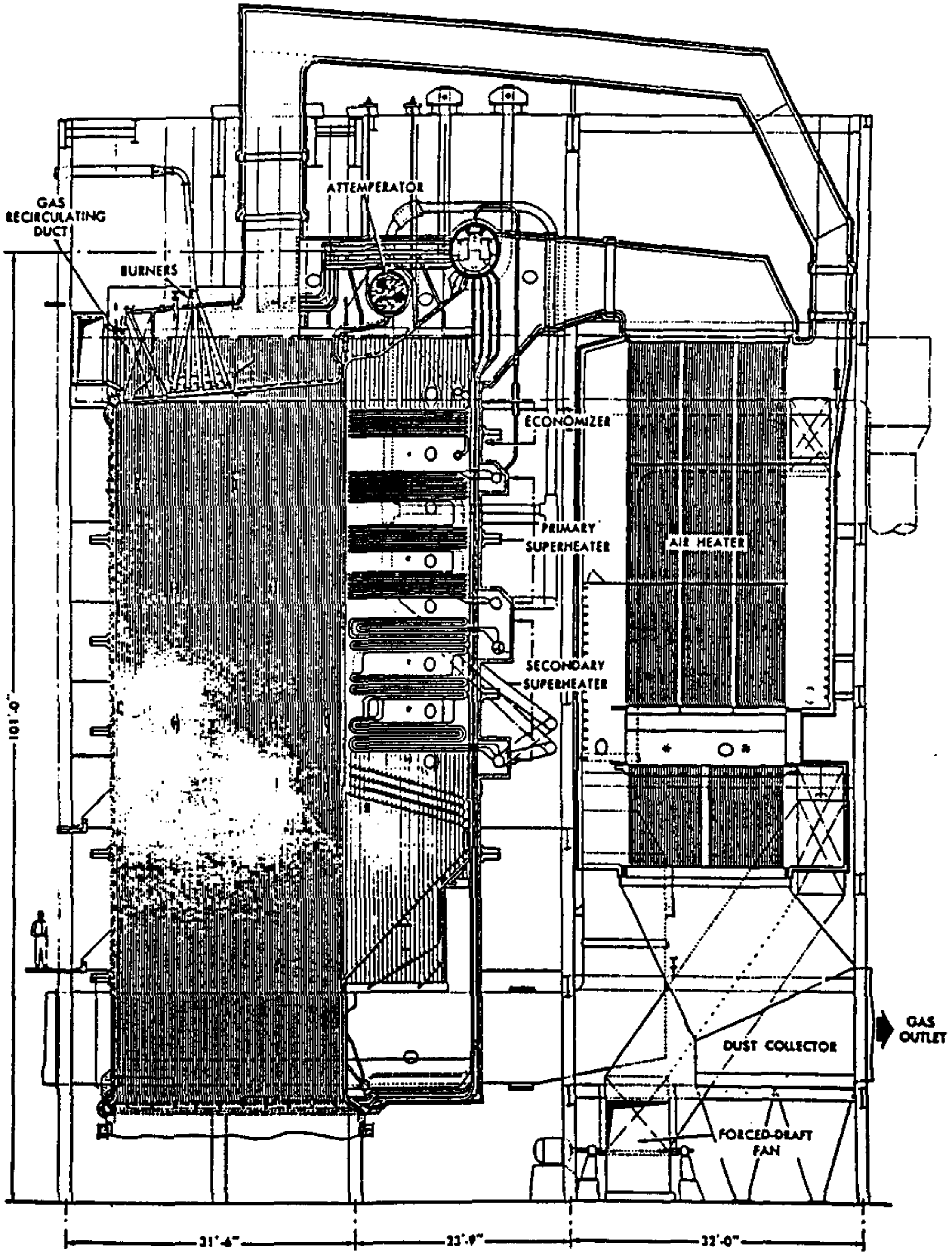


Figure 3-1. PSCo Arapahoe Unit 4

evenly across the furnace roof. A secondary air windbox surrounded each burner and allowed air flow around each of the individual coal nozzles, resulting in a checkerboard pattern of coal/primary air and secondary air streams. The burners had no provisions to control the rate of fuel and secondary air mixing.

The burners were numbered one through twelve from west to east. Each of the four attrition mills supplied primary air and coal to three of the burners. The coal piping allowed each mill to supply two burners in one furnace half and one in the other half. The secondary air ducts were positioned behind the burners and included a secondary air damper for each burner. When a single burner was removed from service, the secondary air flow was also stopped by closing the associated secondary air damper. The dampers were manually controlled at the burner deck and were intended for on/off duty only.

3.2 Low-NO_x Burners

Babcock & Wilcox (B&W) was selected to provide the low-NO_x burners for the Arapahoe Unit 4 project. B&W's DRB-XCL® burner had been successfully used to reduce NO_x emissions on wall-fired boilers but had never been used in a vertically-fired furnace. The burner (Figure 3-2) has two main features that limit NO_x formation. The first feature is a sliding air damper. In many older burners, a single register is used to control both total secondary air flow to the burner and the rate of air/fuel mixing. The use of the sliding damper in the DRB-XCL® burner separates the functions and allows the secondary air flow to be controlled independently of the spin. The burner includes a 30-point pitot tube grid so that a relative indication of the secondary air flow at each burner is possible. The second feature of the burner is dual spin-vane registers. The most important variable in the control of the formation of NO_x is the rate at which oxygen is mixed with the fuel in the near-burner region. The ability to adjust both inner and outer registers provides more control over the rate of combustion and thus the amount of NO_x formed.

A low-NO_x retrofit on a top-fired unit is much more complex and expensive than modifications to most wall- or tangential-fired units. At Arapahoe Unit 4, the modifications

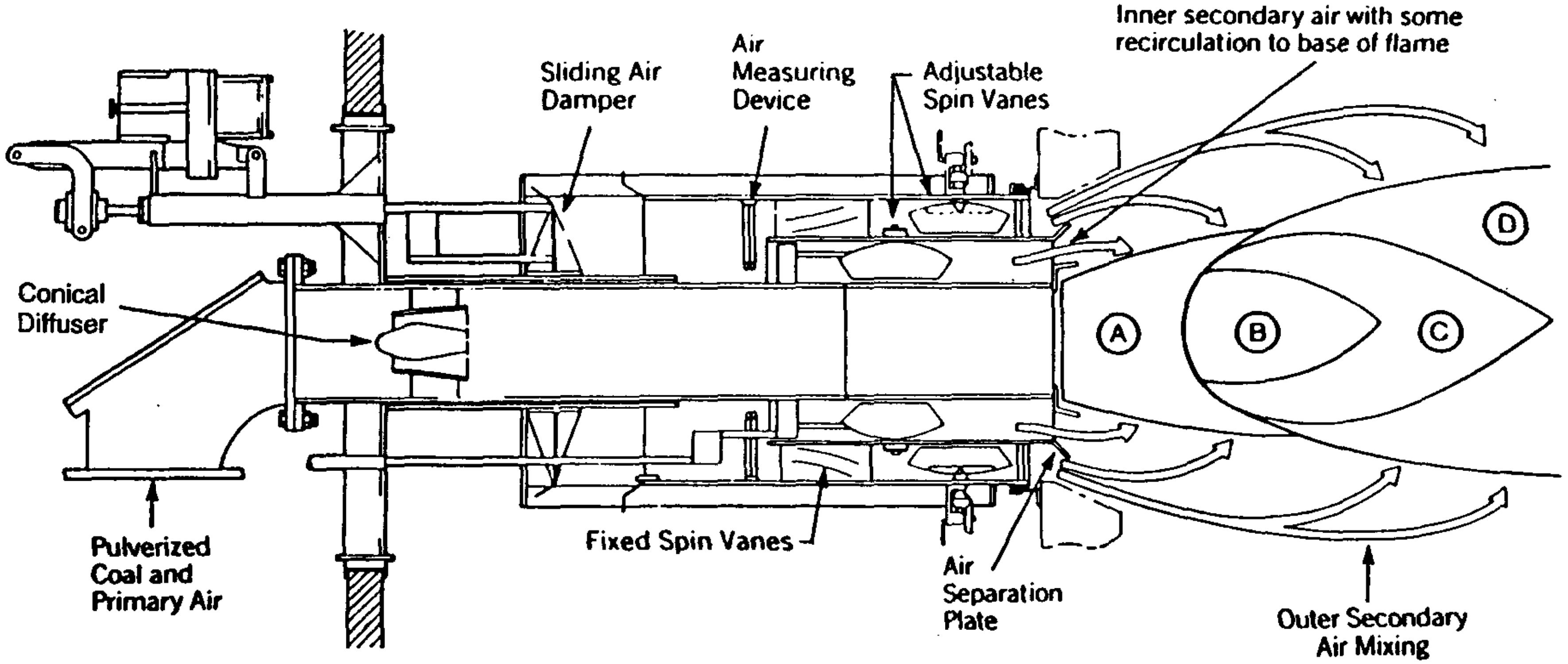


Figure 3-2. B&W DRB-XCL® Low NO_x Burner

required the replacement of all boiler roof tubes to provide the circular openings required for a conventional burner. The burners were placed in 4 rows of 3 burners as shown in Figure 3-3. One major design problem of the retrofit was locating the secondary air ductwork, which originally entered the windbox at the rear (north side) of the furnace roof. The new burners required significantly more space than the original intertube burners, so there are now four burners where the secondary air duct was originally placed. Smaller ductwork was added to the furnace roof and the remaining combustion air was added through an abandoned gas recirculation duct that entered the front of the windbox.

Arapahoe Unit 4 was originally designed with the ability to fire 100 percent natural gas. Natural gas firing capability was maintained with the DRB-XCL® burners by installing a gas ring header at the tip of the burner. However, the burner is not specifically designed to be a low-NO_x burner with natural gas firing.

3.3 Overfire Air

While low-NO_x burners alone have proven to be effective for reducing NO_x emissions, combustion staging can provide further reductions. Overfire air delays combustion by redirecting a part of the secondary air downstream of the main combustion zone. Three B&W dual-zone NO_x ports (Figure 3-4) were added to each side of the furnace approximately 20 feet below the boiler roof. These ports can inject up to 28 percent of the total combustion air through the furnace sidewalls. The NO_x ports separate the overfire air into two streams. The outer area of the port contains adjustable spin-vane registers that can be used to spread the overfire air next to the wall. The center area of the port uses a sliding disk damper to control air flow. This core zone injects a high velocity jet across the furnace toward the division wall. This two-stage air injection allows for faster mixing and more equal distribution of the air and combustion gases in the furnace.

The NO_x ports are located on the two sides of the furnace in a small windbox. New ductwork was added that directs secondary air from the boiler roof to the overfire air windbox. Each duct that supplies the overfire air windboxes contains an opposed blade

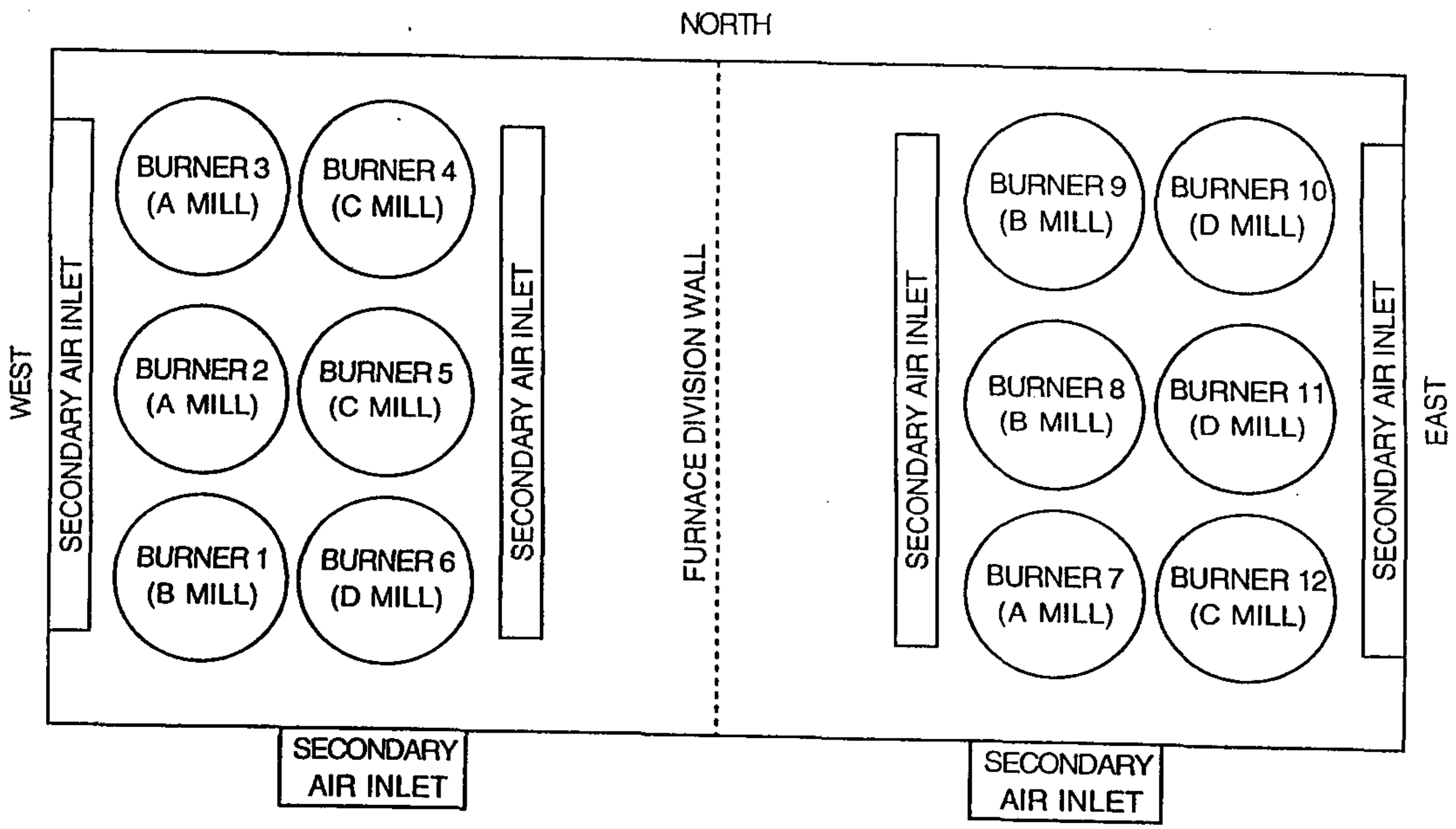


Figure 3-3. Plan View of Burner Arrangement after Retrofit

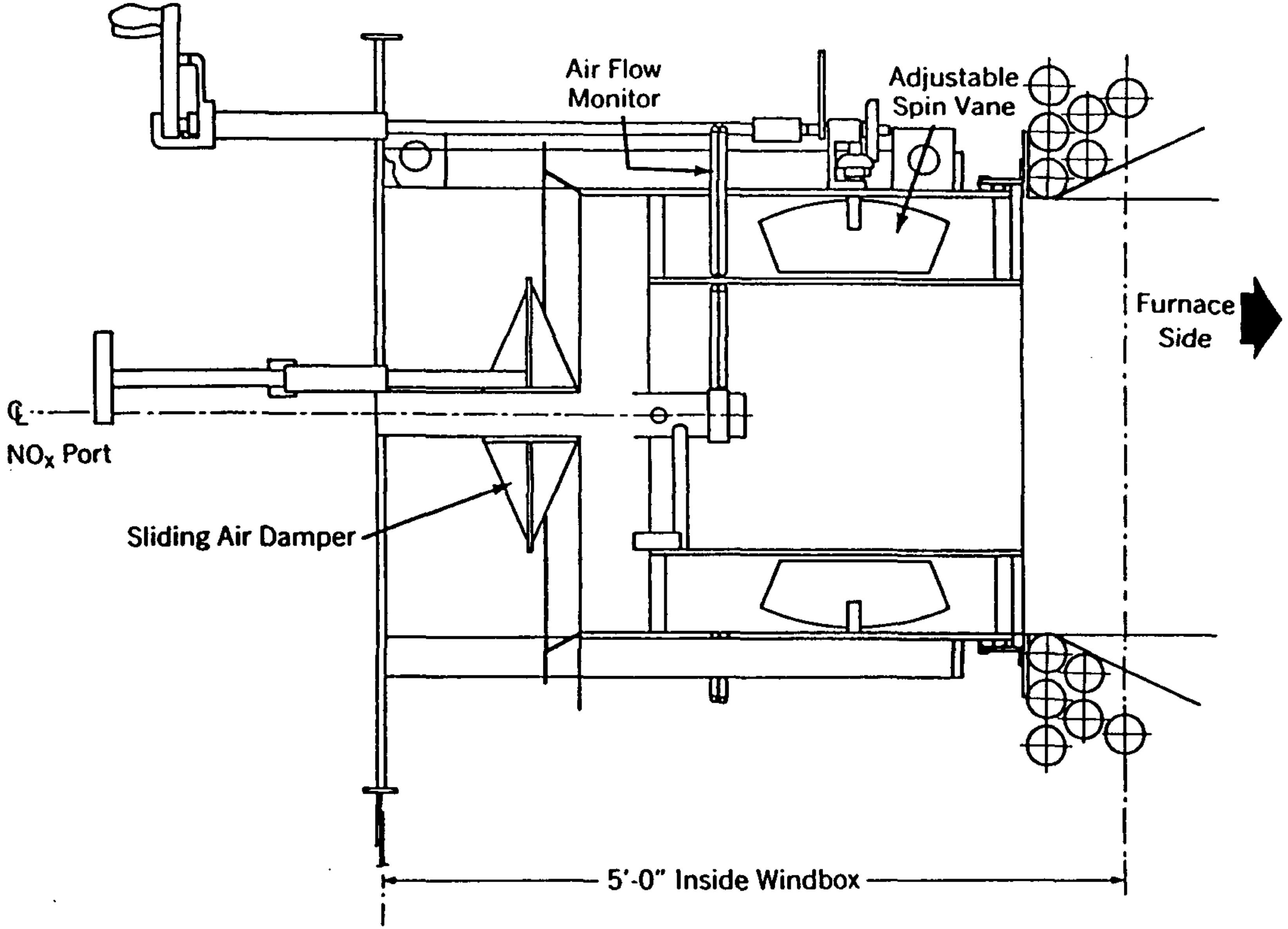


Figure 3-4. B&W Dual Zone NO_x Port

louver damper to control air flow. The ducts also contain a pitot tube grid with a flow straightener to measure total overfire air flow.

3.4 Selective Non-Catalytic Reduction

The purpose of the SNCR system at Arapahoe Unit 4 was to further reduce the final NO_x emissions obtained with the combustion modifications so that the goal of 70 percent NO_x removal could be achieved. Urea was selected as the base chemical for the SNCR system, because urea, unlike either aqueous or anhydrous ammonia, is not a toxic chemical. Urea injection is a simple process. A liquid solution of urea is injected into the boiler. Urea decomposes at approximately 1700 to 1900°F, and then reacts with NO_x to form primarily nitrogen and water. The disadvantage of urea injection, as with any SNCR chemical, is that the process is very temperature-sensitive. If the temperature is too high, some urea can be converted to NO_x. If the temperature is too low, the products of decomposition do not remove NO_x, and NH_3 becomes an unacceptable new pollutant. PSCo selected NOELL, Inc. to design and supply the urea-based SNCR system for the project.

The NOELL, Inc. SNCR system is designed to achieve a high degree of mixing between the flue gas and the reducing reagent in short residence times. Before the detailed design of the SNCR system was completed, the basic temperature distribution and velocity flow patterns within the boiler were characterized through two separate efforts:

1. on-site flue gas temperature measurements using acoustic pyrometry and High Velocity Thermocouple (HVT) measurements, and
2. laboratory cold flow testing using a 1:10 scale model of the Arapahoe Unit 4 boiler.

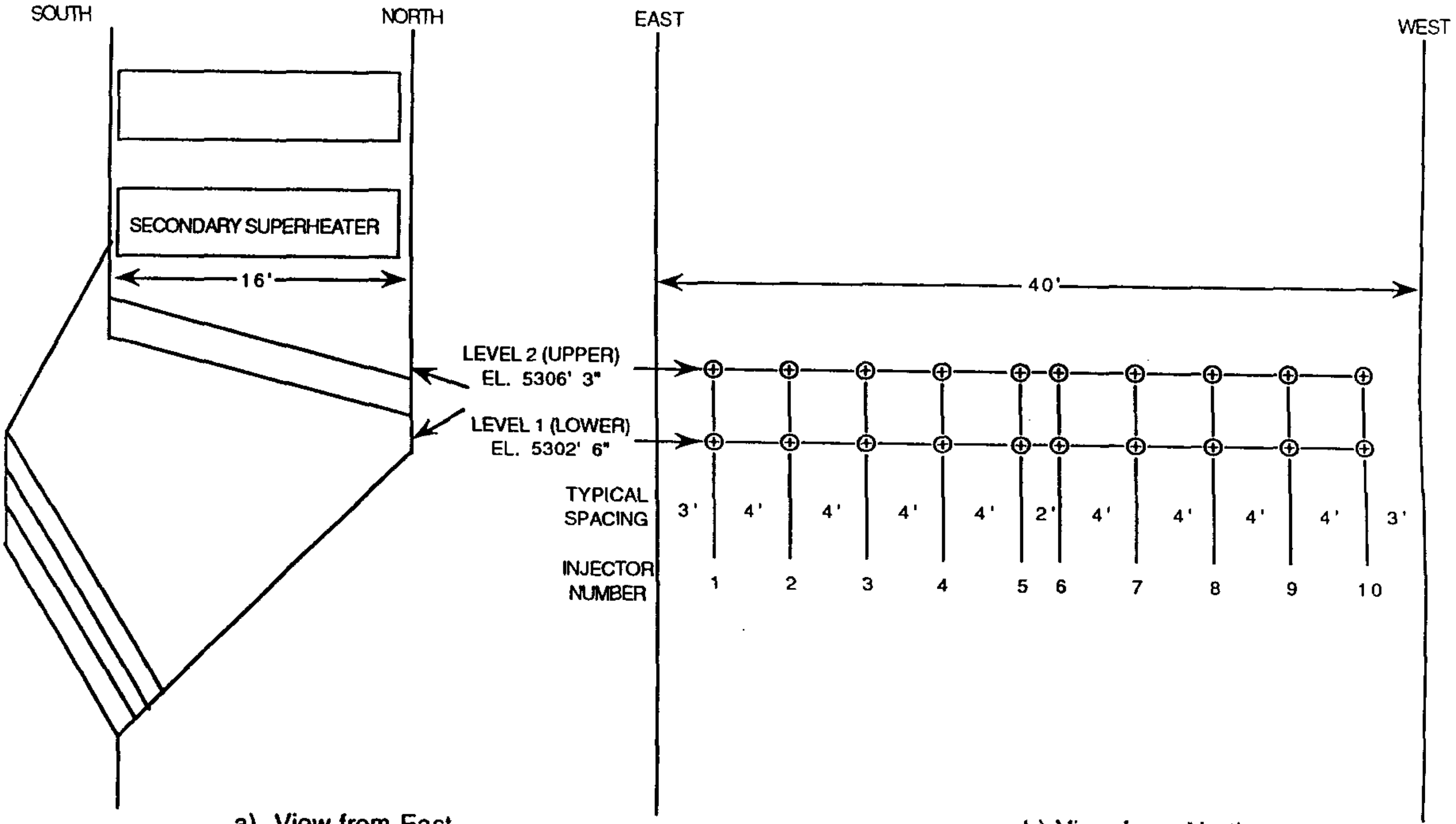
These two efforts were discussed in detail in the report presenting the results of the first phase of the SNCR testing (Smith, et al., 1993).

As a result of the temperature measurement and cold flow modeling efforts, two rows of ten wall-mounted injection nozzles were installed on the Arapahoe Unit 4 boiler; one at elevation 5302'6" and one at elevation 5306'3". As shown in Figure 3-5, these two levels were placed immediately upstream and downstream of the second set of screen tubes. The injection angle for the lower level of nozzles (Level 1) is oriented 45° down from horizontal, and the angle of the upper level nozzles (Level 2) is 15° above horizontal.

The purpose of two levels of injectors was to have some means of temperature control for the urea injection system. The upper nozzles were expected to operate in the range of 80 to 100 MWe. As the load was further reduced and flue gas temperatures decreased, the lower level would be used. During the initial test program, it was found that over the entire load range, either the flue gas was too cold or the residence times too low for effective NO_x reduction at the upper injection level. Therefore, the majority of the tests during the initial SNCR test program were run using only the lower (Level 1) injectors.

Testing performed after the low-NO_x combustion system retrofit, showed that the effectiveness of the SNCR system at low loads was reduced. In addition to reducing the NO_x emissions significantly, the retrofit also reduced the temperature of the flue gas at the furnace exit by nominally 170°F across the load range. Since the SNCR process is very sensitive to changes in flue gas temperature, this reduction made the flue gas temperature too cold for efficient NO_x removal at reduced loads, even at the lower (hotter) injection location.

Recently an additional SNCR injection location was installed to further increase low load performance (Smith, et al., 1996b). The new injection location makes use of a pair of unused sootblower openings in order to avoid the cost of installing new penetrations and the associated outage. Figure 3-6 shows the new location at the furnace exit relative to the two existing locations. The new injectors consist of a pair of in-furnace lances which provide access to a region of more optimal flue gas temperature at low loads. At higher loads, the lances retract from the boiler, and urea injection shifts to the Level 1 location. The NOELL, Inc. Advanced Retractable Injection Lances (ARILs) are air-cooled, and the cooling air provides the injection momentum necessary to quickly mix the urea with the



a) View from East

b) View from North

Figure 3-5. Arapahoe Unit 4 SNCR Injection Nozzle Location

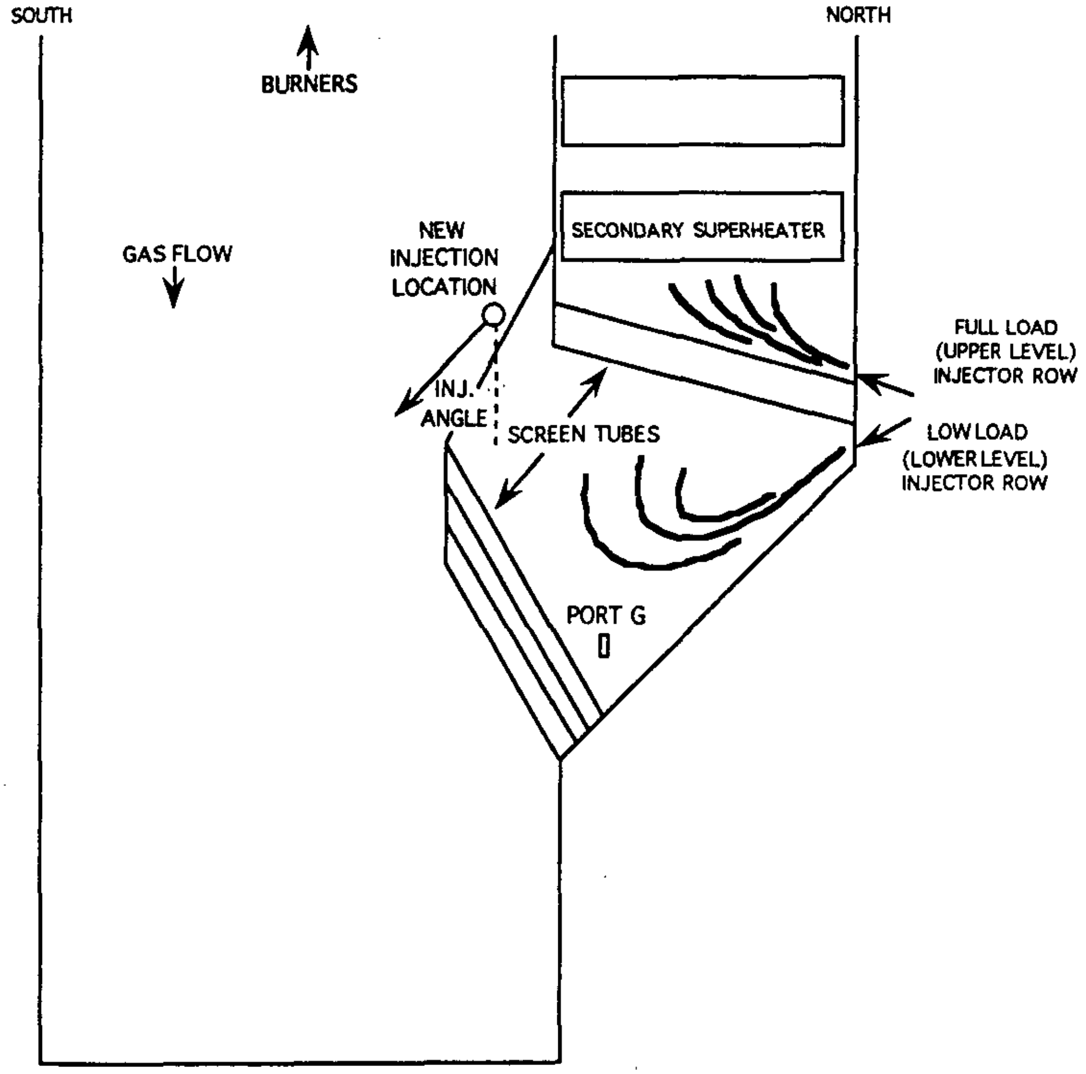


Figure 3-6. SNCR Injection Locations

flue gas. Each lance has a single row of nine injection nozzles distributed on two-foot centers. Automatic control of the lance injection angle allows access to the optimum injection temperature under load following operation.

After the low-NO_x combustion system retrofit, the Level 2 injection location on the back wall was no longer usable due to the decrease in furnace exit gas temperature. The air and liquid lines which were originally dedicated to these injectors were used to supply the ARIL lances. When the lances were installed, a flowmeter and control valve were added to the liquid line supplying the two lances. The new flowmeter and valve provides a means of regulating the chemical flows between the two injection levels if it is desired to run the lance and Level 1 injection locations simultaneously.

Other than the addition of the valve and flowmeter, the existing SNCR system was unchanged. A simplified flow diagram of the system is shown in Figure 3-7. The system may be separated into four simple subsystems: urea recirculation, dilution, ammonia conversion, and atomization. The urea recirculation loop handles the storage and heating of the base urea chemical. Urea is received in a 65 percent (by weight) liquid solution and is stored in one of two 20,000 gallon tanks. A 65 percent solution must be maintained above 115°F to prevent crystallization of the urea. After delivery, the urea is diluted to approximately a 37.5 percent concentration. Urea at this concentration reduces the crystallization point to below 14°F, which eliminates the need to constantly recirculate and heat the solution.

In the dilution system, a small slipstream of the urea from the recirculation loop is filtered, mixed with softened water to further dilute the urea, and is then pumped at high pressure (100 to 1000 psig) to the injectors. The system at Arapahoe Unit 4 uses one of two positive displacement pumps driven by AC variable speed drives. The variable speed drives allow the total liquid flow to be varied from 2.0 to 10.5 gpm.

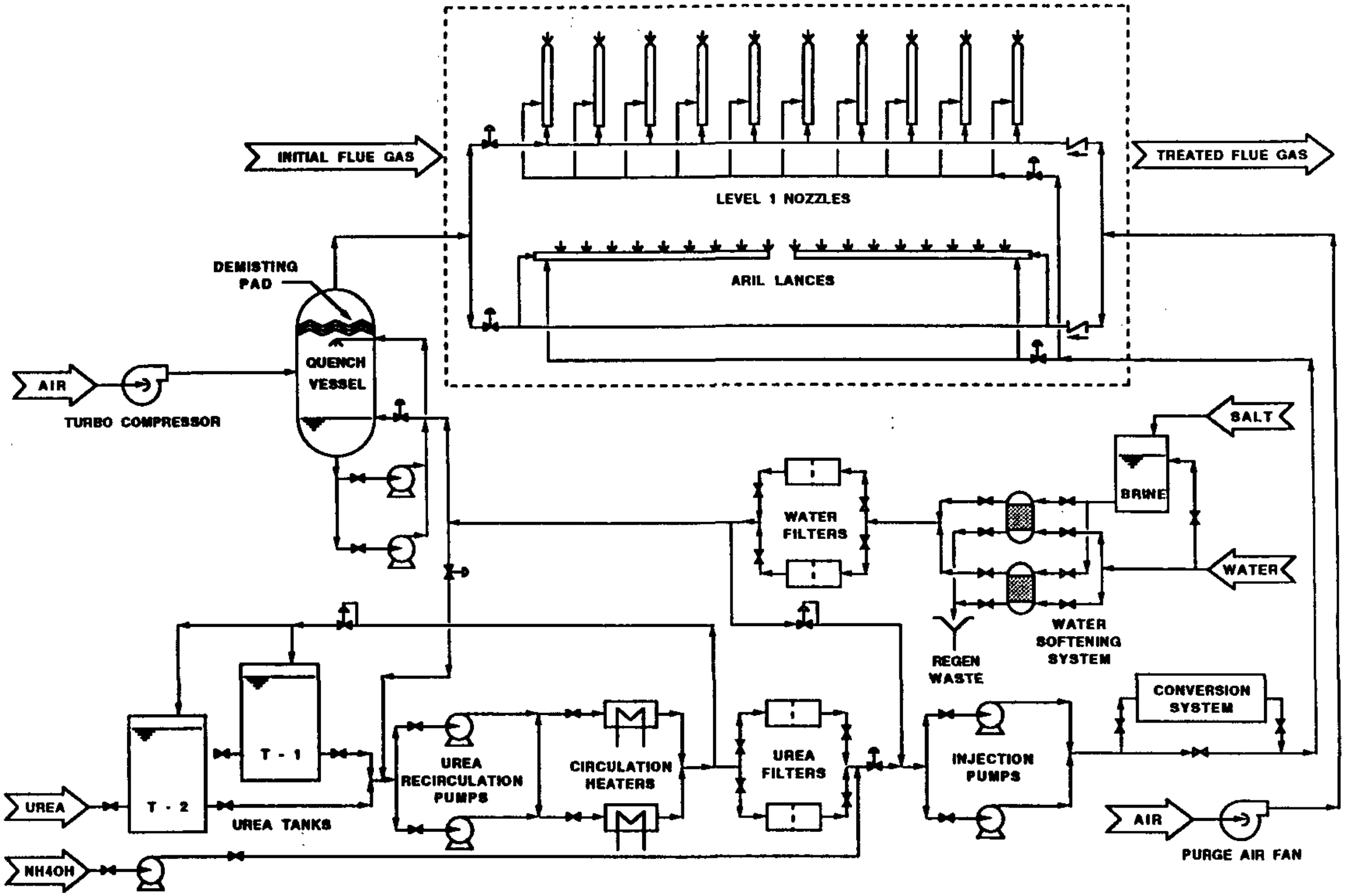


Figure 3-7. Arapahoe Unit 4 SNCR System Flow Diagram

The ammonia conversion system was added after the initial SNCR test phase. This system first heats the diluted urea solution and then passes the chemical over a proprietary catalyst that causes the urea to convert to ammonia-based compounds. The system can be bypassed so that either urea or ammonia compounds may be injected as selected by the control operator. The ammonia conversion system was not utilized during the current phase of testing.

The SNCR system at Arapahoe Unit 4 uses NOELL, Inc.'s proprietary dual-fluid injection nozzles to distribute the urea or ammonia compounds evenly into the boiler. A centrifugal compressor is used to supply a large volume (up to 9000 scfm) of medium pressure (4 to 12 psig) air to the injection nozzles to help atomize the solution and rapidly mix the chemical with the flue gas. The volume of air supplied is controlled by variable inlet guide vanes and a variable diffuser assembly, which automatically delivers a preset discharge pressure.

The urea injection system is controlled by a programmable logic controller (PLC). The PLC is operated using an IBM compatible computer through a man-machine software package, and controls all the functions of the system (equipment on/off, valves open/close, etc.), except for five local control systems which are in local control panels (LCPs): the two lances, the centrifugal compressor, the circulation heaters and the water softening skid. These LCPs control the equipment and receive the main commands and transmit the key information to and from the PLC.

From the computer, the SNCR system can be either manually set, or operated under automatic control. Under automatic control operation, the urea flow rate is set by a feed forward control function using a boiler load signal. The system also utilizes feedback control to trim the urea flow rate by an amount set by the operator. The feedback control loop can use either a stack NO_x signal or a stack NH_3 signal.

3.5 Dry Sorbent Injection

A combination of dry technologies is being demonstrated at Arapahoe Unit 4 to reduce SO_2 emissions. PSCo designed and installed a Dry Sorbent Injection (DSI) system that can inject either calcium- or sodium-based reagents into the flue gas upstream of the fabric filter. The DSI system at Arapahoe Unit 4 utilizes two identical preparation and injection systems to provide the required capacity at high sorbent flow rates and redundancy at lower flow rates. These two systems are entirely separate up to and including the sorbent injectors in the duct. This system also allows sorbent injection at either the fabric filter inlet or the economizer inlet by manual piping changes. The economizer injection location was utilized during the calcium-based sorbent injection tests (Shiomoto, et al., 1994). During the sodium-based sorbent injection tests (Smith, et al., 1996a) the system was modified to allow injection of sodium bicarbonate into a region of higher flue gas temperature at the air heater inlet. This modification was incorporated into the system using the existing economizer injection piping.

Figure 3-8 shows one of the two sorbent preparation and injection systems. Each system includes a storage silo, variable speed screw feeder, rotary air lock, blower for conveying air, pulverizer to grind the sorbent, distributor to split the sorbent stream, and injectors. The two sorbent preparation and injection systems (labeled A and B for the testing) are identical in capacity and operation. Each has separate controls and can be independently operated from a control screen on the Arapahoe Unit 4 Distributed Control System (DCS). The following paragraphs describe one of the two identical systems.

Sorbent is stored in a silo with a capacity of approximately 6100 cubic feet. Dry sorbents are transported by truck and pneumatically loaded into the top of the silo. The silo is vented at the top through a small fabric filter system which prevents fugitive dust emissions. An ultrasonic level indicator provides continuous silo level measurements.

A slide gate is installed at the bottom of the silo hopper to allow isolation from the feeder when necessary. Directly below the slide gate is a variable speed screw feeder. The

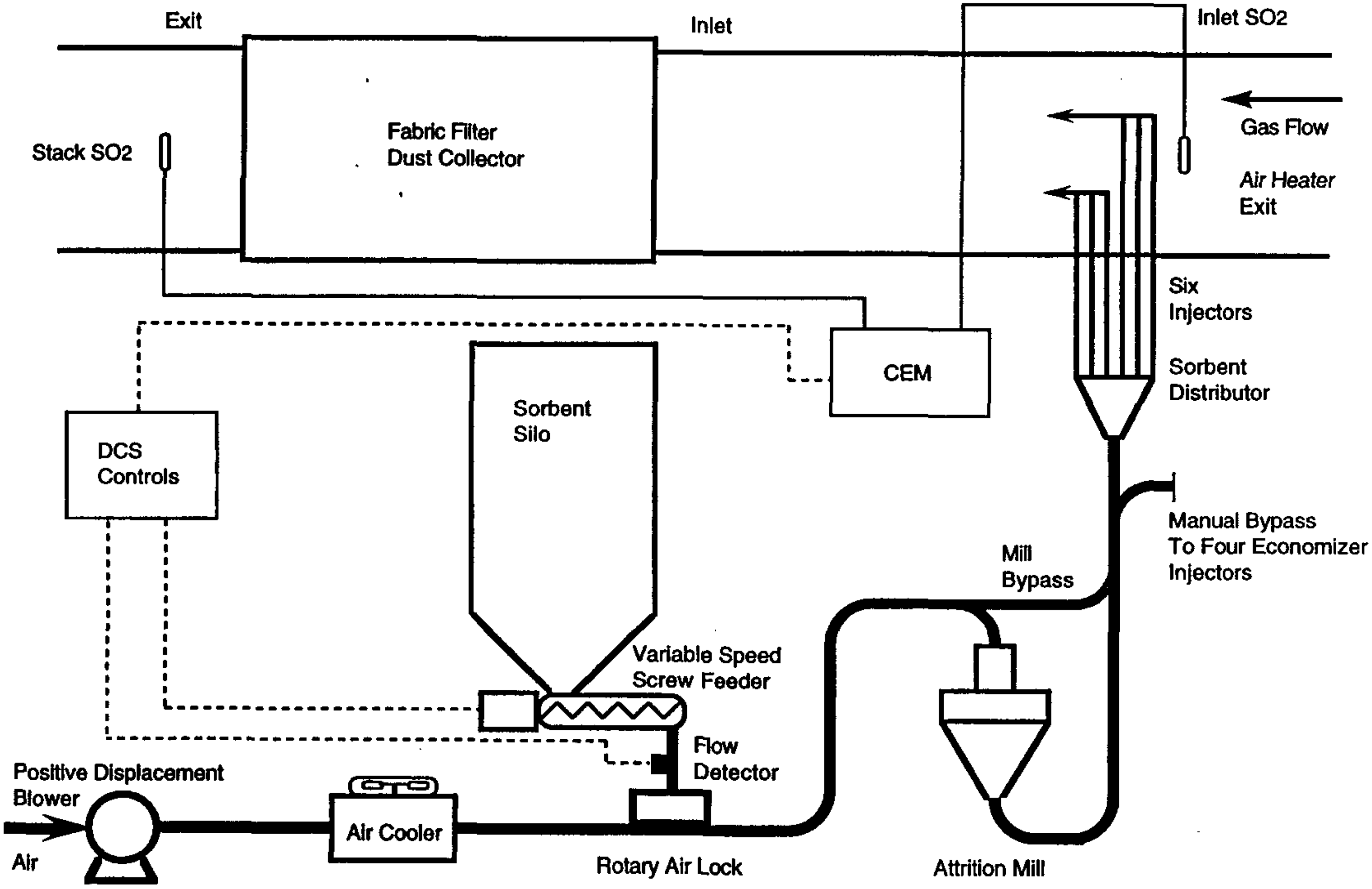


Figure 3-8. Simplified Diagram of One Sorbent Handling System and the Process Controls

volumetric screw feeder provides the sorbent flow control for the system and can be operated with local controllers in the sorbent preparation building or from a screen on the DCS. The feeder can be operated in either a manual or automatic mode. In the manual mode, the operator sets a constant screw speed. In the automatic mode, an SO_2 removal setpoint is input and the control system varies the feed rate to maintain the setpoint SO_2 removal. The automatic control system also incorporates a trim control to limit NO_2 emission levels to less than 20 ppm. For the majority of the current test phase, the feeder was run in the automatic mode without the NO_2 trim control.

The screw feeder delivers sorbent directly into the top of a rotary air lock which provides the necessary isolation between the sorbent feed and the conveying air systems. The air lock is used for isolation, not feed rate control, and therefore is operated at a constant rotational speed. The air lock is vented to relieve the higher pressure from the conveying air and help prevent pressurization of the bottom of the silo and screw feeder. The vent line extends up to the top of the silo and into the fabric filter venting system. A flow detection probe installed between the exit of the screw feeder and the inlet of the air lock is used to detect the loss of sorbent flow. When properly calibrated for sorbent type, this probe determines loss of flow and displays an alarm on the DSI control screen.

The conveying air system passes just below the rotary air lock, which allows the sorbent to drop into and be dispersed within the air. The air is supplied from a positive displacement blower that operates at a constant speed and air flow rate (nominally 660 cfm at 9 psig). Blower air pressure is monitored to determine if plugging occurs or if sorbent flow is abnormal. The air supply pressure is limited to 10 psig by a relief valve installed downstream of the blower. An air-to-air heat exchanger installed downstream of the blower cools the conveying air whenever the sorbent pulverizers are in use. This heat exchanger cools the air to reduce the mill exit air temperature and prevent sorbent overheating. After the air cooler, the air flows under the rotary air lock and picks up the sorbent flow. After the sorbent and air are mixed, the flow can be directed either into or around the Entoleter attrition mill via manual piping changes. During the current series of tests, the mill was used to pulverize the sodium-based sorbents to approximately 90 percent passing through 400 U.S. Standard mesh.

After exiting the mill, the sorbent and carrier air are piped to one of the injection locations at either the fabric filter inlet or the air heater inlet. The piping at each injection location is very similar, although the number of injectors differs. Most of the testing was performed at the fabric filter inlet location. A distributor is installed on the top of the air heater exit duct to split the sorbent flow to each injector. A single pipe supplies the sorbent from the preparation system and the flow is evenly split into six injection streams. At the outlet of the distributor is a separate ball valve on each line that is used to isolate each injector from the system. The piping for injection at the air heater inlet is identical, except that a distributor divides the flow into four streams instead of six.

3.6 Balance of Plant

Besides the installation of the emission control equipment, the Integrated Dry NO_x/SO_2 Emissions Control System project also included required upgrades to the existing plant. Arapahoe Unit 4 originally used a Bailey pneumatic control system with limited controls for burner management. Due to the complexity of the retrofit a new Distributed Control System (DCS) was required to control the boiler and other pollution control equipment added as part of the project. The flyash collection system was also converted from a wet to a dry collection system to allow dry collection of the ash and injection waste products. A Continuous Emissions Monitor (CEM) system was installed at Arapahoe Unit 4 to collect data for the extensive test program. This monitor allows measurements of N_2O, NH_3, NO_2, and H_2O in addition to the more common species.

4.0 MEASUREMENT METHODS

The evaluation of the performance of the integrated system required the documentation of gaseous emissions and NH_3 slip levels, as well as boiler operational performance parameters. This section summarizes the measurement methods that were utilized during this phase of the program.

4.1 Gas Analysis Instrumentation

An Altech 180 Continuous Emission Monitoring (CEM) system was purchased as part of the Integrated Dry NO_x/SO_2 Emissions Control System and installed during the low-NO_x combustion system retrofit. The CEM system utilizes a Perkin Elmer MCS 100 infrared gas analyzer which is capable of continuously analyzing eight gas species simultaneously, using a combination of gas filter correlation and single-beam dual-wavelength techniques.

The analyzer cycles through and measures all eight gas species in approximately 22 seconds. In that time, two readings are made for each gas species to be measured. The first reading is a reference value at a known wavelength and gas concentration (either 0 or 100 percent), and the second is a measured reading to determine the quantity of the desired species in the sample stream. Table 4-1 provides a listing of the full scale range, measurement technique, and interfering species for each of the gases measured.

Table 4-1
Gas Species Measured by Perkin Elmer MCS 100 Analyzer

Measured Species	Range	Measurement Technique	Interfering Species
NO	0-800 ppm	Gas Filter Correlation	H_2O
CO	0-500 ppm	Gas Filter Correlation	H_2O
SO_2	0-800 ppm	Single Beam Dual Wavelength	NH_3, H_2O
NO_2	0-100 ppm	Single Beam Dual Wavelength	NH_3, SO_2, H_2O
CO_2	0-20 volume %	Single Beam Dual Wavelength	H_2O
H_2O	0-15 volume %	Single Beam Dual Wavelength	None
N_2O	0-100 ppm	Single Beam Dual Wavelength	CO, CO_2, H_2O
NH_3	0-50 ppm	Gas Filter Correlation	CO_2, H_2O

Using the gas filter correlation technique, the analyzer takes a reference reading at a known wavelength and a known concentration of gas, usually 100 percent. The analyzer then takes another reading at the same wavelength for the sample gas and records the energy absorbed by the sample. The relative difference in energy is then representative of the concentration in the sample gas.

Likewise in the single-beam dual-wavelength method, a reference reading is taken at a wavelength where the desired species does not absorb energy (zero percent reference). The analyzer then takes a measured reading at a wavelength where the desired species is known to absorb energy. The relative difference in energy is again representative of the concentration of the species in the sample stream.

Once the ratio of reference to measure energy is calculated, the energy level is corrected to account for interferences via reference tables for each specific gas. After correction for interferences, the data is zero adjusted, converted to the appropriate units, calibration corrected, and output for display and recording.

Since O_2 is not infrared active, the CEM system also contains an Ametek O_2 analyzer. The sample cell is a zirconium oxide closed end tube with electrodes of porous platinum coated onto the inside and outside of the tube. The cell produces a millivolt signal proportional to the relative difference of O_2 inside and outside of the cell. The millivolt signal is converted to percent O_2, scaled (0 to 25 percent), and then displayed and recorded.

All CEM analyzer and sampling system functions, including a daily automatic calibration sequence, are controlled by the MCS 100 PLC. The measured gas concentration data is displayed on a dedicated 486-based computer, which also provides data logging, manipulation and reporting functions.

A Relative Accuracy Test Audit (RATA) was performed on March 5, 1993 in order to verify the accuracy of the CEM system. The audit was performed by TRC Environmental Corp. in accordance with the requirements established in 40 CFR, Part 60, Appendices A and F.

Complete documentation of the audit is contained in a separate report (TRC Environmental Corp., 1993), and the results are summarized in Table 4-2.

Table 4-2
CEM RATA Results

Parameter	Relative Accuracy (%)
CO_2 (%, wet)	2.64
Moisture (%)	7.86
O_2 (%, wet)	17.81
NO (ppm, wet)	1.53
NO (lb/MMBtu, wet*)	5.93
NO (ppm, dry)	1.02

* Calculated on an O_2 basis

Acceptance criteria for RATA evaluation of component instruments of the CEM is 20 percent. Based upon the results, all individual parameters were found to be within the acceptance criteria.

4.2 Gas Sampling System

As shown in Table 4-1, the MCS 100 was configured to measure NH_3. This capability imposes special requirements upon the design of the CEM sampling system. In order to maintain the integrity of the sample, the entire sampling system (probe, sample line, pump, flowmeter, and sample cell) must be maintained at 230°C (445°F). Due to these heat tracing requirements, the CEM system was configured to sample from only two different single-point locations. First, at the exit of the air preheater in the duct leading to the fabric filter, and the second downstream of the fabric filter and induced draft fans, in the duct leading to the common stack for Units 3 and 4.

In order to obtain a representative composite gas sample, as well as provide the ability to look at discrete areas of the flue gas flow, Fossil Energy Research Corp. (FERCo) provided a sample gas conditioning system which allowed sampling from additional unheated sample probes. Although the MCS 100 is utilized as the gas analysis instrumentation, the measurement of NH_3 at the additional sampling locations is not possible due to the lack of high temperature heat tracing. A schematic of the sample gas conditioning system is shown in Figure 4-1. The system can accommodate up to 24 individual sample lines. Up to 12 of these can be composited together and then analyzed. Each of the individual sample streams is dried in a refrigerated dryer where the gas is cooled and the moisture is dropped out in a trap. Each stream then passes through a metering valve and rotameter, after which all the streams are blended together in a manifold and directed to a pair of sample pumps. The rotameters are used to balance the individual flows in order to provide an accurate composite blend. Downstream of the pumps, a portion of the composited sample is diverted to a final pass through the condenser (where the increased pressure aids in the removal of any remaining moisture), through a final particulate filter, and then to the Altech CEM for analysis.

The location of the unheated sample probes during the current phase of testing was identical to that for the previous phases of SNCR and DSI tests, namely: 12 probes at the exit of the economizer, 6 probes at the exit of the air preheater, and one probe in the fabric filter outlet duct leading to the stack. The sample probe grid in the horizontal duct at the economizer exit is shown in Figure 4-2. Since this duct is 40 feet wide and only 7 feet deep, an array of probes positioned two high by six wide was deemed adequate to obtain a representative gas sample. The short probes were located at one-fourth of the duct depth, and the longer probes at three-fourths of the duct depth. This spacing vertically divided the duct into equal areas. The use of two probe depths also provided the opportunity to ascertain any vertical stratification of gas species within the duct. Individual sample probes consisted of stainless steel tubing with sintered metal filters on the ends. The sample lines which transported the gas to the sample conditioning system, consisted of polyethylene tubing which was heat traced and insulated to prevent freezing during the winter months.

Figure 4-2 also shows the location of the four PSCo O_2 probes at the economizer exit which are used for boiler trim control. The PSCo equipment uses *in situ* probes that determine the O_2 concentration on a wet basis. These probes (numbered A, B, C and D)

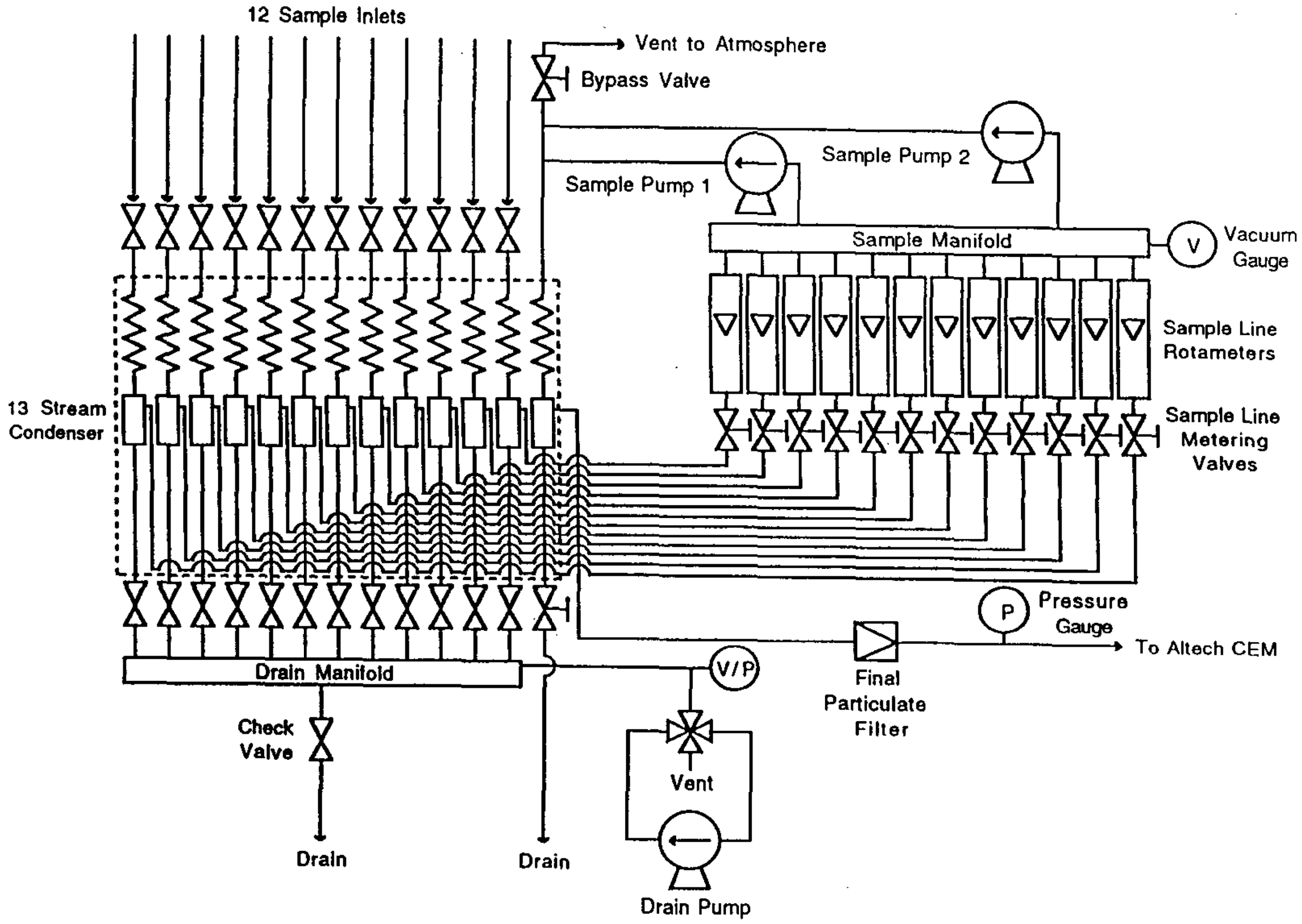


Figure 4-1. Sample Gas Conditioning System

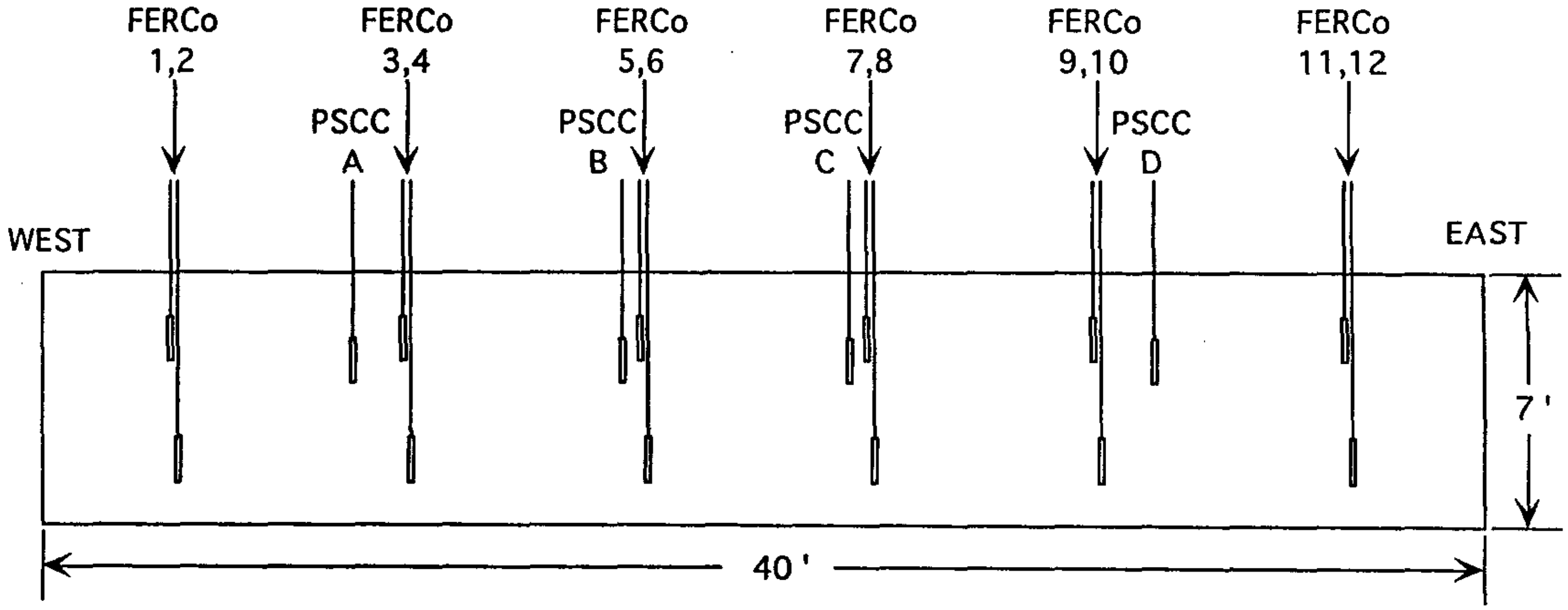


Figure 4-2. Economizer Exit Sampling Locations

are located approximately three feet upstream of the FERCo grid, and very near probe Numbers 3, 5, 7 and 9. The importance of the position of the 12-point grid relative to the four PSCo probes was realized during the baseline and retrofit burner tests (Shiomoto, et al., 1992; Smith, et al., 1994a) when it was found that the average O_2 measured from the grid was nominally 1.0 to 1.5 percent higher than the average indicated in the control room. This difference was attributed to the inability of the four PSCo probes to detect the elevated O_2 levels along the east and west sides of the duct which result from both air in-leakage and overfire air that didn't penetrate to the center of the furnace.

Gas sample probes were also installed at the air heater exit and the stack (fabric filter outlet duct) locations. Whereas the 12-point economizer exit sampling grid was utilized for detailed point-by-point measurements, the air heater exit and stack sampling probes were only used to obtain general duct averages at these locations. Therefore, only a limited number of probes were utilized at these test locations; six at the air heater exit and a single probe at the stack location. Figure 4-3 shows the location of the probes at the air heater exit. These sample probes and tubing were similar to the installation at the economizer exit. The staggered probes were installed at one-fourth and three-fourths duct depths, similar to the economizer exit. The figure also shows the location of the heated probe for the CEM system at the exit of the air heater. This probe is not in the same plane as the six-point grid, but approximately 3 feet upstream. At the stack sampling location, the heated probe for the CEM system is approximately 20 feet upstream of the unheated probe installed during the baseline burner tests. Only a single probe is used for both the CEM and the unheated probe locations since both are downstream of the fabric filter and induced draft fans where little stratification of the flue gas stream is expected. Figure 4-4 shows the installation of the unheated probe in the fabric filter outlet duct.

The current phase of testing consisted of both base-loaded parametric tests and long-term load-following tests. The DSI and SNCR control systems were run manually during the parametric tests, where the sodium and urea feedrates were set to achieve target 2Na/S and N/NO ratios. During the long-term tests, both control systems were run in the

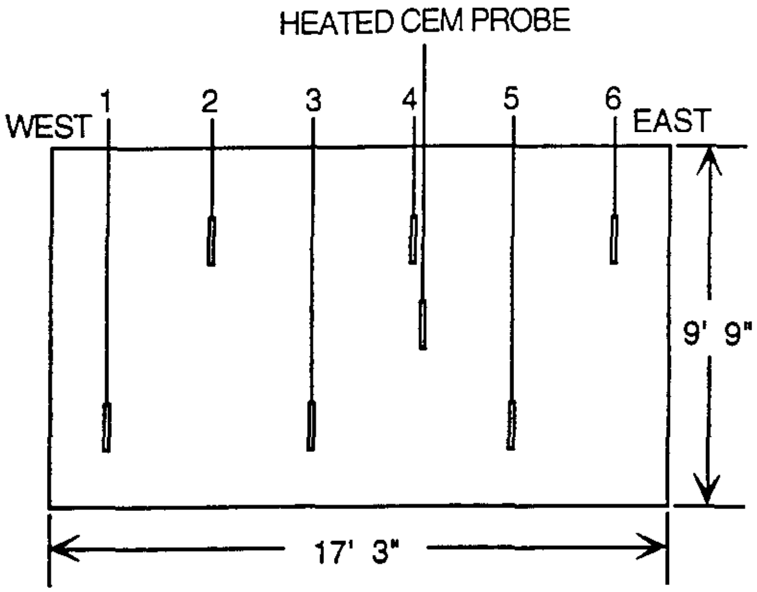


Figure 4-3. Air Heater Exit Sampling Locations

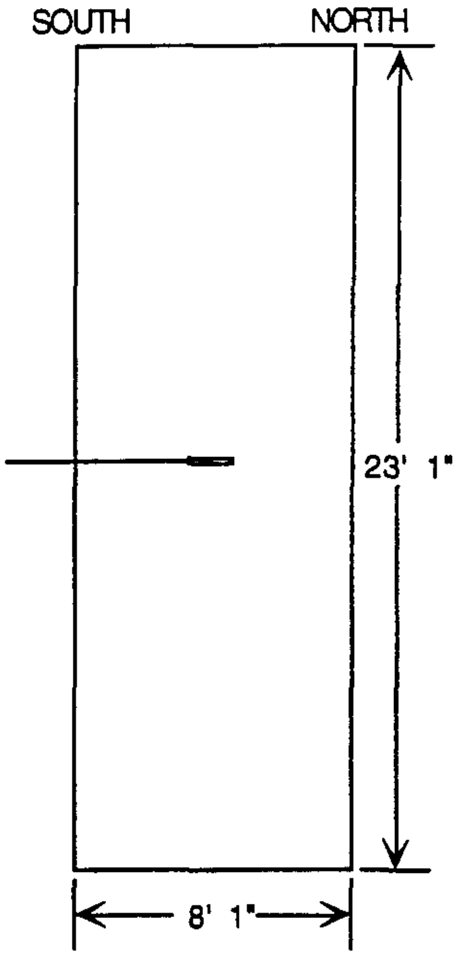


Figure 4-4. Fabric Filter Outlet Duct Sampling Location

automatic mode. The unheated probes at the air heater exit and stack sampling locations were not utilized during the current test phase. The economizer exit sampling grid was used during the parametric tests to determine the baseline SO_2 and NO_x levels before each test. This information was then used to calculate the sodium and urea flow rates corresponding to the target 2Na/S and N/NO ratios. During the load-following tests, the economizer exit sampling grid was used infrequently, since the stack location was the main area of interest. Unless noted otherwise, all gas analysis results presented in this report are from the heated CEM sampling location at the stack.

4.3 NH_3 Measurements

The measurement of NH_3 emissions is an important aspect of quantifying the performance of a SNCR system. Traditionally, batch or wet chemical sampling techniques have been used for this purpose. However, the time delay between the collection of the sample and the delivery of the results, due to the required laboratory analysis, is less than optimal when trying to optimize process performance in a field test situation. Recently, a number of continuous ammonia analyzers have become available, which could provide the on-line performance desirable for a field test program. However, these analyzers are considered to be in a developmental and proving stage, due to difficulties in obtaining and preserving valid gas samples, especially in sulfur-laden environments.

Both wet chemical and continuous NH_3 analysis techniques were used during the current test program. While EPA has published a draft method for the wet chemical determination of ammonia from stationary sources (draft Method 206), the method is most appropriate for stack gas compliance testing (U.S. EPA, 1996). The method described below differs somewhat from the draft EPA Method 206, but has been used by Fossil Energy Research Corp. and others for numerous test and compliance programs. It has been accepted for compliance work by local air regulator districts in California and has been proven accurate. Flue gas samples are withdrawn from the duct through a stainless steel probe, and are then passed through three impingers as shown in Figure 4-5. The first two impingers contain 0.02N sulfuric acid (H_2SO_4) and the final impinger is dry. Nominally two cubic feet of flue gas is passed through the impinger train during each test at a rate of approximately

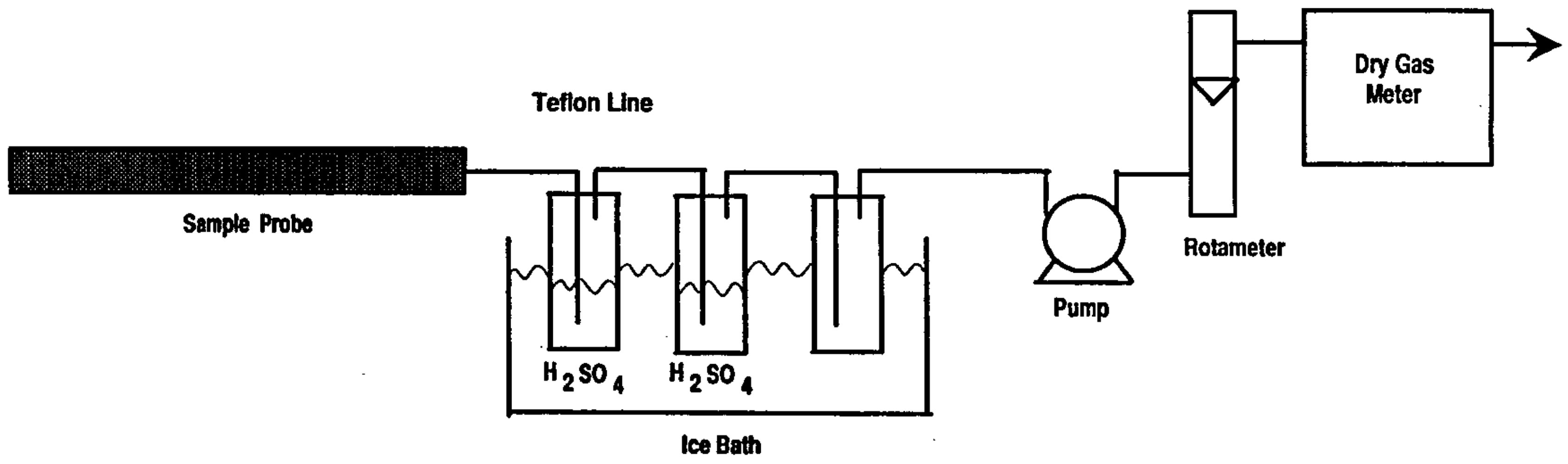


Figure 4-5. NH_3 Sample Train Schematic

0.2 ft^3/min. Total sample times were nominally 10 to 12 minutes for each test. At the conclusion of each test, the sample probe, teflon line, and sampling train glassware are washed with dilute H_2SO_4 into the bottle containing the impinger solution. The sample solution is then analyzed for ammonia.

During the integrated system tests, the sample solutions were analyzed on-site using the Direct Nesslerization Method. In this method, the Nessler reagent and a stabilizing agent (EDTA) are added to the sample solution and mixed thoroughly. After the reaction is complete (a minimum of ten minutes is required), the light absorbance of the sample is determined photometrically at a wavelength of 425 nm. The reading is compared to the absorbance of standard solutions to determine the ammonia concentration in the sample. Using this method, an NH_3 emission value could be obtained in a manner of minutes after the completion of a test.

During the integrated system tests, wet chemical ammonia samples were collected at both the inlet and outlet of the fabric filter. The inlet samples were obtained from a set of six ports located in the air heater exit duct (just upstream of the ports used for the continuous gas analysis samples shown in Figure 4-3). Generally, composite samples were obtained along the center line of the duct at this location. Fabric filter outlet samples were collected adjacent to the continuous gas sampling location shown in Figure 4-4.

During the post-retrofit SNCR tests (Smith, et al., 1994a), point-by-point wet chemical measurements across the duct at the air heater exit location showed that the NH_3 profile was for far from uniform. A comparison of the CEM NH_3 measurements at this location to single-point wet chemical measurements made through the port adjacent to the CEM probe (Port Number 4 in Figure 4-3) showed good agreement between the two methods. During the current phase of SNCR tests, the CEM was used as an indication of trends in NH_3 slip at the air heater exit. However, it could never be used as an absolute measurement due to the stratification of the flue gas at this location.

A limited number of wet chemical measurements were also made at the stack during the post-retrofit SNCR tests. These results showed good agreement with the CEM NH_3 measurements at this location, and both methods indicated that the ash in the fabric filter provided a substantial capacity for the absorption and desorption of NH_3. These tests showed that with the ash in the fabric filter free of NH_3, it could take upwards of three to four hours for NH_3 emissions measured at the exit of the fabric filter to stabilize.

During the current phase of tests, a much larger number of wet chemical measurements were made at the stack in order to better define the accuracy of the CEM NH_3 measurements at this location. Figure 4-6 shows a crossplot of all of the wet chemical and CEM measurements at the stack. The wet chemical technique reports the results on a dry basis (ppm,d), while the CEM results are on a wet basis (ppm,w). The data points shown in the figure are a crossplot of the wet and dry measurements, and the solid line is a linear curve fit of those points. The dashed line is a curve fit where the CEM results have been corrected to dry conditions by assuming a nominal flue gas moisture content of 8 percent. The results show that the CEM slightly underreports the emissions at levels above 10 ppm, and overreports the emissions at levels below 10 ppm. As shown in the figure, it was found that the CEM usually reported NH_3 slip levels of 2 to 4 ppm without urea injection, and frequent zero and span calibrations failed to correct the "offset". Although it was believed that the offset was due to an interference with either CO_2 or H_2O, it was not considered to be significant enough to warrant further investigation.

4.4 Furnace Exit Gas Temperature Measurements

During the course of the current test series, furnace exit gas temperature (FEGT) measurements were made in order to provide a comparison with those recorded during the post-retrofit SNCR tests. The temperature measurements were made using an acoustic pyrometer.

The acoustic pyrometry system, manufactured by Combustion Developments Ltd. of England, was utilized to provide a continuous assessment of the furnace exit gas temperatures. The acoustic pyrometer sends a sound pulse across the furnace; the transit

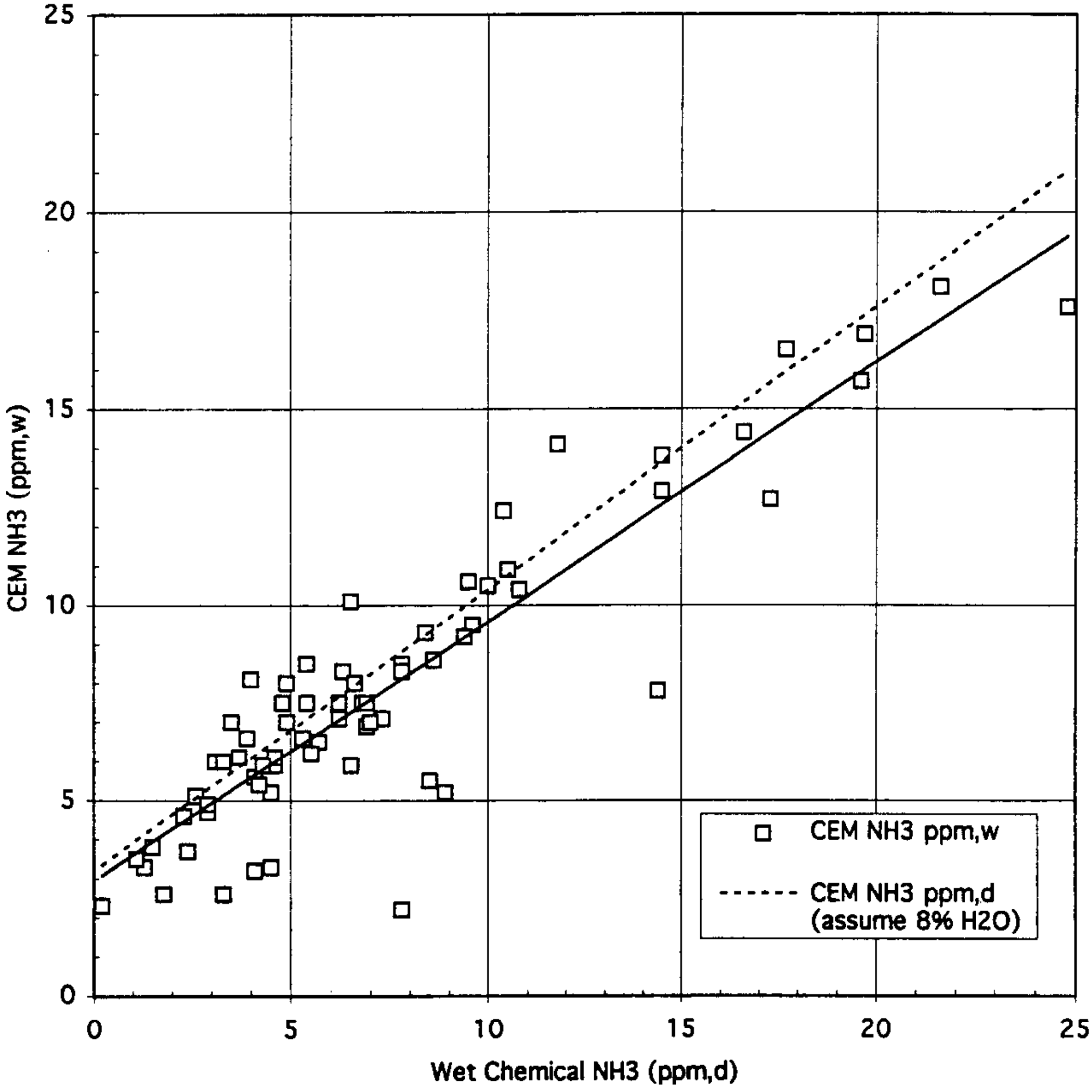


Figure 4-6. Crossplot of Wet Chemical and CEM NH_3 Slip Measurement at Stack

time for the pulse is measured and, thus, the mean speed of sound across the furnace is determined. The average temperature along the path can then be determined from the speed of the sound pulse. The acoustic temperature measurement technique requires a clear line of sight across the furnace at the measurement location. Since the boiler has a division wall running the length of the furnace, the first available location with acceptable access for the acoustic instrument was through a pair of ports just downstream of the first set of screen tubes (Port G in Figure 3-6).

5.0 RESULTS FROM APPLICATION OF THE INDIVIDUAL TECHNOLOGIES

This section provides a brief summary of the test results for the individual technologies which are used in the integrated system: LNB/OFA, SNCR and sodium-based DSI. These tests were performed previous to the current phase of testing. Complete documentation of these tests are contained in separate reports (Smith, et al., 1994a; Smith, et al., 1996b; and Smith, et al., 1996a, respectively).

5.1 Low-NO_x Burner/Overfire Air Test Results

During the low-NO_x burner/overfire air tests, the performance of the new combustion system was compared to that of the original combustion system, as documented during the baseline test program. Complete documentation of the baseline and LNB/OFA tests is contained in separate reports (Shiomoto, et al., 1992; Smith, et al., 1994a).

The LNB/OFA test program was conducted over a twelve week period from August 6 to October 29, 1992. The test program consisted of two separate phases. During the first, optimum operating conditions and settings for the burners and overfire air ports were identified. The second phase consisted of a detailed series of tests to assess the performance of the low-NO_x combustion system as a function of various operating parameters. These parameters included boiler load, excess air level, overfire air flow rate, and number of mills in service. These parameters represent the primary factors influencing NO_x, CO emissions, and flyash carbon levels. Immediately following the completion of the base-loaded optimization and parametric tests, the boiler was operated for two months (November and December 1992) under normal load following conditions. During this time, emissions data were collected automatically with the Unit 4 CEM.

After optimization, NO_x emissions with the retrofit combustion system were 63 to 69 percent lower than those for the original combustion system, depending on boiler load (Figure 5-1). These results were obtained under base loaded conditions with maximum overfire air (corresponding to 24 percent of the total secondary air flow at full load). OFA

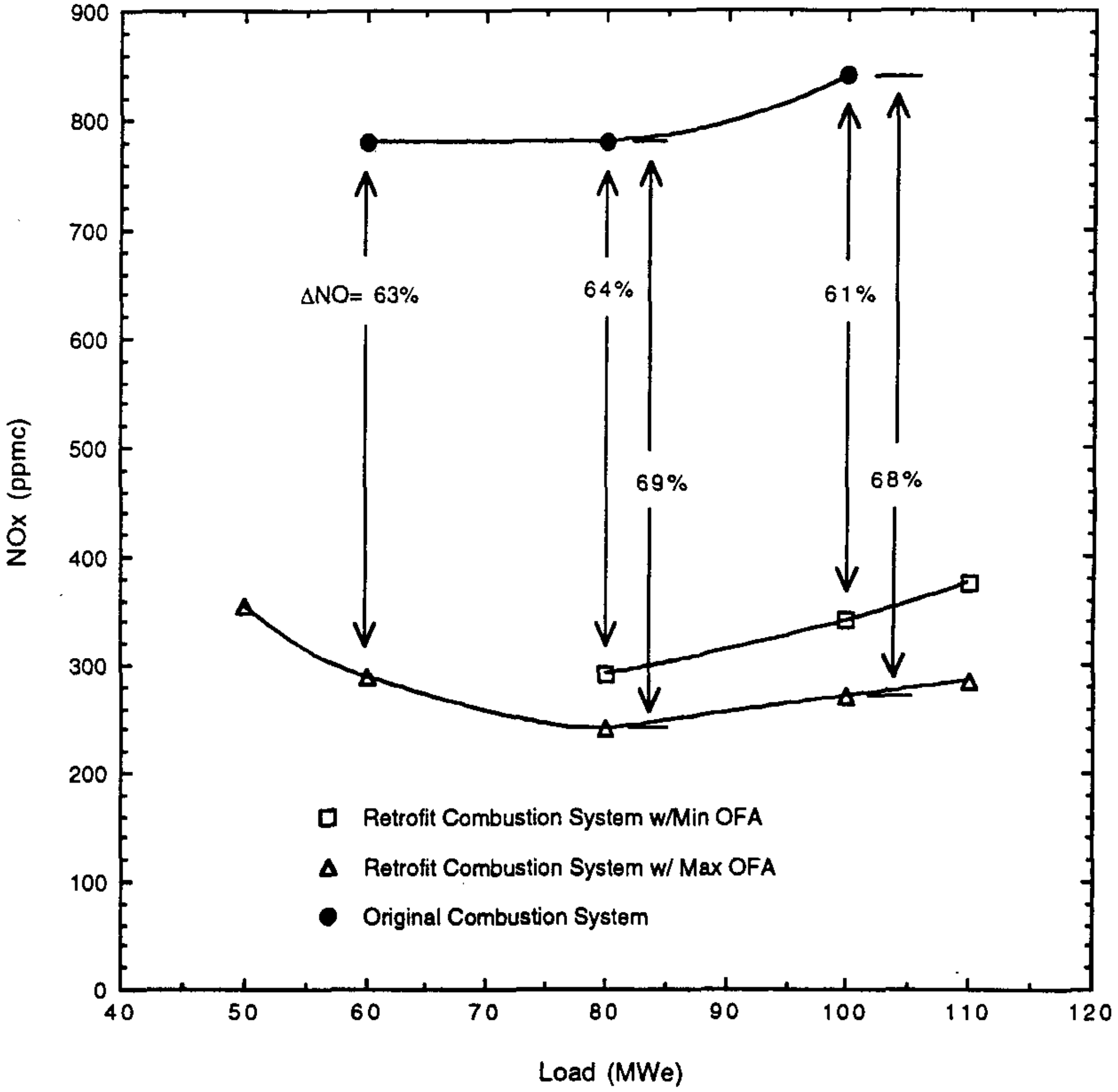


Figure 5-1. NO_x Emissions as a Function of Boiler Load for the Original and Retrofit Combustion Systems

port cooling requirements preclude reducing the overfire air flow to zero at Arapahoe Unit 4, thereby limiting the minimum overfire air condition to approximately 15 percent of the total secondary air. Increasing the overfire air flow from 15 to 25 percent resulted in only a 5 to 10 percent increase in NO_x removal. This suggests that the majority of the NO_x removal was due to the low-NO_x burners, and not the overfire air system. However, it must be noted that it was not possible to completely separate the relative roles of the burners and overfire air system at this particular installation due to the inability to reduce the overfire air flow to zero. It should also be noted that the difference between NO and NO_x emissions was monitored on most tests during the LNB/OFA tests, and the difference was found to be insignificant within the limits of detection. Thus, the terms NO and NO_x were used interchangeably during the LNB/OFA tests.

At Arapahoe Unit 4, significant reductions in CO emissions and flyash carbon levels were seen with increasing overfire air flow rates. This was contrary to what was expected, and is attributed to increased overfire air penetration to the center of the furnace and increased mixing at the higher flow rates. Overall CO emissions and flyash carbon levels did not increase during base loaded operation as a result of the combustion system retrofit.

The long-term CEM data showed that NO_x emissions increased by up to 20 percent during normal load following operation when compared to base loaded conditions. The increase was due to the higher excess air levels normally maintained during load following operation. The long term data also showed that CO emissions increased substantially. Part of the increase was due to maldistribution of the overfire air, and the remainder of the increase was due to variations in boiler operating parameters which are inherent in load following operation.

5.2 SNCR Test Results

The LNB/OFA/SNCR test program was conducted over a thirteen (13) week period from January 11, to April 9, 1993. During this time period, a parametric investigation of the effects of boiler load, chemical injection rate, and injection system parameters (mixing air and dilution water flow rates) was conducted with urea injection. Liquid injection nozzle diameters were optimized with urea injection before the parametric performance tests were conducted. The effect of operating the SNCR system with various mill out of service patterns was also assessed. Following the low-NO_x combustion system retrofit, two modifications were made to the SNCR system to enhance low-load performance. A subsystem was added to the existing SNCR injection system which allowed on-line conversion of a urea solution to ammonium compounds (since ammonia operates at lower temperature window than urea). In addition, another injection location was added at a *higher temperature region of the furnace.*

The parameters found to have the greatest effect on process performance were boiler load and chemical injection rate (N/NO molar ratio). The effects of mixing air and dilution water flow rates were found to be small over the range of flows tested. Variations in boiler load showed the largest effect on system performance, due to the impact on the local flue gas temperatures in the area of chemical injection. SNCR is a highly temperature-dependent process with only a narrow window available for maximum NO_x removal.

As expected, increased SNCR chemical flow rates yielded higher NO_x removals, with the tradeoff of higher NH_3 emissions accompanying the increased removals. The results showed that NO_x removals were higher with urea than with converted urea for a given chemical injection rate, over nearly the entire boiler load range. NH_3 emissions were also found to be higher with urea. Therefore, for a given NH_3 emission limit, converted urea tended to provide higher NO_x removals than urea. As shown in Figure 5-2, for a 10 ppm NH_3 emission limit NO_x removals of 19 to 47 percent were achievable with converted urea over the load range of 60 to 100 MWe, while urea injection resulted in removals of only 11 to 45 percent. However, over the load range of 80 to 100 MWe, urea was the most efficient chemical since the increased NO_x removals with converted urea required higher chemical feed rates.

With urea at a nominal N/NO molar ratio of 1.0, 29 to 35 percent of the NO_x reduced was converted to nitrous oxide (N_2O). N_2O emissions with converted urea were lower than with

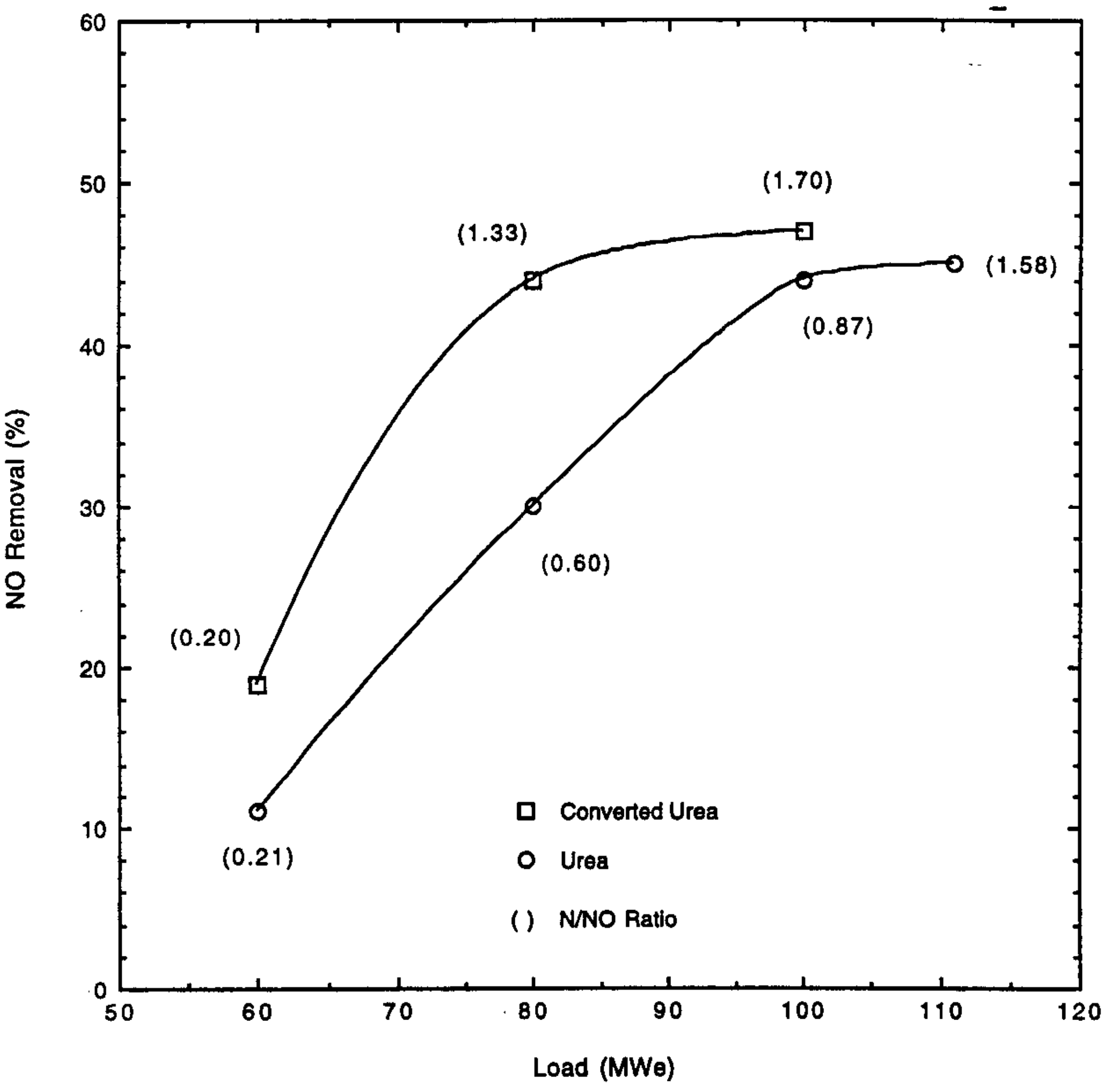


Figure 5-2. Comparison of NO Removals for Urea and Converted Urea for a Fixed NH_3 Slip Level of 10 ppm

urea injection. With converted urea, the fraction of the NO_x reduced which was converted to N_2O ranged from 3 to 8 percent at similar N/NO ratios.

Testing performed after the low-NO_x combustion system retrofit showed that in addition to reducing the NO_x emissions significantly, the retrofit also reduced the temperature of the flue gas at the furnace exit. Figure 5-3 shows that the decrease in FEGT was nominally 170°F across the load range of 60 to 100 MWe. Since the SNCR process is very sensitive to changes in flue gas temperature, the effectiveness of the SNCR system at low loads was reduced. Recently, an additional SNCR injection location was installed in order to increase the NO_x removal performance at low loads. The new injectors consist of a pair of retractable in-furnace lances which were designed to provide a high degree of load following flexibility through on-line adjustments of the injection angle.

The ARIL Lance test program was conducted over the period of April 20 to December 21, 1995. Completion of these SNCR tests was delayed due to some minor start-up problems with the lance control system, some more serious concerns regarding lance bending due to thermal stress, a planned Arapahoe Unit 4 turbine outage, and a two-week test burn of a Powder River Basin Coal. In total, approximately ten weeks of SNCR tests were completed. The majority of the testing consisted of parametric variations aimed at defining the optimum injection locations (the existing wall injectors or the new retractable lances), lance injection angle, and chemical injection rate as a function of boiler load. The effect of operating the SNCR system with various coal mill out-of-service patterns was also assessed over the load range. The urea conversion system was not used during any of these tests.

The performance of an ammonia or urea-based SNCR system must be assessed in terms of achievable NO_x removal for a given level of NH_3 slip. There are four factors that must be considered when determining an "acceptable" NH_3 slip operating level:

1. NH_3/SO_3 reactions forming ammonia bisulfate and/or ammonia sulfate can foul air preheater surfaces;

2. plume reactions between NH_3 and HCL or SO_2 can lead to plume visibility through the formation of ammonium chloride or ammonium sulfite (Muzio, et al., 1997);
3. absorption of NH_3 on the flyash can lead to ash disposal or handling concerns; and/or
4. a regulatory limit on NH_3 emissions.

Arapahoe Unit 4 uses a low sulfur Colorado coal that leads to SO_3 emissions of less than 1 ppm. The Unit also uses a tubular air heater that is not as sensitive to plugging by solid particles. Arapahoe also fires a very low chlorine coal resulting in chlorine emissions of less than 1 ppm. While SO_2 emissions are low, NH_3 will react rapidly with SO_2 at temperatures below 32°F. Testing at Arapahoe found that at ambient temperatures below 32°F, a visible plume would form at NH_3 levels above 10 ppm. The plume visibility increased as the ambient temperature decreased and NH_3 slip increased. NH_3 can also absorb on the flyash. The amount of absorption varies with ash composition. NH_3 absorption on ash may affect ash sales and may cause ash handling concerns. Finally, NH_3 slip emissions are not currently regulated in Colorado.

Lacking any regulatory limit on NH_3 slip and due to the low SO_3 and HCl emissions, the project team selected 10 ppm as the target NH_3 slip for tuning Arapahoe Unit 4's SNCR system. For a high sulfur/high chlorine coal, 10 ppm NH_3 slip may be the maximum that could be tolerated due to plume and air heater concerns. At Arapahoe it was believed this limit would provide a conservative limit that would minimize operational problems. While there are no formal federal or state NH_3 emission limits, some site specific local permits have limited NH_3 emission to 10 to 25 ppm.

Figure 5-4 shows the NO removal achievable at a NH_3 slip limit of 10 ppm as a function of load. The figure includes data from both the Level 1 injectors and the ARIL lances, and clearly shows that the addition of the lances has substantially improved the low-load performance of the Arapahoe Unit 4 SNCR system. Before installation of the lances, the wall (Level 1) injectors were capable of providing only 11 percent NO removal at 60 MWe.

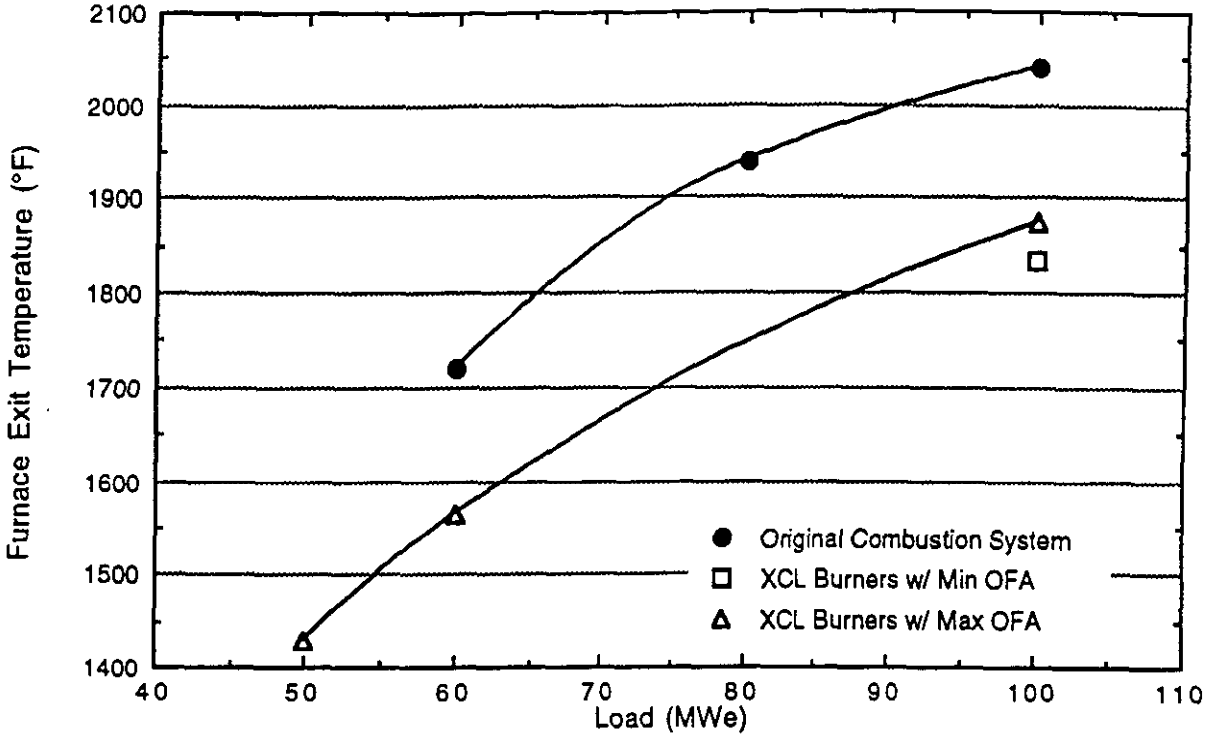


Figure 5-3. Furnace Exit Flue Gas Temperatures

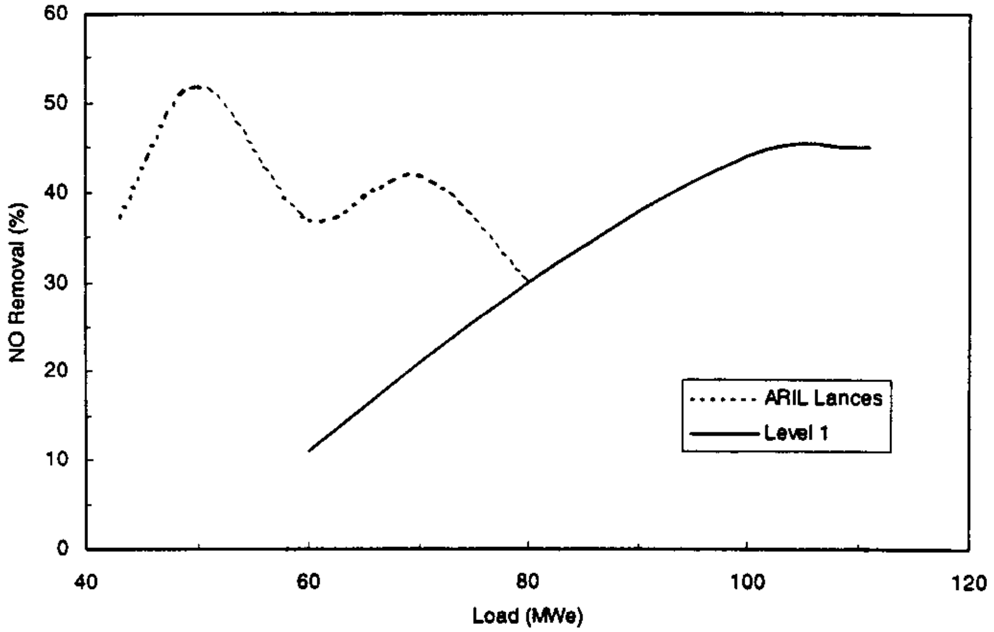


Figure 5-4. NO Removal as a Function of Load for NH_3 Slip Limit of 10 ppm

With the ARIL lances however, NO removals in excess of 35 percent are achievable at the same load and NH_3 slip limit. The lances also extended the operating range of the SNCR system down to the minimum load condition of 43 MWe.

5.3 DSI Test Results

Parametric testing of the sodium-based DSI system was conducted during the period of August 4, 1993 to May 27, 1994. The primary injection location was downstream of the air heater, at the inlet of the fabric filter dust collector. Two sodium-based sorbents were tested, sodium sesquicarbonate and sodium bicarbonate. The sodium compounds were processed through an attrition mill prior to injection, in order to reduce the particle size and increase the SO_2 removal effectiveness. Humidification was briefly tested with sodium sesquicarbonate by atomizing water into the flue gas, and cooling the average gas temperatures closer to the saturation point. Sodium bicarbonate injection was performed at two locations: in-duct (downstream of the air heater ahead of the fabric filter) and at a higher temperature location at the inlet to the air heater.

The primary operating parameter for the sodium injection processes was the normalized stoichiometric ratio, which is the amount of sorbent injected relative to the mass flow of sulfur in the flue gas. The chemical reactions require two molecules of sodium to react with each molecule of sulfur (SO_2) to form sodium sulfate, therefore the normalized stoichiometric ratio is expressed as 2Na/S, where a unity value is equivalent to the stoichiometric concentration. Parametric variations of the 2Na/S ratio, sorbent type, and boiler load were performed for the sodium injection tests. In the cases when humidification was utilized, the primary operating variable was the approach to saturation temperature of the flue gas. Saturation temperatures of the flue gas ranged from 112 to 118°F, depending on boiler operating conditions. During these tests, the humidification system was used to vary the approach to saturation from 50 to 90°F.

With a nominal 2Na/S ratio of 2.0, the SO_2 removals with in-duct sodium sesquicarbonate injection ranged from 64 to 78 percent (Figure 5-5). Alternatively, the 2Na/S ratio required for 70 percent SO_2 removal ranged from 1.6 to 2.2. Sorbent utilization decreased with increasing sorbent injection rates, as shown by the tapering off of the SO_2 removals as the 2Na/S ratio was increased to higher levels. The scatter apparent in Figure 5-5 represents day-to-day variations that were seen in the process. It is believed that a large portion of these variations resulted from day-to-day changes in sorbent feed rate and not the effectiveness of the process at a given 2Na/S ratio. Since the sorbent feed was based on the calibration of a volumetric screw system, any loss in feed capacity could not be readily detected. This would cause the actual 2Na/S to be lower than the set point.

The in-duct injection of sodium bicarbonate showed erratic results which are attributed to the relatively low flue gas temperatures at the fabric filter inlet (i.e., approximately 230 to 270°F). Since the operating temperatures for the duct and baghouse at Arapahoe Unit 4 were on the low side for optimum use of sodium bicarbonate, modifications were made and additional testing was conducted with injection at the economizer exit (air heater inlet) during April and May 1994. These results were more consistent than those for duct injection and showed that a 2Na/S ratio of approximately 1.1 was required for a 70 percent SO_2 removal (Figure 5-5).

There were no apparent problems associated with the use of the sodium injection system with regard to the operation of the boiler or any cold-end equipment. Chronic problems with sorbent feed, injection system deposit formation and plugging, and sorbent pulverizer operation were encountered throughout the test program. However, all of these problems are deemed manageable by routine maintenance procedures.

In addition to determining the SO_2 removals achievable with the injection of sodium sesquicarbonate and sodium bicarbonate, the evaluation of the impact of the sodium compounds on NO_2 emissions and NO_x removal was also an important element of this test phase. One of the more interesting observations from the test program was the process dynamics of NO_2 formation with sodium injection. Time-resolved measurements showed that the NO_2 emissions were not only dependent on the amount of sodium injected but also on the cleaning cycle of the Arapahoe Unit 4 fabric filter. With both sodium sesquicarbonate and sodium bicarbonate, the NO_2 emissions were found to increase

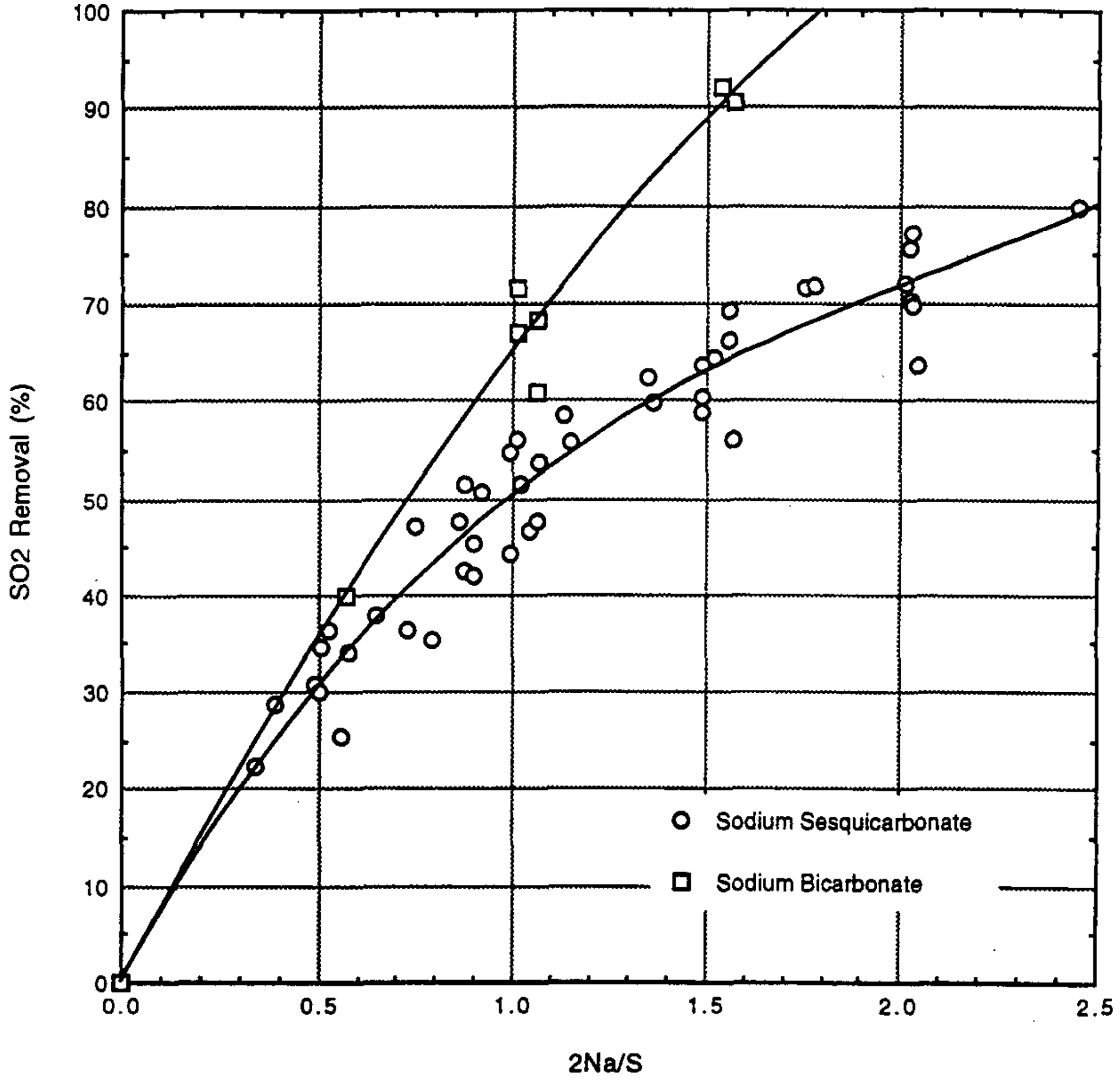


Figure 5-5. Comparison of SO_2 Removals for Injection of Sodium Sesquicarbonate (Fabric Filter Inlet) and Sodium Bicarbonate (Air Heater Inlet)

markedly just after a cleaning cycle. This suggests that there is an interaction between the NO_2 and the flyash. This was further confirmed by measurements made in each individual fabric filter compartment which showed that the NO_2 levels were not just a function of the SO_2 removal in each compartment, but also appeared to be related to the amount of fly ash collected in each compartment. This phenomena accounts for the high degree of variability in NO_2 emissions and NO_x reductions reported not only in this test program, but in previously reported full-scale sodium injection demonstrations (Fuchs, et al., 1989; Muzio, et al., 1984).

In terms of the levels of NO_2 produced, sodium sesquicarbonate produced NO_2 levels of nominally 10 ppm at a nominal 2Na/S ratio of 2.0 (although there were a few occasions where the NO_2 level reached almost 30 ppm). The NO_2 levels with sodium bicarbonate injection were generally higher. At a nominal 2Na/S ratio of 1.0, NO_2 levels with sodium bicarbonate injection were nominally 20 ppm with levels occasionally reaching 50 ppm. No plume coloration was noted with sodium sesquicarbonate injection, although some plume coloration was observed with sodium bicarbonate injection when NO_2 levels exceeded 35 ppm.

Both sodium sorbents resulted in NO_x removals of nominally 10 percent. These levels are consistent with those reported in the previous full-scale demonstrations mentioned above (Fuchs, et al., 1989; Muzio, et al., 1984).

After completion of the parametric tests with both sorbents, a long-term test of nominally four months duration (November 1994 to March 1995) was conducted with sodium sesquicarbonate injection ahead of the fabric filter. During this test, the control system was set to achieve a 40 percent SO_2 removal. Daily average SO_2 removals of 40 percent were easily achievable during the four-month period, although there were brief periods when the sodium injection system was off-line due to minor problems with plugging the sorbent transport lines or system maintenance requirements.

After completion of the four-month test, both the A and B DSI systems were modified in an effort to reduce the plugging problems, and then a second long-term test was run with a SO_2 removal set point of 70 percent. This test was run for four weeks and ended when Arapahoe Unit 4 was taken off-line for a scheduled 10-week outage (July 19, 1995). At the end of the test, the rolling average SO_2 removal was 67.9 percent, just short of the goal of 70 percent. A number of mechanical problems resulted in a system availability of only 94 percent for the four-week test.

After the outage, further modifications were made to both DSI systems and a second 70-percent long-term test started in January 1996. This test had been running for 10 days when the new flyash removal system plugged, and both DSI systems had to be shut down. The rolling average SO_2 removal at the end of the 10-day test was 74 percent. The problem with the flyash removal system was attributed to some residual effects of a Power River Basin coal test burn ran two months before. The plugging was not a result of the sodium injection test, as it occurred downstream of the flyash silo.

6.0 PARAMETRIC TEST RESULTS

This section presents the results of the parametric testing of the integrated system, as well as the results of two initial load-following tests. These tests were run during the time period between February 7 and June 16, 1994, before the installation of the new urea-injection lances (April 1995). This time period overlapped with the last four months of the parametric tests with sodium-based DSI alone (Smith, et al., 1996a), when the sodium bicarbonate injection location was moved upstream of the air heater.

In general, each of the parametric tests was run over the course of a single day, where the boiler load was held constant and both the DSI and SNCR control systems were run manually (i.e., at fixed 2Na/S and N/NO ratios). The goal of these tests was to assess if running the systems simultaneously resulted in reductions in stack NO_2 and NH_3 emissions, relative to the cases with only the DSI or SNCR system operating alone. Most of the parametric tests were run with the integrated system (simultaneous DSI and SNCR), but occasionally DSI- or SNCR-only tests were run to provide a basis of comparison for the integrated tests. The non-integrated tests also provided the opportunity to compare the current performance of the DSI and SNCR systems to that recorded during the previous DSI- and SNCR-only test phases (Smith, et al., 1996a and 1994b). This benchmarking process was especially important with regard to the SNCR system, since the previous SNCR-only tests (Smith, et al., 1994b) showed that the performance of the system could vary significantly with time due to changes in temperature profiles in the furnace. In addition to the obvious boiler operational parameters such as load, number of coal mills in service and excess O_2 level, the flue gas temperature distribution can be affected by more subtle effects such as cleanliness of the furnace walls or the condition (grinding performance) of the individual coal mills. The benchmarking of the DSI system was less important, since the performance of the SO_2 removal process is only minimally affected by boiler operational parameters, and thus really only a function of the sorbent injection rate (2Na/S ratio).

During the parametric tests when both the DSI and SNCR systems were run simultaneously, the DSI system was normally started first, and the SNCR system was started later, after the SO_2 removal had stabilized. The goal of this approach was to provide a direct assessment of the effect of urea injection on NO_2 emissions, since the NO_2 levels usually stabilized relatively quickly both before and after urea injection. On only a few occasions were the tests run in the reverse manner (starting the SNCR system first), as the stack NH_3 emissions were found to take much longer to stabilize due to adsorption and desorption on the flyash deposited in the FFDC. During the parametric tests, it quickly became apparent that assessing the effect of the integrated system on stack NH_3 emissions would require a time scale longer than that of a single 10- to 12-hour test day where constant load could be provided. Since the PSCo Load Dispatch Center was unable to block load on Arapahoe Unit 4 for longer periods, the effect on NH_3 emissions had to be assessed during the long-term load-following tests.

The initial parametric tests were run with sodium bicarbonate injection ahead of the FFDC. However, as found during the sodium-based DSI-only tests (Smith, et al., 1996a), the results of the integrated tests were erratic due to low flue gas temperatures at the injection location. The DSI system was subsequently modified to allow injection ahead of the air heater, and the consistency of the results with sodium bicarbonate improved. The remaining parametric tests were run with either sodium sesquicarbonate injection ahead of the FFDC, or with sodium bicarbonate injection ahead of the air heater. The results of the initial parametric tests with sodium bicarbonate injection ahead of the FFDC are included in the data summary attached to this report as Appendix A. However, these results are not discussed further in the body of the report.

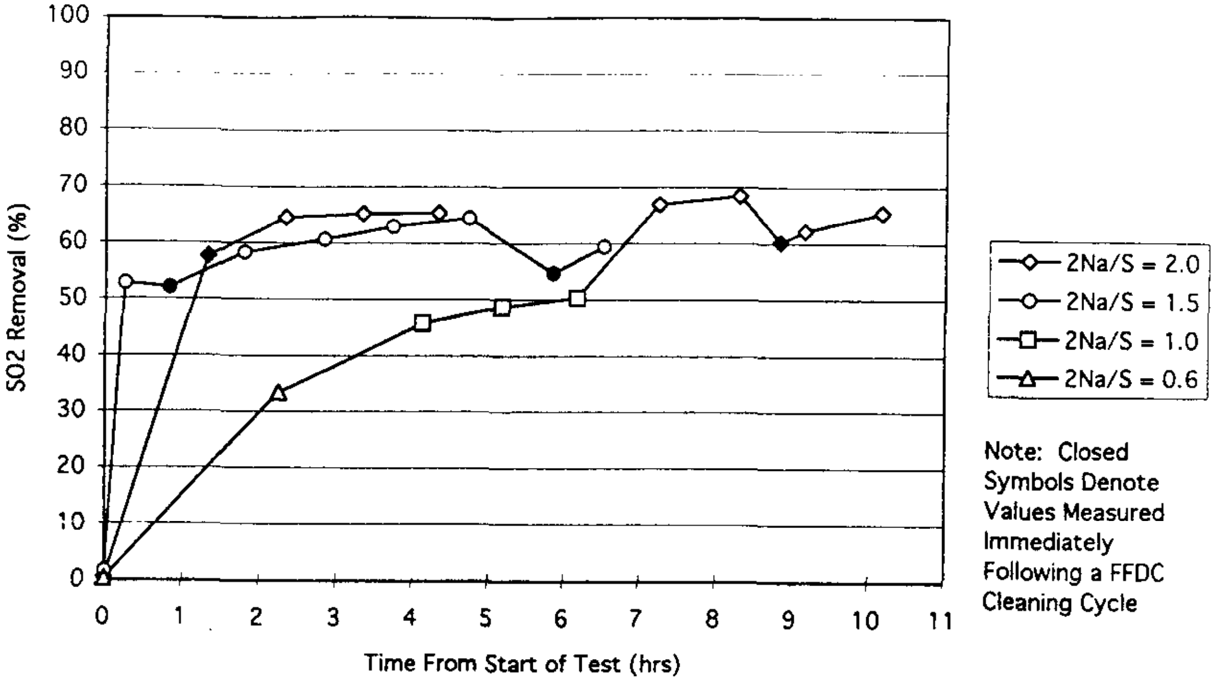
6.1 Sodium Sesquicarbonate Injection Ahead of the FFDC

The parametric tests with sodium sesquicarbonate injection ahead of the FFDC were run during three one-week test periods. The first two were in February and March of 1994, during the time when the DSI system was being modified to allow injection ahead of the air heater. The third week was in May 1994, after completion of the air heater injection tests with sodium bicarbonate. In total, thirteen tests were run during these three weeks (essentially one per day). Only five of these tests were run with the integrated system (both the DSI and SNCR systems operating simultaneously). The remaining tests were run with just one of the two systems operating in order to provide a basis of comparison for the integrated tests.

The SO_2 removal and NO_2 emission results for the DSI-only tests with sodium sesquicarbonate injection ahead of the FFDC are shown in Figure 6-1. These tests were run over a period of three consecutive days in May, where a single test was run on each of the first two days (one day each at 2Na/S ratios of 1.5 and 2.0). On the third day, three separate tests were run where the 2Na/S ratio was set at 0.6 for the first two hours, then increased to 1.0 for the next four hours, and then increased again to 2.0 for the final four hours. In each of these cases, the duration of the test was sufficient to allow the SO_2 removals to stabilize before the 2Na/S ratio was changed. The SO_2 removal results shown in Figure 6-1 agree well with the results of the previous DSI-only tests discussed in Section 5.3. In addition, the NO_2 emission results in Figure 6-1 follow the same trends seen during the earlier tests where each FFDC cleaning cycle is followed by a substantial increase in NO_2 emissions, and then a slow decline in the level until the next cleaning cycle. With sodium sesquicarbonate injection alone at 2Na/S = 2.0, SO_2 removals were nominally 70 percent and stack NO_2 emissions ranged from 10 to 15 ppm.

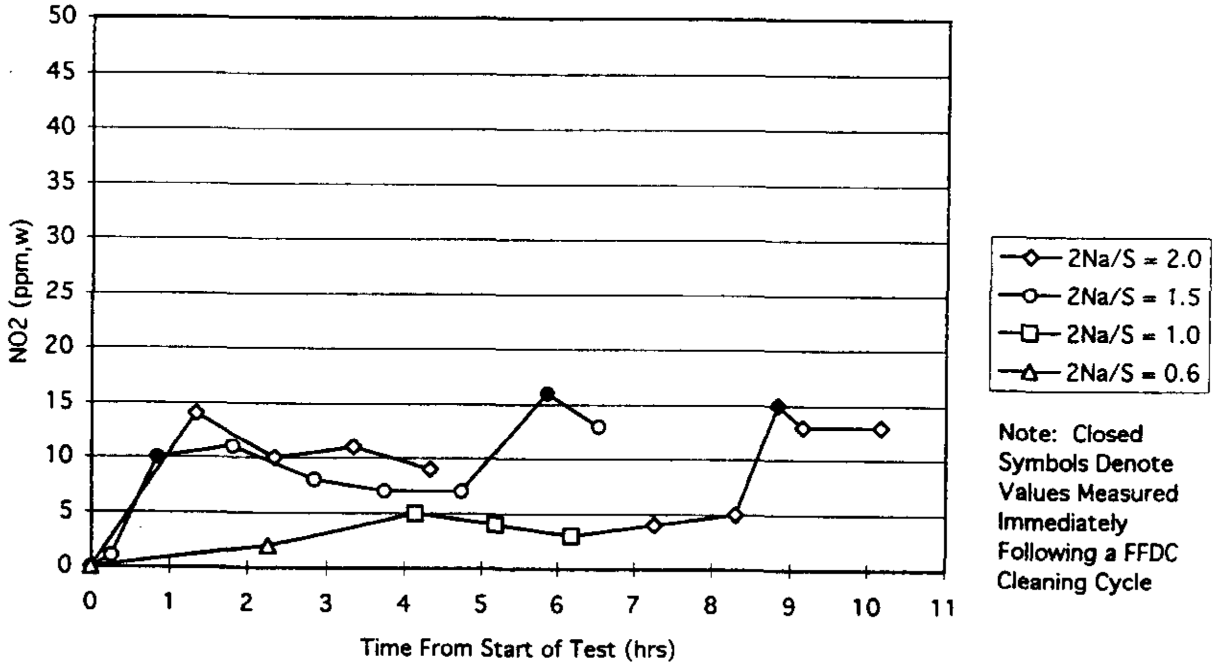
The results of the SNCR-only tests run during the current test phase are shown in Figure 6-2. The tests were run over a relatively narrow range of boiler loads (98 to 112 MWe), with both three and four mill-in-service configurations. The results show that while NO_x removals and N_2O emissions were relatively insensitive to the number of mills in service, NH_3 emissions were much higher with the three-mill configuration. These trends are consistent with those seen during the two previous phases of SNCR tests (Smith, et al., 1993 and 1994b). In addition, Figure 6-2 shows that a nominal NO_x removal of 45 percent is attainable at a NH_3 slip limit of 10 ppm (with all four mills in service). These results agree well with the 100 and 110 MWe results of the previous SNCR-only tests shown in Figure 5-4.

The results of one of the first integrated tests with sodium sesquicarbonate injection ahead of the FFDC are shown in Figure 6-3. The DSI system was run for approximately three



Note: Closed Symbols Denote Values Measured Immediately Following a FFDC Cleaning Cycle

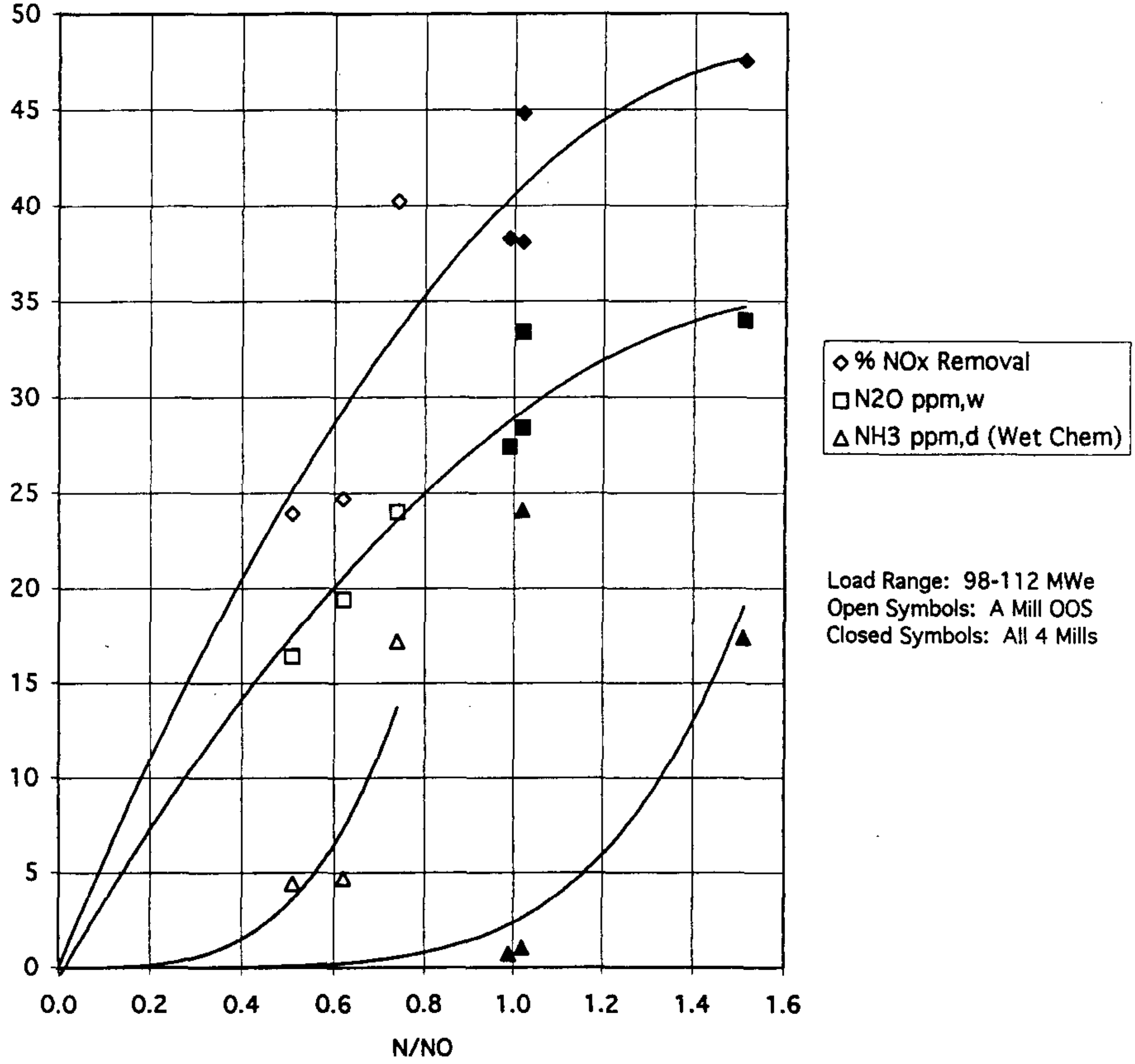
(a) SO_2 Removal



Note: Closed Symbols Denote Values Measured Immediately Following a FFDC Cleaning Cycle

(b) NO_2 Emissions

Figure 6-1. SO_2 Removal and NO_2 Emission Results for DSI-only Tests with Sodium Sesquicarbonate Injection (Load Range = 100 - 108 MWe, C Mill OOS)



Load Range: 98-112 MWe
Open Symbols: A Mill OOS
Closed Symbols: All 4 Mills

Figure 6-2. NO_x Removal, N_2O Emission, and NH_3 Slip Results for SNCR-only Tests (Level 1 Injection) hours before the SNCR system was started, and the 2Na/S and N/NO ratios were set at 2.0 and 0.6, respectively. The results show that although the SO_2 and NO_x removals had stabilized by the time urea injection began, the NO_2 emissions had only just begun to increase. The levels of SO_2 and NO_x removal measured before urea injection (nominally 73 and 13 percent, respectively) are consistent with the results of the sodium-based DSI-only tests discussed above. Figure 6-3 also shows that the NO_2 emissions did not exceeded 3 ppm with both the DSI and SNCR systems in operation. The NO_2 emissions during this test were too low to see any measurable decrease after starting the SNCR system. However, the lack of a large increase in NO_2 emissions after the FFDC cleaning cycle, as well as the increase seen at the end of the test when the SNCR system was turned off, indicate that the NO_2 emissions were indeed reduced when the integrated system was in operation.

The results of the integrated test shown in Figure 6-3 indicate that the DSI system did not affect the SNCR NO_x removal or N_2O emissions. The increases in NO_x removal and N_2O emissions measured after the SNCR system was started are comparable to the levels shown for the SNCR-only tests in Figure 6-2 (at N/NO = 0.6). Figure 6-3 also shows the results of the CEM and wet chemical measurements of the stack NH_3 emissions. The results of the two methods are not only consistent with each other, but also agree well with the results of the 3-mill SNCR-only tests at N/NO = 0.6 (Figure 6-2). While these results suggest that there was no change in NH_3 emissions with the integrated system, the results may not necessarily be conclusive. The previous SNCR test phases (Smith, et al., 1993 and 1994b) showed that the day-to-day variability in the flue gas distribution at the chemical injection location resulted in a repeatability in the NH_3 slip levels which was on the order of 3 to 4 ppm.

Figure 6-4 shows the results of a second integrated test where the DSI system was run for a longer period of time in an effort to attain a higher NO_2 emission level before starting the SNCR system. The 2Na/S and N/NO ratios were set at 2.0 and 1.0, respectively. Similar to the test shown in Figure 6-3, a FFDC cleaning cycle occurred shortly after the SNCR system was started. The SO_2 removal, NO_x removal and N_2O emissions for the integrated

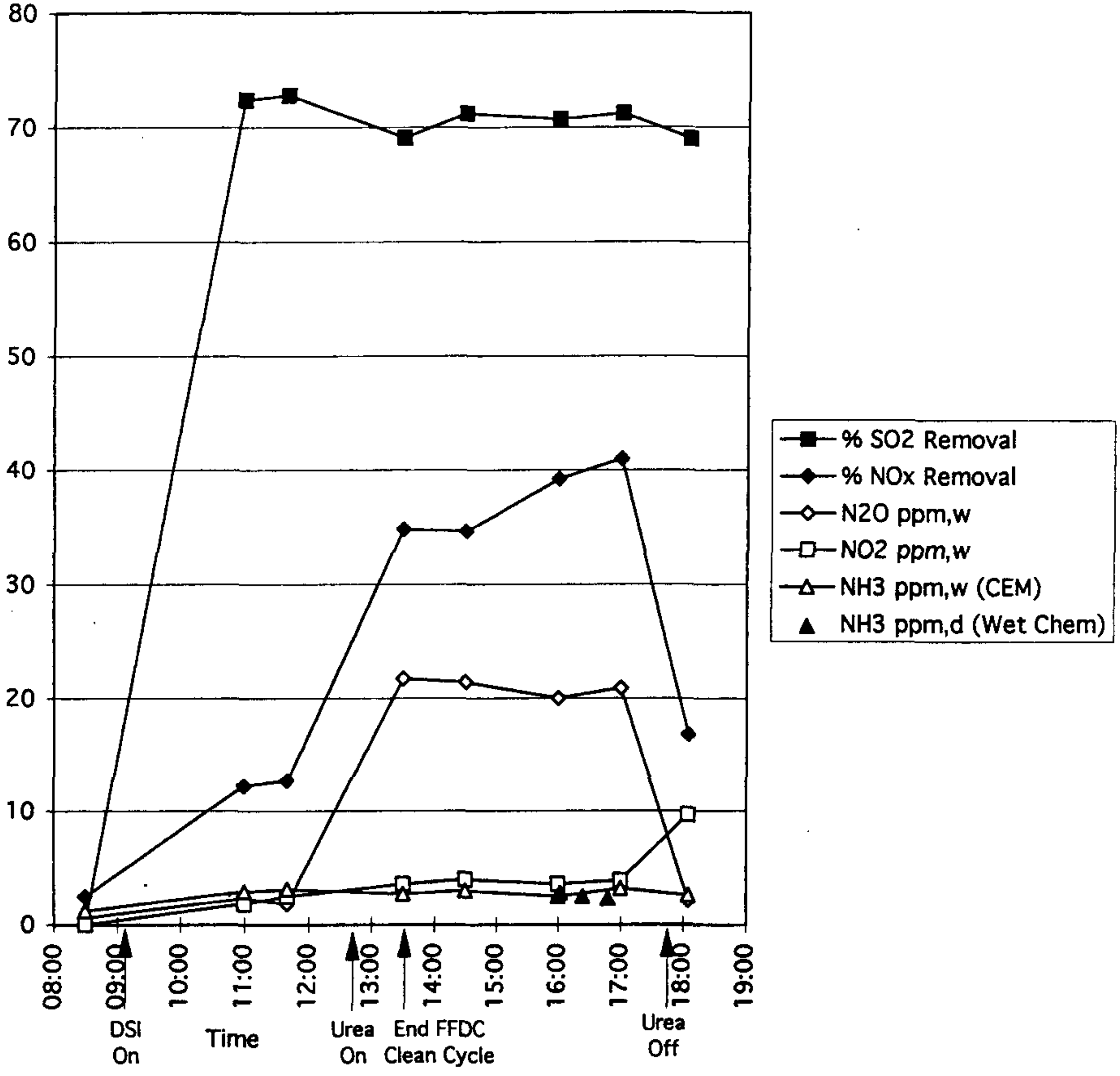


Figure 6-3. Time History of 100 MWe Integrated Test with Sodium Sesquicarbonate Injection (2Na/S = 2.0, N/NO = 0.6, A Mill OOS)

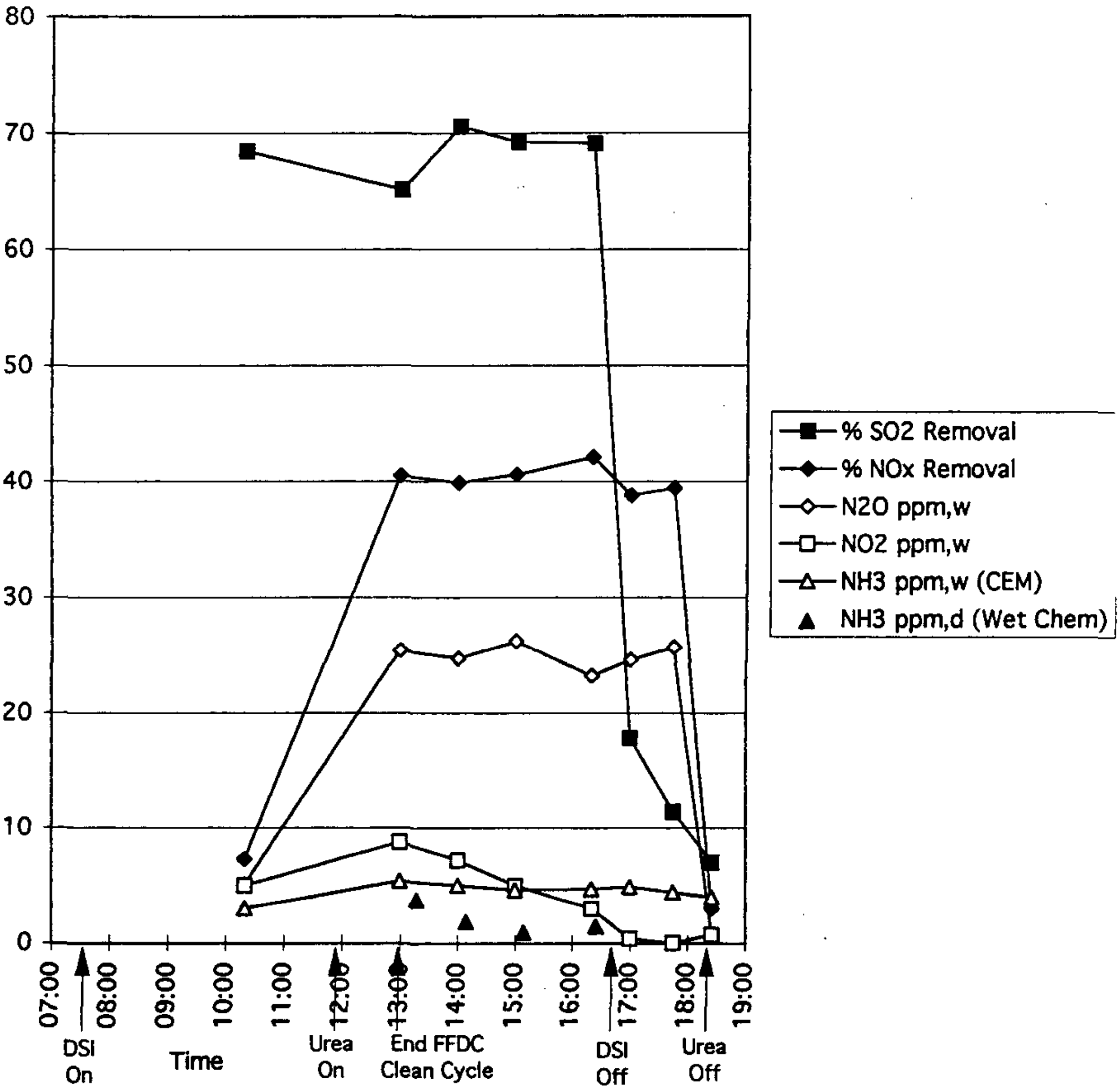


Figure 6-4. Time History of 95 MWe Integrated Test with Sodium Sesquicarbonate Injection (2Na/S = 2.0, N/NO = 1.0, 4 Mills in Service)

test are consistent with the levels seen during the DSI- and SNCR-only tests in Figures 6-1 and 6-2, respectively. Additionally, the trend in NO_2 emissions during the integrated test is similar to that seen for the DSI-only tests where there is an increase in NO_2 emissions immediately after the FFDC cleaning cycle, and then a slow decline. Overall, however, the results show that the NO_2 emission levels are lower with the integrated system (ranging from 5 to 10 ppm, rather than 10 to 15 ppm with the DSI system alone).

The results of the NH_3 slip measurements in Figure 6-4 show that the agreement between the CEM and wet chemical techniques was not quite as good as it was in Figure 6-3. Generally, the wet chemical measurements show levels of 1 to 2 ppm, which are consistent with the SNCR-only results in Figure 6-2 (at N/NO = 1.0 with all four mills in service). Although the CEM results show a NH_3 slip level of 3 ppm before urea injection began (due to the slight zero "offset" discussed in Section 4.3), the measurements indicate a 1 or 2 ppm increase with urea injection, consistent with the wet chemical results.

In the tests shown in Figures 6-3 and 6-4, the NH_3 emissions were too low to assess any effect of the integrated system. An accurate assessment of the effect would require running the SNCR system at a higher N/NO ratio where stack NH_3 emissions would be in the 10 to 15 ppm range. In addition, a better method of running the test would be to start the SNCR system first, let the stack NH_3 emissions stabilize, and then start the DSI system and continue monitoring the NH_3 slip. However, as mentioned above, the time required for the NH_3 emissions to stabilize both before and after sodium injection was usually greater than that available in a single 10-hour test day.

The results shown in Figures 6-3 and 6-4 indicate that NO_2 emissions were reduced with the integrated system. However, it was determined that parametric short term testing would not supply the necessary data to document the synergistic benefits of the integrated system and longer-term load following operation of the system would provide the most meaningful data. A load-following test was run in order to provide a better assessment of the "average" NO_2 emission levels with the integrated system. Both the DSI and SNCR control systems were operated in the automatic control mode, where the DSI system was set to maintain 70 percent SO_2 removal and the SNCR system set to limit the stack NH_3 slip to 10 ppm. The test was run for approximately 100 hours. During this time, the 24-hour day-to-day operation of both injection systems was monitored by plant personnel, and FERCo personnel were onsite only during the day to collect test data as well as address any operational problems which became apparent during the previous night. During the day, the SNCR system was shut down periodically in order to measure the baseline NO_x emissions and calculate the NO_x removal and N/NO ratio.

The results of the 100-hour test are shown in Figure 6-5. Note that during this test, data was only collected during the day when the unit was operated at nominally constant load. During the intervening periods, the unit was in a load following mode and process data was not collected. Thus, even though lines are drawn between the groups of data points, it does not mean that the unit was at steady condition. Generally, the boiler load ranged from 90 to 100 MWe during the day when test personnel were onsite. C Mill was OOS for maintenance for the entire duration of the test, and the N/NO ratio ranged from 0.6 to 0.8 during the days. The NH_3 slip and N_2O emissions (nominally 10 and 20 ppm, respectively) are comparable with the SNCR-only results shown in Figure 6-2 for 3-mill operation with N/NO ratios of 0.6 to 0.8. Overall, NO_x removals ranged from 40 to 50 percent during the test. These removals are consistent with the levels which would be expected by combining the appropriate SNCR- and DSI-only results (roughly 30 to 35 percent from SNCR and 10 to 15 percent from DSI). The most notable result of the test was the reduction in the NO_2 emissions. Figure 6-5 shows that the NO_2 emissions generally ranged from 1 to 3 ppm. This represents a substantial reduction from the levels seen during the DSI-only tests (Figure 6-1), where the NO_2 emissions varied from 10 to 15 ppm (at a nominal SO_2 removal of 70 percent).

A second interesting result of the long-term test shown in Figure 6-5 was the appearance of a strong NH_3 odor in the flyash. This odor became noticeable at the ash unloading station after about 30 hours of testing (towards the end of the second "day"). At this time, the upper and lower limits of the NH_3 trim control were set at 10 and 8 ppm, respectively. If the stack NH_3 emissions were above 10 ppm, the control system would decrease the

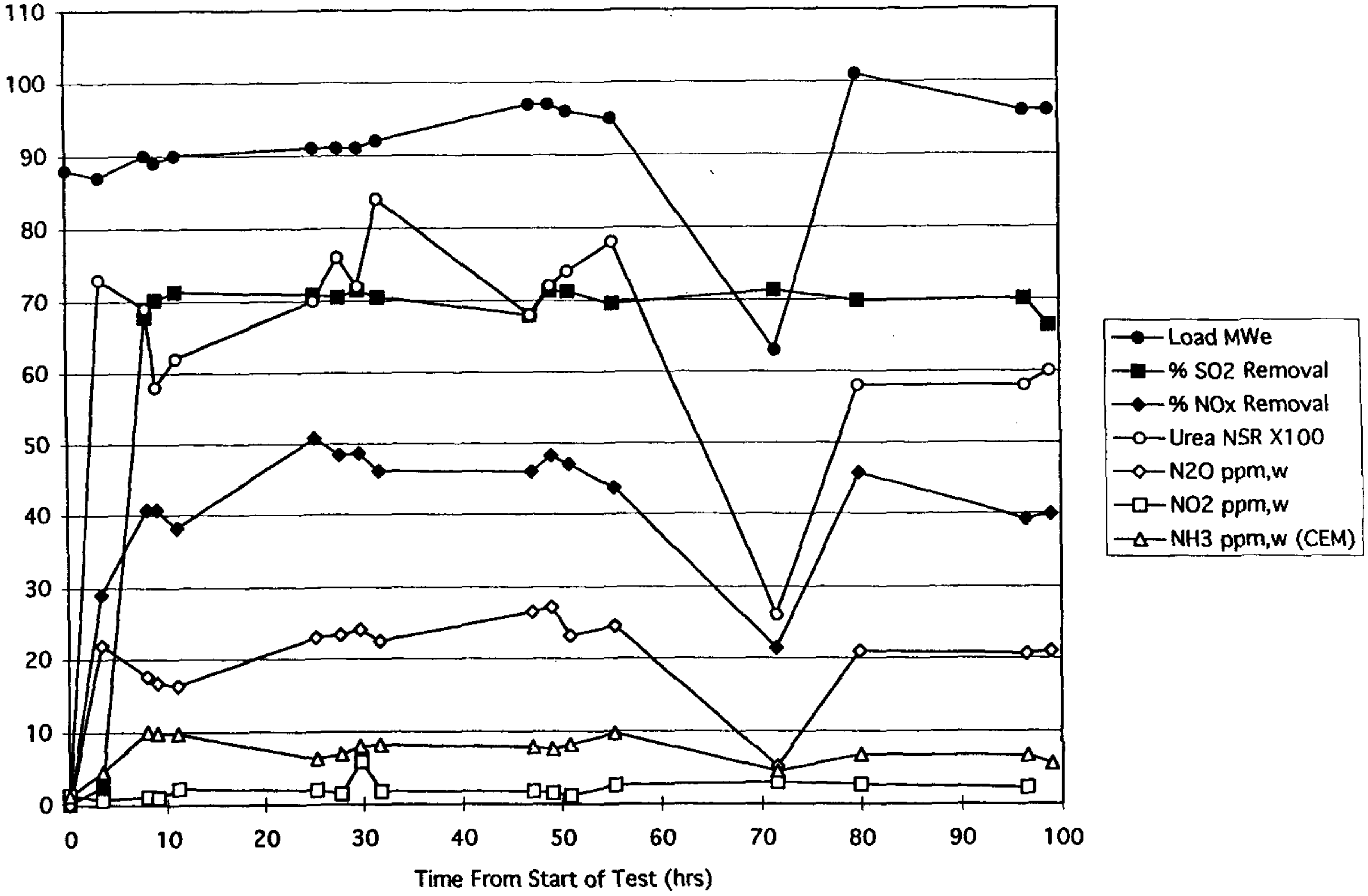


Figure 6-5. Results of 100-Hour Integrated Test with Sodium Sesquicarbonate Injection (C Mill OOS for Entire Test)

urea flow by up to 30 percent in order to reduce the slip below the 10 ppm limit. If the NH_3 slip was below 8 ppm, the control system would raise the urea flow (by up to 20 percent) in order to increase the slip to the 8 to 10 ppm range. At the end of the third "day" (approximately 55 hours into the test), the odor had worsened and the upper and lower trim setpoints were reduced to 5 and 3 ppm, respectively. This adjustment can be seen in Figure 6-5, where stack NH_3 emissions were nominally 10 ppm previous to the 60-hour mark, and nominally 5 ppm after that time. Unfortunately, by the time the adjustment was made, the odor at the unloading station had become strong enough to require the ash truck drivers to wear NH_3 respirators. By the end of the final "day" of testing, the odor had been reduced to the point where respirators were no longer necessary. However, the odor was still very strong. The appearance of this problem was unexpected, as a significant amount of long-term testing had been completed during the previous phase of SNCR-only tests, with only a slight NH_3 odor. The reason for this odor problem is related to the integration of sodium and urea injection and is discussed in Section 7. Ash handling at the station was later changed to a totally dry system which eliminated the NH_3 odor concern.

The long-term test shown in Figure 6-5 was run in June 1994, near the end of the integrated system tests without the ARIL urea-injection lances. By this time, the proof-of-concept lance tests had been successfully completed, and NOELL, Inc. had started the design process for the new ARIL lances. Further testing of the integrated system with sodium sesquicarbonate injection ahead of the FFDC (and further investigation of the flyash odor problem) was put on hold until the installation and optimization of the new lance hardware was complete. Long-term testing of the integrated system with the ARIL lances resumed in February 1995. The results of these tests will be presented in Section 7.

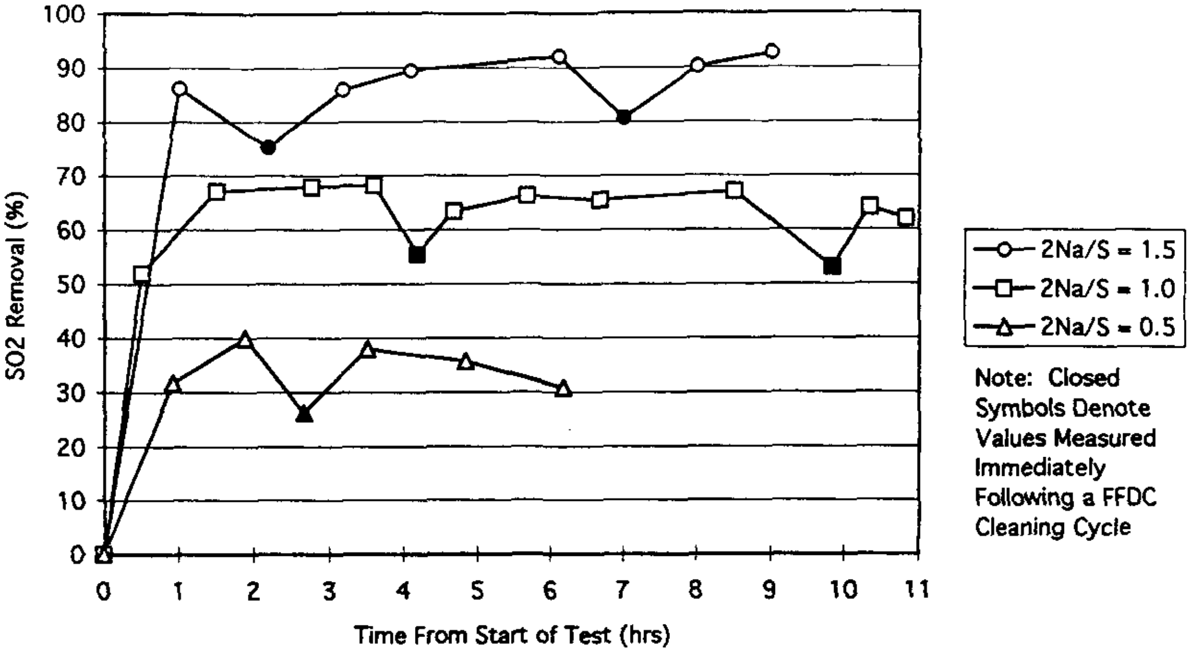
6.2 Sodium Bicarbonate Injection Ahead of the Air Heater

Although the consistency of the results with sodium bicarbonate improved when the injection location was moved to the higher-temperature region ahead of the air heater, only a limited number of tests were run with this injection configuration. The relocation of the sorbent injectors required a reduction in the number of injectors from six to four, and the higher sorbent loading to each injector increased the frequency of injector and transport line plugging. Additionally, detailed gas concentration measurements in the individual FFDC compartments showed that the distribution of sorbent across the cross section of the duct was often highly nonuniform, even when all four injectors seemed to be flowing (Smith, et al., 1996a). As shown in Figure 5-5, only seven tests were run with this injection configuration during the sodium-based DSI-only tests, and as will be discussed below, even fewer were run during the testing of the integrated system.

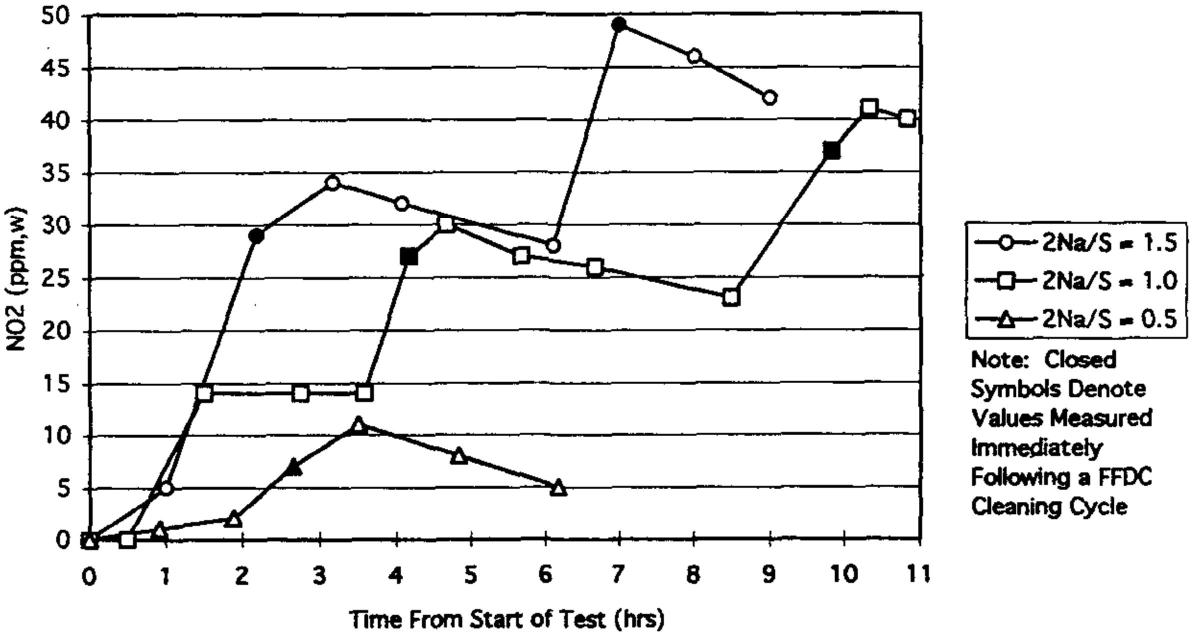
The SO_2 removal and NO_2 emission results for three DSI-only tests with sodium bicarbonate injection ahead of the air heater are shown in Figure 6-6. The trends in the results are similar to those seen for sodium sesquicarbonate injection ahead of the FFDC (Figure 6-1), where each FFDC cleaning cycle was followed by a slight decrease in SO_2 removal and a substantial increase in NO_2 emissions. Overall, however, the levels of SO_2 removal and NO_2 emissions were significantly higher during the sodium bicarbonate tests. At a 2Na/S ratio of 1.0, SO_2 removals were nominally 65 percent and stack NO_2 emissions reached levels in excess of 40 ppm after two FFDC cleaning cycles.

The tests with sodium bicarbonate injection ahead of the air heater were run in April 1994, near the end of the integrated system tests without the ARIL urea-injection lances. At this time, the focus of the integrated testing was on longer-term load-following tests, and thus only two parametric tests were run. During these tests, the SNCR system was started first, and allowed to stabilize for a number of hours before the DSI system was started. As mentioned previously, the goal of running the tests in this manner was to establish a reasonably stable NH_3 slip level at the stack, and then see if the level was reduced after the DSI system was started.

Figure 6-7 shows the results of one of the parametric tests with sodium bicarbonate injection ahead of the air heater. During this test, the SNCR system was allowed to stabilize for three hours before the DSI system was started, and the N/NO and 2Na/S ratios were both set at 1.1. Although the NO_x removal and N_2O emissions were stable, the stack NH_3 emissions were still slowly increasing when the DSI system was started. It was



(a) SO_2 Removal



(b) NO_2 Emissions

Figure 6-6. SO_2 Removal and NO_2 Emission Results for DSI-only Tests with Sodium Bicarbonate Injection (100 MWe, 4 Mills in Service)

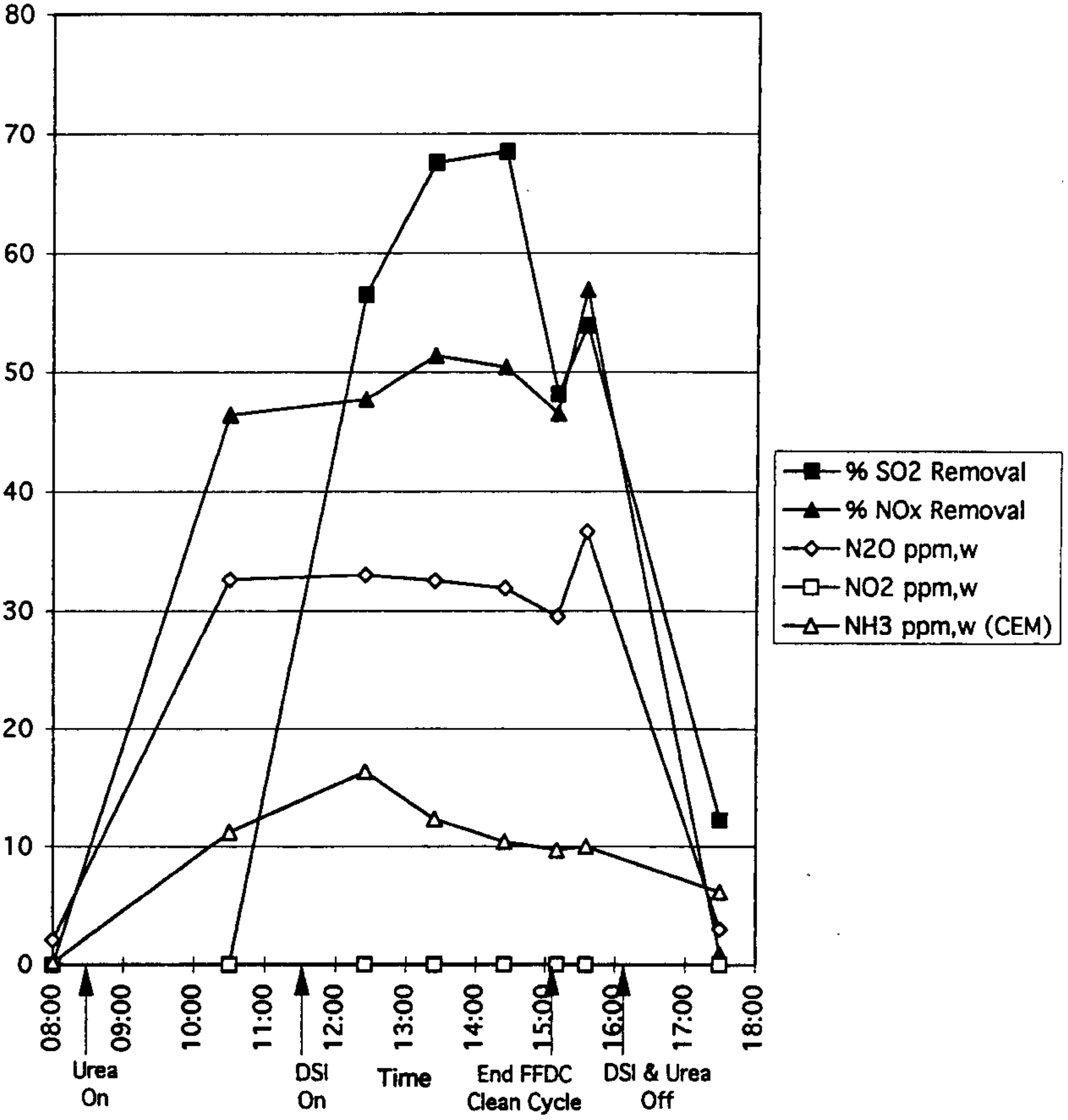


Figure 6-7. Time History of Integrated Test with Sodium Bicarbonate Injection (2Na/S = 1.1, N/NO = 1.1, 100 MWe, 4 Mills in Service)

necessary to start the DSI system before the NH_3 slip had stabilized due to limited time available to complete the test (this was the case with all of the tests run where the SNCR system was started first). The results show that the NH_3 emissions continued to increase for a short time after the DSI system was started, but after one hour the level peaked at 16 ppm, and then began to fall. By the end of the test, the NH_3 slip level had decreased to 10 ppm. This test was the only occasion during the parametric testing (with either sorbent) where there was a direct indication of a reduction in NH_3 slip. Other tests were run where the SNCR system was started first, but due to boiler upsets, time limitations (10-hour test days), or DSI and/or SNCR equipment problems, none were successful.

The levels of SO_2 removal, NO_x removal and N_2O emissions for the integrated test shown in Figure 6-7 are all consistent with the levels that would be expected from the DSI- and SNCR-only results discussed previously (Figures 6-6 and 6-1, respectively). Although the NO_x removal can be seen to increase when the DSI system is turned on, it decreases during the cleaning cycle. On the other hand, the NO_2 emissions show that there was a substantial reduction relative to the DSI-only case. The DSI-only tests with sodium bicarbonate (Figure 6-6) showed that at 2Na/S = 1.0, NO_2 emissions quickly increased to 15 ppm, and then jumped to 30 ppm after the first FFDC cleaning cycle. The integrated test was run at a similar sorbent injection rate, but there were no measurable NO_2 emissions either before or after the FFDC cleaning cycle. It was hypothesized that the decrease in NH_3 slip was an indication of an interaction between the NH_3 slip and a product of the DSI process (likely either NO_2 or one of its precursors). In addition, it was believed that the lack of any measurable NO_2 emissions indicated that there was a large excess of adsorbed NH_3 in the FFDC at the time when sorbent injection began. However, the test could not be run long enough to determine if the "excess NH_3" was a transient phenomena (resulting from running the SNCR system for three hours before starting the DSI system), and if it was, how the NO_2 emissions would be affected after the NH_3 levels in the FFDC returned to "normal".

A load-following test was run in order to provide a better assessment of the "average" NO_2 emissions for the integrated system with sodium bicarbonate injection ahead of the air heater. *It was necessary to run the DSI system in a manual control mode during this test,* and thus test personnel were onsite 24 hours a day. In the automatic mode, the CEM continually switches between the heated probes at the inlet and outlet of the FFDC. When the sorbent is injected ahead of the FFDC (i.e., just downstream of the inlet CEM sampling location), the control system calculates the SO_2 removal across the FFDC after each switching cycle, and then adjusts the sorbent feedrate to maintain the SO_2 removal setpoint. When the sorbent injection location was moved to a point upstream of the air heater, this control scheme is no longer applicable because the inlet CEM sampling location was now downstream of the sodium injection location.

While the PSCo System Dispatch Center was unable to block the load on Arapahoe Unit 4 for the duration of the long-term test, it was also not possible for the test personnel to manually adjust the sorbent feedrate and maintain a target SO_2 removal while the boiler load was continually changing. To allow a long-term test to be completed, the System Dispatch Center agreed to utilize the unit for regulation, but only on a limited basis. Rather than vary the load continuously, the load would be blocked for periods of 3 to 4 hours as dictated by system demand. This allowed the test personnel ample time to adjust the sorbent feedrate, as well as collect at least two sets of emissions data (normally collected at two hour intervals). Additionally, the System Dispatch Center would provide the test *personnel with 10 to 15 minutes notice before changing load. This advance notice* provided the test personnel with a chance to collect a final set of data before the load change.

The results of the load-following test with sodium bicarbonate injection ahead of the air heater are shown in Figure 6-8. Throughout the test, the sorbent feedrate was adjusted to maintain a 2Na/S ratio of 1.0. This setpoint was based on the results of the DSI-only tests (Figure 6-6), which showed that this feedrate resulted in a SO_2 removal of approximately 70 percent. Figure 6-8 shows that for the most part, SO_2 removals were in the 60 to 70 percent range throughout the duration of the test. The results also show that there was a substantial reduction in NO_2 emissions with the integrated system. While the results of the DSI-only tests (Figure 6-6) indicated that the NO_2 emissions could exceed

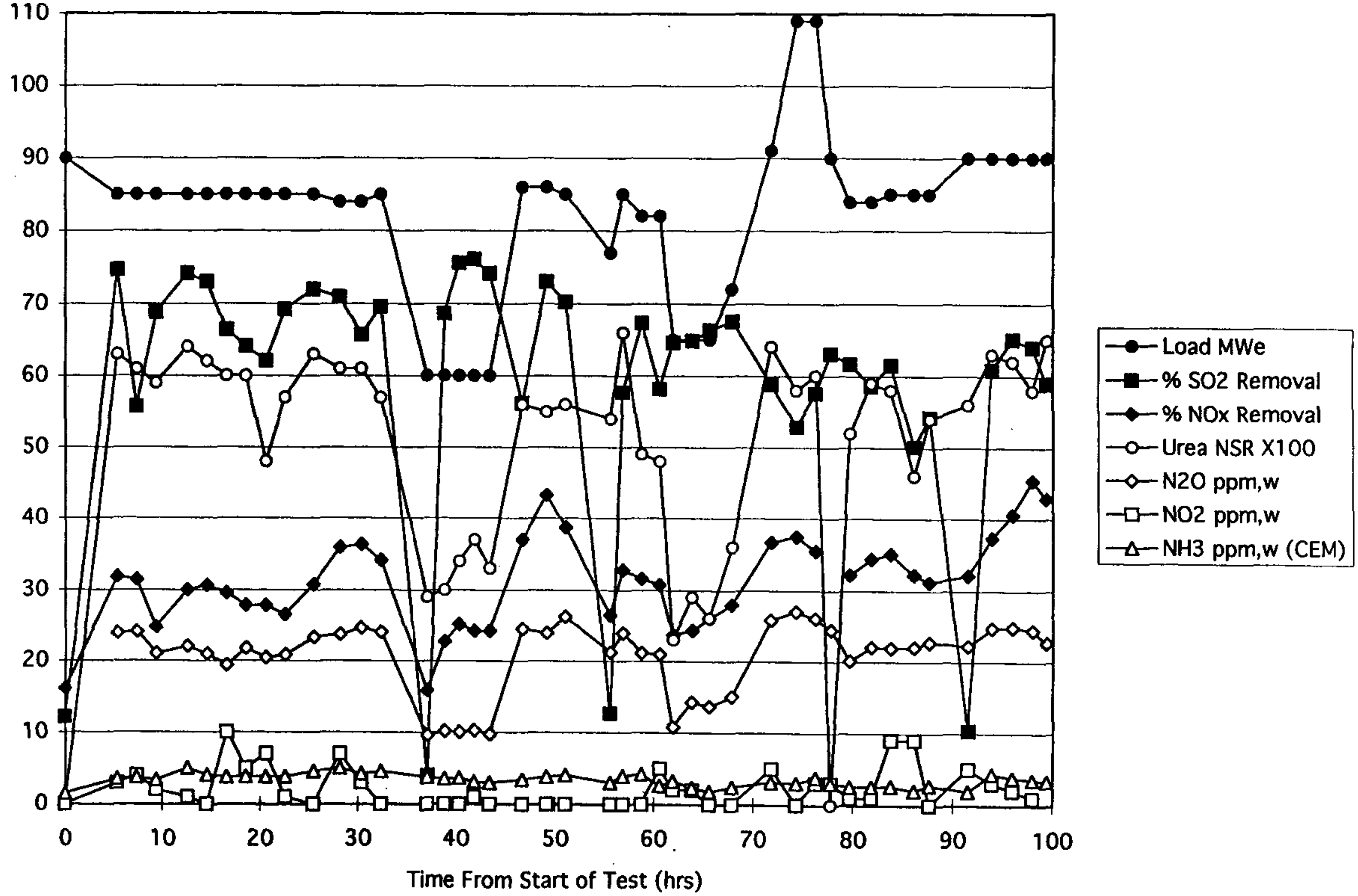


Figure 6-8. Results of 100-Hour Integrated Test with Sodium Bicarbonate Injection (C Mill OOS for Entire Test)

40 ppm at 2Na/S = 1.0, during the load-following test levels were nearly always less than 5 ppm, and never exceeded 10 ppm.

The SNCR control system was run in the automatic control mode during the test shown in Figure 6-8. Similar to the load-following test with sodium sesquicarbonate (Figure 6-5), the upper and lower NH_3 trim control setpoints were 10 and 8 ppm, respectively, and the maximum negative trim on the urea injection rate was limited to 30 percent. However, the maximum positive trim was limited to 10 percent (compared to 20 percent for the sodium sesquicarbonate test). The boiler load varied from 80 to 90 MWe for the majority of the test, and during these times, the N/NO ratio was nominally 0.6. The NO_x removals and N_2O emissions shown in Figure 6-8 are consistent with the levels that would be expected from the application of the individual DSI and SNCR technologies (Figures 6-6 and 6-2, respectively). The stack NH_3 emissions were nominally 5 ppm, and there were no reports of excessive NH_3 odors at the flyash unloading station.

Figure 6-8 shows that there were three occasions during this long-term test where the SO_2 removal dropped to a level below 20 percent. These three occurrences correspond to times when it was necessary to take the DSI system off-line in order to clean the pulverizer. During the early stages of the test program, it was found that when the DSI system was run continuously over the course of many days, pulverizer vibration levels would slowly increase to the point where it became necessary to shut the pulverizer down. The imbalance was a result of a buildup of sorbent of the rotating disk within the pulverizer. This problem was found to occur more frequently with sodium bicarbonate than with sodium sesquicarbonate. Flushing the pulverizer with a very low flowrate of water while it was running was found to quickly remedy the problem. The sorbent feeder was off during this procedure, and a drain valve at the pulverizer exit was opened so that only the pulverizer (and not the transport line leading upstairs to the splitter valve) was washed. After the wash, the inside of the pulverizer was dried by allowing it to run for approximately one hour without water or sorbent. Although this procedure was fairly straightforward, it still required approximately two hours to complete. It was not possible to simply switch to the other feed system during the time period when this test was run, as the other storage silo contained sodium sesquicarbonate. Therefore, whenever a pulverizer wash was necessary during the long-term test shown in Figure 6-8, the sorbent flow was off for approximately two hours.

As mentioned previously, only a few tests were run with sodium bicarbonate injection ahead of the air heater. This was partially due to the temporary nature of the modifications which were made to the original DSI injection system. Flexible rubber hoses were used to transport the sorbent from the four-way splitter on the east side of the boiler. This splitter was originally used to inject calcium hydroxide at the economizer inlet during the calcium-based DSI-only tests (Shiomoto, et al., 1994). The hoses ran up the east side of the boiler to the horizontal duct at the air heater inlet, and then across the top of the duct to the four vertical injection locations. It was found that the sorbent had a tendency to drop out of suspension and deposit in the horizontal hose runs. This was especially a problem in the hoses leading to the two westernmost injectors, as these horizontal runs were 20 to 30 feet long.

As the deposits in these hoses accumulated, the sorbent and transport air flow would slowly become biased to the east side of the duct, and the westernmost transport lines would eventually become completely blocked. Although it was found that vigorously shaking each hose every few hours would keep the rate of deposition to a minimum, this was hardly a long-term solution. These plugging problems, combined with the pulverizer difficulties described above and the lack of automatic control capabilities, restricted any further long-term testing with sodium bicarbonate injection at the air heater inlet. Thus, all of the integrated testing performed after the installation of the ARIL urea-injection lances was performed with sodium sesquicarbonate injection ahead of the FFDC.

7.0 LONG-TERM LOAD-FOLLOWING TEST RESULTS

The integrated parametric tests described in the previous section were completed in June 1994. As mentioned above, these tests were run concurrently with the final parametric tests with sodium-based DSI alone. After the parametric DSI-only tests were complete, long-term load-following tests were planned to demonstrate that the DSI system was capable of maintaining 70 percent SO_2 removal for an extended period of time. Once the DSI system was operational, Arapahoe Station was required to achieve a yearly-average SO_2 removal of 20 percent. Additionally, the permit required that the DSI system be run on a daily basis during Denver's "brown cloud" season (November 1 to February 28). As there was no urgency to complete the DSI-only tests (further testing with the integrated system could not proceed until after the new ARIL lances were installed and optimized), the long-term DSI-only tests were postponed until November 1994. These tests were run with sodium sesquicarbonate injection ahead of the FFDC, and the plan was to maintain a rolling-average SO_2 removal of 40 percent for two months, and then increase the removal to 70 percent for two more months. Testing began in mid-November 1994, and concluded in mid-March 1995. The test at 40 percent removal was successful, but due to a number of DSI equipment problems, only short-term testing of the system at 70 percent SO_2 removal was possible during the final two months.

The new urea-injection lances were installed in April 1995, and the optimization test program ran until mid-December 1995. There were a number of large breaks in the test program during this eight-month period (a 2-week break to modify the lance internal piping arrangements, a scheduled 10-week turbine outage, and a 3-week test burn of a Powder River Basin coal), such that only approximately 11 weeks were actually devoted to the ARIL optimization tests. The ARIL lance optimization tests are documented in a separate report (Smith, et al., 1996b). A second attempt at a long-term DSI-only test with 70 percent SO_2 removal was started in January 1996. The test was successful, and concluded in mid-February just before the long-term tests with the integrated system were scheduled to start.

The original plan for the integrated long-term testing was to run the DSI and SNCR systems simultaneously during the last two weeks of February, 1996, and then run the SNCR system alone for the first two weeks of March. It was hoped that a comparison of the average NH_3 emissions and N/NO ratios for these two long-term load-following tests would provide additional information regarding the amount of NH_3 slip reduction with the integrated system. The new Unit 4 dry flyash collection system failed during the long-term DSI-only test on February 12, just one week before the long-term integrated test was to begin. With the dry flyash collection system out-of-service, the Unit 4 flyash had to be pumped out to the settling ponds along with the ash from the other three units at the station. The long-term DSI-only testing ended at this point, and each day thereafter, the DSI system was run for only a short (2-hour) period in order to meet the permit requirement of running the system each day. It was estimated that at least two weeks would be required to complete the repairs to the dry flyash system, so the scheduling of the long-term integrated and SNCR-only tests was reversed. Testing with urea alone began on February 19. The dry flyash collection system came back on-line February 23, and on February 29, the DSI system began running full-time. Testing of the integrated system continued until March 14, when Unit 4 was taken off-line for a short, unscheduled outage.

The results of the long-term integrated and SNCR-only tests are presented separately in the following sections. The SNCR-only tests (February 19 to 29) are discussed in Section 7.1, while the integrated tests (February 29 to March 14) are discussed in Section 7.2. On March 8 (approximately half-way through the integrated test), a strong NH_3 odor again appeared at the Unit 4 flyash unloading station. The odor problem continued through the remainder of the integrated test. Flyash samples were collected on four occasions during the final week of testing, and the results of the analysis of these samples are presented in Section 7.3.

Table 7-1 provides a chronology of the long-term tests showing the test dates and times, key features of the test period, and the figure in which the results are presented. The objectives of the long-term integrated tests were to: (1) monitor the automatic operation of

Table 7-1

Chronology of the Long-Term Integrated Tests

Day	Time	Comments	Figure No.
19 Feb 96	1830	Begin SNCR-only test, NH_3 trim at 10 ppm/8 ppm	7-1
25 Feb 96	1305	Change NH_3 trim to 8 ppm/6 ppm	7-7
27 Feb 96	0530 2220	Change NH_3 trim to 8 ppm/ 7 ppm ARIL lance liquid line frozen, change to Level 1 injection only	7-9 7-9
29 Feb 96	1555	Integrated test begins, SO_2 removal set at 75%	7-11
1 Mar 96	1130 1440 ~2300	DSI system off SNCR system off DSI system on at 75% SO_2 removal	7-12 7-12 7-12
4 Mar 96	1430	SNCR system on. NH_3 trim at 8 ppm/7 ppm. ARIL lances and Level 1 injectors operating	7-15
5 Mar 96	1030	DSI feeders and air locks trip off (restart at 1330)	7-16
6 Mar 96	0630 0745	DSI feeders and air locks trip off (restart at 1830) East ARIL lance liquid line frozen, change to Level 1 injection only	7-17 7-17
8 Mar 96	0920 1000	NH_3 odor at ash silo. DSI system off SNCR system off	7-19 7-19
10 Mar 96	0805 1400 1800 2155	SNCR system on in manual control mode DSI system on in automatic control mode at 75% removal SNCR system to automatic control mode. NH_3 trim at 8 ppm/7 ppm SNCR system off	7-21 7-21 7-21 7-21
11 Mar 96	0700	SNCR system on in automatic control mode. NH3 trim at 8 ppm/7 ppm. ARIL lances and Level 1 injectors operating	7-22
12 Mar 96	1005 1500 1725 2115	NH_3 odor at ash silo. SNCR system off SNCR system on. NH_3 trim at 5 ppm/4 ppm NH_3 trim to 4 ppm/3 ppm NH_3 trim to 4.5 ppm/4 ppm	7-23 7-23 7-23 7-23
13 Mar 96	0320	NH_3 trim to 4 ppm/3.5 ppm	7-24
14 Mar 96	0640 2045 2115 2300	NH_3 trim to 4.5 ppm/4 ppm DSI system off SNCR system off Unit off-line	7-25 7-25 7-25 7-25

the integrated system, and (2) document the synergistic benefits of the combined sodium/SNCR operation. With the unit in automatic control, process parameters varied in response to changes in input parameters. Because of the dynamic nature of the tests, it is difficult to effectively present the results in a parametric fashion. Rather, the results are presented chronologically.

As the reader progresses through Section 7, the following observations can be made:

- NO_2 emissions are dramatically reduced when the sodium-based DSI system is used in conjunction with the urea-based SNCR system.
- Comparably, NH_3 slip from the SNCR system is reduced when the DSI system is in service. (With automatic operation of the system, this is reflected by a higher urea injection rate for a given NH_3 slip setpoint.)
- Without the SNCR system, NO_2 emissions exhibit a large increase following a FFDC cleaning cycle. The SNCR system suppressed this spike, although some increase can be noted.
- Operation of the integrated system (at an 8 ppm NH_3 slip limit) resulted in an odor problem around the ash silo. (This was not encountered with the SNCR system alone.) This is attributed to the solubility of the sodium compounds increasing the release of NH_3 when the ash is wetted for transport.

7.1 SNCR-Only Test Results

In retrospect, it was actually fortunate that the long-term integrated test was delayed until March, as the integration of the ARIL lances into the existing automatic SNCR control system proved to be more difficult than originally anticipated. The urea-only test provided the opportunity to fine-tune the operation of the SNCR control system in the fully-automatic, load-following mode before the integrated test began. During the initial days of the long-term SNCR-only test, a white detached plume was frequently visible. This detached visible plume occurred occasionally during the winter months and was attributed to NH_3/SO_2 reactions forming solid compounds such as $(NH_4)_2SO_3$. This reaction mechanism was discussed in Section 5.2 of this report and thermochemical calculations were presented in Muzio, et al., (1997). The CEM NH_3 measurements at the stack indicated that the NH_3 slip was higher than expected when the Level 1 injectors were in service and lower than expected when the ARILs were in operation. Wet chemical measurements at the FFDC inlet confirmed that the slip levels were frequently well above 10 ppm when Level 1 was in operation. During the first seven days of the test, the SNCR control setpoints were repeatedly modified in an effort to reduce the NH_3 slip for Level 1 injection, and increase the NH_3 slip (i.e., increase the NO_x removal) for injection with the ARIL lances.

The SNCR control system utilizes a "percent" boiler load signal (rather than an absolute MW signal) as the primary control input. This signal ranges from 0 to 100 percent where the upper limit is defined by a gross load of 150 MWe (which is well above the operational maximum for Arapahoe Unit 4). In the control program, the overall range of minimum to maximum operating load is divided into twelve smaller ranges. Each of these ranges covers a 5 percent increment of the boiler load input signal between 35 and 95 percent. Within each of these ranges, any combination of injection location (ARIL, Level 1 or both), injection angle (applicable to ARIL injection only), total liquid flow, and urea flow may be specified.

Table 7-2 shows the settings for the SNCR control system "tuning table" which were used when the long-term urea-only test began on February 19, 1996. These settings were based on the results of the ARIL optimization tests (Figure 5-4), where the NH_3 slip at the FFDC inlet was limited to 10 ppm. The urea flowrate for each load range is input into the table on the basis of a full-strength solution (i.e., a concentration of 100 percent). The actual concentration of the urea solution in the storage tank is a variable which must also be entered into the control program. The program uses the full-strength urea flowrates and the concentration information to calculate the actual solution flowrates for each load range. The concentration of the solution in the tank was measured periodically throughout the test program, usually both before and after the delivery of a new load of chemical.

As mentioned above, the tuning table settings were adjusted repeatedly during the first week of the SNCR-only test. The final adjustments were made on February 25, 1996, and the resulting settings are shown in Table 7-3. Overall, the urea flowrates for injection at the Level 1 location were reduced, while the flowrates for the ARIL injection setpoints were

Table 7-2

Initial Settings for SNCR Control System (Feb. 19, 1996)

Urea Computer Range Number	Urea Computer % Load Range	Unit 4 Control Room Net MW Range	Injection Location and Angle	Total Liquid Flowrate (gpm)	Urea Flow @ 100% (gpm)	Urea Flow @ 36.14% (gpm)
0	35-40	44-50	ARIL @ 90°	4	0.334	0.92
1	40-45	50-56	ARIL @ 45°	4	0.286	0.79
2	45-50	56-63	ARIL @ 22°	4	0.305	0.84
3	50-55	63-69	ARIL @ 22°	4	0.366	1.01
4	55-60	69-76	Level 1	2	0.209	0.58
5	60-65	76-82	Level 1	2	0.231	0.64
6	65-70	82-88	Level 1	4	0.277	0.77
7	70-75	88-94	Level 1	6	0.324	0.90
8	75-80	94-100	Level 1	6	0.411	1.14
9	80-85	100-107	Level 1	6	0.647	1.79
10	85-90	107-113	Level 1	6	0.883	2.44
11	90-95	113 up	Level 1	6	0.883	2.44

Table 7-3

Final Settings for SNCR Control System (Feb. 25, 1996)

Urea Computer Range Number	Urea Computer % Load Range	Unit 4 Control Room Net MW Range	Injection Location and Angle	Total Liquid Flowrate (gpm)	Urea Flow @ 100% (gpm)	Urea Flow @ 36.14% (gpm)
0	35-40	44-50	ARIL @ 90°	4	0.293	0.81
1	40-45	50-56	ARIL @ 45°	4	0.440	1.22
2	45-50	56-63	ARIL @ 22°	4	0.483	1.34
3	50-55	63-69	ARIL @ 22°	5	0.526	1.46
4	55-60	69-76	Level 1	2	0.180	0.50
5	60-65	76-82	Level 1	2	0.201	0.56
6	65-70	82-88	Level 1	2	0.222	0.61
7	70-75	88-94	Level 1	4	0.272	0.75
8	75-80	94-100	Level 1	4	0.301	0.83
9	80-85	100-107	Level 1	6	0.329	0.91
10	85-90	107-113	Level 1	6	0.518	1.43
11	90-95	113 up	Level 1	6	0.706	1.95

generally increased. The settings for the NH_3 trim control were also changed during the first week of the SNCR-only test. When the test began, the upper and lower NH_3 trim control setpoints were 10 and 8 ppm, respectively. The maximum positive and negative urea flow bias limits were set at 50 and 35 percent, respectively. By February 25, the setpoints had been reduced to 8 and 6 ppm, respectively, and the maximum negative bias limit had been increased to 75 percent.

In addition to the changes to the tuning table and trim control settings made during the first week of testing, there were also a number of modifications made to the SNCR control system logic. These modifications primarily involved efforts to limit increases in NH_3 slip that occurred whenever the boiler load moved between load ranges in the tuning table. This problem was especially severe when the injection location switched between Level 1 and the ARIL lances, where the stack NH_3 emissions often "spiked" to levels in excess of 20 ppm. These minor problems with the control system logic were resolved by the time the integrated system began running full-time on February 29, 1996.

Figures 7-1 through 7-11 show the 10-minute averages of boiler load, SO_2 removal, NO_x removal, N/NO ratio, NH_3 slip, and NO_2 and N_2O emissions as a function of time for each day during the long-term test with SNCR alone (February 19 to 29, 1996). During the two earlier 24-hour integrated tests described in Section 6 (Figures 6-5 and 6-8), both the SNCR and DSI systems were periodically turned off in order to check the baseline NO_x emissions. This would then allow the calculation of the NO_x removal and N/NO ratio. For the long-term integrated and SNCR-only tests, baseline stack NO_x emission levels were obtained by reviewing recent CEM data collected at times when neither the SNCR nor the DSI systems were running. This data was sorted on the basis of load, where the gross load range of 50 to 120 MWe was divided into seven increments of 10 MWe. The NO_x emission data within each 10 MWe range was then correlated to stack O_2 levels using a linear curve fit. From these correlations, baseline NO_x emission levels could be predicted from the boiler load and stack O_2 data. Since the CEM system was operated in the normal mode of continuously switching between the inlet and outlet locations during the long-term

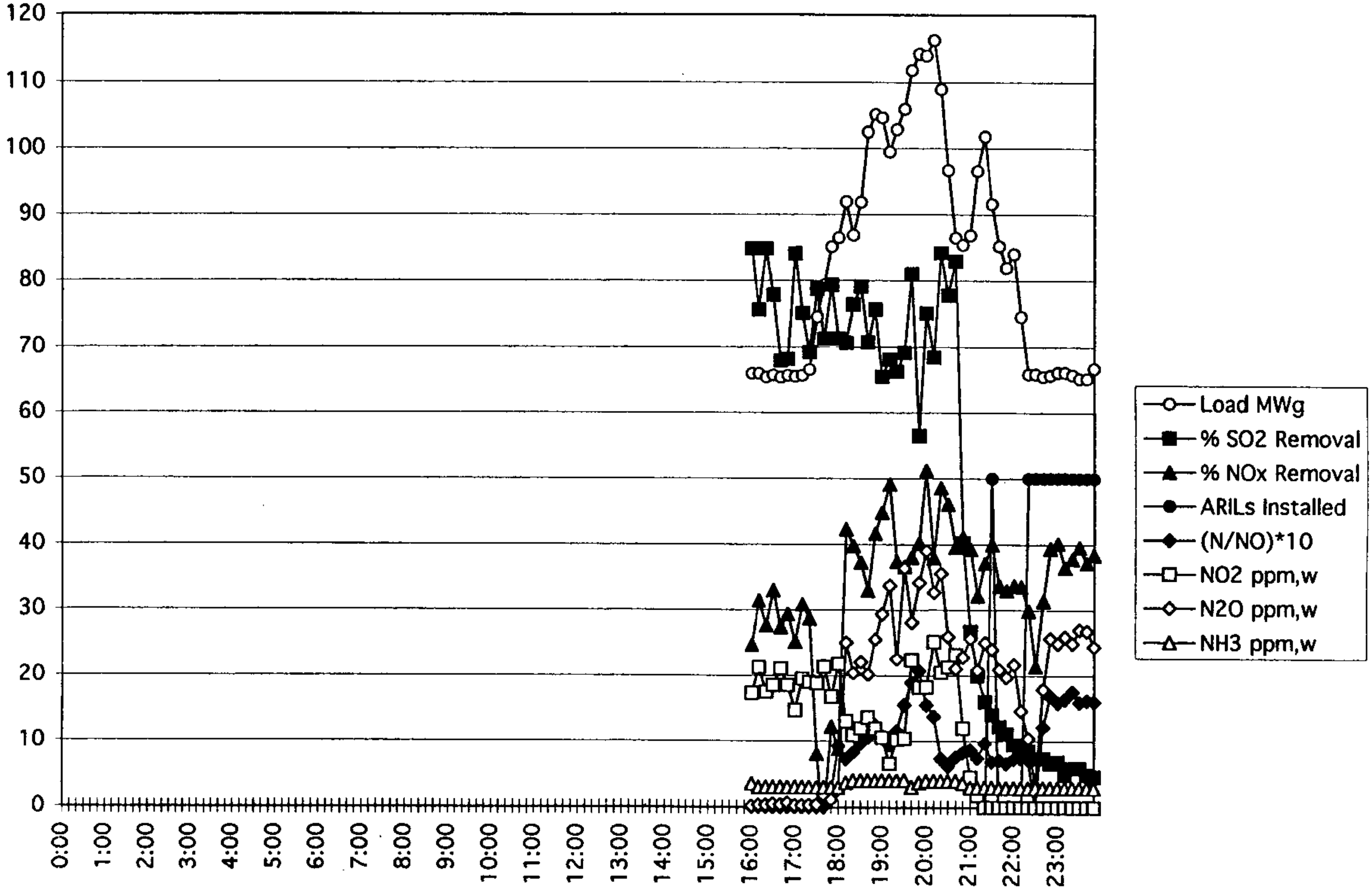


Figure 7-1. Long-Term Load-Following Test Results for February 19, 1996

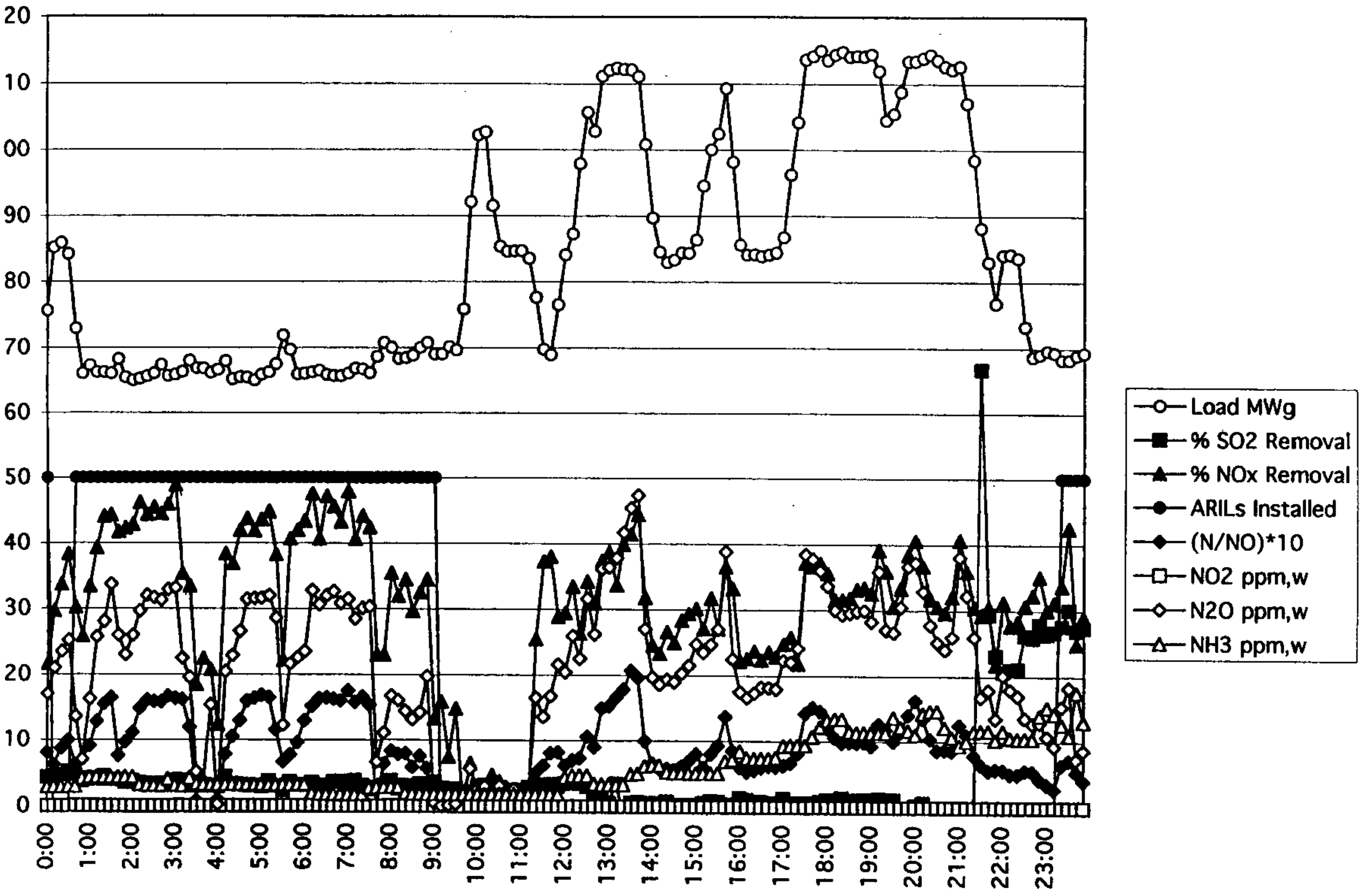


Figure 7-2. Long-Term Load-Following Test Results for February 20, 1996

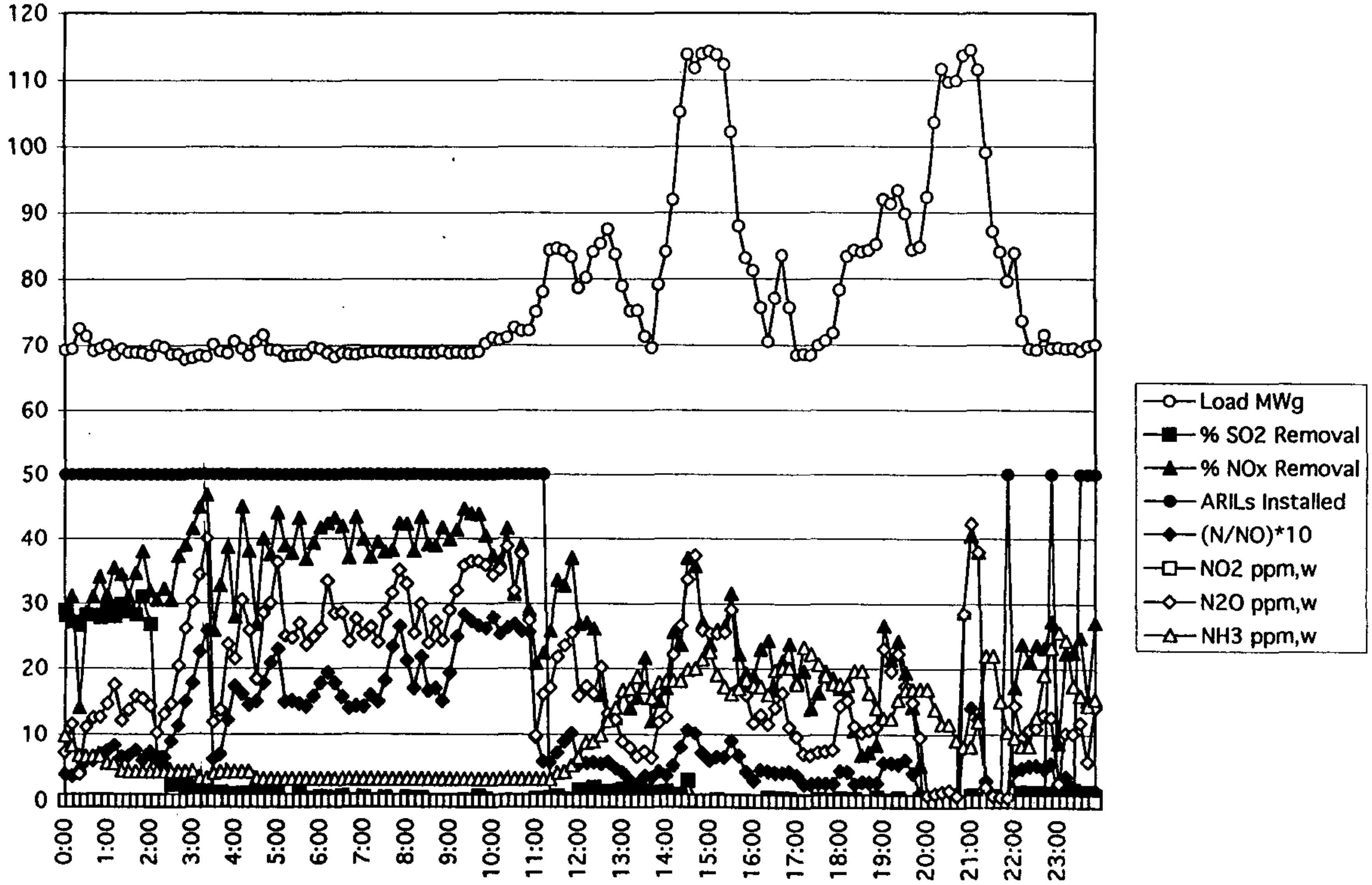


Figure 7-3. Long-Term Load-Following Test Results for February 21, 1996

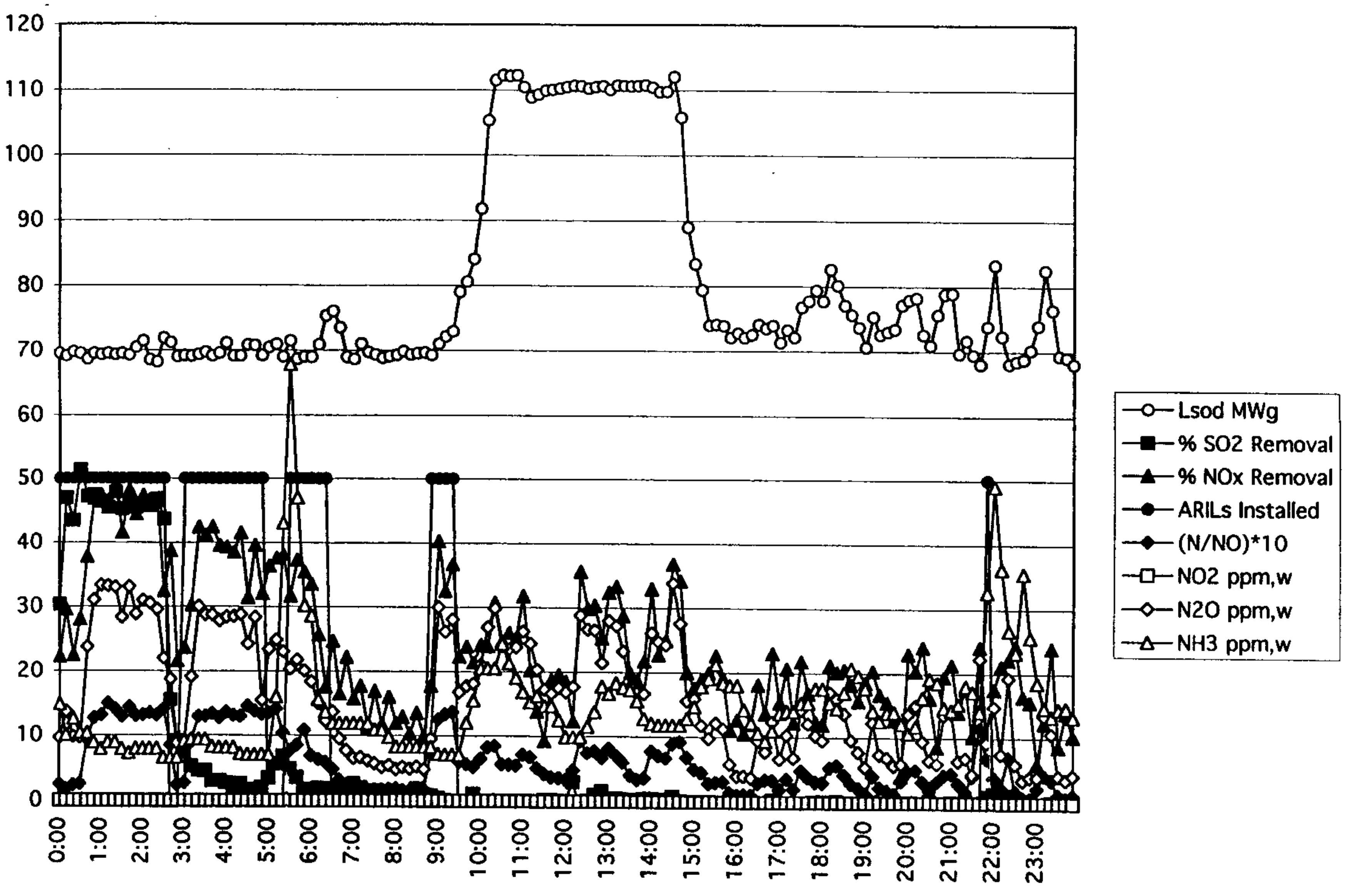


Figure 7-4. Long-Term Load-Following Test Results for February 22, 1996

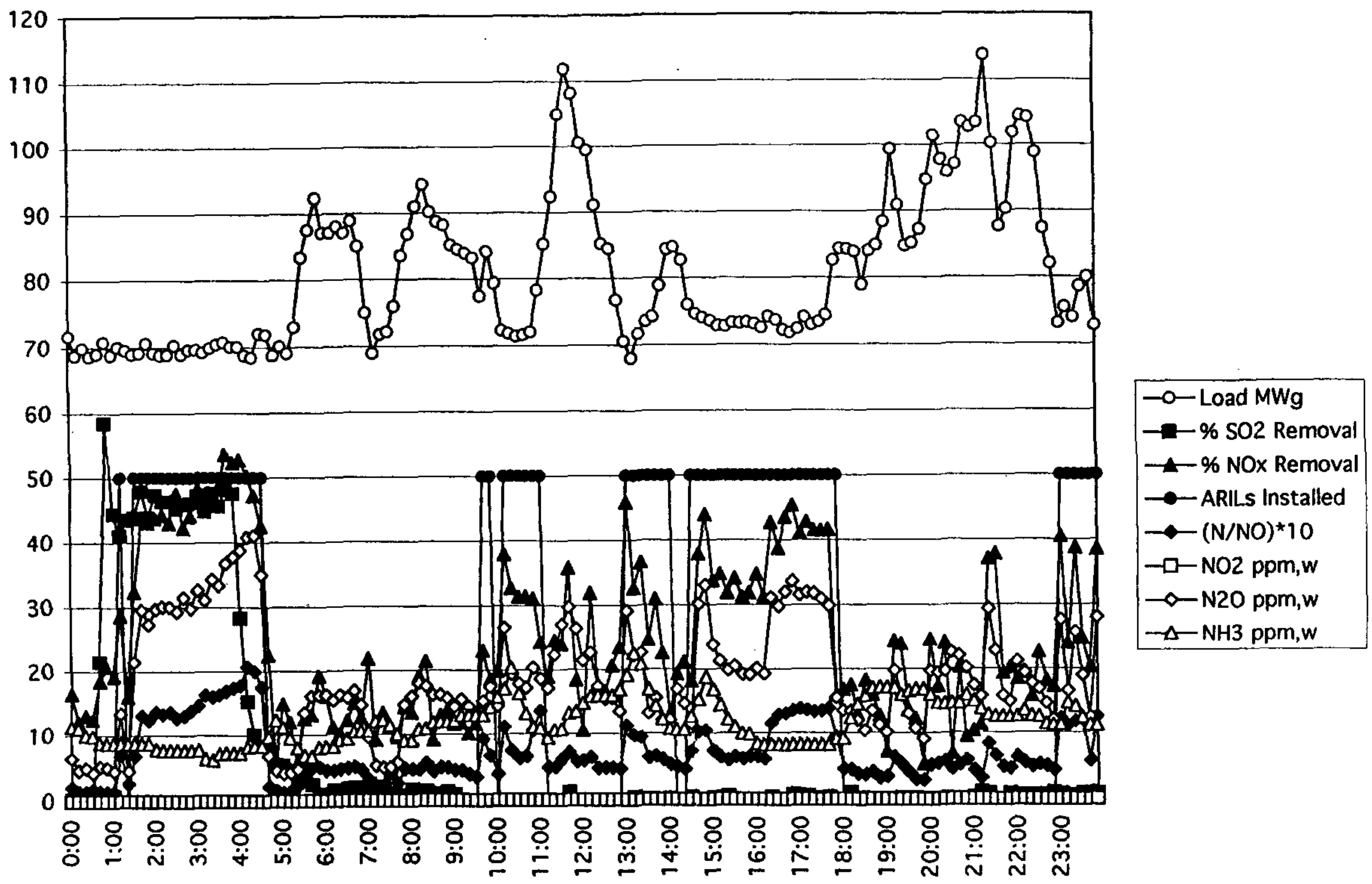


Figure 7-5. Long-Term Load-Following Test Results for February 23, 1996

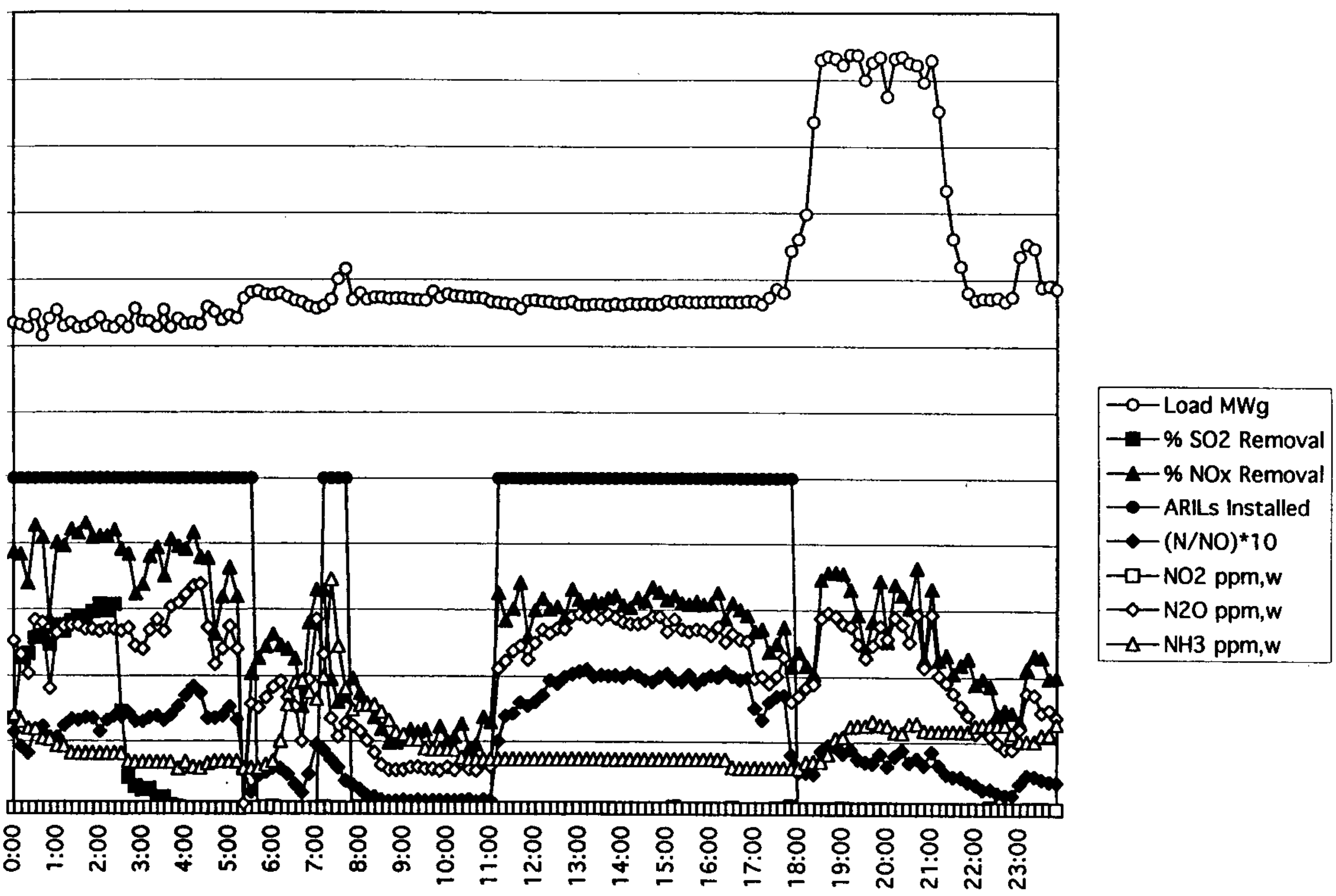


Figure 7-6. Long-Term Load-Following Test Results for February 24, 1996

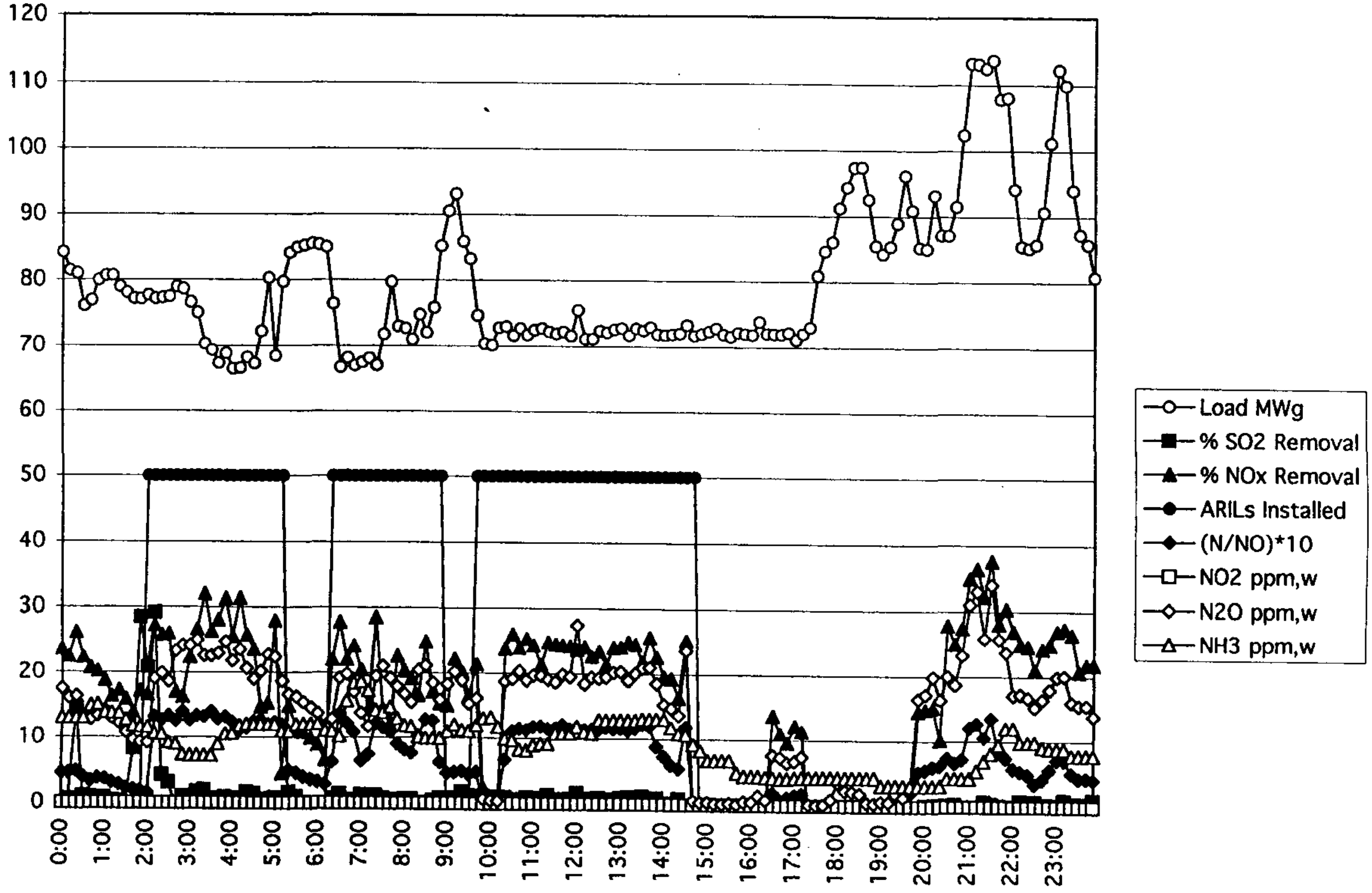


Figure 7-7. Long-Term Load-Following Test Results for February 25, 1996

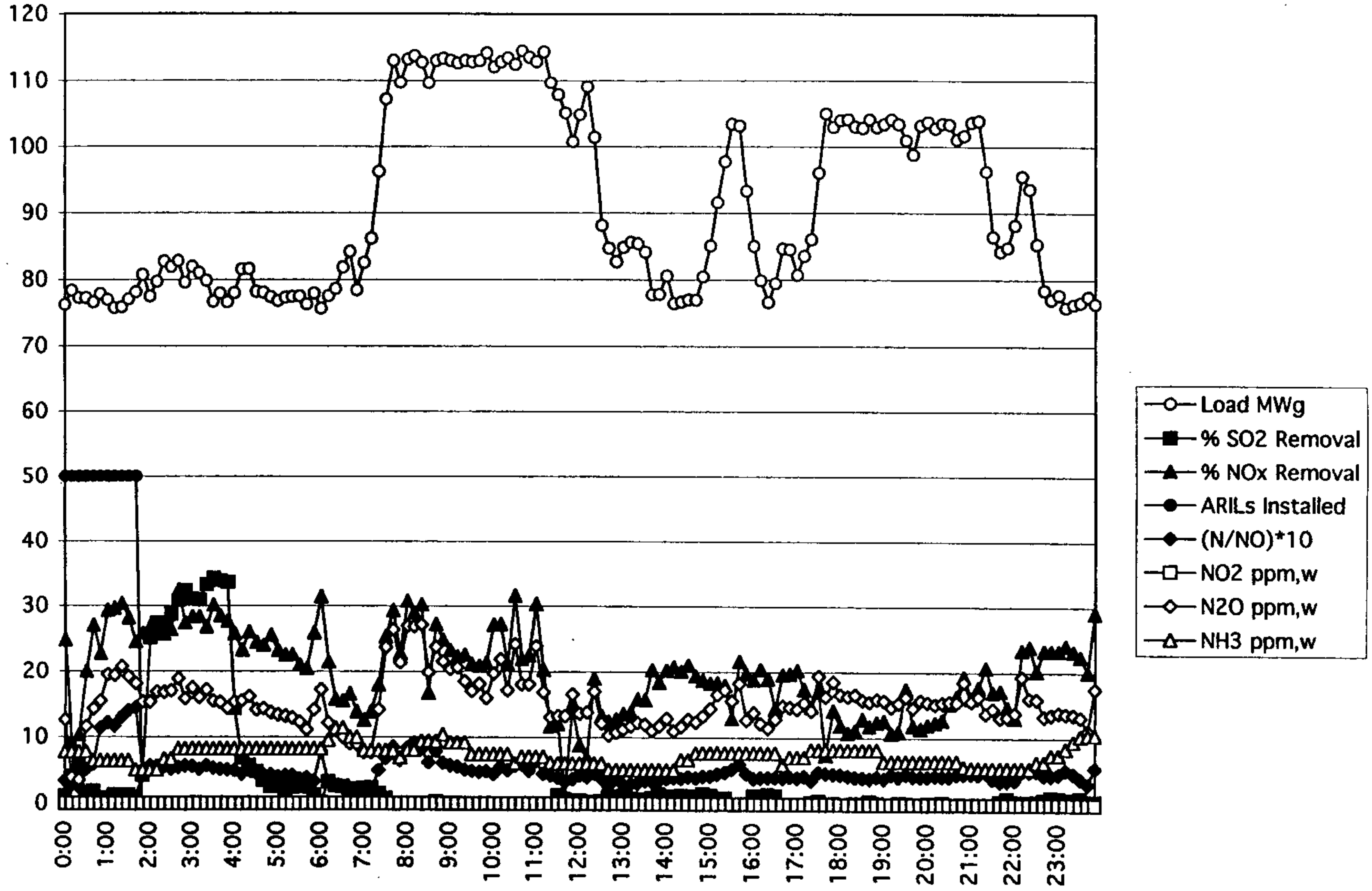


Figure 7-8. Long-Term Load-Following Test Results for February 26, 1996

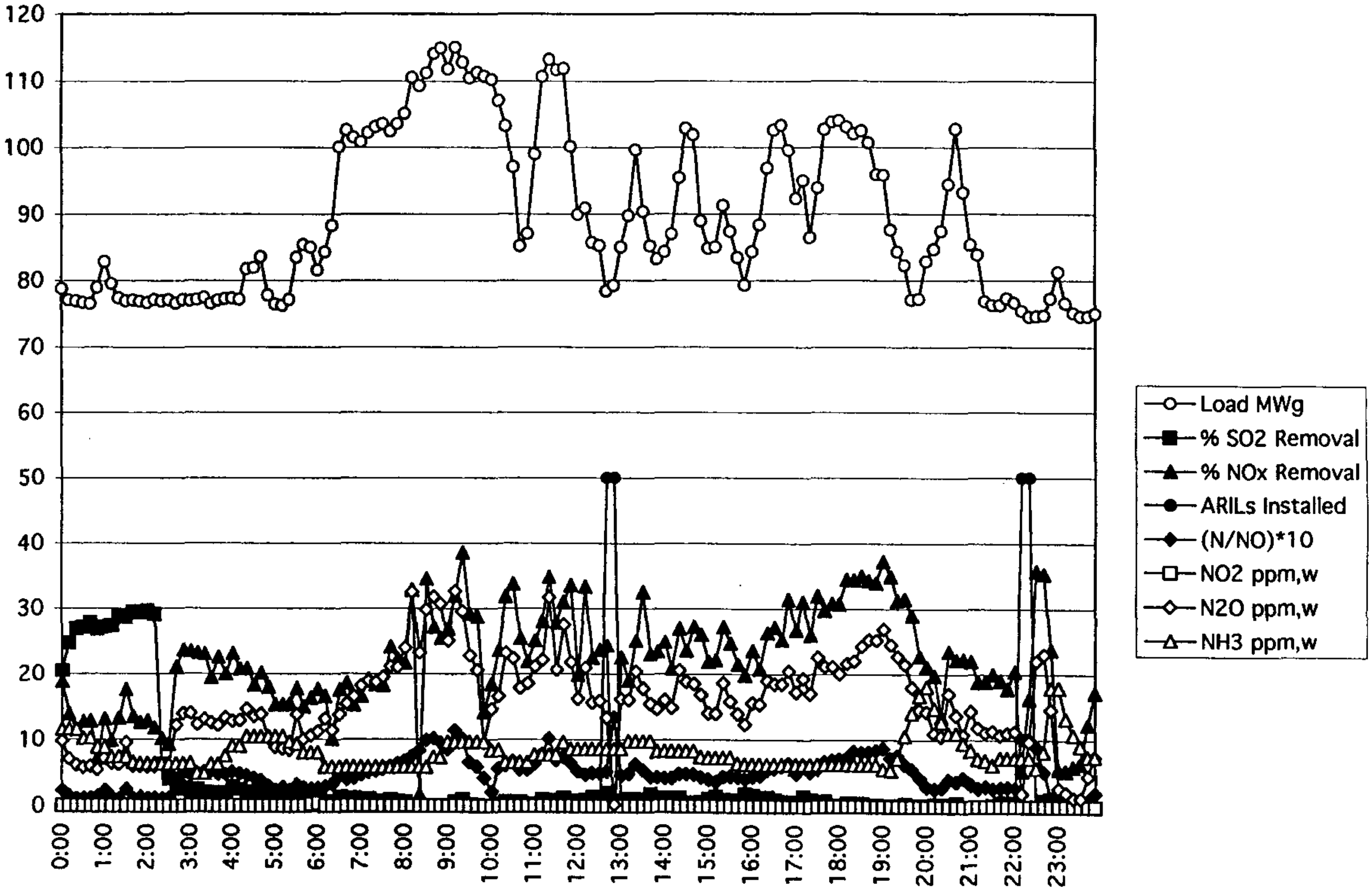


Figure 7-9. Long-Term Load-Following Test Results for February 27, 1996

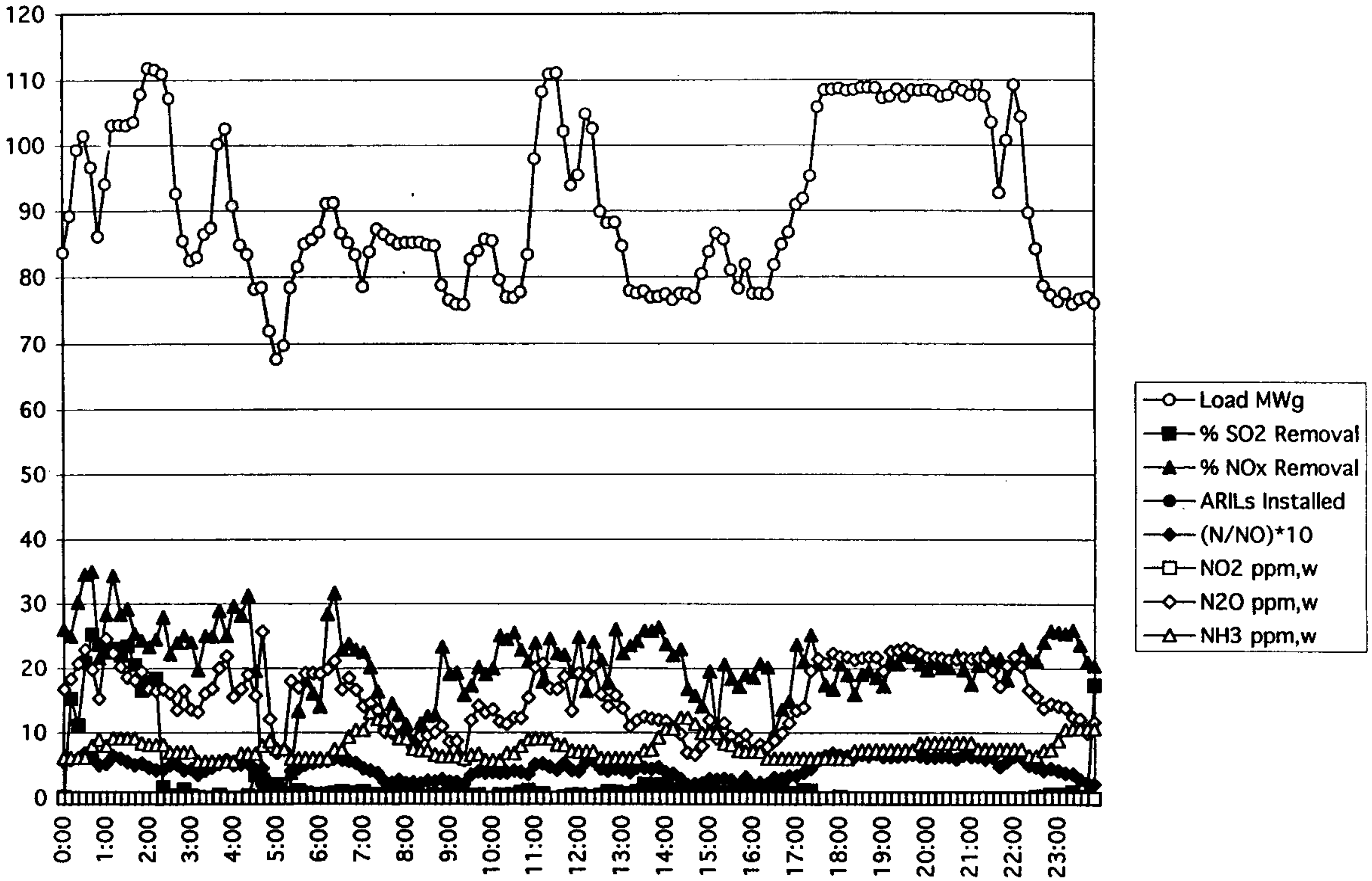


Figure 7-10. Long-Term Load-Following Test Results for February 28, 1996

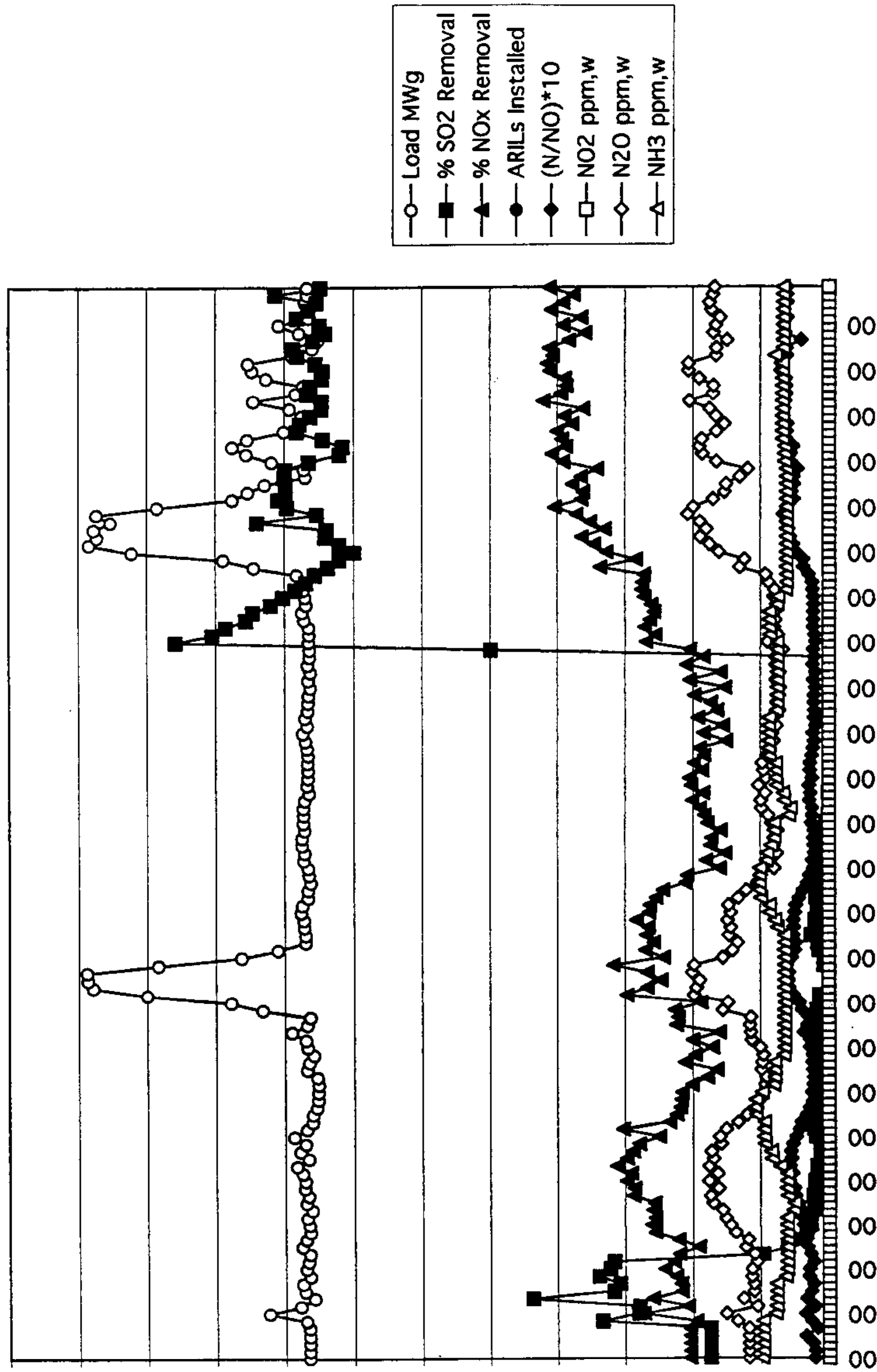


Figure 7-11. Long-Term Load-Following Test Results for February 29, 1996

tests, baseline NO_x levels (as well as NO_x removals and N/NO ratios) could be estimated each time the CEM sampled the outlet (stack) location.

The long-term SNCR-only test began at approximately 1800 hrs on February 19 (Figure 7-1). The DSI system was in operation at this time, with the SO_2 removal averaging about 75 percent and NO_2 emissions of approximately 20 ppm. Urea injection began at 1800 hrs, and the DSI system was shut down just before 2100 hrs. The lance insert/retract mechanism was tested manually at 2130 hrs, and at 2230 hrs the load dropped to a level where the control system inserted the lances automatically. Note that the stack NH_3 emissions monitor was reading 3 to 4 ppm throughout the eight-hour period, even without urea injection.

The 10-minute average data for the first full day of 24-hour testing (February 20) is shown in Figure 7-2. The trends in stack NH_3 emissions shown in this figure are typical of those seen during the first week of the long-term urea-only test. From 0100 to 0900 hrs, the boiler load was low, urea injection was at the ARIL location, and CEM NH_3 emissions at the stack were in the 3 to 4 ppm range (which essentially corresponds to a "zero" level). The data show that the N/NO ratio varied quite significantly during this time. This was not a result of control system problems, but rather problems with the water softening skid which provided dilution water for the urea injection system. The SNCR system was shut down at 0900 hrs to fix the problem with the softening skid; when the system was put back into service at 1100 hrs, the load had increased and urea injection moved to the Level 1 location. The NH_3 emissions slowly increased throughout the remainder of the day, and although the upper NH_3 trim control setting was 10, the NH_3 slip was averaging between 10 and 15 ppm by the end of the day.

Figure 7-2 also shows that the DSI system was started at approximately 2130 hrs in order to meet the permit requirement for the day. The DSI system was run at the minimum sorbent feedrate which resulted in SO_2 removals of only 20 to 30 percent. DSI injection continued until 0200 hrs the following day (February 21) so that the permit requirement for that day was also satisfied.

Figures 7-3 through 7-6 show the 10-minute average data for February 21 through 24. The trends in NH_3 slip during this time are generally similar to those seen in Figure 7-2. Namely, the NH_3 slip is high with Level 1 injection, and low when injecting at the lance location. However, the data also show that the difference in the slip levels for injection at the two locations became smaller as time progressed. As mentioned above, the tuning table settings were repeatedly adjusted during this time to provide more consistent levels of NO_x removal and NH_3 slip. In addition, efforts were underway to identify and modify the problem areas in the control system logic. By mid-afternoon on February 25 (Figure 7-7), the tuning table settings were finalized as shown in Table 7-2, and the majority of the logic problems had been resolved. Although the NH_3 slip at the stack was averaging about 10 ppm, the level was slowly swinging between approximately 7 and 13 ppm. In addition, a white detached plume appeared at the stack whenever the slip levels exceeded approximately 10 ppm. Since operation with a visible plume was not acceptable, the NH_3 trim control setpoints were reduced from 10 and 8 ppm, to 8 and 6 ppm at 1300 hrs on February 25.

From the time when urea injection began on February 19, to the time when the NH_3 trim control setpoints were reduced on February 25, the average NO_x removal and NH_3 slip were 27.0 percent and 10.3 ppm, respectively. (These averages do not include the times when the urea system was shut down to maintain the water softening skid.) This level of NO_x removal is markedly lower than what would be expected based upon the results of the parametric ARIL lance optimization tests (Figure 5-4). With the exception of the data at 50 MWe, Figure 5-4 shows that at a NH_3 slip limit of 10 ppm, NO_x removals ranged from nominally 37 to 45 percent. However, it must be remembered that the parametric tests were run at base-loaded operating conditions with test personnel closely monitoring all boiler variables. During load-following operation, oxygen levels can vary significantly and rapidly. This mode of operation tends to increase both NO and CO emissions, but more importantly, it can have a large impact on the flue gas temperature profile at the SNCR injection location. The results of the long-term, load-following tests performed during the post-retrofit SNCR test phase (Smith, et al., 1994b), showed that the NO_x removals achieved during the long-term test were nominally 10 percent (net) lower than the removals achieved during the base-loaded parametric tests (over the load range of 70 to 100 MWe). As mentioned above, the average NO_x removal for the first six days of the long-term urea-only test (February 19 to 25), was 27.0 percent. The average boiler load during this time period was 80 MWg (corresponding to approximately 75 MWe). Since Figure 5-4 shows that nominally 37 percent NO_x removal was achieved at this load under carefully-controlled base-loaded conditions, the 27 percent average removal for the long-term testing from February 19 to 25, was not totally unexpected.

The SNCR system was taken off-line from 1500 to 1945 hrs on February 25 to load (and dilute) a new delivery of urea into the storage tank. Figures 7-7 and 7-8 show that after the urea injection system was placed back in service (with the reduced NH_3 trim control setpoints), the control system was usually able to maintain the NH_3 emissions at levels below 10 ppm. In addition, there were no occurrences of a white detached plume at the stack during this time period. However, Figure 7-8 also shows that the NO_x removals during this time were reduced, averaging nominally 20 percent. At 0530 hrs on February 27, the lower NH_3 trim control setpoint was increased from 6 to 7 ppm. This increase reduced the width of the control window from 2 ppm to 1 ppm NH_3, which in turn allowed higher urea injection rates at the lower end of the control range. Figure 7-9 shows that after this small change was made, NO_x removals increased to the 20 to 30 percent range. With the exception of a short excursion between 1930 and 2030 hrs, the NH_3 slip remained at or below the 10 ppm limit for the remainder of the day.

The excursion in stack NH_3 emissions at 1930 hrs was a result of both FFDC cleaning and sootblowing cycles starting at approximately 1900 hrs. The previous test phases with SNCR alone (Smith, et al., 1993 and 1994b), have shown that sootblowing either within or upstream of the urea-injection location usually results in an increase in the NH_3 slip levels ahead of the FFDC. However, since the previous tests were relatively short in duration, the flyash collected in the FFDC was not fully "conditioned" with NH_3, and thus had the "capacity" to adsorb the temporary increase in slip. In these cases, an increase in slip was not usually seen at the stack sampling location. In the case of 24-hour load-following operation, however, the flyash in the FFDC is either at or near its capacity for NH_3

absorption, and any increase in slip at the FFDC inlet will also likely be seen at the stack. When the FFDC cleans, the amount of flyash on the bags is drastically reduced, as is the capacity to adsorb excess NH_3. The combination of sootblowing and FFDC cleaning at 1900 hrs on February 27 resulted in an increase in stack NH_3 emissions which was more severe than usually seen due to sootblowing alone.

Early in the day on February 27, an arctic cold front moved into the Denver area, and the ambient temperature dropped to below 40°F. That evening, the temperature dropped to below 0°F, and when the ARILs inserted shortly after 2200 hrs (Figure 7-9), the liquid lines supplying each lance were completely frozen. Although the material necessary to insulate and heat-trace these lines had been purchased, and was on-site, plant maintenance crews had been unable to schedule the time to perform the work. The lances were retracted, and the tuning table was changed to allow injection only at the Level 1 location until the liquid lines were unfrozen. Unfortunately, the weather remained very cold, and the lines did not thaw for nearly a week.

From the time when the lower NH_3 trim control setpoint was increased from 6 to 7 ppm to the time when the ARIL liquid lines froze (nominally 0530 to 2110 hrs on February 27), the average NO_x removal and NH_3 slip were 24.2 percent and 7.3 ppm, respectively. Table 7-4 shows that although this level of NO_x removal was below that achieved with the NH_3 trim setpoints at 10 and 8 ppm, it was a marked improvement over the level achieved with the setpoints at 8 and 6 ppm. The results in Table 7-4 also indicate that increasing the lower trim setpoint from 6 to 7 ppm had a negligible impact on the stack NH_3 emissions. Although there were no occurrences of a visible white plume when the trim setpoints were at 8 and 6 ppm, there were a number of occurrences during the period of February 27 to 29, when the setpoints were at 8 and 7 ppm.

The previous test phases with SNCR alone (Smith, et al., 1993 and 1994b), have shown that stack NH_3 slip levels of less than 10 ppm generally do not result in a visible plume, unless the ambient temperature falls below approximately 35°F. Normally, visible plumes from SNCR systems are associated with the formation of ammonium chloride ($NH_4C\ell$).

Table 7-4

Effect of NH_3 Trim Control Setpoints on NO_x Removal and NH_3 Slip During Long-Term SNCR-Only Testing

Time Period	NH_3 Trim Control Setpoints (ppm upper/ppm lower)	Average NO_x Removal (%)	Average NH_3 Slip (ppm)
0000 hrs 20 Feb 96 - 1430 hrs 25 Feb 96	10/8	27.0	10.3
1950 hrs 25 Feb 96 - 0530 hrs 27 Feb 96	8/6	20.0	7.0
0540 hrs 27 Feb 96 - 2110 hrs 27 Feb 96	8/7	24.2	7.3

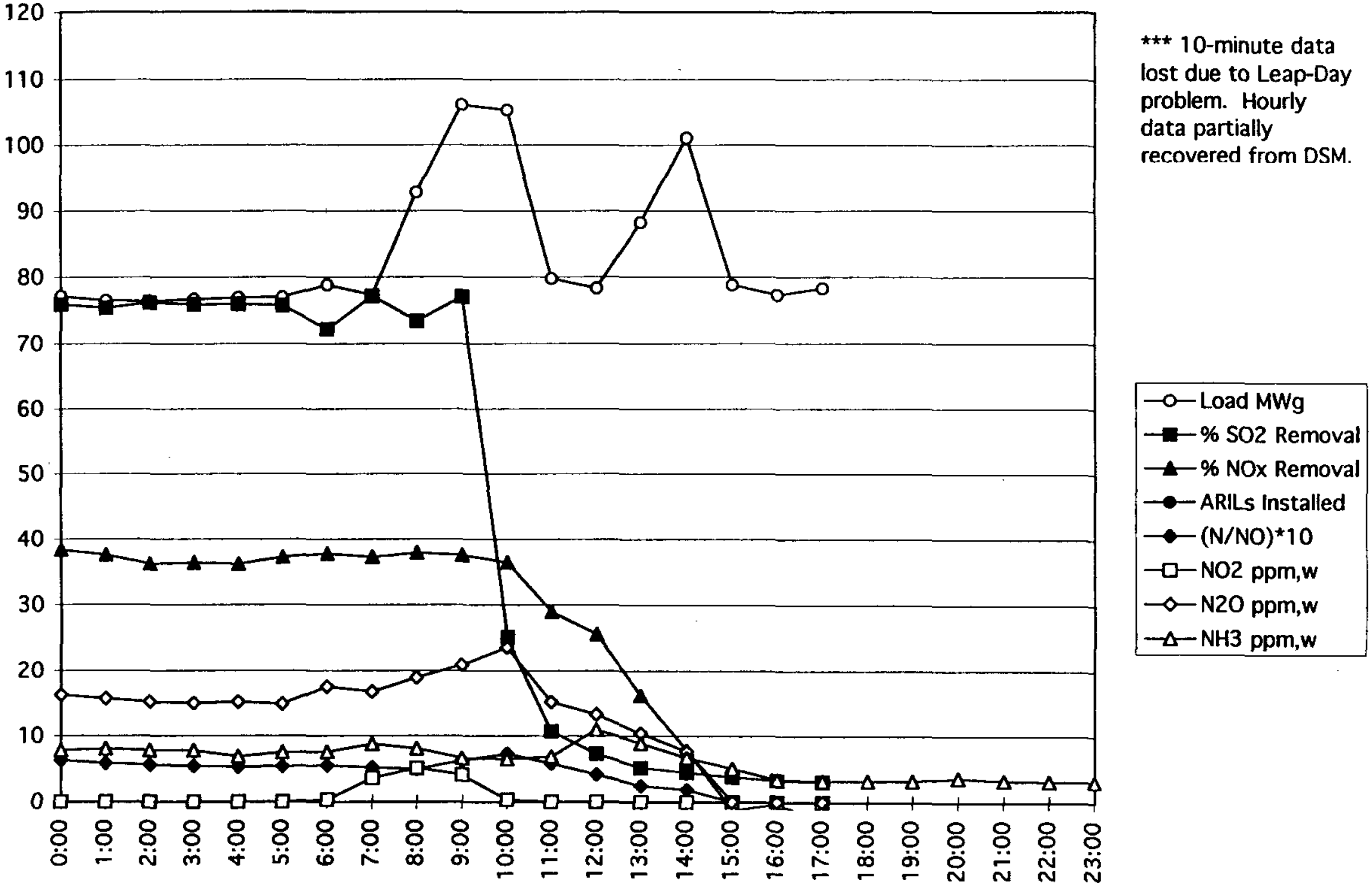
However, the low chlorine content of the coal fired at the Arapahoe station, combined with the dependency on the ambient temperature, indicate that the plume is more likely due to a NH_3/SO_2 reaction. As the ambient temperature began to fall during the afternoon on February 27, a faint white plume appeared at approximately 1650 hours. The NH_3 slip was only 6 ppm at the time, but the ambient temperature had dropped to approximately 19°F. During the following two days, the plume appeared and disappeared sporadically as the daytime ambient temperature varied between 10 and 25°F. Figures 7-10 and 7-11 show that the stack NH_3 emissions generally ranged between 6 and 10 ppm during these two days. As the ambient temperature dropped below 30°F, it became more difficult to detect the presence of a detached (ammonium) plume, because the moisture in the flue gas would condense, and an attached steam plume would appear. The plume finally disappeared at approximately 1500 hrs on February 29, when the ambient temperature increased to 35°F. Just a few hours later, the long-term testing with the integrated system began. The results of these tests are discussed in the following section.

7.2 Integrated Test Results

On February 29 (Figure 7-11), the boiler load was nearly constant for the first seventeen hours of the day. The N/NO ratio and NH_3 emissions were also relatively steady during this time. At 1600 hrs, the DSI system was started with a 75 percent SO_2 removal setpoint with the hope that the load would remain steady and it would be possible to assess the beneficial effects of running the integrated system. Although, the load increased significantly about two hours after the DSI system was started, it eventually settled back down to a level which was similar to the level before the increase. Figure 7-11 shows that the average NH_3 emissions with and without sodium injection were similar, which was expected since the NH_3 trim control was functioning during both of these tests. However, the results also show that there was a substantial increase in the N/NO ratio. Since the SNCR control system was set to maintain the NH_3 emissions within the range of 7 to 8 ppm, it should have increased the urea injection rate if the DSI system reduced the NH_3 emissions. A temporary increase was expected as a result of the load swing, but the N/NO ratio should have returned to the pre-swing level within 2 to 3 hours (as was seen after the "morning demand peak" between 0800 and 0900 hrs). When the DSI system was started at 1600 hrs, there was an immediate 10 percent increase in the NO_x removal, which is consistent with the increases seen during sodium-based DSI-only tests (Smith, et al., 1996a). After this initial NO_x removal increase, there was another slower increase (amounting to nominally 10 to 15 percent removal) which occurred as the N/NO ratio increased. Although the scaling of the data make it difficult to see, Figure 7-11 indicates that the N/NO ratio basically doubled after the DSI system was started. The increase in N_2O emissions (from nominally 8 to 16 ppm), confirms that the N/NO ratio was increased by roughly a factor of two. These results clearly indicate that there was a substantial reduction in the stack NH_3 slip, when the SNCR and DSI systems were run concurrently.

Figures 7-12 through 7-14 show the data for the period of March 1 to 3. The 10-minute average data for March 1 and 3 were lost due to a problem with the primary data logging system for the Altech CEM. The 10-minute data for February 29 and March 2 were recovered, but the hourly-average data from a backup data logging system had to be substituted for March 1 and 3.

Test personnel were off site from approximately 1500 hrs March 1 to 1100 hrs March 4. The DSI and SNCR systems were shut down before leaving the site, and the control operator restarted the DSI system shortly before midnight on March 1. Although both the A and B DSI systems were running at this time, and the 10-minute data in Figures 7-13 and



*** 10-minute data lost due to Leap-Day problem. Hourly data partially recovered from DSM.

Figure 7-12. Long-Term Load-Following Test Results for March 1, 1996

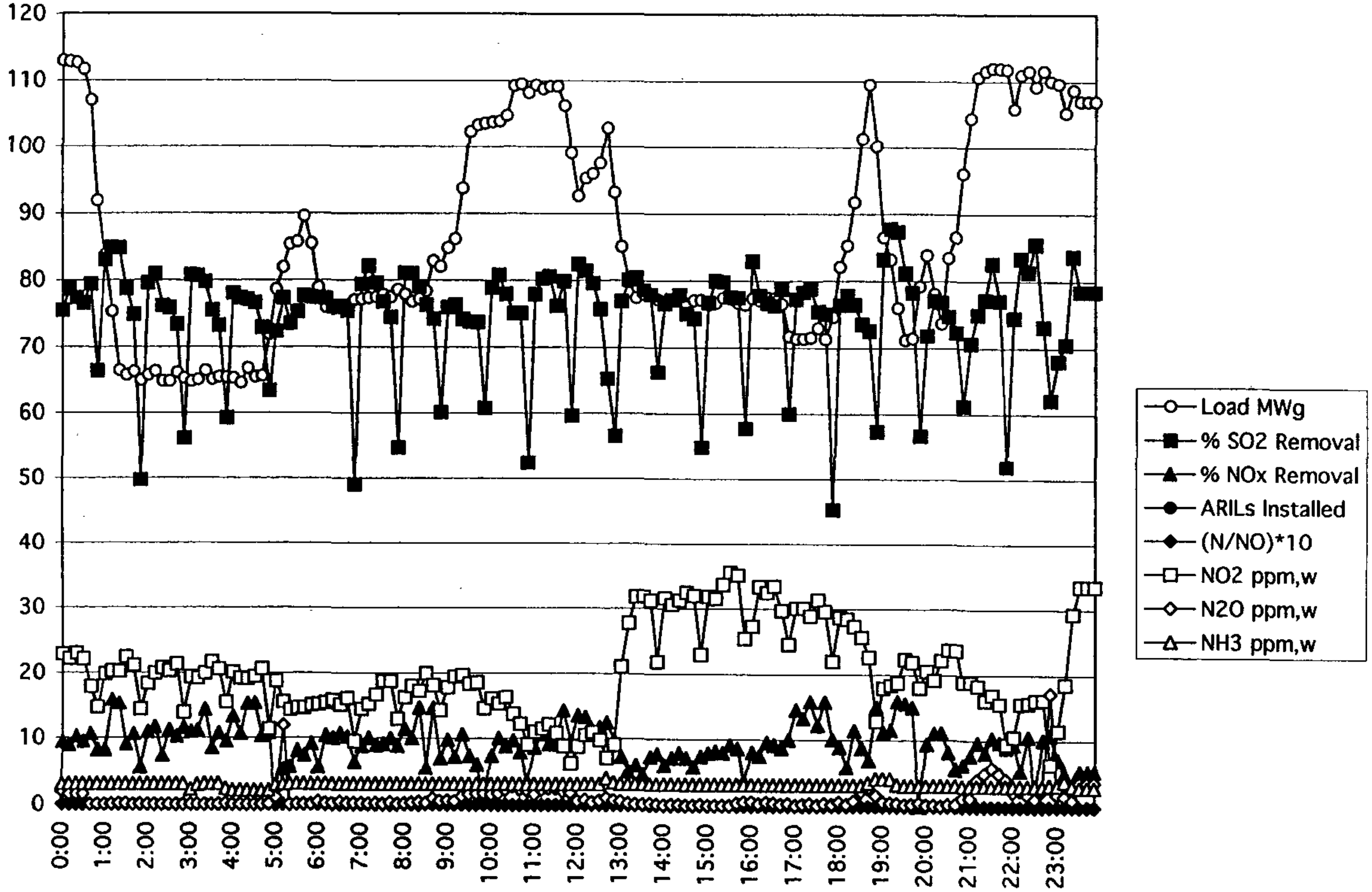
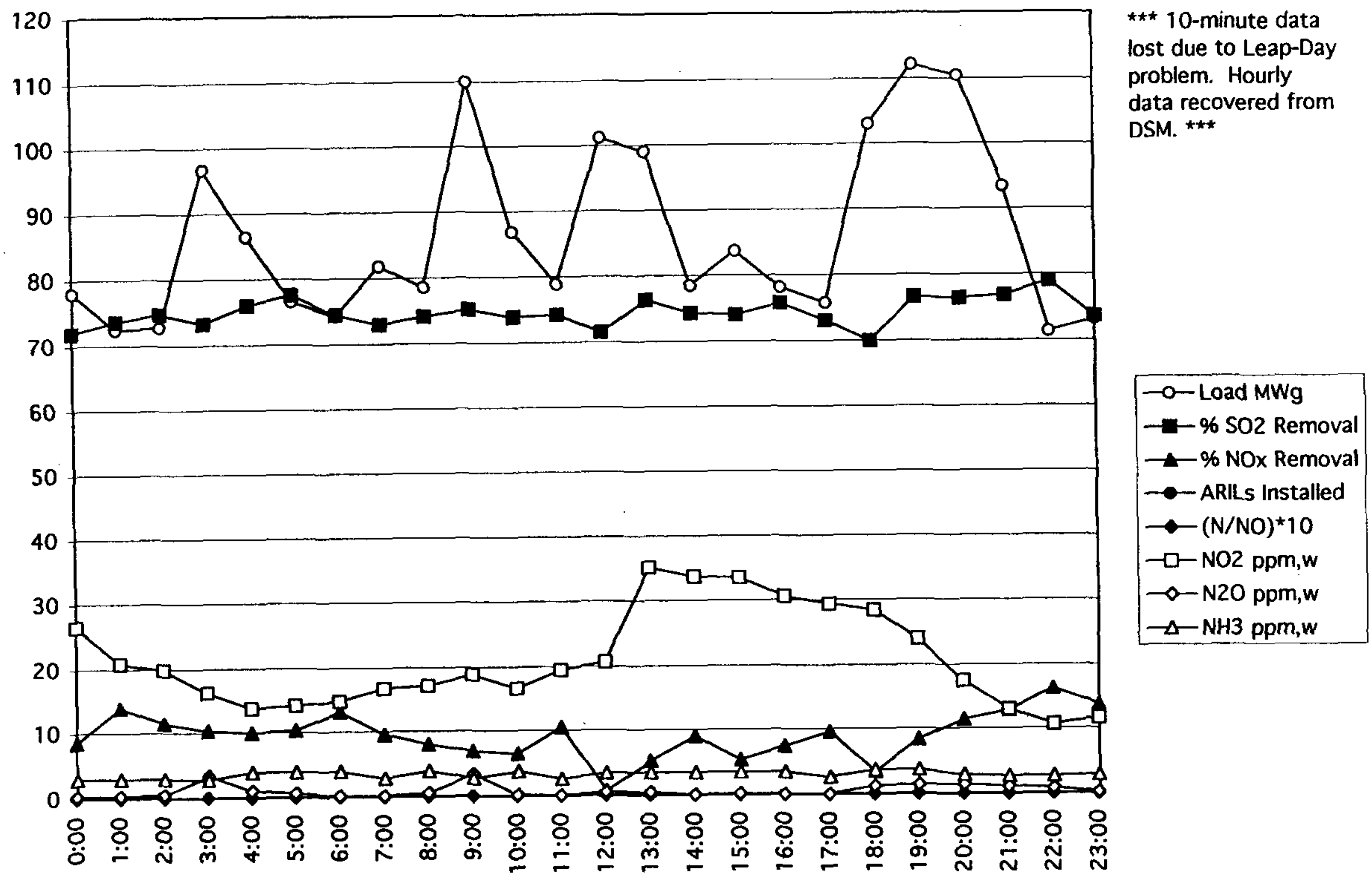


Figure 7-13. Long-Term Load-Following Test Results for March 2, 1996



*** 10-minute data lost due to Leap-Day problem. Hourly data recovered from DSM. ***

Figure 7-14. Long-Term Load-Following Test Results for March 3, 1996

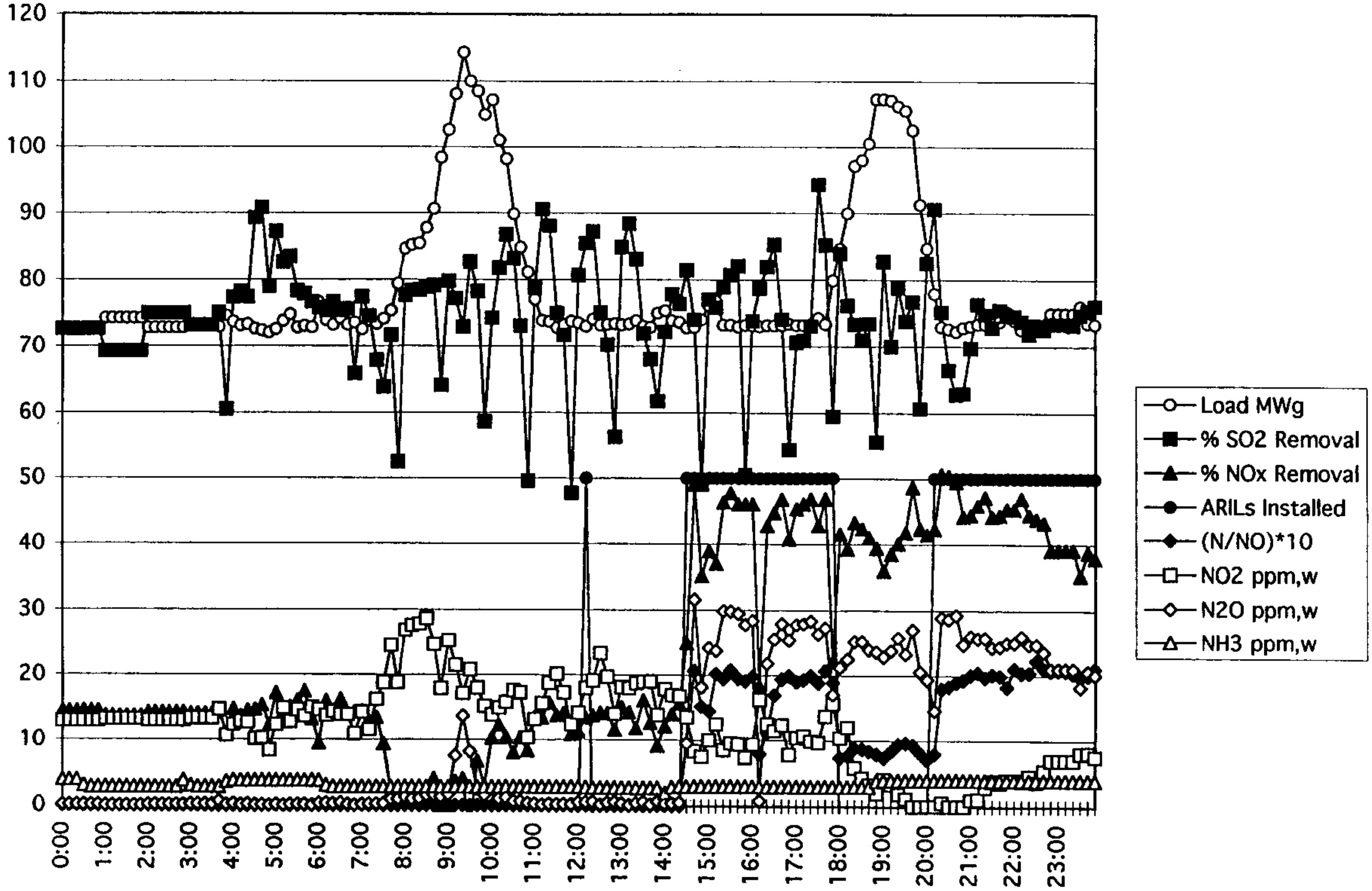


Figure 7-15. Long-Term Load-Following Test Results for March 4, 1996

7-15 show that the SO_2 removal (i.e., the sorbent feedrate) was erratic. When test personnel arrived back on-site on March 4, the discharge pressure on the B system was very high, but no blocked injectors or transport lines could be found. The B system was taken off-line at 2030 hrs (Figure 7-15) to wash the pulverizer, and when it was returned to service at 0330 hrs the following day (Figure 7-16), the pressure was back to normal and sorbent feedrate was much improved.

When the test personnel arrived back on-site on March 4, the ARIL liquid lines were finally unfrozen, and the SNCR system was placed back in service at 1420 hrs (Figure 7-15). The boiler load was fairly steady at this time, and was low enough for the control system to insert the lances. Although the DSI feedrate was not very consistent, Figure 7-15 shows that there was nominally a 50 percent reduction in the NO_2 emissions when urea injection began. The load remained steady for nearly four hours, and then it increased for the usual "evening demand peak" at 1800 hrs. When the lances retracted, the N/NO ratio dropped (per the tuning table settings), and the NO_2 emissions were also seen to decrease. By 1900 hrs, the NO_2 emissions had been reduced to near-zero levels. This effect is believed to be due to the overall difference in the NH_3 emission tendencies between injection at the Level 1 and ARIL locations. Although the effort was made to set-up the tuning table for the SNCR system such that the NH_3 slip was limited to 10 ppm throughout the load range, the Level 1 location is "cooler" overall than the ARIL location; thus injection at Level 1 is more sensitive to variations in the flue gas temperature profile. Therefore, in general, urea injection at the Level 1 location results in higher NH_3 slip levels at the FFDC inlet. Since the NH_3 emissions are generally higher with urea injection at the Level 1 location, it would be expected that the reduction in stack NO_2 emissions would also be higher (relative to injection at the ARIL location).

The hypothesis put forth in the preceding paragraph is not only supported by the decrease in NO_2 emissions seen when the urea injection switched from the lances to Level 1 at 1800 hrs in Figure 7-15, but also by the increase in NO_2 seen when the lances were re-inserted at 2000 hrs. When the lances went in at this time, the NO_2 emissions were

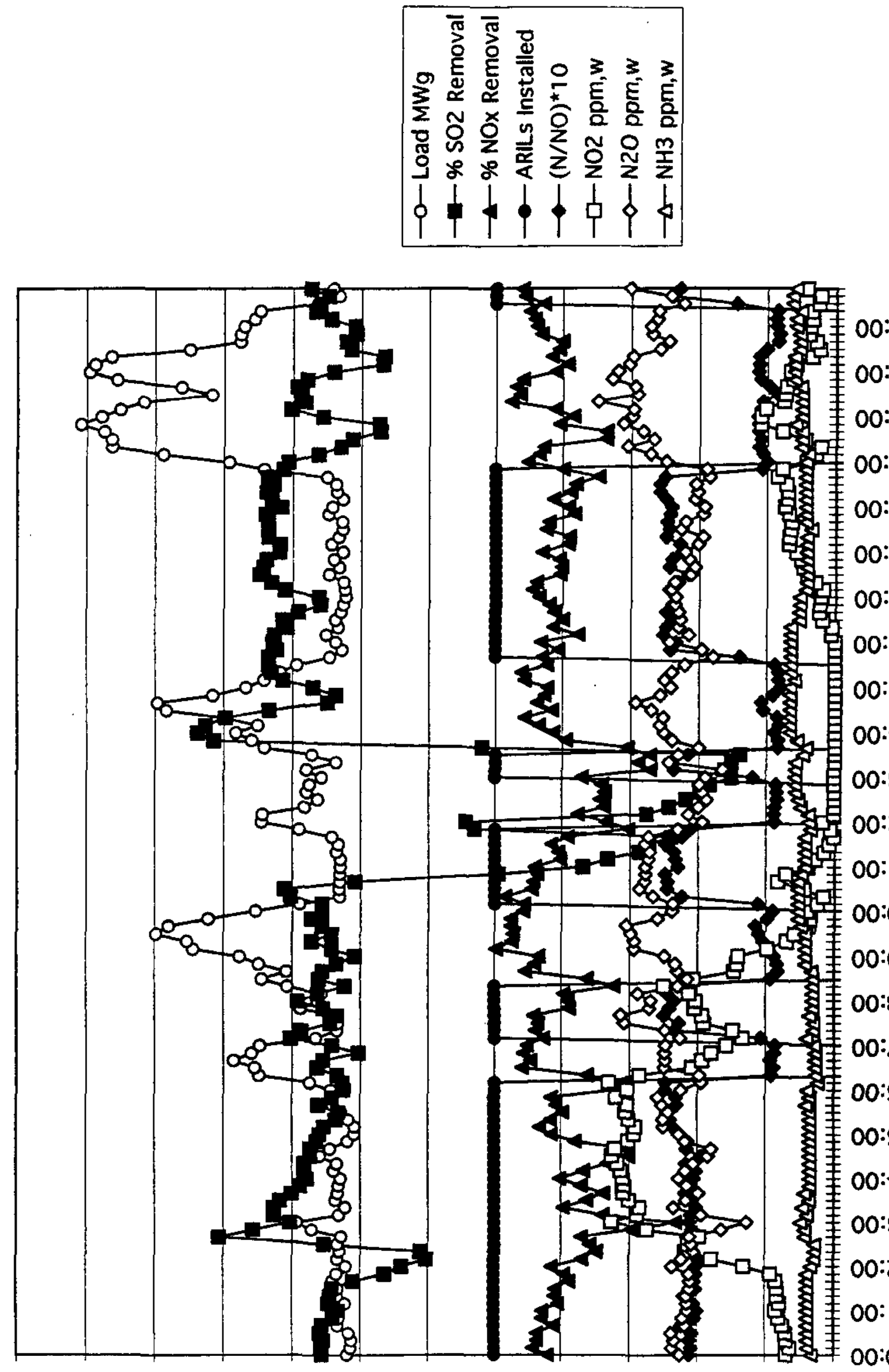


Figure 7-16. Long-Term Load-Following Test Results for March 5, 1996

essentially zero. After an hour, however, the NO_2 emissions slowly began to increase, finally leveling out at approximately 8 ppm. Figure 7-16 shows a large increase in NO_2 emissions at 0200 hrs the following moming (March 5). Between 0140 and 0215 hrs, the FFDC went through a cleaning cycle, and the NO_2 emissions increased from nominally 8 ppm, to approximately 30 ppm. The NO_2 emissions stayed at this level until the lances retracted at 0615 hrs, and then the levels began to drop. Figure 7-16 shows that this pattem of increasing NO_2 emissions during urea injection at the ARIL location, and decreasing NO_2 emissions during Level 1 injection, continued throughout the day.

On March 5 (Figure 7-16), there was a sharp decrease in SO_2 removal between 1030 and 1330 hrs. This was a result of both the A and B DSI systems being taken off-line for a short period of time. On the following day (Figure 7-17), there was a much longer time span (nearly 12 hours) where both DSI systems were off-line. In both of these cases, the feeders and rotary air locks on both injection systems tripped off without any input from either the control operator or the test personnel. After the second occurrence (0630 hrs on March 6) the DSI system was thoroughly checked out. No problems could be found in either the control system, or in the feeders or air locks themselves. The DSI system was restarted at 1830 hrs, and the problem did not recur.

In addition to the DSI problems experienced on March 6, the ambient temperature again dropped to below freezing levels during the early moming hours. The ARILs were in operation throughout the previous night, and while liquid was flowing there were no problems with freezing. There was a moming demand peak between 0530 and 0700 hrs, and although the lances were retracted for only 90 minutes, the liquid line to the east lance was found to be frozen when the lances were re-inserted at 0700 hrs. Once again, it was necessary to change the tuning table to allow urea injection at the Level 1 location only, while the liquid line thawed. Early the following moming (Figure 7-18), another load of urea was delivered, and the SNCR system was shut down from 0225 to 0730 to load and dilute the chemical. The lances were inserted when the system was restarted, but the line was still frozen and the lances were retracted again.

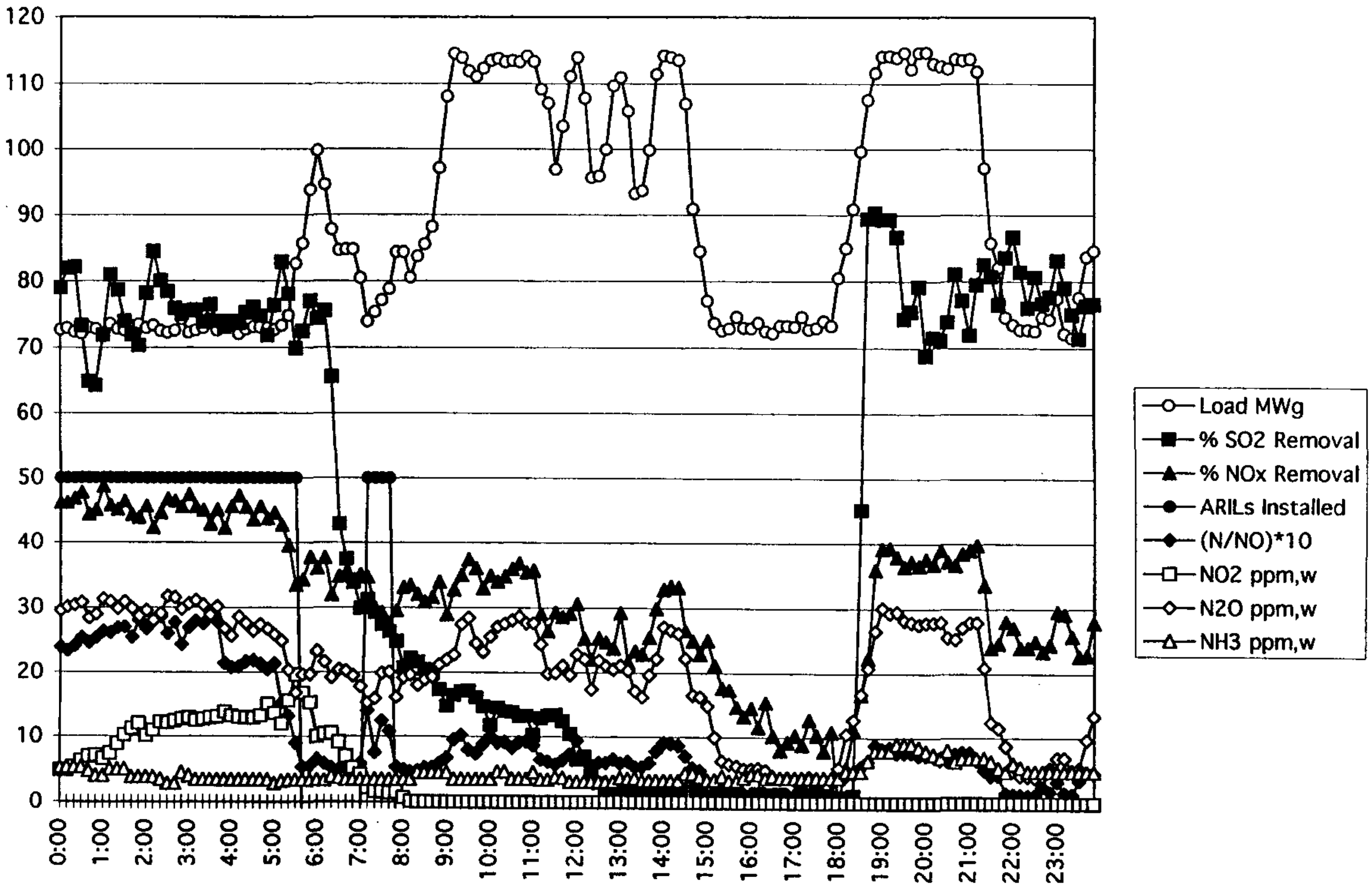


Figure 7-17. Long-Term Load-Following Test Results for March 6, 1996

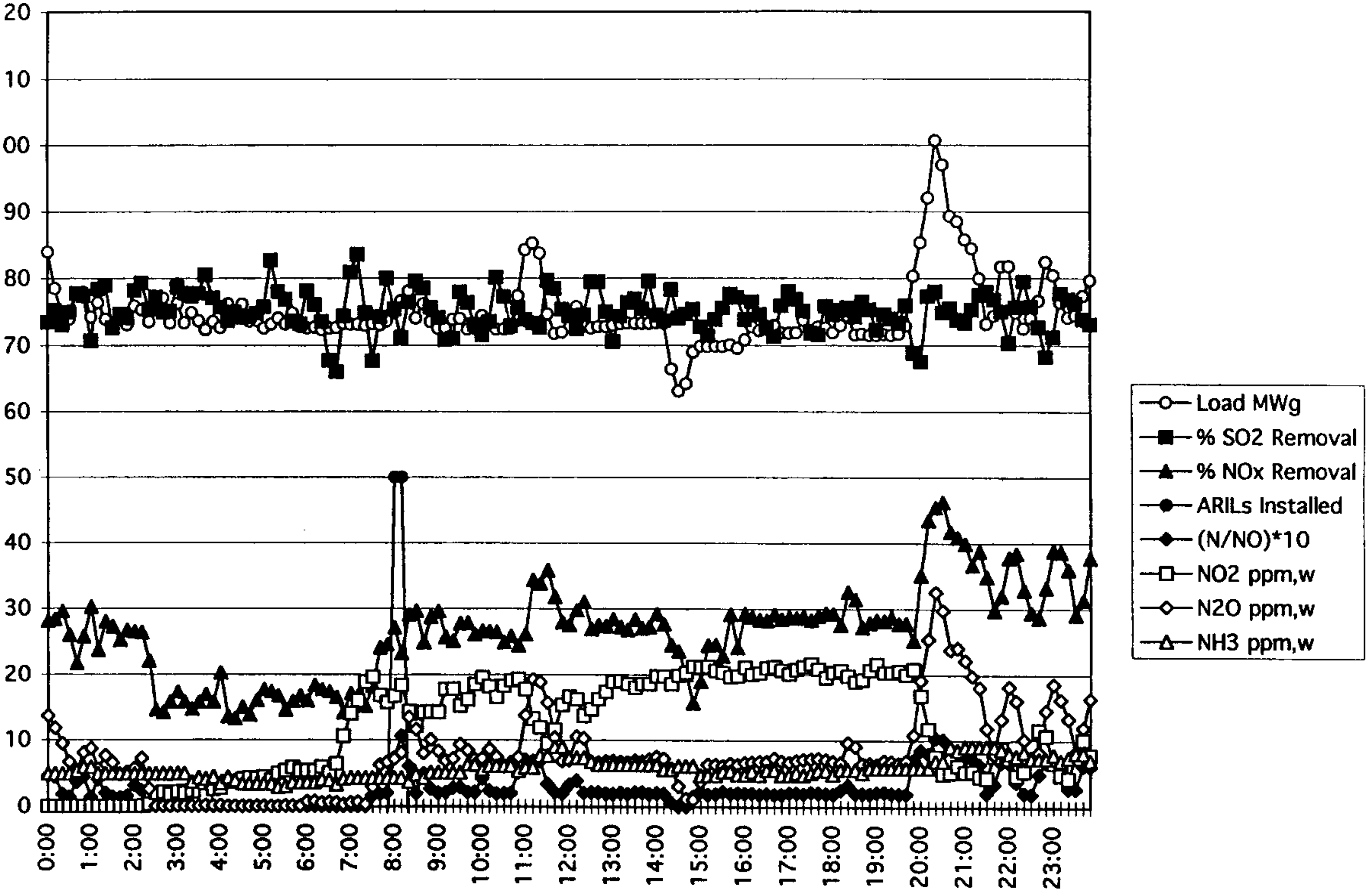


Figure 7-18. Long-Term Load-Following Test Results for March 7, 1996

Figures 7-15 and 7-16 show that the NO_x removals generally ranged from 35 to 45 percent when SNCR and DSI systems were run concurrently. The NH_3 trim control setpoints for the SNCR system were set at 8 and 7 ppm throughout this time, and there were no occurrences of a detached white plume. The average NO_x removal and NH_3 slip for the period of 1440 hrs March 4 (when urea injection began) to 0620 hrs March 6 (when the DSI feeders tripped off the second time) were 41.3 percent and 3.7 ppm, respectively. Compared to the SNCR-only results (Table 7-3), the NO_x removals with the integrated system were nominally 17 percent higher (on a net basis) for operation with NH_3 trim control settings of 8 and 7 ppm. However, not all of this increase can be attributed to a "performance improvement" for the SNCR system. The previous test phase with sodium-based DSI alone (Smith, et al., 1996a), showed that sodium sesquicarbonate injection at a 2Na/S ratio of 2 (that required for a nominal SO_2 removal of 70 percent) resulted in NO_x removals of approximately 10 percent. This level of NO_x removal was confirmed during the current test phase, when the DSI system was run alone during the weekend of March 2 and 3. The average NO_x removal for the time period of 0100 hrs March 2 (Figure 7-13) to 1430 hrs March 4 (Figure 7-15), was 9.8 percent. Therefore, for the integrated test described above (1440 hrs March 4 to 0620 hrs March 6), the "synergistic benefit" of operating the SNCR and DSI systems concurrently, resulted in a net increase in the SNCR NO_x removal of nominally 11 percent.

The results of the integrated testing from 1440 hrs March 4 to 0620 hrs March 6 also confirmed the second "synergistic benefit" of the integrated system; namely, reduced NO_2 emissions. The average NO_2 emissions during the integrated test were 9.4 ppm. In contrast, the average NO_2 emissions during the previous weekend (0100 hrs March 2 to 1430 hrs March 4) when the DSI system was run alone, were 19.4 ppm. In both of these cases, the SO_2 removal setpoint for the DSI control system was 75 percent. Running the SNCR and DSI systems concurrently, resulted in a reduction in the stack NO_2 emissions of nominally 50 percent.

The SNCR system was run with only the Level 1 urea injectors until the morning of March 8. At this point, the integrated system had been running more or less continuously for four days, and a heavy NH_3 odor had developed at the Unit 4 flyash unloading silo. Measurements of the ambient NH_3 concentration showed levels of 35 to 50 ppm at various locations inside the unloader room at the base of the silo. These levels were deemed unacceptable, and the DSI and SNCR systems were shut down at 0920 and 1000 hrs, respectively (Figure 7-19). Plant personnel were notified that neither system would be run for a period of two days in order to purge all of the "high NH_3" ash from the silo, and a sample of the flyash in the FFDC hoppers was collected for later analysis (these results will be discussed in Section 7.3).

Figures 7-19 and 7-20 show that both injection systems remained off until the morning of March 10. Rather than simply restarting both the DSI and SNCR systems in the automatic load-following mode, an effort was made to run a test which would provide additional insight into the NH_3-ash interaction. Since March 10 was a Sunday, the PSCo System Dispatch Center agreed to block the load on Unit 4 from 0700 to 1800 hrs. The goal of this test was to start the SNCR system first, let the stack NH_3 emissions stabilize in the 15 to 20 ppm range, then start the DSI system, and monitor the NH_3 emissions. It was hoped that the initial 15 to 20 ppm range would allow an accurate assessment of the reduction in NH_3 slip. Figure 7-21 shows that the SNCR system was started at 0800 hrs, and after four hours, the NH_3 emissions finally reached a level of 15 ppm. The urea flowrate was controlled manually during this test, and when the slip reached 15 ppm, no further adjustments were made. The system was then allowed to run for two more hours in order to insure that the stack emissions were stable. At 1400 hrs, the NH_3 slip had stabilized at a level of approximately 16 ppm, and the DSI system was started in the automatic control mode with a SO_2 removal setpoint of 75 percent. The NH_3 emissions began to decrease within 30 minutes, and by the time the unit was released for load regulation at 1800 hrs, the slip had been reduced by 50 percent (down to approximately 8 ppm).

At 1800 hrs, the SNCR control system was put back into the automatic mode with upper and lower trim control setpoints of 8 and 7 ppm, respectively. The maximum positive and negative bias limits were set at 75 and 50 percent, respectively, but since the NH_3 slip was already in the 7 to 8 ppm range, the urea flowrate remained steady. Although the unit had

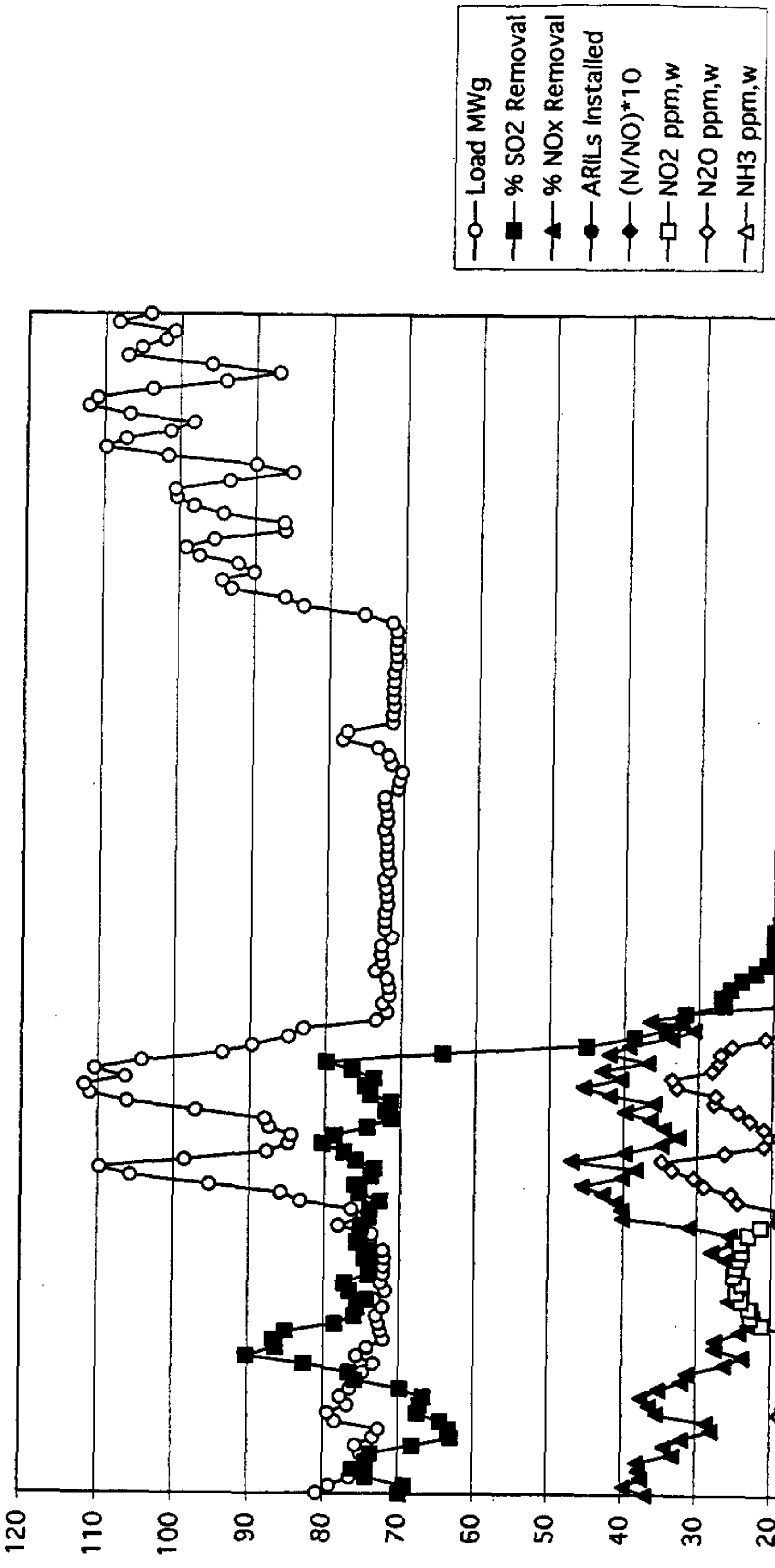


Figure 7-19. Long-Term Load-Following Test Results for March 8, 1996

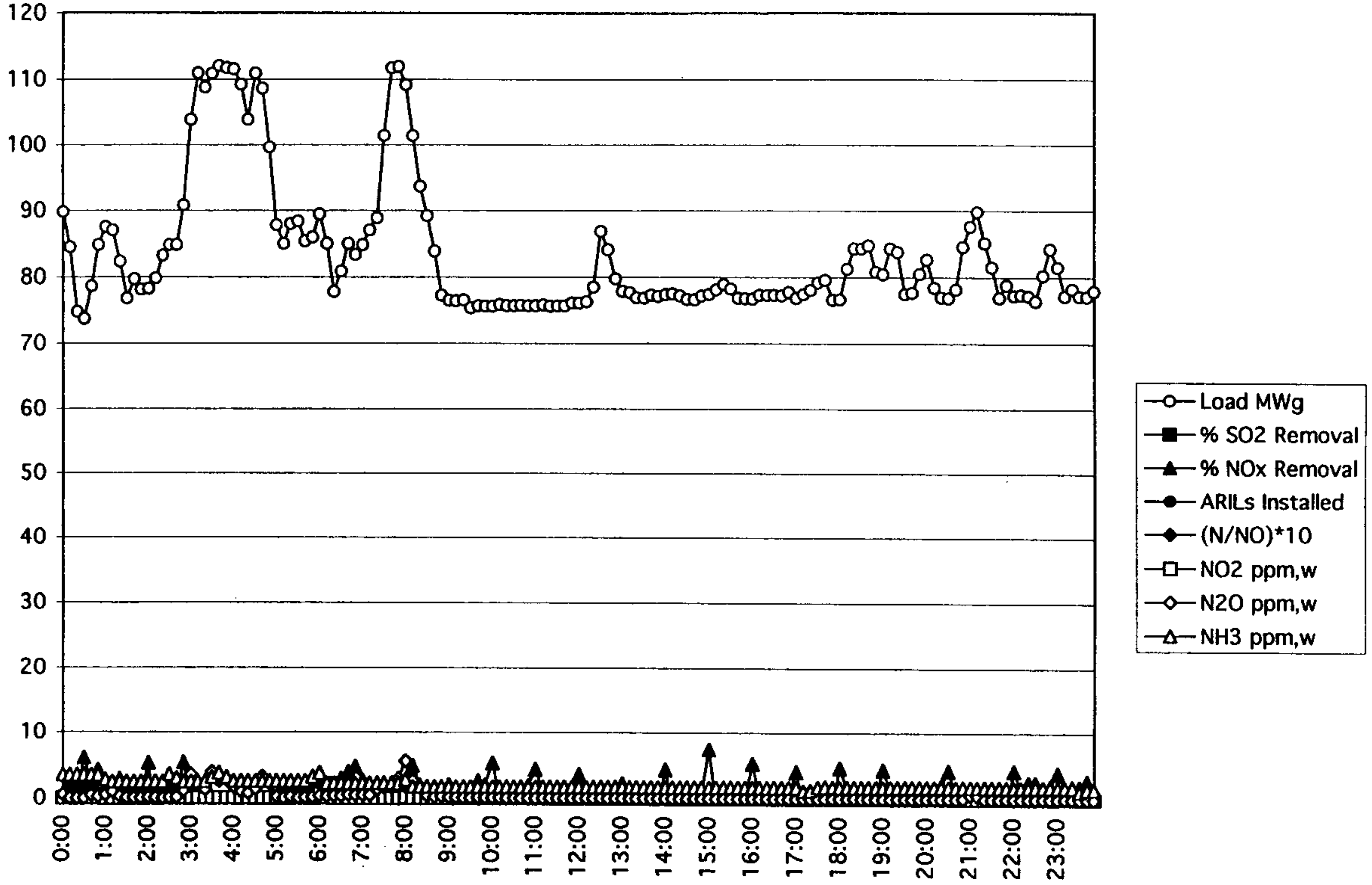


Figure 7-20. Long-Term Load-Following Test Results for March 9, 1996

been released for load regulation, the load remained constant. Figure 7-21 shows that NO_2 emissions began to appear at the stack at about 1600 hrs (approximately two hours after the DSI system was started). By 2000 hrs, the NO_2 emissions had leveled-out at approximately 6 ppm. A FFDC cleaning cycle occurred between 2035 and 2110 hrs, and the NO_2 emissions increased to 20 ppm. The SNCR system was shut down at 2150 hrs, and the NO_2 emissions increased again, this time to approximately 28 ppm.

Since the test on March 10 (Figure 7-21) was run at a urea flowrate which produced an initial stack NH_3 emission level in excess of 10 ppm, the SNCR system was not run during the early morning hours of the next day in hopes of avoiding another episode of heavy NH_3 odor at the flyash silo. The SNCR system was restarted at 0700 hrs on March 11 (Figure 7-22). By this time, the liquid line to the east ARIL had thawed, and the tuning table was changed to allow lance insertion. However, as shown in Figure 7-22, the load never dropped low enough to use the lances. Four hours after urea injection began, the NH_3 emissions slowly increased to a level of 9 ppm, and then the trim control system reduced the N/NO ratio slightly to maintain the slip at the 8 ppm limit. Figure 7-22 also shows that after one hour of urea injection, the NO_2 emissions were reduced from nominally 25 ppm to a level below 5 ppm. At 1500 hrs, a FFDC cleaning cycle began, and the NO_2 emissions jumped to 20 ppm. Three hours later, however, the NO_2 emissions were back down to zero.

The NO_2 emissions remained at near-zero levels until 0440 hrs on March 12 (Figure 7-23). At this time, the FFDC cleaned again and the NO_2 emissions jumped to approximately 16 ppm. Unlike the previous evening, however, the NO_2 emissions did not decrease after the FFDC cleaning cycle and remained within the range of 14 to 16 ppm. Figures 7-22 and 7-23 show that the boiler load was reasonably steady from 2100 hrs on March 11 to 0900 hrs on March 12. Although it is difficult to see, the data also show that the trim control system reduced the urea flowrate (i.e., N/NO ratio) during this time. (A better indication of the flowrate reduction is the decrease in NO_x removal and N_2O emissions over the same time period.) Since the boiler load was relatively constant, the reduced urea flow resulted in reduced levels of NH_3 slip ahead of the FFDC. It is believed that the higher NO_2

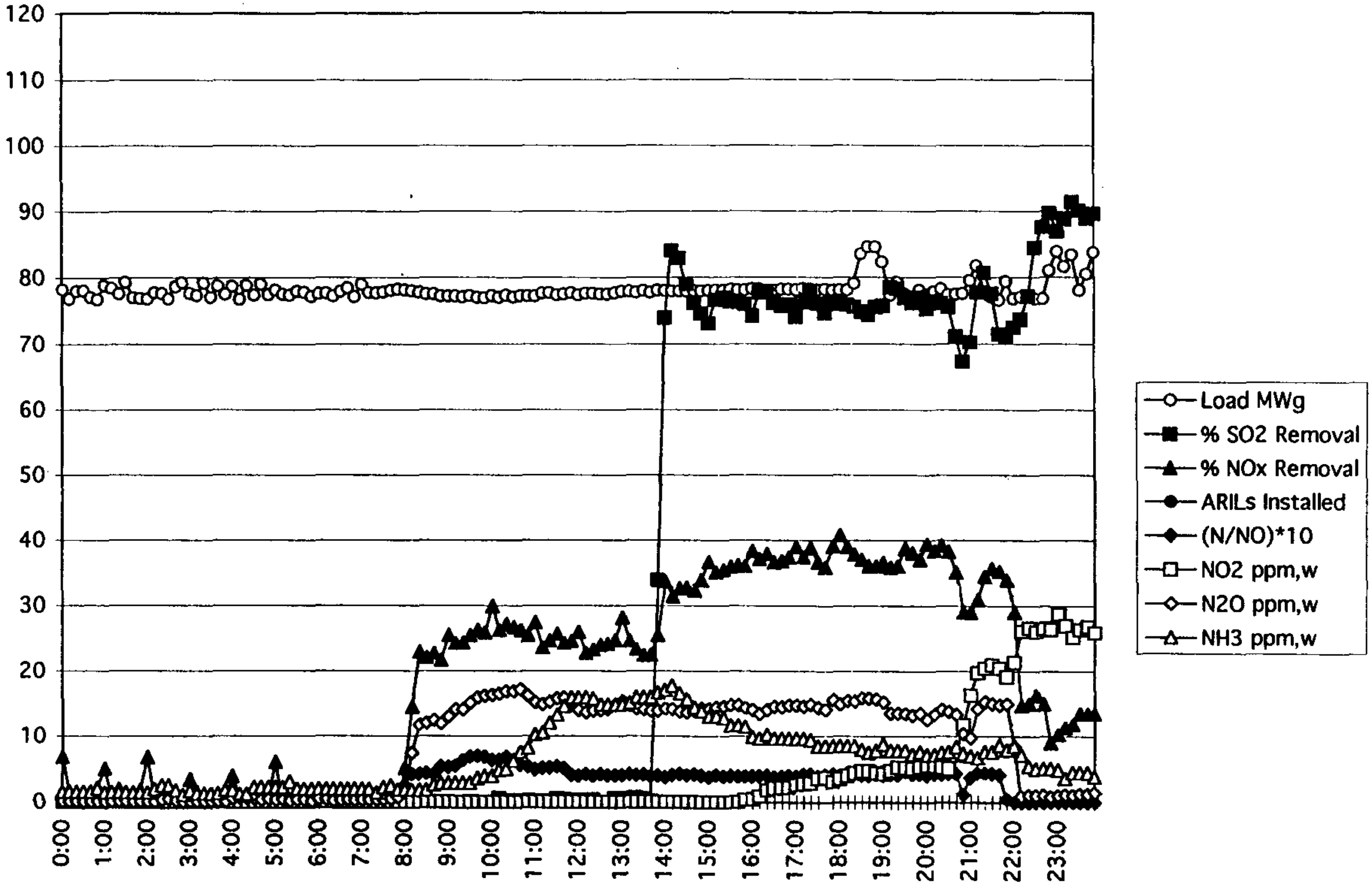


Figure 7-21. Long-Term Load-Following Test Results for March 10, 1996

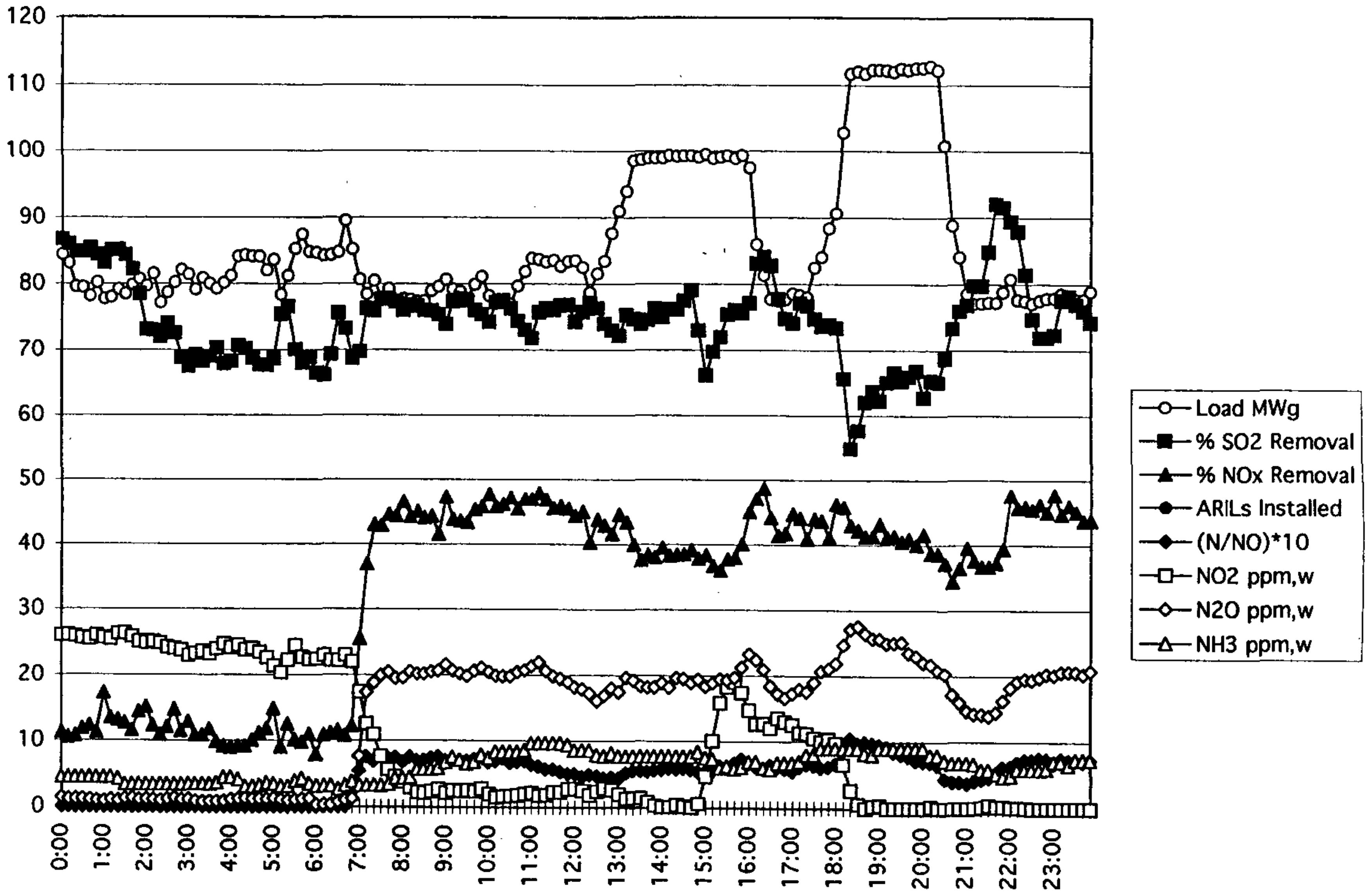


Figure 7-22. Long-Term Load-Following Test Results for March 11, 1996

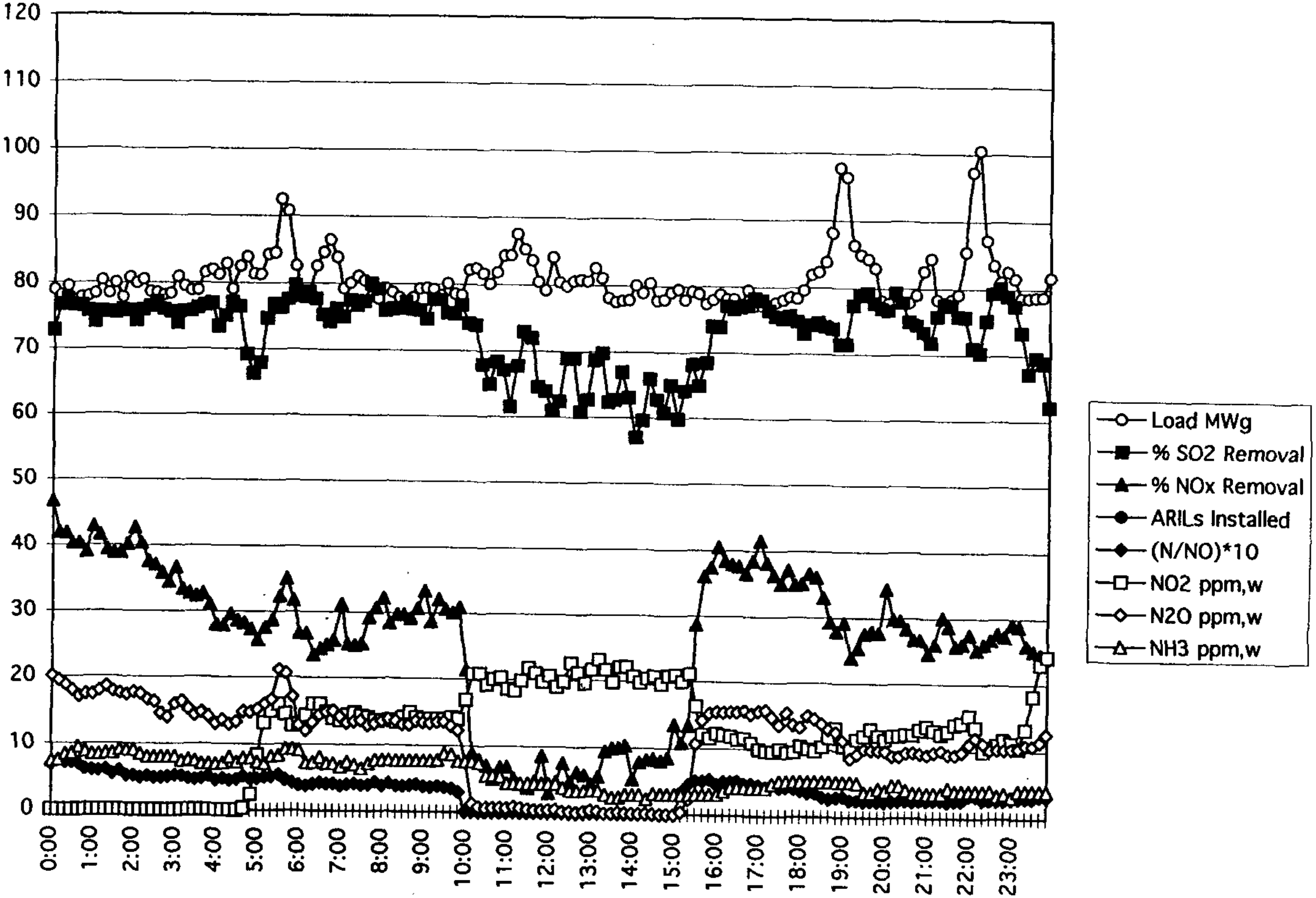


Figure 7-23. Long-Term Load-Following Test Results for March 12, 1996

emissions at the stack between 0600 and 0900 hrs in Figure 7-23 are due to the lower levels of NH_3 emissions at the FFDC inlet.

The SNCR system was shut down at 0950 hrs on March 12 (Figure 7-23) after it was found that the ambient NH_3 emissions in the flyash unloader room had risen to approximately 60 ppm. A flyash sample from the FFDC hoppers was collected for later analysis of the NH_3 content. The SNCR system was restarted five hours later, after the stack NH_3 emissions had fallen to "zero" (i.e., a 2 to 3 ppm reading on the CEM). The upper and lower NH_3 trim control setpoints were reduced to 5 and 4 ppm, respectively, and the maximum bias limit was reduced to 10 percent in an effort to limit the NH_3 emissions at the FFDC inlet to 5 ppm. The average NO_x removal and NH_3 slip for the preceding 27-hour time period (0700 hrs March 11 to 0950 hrs March 12) were 38.7 percent and 6.9 ppm, respectively. This level of NO_x removal agrees well with the level achieved during the previous period of integrated testing when the ARIL lance liquid lines were not frozen (1440 hrs March 4 to 0620 hrs March 6). Compared to the SNCR-only results with NH_3 trim control settings of 8 and 7 ppm (Table 7-3), 39 percent NO_x removal with the integrated system represents a "synergistic benefit" of nominally 8 percent SNCR NO_x removal (on a net basis). In addition, the average NO_2 emissions during this time period were 8.1 ppm. As seen before, this represents approximately a 50 percent reduction when compared to the levels for DSI alone (nominally 19 ppm).

After the SNCR system was restarted at 1500 hrs on March 12, wet chemical measurements showed that the NH_3 slip at the FFDC inlet was varying between 12 and 22 ppm. At 1725 hrs, the upper and lower NH_3 trim control setpoints were reduced to 4 and 3 ppm, respectively. Figure 7-23 shows that there were corresponding reductions in N/NO ratio, NO_x removal, and N_2O emissions at this time. At 2030 hrs, wet chemical measurements showed that the NH_3 slip at the FFDC inlet had been reduced to 3 ppm. At 2115 hrs, the trim settings were increased slightly to 4.5 and 4 ppm, with the hope of increasing NO_x removals. At 0320 hrs on March 13 (Figure 7-24), the NH_3 slip at the FFDC inlet were again above 10 ppm, and the NH_3 trim control setpoints were reduced slightly to 4 and 3.5 ppm. A slight reduction in the N/NO ratio can be seen in Figure 7-24 at this time. The figure also shows that there were three occasions on March 13 when the N/NO ratio "went to zero". During each of these occasions, the primary urea pump was taken off-line in order to address a sudden loss of pressure (the backup pump was also off-line at this time). During the first two occasions (0730 and 1200 hrs), it was believed that the problem was within the water softening skid in the SNCR control building. On the final occasion (1800 hrs), the internal pump check valves were cleaned, and the problem resolved.

When the SNCR system was restarted at 1500 hrs on March 12, the NO_2 emissions were immediately reduced by approximately 50 percent (Figure 7-23). A FFDC cleaning cycle began at 2310 hrs, and after the cleaning, the NO_2 emissions jumped to 20 ppm and remained at that level throughout the early morning hours of the following day. Figure 7-24 (March 13) shows that despite the low N/NO ratios (due to the reductions in the trim control setpoints), switching the urea flow on and off throughout the day resulted in noticeable increases and decreases in the NO_2 emissions. However, it must also be noted that the large increase at 1800 hrs was not entirely due to the lack of urea flow, as there was also a FFDC cleaning cycle at this time. After the cleaning cycle, the NO_2 emissions quickly returned to the range of 5 to 10 ppm.

Figure 7-25 shows that the ARILs were inserted at approximately 0030 hrs on March 14. The lances were inserted manually at this time to test a modification made to the control program during the previous night. Wet chemical measurements made throughout the previous day showed that the NH_3 slip at the FFDC inlet was only 3 to 4 ppm, so the trim control setpoints were increased to 4.5 and 4 ppm when the lances were inserted. The lances were retracted at 0250 hrs and injection at the Level 1 location continued throughout the remainder of the day. A FFDC cleaning cycle at 1220 hrs resulted in an increase in the NO_2 emissions, which was followed by a very slow decline. At 2045 hrs, test personnel were notified that the unit was coming off-line unexpectedly to address a turbine steam flow control problem. The DSI system was shut down immediately, the SNCR system was shut down at 2100 hrs, and the unit came off-line at 2300 hrs. Since

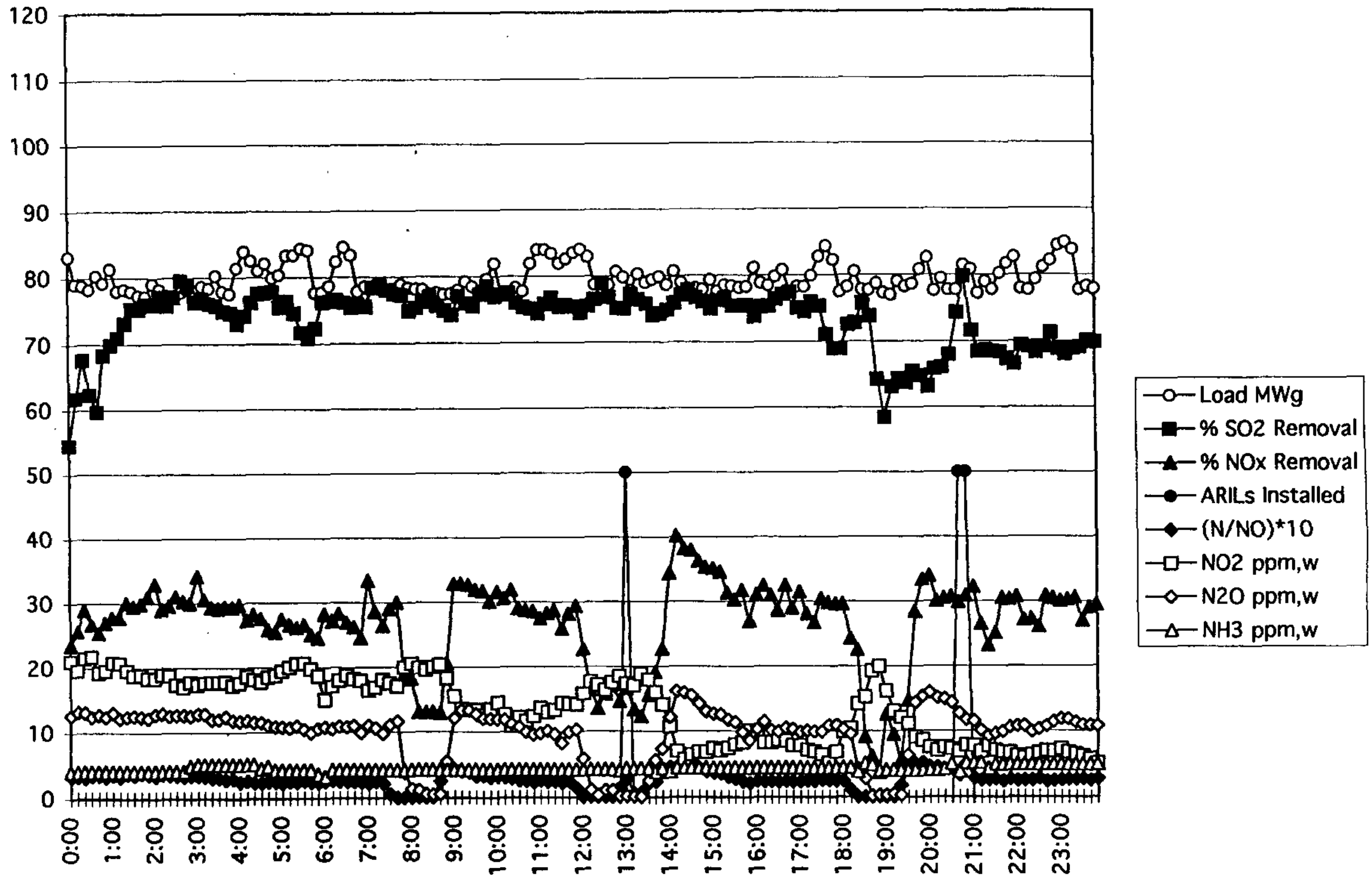


Figure 7-24. Long-Term Load-Following Test Results for March 13, 1996

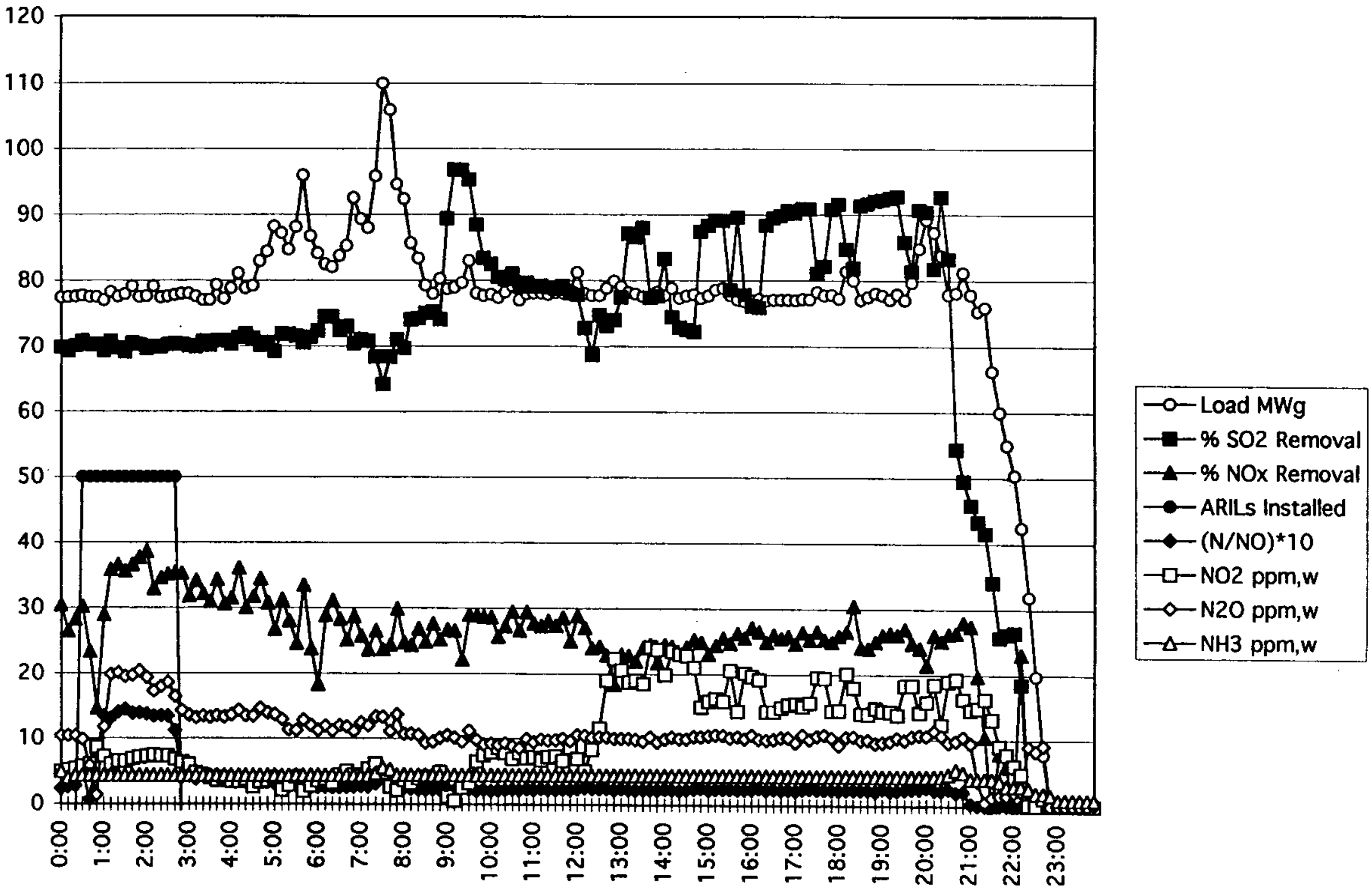


Figure 7-25. Long-Term Load-Following Test Results for March 14, 1996

the unit was not expected to be back on-line until the afternoon of March 16, the long-term integrated test came to a conclusion at this point in time.

Reducing the NH_3 odor at the ash silo was the main focus of the final two and one-half days of the integrated test. The average NO_x removal and NH_3 slip for this time period (1530 hrs March 12 to 2110 hrs March 14), were 28.8 percent and 4.0 ppm, respectively. Since the DSI NO_x removals were nominally on the order of 10 percent, the SNCR contribution was only approximately 21 percent. The average N/NO ratio and N_2O emissions during this time period were 0.33 and 11.5 ppm, respectively. Figure 6-2 shows that with urea injection alone, a N/NO ratio of 0.33 results in NO_x removal levels of approximately 16 percent. The difference between 16 and 21 percent NO_x removal is within the day-to-day repeatability of the process.

Even with the low urea injection rate, NH_3 *odors at the ash silo were still very strong* throughout the final day of testing . Measurements of the ambient NH_3 concentration in the silo unloader room were made on three occasions throughout the day. The results of these measurements ranged from 45 to 65 ppm. A flyash sample was collected from the FFDC hoppers at 0700 hrs on the final day of testing (March 14). Another sample was collected early the following morning (March 15), after the boiler came off-line. The results of the analysis of these samples are discussed in Section 7.3.

The CEM *stack* NH_3 *emissions were nominally 4 to 5 ppm throughout the final two and* one-half days of the integrated test. Since the "zero level" for the stack NH_3 monitor was approximately 3 ppm, the "real" concentration was in the 1 to 2 ppm range. Wet chemical NH_3 measurements at the inlet of the FFDC ranged from 2 to 4 ppm during the final 40 hours of the test. Thus, the urea injection rate during this time period was too low to determine if there was a reduction in the NH_3 slip with the integrated system. However, the average NO_2 emissions for the time period of 1530 hrs March 12 to 2110 hrs March 14 were 11.6 ppm. This was a nominal 40 percent reduction relative to the NO_2 emission level *for DSI alone (19.4 ppm). This result indicates that very little* NH_3 *slip is needed at the* FFDC inlet in order to realize a substantial reduction in NO_2 emissions at the stack.

The previous discussion presented the long-term data in a chronological format. This presentation format illustrated the dynamic behavior of the system and the discussion pointed out some of the interactions of the SNCR and DSI systems. These interactions can be better illustrated by cross plotting some of the long-term data and comparing the overall average performance. These cross plots and averages were constructed using 10 minute average data from the CEM for the period February 19, 1996, through March 14, 1996.

Before presenting these summarized results, it should be noted that these plots are based on the long-term data from the CEM. As such, it includes periods of transient boiler operation and transient operation of the SNCR and DSI systems, so the data will exhibit more scatter than the parametric tests.

Figure 7-26 shows the NO_2 emissions as a function of load for time periods when the DSI system was operated alone and for the integrated operation of the system. Again, while there is scatter in the data, Figure 7-26 clearly illustrates that the NO_2 emissions are lower when the integrated system is operated. With the sodium-based DSI system operating alone, the NO_2 levels ranged from nominally 10 to 35 ppm. For the majority of the time with the integrated system, the NO_2 levels were less than 10 ppm. In fact, taking a simple arithmetic average, the NO_2 levels with the DSI system alone were 20 ppm, and were only 8 ppm with the integrated system.

While the integrated system includes low NO_x burners and overfire air, the NO_x removal shown includes only that obtained with SNCR and DSI. The total NO_x reduction is estimated to be 75% to 80%, but an accurate overall removal cannot be calculated due to the long period since the combustion retrofit.

Table 7-5 provides a summary of the long-term data in terms of average SO_2 and NO_x removal, NH_3 slip, and N/NO ratio. In Table 7-5, overall averages are shown as well as the averages for the periods when the ARIL lances and Level 1 injector were in use.

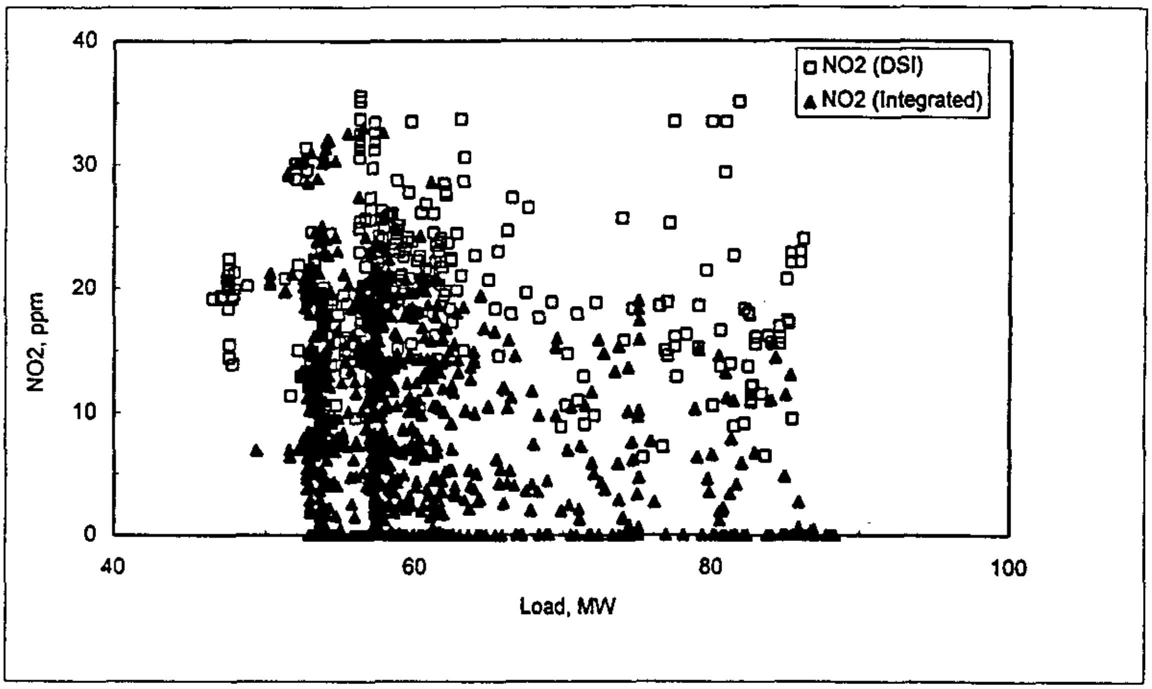


Figure 7-26. Long-Term System Operation: NO_2 Emissions versus Load

Table 7-5
Summary of the Automatic Integrated Long-Term Test Incorporating the ARIL Lances
(February 19 through March 14, 1996)

	Integrated System	SNCR Only	DSI Only
SO_2 Removal, %	76	--	74
NO_x Removal, %	34	23	
N/NO Ratio, molar	0.74	0.72	
NH_3 Slip, ppm	5	9	
NO_2	8		20
ARIL Lances			
N/NO, molar	2.03	1.27	
NO_x Removal, %	40	33	
NH_3 Slip, ppm	4	8	
Level 1 Injectors			
N/NO, molar	0.46	0.43	
NO_x Removal, %	33	18	
NH_3 Slip, ppm	5	10	

The advantages of the integrated system are clearly shown in Table 7-5. As discussed above, the NO_2 levels were less than half those when operating the DSI system alone. This decrease in NO_2 is again due to the chemical interaction between the NH_3 slip from the SNCR system and the sodium/SO_2 in the fabric filter.

Considering the overall performance for the period from February 19, 1996 through March 14, 1996, the integrated and SNCR-only periods averaged about the same overall N/NO ratio. However, the NO_x reduction with the integrated system was 11 percentage points higher due primarily to the NO_x removal, which occurs during the sodium-SO_2 reactions. More importantly, the NH_3 slip with the integrated system was about half that of the SNCR only test periods.

These interactions can be seen more clearly by looking at the integrated system performances during periods when the ARIL lances and Level 1 injectors were being used. As seen in Table 7-5, with the ARIL lances the SNCR system was able to operate at a considerably higher N/NO ratio in the integrated mode (N/NO of 2.03 compared to 1.27 for the SNCR system alone). Yet the ammonia slip was one-half of the SNCR-alone periods. The DSI system reduces the ammonia slip for a given urea injection rate and the automatic control system responds by increasing the urea injection rate. During this long term test period, the Level 1 injectors operated at about the same N/NO ratio during both the integrated and SNCR-alone periods. But, again, the ammonia slip is half during the integrated test periods.

These long-term tests clearly showed the benefits of the long-term system:

- lower NO_2 emissions due to the interaction of the SNCR ammonia slip with sodium-SO_2 reactions
- higher NO_x removal due to the additional NO_x removal associated with the sodium-SO_2 *reactions*
- lower NH_3 slip due to the presence of the sodium. For the automatic control system used at the Arapahoe site, this was manifest not only by lower slip at a set N/NO ratio, but because of the trim system, a higher N/NO ratio with higher NO_x removal for a setpoint NH_3 slip level.

7.3 Solids Analysis Results

During the previous sodium-based DSI-only tests (Smith, et al., 1997a), the results of flyash solids analysis were used to calculate a sodium utilization value, which provided a check of the value calculated from the SO_2 removal and the sorbent feedrate. These tests showed that while the sodium content of the material deposited on the FFDC bags was similar to that for the material deposited in the FFDC hoppers, the sulfate level was much higher for the material on the bags. Therefore, calculation of the sodium utilization from the solids analysis required a sample representative of the ash deposited throughout the FFDC. A special flyash sampling protocol was developed during these previous DSI-only tests which provided such a sample. Unfortunately, this protocol was time consuming, requiring approximately 3 to 4 hours to perform.

During the current test phase, the primary reason for collecting flyash samples was to provide an indication of the level of NH_3 absorption on the ash, and thus hopefully provide some insight into the odor problem. Therefore, a simpler sampling protocol was utilized. For each of the flyash samples from the final week of the long-term integrated test, individual samples were collected from each of the FFDC hoppers and then the hopper samples were combined to make a single composite sample. No attempt was made to coordinate the collection of these samples with the timing of the FFDC cleaning cycle. Thus, while the samples are characteristic of the ash deposited in the hoppers, they are not likely representative of the flyash deposited throughout the FFDC (i.e., on the bags as well as in the hoppers).

The flyash samples collected during the final week of the long-term integrated test were also sent to an independent outside laboratory (Desert Analytics in Tucson, Arizona) for further analysis. Each sample was analyzed for sulfate, sulfite, nitrate and nitrite using ion chromatography. In addition, the sodium content of each sample was determined using atomic absorption. Table 7-6 presents the results of these analyses, as well as the results for two other samples; one from a test without either sodium or urea injection (T982-1), and one from a test with sodium injection alone (T704). Calcium analyses were performed on the "baseline" (T982-1) and "DSI-only" (T704) samples, as well as on one of the samples from the integrated testing (3/14/96).

The analysis of the T982-1 sample show that the "baseline" ash had sodium and calcium levels of 0.24 and 0.80 percent, respectively. These levels are a result of the naturally occurring mineral content of the coal fired at the Arapahoe Station. The analysis also shows that the baseline coal ash had a sulfate content of 0.80 percent. While this amount is small, it is significant relative to the levels found in the other five samples. The sulfate found in the baseline ash is most likely in the form of $CaSO_4$, and was probably formed in the hotter flue gas temperature regions at the furnace exit. The calcium analysis for this sample shows that there was ample calcium available to account for the level of sulfate found.

The DSI-only sample (T704) was collected during a test with sodium sesquicarbonate injection at the FFDC inlet. This test was run at a nominal 2Na/S ratio of 1.5, which yielded

Table 7-6

Flyash Solids Analysis Results for the Long-Term Integrated Test

Sample ID	Sulfate (%, Weight)	Sulfite (%, Weight)	Nitrate (%, Weight)	Nitrite (%, Weight)	Sodium (%, Weight)	Calcium (%, Weight)
Baseline Ash T982-1	0.80	<0.10	<0.10	<0.10	0.24	0.68
DSI-Only T704	4.58	<0.10	0.21	<0.10	4.88	0.50
Integrated						
3/8/96	6.00	0.20	0.34	<0.10	9.12	---
3/12/96	4.13	<0.10	0.18	<0.10	8.68	---
3/14/96	4.07	0.19	0.19	<0.10	8.22	0.54
3/15/96	3.96	0.30	0.19	<0.10	8.98	---

an average SO_2 removal of approximately 60 percent. In contrast, the long-term integrated tests were run with a SO_2 removal setpoint of 75 percent, which corresponds to a nominal 2Na/S ratio of 2 to 2.5 (recall Figure 5-5). This difference in the 2Na/S ratios is reflected in the differences seen in the sodium concentrations shown in Table 7-6.

Table 7-6 also shows that the sulfate levels for the five ash samples with sodium injection ranged from nominally 4 to 6 percent. Sulfite was detected in three of the five samples, but only at very low levels. These results are consistent with those found during the sodium-based DSI-only tests (Smith, et al., 1997a), where a similar analysis showed that nearly all of the captured sulfur was in the form of sulfate.

There were no measurable levels of nitrite in any of the six samples, while the five samples with sodium injection contained low levels of nitrate (these levels were only two to three times the detection limit of the analysis technique). The nitrates are a product of the NO_x removal chemistry associated with the sodium injection process (Smith, et al., 1997a). The level of SO_2 removal, as well as the level of NO_x removal, is dependent on the sorbent injection rate in this process. Thus, the ratio of sulfate to nitrate can be expected to remain relatively constant. This is the case for all five of the samples with sodium injection shown in Table 7-6. (Although the sulfate level for the 3/8/96 integrated sample was nominally 50 percent higher than the other samples, the nitrate levels were also higher by roughly the same amount.) The results shown in Table 7-6 indicate that the integrated system (i.e., the urea injection process) did not lead to increased nitrate levels in the flyash, relative to the levels found in the DSI-only samples.

This raises an interesting question as to how the ammonia slip from the SNCR process reduces the NO_2 emissions from the sodium-SO_2 chemistry. Two different mechanisms have been put forth for the production of NO_2 from the dry sodium injection process. These were discussed in the test report documenting the sodium injection test results (Smith, et al., 1997a). These two mechanisms are shown schematically in Figure 7-27. The Solvay mechanism suggests the formation of an intermediate compound, sodium pyrosulfite (NaS_2O_5). The pyrosulfite then reacts with NO to form sodium nitrate ($NaNO_3$) and sodium

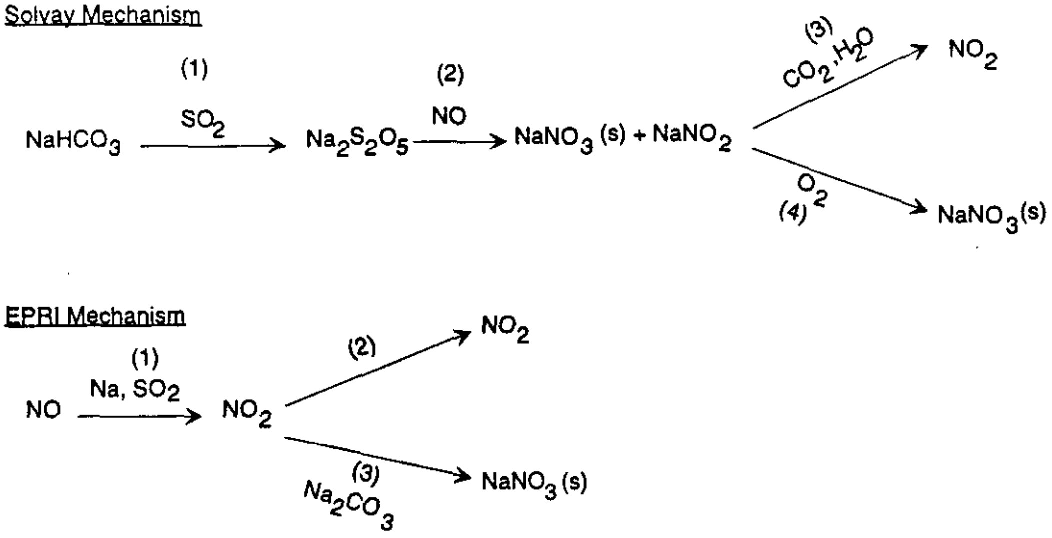


Figure 7-27. Schematic Representation of the Two Postulated Mechanisms for NO_2 Formation

nitrite ($NaNO_2$). The formation of the solid sodium nitrate represents NO_x reduction. The $NaNO_2$ is thought to be unstable and can follow two paths. If it reacts with CO_2 and H_2O, it will liberate NO_2. On the other hand, if it reacts with O_2, it oxidizes to $NaNO_3$, resulting in additional NO_x reduction.

The second mechanism, referred to as the EPRI mechanism, suggests a catalytic-type reaction (unspecified) between the sodium compound and SO_2 that forms NO_2 directly. The NO_2 can then be either emitted, or react with the sodium carbonate to form solid $NaNO_3$. Again, the solid $NaNO_3$ represents NO_x reduction.

Two possible paths can be postulated as to how the NH_3 interacts with the sodium-SO_2 system to reduce NO_2. Both can be explained relative to the two mechanisms for NO_2 formation shown in Figure 7-27. The first, and simplest, has the NO_2 formed by either of the mechanisms shown in Figure 7-27. The ammonia slip would then react with the NO_2 forming ammonium nitrite or ammonium nitrate. If this mechanism is correct, the ash nitrite or nitrate concentrations would increase along with an increase in NO_x removal.

On the other hand, the ammonia could interact with the sodium-SO_2 chemistry to reduce the amount of NO_2 formed, rather than remove it after it is formed. In terms of the Solvay mechanism, this could involve an interaction with the first step reducing the amount of sodium pyrosulfite that is formed, or possibly the second step changing relative amounts of $NaNO_3$ and $NaNO_2$ that are formed. In terms of the EPRI mechanism, the ammonia would again interfere with the first step, producing less NO_2. If this latter mechanism is correct, then according to either the Solvay or EPRI mechanisms, the overall amount of NO_x reduction would be reduced and the ash nitrate levels reduced. The exception would be with the Solvay mechanism if the relative amounts of $NaNO_3$ and $NaNO_2$ formed are influenced by the NH_3. In this latter case, the NO_x reduction and ash nitrate levels could remain relatively constant along with a decrease in NO_2.

The ash analysis presented in Table 7-6 suggests that the nitrate levels with and without SNCR injection remained approximately equal. At first reading, this suggests that neither of the two postulated mechanisms are correct. However, the SNCR system reduces NO_x emission into the DSI process by 25 to 50%, depending on operating conditions. With reduced NO_x emission into the DSI process, it would be expected that the nitrate levels would also be reduced by 25 to 50%. As the NO_x was reduced while the nitrate levels remained approximately constant, more nitrate was formed as a percentage of the inlet NO_x. This tends to discount the second mechanism described above where nitrate levels either decrease or remain constant and overall NO_x reduction is reduced. It also suggests that the first proposed mechanism which removes NO_2 after it is formed and overall NO_x reduction is increased is more likely occurring.

Due to the very low levels of nitrate in the ash and the difficulty in obtaining a representative sample, it was not possible to prove the suggested mechanism. However, all samples were obtained using the same method and should be sufficiently accurate to determine the relative trend of increasing or decreasing nitrate in the solid sample.

In addition to the change in the solid samples, the DSI NO_x removal should also be increased if the proposed reaction is occurring. However, the expected increase in NO_x

removal is only a few percent and normal process variation prevents this increase from being accurately determined.

While it is difficult to delineate detailed chemical mechanisms with full-scale utility boiler tests, the ash analysis in Table 7-6 would tend to support a direct reaction of NH_3 with NO_2, rather than a mechanism that shuts down the nitrogen chemistry associated with the sodium-SO_2 reaction. This latter mechanism would have been expected to markedly decrease both NO_2 and ash nitrate (i.e., NO_x removal).

An issue that needs to be addressed with any post-combustion NO_x reduction technology with NH_3 slip is the absorption of ammonia on the flyash. This can have impacts ranging from personnel safety while handling the ash, odor problems, or impacting the saleability of the ash for future use as a cement aggregate. In the latter, a saleable product becomes a disposal problem with an attached economic penalty. At the Arapahoe Station, the ash is not sold for use in cement, and the only problem that has been encountered has been the NH_3 odor at the Unit 4 ash silo during the long-term testing of the integrated system.

At Arapahoe Unit 4, the ash is removed from the FFDC hoppers with a vacuum system and transported dry to the ash silo. When loaded onto trucks for transport to the disposal site, the ash is wetted with approximately 20 percent water (by weight) in order to minimize fugitive dust emissions. Depending on the specific ash characteristics, this wetting process can result in the release in NH_3 vapors from the ash. Whether or not NH_3 is released from the ash depends primarily on the pH of the aqueous phase on the surface of the ash particles. Figure 7-28 shows the equilibrium relation between the aqueous (ammonium) and vapor (ammonia) phases as a function of pH. As the pH increases above a level of 9 to 9.5, there is an increased release of vapor-phase ammonia.

Flyash samples were collected on four occasions during the final week of the long-term test with the integrated system. As mentioned above, samples were collected from each FFDC compartment hopper, and then the individual hopper samples were combined to provide a representative composite of the ash deposited in the hoppers. The composite samples

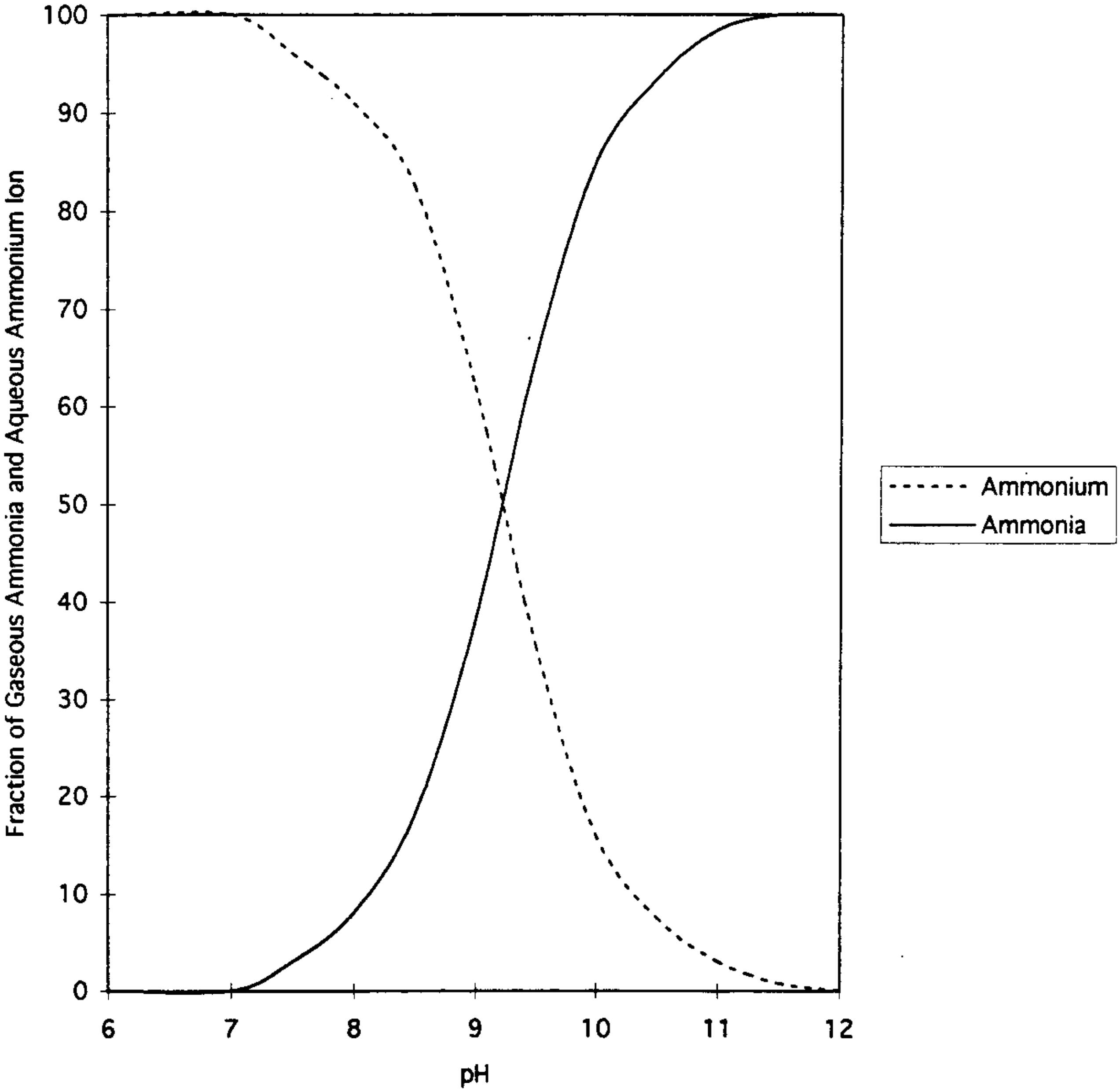


Figure 7-28. Fraction of Gaseous Ammonia and Aqueous Ammonia Ion as a Function of pH

were then analyzed to determine the adsorbed NH_3 content. The analysis was performed by placing 1 gram of ash in 200 ml of 0.02N sulfuric acid, and then analyzing the solution for ammonia using a specific ion electrode.

Flyash samples collected during the urea-injection tests performed after the low-NO_x combustion system retrofit (Smith, et al., 1994b) were also analyzed for ammonia using the method described above. Table 7-7 shows that the ammonia content of these samples varied over the range of 100 to 200 ppm (measured on a weight basis), where the lower end of the range corresponded to a stack NH_3 level of 4 ppm, and the upper end to stack NH_3 levels of 7 to 9 ppm. During the long-term testing with the SNCR system alone (Section 7.1), there were no incidents of excessive NH_3 odors during the ash handling process when the stack NH_3 slip limit was set at 8 ppm, although a slight NH_3 odor was occasionally noted.

Table 7-7

Flyash Ammonia Levels for Tests with Urea Injection Only
(Samples Collected During Post-Retrofit SNCR Tests (Smith, et al., 1994b))

Test Number	Date	Average CEM Stack NH_3 Emissions (ppm)	Flyash NH_3 Level (ppm, weight)
556	3/10/93	4	103
557	3/10/93	7	199
558	3/11/93	9	217

The results of the long-term integrated tests (Section 7.2) showed that when the SNCR system was operated in conjunction with the DSI system, the urea injection rate could be increased substantially while maintaining the 8 ppm NH_3 slip limit at the stack. This is one *of the synergistic benefits of the patented Integrated Dry NO_x/SO_2 Emissions Control* System demonstrated during this project. However, Table 7-8 shows that during these tests, the ammonia concentration in the ash increased to the range of 400 to 700 ppm (weight basis), and as discussed previously, there was a heavy NH_3 odor at the ash silo *during long-term testing. Reducing the* NH_3 *slip limit to the range of 4 to 5 ppm reduced* the ammonia concentration in the flyash to approximately 150 ppm (weight basis), but the odor problem persisted. The ammonia content of the ash samples collected during the integrated tests was higher for comparable stack ammonia levels than with urea injection alone. However, a difference in ash ammonia contents from nominally 100 ppm to 150 ppm would not be expected to significantly increase the odor problem.

Table 7-8

Flyash Ammonia Levels for Tests with both Urea and Sodium Injection

Date	Time	Upper NH_3 Trim Control Setpoint (ppm)	Average CEM Stack NH_3 Emissions (ppm)	Flyash NH_3 Level (ppm, weight)
3/08/96	1045	8.0	6.8	702
3/12/96	0730	8.0	7.1	466
3/14/96	0700	4.0	3.9	143
3/15/96	0800	4.5	4.2	155

Another possible reason for the odor problem was the sodium changing the pH of the ash. A higher pH could release more NH_3. The pH resulting from placing 0.5 grams of ash in 200 ml of distilled water was 9.3, for an ash sample from a test without sodium injection. The same test run with an ash sample from a test with sodium injection resulted in a pH of 10.3. This pH increase relates to nearly doubling the ammonia gaseous fraction as shown in Figure 7-28, but the local NH_3 was much greater.

An interesting observation was made during the pH measurements. While the presence of sodium was found to slightly increase the final pH, it was also found to have a large effect on the rate at which the pH changed when the ash was wetted. Figure 7-29 shows the change in pH versus time after 0.5 gm of ash is placed in 200 ml of distilled water and stirred. With the coal ash alone, almost 30 minutes are required for the soluble components of the ash to dissolve and change the pH to a final value of 9.3. However, with sodium present in the ash sample, the pH increases almost instantaneously, presumably because of the higher solubility of the sodium compounds in the ash. This more rapid development of the high pH level results in more rapid and localized release of the ammonia vapor, and explains the odor problem encountered when concurrently operating the SNCR and DSI systems.

Since the completion of this testing, Arapahoe has investigated and found that the ash can be handled and dumped with acceptable fugitive dust emissions with no water addition by using a bottom dump trailer. Necessary compaction moisture is added at the disposal site. This method lowers the ash transport costs by not hauling the 20% water and will eliminate the NH_3 odor problems at the plant.

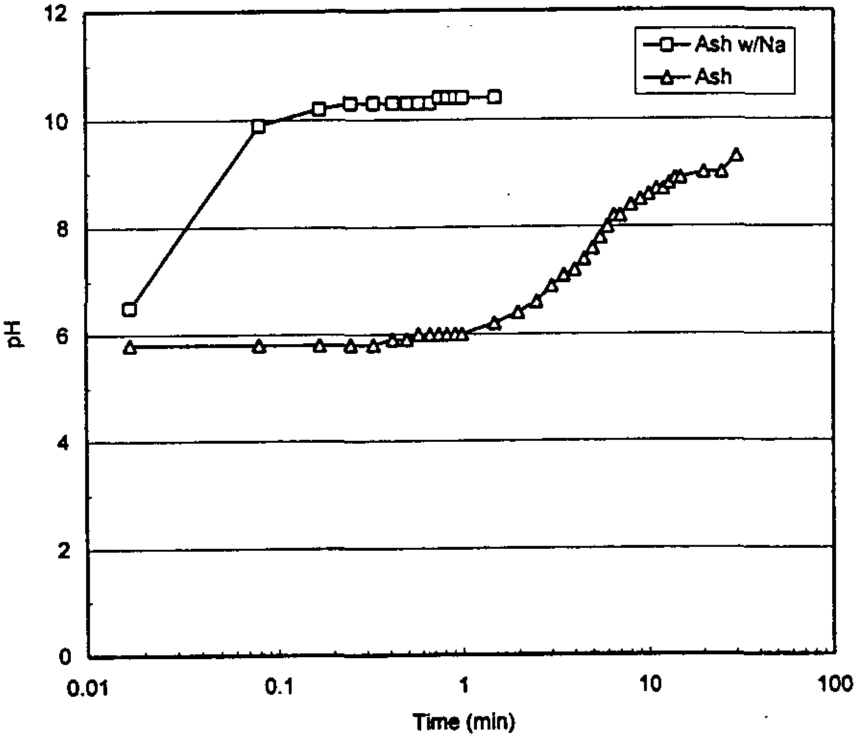


Figure 7-29. pH versus Time for Coal Ash and Coal Ash/Sodium Mixture (0.5 gm of Ash in 200 ml of H_2O)

8.0 SUMMARY AND CONCLUSIONS

The following observations and conclusions can be made pertaining to each of the test activities performed during the evaluation of the Integrated Dry NO_x/SO_2 Emissions Control System on the Arapahoe Unit 4 boiler.

Parametric Tests

- The results of the parametric tests provided indications that the NO_2 emissions were substantially reduced when the DSI and SNCR systems were run concurrently. However, it was not possible to quantify the actual reduction levels due to the short duration of the tests, and the effect of FFDC cleaning cycles.
- Generally, the parametric tests were too short in duration to assess if the NH_3 emissions were reduced with the integrated system (due to the time required for the stack NH_3 emissions to stabilize as a result of adsorption and desorption on the flyash in the FFDC). Although one test did provide a positive indication, it was necessary to assess this effect during the long-term load-following tests.

Long-Term SNCR-Only Tests

- During the first seven days of the long-term test with SNCR alone, the control set points for the SNCR "tuning table" were repeatedly modified in an effort to maintain NH_3 emissions at, or below, 10 ppm. The original settings were based upon the results of the parametric ARIL optimization tests (Smith, et al., 1996b), and it was found that NH_3 emissions were generally higher during load-following operation. In addition to the changes to the tuning table, a number of modifications were also made to the SNCR control system logic during the first week. These modifications were necessary to limit increases in NH_3 emissions that occurred whenever the boiler load moved between load ranges in the tuning table.
- Long-term load-following operation with the upper and lower NH_3 trim control set points at 10 and 8 ppm, respectively, yielded a nominal average NO_x removal 27 percent. This level of NO_x removal was slightly lower than what was expected based upon the results of the parametric ARIL optimization tests (Smith, et al., 1996b), and the post-retrofit SNCR tests performed before the new lances were installed (Smith, et al.,1994b). The ARIL tests indicated that under closely controlled conditions, the average NO_x removal across the load range was approximately 40 percent. However, the post-retrofit tests showed that the NO_x removals achieved during load-following operation were nominally 10 percent lower (on a net basis) than the removals achieved during closely controlled parametric tests (for the same NH_3 slip level).

- During the long-term load-following test with the NH_3 trim control set points at 10 and 8 ppm, a detached white plume frequently appeared at the stack whenever the NH_3 emissions exceeded 10 ppm and the ambient temperature was less than 35°F. Reducing the NH_3 trim control set points to 8 and 6 ppm eliminated the plume problem. At ambient temperatures of less than 30°F, a plume often formed with stack NH_3 emissions of only 5 to 10 ppm. This is attributed to a reaction between NH_3 and SO_2. It was also determined that at ambient temperatures of less than approximately 10°F, a white detached plume would appear with NH_3 slip levels as low as 5 ppm. However, at these low temperatures it was often difficult to see the ammonium plume due to the attached steam plume that formed when the moisture in the flue gas condensed.

- Although reducing the NH_3 trim control set points to 8 and 6 ppm reduced the plume problem, the average NO_x removal achieved during load-following operation was reduced to nominally 20 percent. Increasing the lower trim control set point to 7 ppm increased the average NO_x removal to nominally 24 percent, without a significant increase in average stack NH_3 emissions.

Long-Term Integrated Tests

- Long-term load-following operation of the integrated system with the NH_3 trim control set points at 8 and 7 ppm, yielded average NO_x removals of nominally 40 percent. Compared to the long-term SNCR-only tests at the same trim settings, this represented a net NO_x removal increase of approximately 16 percent. Since the DSI system alone reduced NO_x emissions by nominally 10 percent, the integrated system resulted in a "synergistic benefit" to the SNCR NO_x removal of approximately 9 percent (net).

- Approximately four days after the long-term integrated test began, a heavy NH_3 odor developed at the Unit 4 flyash unloading silo. The appearance of the odor was attributed to operating the SNCR and DSI systems concurrently, as a significant amount of long-term SNCR-only testing had been completed during the current test phase, as well as during the post-retrofit SNCR tests (Smith, et al., 1994b), with only minor occurrences of NH_3 odor.

- The upper and lower NH_3 trim control set points were reduced in an effort to limit the NH_3 emissions at the FFDC inlet, and thus reduce the odor problem. With the set points at nominally 4.5 and 4 ppm, the average overall NO_x removal was reduced to approximately 29 percent, which corresponds an average SNCR NO_x removal of nominally 21 percent. At this low level of NO_x removal, it was not possible to discern a "synergistic benefit" of the integrated system. Additionally, the NH_3 odor problem was not substantially affected by the reduction in NH_3 trim control set points, even though ash NH_3 concentrations were reduced by nominally 50%. Handling the ash dry was successfully tested at Arapahoe. If water is not added, the NH_3 vapor is not released from the ash.

- The long-term integrated tests also showed that operating the SNCR and DSI systems concurrently, resulted in substantially reduced NO_2 emissions when compared to operating the DSI system alone. The average NO_2 emissions were reduced nominally 50 percent when the integrated system was run with the NH_3 trim control set points at 8 and 7 ppm. With the set points at nominally 4.5 and 4 ppm, the reduction was approximately 40 percent.

- The long-term testing showed that the integration of SNCR and DSI resulted in lower NH_3 slip than with SNCR only. With a control system tuned to limit NH_3 slip, NO_x reduction can be increased by increasing the urea injection rate.

- Solids analysis suggests that the NO_2 and NH_3 emissions are reduced by a direct reaction of NH_3 and NO_2 which results in slightly increased NO_x reduction and increased waste nitrate formation.

9.0 REFERENCES

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APPENDIX A

Detailed Data Summary for Parametric Tests

PSCC Arapahoe Unit 4 Sodium/Urea Injection Summary

Calcs based on: Bicarbonate (b) 0.274
Sesquicarb. (s) 0.297

				Sorbent Feed			Injector cal		Urea injection---------					ΔSO2 Reduction				ΔNOx Calcs-----------			Baghouse Temps				Economizer Exit, dry (1-12)· Base						
Test	Date & Time	Load	O2cr	Na	A (w)	B (e)	Flow	2Na	Urea	Total	Inj air	Conc	N/NO	Cmp	Calc		Util	Overall	SNCR	Na	Taho	Grid	Out	IDin	O2	SO2	NO	CO	NO2	CO2	N2O
		MWe	%wet	b/s	%	%	lb/min	S*	gpm	gpm	psi	wt%		%	%	ppmc	%	%	%	%	°F	°F	°F	°F	%dry	ppm	ppm	ppm	ppm	%	ppm
SODIUM BICARBONATE DUCT INJECTION																															
764	2/7/94 8:36	100	4.95	b	0	41	45.9	1.00	0.00	0.00	0.0	37	0.00	0	-3.5	-18	-3	4.0	0	4	252	245	224	235	5.60	458	264	30	5	13.39	
764	2/7/94 16:10	100	4.95	b	0	60	66.6	1.46	1.50	4.00	8.0	37	1.09	67	67.2	346	46	15.7	0	16	262	254	244	250	6.00	448	249	34	5	12.95	0.8
764	2/7/94 18:10	100	4.90	b	0	41	45.9	0.95	1.50	4.00	8.0	37	1.09	74	74.5	409	79	46.1	41	9	263	255	244	252	6.00	448	249	34	5	12.95	0.8
764	2/7/94 19:40	100	4.89	b	0	41	45.9	0.96	0.00	4.00	8.0	37	0.00	68	66.9	362	70	15.0	0	15	263	255	245	252	6.00	460	262	28	3	12.88	-0.3
765	2/8/94 8:00	100	4.92	b	0	0	0.0	0.00	0.00	0.00	0.0	37	0.00	0	-1.4	-7		1.5	0	1	251	243	230	235	6.00	455	264	52	5	12.95	1.9
765	2/8/94 9:50	100	4.48	b	41	0	48.3	1.07	0.00	0.00	0.0	37	0.00	67	71.4	367	67	21.4	0	21	251	243	230	238	6.10	443	267	56	4	13.02	3.4
765	2/8/94 12:20	100	4.43	b	41	0	48.3	0.98	0.00	0.00	0.0	37	0.00	66	63.4	355	65	17.1	0	17	250	242	230	237	5.70	485	259	62	3	13.21	-0.8
765	2/8/94 14:00	100	4.43	b	42	0	49.5	1.00	0.00	0.00	0.0	37	0.00	68	66.7	384	68	21.6	0	22	252	244	232	240	5.70	485	259	62	3	13.21	-0.8
765	2/8/94 16:10	100	4.43	b	52	0	61.2	1.32	0.00	0.00	0.0	37	0.00	86	86.2	452	65	20.9	0	21	253	244	231	240	5.50	460	246	220	4	13.46	0.0
765	2/8/94 17:50	100	4.42	b	52	0	61.2	1.46	0.00	0.00	0.0	34	0.00	87	87.0	412	59	17.1	0	17	247	239	229	237	5.50	460	246	220	4	13.46	0.0
766	2/9/94 8:00	95	5.04	b	0	0	0.0	0.00	0.00	0.00	0.0	34	0.00	0	-3.4	-16		4.0	0	4	242	235	219	230	5.80	420	250	36	5	13.22	1.1
766	2/9/94 9:50	95	5.06	b	35	0	41.3	0.96	0.00	0.00	0.0	34	0.00	37	37.7	189	38	7.8	0	8	251	243	228	238	5.80	420	250	36	5	13.22	1.1
766	2/9/94 10:50	95	5.09	b	35	0	41.3	1.04	0.00	0.00	0.0	34	0.00	60	60.4	284	58	5.2	0	5	255	242	232	244	5.80	420	250	36	5	13.22	1.1
766	2/9/94 11:50	95	5.03	b	35	0	41.3	1.08	0.00	0.00	0.0	34	0.00	74	73.8	336	68	8.4	0	8	260	252	239	248	5.80	420	250	36	5	13.22	1.1
766	2/9/94 12:55	95	5.00	b	33	0	38.9	1.04	0.00	0.00	0.0	34	0.00	82	81.8	384	79	9.5	0	10	262	255	244	252	5.85	370	255	72	5	13.09	1.4
766	2/9/94 13:50	95	4.99	b	32	0	37.7	1.06	0.00	0.00	0.0	34	0.00	92	90.6	384	85	3.4	0	3	263	258	247	256	5.85	370	255	72	5	13.09	1.4
766	2/9/94 16:15	95	4.99	b	30	0	35.4	1.04	1.33	2.00	4.4	34	0.92	72	71.0	288	68	37.5	33	7	267	260	252	260	5.85	370	255	72	5	13.09	1.4
766	2/9/94 17:35	95	4.80	b	30	0	35.4	1.05	1.33	2.00	4.4	34	0.92	73	72.5	291	69	38.0	33	8	265	258	261	258	5.85	370	255	72	5	13.09	1.4
766	2/9/1994 NITE	80	4.80	b	25	0	29.5	1.03	1.33	2.00	4.4	34	1.09	73	72.5	291	71	38.0	33	8	265	258	261	258	5.85	370	255	72	5	13.09	1.4
767	2/10/94 7:45	97	5.00	b	25	0	29.5	0.88	0.00	0.00	0.0	34	0.00	59	58.5	229	67	9.7	0	10	253	245	233	242	6.00	323	259	49	5	12.86	1.6
767	2/10/94 9:33	95	5.10	b	28	0	33.1	1.00	0.00	0.00	0.0	34	0.00	91	89.6	351	89	14.4	0	14	258	252	243	249	6.60	315	273	40	3	12.77	0.8
767	2/10/94 10:12	95	5.20	b	28	0	33.1	1.00	0.00	0.00	0.0	34	0.00	82	78.3	308	78	14.2	0	14	262	255	244	252	6.60	315	273	40	3	12.77	0.8
767	2/10/94 10:49	94	5.10	b	28	0	33.1	0.96	0.00	0.00	0.0	34	0.00	74	73.4	296	75	13.2	0	13	265	258	245	255	6.60	315	273	40	3	12.77	0.8
767	2/10/94 12:14	94	5.10	b	28	0	33.1	0.97	1.60	2.00	4.4	34	0.99	73	73.6	302	76	47.3	44	5	270	263	252	261	6.60	315	273	40	3	12.77	0.8
767	2/10/94 13:50	94	4.90	b	28	0	33.1	1.00	1.60	2.00	4.5	34	0.99		62.6	249	63	45.6	44	2	271	263	254	262	6.60	315	273	40	3	12.77	0.8
767	2/10/94 15:11	94	4.90	b	28	0	33.1	1.00	1.60	2.00	4.5	34	0.99		37.6	150	38	49.1	44	8					6.60	315	273	40	3	12.77	0.8
767	2/10/94 16:19	94	4.90	b	28	0	33.1	1.00	1.60	2.00	4.5	34	0.99		21.7	86	22	43.0	44	-3					6.60	315	273	40	3	12.77	0.8
767	2/10/94 17:05	94	5.05	b	28	0	33.1	0.93	1.60	2.00	4.5	34	0.99	35	35.0	149	37	42.6	44	-2	264	257	250	256	6.60	315	273	40	3	12.77	0.8
SODIUM SESQUICARBONATE DUCT INJECTION																															
769	2/14/94 8:30	98	3.90	s	0	0	0.0	0.00	0.00	0.00	0.00	34	0.00	0				-3.5	0		258	252	239	248	6.10	325	260	35	5	12.51	1.6
769	2/14/94 10:00	98	3.90	s	0	0	0.0	0.00	1.15	2.00	4.40	34	0.74	0				36.2	38		263	256	241	251	6.10	325	260	35	5	12.51	1.6
769	2/14/94 11:00	98	4.00	s	0	0	0.0	0.00	1.15	2.00	4.40	34	0.74	0				36.8	39		265	259	244	254	6.10	325	260	35	5	12.51	1.6
769	2/14/94 12:05	98	4.00	s	0	0	0.0	0.00	1.15	2.00	4.40	34	0.74	0				36.9	39		270	263	249	260	6.10	325	260	35	5	12.51	1.6
769	2/14/94 13:00	98	4.00	s	0	0	0.0	0.00	1.15	2.00	4.40	34	0.74	0				37.7	39		273	267	254	262	6.10	325	260	35	5	12.51	1.6
769	2/14/94 14:10	98	4.00	s	0	0	0.0	0.00	1.15	2.00	4.40	34	0.74	0				35.4	39		273	267	255	264	6.10	325	260	35	5	12.51	1.6
769	2/14/94 15:30	98	4.70	s	0	0	0.0	0.00	1.15	2.00	4.40	34	0.74	0				36.4	39		275	268	257	265	6.10	325	260	35	5	12.51	1.6
769	2/14/94 16:40	98	4.80	s	0	0	0.0	0.00	1.15	2.00	4.50	34	0.74	0				36.3	39		275	269	258	265	6.10	325	260	35	5	12.51	1.6
769	2/14/94 17:30	98	4.80	s	0	0	0.0	0.00	1.15	2.00	4.60	34	0.74	0				38.1	39		273	267	258	265	6.10	325	260	35	5	12.51	1.6

PSCC Arapahoe Unit 4 Sodium/Urea Injection Summary

		Economizer Exit, dry (1-12): w/Urea							Baghouse Inlet Gas Analysis, wet									Stack Gas Analysis, wet									WET CHEM NH3		
Test	Date & Time	O2	SO2	NO	CO	NO2	CO2	N2O	O2	SO2	NO	CO	NO2	CO2	H2O	N2O	NH3	O2	SO2	NO	CO	NO2	CO2	H2O	N2O	NH3	inlet	stk	Comments
		%dry	ppm	ppm	ppm	ppm	%	ppm	%	ppm	ppm	ppm	ppm	%	%	ppm	ppm	%	ppm	ppm	ppm	ppm	%	%	ppm	ppm	ppm	ppm	
SODIUM BICARBONATE DUCT INJECTION																													
764	2/7/94 8:36	5.60	456	264	30	5	13.39		4.30	427	239	26	-1	12.68	9.03			5.90	399	224	54	0	11.60	8.26					AMill OOS,
764	2/7/94 16:10	6.00	448	249	34	5	12.95	0.8	4.40	419	219	39	-2	12.40	9.30	2.4	2.3	5.90	125	163	33	27	11.63	8.56	1.6	2.4			Na System Auto
764	2/7/94 18:10	6.10	446	146	44	3	12.78	31.0	4.90	434	131	40	-2	12.15	8.98	40.8	7.2	6.20	102	104	38	15	11.20	8.19	30.4	3.7			
764	2/7/94 19:40	6.00	460	262	28	3	12.88	-0.3	5.00	425	234	24	-2	11.91	8.91	1.6	0.8	6.30	129	165	23	29	11.32	8.29	1.2	2.3			
765	2/8/94 8:00	6.00	455	264	52	5	12.95	1.9	4.80	436	235	33	-1	12.24	8.51	2.0	0.4	6.30	401	231	27	0	11.34	7.72	1.7	0.1			AMill OOS,
765	2/8/94 9:50	6.10	443	267	56	4	13.02	3.4	4.00	432	228	114	-2	12.67	8.78	9.2	1.3	5.70	111	158	51	36	11.79	8.03	2.8	2.5			Na System on @
765	2/8/94 12:20	5.70	485	259	62	3	13.21	-0.8	4.10	468	230	69	-1	12.84	8.74	2.3	0.1	5.90	153	158	42	33	11.58	7.81	3.0	2.1			8:51
765	2/8/94 14:00	5.70	485	259	62	3	13.21	-0.8	4.20	464	229	58	-1	12.78	8.77	1.0	0.4	5.50	134	152	99	34	11.94	8.09	3.8	2.0			
765	2/8/94 16:10	5.50	460	246	220	4	13.46	0.0	3.80	447	227	220	0	13.08	8.94	5.3	0.4	5.40	56	143	183	34	11.97	8.14	2.4	2.1			
765	2/8/94 17:50	5.50	460	246	220	4	13.46	0.0	3.60	408	229	424	2	13.02	9.00	-1.5	0.9	5.60	47	143	126	40	11.88	8.11	2.1	1.6			Urea ship/dilution
766	2/9/94 8:00	5.80	420	250	36	5	13.22	1.1	4.40	399	230	32	-1	12.72	8.61	2.2	1.0	5.80	377	218	37	0	11.87	8.00	1.5	1.0			AMill OOS,
766	2/9/94 9:50	5.80	420	250	36	5	13.22	1.1	4.50	408	229	47	-1	12.82	8.77	2.7	2.2	5.90	233	198	29	10	11.76	7.97	1.7	3.3			
766	2/9/94 10:50	5.80	420	250	36	5	13.22	1.1	4.90	374	243	25	-1	12.32	8.57	2.2	2.0	6.20	136	181	25	28	11.59	7.94	1.8	2.5			
766	2/9/94 11:50	5.80	420	250	36	5	13.22	1.1	4.60	368	241	28	-1	12.58	8.82	2.4	1.9	5.80	89	175	27	32	11.87	8.17	1.9	3.4			
766	2/9/94 12:55	5.85	370	255	72	5	13.09	1.4	5.00	350	245	25	-1	12.54	8.80	2.2	2.4	5.95	60	172	24	35	11.72	8.11	1.6	2.9			
766	2/9/94 13:50	5.85	370	255	72	5	13.09	1.4	4.70	340	242	27	-1	12.48	8.81	1.8	2.0	6.10	29	180	24	39	11.60	8.11	1.5	2.7			
766	2/9/94 16:15	6.10	318	169	50	3	12.97	27.3	4.70	324	147	50	-2	12.41	9.06	38.7	13.1	6.00	86	134	49	8	11.73	8.43	25.9	3.2			
766	2/9/94 17:35	6.10	318	169	50	3	12.97	27.3	4.50	324	147	52	-1	12.71	9.27	37.6	20.6	5.80	82	138	44	5	11.74	8.49	27.7	3.8	33.0		
766	2/9/1994 NITE	6.10	318	169	50	3	12.97	27.3	4.50	324	147	52	-1	12.71	9.27	37.6	20.6	5.80	82	138	44	5	11.74	8.49	27.7	3.8			
767	2/10/94 7:45	6.00	323	259	49	5	12.86	1.6	4.00	329	234	77	-1	12.99	9.11	3.8	2.0	5.80	122	193	50	21	11.90	8.24	1.7	2.5			AMill OOS,
767	2/10/94 9:33	6.60	315	273	40	3	12.77	0.8	4.70	314	241	36	0	12.59	8.91	3.0	2.4	6.10	30	185	31	31	11.58	8.10	2.6	2.8			
767	2/10/94 10:12	6.60	315	273	40	3	12.77	0.8	4.80	313	234	49	-2	12.67	8.93	4.0	2.8	6.20	62	194	35	21	11.59	8.10	1.9	2.6			
767	2/10/94 10:49	6.60	315	273	40	3	12.77	0.8	4.70	323	230	88	-1	12.63	9.05	1.3	2.8	5.90	80	206	43	16	11.84	8.35	2.3	2.6			
767	2/10/94 12:14	6.30	321	155	70	2	12.97	29.9	4.80	325	134	65	-2	12.45	9.17	42.9	18.3	6.10	79	132	61	1	11.47	8.43	31.5	5.4	47.8		
767	2/10/94 13:50	6.30	321	155	70	2	12.97	29.9	4.40	325	146	63	-1	12.25	9.01	47.8	34.2	6.60	104	132	75	0	11.51	8.40	31.0	9.0	53.2		
767	2/10/94 15:11	6.30	321	155	70	2	12.97	29.9	4.40	325	146	63	-1	12.25	9.01	47.8	34.2	5.90	184	130	83	0	11.57	8.36	33.7	16.6		14.7	
767	2/10/94 16:19	6.30	321	155	70	2	12.97	29.9	4.40	325	146	63	-1	12.25	9.01	47.8	34.2	6.00	230	142	53	3	11.47	8.29	35.4	26.4			
767	2/10/94 17:05	6.20	339	157	56	2	12.95	29.7	5.00	334	137	74	-3	12.04	8.67	48.1	35.0	6.60	195	137	49	2	11.11	8.08	34.5	26.3		35.9	
SODIUM SESQUICARBONATE DUCT INJECTION																													
769	2/14/94 8:30	6.10	325	260	35	5	12.51	1.6	5.10	318	248	34	-1	12.42	8.73	2.3	1.3	6.10	301	243	30	-1	11.83	8.17	1.9	0.6			A mill OOS
769	2/14/94 10:00	6.05	350	162	54	3	13.02	1.5	5.05	323	152	49	-2	12.31	8.86	37.9	4.1	6.00	316	152	49	-2	11.57	8.24	26.9	2.3	22.1		Urea @ 0930
769	2/14/94 11:00	6.00	358	160	57	1	13.13	26.2	4.90	352	150	52	-2	12.46	8.89	37.0	13.4	5.90	333	151	49	-1	11.70	8.33	27.9	2.9	24.9		
769	2/14/94 12:05	6.00	358	160	57	1	13.13	26.2	4.90	352	150	52	-2	12.46	8.89	37.0	13.4	5.95	352	150	54	-1	11.72	8.26	26.9	6.0	23.4	8.3	Stack only
769	2/14/94 13:00	6.00	358	160	57	1	13.13	26.2	4.90	352	150	52	-2	12.46	8.89	37.0	13.4	5.82	367	150	50	-1	11.77	8.27	26.5	5.5		11.3	
769	2/14/94 14:10	6.00	358	160	57	1	13.13	26.2	4.90	352	150	52	-2	12.46	8.89	37.0	13.4	6.05	362	153	47	-1	11.60	8.17	24.9	10.3		14.3	
769	2/14/94 15:30	6.00	358	160	57	1	13.13	26.2	4.90	352	150	52	-2	12.46	8.89	37.0	13.4	5.90	372	152	49	-1	11.89	8.32	25.0	12.2		17.9	
769	2/14/94 16:40	6.00	358	160	57	1	13.13	26.2	4.90	352	150	52	-2	12.46	8.89	37.0	13.4	5.85	390	152	42	0	11.67	8.37	25.0	14.2		17.6	
769	2/14/94 17:30	6.00	358	160	57	1	13.13	26.2	4.90	352	150	52	-2	12.46	8.89	37.0	13.4	5.70	390	150	46	-1	11.99	8.46	24.2	13.9		16.0	

PSCC Arapahoe Unit 4 Sodium/Urea Injection Summary

Calcs based on:

Bicarbonate (b) 0.274

Sesquicarb. (s) 0.297

				Sorbent Feed			Injector cal		Urea Injection---------					ΔSO2 Reduction				ΔNOx Calcs-----------			Baghouse Temps				Economizer Exit, dry (1-12): Base						
Test	Date & Time	Load	O2cr	Na	A (w)	B (e)	Flow	2Na	Urea	Total	Inj air	Conc	N/NO	Cmp	Calc		Util	Overall	SNCR	Na	Taho	Grid	Out	IDin	O2	SO2	NO	CO	NO2	CO2	N2O
		MWe	%wet	b/s	%	%	lb/min	S*	gpm	gpm	psi	wt%		%	%	ppmc	%	%	%	%	°F	°F	°F	°F	%dry	ppm	ppm	ppm	ppm	%	ppm
770	2/15/94 7:55	99	4.70	s	0	0	0.0	0.00	0.00	0.00	0.0	34	0.00	0				4.5	0		254	247	229	241	5.55	445	244	49	2	13.66	0.0
770	2/15/94 10:10	99	4.70	s	0	0	0.0	0.00	0.72	2.00	4.5	34	0.51	0				29.0	28		265	259	245	252	5.55	445	244	49	2	13.66	0.0
770	2/15/94 11:30	99	4.70	s	0	0	0.0	0.00	0.72	2.00	4.5	34	0.51	0				28.1	28		269	263	249	257	5.55	445	244	49	2	13.66	0.0
770	2/15/94 12:15	99	4.70	s	0	0	0.0	0.00	0.72	2.00	4.5	34	0.51	0				28.5	28		272	266	252	262	5.55	445	244	49	2	13.66	0.0
770	2/15/94 13:00	100	4.70	s	0	0	0.0	0.00	0.72	2.00	4.5	34	0.50	0				28.4	28		275	264	256	264	5.55	445	244	49	2	13.66	0.0
770	2/15/94 14:00	99	4.70	s	0	0	0.0	0.00	0.72	2.00	4.5	34	0.51	0				28.9	28		278	271	259	267	5.55	445	244	49	2	13.66	0.0
770	2/15/94 15:00	99	4.70	s	0	0	0.0	0.00	0.72	2.00	4.5	34	0.51	0				28.1	28		279	273	262	268	5.55	445	244	49	2	13.66	0.0
770	2/15/94 16:30	99	4.80	s	0	0	0.0	0.00	0.72	2.00	4.6	34	0.51	0				27.9	28		278	271	262	268	5.55	445	244	49	2	13.66	0.0
771	2/16/94 7:30	101	4.70	s	0	0	0.0	0.00	0.00	0.00	0.0	34	0.00	0				1.5	0		263	257	241	250	5.20	478	238	96	2	14.06	0.8
771	2/16/94 8:30	101	4.90	s	0	0	0.0	0.00	0.85	2.00	4.5	34	0.62	0				27.1	27		266	260	246	255	5.20	478	238	96	2	14.06	0.8
771	2/16/94 9:35	101	4.50	s	0	0	0.0	0.00	0.85	2.00	4.4	34	0.62	0				27.4	27		272	266	251	260	5.20	478	238	96	2	14.06	0.8
771	2/16/94 10:45	101	4.70	s	0	0	0.0	0.00	0.85	2.00	4.4	34	0.62	0				26.3	27		274	268	254	263	5.20	478	238	96	2	14.06	0.8
771	2/16/94 11:50	101	4.60	s	0	0	0.0	0.00	0.85	2.00	4.4	34	0.62	0				25.2	27		276	270	257	265	5.20	478	238	96	2	14.06	0.8
771	2/16/94 12:50	101	4.70	s	0	0	0.0	0.00	0.85	2.00	4.3	34	0.62	0				25.2	27		279	272	259	268	5.20	478	238	96	2	14.06	0.8
772	2/16/94 14:25	100	4.70	s	0	0	0.0		1.03	2.00	4.4	34	0.76	0				27.6	27		281	276	264	272	5.20	478	238	96	2	14.06	0.8
773	2/16/94 15:07	101	4.60	s	0	0	0.0		0.68	2.00	4.4	34	0.49	0				21.1	21		282	275	264	272	5.20	478	238	96	2	14.06	0.8
773	2/16/94 16:15	101	4.60	s	0	0	0.0		0.00			34	0.00	0				-1.7							5.20	478	238	96	2	14.06	0.8
774	2/21/94 8:30	98	5.00	s	0	0	0.0	0.00	0.00	0.00	0.0	34	0.00	0	-0.1	0		2.5	0	3	256	250	233	243	5.65	338	265	158	2	13.61	-3.2
774	2/21/94 11:00	100	5.00	s	70	0	66.5	2.09	0.00	0.00	0.0	34	0.00	71	72.4	282	35	12.2	1	12	259	250	235	246	5.65	338	265	158	2	13.61	-3.2
774	2/21/94 11:40	100	5.00	s	70	0	66.5	2.13	0.00	0.00	0.0	34	0.00	73	72.8	279	34	12.7	0	13	260	250	237	247	5.65	338	265	158	2	13.61	-3.2
774	2/21/94 13:30	99	5.00	s	70	0	66.5	2.11	0.97	2.00	4.5	34	0.63	67	69.1	270	33	34.8	31	6	264	254	243	251	5.65	338	265	158	2	13.61	-3.2
774	2/21/94 14:30	99	5.00	s	70	0	66.5	1.98	0.97	2.00	4.5	34	0.63	70	71.2	297	36	34.6	30	6	263	254	243	252	5.65	338	265	158	2	13.61	-3.2
774	2/21/94 16:00	100	5.10	s	75	0	71.4	1.91	0.97	2.00	4.6	34	0.62	70	70.7	324	37	39.2	33	9	263	254	243	252	5.65	338	265	158	2	13.61	-3.2
774	2/21/94 17:00	100	5.00	s	78	0	74.4	1.93	0.97	2.00	4.6	34	0.62	71	71.2	336	37	41.0	33	13	263	254	243	252	5.65	338	265	158	2	13.61	-3.2
774	2/21/94 17:40	100	5.00	s	78	0	74.4	1.92	0.00	0.00	0.0	34	0.00	72	69.0	328	36	16.6	7	10	263	252	242	251	5.65	338	265	158	2	13.61	-3.2
775	2/22/94 7:45	106	4.30	s	0	0	0.0	0.00	0.00	0.00	0.0	34	0.00	3	-0.1	0		3.1	0	3	257	251	234	245	5.55	360	258	149	4	13.31	0.4
775	2/22/94 8:50	105	4.40	s	79	0	75.4	2.10	0.00	0.00	0.0	34	0.00	67	67.9	285	32	13.1	2	11	258	248	234	245	5.55	360	258	149	4	13.31	0.4
775	2/22/94 10:40	105	4.20	s	82	0	78.3	1.98	0.80	2.00	4.6	34	0.51	64	65.1	301	33	35.4	28	9	261	252	239	248	5.55	360	258	149	4	13.31	0.4
775	2/22/94 11:30	105	4.30	s	91	0	87.2	1.98	0.80	2.00	4.6	34	0.51		67.9	350	34	33.1	23	12	261	251	240		5.55	360	258	149	4	13.31	0.4
775	2/22/94 12:40	104	4.20	s	91	0	87.2	1.95	0.80	2.00	4.6	34	0.51	69	68.8	363	35	34.8	24	14	261	252	240	250	5.55	360	258	149	4	13.31	0.4
775	2/22/94 13:30	103	4.20	s	91	0	87.2	1.88	0.80	2.00	4.6	34	0.51	69	69.7	386	37	39.1	30	12	263	253	241	251	5.55	360	258	149	4	13.31	0.4
775	2/22/94 14:30	104	4.20	s	91	0	87.2	1.86	0.80	2.00	4.5	34	0.51	69	69.3	385	37	36.7	27	12	263	253	242	252	5.55	360	258	149	4	13.31	0.4
775	2/22/94 15:30	106	4.10	s	91	0	87.2	1.74	0.80	2.00	4.5	34	0.50	70	70.1	406	40	37.7	25	16	264	254	243	253	5.55	360	258	149	4	13.31	0.4
775	2/22/94 16:20	106	4.10	s	91	0	87.2	1.81	0.80	2.00	4.5	34	0.50	71	72.4	404	40	38.9	27	16	264	254	243	254	5.55	360	258	149	4	13.31	0.4
775	2/22/94 17:20	106	4.30	s	91	0	87.2	1.89	0.00	0.00	0.0	34	0.00	72	72.5	389	38	18.3	0	18	263	253	243	253	5.55	360	258	149	4	13.31	0.4
776	2/24/94 10:10	98	4.30	s	74	0	70.4	2.20	0.00	0.00	0.0	34	0.00	67	66.7	268	30	9.6	0	10	258	250	238	246	5.70	343	245	66	1	12.95	2.8
776	2/24/94 12:10	97	4.10	s	74	0	70.4	2.26	1.06	2.00	4.4	34	0.76	60	61.3	242	27	42.0	36	9	259	250	242	248	5.70	343	245	66	1	12.95	2.8
776	2/24/94 13:00	96	4.50	s	72	0	68.5	2.22	1.06	2.00	4.3	34	0.76	65	66.8	263	30	36.3	28	11	260	251	243	249	5.70	343	245	66	1	12.95	2.8
776	2/24/94 14:00																														

PSCC Arapahoe Unit 4 Sodium/Urea Injection Summary

		Economizer Exit, dry (1-12): w/Urea							Baghouse Inlet Gas Analysis, wet									Stack Gas Analysis, wet									WET CHEM NH3		
Test	Date & Time	O2	SO2	NO	CO	NO2	CO2	N2O	O2	SO2	NO	CO	NO2	CO2	H2O	N2O	NH3	O2	SO2	NO	CO	NO2	CO2	H2O	N2O	NH3	inlet	stk	Comments
		%dry	ppm	ppm	ppm	ppm	%	ppm	%	ppm	ppm	ppm	ppm	%	%	ppm	ppm	%	ppm	ppm	ppm	ppm	%	%	ppm	ppm	ppm	ppm	
770	2/15/94 7:55	5.55	445	244	49	2	13.66	0.0	4.05	434	218	63	-1	13.05	8.99	0.6	1.3	5.25	396	213	41	0	12.30	8.35	1.5	1.9			A mill OOS
770	2/15/94 10:10	5.45	445	178	99	2	13.84	16.3	4.00	428	158	85	-1	13.19	9.24	20.6	2.4	5.40	393	158	84	-2	12.17	8.48	18.2	1.9	5.7		0955 Urea on
770	2/15/94 11:30	5.45	445	178	99	2	13.84	16.3	4.00	428	158	85	-1	13.19	9.24	20.6	2.4	5.15	413	161	70	-1	12.44	8.74	18.7	1.8	6.4		Stack only
770	2/15/94 12:15	5.45	445	178	99	2	13.84	16.3	4.00	428	158	85	-1	13.19	9.24	20.6	2.4	5.15	418	160	65	-1	12.47	8.79	18.5	2.8		4.4	
770	2/15/94 13:00	5.45	445	178	99	2	13.84	16.3	4.00	428	158	85	-1	13.19	9.24	20.6	2.4	5.25	409	160	50	-1	12.28	8.75	18.4	3.3		4.0	
770	2/15/94 14:00	5.45	445	178	99	2	13.84	16.3	4.00	428	158	85	-1	13.19	9.24	20.6	2.4	5.25	418	158	39	-1	12.42	8.79	18.0	4.1		4.4	
770	2/15/94 15:00	5.45	445	178	99	2	13.84	16.3	4.00	428	158	85	-1	13.19	9.24	20.6	2.4	5.18	418	160	49	-1	12.50	8.99	17.4	3.5		4.4	
770	2/15/94 16:30	5.10	476	160	78	2	14.16	18.8	3.90	455	162	51	-1	13.33	9.59	20.2	5.7	5.10	427	162	64	-1	12.42	8.83	16.4	4.0	8.7		Econ & inlet
771	2/16/94 7:30	5.20	478	238	96	2	14.06	0.8	3.75	460	222	75	0	13.46	9.27	3.8	1.0	5.05	424	212	79	0	12.54	8.60	1.6	1.2			A mill OOS
771	2/16/94 8:30	5.18	480	174	88	2	14.20	19.0	3.90	450	164	62	-2	13.22	9.34	21.9	1.1	5.02	425	157	74	0	12.49	8.78	20.2	1.2	8.9		Urea on 0810
771	2/16/94 9:35	5.18	480	174	88	2	14.20	19.0	3.90	450	164	62	-2	13.22	9.34	21.9	1.1	5.10	400	155	46	0	12.44	8.79	21.6	2.3	7.4	5.2	Stack only
771	2/16/94 10:45	5.18	480	174	88	2	14.20	19.0	3.90	450	164	62	-2	13.22	9.34	21.9	1.1	5.15	378	158	49	-1	12.37	8.82	21.1	3.1		4.3	
771	2/16/94 11:50	5.18	480	174	88	2	14.20	19.0	3.90	450	164	62	-2	13.22	9.34	21.9	1.1	5.12	353	160	54	-1	12.36	8.87	22.0	3.7		5.0	
771	2/16/94 12:50	5.15	393	175	70	1	13.96	20.9	4.10	370	166	77	-1	13.12	9.43	26.4	8.3	5.10	357	160	79	-1	12.49	8.91	20.2	4.0	13.7	4.3	
772	2/16/94 14:25	5.25	376	173	91	1	13.98	22.9										5.10	335	155	61	0	12.37	8.78	25.3	4.9			0.75 n/no
773	2/16/94 15:07	5.12	385	190	100	1	14.05	17.8										5.08	332	170	65	-1	12.36	8.82	19.6	4.4			0.49 n/no
773	2/16/94 16:15																	5.10	323	218	66	-1	12.41	8.79	2.5	3.6			no urea
774	2/21/94 8:30	5.65	338	265	158	2	13.61	-3.2	4.10	327	248	106	-1	13.03	9.12	-0.4	0.5	5.60	298	232	57	-1	11.86	8.36	0.6	1.2			A mill OOS
774	2/21/94 11:00	5.70	332	262	97	2	13.55	-2.4	4.10	325	247	94	-2	12.94	9.08	3.5	0.5	5.52	82	208	128	1	11.95	8.50	2.3	2.9			Na start 0910
774	2/21/94 11:40	5.80	330	263	86	2	13.29	1.4	4.15	318	242	219	0	12.98	9.14	6.4	0.7	5.60	79	205	93	2	11.88	8.45	1.8	3.1			
774	2/21/94 13:30	5.75	328	182	122	1	13.43	21.2	4.30	320	170	161	-1	12.82	9.31	23.1	2.2	5.60	91	151	77	3	11.88	8.71	21.7	2.7	16.6		Urea 1240,BH 1250
774	2/21/94 14:30	5.75	332	183	64	1	13.26	21.3	4.20	344	168	61	-3	12.79	9.29	24.6	1.5	5.70	90	150	99	3	11.82	8.67	21.4	3.0	12.2		
774	2/21/94 16:00	5.55	389	179	107	1	13.54	20.1	4.18	378	165	143	-1	12.99	9.32	27.7	2.0	5.48	102	142	94	3	11.98	8.70	20.0	2.5		2.8	
774	2/21/94 17:00	5.72	394	178	83	2	13.30	20.7	4.00	394	167	127	-1	13.07	9.41	25.7	1.7	5.52	103	137	100	3	11.94	8.67	20.9	3.2		2.3	
774	2/21/94 17:40	5.45	420	249	117	2	13.80	-2.0	3.90	400	236	66	-1	13.08	9.26	0.2	1.4	5.50	112	189	61	9	12.04	8.55	2.1	2.6			Urea off 1740
775	2/22/94 7:45	5.55	360	258	149	4	13.31	0.4	4.45	343	240	146	-3	12.50	8.74	1.5	0.3	5.40	323	228	92	0	11.99	8.35	2.8	0.9			A mill OOS
775	2/22/94 8:50	5.42	364	256	91	2	13.44	0.3	4.30	346	241	33	-1	12.67	8.79	2.7	0.9	5.32	104	205	56	0	12.09	8.39	2.8	2.0			Na 0815
775	2/22/94 10:40	5.68	399	183	55	1	13.29	20.5	4.45	377	172	106	-2	12.53	8.98	20.8	1.7	5.65	122	141	117	8	11.73	8.43	22.7	2.1	2.6		Urea 0915
775	2/22/94 11:30	5.35	453	200	333	1	13.56	17.5	4.00	431	174	174	-1	12.98	9.28	25.2	1.1	5.35	127	148	135	9	11.99	8.63	19.0	4.0	3.0		
775	2/22/94 12:40	5.90	444	192	56	1	13.26	19.6	4.40	431	180	51	-1	12.68	9.05	23.2	1.3	5.68	124	140	63	10	11.78	8.48	19.5	3.2		2.2	
775	2/22/94 13:30	5.40	472	183	175	1	13.54	17.8	4.40	452	171	77	-1	12.80	9.19	23.0	1.8	5.25	130	136	135	8	12.07	8.73	18.3	3.5		2.1	
775	2/22/94 14:30	5.45	483	189	152	1	13.42	19.9	4.12	461	178	142	-2	12.85	9.19	23.4	1.8	5.35	131	140	188	8	11.97	8.66	21.2	3.0		2.0	
775	2/22/94 15:30	5.30	500	197	326	1	13.68	16.2	4.15	480	168	167	-2	12.75	9.20	22.9	1.9	5.35	133	138	162	8	11.93	8.62	17.3	3.5		2.0	
775	2/22/94 16:20	5.35	468	192	233	1	13.38	20.1	4.25	460	172	175	-2	12.77	9.16	22.6	1.5	5.40	118	135	171	8	11.93	8.63	18.5	2.7		2.2	
775	2/22/94 17:20	5.30	467	262	226	2	13.56	-0.5	3.85	453	237	357	-1	13.04	9.18	0.9	0.9	5.25	114	182	300	11	12.12	8.57	3.7	1.8			Urea off 1643
776	2/24/94 10:10	5.70	343	245	66	1	12.95	2.6	4.35	329	224	57	-1	12.34	8.95	2.9	3.5	5.60	101	190	61	8	11.64	8.43	4.7	3.9			A OOS, sorb 70% op
776	2/24/94 12:10	5.40	338	159	141	1	13.06	27.5	4.00	329	132	122	-2	12.42	9.37	35.6	3.1	5.35	117	129	144	0	11.47	8.70	28.2	4.3			urea 1127,BH clean
776	2/24/94 13:00	6.00	317	172	79	0	12.18	28.6	4.55	318	140	61	-1	12.10	9.18	39.9	4.3	5.75	98	138	69	0	11.26	8.51	27.9	4.1			Boiler upset
776	2/24/94 14:00																												1500 abort test

PSCC Arapahoe Unit 4 Sodium/Urea Injection Summary

Calcs based on: Bicarbonate (b) 0.274
Sesquicarb. (s) 0.297

				Sorbent Feed			Injector cal		Urea injection--------					ΔSO2 Reduction				ΔNOx Calcs----------			Baghouse Temps				Economizer Exit, dry (1-12): Base						
Test	Date & Time	Load	O2cr	Na	A (w)	B (e)	Flow	2Na	Urea	Total	Inj air	Conc	N/NO	Cmp	Calc		Util	Overall	SNCR	Na	Taho	Grid	Out	IDin	O2	SO2	NO	CO	NO2	CO2	N2O
		MWe	%wet	b/s	%	%	lb/min	S*	gpm	gpm	psi	wt%		%	%	ppmc	%	%	%	%	°F	°F	°F	°F	%dry	ppm	ppm	ppm	ppm	%	ppm
777	2/25/94 5:00	68.7		s	55	0	51.6	2.28				34			70.4	276	31														
777	2/25/94 8:40	90	4.90	s	64	0	60.5	2.08	0.00	0.00	0.0	34	0.00	60	59.0	233	28	4.5	0	4	242	234	218	229	6.50	317	245	42	4	12.42	3.8
777		90		s	64	0	60.5		0.85	2.00	4.5	34				0															
777																															
778	3/28/94 8:50	100	4.30	s	0	0	0.0	0.00	0.00			34.3	0.00	0	-0.1	0		3.0	0.0	3	267	262	241	254	4.75	339	189	124	3	13.15	4.1
778	3/28/94 9:50	100	4.50	s	0	0	0.0	0.00	0.00			34.3	0.00	0	-3.5	-13		-4.8	0.0	-5	269	265	244	257	4.95	312	185	61	2	12.35	1.4
778	3/28/94 11:50	99	4.40	s	63	0	59.6	1.95	0.00			34.3	0.00	69	66.8	253	34.3	6.9	4.8	3	276	267	255	265	4.95	312	185	61	2	12.35	1.4
778	3/28/94 14:10	100	4.40	s	63	0	59.6	1.94	0.75	6.0	8.2	34.3	0.73	66	65.9	248	34.0	27.8	27.0	3	281	272	261	269	4.95	312	185	61	2	12.35	1.4
778	3/28/94 15:10	100	4.50	s	63	0	59.6	1.97	0.75	6.0	8.2	34.3	0.73	66	67.5	251	34.3	28.5	22.6	8	281	272	262	270	4.95	312	185	61	2	12.35	1.4
778	3/28/94 16:15	100	4.50	s	63	0	59.6	1.96	0.75	6.0	8.1	34.3	0.73	66	66.8	249	34.0	28.5	25.9	4	282	273	262	271	4.95	312	185	61	2	12.35	1.4
778	3/28/94 8:50	100	4.30	s	0	0	0.0	0.00	0.00			34.3	0.00	0	-0.1	0		2.7	0.0	3	267	262	241	254	4.75	372	215	142	3	13.49	4.1
778	3/28/94 9:50	100	4.50	s	0	0	0.0	0.00	0.00			34.3	0.00	0	-3.5	-14		-4.9	0.0	-5	269	265	244	257	4.95	343	210	70	2	12.67	1.4
778	3/28/94 11:50	99	4.40	s	63	0	52.0	1.55	0.00			34.3	0.00	69	66.8	278	43.2	6.9	4.8	3	276	267	255	265	4.95	343	210	70	2	12.67	1.4
778	3/28/94 14:10	100	4.40	s	63	0	52.0	1.54	0.75	6.0	8.2	34.3	0.64	66	65.9	273	42.8	28.5	27.0	3	281	272	261	269	4.95	343	210	70	2	12.67	1.4
778	3/28/94 15:10	100	4.50	s	63	0	52.0	1.56	0.75	6.0	8.2	34.3	0.64	66	67.5	276	43.2	29.1	22.6	9	281	272	262	270	4.95	343	210	70	2	12.67	1.4
778	3/28/94 16:15	100	4.50	s	63	0	52.0	1.56	0.75	6.0	8.1	34.3	0.64	66	66.8	273	42.8	29.1	25.9	4	282	273	262	271	4.95	343	210	70	2	12.67	1.4
779	3/29/94 7:40	111	4.20	s	80	0	78.4	2.01	0.00			34.3	0.00	70	69.9	294	34.8	9.1	0.0	9	263	254	239	251	4.95	360	230	49	4	13.77	-1.1
779	3/29/94 8:00	111	4.20	s	80	0	78.4	2.04	0.00			34.3	0.00	72	71.7	296	35.0	12.4	0.0	12	264	256	241	252	5.00	370	240	39	2	14.05	-1.0
779	3/29/94 11:40	111	4.10	s	0	0	0.0	0.00	1.44	6.0	8.2	34.3	0.97	2				40.0	44.1		274	267	254	263	5.00	370	240	39	2	14.05	-1.0
779	3/29/94 12:50	111	4.20	s	0	0	0.0	0.00	1.44	6.0	8.1	34.3	0.97	1				100.0	44.1		274	268	255	264	5.00	370	240	39	2	14.05	-1.0
780	3/29/94 14:30	111	4.10	s	0	0	0.0	0.00	2.25	6.0	8.1	34.3	1.51	0				45.3	48.7		274	268	254	264	5.00	370	240	39	2	14.05	-1.0
780	3/29/94 15:15	111	4.20	s	0	0	0.0		2.25	6.0	8.1	34.3	1.51	0							275	269	255	266	5.00	370	240	39	2	14.05	-1.0
780	3/29/94 17:40	111	4.30	s	0	0	0.0		0.00	0.0	0.0	34.3	0.00	2							272	264	252	262	4.85	380	236	47	2	14.44	-0.5
781	3/30/94 10:20	97	4.40	s	74	0	70.4	2.12	0.00			34.3	0.00	68	68.4	288	32.3	7.3	0.0	7	267	258	244	255	5.05	268	208	49	2	13.98	-1.2
781	3/30/94 13:00	96	4.40	s	70	0	66.5	2.07	1.14	6.0	8.2	34.3	1.02	67	65.1	267	31.4	40.5	36.7	6	278	269	260	266	5.05	268	208	49	2	13.98	-1.2
781	3/30/94 14:00	96	4.50	s	70	0	66.5	2.13	1.14	6.0	8.1	34.3	1.02	69	70.6	282	33.2	39.9	35.5	7	279	271	261	269	5.05	268	208	49	2	13.98	-1.2
781	3/30/94 15:00	96	4.50	s	67	0	63.5	2.03	1.14	6.0	8.1	34.3	1.02	68	69.2	277	34.1	40.6	33.6	10	281	274	263	272	5.05	268	208	49	2	13.98	-1.2
781	3/30/94 16:20	96	4.50	s	67	0	63.5	2.01	1.14	6.0	8.1	34.3	1.02	66	69.1	280	34.5	42.1	37.1	8	281	274	264	272	5.05	268	208	49	2	13.98	-1.2
781	3/30/94 17:00	96	4.50	s	0	0	0.0	0.00	1.14	6.0	8.2	34.3	1.02	23	17.8	72		38.8	38.0	1	282	277	265	274	5.05	268	208	49	2	13.98	-1.2
781	3/30/94 17:45	96	4.50	s	0	0	0.0	0.00	1.14	6.0	8.1	34.3	1.02	16	11.4	45		39.4	36.8	3	283	277	266	274	5.05	268	208	49	2	13.98	-1.2
781	3/30/94 18:25	96	4.50	s	0	0	0.0		0.00	0.0	0.0	34.3	0.00	7				3.0	0.0	3	278	274	264	272	5.10	347	218	52	2	13.80	1.6
782	3/31/94 7:30	100	4.40	s	0	0	0.0	0.00	0.00	0.0	0.0	34.3	0.00	0				1.8	0.0		267	261	244	254	5.05	343	232	49	3	13.84	-0.9
782	3/31/94 9:10	102	4.40	s	0	0	0.0	0.00	1.31	6.0	8.1	34.3	0.99	1				38.9	39.6		277	272	254	265	5.05	343	232	49	3	13.84	-0.9
782	3/31/94 10:10	101	4.40	s	0	0	0.0	0.00	1.31	6.0	8.1	34.3	1.00	1				37.9	36.2		281	276	258	270	5.05	343	232	49	3	13.84	-0.9
782	3/31/94 11:10	101	4.40	s	0	0	0.0	0.00	1.31	6.0	8.1	34.3	1.00	1				38.1	36.9		284	279	262	273	5.05	343	232	49	3	13.84	-0.9
782	3/31/94 12:25	101	4.40	s	0	0	0.0	0.00	1.31	6.0	8.2	34.3	1.00	1				37.1	36.4		287	282	267	276	5.05	343	232	49	3	13.84	-0.9
782	3/31/94 13:50	101	4.10	s	0	0	0.0	0.00	1.31	6.0	8.1	34.3	1.00	1				36.0	35.0		289	284	272	279	5.05	343	232	49	3	13.84	-0.9
782	3/31/94 15:50	101	4.30	s	0	0	0.0	0.00	1.31	6.0	8.1	34.3	1.00	1				36.9	35.4		290	286	274	281	5.05	343	232	49	3	13.84	-0.9
782	3/31/94 16:20	101	4.50	s	0	0	0.0	0.00	0.00	0.0	0.0	34.3	0.00	0				-3.2	-4.0		287	284	274		5.05	343	232	49	3	13.84	-0.9

PSCC Arapahoe Unit 4 Sodium/Urea Injection Summary

		Economizer Exit, dry (1-12): w/Urea							Baghouse Inlet Gas Analysis, wet									Stack Gas Analysis, wet									WET CHEM NH3		
Test	Date & Time	O2	SO2	NO	CO	NO2	CO2	N2O	O2	SO2	NO	CO	NO2	CO2	H2O	N2O	NH3	O2	SO2	NO	CO	NO2	CO2	H2O	N2O	NH3	inlet	stk	Comments
		%dry	ppm	ppm	ppm	ppm	%	ppm	%	ppm	ppm	ppm	ppm	%	%	ppm	ppm	%	ppm	ppm	ppm	ppm	%	%	ppm	ppm	ppm	ppm	
777	2/25/94 5:00								7.36	264	216				7.31			8.50	72	178		7		6.77					2/25 0200-0500auto
777	2/25/94 8:40	6.50	317	245	42	4	12.42	3.8	4.95	313	237	40	-1	12.17	8.54	5.2	3.0	6.35	117	203	37	11	11.10	7.84	4.9	3.7			A OOS, post BH cln
777																													0920 urea, 1006 BHc
777																													1130 abort 70MW
778	3/28/94 8:50	4.75	339	169	124	3	13.15	4.1	3.55	329	173	160	-3	12.68	9.09	3.5	0.7	4.65	308	168	118	-1	11.96	8.62	1.8	1.2			Base, 4 mills
778	3/28/94 9:50	4.95	312	165	61	2	12.35	1.4	3.70	315	180	62	-2	12.48	8.86	2.2	1.3	4.90	302	175	63	-1	11.89	8.59	2.3	1.2			base
778	3/28/94 11:50	4.60	320	160	52	3	12.89	1.0	3.95	320	183	58	-1	12.46	8.85	1.2	1.5	4.90	100	154	50	1	11.89	8.50	1.7	2.7			1010 NaSC@2
778	3/28/94 14:10	4.95	323	135	36	3	12.85	19.3	4.10	313	131	33	-2	12.25	9.29	18.8	0.8	5.15	100	108	29	10	11.69	8.81	17.3	3.2		4.9	1225Urea@.75
778	3/28/94 15:10	5.30	319	140	37	3	12.96	17.2	4.15	308	128	30	-2	12.13	9.23	18.9	0.4	5.15	94	108	31	8	11.64	8.89	17.7	2.3		2.2	
778	3/28/94 16:15	5.20	323	135	33	2	13.06	16.9	3.90	312	128	29	-1	12.47	9.58	16.9	1.1	5.15	96	108	26	8	11.72	8.96	17.1	2.8		1.8	
778	3/28/94 8:50	4.75	372	215	142	3	13.49	4.1	3.55	361	197	183	-3	13.01	9.09	3.5	0.7	4.65	338	191	135	-1	12.27	8.62	1.8	1.2			Revised calibrations
778	3/28/94 9:50	4.95	343	210	70	2	12.67	1.4	3.70	346	205	71	-2	12.80	8.86	2.2	1.3	4.90	332	199	72	-1	12.19	8.59	2.3	1.2			NO, SO2, CO &CO2
778	3/28/94 11:50	4.60	352	205	60	3	13.22	1.0	3.95	352	208	67	-1	12.78	8.85	1.2	1.5	4.90	110	175	57	1	12.19	8.50	1.7	2.7			& feeder cal
778	3/28/94 14:10	4.95	355	154	41	3	13.18	19.3	4.10	344	149	37	-2	12.56	9.29	18.8	0.8	5.15	110	123	33	10	11.99	8.81	17.3	3.2			
778	3/28/94 15:10	5.30	350	159	42	3	13.29	17.2	4.15	338	146	34	-2	12.44	9.23	18.9	0 4	5.15	103	123	35	8	11.94	8.89	17.7	2.3			
778	3/28/94 16:15	5.20	355	154	38	2	13.39	16.9	3.90	343	146	33	-1	12.79	9.58	16.9	1.1	5.15	105	123	30	8	12.02	8.96	17.1	2.8			
779	3/29/94 7:40	4.95	360	230	49	4	13.77	-1.1	3.75	357	215	52	-1	13.31	9.27	0.1	1.4	4.90	100	177	35	12	12 57	8.76	0.3	2.5			Base, NaSC~2.0,
779	3/29/94 8:00	5.00	370	240	39	2	14.05	-1.0	3.70	352	215	51	0	13.26	9.30	1.5	0.0	4.85	93	177	33	12	12.55	8.79	0.7	3.1			70% auto last nite
779	3/29/94 11:40	5.02	372	134	47	3	14.12	26.8	3.90	351	129	36	-2	13.14	9.88	29.0	3.0	4.90	328	130	33	-1	12.38	9.18	26.7	2.9			0945 urea
779	3/29/94 12:50	5.02	372	134	47	3	14.12	26.8	4.10	350	138	33	-2	12.94	9.66	31.2	5.5											12.7	1210 inlet only
780	3/29/94 14:30	5.15	368	122	42	2	13.75	36.9	4.10	354	118	40	-1	13.03	9.94	41.4	16.1	4.94	333	117	36	-1	12.35	9.41	35.9	4.4		23.6	1315 1.5 N/NO
780	3/29/94 15:15																												1455 inlet only
780	3/29/94 17:40	4.85	380	236	47	2	14.44	-0.5																					Base, 0 N/NO, 0 nsr
781	3/30/94 10:20	5.05	368	208	49	2	13.98	-1.2	4.18	348	197	43	-1	12.88	9.21	2.7	2.4	5.10	104	167	33	5	12.27	8.75	5.1	3.0			Base, 0730 Na inj
781	3/30/94 13:00	5.25	356	130	56	2	13.67	24.9	4.20	337	121	44	-1	12.81	9.49	32.3	5.5	4.98	112	102	47	9	12.28	9.10	25.4	5.4		3.7	1155 Urea, 1233 BHclean
781	3/30/94 14:00	5.20	351	133	59	2	13.72	24.3	4.02	332	127	51	-1	12.87	9.44	28.8	7.1	4.95	92	105	48	7	12.28	9.00	24.7	5.0		1.8	
781	3/30/94 15:00	5.30	346	136	56	1	13.61	24.0	4.05	332	123	54	-2	12.91	9.50	31.0	9.6	5.10	96	105	48	5	12.16	8.85	26.2	4.6		0.9	urea inj plug?
781	3/30/94 16:20	4.90	360	132	66	1	13.99	23.0	3.95	338	123	53	-2	12.93	9.54	28.8	9.1	4.80	99	106	58	3	12.44	9.16	23.2	4.7		1.4	Na flow?
781	3/30/94 17:00	4.80	359	131	68	1	14.14	22.6	4.00	336	121	47	-2	12.95	9.51	31.4	8.9	4.80	263	115	55	0	12.45	9.10	24.6	4.9	3.5		no sorbent
781	3/30/94 17:45	5.10	347	131	44	1	13.80	25.9	4.15	327	119	41	1	12.88	9.53	32.0	9.5	4.75	280	115	39	0	12.43	9.03	25.7	4.4			1717 inlet only
781	3/30/94 18:25	5.10	347	218	52	2	13.80	1.6										4.90	292	190	37	1	12.38	8.87	0.7	4.0			base repeat
782	3/31/94 7:30	5.05	343	232	49	3	13.84	-0.9	4.05	325	218	48	-1	12.99	9.00	1.9	1.2	4.82	309	208	39	0	12.39	8.55	0.6	1.4			base
782	3/31/94 9:10	5.00	348	140	57	1	13.82	27.2	4.00	324	132	52	-2	12.84	9.50	32.8	5.2	4.80	310	130	50	-2	12.41	9.09	27.3	2.4		1.1	0810 urea
782	3/31/94 10:10	5.05	342	148	50	1	13.81	27.2	4.00	322	129	53	-3	12.78	9.30	34.6	7.5	4.82	305	132	48	-1	12.47	8.92	27.4	2.0		0.7	CEM stack-NH3
782	3/31/94 11:10	5.10	338	146	49	1	13.77	28.4	4.08	320	127	47	-3	12.70	9.33	36.2	8.5	4.82	306	132	47	-2	12.31	8.92	28.9	2.5		0.5	"
782	3/31/94 12:25	5.10	339	147	54	1	13.73	27.4	4.20	317	128	49	-3	12.60	9.21	36.0	6.4	5.00	298	132	45	-1	12.19	8.83	28.2	3.5		0.6	"
782	3/31/94 13:50	5.25	333	149	48	1	13.62	28.5	4.50	309	134	44	-2	12.39	9.10	35.4	7.0	5.00	296	135	42	-2	12.07	8.72	28.6	3.0			
782	3/31/94 15:50	5.35	333	147	48	1	13.39	27.8	4.47	308	133	44	-3	12.30	8.92	33.3	5.8	5.10	300	133	39	-2	11.97	8.64	28.4	3.5	9.2		
782	3/31/94 16:20	5.20	339	239	35	1	13.59	-0.7	4.40	317	221	27	-3	12 55	8.56	1.1	5.3	5.15	302	216	24	-1	12.01	8.17	0.9	3.3			Base repeat

PSCC Arapahoe Unit 4 Sodium/Urea Injection Summary

Calcs based on: Bicarbonate (b) 0.274
Sesquicarb. (s) 0.297

				Sorbent Feed			Injector cal		Urea injection---------					ΔSO2 Reduction				ΔNOx Calcs-----------			Baghouse Temps				Economizer Exit, dry (1-12): Base						
Test	Date & Time	Load	O2cr	Na	A (w)	B (e)	Flow	2Na	Urea	Total	Inj air	Conc	N/NO	Cmp	Calc		Util	Overall	SNCR	Na	Taho	Grid	Out	IDin	O2	SO2	NO	CO	NO2	CO2	N2O
		MWe	%wet	b/s	%	%	lb/min	S*	gpm	gpm	psi	wt%		%	%	ppmc	%	%	%	%	°F	°F	°F	°F	%dry	ppm	ppm	ppm	ppm	%	ppm
783	4/1/94 7:40	99	4.40	s	0	0	0.0	0.00	0.00			34.3	0.00	0				-3.3	0.0		268	262	242	254	4.95	350	225	44	2	13.75	-0.7
783	4/1/94 9:10	98	4.30	s	0	0	0.0	0.00	1.86	6.0	8.2	34.3	1.51	0				42.8	43.0		280	274	256	265	4.95	350	225	44	2	13.75	-0.7
783	4/1/94 10:10	98	4.30	s	0	0	0.0	0.00	1.86	6.0	8.1	34.3	1.51	0				44.1	45.2		285	277	262	272	4.95	350	225	44	2	13.75	-0.7
783	4/1/94 11:10	98	4.30	s	0	0	0.0	0.00	1.86	6.0	8.2	34.3	1.51	0				43.2	46.2		286	280	266	274	4.95	350	225	44	2	13.75	-0.7
783	4/1/94 12:10	98	4.40	s	0	0	0.0	0.00	1.86	6.0	8.1	34.3	1.51	0				44.3	46.4		288	282	268	277	4.95	350	225	44	2	13.75	-0.7
783	4/1/94 13:20	98	4.40	s	0	0	0.0	0.00	1.86	6.0	8.1	34.3	1.51	0				45.0	46.1		288	283	271	279	4.95	350	225	44	2	13.75	-0.7
783	4/1/94 14:25	98	4.40	s	0	0	0.0	0.00	1.86	6.0	8.1	34.3	1.51	0				45.9	45.9		289	283	270	277	4.95	350	225	44	2	13.75	-0.7
783	4/1/94 15:45	99	4.30	s	0	0	0.0		0.00			34.3	0.00	1					-1.6		287	282	271	278	4.95	350	225	44	2	13.75	-0.7
784	4/7/94 8:30	100	3.90	s	0	0	0.0	0.00	0.00			34.3	0.00					-5.9	0.0		264	258	242	252	5.10	340	213	90	2	13.07	0.8
785	4/7/94 13:45	100	3.90	s	0	0	0.0	0.00	0.00			34.3	0.00					4.8	0.0		268	264	253	261	5.35	341	229	58	1	13.17	1.0
786	4/8/94 9:50	111	3.70	s	0	0	0.0		0.00			34.3	0.00						0.0		269	265	252	258	5.40	335	255	129	3	13.32	3.9
787																															
788	4/12/94 10:25	112	3.70	s	0	0	0.0	0.00	0.00	0.0	0.0	34.3	0.00					3.2	0.0		267	262	246		5.10	428	236	38	2	13.67	0.4
788	4/12/94 12:05	112	3.70	s	0	0	0.0	0.00	1.50	6.0	8.0	34.3	1.01					41.6	43.6		277	271	252	257	5.10	428	236	38	2	13.67	0.4
788	4/12/94 13:05	112	3.70	s	0	0	0.0	0.00	1.50	6.0	8.0	34.3	1.01					41.7	42.8		279	273	258		5.10	428	236	38	2	13.67	0.4
788	4/12/94 14:14	112	3.70	s	0	0	0.0	0.00	1.50	6.0	8.0	34.3	1.01					40.5	40.4		280	275	261	270	5.10	428	236	38	2	13.67	0.4
788	4/12/94 13:20	112	3.70	s	0	0	0.0	0.00	1.50	6.0	8.0	34.3	1.01					39.1	38.7						5.10	428	236	38	2	13.67	0.4
788	4/12/94 16:20	112	3.70	s	0	0	0.0	0.00	1.50	6.0	8.0	34.3	1.01					36.8	36.3		283	277	265	273	5.10	428	236	38	2	13.67	0.4
788	4/12/94 16:55	112	3.70	s	0	0	0.0	0.00	0.00	6.0	8.0	34.3	0.00					-1.5	-2.2						5.10	428	236	38	2	13.67	0.4
789	4/13/94 9:33	105	4.10	s	0	0	0.0	0.00	0.00	0.0	0.0	34.3	0.00					3.9	0.0		278	271	256	264	6.15	340	251	38	2	12.89	1.3
789	4/13/94 11:00	105	4.10	s	0	0	0.0	0.00	1.60	6.0	8.0	34.3	1.01					44.9	45.4		285	279	264	270	6.15	340	251	38	2	12.89	1.3
789	4/13/94 12:00	105	4.10	s	0	0	0.0	0.00	1.60	6.0	8.0	34.3	1.01					43.6	49.1		286	280	268	273	6.15	340	251	38	2	12.89	1.3
789	4/13/94 13:00	104	4.30	s	0	0	0.0	0.00	1.60	6.0	8.0	34.3	1.02					44.0	48.1		285	280	265	270	6.15	340	251	38	2	12.89	1.3
789	4/13/94 14:00	104	4.10	s	0	0	0.0	0.00	1.60	6.0	8.0	34.3	1.02					44.7	49.3		286	281	267	276	6.15	340	251	38	2	12.89	1.3
789	4/13/94 15:00	104	4.20	s	0	0	0.0	0.00	1.60	6.0	8.0	34.3	1.02					45.8	49.7		287	281	269	277	6.15	340	251	38	2	12.89	1.3
789	4/13/94 16:00	103	4.20	s	0	0	0.0	0.00	1.60	6.0	8.0	34.3	1.03					45.6	49.1		288	283	271	278	6.15	340	251	38	2	12.89	1.3
789	4/13/94 17:00	103	4.20	s	0	0	0.0	0.00	0.00	6.0	8.0	34.3	0.00					10.2	10.9		288	282	274	278	6.15	340	251	38	2	12.89	1.3

PSCC Arapahoe Unit 4 Sodium/Urea Injection Summary

		Economizer Exit, dry (1-12): w/Urea							Baghouse Inlet Gas Analysis, wet									Stack Gas Analysis, wet									WET CHEM NH3		
Test	Date & Time	O2	SO2	NO	CO	NO2	CO2	N2O	O2	SO2	NO	CO	NO2	CO2	H2O	N2O	NH3	O2	SO2	NO	CO	NO2	CO2	H2O	N2O	NH3	inlet	stk	Comments
		%dry	ppm	ppm	ppm	ppm	%	ppm	%	ppm	ppm	ppm	ppm	%	%	ppm	ppm	%	ppm	ppm	ppm	ppm	%	%	ppm	ppm	ppm	ppm	
783	4/1/94 7:40	4.95	350	225	44	2	13.75	-0.7	4.38	323	213	29	-2	12.47	8.89	1.4	0.6	5.12	310	207	27	-1	12.10	8.60	0.9	0.4			base
783	4/1/94 9:10	5.10	338	127	56	1	13.67	31.8	4.20	321	118	51	-3	12.53	9.35	42.9	23.8	4.92	311	117	51	-2	12.23	9.11	34.3	2.2		8.9	0805 urea, 0810 BHc
783	4/1/94 10:10	5.25	328	121	52	1	13.50	34.3	4.25	321	120	47	-3	12.56	9.21	43.8	23.2	4.90	310	115	48	-2	12.12	8.89	36.1	7.2		13.5	
783	4/1/94 11:10	5.10	332	120	57	1	13.81	33.7	4.20	319	115	47	-3	12.66	9.40	44.5	29.9	4.95	309	116	48	-2	12.17	8.94	34.4	13.7		17.7	
783	4/1/94 12:10	4.90	338	121	58	0	13.91	33.5	4.10	316	111	5	-2	12 67	9.56	44.6	22.3	4.88	303	113	48	-1	12.39	9.16	33.8	16.2		17.2	
783	4/1/94 13:20	5.00	340	121	50	0	13.79	32.9	4.12	320	111	47	-2	12.69	9.50	45.1	22.6	4.95	306	112	45	-2	12.16	9.02	35.3	17.9		17.3	
783	4/1/94 14:25	5.30	331	119	46	0	13.61	33.7	4.20	320	112	47	-3	12.56	9.48	43.2	23.7	5.20	300	109	40	-2	11.91	8.88	35.3	17.0	27.4		
783	4/1/94 15:45	5.20	339	225	34	1	13.72	0.9																					1530 urea off
784	4/7/94 8:30	5.10	340	213	90	2	13.07	0.8	3.95	340	202	120	-3	12.78	9.08	1.0	1.6	5.35	313	200	79	-2	11.86	8.46	0.5	0.5			SORBITECH
785	4/7/94 13:45	5.35	341	229	58	1	13.17	1.0	4.20	325	208	70	-2	12.20	8.67	2.5	1.3	5.05	310	200	52	-1	11.82	8.29	2.4	1.5			SORBITECH
786	4/8/94 9:50	5.40	335	255	129	3	13.32	3.9																					SORBITECH
787																													SORBITECH
788	4/12/94 10:25	5.10	428	236	38	2	13.67	0.4	4.15	395	210	31	-3	12.48	9.16	1.2	0.3	5.10	375	205	64	-2	11.96	8.89	2.1	-0.2			baseline, urea on 1105
788	4/12/94 12:05	5.00	409	134	68	2	13.71	29.3	4.25	369	125	42	-3	12.35	9.71	34.3	2.6	5.10	360	123	52	-1	11.95	9.34	29.2	1.7		0.4	NH3stk=0.4
788	4/12/94 13:05	5.10	406	135	71	1	13.78	28.9	4.35	369	121	41	-9	11.57	9.27	36.0	10.0	4.90	361	124	54	-1	12.07	9.43	30.3	1.3		0.6	NH3stk=0.6
788	4/12/94 14:14	5.30	380	139	57	1	13.44	30.4	4.45	348	127	42	-3	12.27	9.74	34.2	8.8	5.00	353	126	51	-1	12.03	9.37	30.1	2.7			
788	4/12/94 13:20	5.50	375	141	43	1	13.29	30.1	4.50	343	131	34	-2	12.07	9.57	36.3	9.9	5.00	335	129	36	-1	11.96	9.42	31.4	3.8			NH3aho=8.3
788	4/12/94 16:20	5.35	371	148	46	1	13.53	29.8	4.35	342	132	38	-2	12.41	9.87	34.5	9.7	5.20	335	132	34	-1	11.85	9.29	30.9	3.2	8.3	0.9	NH3stk=0.9
788	4/12/94 16:55	5.25	375	239	36	1	13.48	0.5	4.35	345	211	33	-3	12.22	9.71	2.4	6.1	5.25	327	212	26	-2	11.71	9.19	1.9	3.7			urea off 1645
789	4/13/94 9:33	6.15	340	251	38	2	12.69	1.3	4.90	320	222	44	-1	12.16	8.91	4.3	3.7	6.00	300	217	37	-1	11.40	8.41	2.9	3.1			baseline, urea on 1005
789	4/13/94 11:00	6.15	332	137	57	0	12.70	33.6	4.50	325	125	70	-2	11.92	9.36	42.9	10.9	5.85	301	126	55	-1	11.43	8.79	33.8	4.5	22.1	4.8	NH3: aho=22.1, stk=4.8
789	4/13/94 12:00	5.85	333	132	74	1	13.22	32.8	4.35	330	121	94	-2	12.33	9.61	43.8	14.9	5.90	300	129	55	-2	11.32	8.76	33.7	8.6		8.3	NH3stk=8.3 &11.1
789	4/13/94 13:00	5.60	340	135	61	0	13.06	33.8	4.35	331	129	85	-2	12.31	9.52	41.5	16.1	5.55	308	130	56	-1	11.64	8.94	34.4	12.1		11.1	NH3stk=12.0
789	4/13/94 14:00	5.70	334	131	64	1	13.16	32.9	4.35	331	129	74	-3	12.23	9.50	42.1	19.3	5.45	311	130	60	-1	11.64	8.90	34.3	17.6		15.5	NH3stk=15.5 & 20.0
789	4/13/94 15:00	5.60	339	131	59	0	13.24	31.8	4.40	330	126	71	-2	12.27	9.51	40.7	20.0	5.30	311	129	54	-2	11.84	9.00	32.6	22.8		21.4	NH3stk=21.4
789	4/13/94 16:00	5.65	350	132	54	4	13.12	31.5	4.60	332	124	64	-3	11.95	9.25	41.8	25.0	5.40	320	129	48	-2	11.67	8.88	31.6	27.0	41.6	24.1	stk=24.1 aho=41.6 #4=33
789	4/13/94 17:00	5.60	375	232	39	1	13.22	0.3	4.65	341	212	34	-2	12.04	9.31	2 4	9.5	5.45	329	210	31	-1	11.70	8.98	1.7	12.4			base check, urea off 1639

PSCC Arapahoe Unit 4 Sodium/Urea Injection Summary
Modified for Air Heater Injection

Calcs based on: Bicarbonate (b) 0.274
Sesquicarb. (s) 0.297

				Sorbent Feed			Injector cal		Urea Injection--------					ΔSO2 Reduction				ΔNOx Calcs---------			Baghouse Temps				Economizer Exit, dry (1-12): Base							Economizer Exit, dry (1-12): w/SNCR						
Test	Date & Time	Load	O2cr	Na	A (w)	B (e)	Flow	2Na	Urea	Total	Inj air	Conc	N/NO	Inlet	Stk		Util	Overall	SNCR	Na	Taho	Grid	Out	IDin	O2	SO2	NO	CO	NO2	CO2	N2O	O2	SO2	NO	CO	NO2	CO2	N2O
		MWe	%wet	b/s	%	%	lb/min	S*	ppm	ppm	psi	wt%		%	%	ppmc	%	%	%	%	°F	°F	°F	°F	%dry	ppm	ppm	ppm	ppm	%	ppm	%dry	ppm	ppm	ppm	ppm	%	ppm
SODIUM BICARBONATE AIR HEATER INJECTION																																						
790	4/14/94 10:00	100	4.50	b	0	0	0.0	0.00	0.00	0.0	0.0	34.3	0.00	3.2	1.9	-6		4.0	0.0	4.1	277	270	255	265	5.95	376	238	39	2	12.66	1.1	5.95	376	238	39	2	12.66	1.1
790	4/14/94 13:45	100	4.30	b	0	34	38.2	1.06	0.00	0.0	0.0	34.3	0.00	21.6	34.2	51	32.2	5.5		7.8	261	275	268	273	5.95	376	238	39	2	12.66	1.1							
790	4/14/94 14:45	100	4.40	b	0	34	38.2	1.06	0.00	0.0	0.0	34.3	0.00	27.1	48.4	87	45.8	6.8		11.1	281	275	267	274	5.95	376	238	39	2	12.66	1.1							
790	4/14/94 15:45	100	4.40	b	0	34	38.2	1.05	0.00	0.0	0.0	34.3	0.00	30.1	59.7	122	57.1	12.2		11.7	280	275	267	273	5.95	376	238	39	2	12.66	1.1							
790	4/14/94 16:45	100	4.40	b	0	34	38.2	1.06	0.00	0.0	0.0	34.3	0.00	29.0	60.8	129	57.1	10.5		16.3	277	272	264	271	5.95	376	238	39	2	12.66	1.1							
790	4/14/94 17:30	100	4.30	b	0	0	0.0	0.00	0.00	0.0	0.0	34.3	0.00					3.6	0.0	16.0	275	269	262	268	5.90	340	235	96	2	12.76	-1.0	5.90	340	235	96	2	12.76	-1.0
791	4/15/94 7:40	101	4.50	b	0	0	0.0	0.00	0.00	0.0	0.0	34.3	0.00	1.9	1.4	-2		1.3	0.0	9.2	265	259	240	251	6.00	341	236	64	1	13.01	-0.8	6.00	341	236	64	1	13.01	-0.8
791	4/15/94 8:30	100	4.30	b	0	33	37.1	1.04	0.00	0.0	0.0	34.3	0.00	29.9	45.3	62	43.5	4.4		12.1	266	261	245	254	6.00	341	236	64	1	13.01	-0.8							
791	4/15/94 9:15	100	4.40	b	0	32	35.9	1.01	0.00	0.0	0.0	34.3	0.00	32.4	43.4	44	42.9	7.6		11.5	267	261	250	256	6.00	341	236	64	1	13.01	-0.8							
791	4/15/94 10:15	100	4.40	b	0	32	35.9	1.02	0.00	0.0	0.0	34.3	0.00	34.2	56.0	87	55.1	11.2		16.4	269	264	251	259	6.00	341	236	64	1	13.01	-0.8							
791	4/15/94 11:15	100	4.40	b	0	32	35.9	1.01	0.00	0.0	0.0	34.3	0.00	34.4	60.9	106	60.0	10.4		16.0	273	267	254	261	6.00	341	236	64	1	13.01	-0.8							
791	4/15/94 12:15	100	4.40	b	0	32	35.9	1.00	0.00	0.0	0.0	34.3	0.00	32.6	64.8	130	64.4	16.7		24.2	275	268	257	264	6.00	341	236	64	1	13.01	-0.8							
791	4/15/94 13:20	100	4.40	b	0	32	35.9	1.01	0.00	0.0	0.0	34.3	0.00	32.7	66.6	136	65.7	8.1		17.1	277	271	259	261	6.00	341	236	64	1	13.01	-0.8							
791	4/15/94 14:15	100	4.40	b	0	32	36.9	1.01	0.00	0.0	0.0	34.3	0.00	33.3	69.7	147	69.3	8.7		17.1	280	274	262	271	6.00	341	236	64	1	13.01	-0.8							
791	4/15/94 15:15	100	4.50	b	0	32	35.9	1.01	0.00	0.0	0.0	34.3	0.00	34.8	71.5	148	70.9	7.9		21.2	282	275	265	274	6.00	341	236	64	1	13.01	-0.8							
791	4/15/94 15:55	100	4.40	b	0	32	35.9	1.01	0.00	0.0	0.0	34.3	0.00	29.8	55.0	102	54.7	4.1		17.5	283	278	271	275	6.00	341	236	64	1	13.01	-0.8							
791	4/15/94 17:00	100	4.40	b	0	32	35.9	1.01	0.00	0.0	0.0	34.3	0.00	32.4	63.5	126	63.1	7.6		12.8	285	278	271	277	6.00	341	236	64	1	13.01	-0.8							
792	4/18/94 8:30	110	3.90	b	0	0	0.0	0.00	0.00	0.0	0.0	34.3	0.00	1.9	0.5	-7		0.1	0.0	3.9	286	281	263	274	5.40	466	241	56	2	13.49	-1.6	5.40	466	241	56	2	13.49	-1.6
792	4/18/94 9:30	110	4.00	b	0	47	52.6	1.05	0.00	0.0	0.0	34.3	0.00	17.9	52.0	176	49.5	10.9		12.6	291	285	272	281	5.40	466	241	56	2	13.49	-1.6							
792	4/18/94 10:30	110	3.90	b	0	47	52.6	1.04	0.00	0.0	0.0	34.3	0.00	20.9	67.0	240	64.5	11.5		13.2	294	289	278	287	5.40	466	241	56	2	13.49	-1.6							
792	4/18/94 11:45	110	3.90	b	0	47	52.6	1.06	0.00	0.0	0.0	34.3	0.00	21.1	67.9	239	64.0	10.8		16.0	297	293	284	292	5.40	466	241	56	2	13.49	-1.6							
792	4/18/94 12:35	110	3.90	b	0	47	52.6	1.06	0.00	0.0	0.0	34.3	0.00		68.2		64.3	13.3		18.3	298	293	288	292	5.40	466	241	56	2	13.49	-1.6							
792	4/18/94 13:10	110	3.80	b	0	47	52.6	1.07	0.00	0.0	0.0	34.3	0.00	21.5	56.4	172	51.9	4.6		9.1	298	292	288	292	5.40	466	241	56	2	13.49	-1.6							
792	4/18/94 13:40	110	3.90	b	0	47	52.6	1.07	0.00	0.0	0.0	34.3	0.00		63.4		59.4	7.7		12.1	298	294	288	293	5.40	466	241	56	2	13.49	-1.6							
792	4/18/94 14:40	110	3.90	b	0	47	52.6	1.02	0.00	0.0	0.0	34.3	0.00	20.1	68.2	246	65.3	7.2		10.7	297	293	288	294	5.40	466	241	56	2	13.49	-1.6							
792	4/18/94 15:40	110	3.90	b	0	47	52.6	1.03	0.00	0.0	0.0	34.3	0.00		65.4		63.3	4.9		11.0	298	294	289	294	5.40	466	241	56	2	13.49	-1.6							
792	4/18/94 17:30	110	4.00	b	0	47	52.6	1.01	0.00	0.0	0.0	34.3	0.00	18.7	67.0	259	66.5	6.5		13.4	295	292	288	293	5.40	466	241	56	2	13.49	-1.6							
792	4/18/94 18:50	110	3.90	b	0	47	52.6	1.01	0.00	0.0	0.0	34.3	0.00		53.1		52.7	3.7		8.8	294	289	287	291	5.40	466	241	56	2	13.49	-1.6							
792	4/18/94 19:20	110	3.90	b	0	47	52.6	1.01	0.00	0.0	0.0	34.3	0.00		64.1		63.7	5.4		10.4				290	5.40	466	241	56	2	13.49	-1.6							
792	4/18/94 19:50	110	3.90	b	0	47	52.6	1.01	0.00	0.0	0.0	34.3	0.00		62.0		61.6	4.0		9.1				289	5.40	466	241	56	2	13.49	-1.6							
793	4/19/94 9:40	110	3.90	b	0	23	25.5	0.51	0.00	0.0	0.0	34.3	0.00	0.1	0.1		0.1	3.5	0.0	3.9	287	281	287	276	5.40	439	241	42	2	13.58	2.0	5.40	439	241	42	2	13.58	2.0
793	4/19/94 11:25	110	3.80	b	0	23	25.5	0.54	0.00	0.0	0.0	34.3	0.00		31.7		58.5	4.9		2.8	291	285	274	283	5.40	439	241	42	2	13.58	2.0							
793	4/19/94 12:25	110	3.80	b	0	23	25.5	0.57	0.00	0.0	0.0	34.3	0.00		39.9		70.3	4.6		7.4	294	289	276	285	5.40	439	241	42	2	13.58	2.0							
793	4/19/94 13:09	110	3.80	b	0	21	23.3	0.52	0.00	0.0	0.0	34.3	0.00		26.2		50.5	0.4		3.3	294	289	276	285	5.40	439	241	42	2	13.58	2.0							
793	4/19/94 14:00	110	3.80	b	0	21	23.3	0.53	0.00	0.0	0.0	34.3	0.00		37.9		71.6	0.8		3.7	295	290	280	286	5.40	439	241	42	2	13.58	2.0							
793	4/19/94 15:20	110	3.80	b	0	21	23.8	0.55	0.00	0.0	0.0	34.3	0.00		35.6		65.2	-0.5		4.5	294	289	279	280	5.40	439	241	42	2	13.58	2.0							
793	4/19/94 16:40	110	3.90	b	0	21	23.8	0.55	0.00	0.0	0.0	34.3	0.00	11.7	30.8	65	55.8	-0.3		9.1	292	288	289	288	5.40	439	241	42	2	13.58	2.0							
794	4/21/94 8:00	110	3.80	b	0	0	0.0	0.00	0.00	0.0	0.0	34.3	0.00	-5.1	0.1	22		-2.6	0.0	-4.2	272	264	246	258	5.30	369	247	78	2	13.7	-1.1	5.3	369	247	78	1.7	13.7	-1.1
794	4/21/94 10:00	110	3.80	b	0	55	61.7	1.57	0.00	0.0	0.0	34.3	0.00	30.1	86.1	227	54.8	10.0		10.3	279	274	262	272	5.30	369	247	78	2	13.7	-1.1							
794	4/21/94 10:35	110	3.60	b	0	55	61.7	1.57	0.00	0.0	0.0	34.3	0.00		90.6		57.7	19.6		19.9					5.30	369	247	78	2	13.7	-1.1							
794	4/21/94 11:10	110	3.60	b	0	55	61.7	1.49	0.00	0.0	0.0	34.3	0.00	29.1	75.3	197	50.5	2.7		4.1	283	276	270	276	5.30	369	247	78	2	13.7	-1.1							
794	4/21/94 12:10	110	3.60	b	0	55	61.7	1.53	0.00	0.0	0.0	34.3	0.00	31.2	85.9	227	56.2	6.9		10.2	279	280	270	279	5.30	369	247	78	2	13.7	-1.1							
794	4/21/94 13:05	110	3.60	b	0	55	61.7	1.51	0.00	0.0	0.0	34.3	0.00	32.3	89.4	240	59.0	7.9		12.9	286	280	273	280	5.30	369	247	78	2	13.7	-1.1							
794	4/21/94 15:06	110	3.60	b	0	55	61.7	1.54	0.00	0.0	0.0	34.3	0.00	29.0	92.1	366	59.9	6.6		14.1	288	284	276	283	5.30	369	247	78	2	13.7	-1.1							
794	4/21/94 16:00	110	3.60	b	0	55	61.7	1.53	0.00	0.0	0.0	34.3	0.00		80.7	336	52.8	-0.9		4.0	288	282	278	283	5.30	369	247	78	2	13.7	-1.1							
794	4/21/94 17:00	110	3.60	b	0	55	61.7	1.53	0.00	0.0	0.0	34.3	0.00	31.9	90.1	242	59.0	7.6		15.6	287	281	288	282	5.30	369	247	78	2	13.7	-1.1							
794	4/21/94 18:00	110	3.60	b	0	55	61.7	1.56	0.00	0.0	0.0	34.3	0.00	29.2	92.6	257	59.1	9.3		13.5	287	281	277	282	5.30	369	247	78	2	13.7	-1.1							
795	4/22/94 8:45	110	4.00	b	0	0	0.0	0.00	0.00	6.0	8.1	34.3	0.00	6.6	3.7	-12		-1.9	0.0	-1.8	263	278	262		5.70	338	254	63	1	13.16	0.4	5.70	338	254	63	1	13.16	0.4
795	4/22/94 9:40	110	4.00	b	0	0	0.0	0.00	2.45	6.0	8.1	34.3	1.50	-4.9	-8.2	-13		46.4	47.4	6.7	286	279	286	275	5.70	338	254	63	1	13.16	0.4	6.00	318	131	82	0	12.96	39.0
795	4/22/94 13:09	110	4.00	b	0	0	0.0		2.45	6.0	8.1	34.3	1.50					46.3			293	286	276	283	5.70	338	254	63	1	13.16	0.4							
795	4/22/94 14:40	110	4.00	b	0	0	0.0	0.00	2.45	6.0	8.1	34.3	1.50	-4.9	-10.1	-20		44.1	47.4	2.7	291	285	275	282	5.70	338	254	63	1	13.16	0.4	6.00	318	131	82	0	12.96	39.0
796	4/22/94 16:31	100	4.90	b	0	30	33.2		1.85	6.0	8.1	34.3									290	285	276	282														
796	4/22/94 14:40	100	4.90	b	0	30	33.2	0.89	1.85	6.0	8.1	34.3	1.12	25.2	60.1	148	67.7	49.0		49.0	289	284	277	284	8.20	301	237	18	1	11.26	-1.1							
797	4/25/94 8:00	100	4.20	b	0	0	0.0	0.00	0.00	6.0	8.1	34.3	0.00		-1.3			-1.3	0.0	5.8	272	266	251	260	6.50	333	230	41	5	12.85	1.3	6.50	333	230	41	5	12.85	1.3
797	4/25/94 10:30	100	4.20	b	0	0	0.0	0.00	1.50	6.0	8.1	34.3	1.06	-1.2	-3.9	-10		46.4		7.9	273	266	252	262	6.50	333	230	41	5	12.85	1.3							
797	4/25/94 12:25	100	4.20	b	0	31	34.3	1.05	1.50	6.0	8.1	34.3	1.06	21.0	56.5	131	53.7	47.7		5.6	272	266	254	264	6.50	333	230	41	5	12.85	1.3							
797	4/25/94 13:25	100	4.20	b	0	31	34.3	1.01	1.50	6.0	8.1	34.3	1.06	21.8	67.6	177	67.1	51.4		15.8	269	264	254	263	6.50	333	230	41	5	12.85	1.3							
797	4/25/94 14:25	100	4.20	b	0	31	34.3	1.06	1.50	6.0	8.1	34.3	1.06	20.4	66.5	176	64.6	50.4		8.5	269	263	251	261	6.50	333	230	41	5	12.85	1.3							

PSCC Arapahoe Unit 4 Sodium/Urea Injection Summary

		Econ Exit, dry (1,2,11,12); w/Sorb							Baghouse Inlet Gas Analysis (AHO 1-6,dry)									Stack Gas Analysis, wet									WET CHEM NH3		
Test	Date & Time	O2	SO2	NO	CO	NO2	CO2	N2O	O2	SO2	NO	CO	NO2	CO2	H2O	N2O	NH3	O2	SO2	NO	CO	NO2	CO2	H2O	N2O	NH3	inlet	stk	Comments
		%dry	ppm	ppm	ppm	ppm	%	ppm	%	ppm	ppm	ppm	ppm	%	%	ppm	ppm	%	ppm	ppm	ppm	ppm	%	%	ppm	ppm	ppm	ppm	
790	4/14/94 10:00	7.70	331	211	26	1	11.22	1.0	4.60	351	206	51	-3	11.91	8.7	2.9	1.0	5.65	332	209	28	-1	11.35	8.4	2.7	1.1			baseline, bicarb on 1330
790	4/14/94 13:45	7.75	300	215	23	1	11.21	0.6	4.45	260	199	103	4	12.12	9.1	2.7	2.4	5.60	203	205	59	0	11.41	8.5	1.1	2.4			FFDC clean 1325-1400
790	4/14/94 14:45	7.75	301	219	23	2	11.16	0.6	4.50	242	198	99	6	12.01	9.0	1.8	3.0	5.65	159	200	54	1	11.44	8.5	2.7	2.7			
790	4/14/94 15:45	7.70	305	209	23	1	11.26	0.6	4.40	235	192	178	7	12.28	9.3	5.1	3.2	5.55	126	188	66	3	11.53	8.6	2.5	3.2			
790	4/14/94 16:45	8.05	292	219	17	1	10.93	0.4	4.55	233	197	118	8	12.16	9.0	3.4	2.0	5.60	120	189	51	4	11.48	8.7	2.6	3.2			
790	4/14/94 17:30	8.20	291	229	15	1	10.92	-0.4	4.20	331	204	197	-2	12.34	9.3	7.0	0.6	5.55	241	205	89	1	11.46	8.6	2.1	1.3			Bicarb off 1700
791	4/15/94 7:40	8.35	289	216	20	2	11.05	-0.4	4.40	329	207	102	-2	12.50	9.1	2.9	0.0	5.65	301	210	56	-1	11.62	8.5	2.6	0.5			baseline, bicarb on 0800
791	4/15/94 8:30	8.05	290	221	21	2	11.14	0.4	4.50	229	199	99	4	12.38	9.1	2.3	3.3	6.00	162	200	42	0	11.57	8.5	2.2	2.5			FFDC clean 0840-0915
791	4/15/94 9:15	8.05	289	212	21	2	11.13	0.5	4.50	220	198	58	6	12.45	9.1	3.4	3.5	5.75	170	192	43	5	11.62	8.5	2.4	3.7			
791	4/15/94 10:15	8.00	289	217	22	2	11.21	0.2	4.30	216	195	103	10	12.63	9.2	5.1	2.7	5.70	132	181	50	9	11.70	8.6	2.0	2.5			
791	4/15/94 11:15	8.30	283	213	21	1	10.82	0.0	4.35	215	195	164	9	12.58	9.2	3.7	2.9	5.90	116	180	70	9	11.53	8.5	2.4	2.8			
791	4/15/94 12:15	8.20	288	216	21	1	11.18	0.3	4.60	220	192	92	9	12.36	9.0	4.0	3.0	6.00	105	161	47	9	11.46	8.4	1.1	2.8			
791	4/15/94 13:20	8.45	280	219	18	1	11.01	0.6	4.60	218	193	90	8	12.25	9.0	4.3	2.5	5.80	100	188	51	7	11.59	8.5	2.3	2.0			
791	4/15/94 14:15	8.40	283	218	22	1	10.92	-0.2	4.70	216	193	86	9	12.23	9.0	3.8	2.1	6.00	90	183	51	8	11.40	8.4	2.5	2.7			
791	4/15/94 15:15	8.55	279	229	14	1	10.80	-0.8	4.45	214	197	76	11	12.42	9.1	1.6	3.0	5.90	85	186	46	8	11.54	8.5	2.0	2.2			FFDC clean 1520-1555
791	4/15/94 15:55	8.55	280	228	14	1	10.86	-1.0	4.95	224	201	59	9	12.05	8.6	2.2	2.9	5.90	135	187	41	15	11.49	8.4	1.0	2.3			
791	4/15/94 17:00	8.10	290	215	23	1	11.14	-0.4	4.65	220	198	49	9	12.25	8.9	1.5	2.9	5.85	110	179	35	17	11.50	8.4	1.2	2.3			
792	4/18/94 8:30	7.50	400	217	55	1	11.86	-0.5	5.35	455	250	34	2	13.49	0.0	-1.0	1.2	5.20	410	218	33	-2	11.97	9.0	1.1	-0.6			Baseline, bicarb on 0900
792	4/18/94 9:30	7.40	389	214	54	2	11.54	0.0	5.26	370	241	55	6	13.56	0.0	0.4	1.0	5.10	193	200	51	-5	11.59	8.8	4.9	3.2			
792	4/18/94 10:30	7.35	395	215	45	2	12.00	-0.6	5.10	364	239	68	7	13.56	0.0	-1.6	1.2	4.95	135	181	51	14	12.35	9.1	2.0	2.2			
792	4/18/94 11:45	7.55	381	221	41	1	11.62	1.1	5.30	351	242	65	7	13.52	0.0	0.7	1.1	5.10	126	181	42	14	12.01	8.8	1.5	2.5			
792	4/18/94 12:35	7.55	381	221	41	1	11.62	1.1										5.20	125	174	38	14	12.09	9.1	1.6	2.9			FFDC clean 1235-1310
792	4/18/94 13:10	7.50	380	219	53	2	11.84	1.9	5.25	348	240	62	8	13.60	0.0	0.2	0.9	5.20	175	180	49	27	12.14	8.9	0.6	2.6			
792	4/18/94 13:40	7.50	380	219	53	2	11.84	1.9										5.05	145	172	49	30	12.18	8.9	1.1	2.2			
792	4/18/94 14:40	7.36	404	220	69	1	11.89	1.6	5.35	370	247	48	7	13.48	0.0	-0.4	1.6	5.10	140	175	63	27	12.26	9.0	1.9	1.5			
792	4/18/94 15:40	7.40	395	225	34	1	11.63	-0.1										5.30	139	179	22	26	12.01	8.8	1.1	2.8			
792	4/18/94 17:30	7.20	412	225	21	2	11.84	0.3	5.30	381	245	33	9	13.36	0.0	0.7	1.2	5.15	138	176	26	23	12.10	8.9	1.8	3.3			
792	4/18/94 18:50	7.20	412	225	21	2	11.84	0.3										5.15	195	172	22	37	12.13	9.2	1.3	2.4			FFDC clean 1815-1850
792	4/18/94 19:20	7.20	412	225	21	2	11.84	0.3										5.10	150	165	28	41	12.06	9.1	1.5	3.0			
792	4/18/94 19:50	7.20	412	225	21	2	11.84	0.3										5.15	158	168	31	40	12.17	9.1	1.6	1.9			
793	4/19/94 9:40	7.10	398	216	25	2	12.32	-1.2										5.00	400	213	42	-2	12.30	9.3	0.1	1.5			
793	4/19/94 11:25	7.00	377	212	257	2	12.19	2.9										5.20	255	205	131	1	12.20	9.2	2.1	2.4			
793	4/19/94 12:25	7.20	355	220	31	2	11.69	-0.6										5.15	215	205	48	2	12.17	9.3	0.5	3.3			
793	4/19/94 13:09	7.20	355	220	31	2	11.69	-0.6										5.10	265	210	32	7	12.15	9.3	0.9	2.3			FFDC cclean1230-1305
793	4/19/94 14:00	7.10	350	222	32	2	12.20	-0.5										5.10	218	205	25	11	12.13	9.3	0.9	3.5			
793	4/19/94 15:20	7.20	344	225	27	1	11.95	-0.6										6.00	211	198	23	8	11.53	8.9	0.6	2.8			
793	4/19/94 16:40	7.50	332	230	22	2	11.66	0.4	5.30	341	255	28	5	13.64	0.0	-0.3	2.1	5.20	235	211	27	5	12.07	9.4	1.4	3.6			
794	4/21/94 8:00	6.70	339	222	58	1	12.69	0.0	5.10	396	275	65	3	14.96	0.0	-2.1	1.7	4.90	333	230	52	-2	12.52	9.7	0.1	1.0			Start feed @0900
794	4/21/94 10:00	6.90	317	222	44	2	11.92	1.0	4.90	253	244	71	10	13.99	0.0	0.3	2.0	4.90	44	196	71	5	12.52	9.6	1.3	4.4			
794	4/21/94 10:35	6.90	317	222	44	2	11.92	1.0										4.85	30	180			12.52	9.6					FFDC start clean
794	4/21/94 11:10	7.10	329	222	61	1	12.45	1.9	5.20	265	257	62	11	14.73	0.0	0.3	2.1	5.10	61	185	53	29	12.38	9.6	4.5	3.6			
794	4/21/94 12:10	7.00	323	228	41	2	12.10	0.6	5.00	254	250	45	10	13.79	0.0	0.7	2.0	4.90	46	173	46	34	12.58	9.7	1.2	4.6			
794	4/21/94 13:05	7.40	317	226	41	2	11.90	0.1	5.10	251	246	40	11	13.59	0.0	3.0	2.2	5.00	35	172	36	32	12.45	9.5	1.7	3.6			
794	4/21/94 15:08	7.40	312	227	39	2	11.78	0.90	5.4	254	253	44	12	13.9	0.0	-0	1.4	5.30	25	171	37	28	12.21	9.3	1.7	4.4			
794	4/21/94 16:00	7.40	314	225	33	1	11.97	0.1										5.40	61	170	31	49	11.99	9.1	1.3	4.2			FFDC clean 1520-1555
794	4/21/94 17:00	7.30	317	236	35	2	12.02	-0.2	5.30	247	250	40	11	13.66	0.0	0.5	1.4	5.00	32	160	49	46	12.38	9.2	1.0	4.4			
794	4/21/94 18:00	7.30	309	226	39	2	11.80	0.6	5.40	249	266	32	12	13.91	0.0	0.0	2.4	5.10	24	159	34	42	12.36	9.1	1.4	4.0			
795	4/22/94 8:45	7.40	323	226	110	1	12.35	-0.2	6.50	344	270	40	2	13.32	0.0	0.6	1.7	5.40	311	234	40	-3	12.09	9.6	1.4	-1.9			
795	4/22/94 9:40	7.30	291	131	130	0	12.19	32.7	5.70	341	145	68	0	13.24	0.0	40.0	0.7	5.40	312	125	72	-4	12.12	9.7	40.0	-0.6	26.0		UREA on @0915
795	4/22/94 13:09																	5.45	316	124	45	-3	12.10	9.6	42.4	14.2	22.0		
795	4/22/94 14:40	7.30	291	131	130	0	12.19	32.7	5.70	341	145	68	0	13.24	0.0	40.0	0.7	5.40	318	129	48	-2	12.06	9.5	43.3	34.2			
796	4/22/94 16:31																	6.40	301	138	36	3	11.37	9.0	38.1	42.5			
796	4/22/94 14:40	8.20	301	237	18	1	11.26	-1.1	6.50	255	150	42	5	12.65	0.0	32.9	2.7	6.30	120	121	36	0	11.39	9.1	36.3	29.0			
797	4/25/94 8:00	8.40	310	215	33	4	11.82	1.1										5.70	328	217	36	-1	12.49	10.2	2.1	0.2			
797	4/25/94 10:30	7.50	279	126	49	1	10.95	25.0	5.70	320	141	51	0	12.34	0.0	32.0	1.1	5.50	292	121	42	-3	11.07	9.1	32.6	11.2	12.3		
797	4/25/94 12:25	7.60	275	119	62	1	10.87	27.0	5.70	248	133	56	2	12.38	0.0	32.6	0.4	5.70	120	115	42	-2	11.03	8.9	33.0	16.3			bicarb on @1125
797	4/25/94 13:25	7.40	291	127	76	0	11.12	22.9	5.70	256	139	60	2	12.69	0.0	31.4	1.1	5.40	95	109	50	-1	11.18	8.9	32.5	12.3			
797	4/25/94 14:25	7.10	283	121	70	1	11.06	27.1	5.70	248	138	53	2	12.50	0.0	32.2	0.5	5.40	88	111	52	-1	11.23	9.0	31.9	10.4	28.2		FFDC clean1431-1507

PSCC Arapahoe Unit 4 Sodium/Urea Injection Summary
Modified for Air Heater Injection

Calcs based on: Bicarbonate (b) 0.274
Sesquicarb. (s) 0.297

				Sorbent Feed			injector cal		Urea Injection-------					ΔSO2 Reduction				ΔNOx Calcs----------			Baghouse Temps				Economizer Exit, dry (1-12): Base							Economizer Exit, dry (1-12): w/SNCR						
Test	Date & Time	Load	O2cr	Na	A (w)	B (s)	Flow	2Na	Urea	Total	Inj air	Conc	N/NO	Inlet	Stk		Util	Overall	SNCR	Na	Taho	Grid	Out	fDIn	O2	SO2	NO	CO	NO2	CO2	N2O	O2	SO2	NO	CO	NO2	CO2	N2O
		MWe	%wet	b/s	%	%	lb/min	S*	gpm	gpm	psi	wt%		%	%	ppmc	%	%	%	%	°F	°F	°F	°F	%dry	ppm	ppm	ppm	ppm	%	ppm	%dry	ppm	ppm	ppm	ppm	%	ppm
797	4/25/94 15:10	100	4.20	b	0	31	34.3	1.06	1.50	6.0	8.1	34.3	1.06		48.1		45.4	46.5		1.2	269	263	251	261	6.50	333	230	41	5	12.85	1.3							
797	4/25/94 15:35	100	4.20	b	0	31	34.3	1.06	1.50	6.0	8.1	34.3	1.06	18.0	53.9	132	51.1	56.9		24.4	270	264	253	262	6.50	333	230	41	5	12.85	1.3							
797	4/25/94 17:30	100	4.20	b	0	0	0.0		0.00	0.0	0.0	34.3	0.00					0.9			269	263	250		6.10	318	237	39	2	12.06	1.4							
798	4/26/94 7:55	100	4.20	b	0	0	0.0	0.00	0.00	0.0	0.0	34.3	0.00	1.3	1.3	0		6.4	0.0	5.2	264	258	241	252	5.70	336	237	43	1	12.65	-0.3	5.70	336	237	43	1	12.65	-0.3
798	4/26/94 9:00	100	4.20	b	0	0	0.0		3.00	6.0	8.1	34.3	2.16					54.1							5.70	336	237	43	1	12.65	-0.3							
798	4/26/94 10:16	100	4.20	b	0	0	0.0	0.00	1.40	6.0	8.1	34.3	1.01	2.7	-0.2	-11		43.8	44.4	3.2	266	260	243	254	5.70	336	237	43	1	12.65	-0.3	5.90	325	130	54	1	12.47	28.9
799	4/27/94 8:03	99	4.20	b	0	0	0.0	0.00	0.00	0.0	0.0	34.3	0.00		0.5			-1.8		-8.2	257	250	234	245	6.20	331	256	88	2	12.51	1.8							
799	4/27/94 12:44	99	4.20	b	0	20	22.7	0.65	0.00	0.0	0.0	34.3	0.00	14.0	37.7	94	57.6	-2.1		3.6	259	253	240	250	6.20	331	256	88	2	12.51	1.8							
799	4/27/94 14:09	99	4.20	b	0	20	22.7	0.64	0.00	0.0	0.0	34.3	0.00	17.7	26.6	36	41.7	2.6		-1.3	257	251	242	249	6.20	331	256	88	2	12.51	1.8							
799	4/27/94 15:20	99	4.20	b	0	20	22.7	0.65	0.00	0.0	0.0	34.3	0.00	12.9	35.2	89	54.5	3.1		-0.3	257	251	241	249	6.20	331	256	88	2	12.51	1.8							
800	4/27/94 16:55	83	5.20	b	0	20	22.7	0.77	0.00	0.0	0.0	34.3		21.3	56.2	139	73.1			7.6	250	244	234	243														
800	4/27/94 17:30	83	5.20	b	0	20	22.7	0.76	0.00	0.0	0.0	34.3	0.00	22.3	56.4	136	73.8	7.0		8.0	249	243	242	233	7.30	299	246	34	1	11.50	2.3							
801	4/28/94 7:40	100	4.20	b	0	0	0.0	0.00	0.00	0.0	0.0	34.3	0.00	0.0	1.0	4		0.1		0.1	254	249	232	243	6.30	326	251	89	2	12.35	1.2							
802	NO TEST PULVERIZER VIBRATION																																					
803	5/2/94 12:40	90	4.80	b	0	0	0.0	0.00	0.00	0.0	0.0	34.3	0.00		12.1			16.1							7.00	330	240	41	2	12.17	1.4							
803	5/2/94 18:00	85	5.30	b	0	30	33.7	1.06	0.77	2.4	8.1	34.3	0.63	21.9	74.7	218	69.2	31.8			272	268	259	267	7.00	331	224	70	1	12.26	1.2							
803	5/2/94 20:00	85	5.50	b	0	30	33.7	1.04	0.74	2.4	8.2	34.3	0.61	21.4	55.7	147	53.5	31.4			270	266	259	266	7.00	331	224	70	1	12.26	1.2							
803	5/2/94 22:00	85	5.40	b	0	30	33.7	1.01	0.72	2.4	8.2	34.3	0.59	25.2	68.8	192	67.9	24.7			268	263	255	263	7.00	331	224	70	1	12.26	1.2							
803	5/2/94 23:45	85	5.30	b	0	30	33.7	1.03	0.71	2.4	8.2	34.3	0.58	29.6		306					263	258	250	258	7.00	331	224	70	1	12.26	1.2							
803	5/3/94 1:15	85	5.30	b	0	30	33.7	1.04	0.78	2.4	8.1	34.3	0.64	29.1	74.2	194	71.6	30.0			263	258	248	257	7.00	331	224	70	1	12.26	1.2							
803	5/3/94 3:15	85	5.10	b	0	30	33.7	1.04	0.78	2.4	8.2	34.3	0.62	26.7	73.0	198	70.1	30.6			264	260	250	259	7.00	331	224	70	1	12.26	1.2							
803	5/3/94 5:15	85	5.20	b	0	30	33.7	1.05	0.73	2.4	8.2	34.3	0.60	24.9	66.4	176	63.3	29.6			265	260	250	259	7.00	331	224	70	1	12.26	1.2							
803	5/3/94 7:15	85	5.20	b	0	30	33.7	1.05	0.73	2.4	8.1	34.3	0.60	28.6	64.1	151	61.2	27.8	21.0	8.5	268	261	252	260	7.00	331	224	70	1	12.26	1.2	7.95	304	165	54	0	11.35	18.3
803	5/3/94 9:15	85	6.30	b	0	30	33.7	1.06	0.59	2.4	8.0	34.3	0.48	20.5	62.1	177	59.3	27.8			268	263	253	262	7.00	331	224	70	1	12.26	1.2							
803	5/3/94 11:15	85	5.40	b	0	30	33.7	1.01	0.70	2.4	8.2	34.3	0.57	23.9	69.2	199	66.2	26.5			272	267	257	266	7.00	331	224	70	1	12.26	1.2							
803	5/3/94 14:12	85	5.30	b	0	30	33.7	1.07	0.77	2.4	8.1	34.3	0.63	21.5	72.0	210	67.0	30.7			278	273	263	271	7.00	331	224	70	1	12.26	1.2							
803	5/3/94 16:50	84	5.30	b	0	30	33.7	1.06	0.74	2.4	8.2	34.3	0.61	26.8	70.9	187	66.7	35.9			272	268	259	267	7.00	331	224	70	1	12.26	1.2							
803	5/3/94 19:00	84	5.20	b	0	30	33.7	1.07	0.73	2.4	8.2	34.3	0.61	23.2	65.7	178	61.2	36.3			276	270	262	269	7.00	331	224	70	1	12.26	1.2							
803	5/3/94 21:00	85	5.20	b	0	30	33.7	1.04	0.69	2.4	8.1	34.3	0.57	24.9	69.6	192	67.0	34.1	28.6	7.7	269	264	258	265	7.00	331	224	70	1	12.26	1.2	7.00	330	160	78	1	12.19	20.7
803	5/4/94 1:45	60	7.40	b	0	0	0.0	0.00	0.26	2.3	8.1	34.3	0.29	1.9	4.0	9		15.8	14.0	2.0	256	251	241	250	9.50	273	190	30	0	10.30	2.2	9.60	271	162	38	0	10.02	7.1
803	5/4/94 3:30	60	7.30	b	0	24	27.1	1.17	0.27	2.3	8.2	34.3	0.30	28.7	66.6	166	56.5	22.7			254	249	239	248	9.50	273	190	30	0	10.30	2.2							
803	5/4/94 5:00	60	7.30	b	0	24	27.1	1.13	0.30	2.3	8.2	34.3	0.34	32.9	75.6	164	66.7	25.1			253	249	237	247	9.50	273	190	30	0	10.30	2.2							
803	5/4/94 6:30	60	7.40	b	0	24	27.1	1.13	0.33	2.3	8.2	34.3	0.37	32.5	76.1	169	67.4	24.2			253	248	237	247	9.50	273	190	30	0	10.30	2.2							
803	5/4/94 8:03	60	7.30	b	0	24	27.2	1.16	0.29	2.3	8.1	34.3	0.33	29.5	74.2	166	62.8	24.2			253	248	236	241	9.50	273	190	30	0	10.30	2.2							
803	5/4/94 11:20	86	5.00	b	0	24	27.2	0.86	0.69	2.3	8.1	34.3	0.56	17.7	56.2	160	65.8	37.0			274	268	256	265	7.00	331	224	70	1	12.26	1.2							
803	5/4/94 13:50	88	4.70	b	0	30	33.6	1.02	0.66	2.3	8.1	34.3	0.55	23.4	73.0	214	71.7	43.2			278	272	264	268	7.00	331	224	70	1	12.26	1.2							
803	5/4/94 15:45	85	5.60	b	0	30	33.6	1.00	0.66	2.3	8.1	34.3	0.56	25.6	70.2	197	70.0	38.7			280	274	266	270	7.00	331	224	70	1	12.26	1.2							
803	5/4/94 20:15	77	5.70	b	0	0	0.0	0.00	0.58	2.3	8.1	34.3	0.54	0.2	12.6	53		28.4	24.5	2.1	274	268	261	264	6.70	328	222	102	1	12.60	1.0	6.50	340	170	88	0	12.45	18.0
803	5/4/94 21:30	85	5.00	b	0	24	27.1	0.81	0.76	2.3	8.1	34.3	0.66	21.5	57.7	160	71.5	32.8			274	268	261	264	6.35	340	222	77	1	12.41	1.3							
803	5/4/94 23:25	82	5.00	b	0	30	33.7	1.05	0.56	2.3	8.1	34.3	0.49	23.6	67.3	191	64.1	31.6			269	263	257	261	6.35	340	222	77	1	12.41	1.3							
803	5/5/94 1:15	82	5.10	b	0	30	33.7	1.07	0.53	2.3	8.1	34.3	0.48	23.2	58.2	150	54.4	30.7	19.6	13.5	269	263	256	259	6.35	340	222	77	1	12.41	1.3	6.80	337	173	73	0	12.19	20.2
803	5/5/94 2:35	65	6.50	b	0	24	27.1	1.04	0.22	2.3	8.1	34.3	0.23	25.7	64.6	170	62.0	23.7	12.2	13.5	260	255	249	253	8.50	280	210	40	3	10.68	3.7	8.60	270	183	47	3	10.62	11.8
803	5/5/94 4:30	65	6.90	b	0	24	27.1	1.06	0.28	2.3	8.1	34.3	0.29	24.4	64.9	171	60.3	24.3			262	256	248	252	8.50	280	210	40	3	10.68	3.7							
803	5/5/94 6:15	65	6.90	b	0	24	27.1	1.09	0.25	2.3	8.0	34.3	0.26	23.9	66.3	177	60.8	26.0			262	256	248	253	8.50	280	210	40	3	10.68	3.7							
803	5/5/94 8:30	72	6.30	b	0	24	27.1	0.95	0.39	2.3	8.4	34.3	0.36	26.9	67.6	178	71.1	27.9	15.6	14.2	268	262	252	258	7.95	300	220	50	2	11.39	1.2	8.00	300	185	51	1	11.12	12.7
803	5/5/94 12:30	91	5.10	b	0	30	33.7	0.98	0.85	3.6	7.6	34.3	0.64	21.8	58.8	158	60.0	36.7	29.2	10.1	283	278	268	272	6.30	335	240	62	1	12.57	1.5	6.20	338	171	64	0	12.61	25.8
803	5/5/94 15:00	109	4.60	b	0	30	33.7	0.99	1.10	4.8	7.9	34.3	0.58	16.2	52.9	130	53.5	37.5	26.6	12.0	295	287	280	283	5.90	288	295	35	1	12.20	0.7	5.90	290	210	43	0	12.33	26.0
803	5/5/94 16:55	109	4.50	b	0	30	33.7	0.99	1.14	4.8	8.0	34.3	0.60	18.4	57.6	139	58.2	35.5			294	288	282	284	5.90	288	295	35	1	12.20	0.7							
803	5/5/94 18:25	90	5.20	b	0	30	33.7	1.04	0.66	2.3	8.0	34.3			63.1		60.7				282	277	274	276														
803	5/5/94 20:20	84	5.40	b	0	24	27.1	0.89	0.66	2.3	8.1	34.3	0.52	19.5	61.7	172	69.6	32.2	23.0	11.6	273	269	258	266	6.60	300	245	44	2	11.89	0.6	6.70	310	190	56	1	12.13	19.2
803	5/5/94 22:30	84	5.50	b	0	24	27.1	0.89	0.76	2.3	8.1	34.3	0.59	22.1	58.6	149	66.3	34.4			267	262	255	262	6.60	300	245	44	2	11.89	0.6							
803	5/6/94 0:25	85	5.50	b	0	24	27.1	0.89	0.78	2.3	8.1	34.3	0.58	20.2	61.5	167	69.3	35.1			265	260	253	260	6.60	300	245	44	2	11.89	0.6							
803	5/6/94 2:45	85	5.50	b	0	24	27.1	0.89	0.60	2.3	8.1	34.3	0.46	17.5	50.1	131	56.4	32.2			263	259	251	257	6.60	300	245	44	2	11.89	0.6							
803	5/6/94 4:20	85	5.50	b	0	24	27.1	0.90	0.71	2.3	8.1	34.3	0.54	19.1	54.3	140	60.6	31.2			265	259	251	258	6.60	300	245	44	2	11.89	0.6							
803	5/6/94 8:12	90	4.90	b	0	0	0.0		0.78	2.3	8.1	34.3	0.56			27		32.1	26.1	5.2	272	266	254	262	6.30	319	249	45	1	12.54	0.2	6.30	319	179	69	0	12.48	21.1
803	5/6/94 10:35	90	4.90	b	0	30	33.7	1.06	0.86	3.6	7.3	34.3	0.63	22.1	60.9	155	57.4	37.3			271	264	257	264	6.30	319	249	45	1	12.54	0.2							
803	5/6/94 12:40	90	4.70	b	0	30	33.7	1.00	0.84	3.6	7.1	34.3	0.62	20.2	65.1	169	64.8	40.6			271	265	258	265	6.30	319	249	45	1	12.54	0.2							
803	5/6/94 14:40	90	4.60	b	0	30	33.7	0.82	0.79	3.6	8.4	34.3	0.58	21.6	64.0	219	78.3	45.4			273	268	260	267	6.30	319	249	45	1	12.54	0.2							
803	5/6/94 16:05	90	4.50	b	0	30	33.7	0.83	0.89	3.6	8.0	34.3	0.65	19.2	58.9	203	71.3	42.9			274	268	261	268	6.30	319	249	45	1	12.54	0.2							
803	5/7/94 11:25	80	5.60	b	0	24	27.1	0.72	0.51	2.3	8.0	34.3	0.47	20.9	48.9	147	67.6	32.0	20.8	13.5	270	262	254	260	6.70	410	215	41	2	12.33	1.8	6.80	415	169	53	0	12.06	17.9
803	5/7/94 13:30	80	5.60	b	0	24	27.1	0.77	0.57	2.3	8.0	34.3	0.53	18.2	49.6	155	64.5	32.7			276	267	258	264	6.70	410	215	41	2	12.33	1.8							
803	5/7/94 16:20	80	5.70	b	0	30	33.7	1.01	0.85	2.3	8.0	34.3	0.60		63.2		62.9	30.1			275	271	265	272	6.70	410	215	41	2	12.33	1.8							

PSCC Arapahoe Unit 4 Sodium/Urea Injection Summary

		Econ Exit, dry (1,2,11,12): w/Sorb							Baghouse Inlet Gas Analysis (AHO 1-6,dry)									Stack Gas Analysis, wet									WET CHEM NH3		
Test	Date & Time	O2 %dry	SO2 ppm	NO ppm	CO ppm	NO2 ppm	CO2 %	N2O ppm	O2 %	SO2 ppm	NO ppm	CO ppm	NO2 ppm	CO2 %	H2O %	N2O ppm	NH3 ppm	O2 %	SO2 ppm	NO ppm	CO ppm	NO2 ppm	CO2 %	H2O %	N2O ppm	NH3 ppm	inlet ppm	stk ppm	Comments
797	4/25/94 15:10	7.10	283	121	70	1	11.06	27.1										5.40	145	119	45	0	11.26	9.0	29.5	9.7			
797	4/25/94 15:35	7.10	284	128	57	0	11.31	23.5	5.90	253	137	51	2	12.23	0.0	30.0	1.6	5.10	132	100	47	-2	11.16	9.0	36.6	10.0	27.3		Feed becoming erratic, running out of bc
797	4/25/94 17:30																	5.70	275	215	28	-1	11.04	8.5	3.0	6.2			
798	4/26/94 7:55	7.60	298	204	43	2	11.23	-0.3	5.70	336	237	43	1	12.65	0.0	-0.3	2.7	5.30	305	205	64	-3	11.50	8.6	1.6	2.3			
798	4/26/94 0:00																	5.20	299	102	65	-3	11.48	9.0	46.0	2.9			
798	4/26/94 10:16	7.30	296	124	72	0	11.33	23.7	5.40	326	145	57	0	12.77	0.0	30.1	2.1	5.20	301	124	49	-3	11.48	9.0	31.0	11.9	20.9		ABORT:ERRATIC FEED
799	4/27/94 8:03	7.70	301	217	163	2	11.26	0.6										6.00	298	237	51	-2	11.26	8.4	3.0	0.5			
799	4/27/94 12:44	6.50	275	229	66	2	10.26	4.1	6.30	278	261	66	5	12.31	0.0	1.6	0.5	6.20	179	232	44	1	11.03	8.3	2.7	1.7			
799	4/27/94 14:09	7.60	303	224	102	1	11.36	6.1	5.80	263	262	63	4	12.60	0.0	2.7	0.4	5.90	221	227	62	-1	11.25	8.5	3.8	2.8			FFDC clean1330-1409
799	4/27/94 15:20	7.80	294	222	131	1	11.13	3.8	6.10	269	259	192	4	12.54	0.0	0.6	-0.3	5.90	192	225	93	0	11.35	8.6	4.2	2.8			
800	4/27/94 16:55	8.70	272	227	33	1	10.34	1.9	7.10	242	249	27	7	11.51	0.0	2.4	0.4	6.70	122	213	27	3	10.58	8.1	2.8	2.2			
800	4/27/94 17:30	8.70	273	225	37	1	10.37	2.6	7.10	240	246	31	6	11.62	0.0	2.1	0.2	6.80	122	208	26	4	10.55	7.9	3.5	1.6			
801	4/28/94 7:40	7.80	299	226	81	1	11.18	2.8	7.80	299	226	81	1	11.18	0.0	2.8	0.9	5.60	305	235	53	-2	11.46	8.6	3.3	0.8			
802	NO TEST PULVERIZER VIBRATION																												
803	5/2/94 12:40	8.00	312	213	51	1	11.46	1.7										6.30	310	213						1.5			Base@90MW, Urea on 1510, DSI on 1615
803	5/2/94 18:00	9.10	273	140	57	1	10.30	22.7	7.15	245	163	55	6	12.00	0.8	24.0	1.5	6.90	71	135	59	-1	11.00	9.0	23.9	3.5			1726 mill probs, go to 85MW
803	5/2/94 20:00	8.75	291	142	69	0	10.63	18.7	7.20	255	170	50	6	12.53	0.7	23.1	0.9	6.75	130	133	51	3	11.00	9.0	24.1	3.7			FFDC clean 1923-1958
803	5/2/94 22:00	9.25	287	150	93	0	10.36	14.6	7.65	241	175	53	4	11.54	0.8	20.0	1.4	7.25	91	140	52	4	10.51	8.6	21.0	3.3			Sootblow 2055-2315
803	5/2/94 23:45	8.70	298	161	66	1	10.70	14.1	7.20	231	165	66	5	11.97	0.8	22.0	0.6												
803	5/3/94 1:15	8.40	301	156	67	0	10.97	14.6	7.15	232	166	56	5	12.05	0.8	22.0	1.0	7.05	75	135	54	2	10.71	8.6	22.0	5.0			DSI off 0003-0040
803	5/3/94 3:15	8.60	295	149	103	0	10.74	14.8	7.40	234	160	55	5	11.64	0.8	21.2	1.4	7.10	78	134	50	1	10.52	8.4	20.9	4.0			
803	5/3/94 5:15	9.00	283	147	83	0	10.46	17.7	7.50	236	169	59	4	11.75	0.8	19.3	0.2	7.10	98	138	90	-1	10.54	8.4	19.4	3.7			DSI off 0418-0447
803	5/3/94 7:15	8.95	285	150	75	0	10.46	0.8	7.50	225	172	153	5	11.83	0.8	20.3	1.0	7.10	103	131	51	10	10.73	8.5	21.7	3.8			FFDC clean 0610-0645
803	5/3/94 9:15	9.45	273	152	78	0	10.11	13.2	7.52	250	173	48	4	11.66	0.8	19.5	1.3	7.20	108	135	45	5	10.53	8.3	20.4	3.8			DSI off 0805-0835
803	5/3/94 11:15	9.60	278	143	56	0	10.12	15.0	7.36	250	166	55	5	11.91	0.8	21.3	1.3	7.42	89	133	41	7	10.50	8.2	20.6	3.8			DSI off 0957-1010
803	5/3/94 14:12	8.55	287	136	86	-1	10.59	17.0	6.75	255	160	71	4	12.29	0.8	21.7	1.3	7.00	79	135	58	1	11.00	8.4	23.3	4.5			DSI off1210-1234
803	5/3/94 16:50	8.60	292	136	79	0	11.04	16.4	6.90	240	158	62	5	12.27	0.9	23.2	1.1	6.55	86	130	58	-1	11.20	9.0	23.7	5.0			DSI off 1430-1600
803	5/3/94 19:00	8.55	290	145	104	0	11.02	14.6	6.90	249	156	76	5	12.26	0.9	23.2	0.5	6.60	100	121	72	7	11.16	9.0	24.6	4.2			FFDC clean 1740-1815
803	5/3/94 21:00	8.00	310	141	123	0	11.31	15.6	6.90	249	160	74	5	12.29	0.9	22.1	1.2	6.70	90	128	65	3	11.05	9.0	24.0	4.5			Sootblow 1853-2112
803	5/4/94 1:45	10.6	250	149	40	0	9.36	4.9	9.00	279	171	45	0	10.47	0.8	8.5	0.7	8.75	245	150	36	-2	9.56	7.8	9.5	3.7			DSI off 2135-0223, Urea off 2206-0130
803	5/4/94 3:30	10.6	241	147	34	0	8.96	5.8	9.20	192	161	38	5	10.33	0.9	8.5	1.6	8.80	77	137	37	-2	9.46	7.8	10.1	3.5			Now using #6 SNCR pump
803	5/4/94 5:00	10.6	249	150	35	0	9.24	5.1	9.00	190	156	38	5	10.35	0.9	9.0	1.3	8.75	62	132	37	0	9.56	7.7	10.0	3.6			
803	5/4/94 6:30	10.6	250	150	38	0	9.40	5.1	9.00	192	158	44	5	10.49	0.8	8.9	0.7	8.75	61	133	36	0	9.60	7.7	10.2	3.1			
803	5/4/94 8:03	10.6	240	150	39	0	9.11	6.0	9.03	192	159	42	5	10.49	0.8	9.1	1.2	8.82	63	132	35	1	9.53	7.7	9.7	2.9			DSI off 1030-1050
803	5/4/94 11:20	8.45	290	126	335	2	10.86	21.9	6.90	266	154	119	4	12.41	0.8	29.2	0.7	6.60	127	127	104	0	11.16	8.8	24.5	3.4			Load increased to 86MW, DSI setpoint unchanged
803	5/4/94 13:50	8.90	290	140	94	0	10.65	20.6	6.50	263	152	116	4	12.64	0.8	27.7	1.3	4.90	92	130	155	0	11.13	8.9	23.9	3.6			Changed Urea nozzles to larger size 1220
803	5/4/94 15:45	8.80	300	140	80	0	10.91	17.6	6.36	266	147	91	4	12.99	0.8	25.1	0.9	6.70	91	122	62	0	11.24	9.0	26.2	4.0			FFDC clean 1640-1715
803	5/4/94 20:15	8.80	290	150	133	0	10.36	8.4	6.50	340	170	86	0	12.45	0.8	18.0	0.9	7.00	252	141	114	-2	10.58	8.9	21.2	3.0			DSI off 1930-2035, Urea off 1930-2000
803	5/4/94 21:30	8.50	308	137	209	0	10.93	18.6	6.50	277	151	166	3	12.54	0.9	26.6	0.6	6.50	132	130	76	-1	10.76	8.8	23.9	3.9			Load slowly increased to 85MW
803	5/4/94 23:25	8.40	307	142	116	0	11.01	15.1	6.85	260	161	67	4	12.22	0.8	20.4	0.2	6.70	99	130	68	-1	11.03	8.9	21.1	4.2			Sootblow 1910-2224, FFDC Clean 2335-0008
803	5/5/94 1:15	8.20	306	148	103	0	11.10	15.6	7.10	252	159	77	6	11.93	0.8	21.5	1.1	6.80	124	131	63	0	10.77	8.6	20.9	2.6			DSI off 0008-0045,m Urea off 0008-0031
803	5/5/94 2:35	9.10	289	161	76	0	10.61	8.3	8.70	219	188	44	6	10.50	0.8	9.8	1.5	8.30	85	139	36	5	9.76	7.9	10.7	3.2			0130 drop to 65MW
803	5/5/94 4:30	9.20	277	154	70	1	10.06	9.2	8.50	219	170	56	5	10.72	0.8	13.3	0.4	8.40	90	139	46	2	9.52	7.9	14.2	2.3			DSI off 0303-0334, Urea off 0317-0334
803	5/5/94 6:15	9.65	283	156	56	0	9.80	8.7	8.40	219	169	58	5	10.61	0.8	12.6	0.4	8.45	85	135	48	2	9.49	7.9	13.6	1.6			
803	5/5/94 8:30	8.95	293	157	161	0	10.67	9.0	7.90	230	166	104	4	11.29	0.8	16.3	-0.5	7.65	90	140	74	0	10.03	8.2	15.0	2.4	11.4		DSI off 0915-1015, Urea off 0915-0945, FFDC 1015-1045
803	5/5/94 12:30	8.25	302	145	100	0	11.03	19.5	6.25	270	180	76	3	12.55	0.8	30.5	0.1	6.45	124	132	59	0	10.98	8.7	25.8	3.1	20.5		DSI off 1100-1140, Urea off 1103-1125
803	5/5/94 15:00	8.05	255	156	61	0	10.60	22.1	5.85	247	202	40	3	12.21	0.8	26.5	0.0	5.85	121	155	36	5	10.77	10.0	27.0	3.0			DSI off 1525-1605, Urea off 1548-1605
803	5/5/94 16:55	7.80	260	169	75	0	10.77	21.0	5.90	240	207	41	3	12.20	0.8	25.5	0.4	6.00	106	163	36	0	10.56	8.9	26.0	3.7	13.7		Gas on Burners 4,5&12 1413-1744
803	5/5/94 18:25	8.90	273	170	47	0	10.41	14.9										6.65	104	139	44	3	10.61	8.9	24.4	3.0			Quick test, dropping load
803	5/5/94 20:20	9.10	270	168	48	0	10.36	13.0	6.80	256	177	59	3	12.14	0.9	20.6	0.5	6.65	109	145	57	3	10.67	8.7	20.1	2.5	27.9		Sootblow 1906-2130
803	5/5/94 22:30	8.90	275	170	46	0	10.55	12.6	6.70	250	189	49	4	12.19	0.8	20.4	0.0	6.60	116	142	45	1	10.94	8.8	22.0	2.5	14.2		DSI off 2034-2106, Urea off 2034-2051
803	5/6/94 0:25	8.90	271	162	55	0	10.60	13.2	6.60	254	172	53	4	12.24	0.9	21.6	0.2	6.60	106	140	48	1	11.04	8.9	21.9	2.6	13.1		
803	5/6/94 2:45	8.60	273	165	48	1	10.36	13.0	6.80	259	179	48	4	12.44	0.8	20.2	-0.1	6.50	141	140	42	9	11.02	9.0	22.0	2.0	8.8		FFDC clean 0135-0210
803	5/6/94 4:20	9.20	262	12	50	0	10.17	13.5	6.90	250	175	45	4	12.01	0.9	21.4	0.5	6.75	126	140	40	9	10.85	8.8	22.7	2.7	13.8		
803	5/6/94 8:12								6.30	319	179	69	0	12.46	0.8	21.1	0.6	6.10	266	152	58	-2	11.21	9.1	22.2	1.9			Sootblow 0730-, DSI off 0635-0820, Urea off 0742-0800
803	5/6/94 10:35	7.95	289	163	82	0	11.25	15.7	6.15	253	173	60	4	12.64	0.9	24.0	0.6	5.90	114	135	57	5	11.49	9.3	24.7	4.3			FFDC clean 0850-0925
803	5/6/94 12:40	7.65	312	150	148	0	11.58	17.4	6.03	276	166	77	4	12.81	0.9	24.0	0.7	5.80	108	131	75	3	11.51	9.4	24.6	3.6	19.9		
803	5/6/94 14:40	7.95	375	140	422	1	11.26	20.2	5.90	336	155	152	4	12.97	0.8	22.2	0.2	5.55	139	123	158	2	11.71	9.6	24.4	3.5	13.5		
803	5/6/94 16:05	8.05	368	150	164	0	11.23	19.6	5.60	345	155	216	4	13.00	0.8	24.3	0.0	5.75	155	128	133	1	11.59	9.5	22.7	3.3	4.8		FFDC1710-1740, DSI off 1640-1700,urea off 1745-1815
803	5/7/94 11:25	8.30	369	139	61	3	10.96	17.2	6.70	323	152	56	6	12.10	1.2	19.6	0.9	6.60	186	119	53	10	10.99	8.9	20.0	2.5	6.3	4.4	FFDC 0905-0940, DSI off 1145-1237,urea off 1145-1210
803	5/7/94 13:30	8.60	339	141	75	0	10.76	14.8	6.80	314	164	55	3	12.36	0.8	19.1	0.9	6.80	170	124	45	2	10.80	8.9	22.5	3.0			Sootblow 1330-1600
803	5/7/94 16:20	8.50	325	154	67	0	10.78	15.7										6.60	120	130	49	3	10.88	8.8	21.3	3.3			

PSCC Arapahoe Unit 4 Sodium/Urea Injection Summary
Modified for Air Heater Injection

Calcs based on: Bicarbonate (b) 0.274
Sesquicarb. (s) 0.297

				Sorbent Feed			Injector cal		Urea Injection--------					ΔSO2 Reduction				ΔNOx Calcs----------			Baghouse Temps				Economizer Exit, dry (1-12): Base							Economizer Exit, dry (1-12): w/SNCR						
Test	Date & Time	Load	O2cr	Na	A (w)	B (e)	Flow	2Na S*	Urea	Total	Inj air	Conc	N/NO	Inlet	Stk		Util	Overall	SNCR	Na	Taho	Grid	Out	IDin	O2	SO2	NO	CO	NO2	CO2	N2O	O2	SO2	NO	CO	NO2	CO2	N2O
		MWe	%wet	b/s	%	%	lb/min		gpm	gpm	psi	wt%		%	%	ppmc	%	%	%	%	°F	°F	°F	°F	%dry	ppm	ppm	ppm	ppm	%	ppm	%dry	ppm	ppm	ppm	ppm	%	ppm
803	5/8/94 10:40	80	6.20	b	0	24	27.1	0.91	0.55	2.3	8.2	34.3		18.4	58.3	165	63.7				273	268	255	264														
803	5/8/94 12:50	76	6.40	b	0	24	27.1	0.98	0.40	2.3	8.1	34.3		19.9	64.0	182	66.6				271	266	258	265														
803	5/8/94 15:10	78	6.30	b	0	24	27.1	0.94	0.41	2.3	8.2	34.3	0.34	19.9	67.5	198	71.9	31.3	13.6	20.1	270	265	258	264	7.70	298	232	34	1	11.34	0.9	7.60	296	202	42	0	11.43	10.6
803	5/9/94 8:40	80	6.10	b	0	0	0.0		0.52	2.3	8.1	34.3	0.41			19		28.2	19.2	9.1	268	261	249	257	7.75	297	235	27	1	11.55	0.7	7.60	289	192	43	2	10.64	12.0
803	5/9/94 9:55	74	6.30	b	0	24	27.1	0.97	0.52	2.3	8.2	34.3		23.0	56.9	142	58.6				259	254	246	254														
803	5/9/94 12:35	91	5.00	b	0	30	33.7	1.00	0.65	2.3	8.1	34.3		24.9	66.5	173	66.3				271	264	256	263														
803	5/9/94 16:18	80	5.80	b	0	30	33.7	1.14	0.62	2.3	8.1	34.3		26.2	77.5	212	68.2				264	260	254	262														
803	5/10/94 8:20	54	7.70	b	0	21	23.6	1.14	0.00	2.3	8.4	34.3	0.00	30.2	68.2	156	60.1	4.5			247	241	231	238	9.40	181	203	37	10	9.88	2.9							
803	5/10/94 11:15	54	7.70	b	0	21	23.6	1.10	0.00	2.3	8.0	34.3	0.00	28.1	71.7	194	65.4	7.7			252	246	237	244	9.30	201	202	36	9	10.11	1.3							
803	5/10/94 14:15	54	7.90	b	0	21	23.6	0.99	0.00	2.3	8.0	34.3		29.9	69.4	185	69.8				257	251	243	250														
803	5/11/94 9:55	65	6.30	b	0	0	0.0		0.00	0.0	0.0	34.3									251	248	231	240														
803	5/11/94 15:00	65	6.60	b	0	0	0.0		0.00	2.3	8.0	34.3									267	262	249	255														
804	5/12/94 8:10	103	4.60	b	0	0	0.0		1.02	4.8	8.0	34.3	0.65					32.8	33.8	-1.9	273	266	251	260	6.80	405	242	92	1	12.36	-0.8	6.90	403	159	85	0	12.26	22.9
804	5/12/94 13:30	108	4.80	b	0	0	0.0		1.18	4.8	8.0	31.6	0.61					41.0	39.6	1.9	288	282	272	278	6.70	404	265	164	1	12.34	2.6	6.70	395	160	197	0	12.25	26.0
804	5/12/94 16:20	108	4.60	b	0	0	0.0		1.18	5.8	8.0	31.6	0.61					40.7	42.0	-2.8	290	285	278	280	6.70	404	265	164	1	12.34	2.6	6.40	422	157	226	0	12.53	29.4
804	5/13/94 6:30	101	4.80	b	0	0	0.0		1.26	5.8	8.2	31.6	0.72					39.5	45.2	-9.4	289	263	248	255	7.00	395	250	77	1	11.93	1.4	6.40	409	143	141	2	12.60	26.3
804	5/13/94 9:10	68	6.70	b	0	0	0.0		0.28	2.3	8.2	31.6	0.25					12.4	12.9	-0.4	253	248	240	246	8.60	339	210	37	0	10.89	1.4	8.60	339	183	48	0	10.84	8.7
804	5/13/94 11:50	68	6.70	b	0	0	0.0		0.28	2.3	8.2	31.6	0.25					10.5	13.6	-3.7	254	248	238		8.60	339	210	37	0	10.89	1.4	8.70	329	180	43	0	10.72	7.9
804	5/13/94 13:20	80	6.10	b	0	0	0.0		0.68	2.3	8.1	31.6	0.51					21.8	26.2	-6.1	258	251	238	247	7.60	330	230	40	1	11.72	1.3	7.50	341	171	57	0	11.79	16.8
805	5/17/94 15:11	103	4.40	b	0	0	0.0	0.00	0.00	0.0	0.0	34.3	0.00	2.7	6.9	18		4.2		-4.5	282	274	262	269	8.30	298	224	116	2	10.62	5.2	8.30	298	224	116	2	10.62	5.2
805	5/17/94 17:48	101	4.36	b	0	34	38.2	0.00	0.00	0.0	0.0	31.6	0.00	21.5	59.7	163		10.2		3.2	289	282	276	281	8.30	298	224	116	2	10.62	5.2	8.30	298	224	116	2	10.62	5.2
805	5/18/94 7:56	81	5.80	b	0	30	33.7	0.00	0.00	0.0	0.0	31.6	0.00	25.3	76.5	208		10.1		-1.7	255	249	241	249	8.20	288	205	37	2	10.95	2.0	8.20	288	205	37	2	10.95	2.0
805	5/18/94 9:35	104	4.60	b	0	30	33.7	0.00	0.00	0.0	0.0	31.6	0.00	18.4	51.4	141		1.1		11.5	278	270	260	267	7.80	298	229	73	1	11.23	2.1	7.80	298	229	73	1	11.23	2.1
805	5/18/94 12:30	104	4.60	b	0	30	33.7	0.00	0.00	0.0	0.0	31.6	0.00	14.6	51.4	146		1.6		2.3	281	273	266	273	8.20	283	231	106	1	10.90	2.9	8.20	283	231	106	1	10.90	2.9
806	5/19/94 9:41	100	4.70	b	0	30	33.7	0.00	0.00	0.0	0.0	31.6	0.00	17.6	57.5	157		4.6		9.2	270	263	254	261	7.50	294	220	131	2	11.37	3.6	7.50	294	220	131	2	11.37	3.6
806	5/19/94 10:00	100	4.70	b	0	30	33.7	0.00	0.00	0.0	0.0	31.6	0.00	17.6	58.2	160		3.4		5.2	270	263	254	261	7.50	294	220	131	2	11.37	3.6	7.50	294	220	131	2	11.37	3.6
807	5/19/94 11:00	80	5.90	b	0	20	22.7	0.00	0.00	0.0	0.0	31.6	0.00	18.6	54.2	137		7.0		2.9	267	261	255	261	8.50	268	221	35	1	10.55	3.1	8.50	268	221	35	1	10.55	3.1
808	5/19/94 13:00	97	4.70	b	0	48	53.1	0.00	0.00	0.0	0.0	31.6	0.00	31.1	77.7	184		2.5		5.9	278	273	265	270	7.80	290	212	106	1	11.29	3.7	7.80	290	212	106	1	11.29	3.7
809	5/19/94 14:00	80	5.90	b	0	48	53.7	0.00	0.00	0.0	0.0	31.6	0.00	27.2	80.2	207		12.5		3.3	273	268	262	269	8.60	269	220	34	1	10.53	2.3	8.60	269	220	34	1	10.53	2.3
810	5/19/94 15:30	80	5.90	b	0	45	50.7	0.00	0.00	0.0	0.0	31.6	0.00	29.9	65.9	221		16.8		3.0	272	266	260	266	9.00	263	212	32	0	10.25	2.2	9.00	263	212	32	0	10.25	2.2
810	5/19/94 16:30	80	5.90	b	0	45	50.3	0.00	0.00	0.0	0.0	31.6	0.00		65.4			18.1		14.1	272	266	260	266	9.25	255	211	24	0	9.68	1.5	9.25	255	211	24	0	9.68	1.5
SODIUM SESQUICARBONATE AIR HEATER INJECTION																																						
812	5/23/94 10:38	103	3.40	s	0	0	0.0	0.00	0.00	0.0	0.0	31.6	0.00	0.8	4.6	18		-3.7	15	-4.1	281	274	263	271	4.90	410	248	216	2	13.85	6.2	4.90	410	248	216	2	13.85	6.2
812	5/23/94 12:35	102	3.40	s	0	45	39.4	0.00	0.00	0.0	0.0	31.6			29.0					-1.0	287	280	271	276														
813	5/23/94 14:00	110	3.90	s	0	45	39.6	0.00	0.00	0.0	0.0	31.6	0.00	5.3						-1.9	292	288	278		5.20	320	285	30	2	12.34	0.5							
813	5/23/94 15:40	107	3.90	s	0	45	39.6	0.00	0.00	0.0	0.0	31.6		19.2	31.2	97				-8.5	290	283	278	282														
814	5/23/94 16:06	108	3.80	s	0	75	67.6	0.00	0.00	0.0	0.0	31.6		24.0	74.7	195				-2.0	288	283	277															
815	5/23/94 17:45	95	4.00	s	0	75	67.6	0.00	0.00	0.0	0.0	31.6		23.3	67.9	234				3.1	282	278	275	282														
816	5/23/94 19:25	96	4.10	s	0	45	39.4	0.00	0.00	0.0	0.0	31.6		16.3	50.1	178				3.2	277	272	269	274														
817	5/24/94 8:10	106	3.90	s	0	0	0.0	0.00	0.00	0.0	0.0	31.6		0.4	-3.8	-21				-4.6	277	269	254	264														
817	5/24/94 11:35	105	3.90	s	0	71	63.6	0.00	0.00	0.0	0.0	31.6		17.3	54.7	186				-6.4	285	277	270	277														
817	5/24/94 12:40	104	4.10	s	0	71	63.6	0.00	0.00	0.0	0.0	31.6		21.9	63.7	221				-1.5	286	279	277	278														
817	5/24/94 14:11	104	4.10	s	0	71	63.6	0.00	0.00	0.0	0.0	31.6		20.0	48.3	142				6.6	284	278	273	279														
817	5/24/94 15:09	105	4.00	s	0	71	63.6	0.00	0.00	0.0	0.0	31.6		23.7	54.1	154				3.5	284	278	273	278														
817	5/24/94 16:09	104	3.90	s	0	71	63.6	0.00	0.00	0.0	0.0	31.6		20.7	55.6	170				3.3	278	272	268	274														
817	5/24/94 17:10	105	4.10	s	0	71	63.6	0.00	0.00	0.0	0.0	31.6		19.7	59.8	190				3.4	280	273	267	274														
817	5/24/94 18:00	105	4.10	s	0	71	63.6	0.00	0.00	0.0	0.0	31.6		21.2	63.4	199				2.3	280	273	268	274														
817	5/24/94 18:40	105	4.10	s	0	71	63.6	0.00	0.00	0.0	0.0	31.6			63.9					10.9	280	273	268	281														
817	5/24/94 19:17	105	4.10	s	0	71	63.6	0.00	0.00	0.0	0.0	31.6			41.6					13.8	280	273	268	274														

		Econ Exit, dry (1,2,11,12): w/Sorb							Baghouse Inlet Gas Analysis (AHO 1-6,dry)									Stack Gas Analysis, wet									WET CHEM NH3		
Test	Date & Time	O2	SO2	NO	CO	NO2	CO2	N2O	O2	SO2	NO	CO	NO2	CO2	H2O	N2O	NH3	O2	SO2	NO	CO	NO2	CO2	H2O	N2O	NH3	inlet	stk	Comments
		%dry	ppm	ppm	ppm	ppm	%	ppm	%	ppm	ppm	ppm	ppm	%	%	ppm	ppm	%	ppm	ppm	ppm	ppm	%	%	ppm	ppm	ppm	ppm	
803	5/8/94 10:40	8.90	278	151	67	1	10.42	13.9	7.60	247	180	59	5	11.37	1.1	17.5	0.8	7.40	115	160	44	2	10.42	7.6	14.6	2.5	18.5	4.3	Sootblow 1010-1505
803	5/8/94 12:50	9.65	260	159	55	0	9.75	8.5	7.90	237	181	52	5	11.13	0.9	10.1	0.4	7.80	96	142	40	-1	10.50	7.5	12.6	3.4			
803	5/8/94 15:10	9.00	275	167	56	0	10.39	6.9	7.70	241	180	43	4	11.39	0.8	13.1	0.8	7.40	89	143	36	1	10.33	7.9	13.4	3.5	7.7	2.7	DSI off 1524-1627, Urea off 1524-1558
803	5/9/94 8:40								7.60	269	192	43	2	10.64	1.1	12.0	1.2	7.20	252	161	38	-3	10.46	8.3	16.6	4.0			DSI off 0315-0916, Urea off 0842-0916
803	5/9/94 9:55	9.40	270	175	36	0	10.23	6.6	7.50	239	192	33	4	11.74	0.8	12.0	0.5	7.30	120	163	28	-1	10.36	8.2	10.2	3.5			
803	5/9/94 12:35	8.00	301	150	129	0	11.46	17.5	6.25	253	170	63	4	12.52	1.0	20.8	1.2	6.10	101	129	56	13	11.33	9.0	22.1	4.0	20.0	5.5	FFDC clean 1100-1135
803	5/9/94 16:18	8.80	261	157	60	0	10.64	15.7	7.00	235	170	54	4	12.19	0.8	17.4	0.7	7.00	63	130	46	6	10.71	8.9	17.5	3.5	14.3		
803	5/10/94 8:20	10.6	237	173	70	0	9.26	3.5	9.40	161	203	37	10	9.88	1.0	2.9	0.7	9.10	75	164	32	17	9.07	7.4	3.4	4.0	6.8	1.6	B&C mills OOS, Urea control valve at zero (automatic)
803	5/10/94 11:15	11.0	236	169	52	0	8.80	3.1	9.30	201	202	36	9	10.11	0.8	1.3	0.8	9.10	69	156	29	16	9.17	7.5	2.5	2.5	1.3		B&C mills OOS, Urea control valve at zero (automatic)
803	5/10/94 14:15	10.4	276	169	62	0	9.37	2.0	9.25	211	196	33	10	10.01	0.9	1.4	1.3	9.20	82	158	24	16	9.07	7.2	2.2	3.1			B&C mills OOS, Urea control valve at zero (automatic)
803	5/11/94 9:55																	7.90	263	214	43	-1	10.14	7.8	4.4	2.3			C&D mills OOS, DSI off 0300, Urea off 1700 5/10/94
803	5/11/94 15:00																	7.85	330	169	42	-2	10.11	8.2	2.3	1.7			C mill OOS, DSI and Urea still off
804	5/12/94 8:10								6.35	413	172	105	2	12.57	1.2	25.4	2.0	6.20	376	151	101	-3	11.26	9.2	24.7	5.6	16.6	2.9	C mill OOS, Urea off 0826-0858
804	5/12/94 13:30								6.00	421	182	239	0	12.93	0.8	28.9	2.0	5.80	380	149	351	-3	11.56	9.3	30.5	4.5	13.1		C mill OOS, FFDC clean 1200-1235, Urea off 1030-1302
804	5/12/94 16:20								5.80	433	176	264	1	12.90	1.1	26.6	1.6	5.80	400	149	347	-3	11.64	9.3	31.6	8.9	16.5		Total liquid flow increased, sootblow on hold during data
804	5/13/94 6:30								6.10	405	170	91	3	12.53	1.6	28.3	1.1	5.90	385	145	111	-3	11.62	9.5	29.3	7.0	23.7		FFDC 0606-0643, Urea off 0703-0730,sootblow 0626-0850
804	5/13/94 9:10																	8.05	310	170	41	-4	9.92	8.2	10.2	8.5	17.0		Urea off 0917-0932
804	5/13/94 11:50								8.10	331	200	39	1	11.13	1.0	8.4	0.7	7.95	302	174	35	-3	9.93	8.6	9.3	7.0	12.9		
804	5/13/94 13:20																	7.25	399	163	40	-3	10.47	9.0	16.5	7.5	20.1		Unit regulating 80-85MW, Urea off 1330
805	5/17/94 15:11	8.30	296	224	116	2	10.62	5.2	6.20	336	264	118	2	12.38	0.0	0.9	0.6	6.60	276	219	72	-1.8	10.8	8.0	4.1	0.6			C mill OOS, PULVERIZER @4000 rpm
805	5/17/94 17:46	8.40	299	222	74	1	10.65	2.6	6.40	272	240	60	6	12.16	0.0	0.4	1.3	6.30	124	200	78	7.8	11.1	8.2	3.1	2.4			Start bicarb @1645 hrs
805	5/18/94 7:56	8.20	266	205	37	2	10.95	2.0	7.40	227	219	32	9	11.56	0.0	1.3	0.0	7.60	62	165	31	6.6	10.4	7.7	2.0	2.1			
805	5/18/94 9:35	7.80	296	229	73	1	11.23	2.1	5.90	263	263	54	6	12.73	0.0	2.1	0.7	6.30	141	210	36	13.1	11.2	8.3	2.7	2.2			1 HR After Clean
805	5/18/94 12:30	8.20	263	231	106	1	10.90	2.9	5.90	265	274	126	5	12.67	0.0	1.4	0.3	6.30	139	224	67	6.0	11.1	8.5	2.4	2.5			
806	5/19/94 8:41	7.50	294	220	131	2	11.37	3.6	6.20	266	252	62	7	12.53	0.0	3.4	1.1	6.30	120	190	67	12.5	11.2	8.6	3.6	2.0			
806	5/19/94 10:00	7.50	294	220	131	2	11.37	3.6	6.20	266	252	62	7	12.53	0.0	3.4	1.1	6.50	116	193	62	9.5	10.9	8.4	3.3	3.0			
807	5/19/94 11:00	8.50	266	221	36	1	10.55	3.1	7.30	239	232	37	7	11.47	0.0	2.7	2.0	7.50	116	188	32	7.7	10.2	7.8	3.9	2.3			
808	5/19/94 13:00	7.80	290	212	106	1	11.29	3.7	6.60	218	231	45	9	12.22	0.0	2.4	1.2	6.50	62	187	50	11.9	11.0	8.7	3.6	3.1			
809	5/19/94 14:00	8.60	269	220	34	1	10.53	2.3	7.00	221	232	35	9	11.74	0.0	2.4	1.2	7.50	51	174	29	9.5	10.2	8.2	3.8				
810	5/19/94 15:30	9.00	263	212	32	0	10.25	2.2	7.40	209	225	37	9	11.72	0.0	1.4	1.5	7.40	37	165	33	10.0	10.3	8.1	3.4	2.7			
810	5/19/94 16:30	9.25	255	211	24	0	9.66	1.5										7.40	38	166	30	9.3	10.2	8.1	3.7	2.9			
SODIUM SESQUICARBONATE AIR HEATER INJECTION																													
812	5/23/94 10:38	6.50	371	223	155	2	12.31	6.3	4.60	411	260	216	2	13.75	0.0	5.0	-1.2	5.40	335	223	170	-1.7	11.8	8.8	5.5	-1.3			
812	5/23/94 12:35	5.90	425	207	676	1	12.81	5.2										5.35	276	209	131	-0.6	11.8	8.7	6.3	0.6			
813	5/23/94 14:00	6.50	310	250	45	1	11.45	4.9	5.20	320	265	30	2	12.34	0.0	0.5	-1.1												
813	5/23/94 15:40	6.50	310	250	45	1	11.45	4.9	4.80	280	265	43	6	12.68	0.0	0.2	-1.7	5.00	163	217	38	-1.8	10.9	10.9	2.7	1.2			
814	5/23/94 16:05	6.50	310	250	45	1	11.45	4.9	5.00	260	274	35	6	12.56	0.0	0.4	-1.2	5.00	74	199	35	5.7	11.0	10.9	1.6	-0.4			
815	5/23/94 17:45	7.50	393	221	78	1	11.76	1.4	5.60	344	236	73	11	13.10	0.0	1.6	-1.6	5.90	124	184	45	11.7	11.6	8.6	3.0	0.2			
816	5/23/94 19:25	7.20	404	215	142	2	11.78	2.2	5.50	380	235	82	6	13.27	0.0	0.7	-0.7	5.90	194	181	82	9.1	11.5	8.7	3.5	0.0			
817	5/24/94 8:10	7.60	367	223	82	2	11.45	2.9	5.60	420	255	145	1	13.16	0.0	3.1	1.1	5.65	362	213	151	-2.2	11.6	9.1	1.5	0.5			
817	5/24/94 11:35	7.75	365	225	92	1	11.41	2.0	5.55	352	245	132	9	13.02	0.0	-1.0	1.3	5.90	165	200	99	3.1	11.5	8.9	2.5	2.3			
817	5/24/94 12:40	7.50	397	223	224	1	11.75	2.3	5.55	365	240	174	9	13.26	0.0	0.3	0.9	5.82	142	188	141	6.4	11.5	9.0	4.8	1.3			
817	5/24/94 14:11	7.60	373	220	147	1	11.56	2.3	5.60	343	235	104	9	13.11	0.0	2.8	1.1	5.90	190	187	118	12.6	11.5	9.1	4.3	2.6			
817	5/24/94 15:09	7.40	383	217	225	1	11.85	0.6	5.40	335	235	231	9	13.40	0.0	3.5	0.9	5.80	172	185	141	10.2	11.5	9.0	3.8	2.2			
817	5/24/94 16:09	7.10	374	220	202	1	11.93	3.3	5.30	335	245	131	8	13.36	0.0	4.7	0.3	5.70	159	187	106	9.5	11.6	9.2	3.8	2.7			
817	5/24/94 17:10	7.10	365	218	289	1	11.97	1.8	5.36	330	242	196	8	13.42	0.0	2.4	0.3	5.60	142	185	176	9.1	11.7	9.2	5.4	3.0			
817	5/24/94 18:00	7.30	360	222	332	1	11.87	3.3	5.30	325	237	169	8	13.49	0.0	3.1	1.0	5.60	130	187	196	6.2	11.7	9.1	3.9	2.6			
817	5/24/94 18:40	6.80	367	218	489	1	12.09	4.2										5.60	126	186	199	8.2	11.1	9.0	3.8	3.0			
817	5/24/94 19:17	7.30	360	222	332	1	11.87	3.3										5.50	209	195	118	10.4	11.1	9.0	2.9	3.0			

PSCC Arapahoe Unit 4 Sodium/Urea Injection Summary

		Baghouse Inlet Gas Analysis									Stack Gas Analysis, wet									WET CHEM NH3		
Test	Date & Time	O2	SO2	NO	CO	NO2	CO2	H2O	N2O	NH3	O2	SO2	NO	CO	NO2	CO2	H2O	N2O	NH3	inlet	stk	Comments
		%	ppm	ppm	ppm	ppm	%	%	ppm	ppm	%	ppm	ppm	ppm	ppm	%	%	ppm	ppm	ppm	ppm	
SODIUM SESQUICARBONATE DUCT INJECTION																						
818	5/25/94 11:45	6.10	318	226	80	-5	11.11	8.93	2.7	1.3	6.10	313	232	172	-4	11.13	8.89	3.7	1.6			DUCT INJECTION
818	5/25/94 12:35	6.10	318	226	80	-5	11.11	8.93	2.7	1.3	6.10	150	217	125	-3	11.13	9.03	3.6	2.3			FFDC START CLEAN
818	5/25/94 13:12	6.20	321	224	91	-5	10.94	8.95	2.1	1.1	6.00	156	213	214	6	11.26	9.14	3.6	2.8			FFDC FINISHED CLEAN
818	5/25/94 14:10	6.20	321	224	91	-5	10.94	8.95	2.1	1.1	5.90	137	198	236	7	11.33	8.95	4.2	2.5			
818	5/25/94 15:12	6.20	321	224	91	-5	10.94	8.95	2.1	1.1	5.95	128	203	120	4	11.27	9.22	3.0	2.7			
818	5/25/94 16:06	6.20	321	224	91	-5	10.94	8.95	2.1	1.1	6.00	120	205	110	3	11.22	9.32	5.2	2.7			
818	5/25/94 17:06	6.55	313	222	43	-5	10.74	8.92	3.0	0.3	6.30	113	207	67	3	10.99	9.04	3.8	3.5			LOAD DROPPED @1640
818	5/25/94 18:13	6.55	313	222	43	-5	10.74	8.92	3.0	0.3	5.90	146	197	78	12	11.34	9.46	3.0	3.2			FFDC FINISHED CLEAN
818	5/25/94 18:53	6.55	313	222	43	-5	10.74	8.92	3.0	0.3	6.20	130	196	87	9	11.14	9.19	2.2	2.5			
819	5/26/94 7:30	6.00	322	217	73	-5	11.30	9.05	1.0	1.2	5.90	323	219	160	-4	11.50	9.14	3.5	1.7			
819	5/26/94 10:05	6.10	315	217	86	-4	11.15	8.87	1.8	1.5	5.90	213	217	162	-2	11.42	8.97	4.6	3.5			BH CLEAN START @ 1035
820	5/26/94 11:58	6.10	315	217	86	-4	11.15	8.87	1.8	1.5	5.70	175	203	128	1	11.66	9.28	6.1	2.8			
820	5/26/94 13:00	6.10	315	217	86	-4	11.15	8.87	1.8	1.5	5.95	163	203	166	0	11.31	9.05	4.5	3.5			
820	5/26/94 14:00	6.10	315	217	86	-4	11.15	8.87	1.8	1.5	5.75	160	212	162	-1	11.36	9.21	5.8	3.6			
821	5/26/94 15:05	6.10	315	217	86	-4	11.15	8.87	1.8	1.5	5.90	105	200	209	0	11.40	9.24	3.2	4.2			
821	5/26/94 16:06	6.10	315	217	86	-4	11.15	8.87	1.8	1.5	5.95	100	200	131	1	11.13	9.00	2.3	3.5			BH clean start @ 1600
821	5/26/94 16:40	6.10	315	217	86	-4	11.15	8.87	1.8	1.5	6.10	125	196	219	11	11.20	9.12	5.2	3.8			BH clean end @ 1635
821	5/26/94 17:00	6.10	315	217	86	-4	11.15	8.87	1.8	1.5	5.95	120	193	197	9	11.25	9.18	4.2	3.0			
821	5/26/94 18:00	6.10	315	217	86	-4	11.15	8.87	1.8	1.5	5.90	110	193	93	9	11.39	9.21	5.9	5.9			
822	5/27/94 7:30	6.20	310	226	32	-4	11.11	8.94	2.8	2.4	6.30	307	237	39	-3	11.00	8.78	2.8	1.7			Baseline
822	5/27/94 9:20	6.20	310	226	32	-4	11.11	8.94	2.8	2.4	6.60	128	212	37	11	10.81	8.70	3.3	3.2			BH clean end 0915
822	5/27/94 10:20	6.25	313	230	45	-5	10.93	8.93	3.0	2.2	6.35	110	207	48	7	11.03	8.92	2.7	4.4			
822	5/27/94 11:20	6.25	313	230	45	-5	10.93	8.93	3.0	2.2	6.40	106	213	51	8	10.94	8.78	2.5	3.5			
822	5/27/94 12:20	6.25	313	230	45	-5	10.93	8.93	3.0	2.2	6.30	109	210	60	6	10.98	8.52	3.3	3.6			
823	6/6/94 8:35	6.80	297	186	415	-6	10.67	9.04	9.1	0.3	6.80	297	193	414	-5	10.92	9.00	6.0	1.2			Baseline, load following, mill 4A problems
823	6/6/94 12:30	6.75	282	120	409	-5	10.67	8.56	36.0	21.6	6.40	283	145	462	-3	10.78	8.50	27.9	4.5	25.3		Urea only, BH clean 1000, mill 4A normal
823	6/6/94 17:10	6.70	276	123	202	-7	10.52	8.44	35.5	28.8	6.30	92	135	192	-4	10.99	8.60	23.6	10.0			Na+urea, BH clean 1520, 4A mill 65% manual, 2 inj. plugged
823	6/6/94 18:10	6.60	272	122	77	-5	10.51	8.57	37.1	28.0	6.45	82	133	123	-3	10.89	8.64	22.7	9.8			4A mill 65% manual, 2 inj. plugged
823	6/6/94 20:15	6.60	275	118	89	-5	10.62	8.61	36.8	29.3	6.70	78	135	74	-4	10.74	8.85	22.3	9.7			4A mill 65% manual, 2 inj. plugged
823	6/7/94 10:20	6.80	270	118	58	-5	10.65	8.36	34.7	12.8	6.20	82	115	128	-2	11.13	8.63	28.9	6.2	21.8		BH clean 0816
823	6/7/94 12:50	6.95	268	122	58	-5	10.57	8.31	34.3	14.4	6.45	82	118	81	-3	11.08	8.53	29.3	6.8			
823	6/7/94 14:50	7.10	268	126	45	-6	10.41	8.32	33.8	15.3	6.45	80	118	67	-3	11.09	8.62	30.0	7.9			
823	6/7/94 16:50	7.10	272	120	51	-6	10.32	8.11	34.3	12.7	6.60	83	115	61	1	11.00	8.43	28.4	8.1	14.4		BH clean 1600
823	6/8/94 8:10	6.40	282	115	105	-5	10.97	9.15	36.3	15.0	5.70	95	115	206	-3	11.61	9.51	32.5	7.8			BH clean end 0715
823	6/8/94 10:10	6.50	285	112	114	-4	10.93	8.58	36.3	15.0	5.85	85	110	246	-3	11.55	9.31	33.1	7.5			
823	6/8/94 12:00	6.35	285	115	88	-5	10.93	9.02	36.1	13.6	5.85	85	115	151	-3	11.42	9.27	29.1	8.1	11.6		
823	6/8/94 16:26	6.20	292	126	103	-6	11.01	9.37	35.4	10.8	6.00	90	120	128	-3	11.35	9.63	30.5	9.7			BH clean end 1400
823	6/9/94 8:40	6.90	245	165	40	-5	9.19	7.16	13.2	7.4	8.90	70	162	59	-2	9.43	7.30	11.1	4.4	6.1		B & C coal mills OOS
823	6/9/94 17:00	6.25	295	135	42	-6	11.05	9.13	30.2	8.3	5.75	92	130	69	-2	11.73	9.53	26.9	6.7	9.2		
823	6/10/94 9:40	7.00	303	126	50	-3	10.95	8.67	28.9	4.9	6.20	96	126	64	-2	11.39	8.88	26.6	6.6	10.7		BH end clean 0730
823	6/10/94 12:07	6.60	310	126	46	-5	10.66	8.66	29.3	5.3	6.30	106	124	60	-2	11.33	8.95	26.9	5.5	9.4		
826	6/13/94 13:30	6.20	362	133	33	-4	10.96	8.78	27.1	8.2	6.10	107	126	137	0	11.39	9.30	21.5	6.8			
826	6/15/94 11:40	7.20	345	195	33	-5	10.42	8.64	3.2	1.4	6.90	90	163	62	12	10.76	8.89	4.1	3.7			No urea
826	6/15/94 15:05	7.00	325	195	32	-7	10.36	8.59	3.4	-0.3	6.70	84	170	42	7	10.90	8.92	3.0	2.6			No urea
826	6/15/94 17:05	7.05	325	200	34	-6	10.41	8.57	3.1	-0.8	6.90	80	160	44	26	10.74	8.60	3.1	3.3			No urea
826	6/16/94 0655	6.30	340	219	33	-5	11.26	9.34	2.6	-0.9	6.00	97	200	43	5	11.62	9.54	3.1	3.3			No urea

PSCC Arapahoe Unit 4 Sodium/Urea Injection Summary

Calcs based on: Bicarbonate @274
Sesquicarb. @297

				Sorbent Feed			Injector cal		Urea Injection--------					ΔSO2 Reduction			ΔNOx Calcs----------			Baghouse Temps				Economizer Exit, dry (1-12): Base							Economizer Exit, dry (1-12): w/SNCR						
Test	Date & Time	Load	O2cr	Na	A (w)	B (e)	Flow	2Na	Urea	Total	Inj ai	Conc	N/NO	Stk		Util	Overall	SNCR	Na	Taho	Grid	Out	IDin	O2	SO2	NO	CO	NO2	CO2	N2O	O2	SO2	NO	CO	NO2	CO2	N2O
		MWe	%wet	b/s	%	%	lb/min	S*	gpm	gpm	psi	wt%		%	ppmc	%	%	%	%	°F	°F	°F	°F	%dry	ppm	ppm	ppm	ppm	%	ppm	%dry	ppm	ppm	ppm	ppm	%	ppm
SODIUM SESQUICARBONATE DUCT INJECTION																																					
818	5/25/94 11:45	108	4.40	s	0	66	59.4	1.54	0.00	0.0	0.0	31.6	0.00	1.6	7	1.1	0.0			281	273	262	269	6.10	365	259	295	2	12.71	4.1							
818	5/25/94 12:35	108	4.50	s	0	66	59.4	1.54	0.00	0.0	0.0	31.6	0.00	52.8	232	34.4	5.8			284	272	266	270	6.10	365	259	295	2	12.71	4.1							
818	5/25/94 13:12	108	4.30	s	0	66	59.4	1.51	0.00	0.0	0.0	31.6	0.00	52.0	233	34.5	3.4			284	273	269	273	6.10	364	257	295	1	12.50	-0.1							
818	5/25/94 14:10	108	4.30	s	0	66	59.4	1.51	0.00	0.0	0.0	31.6	0.00	58.3	261	38.6	10.5			284	273	269	273	6.10	364	257	295	1	12.50	-0.1							
818	5/25/94 15:12	108	4.30	s	0	66	59.4	1.51	0.00	0.0	0.0	31.6	0.00	60.7	272	40.2	8.7			279	268	263	270	6.10	364	257	295	1	12.50	-0.1							
818	5/25/94 16:06	108	4.20	s	0	66	59.4	1.51	0.00	0.0	0.0	31.6	0.00	63.0	282	41.7	7.7			277	266	263	267	6.10	364	257	295	1	12.50	-0.1							
818	5/25/94 17:06	106	4.20	s	0	64	57.7	1.49	0.00	0.0	0.0	31.6	0.00	64.5	269	43.3	12.2			276	266	263	267	6.30	350	273	140	2	12.40	1.7							
818	5/25/94 18:13	105	4.20	s	0	64	57.7	1.51	0.00	0.0	0.0	31.6	0.00	54.7	245	36.3	14.9			275	264	258	265	6.30	350	273	140	2	12.40	1.7							
818	5/25/94 18:53	105	4.20	s	0	64	57.7	1.51	0.00	0.0	0.0	31.6	0.00	59.4	266	39.5	14.2			275	264	258	265	6.30	350	273	140	2	12.40	1.7							
819	5/26/94 7:30	105	3.90	s	0	0	0.0	0.00	0.00	0.0	0.0	31.6	0.00	0.3	1		2.6			270	261	245	255	5.70	366	253	234	4	12.92	3.5							
819	5/26/94 10:05	101	4.10	s	0	24	20.1	0.56	0.00	0.0	0.0	31.6	0.00	33.3	145	59.2	1.6			273	263	250	260	5.65	360	252	172	2	13.03	1.1							
820	5/26/94 11:58	100	4.10	s	0	41	36.0	1.02	0.00	0.0	0.0	31.6	0.00	45.8	199	45.0	7.9			275	265	257	264	5.65	360	252	172	2	13.03	1.1							
820	5/26/94 13:00	100	4.20	s	0	41	36.0	1.02	0.00	0.0	0.0	31.6	0.00	46.7	212	47.9	6.9			274	264	255	264	5.65	360	252	172	2	13.03	1.1							
820	5/26/94 14:00	100	4.00	s	0	41	36.0	1.02	0.00	0.0	0.0	31.6	0.00	50.3	219	49.5	4.2			274	263	256	263	5.65	360	252	172	2	13.03	1.1							
821	5/26/94 15:05	101	4.20	s	0	78	70.6	1.97	0.00	0.0	0.0	31.6	0.00	67.0	291	33.9	6.1			275	264	256	264	5.65	360	252	172	2	13.03	1.1							
821	5/26/94 16:08	101	4.00	s	0	78	70.6	1.97	0.00	0.0	0.0	31.6	0.00	68.5	298	34.7	7.8			275	265	260	263	5.65	360	252	172	2	13.03	1.1							
821	5/26/94 16:40	101	4.10	s	0	78	70.6	1.97	0.00	0.0	0.0	31.6	0.00	60.2	262	30.5	2.8			265	265	259	265	5.65	360	252	172	2	13.03	1.1							
821	5/26/94 17:00	100	3.90	s	0	78	70.6	1.99	0.00	0.0	0.0	31.6	0.00	62.2	270	31.2	6.8			265	264	259	265	5.65	360	252	172	2	13.03	1.1							
821	5/26/94 18:00	100	4.00	s	0	78	70.6	1.99	0.00	0.0	0.0	31.6	0.00	65.4	285	32.8	7.5			274	263	257	263	5.65	360	252	172	2	13.03	1.1							
822	5/27/94 7:30	102	4.80	s	0	80	72.5	2.02	0.00	0.0	0.0	31.6	0.00	0.5	2	0.2	2.3			268	259	240	250	6.50	342	267	66	3	12.23	1.6							
822	5/27/94 9:20	102	4.80	s	0	80	72.5	2.02	0.00	0.0	0.0	31.6	0.00	57.6	249	28.5	4.6							6.50	342	267	66	3	12.23	1.6							
822	5/27/94 10:20	100	4.80	s	0	80	72.5	2.03	0.00	0.0	0.0	31.6	0.00	64.6	283	31.8	11.7			279	266	256	265	6.70	337	270	57	2	12.12	0.6							
822	5/27/94 11:20	100	4.80	s	0	80	72.5	2.03	0.00	0.0	0.0	31.6	0.00	65.2	285	32.0	8.7			279	266	256	265	6.70	337	270	57	2	12.12	0.6							
822	5/27/94 12:20	100	4.80	s	0	80	72.5	2.03	0.00	0.0	0.0	31.6	0.00	65.3	286	32.1	11.8			280	270	261	269	6.70	337	270	57	2	12.12	0.6							
823	6/6/94 8:35	86	4.60	s	0	0	0.0	0.00	0.00	0.0	0.0	31.0	0.00	0.1	0		-4.7			273	264	251	258	6.30	331	215	673	0	11.91	15.0							
823	6/6/94 12:30	87	4.60	s	0	0	0.0	0.00	0.92	2.0	8.0	31.0	0.73	2.5	10		24.3	24.2	0.7	285	277	266	273	6.30	331	215	673	0	11.91	15.0	6.30	310	163	791	1	12.08	27.6
823	6/6/94 17:10	90	4.60	s	0	59	52.6	1.79	0.98	3.1	8.2	31.0	0.69	67.8	271	38.0	36.0	24.4	15.4	281	274	267	274	6.45	317	232	188	-1	12.36	1.9	6.40	302	176	229	-1	12.15	21.0
823	6/6/94 18:10	89	4.60	s	0	58	62.2	1.84	0.81	3.1	8.2	31.0	0.58	70.2	273	38.1	36.0	25.7	13.7	261	271	267	272	6.45	317	232	188	-1	12.36	1.9	6.40	308	173	258	-1	12.54	19.3
823	6/6/94 20:15	90	4.50	s	0	64	57.2	1.97	0.88	3.1	8.1	31.0	0.62	71.3	280	36.1	33.5	27.2	8.4	280	270	265	270	6.45	317	232	188	-1	12.36	1.9	6.35	305	170	244	-1	12.37	21.7
823	6/7/94 10:20	91	4.60	s	0	62	55.5	1.91	1.02	3.1	8.2	31.0	0.70	70.9	277	37.1	46.1	40.4	10.3	279	270	258	268	6.40	313	235	114	0	12.55	2.4	6.20	308	142	151	1	12.49	31.9
823	6/7/94 12:50	91	4.80	s	0	54	47.7	1.63	1.10	3.1	8.1	31.0	0.76	70.5	276	43.1	43.7	41.3	3.5	283	275	266	274	6.40	313	235	114	0	12.55	2.4	6.50	308	137	110	-1	12.35	29.1
823	6/7/94 14:50	91	4.70	s	0	57	50.7	1.72	1.04	3.1	8.0	31.0	0.72	71.5	284	41.7	43.9	36.1	11.8	285	277	269	277	6.40	313	235	114	0	12.55	2.4	6.60	303	148	69	-1	12.28	27.1
823	6/7/94 16:50	92	4.60	s	0	63	56.3	1.87	1.21	3.1	8.1	31.0	0.84	70.5	283	37.6	41.4	36.5	7.4	285	277	271	277	6.40	312	230	64	-1	12.39	2.4	6.50	305	145	65	-1	12.29	27.2
823	6/8/94 8:10	97	3.90	s	0	80	72.5	2.29	0.94	4.2	8.1	31.0	0.66	67.9	272	29.6	41.3	37.8	6.7	270	260	246	258	5.50	338	223	247	0	13.47	4.8	5.70	320	137	271	1	12.99	29.4
823	6/8/94 10:10	97	4.00	s	0	78	70.4	2.20	1.00	4.2	8.0	31.0	0.72	71.3	288	32.4	43.5	43.0	0.2	273	264	256	263	5.50	338	223	247	0	13.47	4.6	5.75	325	125	291	-1	13.16	27.9
823	6/8/94 12:00	96	4.00	s	0	74	66.8	2.12	1.03	4.2	8.1	31.0	0.74	71.2	286	33.6	42.3	37.6	7.0	279	269	258	267	5.70	330	225	143	0	12.80	1.1	5.75	330	140	221	-1	12.97	28.0
823	6/8/94 16:28	95	4.00	s	0	70	63.5	2.00	1.08	4.2	8.2	31.0	0.78	69.5	285	34.8	38.9	32.5	9.7	283	274	268	273	5.70	330	225	143	0	12.80	1.1	5.90	328	150	146	0	12.81	28.8
823	6/9/94 8:40	63	7.10	s	0	40	34.5	1.55	0.29	2.0	8.1	31.0	0.26	71.3	297	46.0	16.7	13.2	5.0	250	244	235	244	9.00	272	218	71	0	10.40	3.8	8.95	265	190	76	2	10.28	10.4
823	6/9/94 17:00	101	4.50	s	80	0	76.4	2.24	0.95	5.0	8.1	31.0	0.58	69.8	289	31.1	41.0	34.4	10.8	286	277	270	277	6.10	333	245	47	0	12.75	2.0	5.70	330	165	61	1	12.90	26.6
823	6/10/94 9:40	96	4.50	s	79	0	75.8	2.16	0.80	4.2	8.1	31.0	0.56	70.1	314	32.5	34.5	29.1	8.1	275	266	256	265	5.80	357	220	72	2	12.82	3.2	6.00	334	154	60	2	12.43	2.0
823	6/10/94 12:07	96	4.50	s	78	0	72.7	2.08	0.83	4.2	8.1	31.0	0.60	66.4	299	32.2	35.2	28.1	8.7	279	270	260	269	5.80	357	220	72	2	12.82	3.2	6.00	376	156	73	-1	12.94	23.9
826	6/13/94 13:30	96	4.20	s	73	0	69.2	1.76	0.74	4.2	8.1	31.0	0.51	70.5	355	40.2	36.4	28.4	11.1	286	278	271	278	5.80	422	232	134	0	12.97	6.1	5.90	419	165	183	0	12.81	20.0
826	6/15/94 11:40	89	5.40	s	31	31	54.5	1.44	0.00	0.0	0.0	0.0	0.00	74.4	386	51.6	10.2			273	265	258	265	6.90	365	223	65	2	11.51	1.9							
826	6/15/94 15:05	88	5.40	s	30	30	52.0	1.50	0.00	0.0	0.0	0.0	0.00	74.6	358	49.7	14.3			276	268	262	268	6.70	367	235	49	3	11.78	3.5							
826	6/15/94 17:05	87	5.40	s	37	37	65.1	1.90	0.00	0.0	0.0	0.0	0.00	75.6	364	39.9	11.0			276	268	263	268	6.90	365	240	71	1	12.08	1.9							
826	6/16/94 0855	95	4.10	s	34	34	60.9	1.63	0.00	0.0	0.0	31.0	0.00	72.2	347	44.2	15.8			273	264	255	267	6.20	397	275	49	2	13.73	0.8							