NOTICE

**CERTAIN DATA
CONTAINED IN THIS
DOCUMENT MAY BE
DIFFICULT TO READ
IN MICROFICHE
PRODUCTS.**

160
1/16/91

M.S.S. (4)

DOE/ID-10304
(DE91005056)

FIELD TESTING OF A PROBE TO MEASURE FOULING IN AN INDUSTRIAL
FLUE GAS STREAM

By
Manohar S. Sohal

November 1990

Work Performed Under Contract No. AC07-76ID01570

For
U.S. Department of Energy
Office of Industrial Technologies
Washington, D.C.

By
EG&G Idaho, Inc.
Idaho Falls, Idaho

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

This report has been reproduced directly from the best available copy.

Available to DOE and DOE contractors from the Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831; prices available from (615)576-8401, FTS 626-8401.

Available to the public from the National Technical Information Service, U. S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161.

DOE/ID--10304

DE91 005056

FIELD TESTING OF A PROBE TO MEASURE FOULING IN AN INDUSTRIAL FLUE GAS STREAM

Manohar S. Sohal

November 1990

Idaho National Engineering Laboratory
EG&G Idaho, Inc.
Idaho Falls, Idaho 83415

Prepared for
U. S. Department of Energy
Idaho Operations Office, Idaho Falls, Idaho
Sponsored by the Office of the Assistant Secretary for
Conservation and Renewable Energy
Office of Industrial Technologies
Washington, D.C.
Under DOE Contract No. DE-AC07-76ID01570

ABSTRACT

The U. S. Department of Energy, Office of Industrial Technology sponsors work in the area of measuring and mitigating fouling in heat exchangers. This report describes the design and fabrication of a gas-side fouling measuring device, and its testing in an industrial environment. The report gives details of the probe fabrication, material used, controllers, other instrumentation required for various measurements, and computer system needed for recording the data. The calibration constants for measuring the heat flux with the heat fluxmeter were determined. The report also describes the field test location, the tests performed, the data collected, and the data analysis. The conclusions of the tests performed were summarized. Although fouling deposits on the probe were minimal, the tests proved that the probe is capable of measuring fouling in a harsh industrial environment.

EXECUTIVE SUMMARY

The U.S. Department of Energy (DOE), Office of Industrial Technologies has been funding the development of a gas-side fouling measuring device to assist in efficient designing of heat exchangers. The foulants are deposited on the heat transfer surfaces of heat exchangers used to recover energy from hot flue gases in industrial furnaces. The fouling data taken by the probe from a flue gas stream can be useful in accurately designing a heat exchanger for use in the same or a similar flue gas stream. Accurate fouling factor information can avoid the need for overdesigning (providing more than required heat transfer surface area) a heat exchanger. The fouling probe can also be used to assess the effect of changing the type of fuel on the fouling deposition. Initially, under DOE's sponsorship, Jet Propulsion Laboratory (JPL), Pasadena, California designed, constructed, and tested in a laboratory setting a foulant measuring device. Subsequently, the Idaho National Engineering Laboratory (INEL) made some improvements to the design of the fouling probe and tested it in an industrial test site to prove its applicability in harsh industrial environment. The fouling probe development is nearing its goal of a technology useful for the industrial application.

The fouling probe works on the principle that fouling deposit on a heat transfer surface provides additional thermal resistance, which decreases the rate of heat transfer through the heat transfer surface. The fouling probe system consists of three components. The first component is the probe, which is designed to measure the decrease in heat flux and calculates the fouling factor. The second component is the control system to control temperatures and cooling air flow rates. The third component is the data acquisition system. The probe consists of a 1.0 in. outside diameter (OD) stainless steel tube with a heat fluxmeter replacing a part of the tube wall to measure the local wall heat flux. Cooling air is supplied to the probe through an inner concentric tube and flows out of the probe through the annular gap between the two tubes. A thermocouple is attached to the inside wall of the outer tube to monitor tube wall temperature. This temperature is maintained at a predetermined fixed value by controlling the cooling air flow rate by a temperature control system. The average heat flux is determined by using the device as a calorimeter, that is, by measuring the inlet and outlet air

temperatures and air mass flow rate, and calculating the heat gained by the flowing air.

The length of the probe depends on the depth to which it needs to be inserted (up to the center of a duct) in a flue stream. Typically, the length could be ~4 to 8 ft. The JPL carried out laboratory tests using natural gas combustion products doped with slaked lime to serve as the foulant. Local and average fouling factors were obtained over a range of parameters including: inside wall temperature, 270 to 1500°F, gas temperature, 745 to 2214°F, heat flux, 3440 to 40800 Btu/h·ft², and gas velocity, 9.91 to 27.7 ft/s. The results obtained confirm that the probe is capable of measuring local and average gas-side fouling factors under laboratory conditions. Subsequently, the INEL fabricated two probes for testing in the flue stream of an industrial site. Energy and Environmental Research Corporation (EER) was subcontracted by the INEL to test the probe in an industrial environment to determine reliability and operability of the probe. The field test site was Whitewater Valley Station of Richmond Power and Light Company at Richmond, Indiana. The furnace is a coal burning facility. The probe was tested in the convection pass of the furnace containing the economizer and superheaters over a broad range of parameters: probe wall temperature, 600 to 1300°F, gas temperature, 820 to 1840°F, heat flux, ~2800 to 8000 Btu/h·ft², and gas velocity, 10 to 20 ft/s. The probe proved to be rugged enough to be capable of withstanding the industrial environment. Following these tests, it is recommended that provision should be made to increase the cooling air flow rate through the probe to a high enough range so that tests could be conducted in the region where flue gas temperature is higher than 1840°F.

ACKNOWLEDGMENTS

Several individuals contributed directly or indirectly to the completion of this project and their contribution is being acknowledged. The project was sponsored by the U. S. Department of Energy, Office of Industrial Technologies with Mr. S. L. Richlen being the program manager. Mr. G. R. Peterson was the project manager at the Idaho Operation Office of the Department of Energy. Dr. M. S. Sohal of EG&G Idaho was the principal investigator and had the overall responsibility of coordinating all the work relating to the project. Mr. S. C. Wilkins of EG&G Idaho fabricated and calibrated the probes. Ms. M. K. Adler of EG&G Idaho was responsible for assembling the data acquisition system and the computer program for the data recording. Mr. Z. J. Frompovicz of Energy and Environmental Research Corporation was responsible for field testing the probes. Some portions of the chapters on field testing and data analysis were taken from a report authored by Mr. Frompovicz and submitted to EG&G Idaho, Inc.

CONTENTS

ABSTRACT	iii
EXECUTIVE SUMMARY	v
ACKNOWLEDGMENTS	vii
1. INTRODUCTION	1
2. FABRICATION, INSTRUMENTATION AND CALIBRATION OF THE PROBE	5
2.1 Fabrication of the Probe	5
2.2 Instrumentation for the Probe	13
2.3 Calibration of the Probe	14
3. DATA ACQUISITION AND ANALYSIS	19
3.1 Data Acquisition System	19
3.2 Fouling Factor Analysis	19
4. TEST SITE DESCRIPTION	23
4.1 Boiler Description	23
4.2 Test Ports Locations	24
5. PROBE OPERATING CHARACTERISTICS	29
5.1 Data Collection Times Interval	29
5.2 Minimum Probe Operating Temperature	30
5.3 Heat Flux Meter Orientation	34
6. FOULING PROBE TEST RESULTS AND DISCUSSION	41
6.1 Fouling Probe Site Characterization	41
6.2 Nonfouling Data	43
6.3 Fouling Data	46
7. CONCLUSION AND RECOMMENDATION	59
7.1 Conclusions	59
7.2 Recommendations	60
8. REFERENCES	61
APPENDIX A—DATA COLLECTION TIME TEST	A-1
APPENDIX B—PROBE ORIENTATION TEST DATA	B-1
APPENDIX C—TEST 13 DATA	C-1
APPENDIX D—TEST 15 DATA	D-1

FIGURES

2-1.	Schematic drawing of gas-sided fouling probe	6
2-2.	Fouling probe data and control system	7
2-3.	Fouling probe assembly	8
2-4.	Engineering drawing of the fouling probe	9
2-5.	Photograph of Option A probe components prior to assembly	10
2-6.	Fouling probe control schematic	15
2-7.	Calibration of probe	16
4-1.	Schematic right side view of Whitewater Unit 2	25
4-2.	Boiler penetrations	26
4-3.	Fouling probe test ports	27
5-1.	Probe air flow as a function of data collection times	31
5-2.	Meter heat flux as a function of data collection times	32
5-3.	Meter heat flux trends as a function of probe orientation	37
5-4.	Air flow trends as a function of probe orientation	38
5-5.	Probe average heat flux as a function of probe orientation	39
6-1.	Test 13 results	48
6-2.	Test 15 results	51
6-3.	Photographs of fouling deposits	54
6-4.	Boiler gas temperature trends during tests 13 and 15 (BPMS)	55

TABLES

2-1.	Heat flux calibration results	17
5-1.	Statistical analysis of data collection time interval	33
5-2.	Summary of probe orientation effects	36
6-1.	Test port characterization	42
6-2.	Averaged condition for the fouling probe	42

FIELD TESTING OF A PROBE TO MEASURE FOULING IN AN INDUSTRIAL FLUE GAS STREAM

1. INTRODUCTION

Many industrial systems (for example, boilers and furnaces) utilize some form of heat transfer equipment to transfer heat from the high temperature flue gases to another fluid. The effectiveness of the heat transfer equipment can be reduced because of the foulant deposition on the outside of the heat transfer surfaces. This process is known as gas-side fouling and is generally defined as an undesirable insulating layer deposited on a heat transfer surface. To improve the heat exchanger performance, knowledge of the flue gas fouling potential and foulants mitigation is needed. Accurate fouling factor information can avoid the need for overdesigning (providing more than required heat transfer surface area) a heat exchanger. The fouling probe can also be useful in measuring the (fouling) impact of changing the type of fuel in the plant.

The U.S. Department of Energy (DOE), Office of Industrial Technologies sponsors research and development in the area of advanced heat exchangers. The U.S. DOE has sponsored several workshops to assess the effects of fouling and define the research needed to mitigate fouling.¹⁻⁴ To measure the fouling characteristics of a specific flue gas stream for the purpose of designing a heat recovery equipment, the DOE sponsored the development of a device capable of measuring gas-side fouling. Marner and MacDavid of the Jet Propulsion Laboratory (JPL) designed, fabricated and laboratory tested a fouling probe.^{5,6} Subsequently, the Idaho National Engineering Laboratory (INEL) made some improvements in the JPL design, and fabricated and calibrated the probe. Under a subcontract, Energy and Environmental Research Corporation (EER) field tested the probe. The EER report⁷ gives the work performed by INEL and the field tests performed by EER. The material related to field test site, and field test data in Chapters 4 through 6 of this report was taken from the EER report.⁷

Rebello et al.,⁸ have given the cost of heat exchanger fouling in U.S. industries. The total fouling cost consists of the energy not transferred as a result of insulating fouling layer, the increased capital cost in oversizing a heat exchanger, and the maintenance cost of foulant removal equipment. The total estimated energy lost in 1982 was $\sim 2.9 \times 10^6$ Btu/y costing $\sim \$9$ billion. Marner and Suitor¹ estimated that the annual cost of gas-side fouling in the U.S. industries is $\sim \$3.6$ billion. In a Pacific Northwest Laboratories study,² the same annual fouling cost in the U.S. was estimated to be in the order of $\$3.9$ billion to $\$7$ billion. The cost figure estimated by various investigators may not be exact, but these figures clearly indicate that it is desirable to understand and mitigate the fouling buildup on the heat exchange equipment.

Few other such probes have also been developed. At the National Engineering Laboratory, East Kilbride, Scotland, a fouling probe of a simpler design^{9,10} than that of the JPL probe was developed. Unlike the JPL probe, this probe does not have a heat fluxmeter. The foulant samples are collected on a cylindrical shell made up of two similar semi-cylindrical shells mounted over the probe. Other probes for measuring fouling in a liquid stream have also been developed and tested.¹¹ These probes are: the Heat Transfer Research, Inc. Portable Fouling Research Unit probe and a hot wire probe based on the design of the Universal Oil Products Monirex instrument.

Somerscales¹² reviewed the fouling of heat transfer surfaces from an historical perspective. He paid particular attention to the fouling of steam boilers and steam condensers. He also discussed the development of scientific methods to study fouling and calculating fouling factors. Watkinson performed a critical review¹³ of fouling caused by organic fluids. This reference also contains references to several other related and useful topics. Epstein⁽¹⁴⁻¹⁶⁾ has given detailed information about the physical mechanisms behind gas-side fouling on a heat transfer surface and classified them as follows:

1. Precipitation fouling - the precipitation or condensation of dissolved substances onto the heat transfer surface. Depending on the chemical composition of the fuel and the industrial process

involved, the combustion products will contain a variety of solid particulates, condensables, and noncondensable gaseous species. As these gases are cooled by heat recovery equipment, the condensables and other solid particles are deposited onto the heat transfer surface. Sometimes the dissolved substances have inverse solubility versus temperature (lower solubility with higher temperature) characteristics, then the precipitation occurs on superheated rather than subcooled surfaces and this mechanism is called scaling.

2. Particulate fouling - the deposition of fine particulates suspended in the flue gas stream onto the heat transfer surface.
3. Chemical reaction fouling - deposits formed at the heat transfer surface resulting from the chemical reaction between the flue gas or other constituents.
4. Corrosion fouling - the solid heat transfer surface reacts with the flue gases to produce corrosion products on the surface.
5. Biological fouling - the attachment of macro- or micro-organisms to a heat transfer surface, resulting into an adherent slimy layer.

The fouling deposits increase thermal resistance of the heat recovery equipment resulting in reduced heat transfer and can also increase blockage in the gas flow path, which results in increased pressure drop and fan power. To remove fouling deposit required additional maintenance. All of these effects contribute to the reduced plant efficiency.

As a result of the successful operation of the probe in industrial environment, the INEL loaned one probe to EER to supplement the tests conducted for Electrical Power Research Institute (EPRI) at several coal fired

plants in Massachusetts, Mississippi, Alabama, and Pennsylvania. Another industrial company has also requested the use of the probe for use in their plant. These tests will meet the objective of transferring the fouling probe technology to industry for commercialization.

2. FABRICATION, INSTRUMENTATION AND CALIBRATION OF THE PROBE

The objective of a heat exchanger designer is to use the fouling measuring device (to be called fouling probe) to calculate the additional resistance, R_f , caused by the foulant deposition on the heat transfer surface. The principle of the fouling probe is to measure the reduction in heat transfer as a result of fouling deposition, which can be related to the fouling resistance. A schematic drawing of the fouling probe is shown in Figure 2-1. Cooling air enters the inner tube, reverses its direction at the end of the inner tube and flows out through the outer tube. The inside tube surface temperature, T_{wi} , is maintained at a preset value by adjusting the air mass flow rate. The average heat flux is determined by using the probe as a calorimeter, that is by measuring the cooling air mass flow rate and rise in its temperature as it cools the probe surface. The probe system consists of three components (see Figure 2-2): the probe for insertion into the flue gas stream, the control system to control temperatures and cooling air flow rates, and the data acquisition system. Basic design of the probe is the same as that of the JPL probe and shown in Figure 2-3.

2.1 FABRICATION OF THE PROBE

Marner and MacDavid^{5,6} gave a detailed description of the probe fabrication. Figure 2-4 shows the engineering drawing for the fabrication of the probe. The main body of the probe consists of a 1.0 in. OD 304 stainless steel tube with a wall thickness of 0.083 in. A 5-3/8 in. long semi-cylindrical section of the probe was removed from the tube. It was replaced by a nearly identical section machined to fit (see Figure 2-5). This replacement section was instrumented with a heat fluxmeter fitted into a window cut in the replacement section, along with its lead wires, and a thermocouple to measure the inside surface temperature of the heat fluxmeter. The heat fluxmeter (model HT-50) was custom made by International Thermal Instrument Company, Del Mar, California. It is a 5/8 x 5/8 in. "curved

Figure 2-1. Schematic Drawing of Gas-Side Fouling Probe.

LF90 0305

Figure 2-2. Fouling Probe Data and Control System.

LF90 0310

Figure 2-3. Fouling Probe Assembly.

Figure 2-4. Engineering drawing of the fouling probe.

Figure 2-5. Photograph of Components Prior to Assembly.

sandwich" with 0.010- and 0.040-in. thick Chromel layers on each side of a 0.031-in. thick alloy of a proprietary composition. For the present application, the manufacturer matched the curvature of the heat fluxmeter with that of a 1-in. OD tube. The heat fluxmeter is a high temperature thermopile that generates a direct current signal from the temperature difference across the heat fluxmeter. Thus, the voltage output is proportional to the heat flux through the meter. The meter was laser-welded into the window machined in the semi-cylindrical replacement section that was an integral part of the tubewall.

A 3/8-in. wide axial groove was machined on the inside surface of the semi-cylindrical section to accommodate the thermocouple and heat fluxmeter lead wires. Bare Chromel-Alumel (Type K) thermocouple wires of 0.020-in. thickness were insulated with single-bore alumina tubes and taken to a location near the end of the instrumented semi-cylinder, where alumina tubes were replaced with Nextel 312 woven ceramic fiber sleeves. Both alumina and Nextel 312 can be safely used above 1800°F. Similarly, 0.020-in. diameter Chromel wires used as heat fluxmeter leads were insulated in the same manner as the thermocouple lead wires. The thermocouple junctions and the Chromel lead wires were attached to the heat fluxmeter by laser-welding. The transition region between alumina and Nextel insulation was firmly held against the tube surface by a strip of stainless steel shim stock laid across the leads and spot-welded in place at both ends. An extra (backup) pair of heat fluxmeter leads and an extra thermocouple to measure the heat fluxmeter inside temperature were also added. The alumina insulated sections were then covered with Caulkcrete 100 castable refractory cement, as was the insulation transition and all the void area around the inner layer of the heat fluxmeter. The inside area of the semi-cylindrical section was made as smooth as possible using the refractory cement. Refractory cement was also used to increase the stiffness and durability of the frayed ends of the Nextel sleeving by curing it overnight.

The Chromel lead-wires for the heat fluxmeter were spliced to the Chromel wire of two separate Type K extension cables, and the Alumel wires of the extension cables were left unattached; only the Chromel wires from the

Chromel-Alumel cables were used. The Alumel weirs were not used to avoid the possibility of introducing extraneous thermo-electric signals at the splices to dissimilar materials. The heat fluxmeter and the thermocouple lead-wires were uniquely marked for identification. The probe was 8-ft in length. The working section of the probe was the final 2 ft. To reduce the cooling air flow needed to maintain the probe surface temperature at a desired value, the first 6-ft length was encased in a 3 in. OD Kaowool HS 45 board refractory (19% alumina and 80% silica) sleeve made by Thermal Ceramics (formerly Babcock & Wilcox). The thermal conductivity values of the Kaowool refractory at 800 and 1400°F are 0.06 and 0.07 Btu/(h·ft²·°F), respectively. A ½-in. OD stainless steel tube, open at both ends, was inserted concentrically through the length of the 1-in. OD tube, which comprises the probe main body, for the flow of air to cool the probe surface. Standoffs (three at 120 degree intervals) were welded around the inner tube circumference near the closed end of the outer tube to ensure centering of the inner tube. The lead-wires (insulated by Nextel sleeving) from the heat fluxmeter were routed through the annulus between the two concentric tubes, and exited from an open arm of the Swagelok union cross at the cooler end of the probe that remains out of the flue gas stream. The thermocouples for measuring air inlet and outlet temperatures were located at the beginning of the 2-ft working section just past the end of the refractory sleeve. These lead-wires were spliced to a fiberglass insulated thermocouple extension cable. The wires were twisted, silver-soldered and the pieces covered with shrink tubing to avoid short circuiting.

The instrumented semi-cylindrical section was then snapped into place in the cutout in the 1-in. OD tube, and laser welded around its periphery. In places where the fit of the machined parts was not perfect, it was necessary to add 308 stainless steel filler wire to complete the welded joint. The slack in the lead-wires was taken at the Swagelok union cross, where these leads exit the probe. The lead-wires were secured in a Conax connector, which was welded to the probe extension. All the lead-wires for thermocouples to

measure temperature of air-inlet, air-outlet, inside surface of the heat fluxmeter, the heat fluxmeter, the air flowmeter, and its pressure transducer were all connected to the data acquisition system (DAS) to record on-line data.

2.2 INSTRUMENTATION FOR THE PROBE

Besides the thermocouples and the heat fluxmeter, several other instruments are used for the fouling probe system. These are described below.

The cooling air first flows through a filter (Balston model A912-DX), then through a valve (a Badger Research model 807 SS), and finally through a flowmeter (Teledyne Hastings-Raydist model ST/LS-2D) with a range of 0 to 750 std L/min with a Hastings readout model PR-4A) from which the flow rate signal goes to the DAS. The flowmeter is calibrated at the factory to convert the measured air flow rate to the mass flow rate at the standard conditions of 0°C and 760 mmHg. A pressure transducer (CEC model 4-350-0001) with a range of 0 to 1000 psi and a Type K thermocouple were installed at the outlet of the flowmeter. The pressure transducer and the thermocouple are actually redundant and measure the needed thermodynamic properties of the cooling air if need arises.

Figure 2-6 shows the control system schematic for the fouling probe. The thermocouple attached to the inside surface of the heat fluxmeter, in addition to being connected to the DAS, was also connected in parallel to a Proportional-Derivative-Integral (PID) instrument microprocessor controller (Eurotherm model 820). The microprocessor has an output in the range of 4 to 20 mA and was connected to an electropneumatic transducer (Fisher Controls Model 546-44) that provides a 3 to 15 psig signal to the flow valve. This provides a feedback loop that can adjust the air flow rate to control the temperature of the heat fluxmeter inside surface. The microprocessor controller was set to a temperature value at which the probe surface was to be maintained.

The feedback control loop only operates correctly if the microprocessor controller is properly tuned. First, the "proportional band parameter" was varied by either doubling or halving its value depending upon whether the control system overshoots or undershoots the set value of the temperature. This was continued until the system was oscillating very close to the set value. Then, the "oscillation (cycle) time, T_o ," (in min) of this state was determined. The "integral time" parameter (also called "reset" in some controllers) equal to $1.6/T_o$ was determined. The "derivative time" (also called "rate" in some systems) equal to $T_o/10$ was determined. Entering these values into the microprocessor in "commissioning mode" caused the system to settle down to the the set value of the temperature within ~10 s, once the thermocouple reading was within the "cutback high" and "cutback low" settings. The PID setting values for probe temperatures of 300 to 600°F are as follows. For higher probe temperatures, different sets of PID values will be needed.

Integral time	: 5.0 s	Cutback high	: 10°F
Derivative time	: 0.3 s	Cutback low	: 10°F
Proportional band	: 6.5%		

2.3 CALIBRATION OF THE PROBE

Calibration of the probes was performed in a horizontal 3-ft long cylindrical furnace with three heating zones. The 2-ft working section at the end of the probe was centered inside the furnace. The furnace was insulated with firebricks and fiberglass. Calibration was performed as a function of the inside wall temperature of the probe. Heat flux calculated from the cooling air mass flow rate and the temperature increase of the cooling air was equated to that calculated from the heat fluxmeter voltage output. A least square fit of the data resulted in the linear coefficients representing the relationship between the heat flux rate and the voltage output of the meters. Figure 2-7 shows the calibration of the probe in a furnace. The heat flux calibration constants are given in Table 2-1.

LF90 0306

Figure 2-6. Fouling Probe Control Schematic.

Figure 2-7. Calibration of Probe.

Table 2-1. Heat flux calibration results

$$(q_{hfm})'' \text{ (Btu/ft}^2\cdot\text{min)} = C_1 E_{hfm} \text{ (}\mu\text{V)} + C_2$$

Probe 1

T_{wi}	C_1	C_2
300	1.99	175
600	2.03	600
800	2.29	956
950	2.30	1357
1100	2.89	1630
1200	3.49	1854
1300	5.32	1918
1400	6.64	2005

Probe 2

T_{wi}	C_1	C_2
300	2.62	144
600	2.65	303
800	2.68	567
950	2.75	812
1100	2.82	1597
1200	2.45	1952
1300	3.88	1400
1400	4.84	1198
1450	5.72	1183

The heat fluxmeter in both the primary and backup probes failed because of delamination during the calibration process. This failure became apparent when the polarity of the heat fluxmeter output changed. The electric resistance of the heat fluxmeter, measured between the Chromel-Chromel leads, increased to several $k\Omega$ at elevated temperature, which increased to $M\Omega$ at room temperature. Therefore, the heat fluxmeters were replaced, but were subjected to the following procedures and tests.

To avoid delamination of the new heat fluxmeters, a narrow seam was made by a pulsed laser along the edges of the heat fluxmeter layers, between outer Chromel and middle alloy layers, and between middle alloy and inner Chromel layers. Care was taken to avoid a short circuit between all three layers. The heat fluxmeters were then thermally cycled between room temperature and 1000°F , and thermally shocked between room temperature and 1500°F . These procedures ensured survivability of the meters during calibration and rigorous field testing.

3. DATA ACQUISITION AND ANALYSIS

3.1 DATA ACQUISITION SYSTEM

Data from the probe is collected by a computer based DAS. The DAS is composed of a HP3852A data acquisition and control unit, and a computer using ASYST 2.0 software. The HP3852A gets input from the following instruments:

1. Three type-K thermocouples
  - a. Cooling air temperature at the probe inlet (T_{a1})
  - b. Cooling air temperature at the probe outlet (T_{a2})
  - c. Probe wall temperature (T_{w1})
2. Output voltage from the heat fluxmeter (E_{hfm})
3. Voltage (E_a) corresponding to the cooling air mass flow rate (m_a).

The ASYST software collects, temporarily stores operating data of the probe on a hard disk, and then on a floppy disk. After the next acquisition sequence is started, the previous data set can be retrieved from the floppy disk for hard copy output and data analysis.

The maximum number of readings that can be stored per data file is 120. The time period for data readings can be set to any of 5 values: 5 s, 0.5, 1, 2, and 5 min. Therefore, the duration of a data file can be anywhere from 10 min to 10 h. Longer test periods would result in multiple data files. The total length and number of files are determined by the data reading interval.

3.2 FOULING FACTOR ANALYSIS

The fouling factors corresponding to each data set are calculated. Two values of fouling factors are calculated: one value (local) is based on the heat transfer determined by the heat fluxmeter, and the other value (average) is based on the heat transfer calculated from the temperature difference of

the cooling air flowing through the probe. The fouling factor (R_f) is defined by

$$R_f = (1/U_o)_f - (1/U_o)_c \quad (3-1)$$

where

U_o = overall heat transfer coefficient

subscripts f, c = "fouled" and "clean" probe conditions,
respectively.

Two methods of determining heat flux, q , are

average heat transfer based on the temperature increase of the cooling air

$$q_{ave} = \dot{m}_a C_{pa} (T_{a2} - T_{a1}) \quad (3-2)$$

where

C_{pa} = average specific heat of cooling air

T_{a1} , T_{a2} = cooling air temperature at the probe inlet and outlet,
respectively,

and local heat transfer as calculated from the heat fluxmeter reading

$$q_{local} = A_o (C_1 E_{hfm} + C_2) \quad (3-3)$$

where

A_o = effective outside surface area of the probe

C_1 , C_2 = constant determined by meter calibration.

The heat transfer to the probe can also be determined in terms of the difference between the gas and the inside wall temperatures and is

$$q = A_o U_o (T_g - T_{wi}) \quad (3-4)$$

where

T_g = temperature of combustion gases

T_{wi} = temperature of the probe inside wall.

Equation (3-4) results in

$$1/U_o = A_o (T_g - T_{wi})/q \quad (3-5)$$

Substituting two expressions for q from Equations (3-2) and (3-3) into Equation (3-5) and then, resulting expressions for $1/U_o$ into Equation (3-1), two equations for the fouling factor, R_f , become

$$(R_f)_{ave} = \left[\frac{A_o (T_g - T_{wi})}{m_a C_{pa} (T_{a2} - T_{a1})} \right]_f - \left[\frac{A_o (T_g - T_{wi})}{m_a C_{pa} (T_{a2} - T_{a1})} \right]_c \quad (3-6)$$

$$(R_f)_{local} = \left[\frac{(T_g - T_{wi})}{(C_1 E_{hfm} + C_2)} \right]_f - \left[\frac{(T_g - T_{wi})}{(C_1 E_{hfm} + C_2)} \right]_c \quad (3-7)$$

In order to calculate expressions for the fouling factors, values of some parameters have to be provided. One is the temperature of flue gas (T_g) surrounding the fouling probe. The other two inputs are the heat fluxmeter calibration constants, C_1 and C_2 , at the probe wall temperature, T_{wi} .

4. TEST SITE DESCRIPTION

The host site selected for the field test of the fouling probe was Richmond Power and Light (RPL) Whitewater Valley Station at Richmond, Indiana. The selected Unit 2 was a demonstration site for a joint Environmental Protection Agency and the EPRI program on sorbent injection for sulfur dioxide emission control. At the time of selection of the fouling probe host site, RPL's Unit 2 was scheduled to operate with different calcium-based sorbents. This schedule would have produced a wide variety of potential fouling characteristics. Because of unavoidable schedule changes of both the programs, no fouling probe tests could be run with sorbent injection. All of the fouling probe tests were performed while the unit was operating in a normal procedure and burning medium-sulfur midwestern coal.

4.1 BOILER DESCRIPTION

RPL's Whitewater Valley Unit 2 (Figure 4-1) is a tangentially-fired steam generator burning midwestern bituminous coal. It has a nominal electrical capacity rating of 61 MWe. The superheater outlet condition at full load results in a steam flow of 540,000 lb/h at 955°F and 1320 psig. Total heat input into the furnace at full load capacity is 651×10^6 Btu/h.

The furnace is equipped with primary and secondary superheaters, economizer, and regenerative air preheater. The primary superheater, the secondary superheater, and the boiler, all having vertical tubes, are arranged in the flow path of the hot flue gases flowing horizontally through the convection pass. The economizer is located in the downward flow of the flue gases.

The fouling deposits at this unit are typical for this particular boiler design. The furnace walls tend to accumulate a layer of slag. Generally, the ash coating deposited on the tubes in the convection pass is of a dusty nature. The dusty deposit contributes to a loss of heat transfer and an

increase in flue gas temperatures. Long retractable sootblowers located strategically throughout the convection pass are effective in removing these deposits and reestablishing boiler operating parameters

4.2 TEST PORTS LOCATIONS

Unit 2 has numerous wall penetrations installed to obtain information regarding the sorbent injection program. A schematic of the openings is shown in Figure 4-2. All ports have a minimum opening of 3- $\frac{1}{2}$ in. and are located in areas critical to monitoring deposit conditions relative to each tube bank. All ports were accessible to the fouling probe testing.

The ports selected for fouling probe testing are highlighted in Figure 4-3. All tests were performed by inserting the probe from the left sidewall into the furnace. This arrangement was necessitated because of the lack of observation doors and minimum working surface area available on the right sidewall. The port location characteristics are:

Port D1: Located in the upper furnace above the combustion zone. Flue gas flow direction is typically vertical; however, strong horizontal components may be present because of the tangential nature of the flame front. Temperatures are ~1800 to 1850°F. Heat transfer from the gases is dominated by radiation heat transfer. Foulant deposition on the probe in this area is indicative of deposition on the primary superheater leading edge tubes and the upper furnace wall.

Port E2: Located in the upper furnace convection pass. Flue gas flow is generally horizontal. Gas temperatures are ~1450°F. Radiation heat transfer from the flue gases is reduced. Foulant deposition on the probe in this area is indicative of fouling on the secondary superheater tube bank.

LF90 0309

Figure 4-1. Schematic right side view of Whitewater Unit 2.

LF90 0307

Figure 4-2. Boiler penetrations.

LF90 0308

Figure 4-3. Fouling probe test ports.

Port F2: Located in the middle of the convection pass. Flue gas flow is horizontal. Gas temperatures are ~1100°F. Radiation heat transfer from the flue gases is minimum. Foulant deposition on the probe in this area is indicative of fouling on the steam generator tube bank.

Port G1: It is located in the rear portion of the convection pass. Flue gas flow is generally horizontal with some downflow components present. Gas temperatures are ~800°F. Foulant deposition on the probe in this area is indicative of the fouling on the economizer surface.

5. PROBE OPERATING CHARACTERISTICS

Before performing the fouling probe tests, the probe was inserted into the furnace to determine the optimum operating parameters and probe configuration for data collection. In addition, data were collected to define the operating range of the probe. The parameters evaluated include:

1. Optimum data collection time interval to reduce the data scatter (noise).
2. Minimum achievable probe wall temperature as a function of the flue gas temperature.
3. The heat fluxmeter orientation relative to the flue gas flow.

5.1 DATA COLLECTION TIME INTERVAL

The DAS required the time interval between two sets of data as an input. The options available for time interval were 5 s, 0.5, 1, 2, and 5 min. A series of preliminary runs were made to evaluate the effect of data collection time interval on data scatter (noise). Time intervals of 1, 2, and 5 min were selected. The probe was inserted through test port E2. The flue gas temperature ranged from 1430 to 1490°F. The probe temperature was set and controlled at 1100°F.

The data were recorded for air flow rate and heat flux (using the meter) over a 2 h period. Complete test data are given in Appendix A and are shown in Figures 5-1 and 5-2. A statistical analysis of the data is presented in Table 5-1. As seen from Table 5-1, the data for 1 min time interval case compare satisfactorily with the corresponding data for the 2 min time interval case, for both the air flow and the meter heat flux measurements. For the 5 min time interval case, there is good agreement between the 1, 2, and 5 min air flow data, but the standard deviation for the heat fluxmeter data is significantly lower than those for the 1 and 2 min cases.

The main cause of the data scatter (noise) is the fluctuations in heat transfer from the flue gases to the probe and response of the probe cooling air flow rate to keep the probe at its preset temperature. By recording the data at a high frequency, these fluctuations become very noticeable, and result in a significant data noise, as evidenced by Runs 1 and 2. Increasing the time interval to 5 min (Run 3), reduced this noise without statistically changing the average value of the data collected.

Another advantage of the longer time interval between two data sets is a decrease in the total number of data sets collected in a given period of time. This significantly reduces the computer disk space needed to store the data and allows better management of the data files.

5.2 MINIMUM PROBE OPERATING TEMPERATURE

For the fouling probe to effectively simulate a heat exchanger tube for the purpose of foulant deposition site, it should operate at a temperature close to that of the tube metal surface. In case of a typical boiler, the lowest and the highest tube temperatures may be those of the economizer ($\sim 400^{\circ}\text{F}$) and the secondary superheater ($\sim 1100^{\circ}\text{F}$), respectively.

Initial tests indicated that if the flue gas temperature was $< 1100^{\circ}\text{F}$, the probe surface temperature could be maintained at any value in the range of 600 to 1000°F . Whenever the flue gas temperature was $> 1100^{\circ}\text{F}$, it was difficult to maintain the probe surface temperature at a low value. If the flue gas temperature was greater than 1800°F , it was necessary to insert only the first 2-ft length of the probe into the furnace in order to obtain a reasonable probe surface temperature. The limiting factor in this case was the cooling air mass flow rate and ability to accurately measure the flow rate.

Test: 04
Run 1: 1 min
Port: E2
11 January 1989

Test: 04
Run 2: 2 min
Port: E2
11 January 1989

Test: 04
Run 3: 5 min
Port: E2
11 January 1989

Figure 5-1. Probe air flow as a function of data collection times.

Test: 04
Run 1: 1 min
Port: E2
11 January 1989

Test: 04
Run 2: 2 min
Port: E2
11 January 1989

Test: 04
Run 3: 5 min
Port: E2
11 January 1989

LF90 0312

Figure 5-2. Meter heat flux as a function of data collection times.

Table 5-1. Statistical analysis of data collection time interval

1. Air mass flow rate, m_a (lb/h), data summary

	Run 1	Run 2	Run 3
Time Interval (min)	1	2	5
Average	98	113	92
Minimum	72	88	65
Maximum	116	133	112
Standard Deviation	8	10	11

2. Meter heat flux, q'' (Btu/ft²·h), data summary

	Run 1	Run 2	Run 3
Time Interval (min)	1	2	5
Average	4985	5578	4937
Minimum	4199	4685	4381
Maximum	5828	6402	5277
Standard Deviation	351	361	215

In order to reasonably control the air mass flow rate, it was desirable to allow the air flow control valve to operate between 50 and 60% open. At high control valve openings, the system produced air flow oscillations. These oscillations resulted from rapidly cooling and heating of the probe surface (hence the sensing thermocouple), which caused the flow control valve to rapidly close and open in response to the probe surface temperature. With these wide range of oscillations, the control system was not capable of controlling the probe surface temperature effectively.

A second requirement was to accurately measure the air mass flow rate. The probe system utilized an air mass flowmeter with a range of 0 to 750 std L/min. Setting the probe surface temperature controller at a low temperature value would allow the air flow control valve to remain fully open, allowing maximum air flow through the probe. But, under these conditions, the air mass flow rate becomes so high that it exceeds the upper limit of the air mass flowmeter and cannot be measured.

Because of these two system operating constraints, the minimum probe operating temperatures, as a function of flue gas temperature are:

Flue Gas Temperature (°F)	Minimum Probe Temperature (°F)
1900	1300
1400	1000
1200	800

For flue gas temperatures below 1400°F, there is no difficulty in maintaining the operating tube metal temperatures. However, at flue gas temperatures >1400°F, the current probe configuration is severely limited in cooling the probe surface to a desired low temperature.

5.3 HEAT FLUXMETER ORIENTATION

The calculation of heat transfer to the cooling air through the probe makes it possible to use the probe as a calorimeter. The heat fluxmeter mounted on the probe surface measures the local heat transfer to the cooling air. Because the heat fluxmeter occupies a particular peripheral position on the probe surface, its readings may depend on the direction the heat fluxmeter is facing. The readings will be influenced by the radiation heat transfer from the flue gases to the heat fluxmeter. Tests were performed to determine the effect of probe orientation on the heat flux values determined by both the heat fluxmeter and the temperature rise of cooling air.

The probe was inserted in each test port (D1, E2, F2, and G1) and rotated clockwise. To define the probe's rotation, assume it was inserted into the Port D1. The starting point (0 degree) was taken when the heat fluxmeter was facing the roof of the furnace. In a 90 degree position the meter was facing the front wall, while in the 270 degree position the meter was facing the superheaters.

The results of this test series are given in Table 5-2 and selected data for air mass flow rate, meter local heat flux, and cooling air average heat flux are given in Figures 5-3, 5-4, and 5-5, respectively. Complete test data are given in Appendix B.

These tests indicated that the heat flux determination by the heat fluxmeter is sensitive to probe orientation. In Figure 5-3, except for the data corresponding to Port F2, the heat flux increased successively as the probe was rotated from a position of 90 to 180 degree, and finally to 270 degree. Higher heat flux indicates higher heat transfer from the flue gases and the furnace walls. At Port F2, which is located deep in the convection pass, the meter at positions of 180 and 270 degree was shielded from the incoming hot flue gases. This resulted in a decrease in heat flux at these positions.

Table 5-2. Summary of probe orientation effects

Test Number: 11A		Flue Gas Temperature: 1840°F	
Test Port : D1		Probe Temperature : 1300°F	
Probe Direction	Meter Heat Flux (Btu/ft ² ·h)	Air Flow Rate (lb/h)	Air Heat Flux (Btu/ft ² ·h)
0°	12,800	195	-----
90°	10,744	215	42,556
180°	15,384	285	58,108
270°	20,584	211	49,233

Test Number: 10A		Flue Gas Temperature: 1439°F	
Test Port : E2		Probe Temperature : 1100°F	
Probe Direction	Meter Heat Flux (Btu/ft ² ·h)	Air Flow Rate (lb/h)	Air Heat Flux (Btu/ft ² ·h)
0°	1523	33	4841
90°	2853	62	7816
180°	4617	71	8225
270°	4877	34	4142

Test Number: 12A1		Flue Gas Temperature: 1125°F	
Test Port : F2		Probe Temperature : 800°F	
Probe Direction	Meter Heat Flux (Btu/ft ² ·h)	Air Flow Rate (lb/h)	Air Heat Flux (Btu/ft ² ·h)
0°	3721	49	4107
90°	3731	84	5289
180°	2117	95	5668
270°	1809	86	5450

Test Number: 11C		Flue Gas Temperature: 823°F	
Test Port : G1		Probe Temperature : 600°F	
Probe Direction	Meter Heat Flux (Btu/ft ² ·h)	Air Flow Rate (lb/h)	Air Heat Flux (Btu/ft ² ·h)
0°	2690	131	5949
90°	1048	124	5997
180°	2003	103	5096
270°	3065	111	5293

Test: 11A
Probe orientation
Port: D1
1 February 1989

Boiler load: 60 MW
Coal: med. sulfur
Sorbent: none
Data time: 5 s.

Probe temp: 1300 °F
Gas temperature: 1840 °F

Test: 10A
Probe orientation
Port: E2
31 January 1989

Boiler load: 64 MW
Coal: med. sulfur
Sorbent: none
Data time: 5 s.

Probe temp: 1100 °F
Gas temperature: 1439 °F

Test: 12-A1
Probe orientation
Port: F2
2 February 1989

Boiler load: 60 MW
Coal: med. sulfur
Sorbent: none
Data time: 5 s.

Probe temp: 800 °F
Gas temperature: 1125 °F

Test: 11C
Probe orientation
Port: G1
1 February 1989

Boiler load: 60 MW
Coal: med. sulfur
Sorbent: none
Data time: 5 s.

Probe temp: 600 °F
Gas temperature: 823 °F

LF90 0313

Figure 5-3. Meter heat flux trends as a function of probe orientation.

Test: 11A
Probe orientation
Port: D1
1 February 1989

Boiler load: 60 MW
Coal: med. sulfur
Sorbent: none
Data time: 5 s.

Probe temp: 1300 °F
Gas temperature: 1840 °F

Test: 10A
Probe orientation
Port: E2
31 January 1989

Boiler load: 64 MW
Coal: med. sulfur
Sorbent: none
Data time: 5 s.

Probe temp: 1100 °F
Gas temperature: 1439 °F

Test: 12-A1
Probe orientation
Port: F2
2 February 1989

Boiler load: 60 MW
Coal: med. sulfur
Sorbent: none
Data time: 5 s.

Probe temp: 800 °F
Gas temperature: 1125 °F

Test: 11C
Probe orientation
Port: G1
1 February 1989

Boiler load: 60 MW
Coal: med. sulfur
Sorbent: none
Data time: 5 s.

Probe temp: 600 °F
Gas temperature: 823 °F

LF90 0314

Figure 5-4. Air flow trends as a function of probe orientation.

Test: 11A
Probe orientation
Port: D1
1 February 1989

Boiler load: 60 MW
Coal: med. sulfur
Sorbent: none
Data time: 5 s.

Probe temp: 1300 °F
Gas temperature: 1840 °F

Test: 10A
Ave HF orientation
Port: E2
31 January 1989

Boiler load: 64 MW
Coal: med. sulfur
Sorbent: none
Data time: 5 s.

Probe temp: 1100 °F
Gas temperature: 1439 °F

Test: 12-A1
Probe orientation
Port: F2
2 February 1989

Boiler load: 60 MW
Coal: med. sulfur
Sorbent: none
Data time: 5 s.

Probe temp: 800 °F
Gas temperature: 1125 °F

Test: 11C
Probe orientation
Port: G1
1 February 1989

Boiler load: 60 MW
Coal: med. sulfur
Sorbent: none
Data time: 5 s.

Probe temp: 600 °F
Gas temperature: 823 °F

LF90 0315

Figure 5-5. Probe average heat flux as a function of probe orientation.

Farther back in the convection pass at Port G1, gas temperature is quite low (823°F). Therefore, the radiation heat transfer from the gases and the furnace walls to the probe is likely to be a minimum. The probe rotation produced a significant variation in heat flux. This may be caused by the flue duct and, hence, the flue gases making a 90 degree turn at this location and the heat fluxmeter may be facing a zone of stagnant pocket of flue gases at 90 and 180 degree positions.

The air mass flow rates and meter average heat flux show some variations as the probe is rotated. However, because the probe is of cylindrical shape, heat transfer to the cooling air should be independent of probe orientation. The variations noted in the average heat flux may be the result of the placement of the air inlet and outlet thermocouples in the probe. The thermocouples are located at the end of the two foot working section of the probe that is exposed to the furnace environment. Therefore, it is possible that the thermocouple monitoring the air outlet temperature is reading a local value of the temperature as the probe is rotated. In a similar manner, the variation in cooling air mass flow rate can be attributed to the placement of the thermocouple monitoring the probe wall temperature. This thermocouple was placed on the inside surface of the heat fluxmeter. As the heat fluxmeter was rotated, it would be exposed to varying temperatures. The probe wall thermocouple would read these varying temperatures and adjust accordingly the cooling air mass flow rate.

6. FOULING PROBE TEST RESULTS AND DISCUSSION

The probe was tested while the boiler was operating under full load conditions for 2 working days, each being an 8 h test. The first long term test (Test 13) was performed with the probe inserted into Port E2 and the probe wall temperature maintained at 950°F. The second test (Test 15) was performed at Port F2 and the probe wall temperature at 800°F. The original plan for fouling probe testing was to perform tests with the probe in the flue streams resulting from the combustion of the normal coal and a high sulfur coal. These tests were to be performed both with and without sorbent injection. Because of unforeseen complications developing in scheduling both the sorbent injection and fouling probe programs, the original test plan had to be abandoned. The following sections describe the test procedures and the results.

6.1 TEST PORT CHARACTERIZATION

Before testing the fouling probe, the following flue gas characteristics at the horizontal plane of the port were determined: flue gas temperature, gas velocity, and gas composition. The flue gas temperatures were also measured after the test to assess any possible deterioration in furnace performance caused by the foulant deposition. These characterizing measurements were made with a water-cooled probe, configured to operate as a suction pyrometer, with an insertion length of 10 ft. A side-stream of flue gas (which was aspirated during the suction pyrometer measurements) was diverted for gas composition analysis. A Teledyne portable gas analyzer was used to determine the percentages of excess oxygen and carbon monoxide present at the test port. These measurements are presented in Tables 6-1 and 6-2. Table 6-1 shows measured values at four locations at distances of 2, 4, 6, and 8 ft from the furnace wall. These data define flue gas conditions at a location where the probe was placed for testing. The flue gas direction is with reference to the left side view of the furnace as shown in Figure 4-2.

Table 6-1. Test Port Characterization

Probe Insertion Depth (ft)	2	4	6	8
Test 13, Port E2				
Pretest				
Gas temperature (°F)	1681	1516	1426	1398
Gas velocity (ft/s)	39.00	22.60	19.12	21.41
Gas flow direction	↑	↑	←-	←-
Excess oxygen (%)	1.5	1.8	1.8	1.9
Carbon monoxide (ppm)	95	96	109	101
Posttest				
Gas temperature (°F)	1651	1523	1456	1427
Test 15, Port F2				
Pretest				
Gas temperature (°F)	1510	1241	1172	1165
Gas velocity (ft/s)	15.95	18.16	10.27	14.49
Gas flow direction	←-	←-	←-	←-
Excess oxygen (%)	3.0	2.4	2.3	2.3
Carbon monoxide (ppm)	120	140	155	158
Posttest				
Gas temperature (°F)	1585	1345	1221	1176

Table 6-2. Average Conditions for the Fouling Probe

Average Values at 7 ft	Test 13 Port E2	Test 15 Port F2
Pretest		
Gas temperature (°F)	1412	1168
Gas velocity (ft/s)	20.51	12.38
Gas flow direction	←-	←-
Excess oxygen (%)	1.85	2.3
Carbon monoxide (ppm)	105	156
Posttest		
Gas temperature (°F)	1441	1198

Average values of the measurements at the 6 and 8 ft locations were taken as test conditions for the probe. This resulted in the average values given in Table 6-2. The flue gas composition was calculated based on the excess oxygen values measured at the probe locations and the chemical analysis of the coal; and the results are given in Table 6-3.

Table 6-3. Weight (Volume) Percentages of Flue Gas Composition

	H ₂ O	CO ₂	N ₂	SO ₂	O ₂
Test 13, Port E2	5.04 (8.33)	22.72 (15.38)	69.91 (74.34)	0.46 (0.22)	1.87 (1.74)
Test 15, Port F2	4.93 (8.15)	22.24 (15.04)	70.06 (74.44)	0.45 (0.21)	2.32 (2.16)

6.2 NONFOULING DATA

A comparison of the heat fluxes measured by the probe and those analytically predicted was made to ascertain the accuracy of the probes measurements. The fouling factor calculations depend on accurately measuring the heat flux. The heat transfer to the probe consists of two components, radiative and convective heat transfer. The probe, when inserted through the ports E2 and F2, was surrounded by several tube banks and this made a simple, but accurate assessment of heat transfer to the probe very difficult. The analysis performed was similar to that given by Marner and MacDavid (Reference 5) and the reader should refer to that report for details of the analysis. Some of the relations and the procedure used by Marner and MacDavid are briefly given here.

The molecular weight, gas constant, and specific heat of the flue gas mixture are determined by the available methods for a gaseous mixture described in standard thermodynamic text books. The viscosity, μ_g , and thermal conductivity, k_g , of the flue gas mixture were determined by using the

relations given in Chemical Engineers' Handbook By Perry and Chilton¹⁷ and are written

$$\mu_g = (\sum \mu_i X_i M_i^{1/2}) / (\sum X_i M_i^{1/2}) \quad (6-1)$$

$$k_g = (\sum k_i X_i M_i^{1/3}) / (\sum X_i M_i^{1/3}) \quad (6-2)$$

Where

X_i = mole fraction of the i th gaseous component

M_i = molecular weight of the i th gaseous component.

The average probe outside wall temperature, T_{wo} , was calculated from the measured probe inside wall temperature using Fourier's law for conduction heat transfer and knowing the thermal conductivities of the probe wall and the Kaowool refractory insulation on the probe. The convective heat transfer was calculated from the relation for the Nusselt number, Nu_g , for the flow of gases over a circular cylinder and is written

$$Nu_g = 0.43 + 0.48 Re_g^{1/2} \quad (6-3)$$

where

Re_g = Reynolds number based on the probe outside diameter.

The radiative heat transfer to the probe, q_r , is determined using the Stefan-Boltzmann equation

$$q_r = \epsilon_{wo} \sigma A_o [(T_{wall})^4 - (T_{wo})^4] \quad (6-4)$$

where

ϵ_{wo} = emissivity of probe outside surface (heated stainless steel)

σ = Stefan-Boltzmann constant

A_o = probe outside surface area (uninsulated)

T_{wall} = furnace wall or other surface temperature

T_{wo} = probe outside wall temperature.

Table 6-4. Comparison of predicted and measured heat fluxes

Test	T (°F)	T_{wq} (°F)	Measured Results			Predicted Results			Ratios	
			q_a (Btu/h)	E_{hfm} (μV)	q_{hfm} (Btu/h)	q_c (Btu/h)	q_r (Btu/h)	$(q_c + q_r)$ (Btu/h)	q_{hfm} / q_a	$(q_c + q_r) / q_a$
13	1412	949	2805	620	3056	2323	297	2620	1.09	0.93
15	1170	799	1738	380	956	1268	168	1436	0.55	0.83

The results of the comparison between predicted and measured heat fluxes are presented in Table 6-4. For both Tests 13 and 15, the radiation component, q_r , is lower than the convection component, q_c . The total heat flux for the probe, $(q_r + q_c)$, was approximately of the same order of magnitude as the measured heat flux.

The radiation term was calculated based on the surrounding environment of the probe. Because the probe was inserted between two heat transfer tube banks (the primary superheater and the secondary superheater), the probe was surrounded by a large area of tube surface, which is at a temperature cooler than that of the flowing gases. The steam outlet temperatures from these banks are 833 and 961°F, respectively. For this analysis, the tube surface temperature was assumed to be about equal to the flue gas temperature. The two fouling tests were performed on either the upstream side or the downstream side of the secondary superheater tube banks. Therefore, the secondary superheater tube bank temperature of 961°F was used as the temperature of a surface radiating to the probe. The total predicted heat transfer was in close agreement to the measured value by the probe heat transfer. Ratios of predicted and measured heat transfer for Tests 13 and 15 were 0.93 and 0.83, respectively.

6.3 FOULING DATA

A summary of the two fouling tests (13 and 15) is graphically presented in Figures 6-1 and 6-2. Each figure consists of seven graphs. The first three graphs represent the operating characteristics of the probes; the probe surface temperature, cooling air inlet and outlet temperatures, air mass flow rate and heat fluxmeter output voltage. These parameters are plotted as functions of the test time (time of the day). The second set of two graphs for each test shows two values of the measured heat fluxes corresponding to the heat fluxmeter and the probe cooling air. The third set of two graphs show the average and local fouling factors corresponding to the measurements by the heat fluxmeter and the cooling air. Complete test data are given in Appendixes C and D.

The fouling factors are based on the difference between the overall heat transfer coefficients determined for a clean probe and that for the fouled probe. The data necessary to determine the clean probe operation was collected during initial probe operation in the furnace. A data sampling time of 5 s was established and the data were collected over a 5-min period. Immediately after taking the clean probe data, fouling test data collection was started. Data sampling time interval was changed to 5 min and the probe was tested for the next 7 to 7½ h.

Test: 13
Port: E2
3 February 1989

Boiler load: 60 MW
Coal: med. sulfur
Sorbent: none
Data time: 5 min

Probe temp: 950 °F
Gas temperature: 1439 °F
Probe orientation: 180 °

Test: 13
Port: E2
3 February 1989

Boiler load: 60 MW
Coal: med. sulfur
Sorbent: none
Data time: 5 min

Probe temp: 950 °F
Gas temperature: 1439 °F
Probe orientation: 180 °

Test: 13
Port: E2
3 February 1989

Boiler load: 60 MW
Coal: med. sulfur
Sorbent: none
Data time: 5 min

Probe temp: 950 °F
Gas temperature: 1439 °F
Probe orientation: 180 °

LF90 0316

Figure 6-1. Test 13 results.

Test: 13
Port: E2
3 February 1989

Boiler load: 60 MW
Coal: med. sulfur
Sorbent: none
Data time: 5 min

Probe temp: 950 °F
Gas temperature: 1439 °F
Probe orientation: 180 °

Test: 13
Port: E2
3 February 1989

Boiler load: 60 MW
Coal: med. sulfur
Sorbent: none
Data time: 5 min

Probe temp: 950 °F
Gas temperature: 1439 °F
Probe orientation: 180 °

LF90 0317

Figure 6-1 (Continued). Test 13 results.

Test: 13
Port: E2
3 February 1989

Boiler load: 60 MW
Coal: med. sulfur
Sorbent: none
Data time: 5 min

Probe temp: 950°F
Gas temperature: 1439°F
Probe orientation: 180°

Test: 13
Port: E2
3 February 1989

Boiler load: 60 MW
Coal: med. sulfur
Sorbent: none
Data time: 5 min

Probe temp: 950°F
Gas temperature: 1439°F
Probe orientation: 180°

Figure 6-1 (Continued). Test 13 results.

LF90 0318

Test: 15
Port: F2
1 March 1989

Boiler load: 60 MW
Coal: med. sulfur
Sorbent: none
Data time: 5 min

Probe temp: 800 °F
Gas temperature: 1169 °F
Probe orientation: 180 °

Test: 15
Port: F2
1 March 1989

Boiler load: 60 MW
Coal: med. sulfur
Sorbent: none
Data time: 5 min

Probe temp: 800 °F
Gas temperature: 1169 °F
Probe orientation: 180 °

Test: 15
Port: F2
1 March 1989

Boiler load: 60 MW
Coal: med. sulfur
Sorbent: none
Data time: 5 min

Probe temp: 800 °F
Gas temperature: 1169 °F
Probe orientation: 180 °

LF90 0319

Figure 6-2. Test 15 results.

Test: 15
Port: F2
1 March 1989

Boiler load: 60 MW
Coal: med. sulfur
Sorbent: none
Data time: 5 min

Probe temp: 800 °F
Gas temperature: 1169 °F
Probe orientation: 180 °

Test: 15
Port: F2
1 March 1989

Boiler load: 60 MW
Coal: med. sulfur
Sorbent: none
Data time: 5 min

Probe temp: 800 °F
Gas temperature: 1169 °F
Probe orientation: 180 °

Figure 6-2 (Continued). Test 15 results.

LF90 0320

Test: 15
Port: F2
1 March 1989

Boiler load: 60 MW
Coal: med. sulfur
Sorbent: none
Data time: 5 min

Probe temp: 800 °F
Gas temperature: 1169 °F
Probe orientation: 180 °

Test: 15
Port: F2
1 March 1989

Boiler load: 60 MW
Coal: med. sulfur
Sorbent: none
Data time: 5 min

Probe temp: 800 °F
Gas temperature: 1169 °F
Probe orientation: 180 °

Figure 6-2 (Continued). Test 15 results.

LF90 0321

Figure 6-3. Photographs of fouling deposits.

Test: 15
BPMS temperatures
Port: E2
3 February 1989

Boiler load: 60 MW
Coal: med. sulfur
Sorbent: none
Data time: 5 min

Probe temp: 950 °F
Gas temperature: 1439 °F (△)
Probe orientation: 180 °

Test: 15
BPMS temperatures
Port: F2
1 March 1989

Boiler load: 60 MW
Coal: med. sulfur
Sorbent: none
Data time: 5 min

Probe temp: 800 °F
Gas temperature: 1169 °F (△)
Probe orientation: 180 °

Figure 6-4. Boiler gas temperature trends during tests 13 and 15 (BPMS).

During the course of the fouling probe tests, the plant operators cleaned the fouled boiler tubes using sootblowers. The time of operating the sootblower was recorded along with other pertinent data. During the sootblower operation, the probe was retracted far enough to minimize any possible damage to the refractory sleeve. Following sootblower operation, the full length of the probe was reinserted.

The heat flux measurements and fouling factors during both tests show similar trends. From the beginning of the test until the operation of the sootblowers, these two parameters remained constant. No significant decrease in heat flux or increase in fouling factors was noted. Following the sootblower operation, there was a decrease in measured heat flux and an increase in the fouling factor. This may be because of the deposition of ash particles on the fouling probe resulting from the sootblowing operation.

The deposition noted on the probe following each test can be described as a fine grained, thin layer of dust. The deposit was light colored, only a few thousandths of an inch in thickness, and easily removed by the touch. Figure 6-3 shows photographs of the probe test section following each test. Although the probe outer surface was completely covered, there did not appear to be a significant amount of ash present to result in a significant decrease in heat transfer. Total sample was estimated at <5 g for each test. In order for this deposit to cause the observed decrease in heat flux and increase in fouling factor, a large percentage of the ash would have had to be deposited immediately following sootblowing.

Changes in the boiler operating conditions can also affect the foulant deposition behavior in the furnace. During normal operation of a tangential fired boiler, ash deposits on the furnace walls and tubes continually increases. This leads to increased insulation on the furnace walls and the tubes resulting in higher flue gas temperatures throughout the unit. The effect of this degradation in furnace performance are shown in Figure 6-4 in terms of flue gas temperatures at various regions in the furnace. These two graphs show calculated gas temperatures for three boiler regions during the fouling probe test periods. The first region is the furnace exit (FEGT), the

second region is the exit from the primary superheater tube banks, Port E2 (PSH-OUT), and the third region is the exit from the secondary superheater tube banks, Port F2 (SSH-OUT). These gas temperatures are based on the on-line boiler monitoring and performance calculations from EER's Boiler Performance Monitoring System (BPMS). Although the calculated gas temperatures are higher than the measured values, the relative trends are reasonably accurate.

The gas temperatures increase continually at each test port before a major sootblowing operation. Following sootblowing, the gas temperatures decrease significantly.

Comparing the fouling factor trends with the flue gas temperature trends, a number of characteristics can be explained. During the first 3 h of the test runs, the fouling probe is coated with ash material. During the same time period, gas temperature in the test region is steadily increasing. Because the fouling factor remains constant over this period, the higher temperature difference between the flue gas and the probe surface negates the increased insulating effect of the ash deposit. This combined effect implies as if there has not been any reduction in the heat transfer to the probe. Following the sootblowing operation, the ash insulation on the furnace walls decreases. This results in higher heat transfer loss through the furnace walls and a lower flue gas temperature. Therefore, heat flux through the fouling probe is reduced. Because the fouling factor is based on the reduction in heat flux, it appears as if more foulants have built up on the probe.

The possibility of such a misleading conclusion occurring is higher when the deposition rate in the upstream (of the test port) region is greater than the deposition rate at the fouling probe location (test port). Although the fouling probe is accurately measuring the heat flux from the flue gases at the test port and the dependent fouling factor calculation, the final conclusions can be deceptive.

The field test data brought forth few other observations in interpretation of data acquisition instruments. The Teledyne Hastings-Raydist air mass flowmeter instruction manual states that its calibration (for converting electrical signals to flow rates) is referenced to standard conditions of 0°C and 760 mmHg. This was interpreted to mean that the instrument measures air volume flow rate at the experimental conditions and uses the air density, ρ_{air} , at standard conditions of 0°C and 760 mmHg to obtain mass flow rate at the experimental conditions of temperature and pressure, (T,p). Therefore, the measured value of flow rate was multiplied by $\rho_{air}(T,p) / \rho_{air}(0^\circ\text{C}, 760 \text{ mmHg})$. The fouling probe was also calibrated using the same premise for measuring the cooling air mass flow rate.

During the field tests, when the average heat flux calculated by the cooling air mass flow rate did not satisfactorily match with that measured by the heat fluxmeter, every possible cause of this discrepancy was examined. Therefore, thermocouples measuring the cooling air temperature, air mass flowmeter, heat fluxmeter calibration curves, and the corresponding data were examined. The manufacturers of the instruments were also contacted. During this investigation the principle on which the flowmeter worked was reexamined. It was determined that the flowing gas is heated by a known amount of heat. Thus, if the heat capacity of the gas is assumed nearly constant over its temperature rise, the gas mass flow rate is proportional to its temperature rise. The instrument measures directly the mass flow rate and the information regarding the standard conditions (0°C and 760 mmHg) is superfluous.

This implied that the calibration curves for the probes and the experimental data were unreliable. Therefore, the probes were recalibrated and the correct calibration curves are given in Table 2-1. Test 15 was conducted using the correct calibration curve. The data except those of the Test 15, have to be used with caution. In spite of some possible errors in earlier tests, general conclusions of the field test are still valid. These conclusions are given in Section 7.

7. CONCLUSIONS AND RECOMMENDATIONS

The gas-side fouling probe was fabricated and field tested in an industrial flue gas environment. Data obtained during the tests characterized the operation and current limitations of the fouling probe. All of the equipment performed well in the plant location and no major problems were experienced with probe control, DAS and data analysis.

7.1 CONCLUSIONS

The orientation of the heatflux meter such that it measures the highest heat flux is necessary to arrive at agreeable results between the heat fluxmeter output and the total heat carried by the cooling air. The probe is made of 304 stainless steel. Therefore, the probe surface cannot be exposed to a higher temperature especially in the high heat flux regions of the boiler. Maximum cooling air flow rate to the probe was limited to 128 lb/h (1590 standard ft³/h). This is adequate to cool the probe temperature in the flue gas temperatures of <1400°F. At gas temperatures >1400°F, the minimum probe temperature to which it can be cooled is significantly limited. This is because of two mechanical constraints. The first constraint is the small size of the air flow control valve to adequately control and permit a high air flow rate. The second constraint is the measuring range of the air flowmeter. It appears that the air flow rates in excess of the upper limit of the instrument is required to allow additional probe cooling, especially in the current configuration.

Although the boiler operating conditions did not result in significantly large foulant deposition, fouling factor measurements by both the heat fluxmeter and cooling air heat transfer appear to adequately represent the furnace fouling conditions. Erroneous fouling factors may be calculated if two values of flue gas temperatures, at the start and end of the fouling test, change significantly. The fouling factor calculation should account for the effect of variation in flue gas temperature.

7.2 RECOMMENDATIONS

The suggested recommendations are intended to increase the applicability of the fouling probe to operate in a varied environment to monitor fouling effects.

1. Increase cooling air flow through the probe:

All restrictions in the controller for the cooling air supply that could limit high air flow rates, should be removed. Controlling large air flow rates using the present air flow control valve is difficult.

2. Increase range of air flow measurement:

The current 0 to 750 std L/min air flowmeter is too limited for the high air flow rates necessary to cool the probe in high flue gas temperature regions. This should be increased to the next available size, 0 to 1500 std L/min.

3. Shield probe wall thermocouple from cooling air flow:

The probe temperature control during high air flow rates appeared to be too sensitive and prevented the control system from establishing an effective temperature control range. By shielding the thermocouple, its response may be slowed down and the control system may start operating effectively.

4. Investigate alternate data acquisition and analysis hardware system

The current DAS does not allow for on-line data examination to judge the quality of the data being collected. In addition, the cost and size of the data acquisition hardware (computer) adds to the overall system price and maneuverability.

8. REFERENCES

1. W. J. Marner and J. W. Sutor, A Survey of Gas-Side Fouling in Industrial Heat-Transfer Equipment, Jet Propulsion Laboratory Report No. JPL-PUB-83-74, November 1983.
2. B. A. Garret-Price, S. A. Smith, R. L. Watts and J. G. Knudsen, Industrial Fouling: Problem Characterization, Economic Assessment and Review of Prevention, Mitigation and Accommodation Techniques, Battelle-Pacific Northwest Laboratories, PNL-4883, February 1984.
3. W. J. Marner and R. L. Webb, (Editors), Workshop on an Assessment of Gas-Side Fouling in Fossil Fuel Exhaust Environments, Jet Propulsion Laboratory, DOE/ID-12138-1 (JPL-PUB-82-67), July 1982.
4. W. J. Marner and S. P. Henslee, A Survey of Gas-Side Fouling Measuring Devices, Jet Propulsion Laboratory, DOE/ID-12138-3 (JPL-PUB- 84-11), March 1984.
5. W. J. Marner and K. S. MacDavid, Development of a Gas-Side Fouling Measuring Device, Jet Propulsion Laboratory, DOE/ID/12138-7, May 1987.
6. W. J. Marner, K. S. MacDavid and L. J. Muzio, "Development of a Gas-Side Measuring Device," Heat Transfer Equipment Fundamentals, Design, Applications and Operating Problems, Edited by R. K. Shah, American Society of Mechanical Engineers Publication HTD-Vol 108, 1989, pp. 305-314.
7. Z. J. Frompovicz, Field Test of a Gas-Side Fouling Measuring Device, Energy and Environmental Research Corporation report to EG&G Idaho, Inc. under a Subcontract No. C88101860, August 1989.

8. W. J. Rebello, S. L. Richlen and F. W. Chiids, "The Cost of Heat Exchanger Fouling in the U. S. Industries," Proceedings of Tenth Annual Industrial Energy Technology Conference, Houston, Texas, September 13-15, 1986, pp. 156-163.
9. J. D. Isdale, A. C. Scott and G. Cartwright, "The Use of Probes to Assess Fouling in Dirty Gas Streams," Proceedings of the Institution of Mechanical Engineers Conference on Installation Effects in Ducted Systems, London, U. K., May 1-2, 1984, pp. 107-118.
10. J. D. Isdale, A. C. Scott, G. Cartwright and N. Glen, "The Use of a Portable Probe to Study Fouling in Exhaust Gas Streams," Institution of Chemical Engineers Symposium Series, Vol. I, No. 86, Pergamon Press, New York, N. Y., 1984, pp. 415-434.
11. P. E. Fetissoff, A. P. Watkinson and N. Epstein, "Comparison of Two Heat Transfer Fouling Probes," Heat Transfer - 1982, Proceedings of the Seventh International Heat Transfer Conference, Munich, W. Germany, Vol. 6, Hemisphere Publishing Corp., Washington, D.C., pp. 391-396.
12. E. F. C. Somerscales, "Fouling of Heat Transfer Surfaces: An Historical Review," Heat Transfer Engineering, Vol. 11, No. 1, 1990, pp. 19-36.
13. A. P. Watkinson, Critical Review of Organic Fluid Fouling, The University of British Columbia Report to Argonne National Laboratory under a Contract No. 73212402, December 1988.
14. N. Epstein, "Fouling in Heat Exchangers," Heat Transfer - 1978, Proceedings of the Sixth International Heat Transfer Conference, Toronto, Canada, Vol. 6, 1979, Hemisphere Publishing Corp., Washington, D.C., pp. 235-253.
15. N. Epstein, "Fouling in Heat Exchangers," Fouling of Heat Transfer Equipment, Edited by E. F. C. Somerscales and J. G. Knudsen, Hemisphere Publishing Corp., Washington, D.C., 1981, pp. 701-734.

16. N. Epstein, "Fouling: Technical Aspects (Afterword to Fouling in Heat Exchangers)," Fouling of Heat Transfer Equipment, Edited by E. F. C. Somerscales and J. G. Knudsen, Hemisphere Publishing Corp., Washington, D.C., 1981, pp. 31-53.
17. R. H. Perry and T. H. Chilton (eds.), Chemical Engineers' Handbook, Fifth edition, New York: McGraw-Hill Book Company, 1973.

APPENDIX A
DATA COLLECTION TIMES
TEST 4 TEST DATA AND ANALYSIS

FOULING PROBE FIELD TEST
 RICHMOND POWER & LIGHT
 WHITEWATER VALLEY STATION
 UNIT 2: PORT E2

TEST 04 - 11 JANUARY 1989
 BOILER LOAD: 56 MW
 PROBE TEMPERATURE: 1100 F
 GAS TEMPERATURE: 1700
 DATA TIME: 1 MINUTE

TEST TIME HR	PROBE TEMP [F	AIR-IN TEMP [F	AIR-OUT TEMP [F	AIR-FLOW RATE LB/HR	HF-METER OUTPUT [V	METER-HF CALC B/FT2-HR	AVE-HF CALC B/FT2-HR	AVE-FF CALC	LOC-FF CALC
9.38	1099	728.1	964.07	108.68	422.30	4493.47	11324.48	-0.0109	0.0024
9.40	1097.39	728.74	961	113.36	454.47	4827.40	11176.71	-0.0133	-0.0025
9.41	1097.17	737.89	971.91	85.55	429.09	4563.85	8840.66	0.0038	0.0013
9.43	1098.3	731.2	967.47	96.57	457.42	4853.02	10075.40	-0.0044	-0.0029
9.45	1098.85	740.7	971.95	90.83	468.22	4970.12	9275.19	0.0007	-0.0044
9.46	1093.26	738.35	969.64	91.21	397.64	4239.58	9315.60	0.0004	0.0067
9.48	1099.72	742.79	972.22	96.25	433.38	4608.48	9793.80	-0.0027	0.0007
9.50	1097.65	738.62	968.42	90.13	436.70	5151.95	9146.00	0.0016	-0.0068
9.51	1097.47	751.36	978.15	72.74	430.01	4573.50	7284.65	0.0181	0.0012
9.53	1097.48	741.86	971.65	84.25	428.97	4562.71	8543.95	0.0061	0.0014
9.55	1098.42	738.62	969.52	94.28	434.67	4621.87	9612.92	-0.0016	0.0005
9.56	1097.63	738.27	969.21	96.20	426.16	4533.54	9810.38	-0.0028	0.0018
9.58	1097.71	742.93	972.61	85.16	435.65	4632.05	8644.67	0.0058	0.0003
9.60	1099.45	740.48	969.98	88.24	479.71	5099.39	9955.95	-0.0037	-0.0059
9.61	1099.12	741.51	971.24	100.54	436.75	4612.33	10199.25	-0.0051	0.0006
9.63	1097.72	737.04	967.01	92.30	480.19	5094.37	9373.13	0.0000	-0.0060
9.65	1096.77	734.92	965.17	84.94	459.56	4860.23	8615.22	0.0054	-0.0032
9.66	1098.13	744.29	973.57	92.00	439.81	4675.23	9314.63	0.0064	-0.0002
9.68	1098.41	739.97	968.6	101.67	436.55	4641.39	10313.38	-0.0058	0.0002
9.70	1099.06	739.2	969.05	92.62	455.78	4841.00	9409.72	-0.0002	-0.0027
9.71	1097.77	739.89	965.35	97.77	449.42	4774.93	9995.53	-0.0039	-0.0013
9.73	1097.24	729.91	961.88	105.99	459.35	4878.05	10956.96	-0.0066	-0.0032
9.75	1097.89	726.75	960.47	113.80	499.22	5291.90	11744.91	-0.0128	-0.0084
9.76	1097.86	730	961.86	105.60	474.38	5029.25	10911.89	-0.0094	-0.0053
9.78	1096.63	732.82	965.03	98.13	508.04	5353.46	10083.90	-0.0045	-0.0094
9.80	1098.53	735.41	967.24	97.26	464.09	4927.25	9956.70	-0.0037	-0.0039
9.81	1097.11	734.6	965.22	91.63	426.63	4538.42	9336.43	0.0002	0.0017
9.83	1099.62	741.34	971.78	79.88	445.87	4733.13	8126.45	0.0067	-0.0013
9.85	1098.25	733.93	965.46	96.51	429.40	4567.17	10171.66	-0.0050	0.0012
9.86	1097.93	736.84	967.17	94.06	461.55	4900.39	9600.04	-0.0015	-0.0035
9.88	1098.04	729.72	963	106.74	496.64	5265.12	10995.54	-0.0093	-0.0081
9.90	1098.11	733.15	965.76	91.66	463.36	4971.53	9414.99	-0.0003	-0.0044
9.91	1098.57	734.06	964.76	96.48	457.26	4856.36	9531.35	-0.0010	-0.0029
9.93	1097.6	732.7	965.24	91.13	502.88	5324.72	9357.73	0.0001	-0.0088
9.95	1097.51	736.11	967.37	81.41	496.04	5155.10	9457.34	-0.0006	-0.0068
9.96	1097.73	738.15	969.74	107.42	481.22	5105.06	10935.42	-0.0093	-0.0061
9.99	1097.39	735.74	966.23	90.44	476.57	5056.80	9207.31	0.0011	-0.0055
10.00	1099.42	735.06	966.03	104.46	508.19	5395.39	10653.19	-0.0075	-0.0095
10.01	1098.63	736.43	965.78	105.00	464.09	4927.25	10614.08	-0.0075	-0.0038
10.03	1098.04	739.74	968.46	94.05	438.77	4664.43	9498.93	-0.0003	-0.0002
10.05	1097.84	734.12	964.13	96.72	482.69	5130.70	9821.69	-0.0029	-0.0065
10.06	1096.59	730.94	961.66	102.54	433.63	4613.67	10446.97	-0.0065	0.0006
10.08	1099.01	738.65	968.51	95.09	455.23	4835.29	9651.34	-0.0018	-0.0026
10.10	1100.14	733.72	964.59	106.56	506.72	5369.75	10663.59	-0.0086	-0.0092
10.11	1097.17	736.13	966.39	89.03	476.85	5059.70	9652.46	0.0012	-0.0056
10.13	1098.38	736.51	966.56	93.09	494.35	5146.64	9461.09	-0.0004	-0.0075
10.15	1098.58	726.96	957.91	114.75	456.17	5156.44	11674.73	-0.0124	-0.0088

FOULING PROBE FIELD TEST
 RICHMOND POWER & LIGHT
 WHITEWATER VALLEY STATION
 UNIT 2: PORT E2

TEST 04 - 11 JANUARY 1989
 BOILER LOAD: 56 MW
 PROBE TEMPERATURE: 1100 F
 GAS TEMPERATURE: 1700
 DATA TIME: 1 MINUTE

TEST TIME HR	PROBE TEMP °F	AIR-IN TEMP °F	AIR-OUT TEMP °F	AIR-FLOW RATE LB/HF	HF-METER OUTPUT UV	METER-HF CALC B/FT2-HR	AVE-HF CALC B/FT2-HR	AVE-FF CALC	LOC-FF CALC
10.16	1099.09	728.38	959.84	111.92	492.49	5222.05	11439.19	-0.0114	-0.0075
10.18	1099.69	724.76	957.15	114.32	513.81	5495.25	11782.75	-0.0129	-0.0106
10.20	1097.86	730.94	960.15	99.87	462.28	4908.47	10108.35	-0.0046	-0.0036
10.21	1096.51	731.18	962.19	97.18	466.70	4954.35	9913.33	-0.0035	-0.0042
10.23	1097.45	722.63	955.7	114.71	522.57	5534.28	11805.91	-0.0130	-0.0110
10.25	1096.69	733.62	964.1	84.04	438.95	4666.30	8553.25	0.0061	-0.0002
10.26	1096.93	726.62	958.26	96.74	480.74	5100.08	9895.35	-0.0033	-0.0061
10.28	1097.76	731	961.84	91.22	543.50	5751.53	9298.50	0.0005	-0.0132
10.30	1097.5	733.75	963.29	86.78	473.32	5023.06	8796.09	0.0041	-0.0051
10.31	1096.51	730.12	959.76	96.46	460.63	4891.34	9781.52	-0.0026	-0.0034
10.33	1099.75	727.5	960.58	111.44	532.25	5634.76	11469.85	-0.0115	-0.0120
10.35	1096.57	731.33	961.31	94.53	516.46	5470.85	9634.11	-0.0017	-0.0104
10.36	1098.27	737.82	966.35	88.71	486.17	5156.44	8952.15	0.0030	-0.0068
10.38	1097.95	725.14	956.66	110.89	455.81	4841.31	11336.85	-0.0109	-0.0027
10.40	1097.58	735.03	963.7	90.32	465.39	4940.75	9099.92	0.0020	-0.0040
10.41	1096.74	730.45	960.85	102.27	458.09	4864.97	10405.01	-0.0063	-0.0030
10.43	1097.93	732.64	963.74	100.69	489.53	5191.32	10230.92	-0.0053	-0.0072
10.45	1096.26	729.32	960.04	101.61	441.87	4696.61	10352.22	-0.0060	-0.0007
10.46	1097.07	733.91	962.07	97.63	443.99	4718.62	9836.36	-0.0030	-0.0010
10.48	1097.32	725.55	955.55	112.97	489.17	5187.58	11473.68	-0.0116	-0.0071
10.50	1098.32	729.55	958.9	115.96	479.50	5067.21	11744.07	-0.0127	-0.0059
10.51	1098.75	736.79	965.78	104.66	506.02	5362.49	10583.00	-0.0072	-0.0092
10.53	1098.97	739.68	967.1	97.45	462.74	4913.24	9736.38	-0.0027	-0.0027
10.55	1097.24	732.4	960.41	100.14	416.09	4429.01	10082.61	-0.0045	0.0035
10.56	1098.18	731.28	960.35	97.52	495.84	5256.82	9864.90	-0.0031	-0.0080
10.58	1098.45	734.09	962.16	100.79	433.56	4610.35	10150.73	-0.0048	0.0006
10.60	1097.34	733.16	961.94	102.74	461.99	4905.46	10379.33	-0.0061	-0.0036
10.61	1099.26	733.78	963.18	102.02	513.29	5437.95	10324.52	-0.0059	-0.0100
10.63	1098.42	730.38	959.59	111.00	550.88	5829.13	11234.87	-0.0105	-0.0139
10.65	1098.23	734.63	962.29	97.72	515.76	5463.59	9823.85	-0.0029	-0.0103
10.66	1097.84	740.9	966.58	90.91	420.46	4474.37	9059.75	0.0022	0.0027
10.68	1096.57	733.14	962.25	98.56	460.23	4837.19	9931.52	-0.0039	-0.0033
10.70	1097.4	729.61	959.32	105.46	547.81	5796.27	10720.71	-0.0079	-0.0137
10.71	1097.37	730.33	960.61	84.39	466.75	4955.28	8613.52	0.0056	-0.0042
10.73	1097.4	731.63	959.9	95.10	484.04	5134.34	9586.08	-0.0014	-0.0065
10.75	1098.4	723.15	959.27	107.72	485.39	5145.23	10993.74	-0.0093	-0.0066
10.76	1101.05	731.02	961.24	116.73	497.90	5279.20	11866.90	-0.0132	-0.0082
10.78	1096.9	731.28	959.62	98.28	394.00	4199.72	9909.66	-0.0034	0.0075
10.80	1097.56	735.47	964.29	85.73	454.54	4828.13	8662.41	0.0052	-0.0025
10.81	1096.32	731.69	959.07	91.93	445.33	4732.53	9230.41	0.0010	-0.0012
10.83	1097.26	734.77	963.01	98.18	473.22	5022.02	9895.24	-0.0033	-0.0051
10.85	1099.13	734.42	963.41	99.00	496.51	5263.77	10010.63	-0.0040	-0.0080
10.86	1098.45	733.29	961.5	99.48	441.72	4695.05	10024.95	-0.0041	-0.0006
10.88	1098.11	728.62	959.02	107.19	515.94	5465.46	10935.57	-0.0089	-0.0103
10.90	1098.47	732.69	961.64	92.72	523.05	5539.26	9374.02	0.0000	-0.0111
10.91	1098.72	735.94	964.07	94.05	483.54	5129.15	9478.59	-0.0007	-0.0064
10.93	1098.55	728.14	958.18	109.59	452.50	4906.95	11122.33	-0.0100	-0.0022

FOULING PROBE FIELD TEST
 RICHMOND POWER & LIGHT
 WHITEWATER VALLEY STATION
 UNIT 2: PORT E2

TEST 04 - 11 JANUARY 1989
 BOILER LOAD: 66 MW
 PROBE TEMPERATURE: 1100 F
 GAS TEMPERATURE: 1700
 DATA TIME: 1 MINUTE

TEST TIME HR	PROBE TEMP IF	AIR-IN TEMP IF	AIR-OUT TEMP IF	AIR-FLOW RATE LB/HR	HF-METER OUTPUT IN	METER-HF CALC B/FT2-HR	AVE-HF CALC B/FT2-HR	AVE-HF CALC	LOC-HF CALC
10.95	1097.4	731.08	960.22	102.20	438.06	4657.06	10341.02	-0.0059	-0.0001
10.96	1098.98	732.38	965.9	80.82	447.11	4751.00	8119.89	0.0097	-0.0014
10.98	1097.38	733.93	963.55	101.86	421.13	4481.33	10328.21	-0.0059	0.0026
11.00	1096.63	737.53	965.71	86.59	431.21	4585.96	8724.03	0.0047	0.0010
11.01	1097.76	741.12	968.59	86.74	427.46	4547.03	8712.75	0.0048	0.0016
11.03	1100.78	728.59	958.96	110.63	502.70	5328.03	11251.09	-0.0102	-0.0087
11.05	1098.83	732.92	961.5	84.15	522.74	5536.04	9503.21	-0.0009	-0.0110
11.06	1096.46	727.1	956.16	93.86	439.55	4672.53	9493.83	-0.0008	-0.0003
11.08	1097.12	726.79	956.32	97.50	418.14	4450.29	9882.25	-0.0033	0.0031
11.10	1098.69	732.88	963.18	101.76	458.89	4873.28	10348.63	-0.0059	-0.0031
11.11	1098.14	735.44	964.04	87.96	459.88	4883.55	8879.19	0.0035	-0.0033
11.13	1098.24	727.93	957.92	106.67	438.99	4666.72	10831.00	-0.0035	-0.0002
11.15	1098.66	732.4	961.94	96.30	507.11	5373.80	9456.96	-0.0006	-0.0093
11.16	1097.54	728.61	958.55	93.30	501.94	5320.14	10082.67	-0.0044	-0.0087
11.18	1097.76	726.79	956.31	107.04	483.77	5131.53	10848.72	-0.0036	-0.0065
11.20	1097.64	725.26	956.79	102.50	471.11	5000.12	10473.55	-0.0067	-0.0043
11.21	1098.4	724.13	956.24	107.31	511.31	5417.40	10996.44	-0.0033	-0.0098
11.23	1098.3	724.78	956.22	113.67	519.00	5497.22	11310.45	-0.0103	-0.0106
11.25	1097.25	731.61	961.14	87.83	526.73	5577.46	8871.73	0.0036	-0.0115
11.26	1096.36	730.99	959.36	92.11	423.88	4509.87	9309.09	0.0004	0.0023
11.28	1096.35	728.44	959.05	93.39	413.86	4405.87	10019.38	-0.0041	0.0039
11.30	1097.92	727.31	958.81	102.56	487.19	5167.03	10461.69	-0.0066	-0.0059
11.31	1096.58	723.6	958.63	100.32	449.51	4775.91	10190.22	-0.0051	-0.0018
11.33	1098.84	727.59	959.34	110.53	482.65	5119.91	11311.28	-0.0102	-0.0063
11.35	1097.58	725.04	958.33	106.51	494.72	5245.19	10972.31	-0.0092	-0.0073
11.36	1098.32	726.07	959.99	110.26	539.42	5709.18	11389.30	-0.0112	-0.0128

AVERAGE	1097.98	732.91	963.20	96.46	469.68	4985.30	10015.16	-0.0035	-0.0043
MINIMUM	1096.26	722.63	952.63	72.74	394.00	4199.72	7284.35	-0.0133	-0.0139
MAXIMUM	1101.05	751.36	978.15	116.73	550.88	5828.13	11876.71	0.0131	0.0075
STD DEV	0.93	5.11	4.59	8.77	33.85	351.35	926.81	0.0056	0.0045

TEST: TEST-04
RUN 1: 1 MINUTE
PORT: E2
11 JANUARY 1989

TEST: TEST-04
RUN 1: 1 MINUTE
PORT: E2
11 JANUARY 1989

TEST: TEST-04
RUN 1: 1 MINUTE
PORT: E2
11 JANUARY 1989

TEST: TEST-04
RUN 1: 1 MINUTE
PORT: E2
11 JANUARY 1989

TEST: TEST-04
RUN 1: 1 MINUTE
PORT: E2
11 JANUARY 1989

TEST: TEST-04
RUN 1: 1 MINUTE
PORT: E2
11 JANUARY 1989

TEST: TEST-04
RUN 1: 1 MINUTE
PORT: E2
11 JANUARY 1989

FOULING PROBE FIELD TEST
 RICHMOND POWER & LIGHT
 WHITWATER VALLEY STATION
 UNIT 2: PORT E2

TEST 04 - 11 JANUARY 1989
 BOILER LOAD: 66 MW
 PROBE TEMPERATURE: 1100 F
 GAS TEMPERATURE: 1700
 DATA TIME: 2 MINUTES

TEST TIME HR	PROBE TEMP °F	AIR-IN TEMP °F	AIR-OUT TEMP °F	AIR-FLOW RATE LB/HR	HF-METER OUTPUT GV	METER-HF CALC B/FT2-HR	AVE-HF CALC B/FT2-HR	AVE-HF CALC	LOC-HF CALC
11.88	1096.85	723.53	995.23	102.56	502.60	5326.99	11352.93	-0.0070	-0.0080
11.86	1097.34	724.26	955.26	107.18	499.82	5298.13	10932.95	-0.0090	-0.0084
11.90	1098.23	722.35	953.08	108.23	560.92	5832.35	11027.15	-0.0095	-0.0149
11.93	1099.06	727.12	957.83	108.46	547.36	5791.60	11049.63	-0.0096	-0.0136
11.96	1097.5	727.4	958	95.94	489.28	5188.73	10073.20	-0.0044	-0.0072
12.00	1095.96	724.14	953.18	98.17	526.87	5578.91	9928.92	-0.0035	-0.0115
12.03	1097.03	722.81	953.56	105.35	488.37	5179.28	10734.65	-0.0080	-0.0071
12.06	1100.19	723.88	954.69	117.04	560.31	5926.02	11928.91	-0.0135	-0.0148
12.10	1099.62	724.42	955.01	120.02	496.45	5263.15	12220.97	-0.0147	-0.0090
12.13	1096.94	724.73	953.57	104.47	535.27	5666.10	10556.87	-0.0071	-0.0124
12.16	1097.12	724.83	954.91	109.70	510.80	5412.10	11145.44	-0.0101	-0.0097
12.20	1097.62	724.99	954.53	103.99	502.47	5325.64	10540.51	-0.0070	-0.0088
12.23	1097.5	729.41	958.08	93.51	472.61	5015.69	9442.32	-0.0005	-0.0050
12.26	1096.65	726.93	955.77	98.61	533.73	5650.64	9964.71	-0.0038	-0.0123
12.30	1098.13	718.72	949.83	119.75	544.13	5758.07	12220.98	-0.0145	-0.0133
12.33	1096.85	730.22	957.13	86.58	470.38	4892.54	8875.67	0.0035	-0.0047
12.36	1097.24	720.4	950.55	110.51	503.98	5383.97	11231.15	-0.0105	-0.0094
12.40	1098.8	719.26	949.48	123.47	501.97	5320.45	12552.09	-0.0160	-0.0087
12.43	1097.33	725.14	954.5	110.45	501.70	5307.27	11186.52	-0.0102	-0.0035
12.46	1095.42	717.66	946.89	109.00	580.81	6138.81	11033.41	-0.0055	-0.0163
12.50	1097.63	726.05	954.26	109.23	504.84	5350.24	11007.49	-0.0094	-0.0090
12.53	1096.76	721.89	953.82	107.27	527.15	5581.92	10938.62	-0.0091	-0.0115
12.56	1096.47	725.11	954.17	102.79	500.05	5300.52	10397.09	-0.0062	-0.0035
12.60	1097.85	720.3	950.52	122.49	527.65	5587.01	12452.47	-0.0156	-0.0116
12.63	1097.47	721.99	953.03	111.72	502.68	5327.82	11398.03	-0.0112	-0.0038
12.66	1098.42	719.08	950.27	117.22	556.53	5886.78	11914.92	-0.0137	-0.0145
12.70	1096.73	723.61	951.47	107.13	508.24	5385.53	10769.27	-0.0083	-0.0094
12.73	1097.9	726.86	956.1	102.25	467.47	4962.34	10350.60	-0.0060	-0.0043
12.76	1099.53	729.2	956.35	112.57	519.59	5503.34	11291.38	-0.0107	-0.0107
12.80	1097.18	724.56	953.35	110.67	440.77	4685.19	11180.95	-0.0102	-0.0005
12.83	1096.84	717.26	948.57	130.07	504.94	5351.28	13285.66	-0.0186	-0.0091
12.86	1097.99	719.74	949.39	120.60	526.46	5574.65	12229.97	-0.0148	-0.0114
12.90	1100.38	725.61	953.71	112.48	547.99	5798.14	11329.54	-0.0109	-0.0136
12.93	1098.87	715.11	944.58	127.36	552.60	5845.99	12905.38	-0.0173	-0.0141
12.96	1097.74	722.36	951.33	108.02	517.79	5484.66	10921.81	-0.0090	-0.0104
13.00	1095.76	721.93	950.33	101.61	498.21	5281.42	10248.12	-0.0054	-0.0083
13.03	1099.86	724.67	953.99	111.24	519.90	5506.56	11264.57	-0.0106	-0.0107
13.06	1098.92	724.54	953.63	115.70	516.45	5470.75	11704.45	-0.0126	-0.0103
13.10	1100.23	713.99	945.06	130.23	491.79	5214.78	13286.20	-0.0185	-0.0074
13.13	1096.14	716.56	945.63	118.06	547.99	5798.14	11942.15	-0.0136	-0.0137
13.16	1099.47	713.04	944.16	133.45	578.11	6110.78	13119.71	-0.0196	-0.0165
13.20	1097.34	724.73	952.27	97.31	535.32	5666.62	9777.48	-0.0026	-0.0124
13.23	1098.66	721.12	949.55	116.74	574.65	6074.87	11775.64	-0.0129	-0.0162
13.26	1102.2	726.93	952.34	124.16	592.59	6261.08	12638.58	-0.0164	-0.0177
13.30	1096.26	712.4	942.19	124.81	526.87	5578.91	12664.62	-0.0164	-0.0115
13.33	1098.7	714	945.41	127.31	606.21	6402.46	13009.37	-0.0176	-0.0189
13.36	1097.53	710.55	941.79	131.41	560.03	5823.11	13419.47	-0.0191	-0.0149

FOULING PROBE FIELD TEST
 RICHMOND POWER & LIGHT
 WHITEWATER VALLEY STATION
 UNIT 2: PORT E2

TEST 04 - 11 JANUARY 1989
 BOILER LOAD: 66 MW
 PROBE TEMPERATURE: 1100 F
 GAS TEMPERATURE: 1700
 DATA TIME: 2 MINUTES

TEST TIME HR	PROBE TEMP °F	AIR-IN TEMP °F	AIR-OUT TEMP °F	AIR-FLOW RATE LB/HR	HF-METER OUTPUT GV	METER-HF CALC B/FT2-HR	AVE-HF CALC B/FT2-HR	AVE-FF CALC	LOC-FF CALC
13.40	1093.07	714.99	944.79	122.19	533.01	5642.64	12399.31	-0.0154	-0.0121
13.43	1097.72	717.32	947.43	117.21	579.76	6127.91	11910.00	-0.0135	-0.0167
13.46	1099.15	720.22	947.93	125.10	549.71	5815.99	12579.14	-0.0161	-0.0138
13.50	1097.09	716.96	947.51	107.38	564.14	5965.77	10932.02	-0.0090	-0.0153
13.52	1099.79	722.35	952.32	121.93	553.79	5959.34	12382.08	-0.0153	-0.0142
13.56	1097	723.56	951.65	100.65	517.76	5484.35	10137.52	-0.0048	-0.0105
13.60	1098.22	731.65	953.57	109.92	476.09	5051.61	11014.41	-0.0094	-0.0055
13.63	1097.25	717.38	945.51	120.35	494.69	5244.88	12123.84	-0.0144	-0.0078
13.66	1098.12	722.97	951.47	115.19	539.20	5706.90	11622.85	-0.0122	-0.0128
13.70	1096.93	709.48	940.64	131.14	533.17	6163.30	13386.27	-0.0190	-0.0170
13.73	1099.05	713.9	945.7	133.49	545.80	5775.40	13663.37	-0.0198	-0.0134
13.76	1096.85	714.65	945.68	114.70	492.22	5281.52	11701.55	-0.0126	-0.0083
13.80	1097.54	717.57	947.99	113.59	590.65	6240.95	11557.21	-0.0136	-0.0176

AVERAGE	1097.89	721.39	951.75	113.42	526.86	5578.85	11537.60	-0.0113	-0.0112
MINIMUM	1095.40	709.43	940.64	81.58	440.77	4665.19	8875.67	-0.0198	-0.0189
MAXIMUM	1102.20	731.65	955.23	133.49	604.11	6402.46	13663.37	0.0035	-0.0005
STD DEV	1.28	4.58	7.16	10.42	34.78	361.92	1087.03	0.0050	0.0038

TEST: TEST-04
RUN 2: 2 MINUTES
PORT: E2
11 JANUARY 1989

TEST: TEST-04
RUN 2: 2 MINUTES
PORT: E2
11 JANUARY 1989

TEST: TEST-04
RUN 2: 2 MINUTES
PORT: E2
11 JANUARY 1989

TEST: TEST-04
RUN 2: 2 MINUTES
PORT: E2
11 JANUARY 1989

TEST: TEST-04
RUN 2: 2 MINUTES
PORT: E2
11 JANUARY 1989

TEST: TEST-04
RUN 2: 2 MINUTES
PORT: E2
11 JANUARY 1989

TEST: TEST-04
RUN 2: 2 MINUTES
PORT: E2
11 JANUARY 1989

FOULING PROBE FIELD TEST
 RICHMOND POWER & LIGHT
 WHITEWATER VALLEY STATION
 UNIT 2: PORT E2

TEST 04 - 11 JANUARY 1989
 BOILER LOAD: 66 MW
 PROBE TEMPERATURE: 1100 F
 GAS TEMPERATURE: 1700
 DATA TIME: 5 MINUTES

TEST TIME HR	PROBE TEMP °F	AIR-IN TEMP °F	AIR-OUT TEMP °F	AIR-FLOW RATE LB/HR	HF-METER OUTPUT GV	METER-HF CALC B/FT2-HR	AVE-HF CALC B/FT2-HR	AVE-HF CALC	LOC-HF CALC
15.25	1098.86	709.89	961.1	85.37	461.38	4899.12	7251.49	0.0115	-0.0035
15.33	1099.34	731.13	964.25	89.76	453.11	4813.23	9137.10	0.0016	-0.0023
15.42	1097.04	741.61	967.47	73.33	466.94	4958.84	7313.63	0.0173	-0.0043
15.50	1097.03	737.88	963.79	86.25	471.14	5000.43	8604.12	0.0057	-0.0048
15.58	1097.87	740.03	962.39	96.52	497.30	5277.16	9498.63	-0.0003	-0.0082
15.67	1095.81	733.94	957.75	90.01	490.99	5206.43	8895.74	0.0034	-0.0074
15.75	1099.44	739	960.53	92.03	472.21	5073.82	9007.61	0.0026	-0.0057
15.83	1099.04	743.16	964.31	82.79	439.94	4676.58	8103.21	0.0029	-0.0004
15.92	1098.26	736.33	959.57	89.83	465.82	4945.21	8653.35	0.0027	-0.0041
16.00	1096.52	732.47	956.86	87.72	470.64	4995.24	8491.88	0.0050	-0.0048
16.08	1097.23	734.36	958.39	97.84	448.34	4763.77	9702.67	-0.0022	-0.0016
16.17	1098.03	728.04	954.3	105.35	453.28	4815.05	10525.77	-0.0049	-0.0023
16.25	1098.44	726.41	952.88	105.95	467.92	4967.01	10585.55	-0.0073	-0.0044
16.33	1097.39	732.68	953.45	91.21	492.73	5224.54	9053.00	0.0022	-0.0076
16.42	1099.01	738.37	961.11	90.86	439.41	4671.03	3946.65	0.0130	-0.0003
16.50	1098.01	740.04	962.54	87.39	487.89	5174.30	9588.25	0.0053	-0.0070
16.58	1099.53	729.67	954.08	109.71	444.43	4723.70	10923.21	-0.0032	-0.0010
16.67	1097.14	735.55	957.43	92.70	442.32	4701.28	9082.59	0.0020	-0.0007
16.75	1097.33	733.62	957.14	86.74	484.22	4929.60	1369.11	0.0052	-0.0029
16.83	1096.61	739.41	962.19	76.83	411.49	4381.27	7551.21	0.0152	0.0043
16.92	1096.46	734.2	959.39	101.75	459.01	4874.52	10140.48	-0.0043	-0.0032
17.00	1098.34	725.87	951.43	112.59	428.56	4558.66	11313.77	-0.0108	0.0014
17.08	1097.9	731.03	957.94	89.19	462.29	4908.57	3914.82	0.0031	-0.0033
17.17	1098.64	719.65	949.79	111.20	562.35	5957.57	11349.89	-0.0110	-0.0151

AVERAGE	1097.86	733.06	958.14	92.17	465.05	4927.25	9193.16	0.0022	-0.0036
MINIMUM	1095.81	709.89	949.79	65.37	411.49	4381.27	7251.49	-0.0110	-0.0151
MAXIMUM	1099.53	743.16	967.47	112.59	563.35	5957.57	11349.89	0.0135	0.0043
STD DEV	0.31	7.40	4.17	11.42	21.36	299.61	1118.37	0.0073	0.0037

TEST: TEST-04
RUN 3: 5 MINUTES
PORT: E2
11 JANUARY 1989

TEST: TEST-04
RUN 3: 5 MINUTES
PORT: E2
11 JANUARY 1989

TEST: TEST-04
RUN 3: 5 MINUTES
PORT: E2
11 JANUARY 1989

TEST: TEST-04
RUN 3: 5 MINUTES
PORT: E2
11 JANUARY 1989

TEST: TEST-04
RUN 3: 5 MINUTES
PORT: E2
11 JANUARY 1989

TEST: TEST-04
RUN 3: 5 MINUTES
PORT: E2
11 JANUARY 1989

TEST: TEST-04
RUN 3: 5 MINUTES
PORT: E2
11 JANUARY 1989

APPENDIX B
PROBE ORIENTATION TEST DATA AND ANALYSIS

FOULING PROBE FIELD TEST
 RICHMOND POWER & LIGHT
 WHITewater VALLEY STATION
 UNIT 2: PORT D1

TEST 11A - 1 FEBRUARY 1989
 BOILER LOAD: 60 MW
 PROBE TEMPERATURE: 1300 F
 GAS TEMPERATURE: 1840
 DATA TIME: 5 SECONDS

HEAT FLUX METER ORIENTATION

TEST TIME HR	PROBE TEMP °F	AIR-IN TEMP °F	AIR-OUT TEMP °F	AIR-FLOW RATE LB/HR	HF-METER OUTPUT uV	METER-HF CALC B/FT2-HR	AVE-HF CALC B/FT2-HR	AVE-FF CALC	LOC-FF CALC
10.35	1297.8	710.7	114.5	203.45	1191.99	12997.01	-53561.7		
10.35	1299.5	705.3	113.3	237.38	1194.34	13021.95	-62047.8		
10.35	1294.6	703.5	113.5	202.81	1052.88	11521.06	-52835.2		
10.35	1295.1	718.7	113.9	134.94	1031.02	11289.12	-36041.9		
10.36	1300.7	725.5	114.3	158.01	1112.14	12149.81	-42648.2		
10.36	1299.4	712.3	114.4	215.83	1111.28	12140.68	-56989.6		
10.36	1296.1	712.0	113.7	172.91	1114.69	12176.86	-45677.3		
10.36	1300.0	714.9	113.5	188.94	1169.55	12758.93	-50175.5		
10.36	1298.0	706.8	113.3	225.62	1199.86	13080.51	-59124.3		
10.36	1297.0	703.6	113.8	227.88	1149.60	12547.26	-59358.3		
10.36	1295.8	709.1	114.0	186.47	1016.03	11130.08	-49003.3		
10.37	1297.1	719.1	113.4	146.01	1083.44	11845.30	-39053.4		
10.37	1301.3	722.5	113.0	168.40	1172.69	12792.24	-45323.9		
10.37	1300.4	707.4	113.2	238.25	1229.58	13395.84	-62523.5		
10.37	1295.9	698.0	115.1	252.58	1175.70	12824.18	-65020.4		
10.37	1294.6	702.9	113.5	202.86	1220.99	13304.70	-52791.8		
10.37	1298.2	708.1	113.2	199.52	1131.50	12355.22	-52417.8		
10.37	1296.0	713.5	113.7	157.65	1056.36	11557.98	-41754.7		
10.38	1300.3	720.9	113.6	158.27	1188.35	12958.39	-42445.1		
10.38	1301.1	708.7	1211.0	235.54	1311.44	14264.38	52244.4		
10.38	1296.1	696.8	112.7	276.98	1278.52	13915.10	-71438.5		
10.38	1295.5	699.7	112.7	243.08	1209.43	13182.05	-63008.5		
10.38	1298.5	705.9	112.6	230.91	1228.80	13387.57	-60496.3		
10.38	1294.8	709.1	112.1	188.98	1111.44	12142.38	-49817.3		
10.38	1298.9	724.6	112.0	139.84	1067.87	11680.10	-37826.1		
10.38	1301.5	723.3	112.1	194.26	1232.30	13424.70	-52431.5		
10.39	1299.5	711.8	112.3	244.75	1288.87	14024.91	-64797.7		
10.39	1293.7	705.9	112.5	225.93	1205.78	13143.33	-59198.6		
10.39	1293.3	719.2	112.6	148.61	1111.78	12145.99	-39807.2		
10.39	1294.4	733.9	112.5	102.68	1004.92	11012.20	-28176.2		
10.39	1301.3	743.6	112.7	125.88	1129.74	12336.54	-35067.8		
10.39	1300.4	725.0	112.5	225.43	1194.27	13021.20	-60972.9		
10.39	1295.2	714.2	112.3	216.69	1159.40	12651.23	-57596.6		
10.40	1295.3	727.5	112.4	129.58	1073.54	11740.26	-35196.2		
10.40	1300.4	735.2	112.2	151.01	1154.34	12597.55	-41548.4		
10.40	1299.3	724.6	112.0	203.93	1167.06	12732.51	-55164.0		
10.40	1297.1	716.4	112.0	238.00	1223.32	13329.43	-63524.6		
10.40	1296.2	717.2	111.8	202.02	1104.86	12072.56	-54005.0		
10.40	1297.5	726.1	112.2	151.05	1169.59	12759.35	-40945.8		
10.40	1298.6	727.6	112.4	167.88	1063.24	11630.98	-45608.7		
10.41	1296.3	729.2	112.2	142.95	1050.05	11491.03	-38947.0		
10.41	1300.4	734.0	112.7	144.62	1042.93	11415.49	-39680.4		
10.41	1299.1	734.4	112.6	131.63	1085.36	11865.67	-36142.4		
10.41	1299.9	731.2	112.6	170.20	1134.52	12387.26	-46494.6		
10.41	1301.4	721.7	112.9	222.67	1251.23	13625.55	-59865.5		
10.41	1295.7	706.2	113.2	260.44	1224.70	13344.07	-68192.6		
10.41	1297.5	710.6	113.2	207.38	1316.84	14321.67	-54705.3		

FOULING PROBE FIELD TEST
 RICHMOND POWER & LIGHT
 WHITEWATER VALLEY STATION
 UNIT 2: PORT D1

TEST 11A - 1 FEBRUARY 1989
 BOILER LOAD: 60 MW
 PROBE TEMPERATURE: 1300 F
 GAS TEMPERATURE: 1840
 DATA TIME: 5 SECONDS

HEAT FLUX METER ORIENTATION

TEST TIME HR	PROBE TEMP [F	AIR-IN TEMP [F	AIR-OUT TEMP [F	AIR-FLOW RATE LB/HR	HF-METER OUTPUT uV	METER-HF CALC B/FT2-HR	AVE-HF CALC B/FT2-HR	AVE-FF CALC	LOC-FF CALC
10.42	1294.9	712.1	113.4	196.53	1179.54	12864.92	-51957.7		
10.42	1299.0	718.9	113.1	191.41	1194.78	13026.62	-51201.7		
10.42	1300.2	717.5	113.3	196.39	1193.02	13007.94	-52402.0		
10.42	1300.0	714.2	113.3	223.08	1282.19	13954.04	-59191.6		
10.42	1295.7	709.3	113.2	224.63	1270.14	13826.19	-59135.7		
10.42	1299.5	711.9	112.7	222.20	1283.02	13962.84	-58796.2		
10.42	1297.2	712.0	112.5	202.42	1294.56	14085.28	-53588.2		
10.43	1296.8	714.1	112.3	192.92	1296.37	14104.49	-51262.3		
10.43	1297.1	714.9	112.3	192.64	1260.17	13720.40	-51261.0		
10.43	1301.5	711.2	112.3	250.64	1333.20	14495.25	-66287.4		
10.43	1296.0	702.4	112.6	249.80	1217.08	13263.22	-65063.6		
10.43	1298.2	710.6	112.3	195.91	1270.21	13826.93	-51757.4		
10.43	1297.6	711.6	112.9	212.18	1278.64	13916.37	-56101.7		

SUMMARY OF 0 DEGREE PROBE ORIENTATION

AVERAGE	1297.84	715.65	131.23	195.86	1175.85	12825.78	-50086.9		
MINIMUM	1293.27	696.80	111.80	102.68	1004.92	11012.20	-71438.5		
MAXIMUM	1301.54	743.60	1210.97	276.98	1333.20	14495.25	52244.38		
STD DEV	2.26	10.08	140.57	38.98	84.00	891.21	16459.17		

10.57	1297.6	654.2	1103.8	283.92	1272.74	13853.77	56369.4		
10.57	1295.2	655.2	1104.4	284.14	1068.93	11691.35	56364.2		
10.57	1295.8	668.0	1109.4	193.19	1047.04	11459.09	37658.1		
10.57	1298.4	671.3	1111.1	219.72	1117.37	12205.30	42671.4		
10.58	1302.2	663.2	1113.4	296.87	1262.78	13748.10	59012.6		
10.58	1297.6	651.1	1107.1	360.95	1103.40	12057.07	72683.0		
10.58	1294.8	658.8	1105.0	253.17	1045.30	11440.63	49878.6		
10.58	1297.0	669.7	1108.4	202.48	1072.43	11728.48	39232.0		
10.58	1298.9	671.4	1109.7	218.02	997.65	10935.07	42203.5		
10.58	1299.8	669.4	1106.4	233.75	961.74	10554.06	45110.2		
10.58	1295.8	673.3	1102.4	189.41	813.36	8979.75	35889.1		
10.59	1296.7	683.1	1107.6	150.23	837.02	9230.78	28160.2		
10.59	1300.1	689.6	1115.1	144.36	872.30	9605.10	27122.4		
10.59	1298.5	687.3	1113.7	163.37	764.57	8462.09	30757.4		
10.59	1295.7	689.4	1110.9	136.58	698.77	7763.95	25419.4		
10.59	1301.3	697.7	1115.8	127.21	871.76	9599.37	23486.8		
10.59	1300.6	688.9	1116.2	177.09	896.93	9866.43	33416.3		
10.59	1297.0	681.3	1113.8	191.38	889.56	9788.23	36555.7		
10.60	1294.6	682.6	1110.7	149.55	771.92	8540.07	28271.8		
10.60	1297.5	692.5	1112.6	120.97	690.59	7677.16	22439.9		
10.60	1299.9	697.4	1118.3	118.35	914.45	10052.31	21994.2		
10.60	1300.0	686.6	1120.4	180.94	945.27	10379.31	34662.2		
10.60	1296.9	678.7	1114.7	191.45	912.22	10028.65	36861.5		
10.60	1298.2	677.2	1115.4	201.70	844.67	9311.95	39028.3		
10.60	1296.5	678.1	1113.0	162.82	894.62	9841.92	31270.8		

FOULING PROBE FIELD TEST
 RICHMOND POWER & LIGHT
 WHITEWATER VALLEY STATION
 UNIT 2: PORT D1

TEST 11A - 1 FEBRUARY 1989
 BOILER LOAD: 60 MW
 PROBE TEMPERATURE: 1300 F
 GAS TEMPERATURE: 1840
 DATA TIME: 5 SECONDS

HEAT FLUX METER ORIENTATION

TEST TIME HR	PROBE TEMP [F	AIR-IN TEMP [F	AIR-OUT TEMP [F	AIR-FLOW RATE LB/HR	HF-METER OUTPUT uV	METER-HF CALC B/FT2-HR	AVE-HF CALC B/FT2-HR	AVE-FF CALC	LOC-FF CALC
10.60	1296.6	677.5	1112.9	188.80	686.33	7631.96	36303.8		
10.61	1299.2	681.0	1115.7	166.29	812.25	8967.97	31915.2		
10.61	1299.8	677.0	1116.0	204.19	894.02	9835.55	39591.3		
10.61	1295.8	668.7	1113.7	209.06	840.03	9262.72	41083.9		
10.61	1297.7	677.1	1117.0	159.25	953.40	10465.57	30930.4		
10.61	1300.8	675.4	1120.1	211.42	972.90	10672.47	41519.7		
10.61	1298.7	667.5	1119.2	234.27	974.37	10688.07	46732.3		
10.61	1294.2	672.0	1112.8	161.31	900.21	9901.23	31394.6		
10.62	1299.8	675.5	1120.1	201.84	943.39	10359.37	39627.6		
10.62	1300.5	671.7	1119.9	216.66	1080.16	11810.50	42876.9		
10.62	1299.9	658.5	1118.9	296.31	1203.94	13123.80	60233.3		
10.62	1298.7	649.1	1116.0	343.90	1208.41	13171.23	70909.6		
10.62	1294.8	649.6	1112.0	283.47	1050.67	11497.61	57879.8		
10.62	1299.2	659.2	1114.9	251.97	1198.60	13067.15	50700.4		
10.62	1292.2	656.7	1109.3	216.95	843.52	9299.75	43358.7		
10.63	1295.6	676.7	1115.2	134.13	823.72	9089.67	25975.1		
10.63	1297.4	691.9	1117.3	94.70	632.89	7064.96	17788.9		
10.63	1300.0	695.6	1123.3	136.07	794.83	8783.15	25700.0		
10.63	1299.1	682.7	1122.6	193.14	854.01	9411.05	37518.7		
10.63	1298.6	679.1	1122.7	178.87	954.69	10479.26	35039.7		
10.63	1299.8	671.5	1123.7	238.66	1051.53	11506.73	47656.5		
10.63	1297.1	657.9	1117.8	293.95	1106.09	12085.61	59699.1		
10.64	1294.7	661.4	1114.7	221.88	961.21	10548.44	44412.6		
10.64	1300.2	666.8	1119.0	232.52	1174.10	12807.20	46426.3		
10.64	1297.3	657.4	1116.3	251.82	1138.98	12434.58	51022.7		
10.64	1299.2	658.7	1116.1	248.57	1185.20	12924.97	50210.5		
10.64	1297.8	654.3	1114.0	283.41	1106.79	12093.04	57527.2		
10.64	1298.1	654.0	1114.0	275.83	1022.79	11201.80	56026.3		
10.64	1298.0	660.1	1115.3	240.10	1177.49	12843.17	48263.1		
10.65	1300.0	651.9	1116.1	317.27	1297.29	14114.25	65041.8		
10.65	1297.3	643.8	1112.7	360.22	1209.07	13178.23	74586.4		
10.65	1296.6	654.0	1114.2	246.60	1068.06	11682.12	50110.9		
10.65	1298.1	661.1	1115.4	225.80	1081.21	11821.64	45245.9		
10.65	1299.0	658.9	1114.9	264.63	1119.64	12229.38	53284.0		
10.65	1295.8	663.7	1113.7	202.51	890.92	9802.66	40234.9		

SUMMARY OF 90 DEGREE PROBE ORIENTATION

AVERAGE	1297.89	670.56	1114.27	215.63	979.67	10744.28	42556.62		
MINIMUM	1292.17	643.79	1102.40	94.70	632.89	7064.96	17788.89		
MAXIMUM	1302.22	697.71	1123.66	360.95	1297.29	14114.25	74586.42		
STD DEV	2.02	13.57	4.73	60.20	158.73	1684.13	12957.18		

10.73	1293.6	619.6	1072.0	261.82	1410.37	15314.03	52296.2		
10.73	1299.1	617.4	1076.9	309.77	1354.68	14723.15	62854.5		
10.73	1297.9	618.6	1075.0	279.97	1295.03	14090.27	56427.1		

FOULING PROBE FIELD TEST
 RICHMOND POWER & LIGHT
 WHITEWATER VALLEY STATION
 UNIT 2: PORT D1

TEST 11A - 1 FEBRUARY 1989
 BOILER LOAD: 60 MW
 PROBE TEMPERATURE: 1300 F
 GAS TEMPERATURE: 1840
 DATA TIME: 5 SECONDS

HEAT FLUX METER ORIENTATION

TEST TIME HR	PROBE TEMP [F	AIR-IN TEMP [F	AIR-OUT TEMP [F	AIR-FLOW RATE LB/HR	HF-METER OUTPUT uV	METER-HF CALC B/FT2-HR	AVE-HF CALC B/FT2-HR	AVE-FF CALC	LOC-FF CALC
10.73	1300.7	619.8	1079.9	293.64	1554.43	16842.50	59664.6		
10.74	1299.0	609.4	1072.0	386.53	1477.29	16024.05	78960.5		
10.74	1293.0	613.0	1071.6	247.73	1416.95	15383.84	50164.4		
10.74	1294.4	619.9	1076.4	210.47	1268.58	13809.63	42428.0		
10.74	1301.2	631.0	1088.3	172.30	1359.52	14774.51	34795.0		
10.74	1296.0	622.6	1080.7	256.94	1325.19	14410.27	51980.6		
10.74	1298.4	624.4	1081.3	212.96	1378.94	14980.55	42964.7		
10.74	1300.5	620.4	1081.8	294.57	1398.74	15190.63	60029.2		
10.75	1293.6	618.5	1076.8	230.05	1326.86	14427.98	46553.8		
10.75	1301.2	619.6	1081.9	284.23	1517.37	16449.30	58030.0		
10.75	1299.1	611.5	1077.7	332.74	1459.07	15330.73	68495.3		
10.75	1295.1	618.5	1079.3	199.96	1141.72	12463.65	40685.4		
10.75	1301.7	621.2	1083.0	275.95	1560.01	16901.71	56278.6		
10.75	1298.3	615.7	1078.2	265.54	1397.41	15176.52	54242.3		
10.75	1302.7	610.3	1077.3	376.27	1677.42	18147.43	77589.0		
10.76	1301.8	595.4	1068.9	487.73	1773.76	19169.59	101976.9		
10.76	1295.3	588.5	1060.2	488.52	1716.66	18563.76	101764.6		
10.76	1290.3	599.6	1062.8	279.78	1275.81	13886.34	57216.6		
10.76	1295.6	613.4	1070.5	235.62	1265.77	13779.82	47549.9		
10.76	1302.6	616.6	1076.1	274.06	1566.00	16965.26	55609.9		
10.76	1300.3	604.4	1070.4	377.66	1617.73	17514.12	77713.9		
10.76	1296.1	599.3	1063.0	385.81	1583.72	17153.27	79005.9		
10.76	1298.2	600.8	1062.8	356.34	1730.60	18711.67	72705.2		
10.77	1299.5	593.9	1061.5	428.67	1733.78	18745.41	88507.8		
10.77	1296.1	591.4	1057.7	419.37	1564.48	16949.13	86346.9		
10.77	1295.2	601.1	1062.4	266.90	1565.13	16956.03	54362.2		
10.77	1298.6	601.9	1065.8	358.21	1652.65	17884.62	73382.5		
10.77	1295.3	597.3	1061.6	357.87	1561.10	16913.27	73365.0		
10.77	1297.3	598.8	1061.2	373.47	1369.49	14880.29	76254.7		
10.77	1294.0	606.6	1065.1	231.53	1623.99	17580.53	46878.9		
10.78	1303.6	604.5	1069.9	365.40	1589.43	17213.85	75094.2		
10.78	1300.1	597.3	1063.2	397.25	1624.85	17589.66	81729.3		
10.78	1295.6	600.3	1061.6	322.91	1531.13	16595.29	65776.0		
10.78	1299.4	602.8	1065.6	329.27	1446.24	15694.61	67285.2		
10.78	1291.2	604.0	1061.2	249.68	1206.13	13147.04	50413.8		
10.78	1297.7	621.4	1073.3	154.60	1234.89	13452.18	30853.3		
10.78	1298.1	628.8	1077.8	148.31	1198.38	13064.81	29404.8		
10.79	1303.3	622.2	1077.9	253.84	1531.25	16596.56	51074.4		
10.79	1294.5	607.1	1068.2	315.78	1198.11	13061.95	64299.9		
10.79	1292.2	618.3	1072.3	171.73	1144.41	12492.19	34428.2		
10.79	1301.0	627.9	1079.4	188.53	1371.45	14901.08	37588.9		
10.79	1300.6	616.8	1072.7	271.18	1394.97	15150.63	54601.6		
10.79	1298.7	611.7	1068.3	297.19	1372.96	14917.11	59926.6		
10.79	1298.3	612.4	1068.4	243.38	1322.07	14377.16	49007.4		
10.80	1296.7	613.5	1065.6	232.20	1380.35	14995.51	46355.2		
10.80	1300.9	611.6	1067.5	278.85	1425.39	15473.39	56141.0		
10.80	1299.3	609.7	1066.8	261.08	1364.29	14825.12	52691.4		

FOULING PROBE FIELD TEST
 RICHMOND POWER & LIGHT
 WHITewater VALLEY STATION
 UNIT 2: PORT D1

TEST 11A - 1 FEBRUARY 1989
 BOILER LOAD: 60 MW
 PROBE TEMPERATURE: 1300 F
 GAS TEMPERATURE: 1840
 DATA TIME: 5 SECONDS

HEAT FLUX METER ORIENTATION

TEST TIME HR	PROBE TEMP [F	AIR-IN TEMP [F	AIR-OUT TEMP [F	AIR-FLOW RATE LB/HR	HF-METER OUTPUT UV	METER-HF CALC B/FT2-HR	AVE-HF CALC B/FT2-HR	AVE-HF CALC	LOC-HF CALC
10.80	1293.6	607.7	1064.5	281.68	1157.09	12626.72	56820.3		
10.80	1290.3	619.4	1069.9	152.56	995.81	10915.54	30345.2		
10.80	1296.2	635.6	1081.0	110.12	955.97	10492.84	21662.4		
10.80	1302.5	638.2	1084.7	169.44	1145.62	12505.03	33406.4		
10.81	1295.6	623.5	1077.0	208.37	1050.79	11498.88	41721.2		
10.81	1302.5	626.6	1081.2	207.28	1459.99	15840.49	41613.7		
10.81	1305.3	609.7	1075.9	366.50	1598.30	17308.28	75453.0		
10.81	1296.5	595.2	1065.5	414.82	1493.36	16194.55	86146.4		
10.81	1291.3	602.0	1064.2	248.20	1391.59	15114.77	50656.4		
10.81	1298.9	606.6	1065.9	270.82	1517.71	16452.90	54923.8		

SUMMARY OF 180 DEGREE PROBE ORIENTATION

AVERAGE	1297.75	611.92	1071.49	285.40	1417.05	15384.87	58108.33		
MINIMUM	1290.30	588.46	1057.66	110.12	955.97	10492.84	21662.38		
MAXIMUM	1305.26	638.21	1088.30	488.52	1773.76	19169.59	101976.9		
STD DEV	3.49	11.10	7.45	83.19	185.16	1964.54	17588.45		

10.90	1299.1	671.4	1194.8	177.39	1958.61	21130.85	40999.1		
10.90	1299.1	665.1	1196.3	252.16	2013.92	21717.69	59145.5		
10.90	1295.5	662.5	1190.1	207.00	1773.59	19167.79	48228.4		
10.90	1298.8	669.3	1195.1	190.85	1785.80	19297.34	44307.3		
10.91	1300.4	664.8	1195.3	245.71	2099.05	22620.92	57558.8		
10.91	1299.5	656.7	1190.8	284.37	2236.35	24077.67	67077.2		
10.91	1295.7	651.8	1186.6	288.35	2191.29	23599.59	68093.7		
10.91	1296.2	651.5	1189.9	284.13	2047.22	22071.00	67546.3		
10.91	1298.8	654.9	1195.7	259.40	2273.99	24477.03	61939.9		
10.91	1296.4	653.4	1191.6	259.84	2006.08	21634.51	61750.0		
10.91	1294.6	660.6	1190.7	191.28	1845.26	19928.21	44772.0		
10.92	1296.1	672.7	1194.5	141.95	1705.85	18449.07	32705.9		
10.92	1299.0	682.0	1199.4	134.07	1613.76	17471.99	30633.4		
10.92	1298.9	684.0	1197.3	146.07	1570.53	17013.32	33112.7		
10.92	1297.2	682.5	1195.3	164.37	1597.44	17298.84	37221.2		
10.92	1298.7	685.1	1198.1	140.34	1654.93	17908.81	31789.0		
10.92	1299.1	679.3	1197.3	205.79	1875.36	20247.57	47072.3		
10.92	1299.6	669.1	1196.6	247.75	2097.11	22600.34	57712.8		
10.93	1296.5	657.5	1191.4	305.69	2058.70	22192.81	72071.1		
10.93	1294.5	660.2	1188.7	212.78	1974.72	21301.78	49652.2		
10.93	1295.5	667.7	1190.3	177.29	1892.62	20430.70	40916.5		
10.93	1297.4	673.3	1196.2	169.83	1828.04	19745.50	39215.8		
10.93	1295.6	675.3	1192.9	167.41	1678.27	18156.44	38267.4		
10.93	1298.4	682.7	1199.4	138.65	1598.24	17307.33	31632.7		
10.93	1299.3	684.5	1198.2	156.89	1585.31	17170.14	35586.3		
10.93	1301.3	675.8	1198.8	231.00	2042.66	22022.62	53348.9		
10.94	1296.1	662.3	1190.9	266.78	2069.53	22307.71	62264.8		
10.94	1295.5	659.6	1192.5	260.58	1967.52	21225.39	61317.2		

FOULING PROBE FIELD TEST
 RICHMOND POWER & LIGHT
 WHITEWATER VALLEY STATION
 UNIT 2: PORT D1

TEST 11A - 1 FEBRUARY 1989
 BOILER LOAD: 60 MW
 PROBE TEMPERATURE: 1300 F
 GAS TEMPERATURE: 1840
 DATA TIME: 5 SECONDS

HEAT FLUX METER ORIENTATION

TEST TIME HR	PROBE TEMP [F	AIR-IN TEMP [F	AIR-OUT TEMP [F	AIR-FLOW RATE LB/HR	HF-METER OUTPUT uV	METER-HF CALC B/FT2-HR	AVE-HF CALC B/FT2-HR	AVE-HF CALC	LOC-HF CALC
10.94	1295.4	666.0	1192.3	186.20	1780.45	19240.57	43268.8		
10.94	1299.7	673.6	1196.6	167.58	1677.98	18153.37	38701.5		
10.94	1296.5	675.6	1194.4	162.17	1599.42	17319.85	37148.4		
10.94	1297.1	680.3	1196.1	151.29	1592.30	17244.30	34456.4		
10.94	1298.7	680.7	1196.6	169.26	1727.89	18682.91	38558.0		
10.95	1301.4	677.6	1200.2	194.12	2006.13	21635.04	44804.1		
10.95	1299.9	667.9	1193.4	233.19	1962.62	21173.40	54113.1		
10.95	1296.3	664.9	1186.6	220.74	1812.13	19576.70	50847.8		
10.95	1295.3	670.5	1188.6	168.85	1697.88	18364.51	38632.4		
10.95	1298.3	677.4	1193.8	151.04	1664.59	18011.30	34443.5		
10.95	1301.4	675.3	1195.6	212.97	1967.26	21222.63	48929.1		
10.95	1297.9	666.4	1191.3	225.23	1994.03	21506.66	52199.3		
10.96	1298.3	664.7	1191.6	231.30	2022.02	21803.63	53813.4		
10.96	1300.7	657.5	1194.0	299.07	2342.73	25206.37	70864.2		
10.96	1299.5	648.6	1192.8	340.25	2440.61	26244.87	81771.2		
10.96	1295.4	643.1	1190.2	354.29	2242.00	24137.62	85591.2		
10.96	1292.5	652.1	1188.2	217.81	2049.25	22092.54	51562.7		
10.96	1298.8	663.6	1198.1	206.08	2052.73	22129.47	48635.6		
10.96	1295.9	663.0	1195.7	205.43	1894.10	20446.40	48320.8		
10.97	1297.8	669.6	1196.9	173.94	1844.26	19917.60	40495.2		
10.97	1292.2	675.4	1196.4	151.49	1880.39	20300.94	34855.1		
10.97	1302.4	676.0	1199.3	181.77	2101.78	22649.89	42003.4		
10.97	1301.2	661.6	1196.3	302.08	2066.89	22279.70	71318.7		
10.97	1295.4	656.6	1192.1	262.42	2191.10	23597.57	62056.1		
10.97	1296.0	658.7	1194.1	238.41	2047.28	22071.64	56366.7		
10.97	1294.5	666.6	1194.2	170.22	1793.89	19383.17	39654.7		
10.98	1298.3	677.6	1198.5	152.10	1688.25	18262.33	34990.1		
10.98	1299.0	681.0	1202.2	146.95	1691.95	18301.59	33823.5		
10.98	1298.9	678.2	1200.5	191.33	1769.67	19126.20	44128.9		
10.98	1297.3	674.1	1196.5	193.25	1755.44	18975.22	44578.6		
10.98	1300.9	675.9	1200.0	194.64	1901.71	20527.14	45047.9		
10.98	1299.2	662.0	1194.3	306.75	2125.82	22904.95	72108.3		

SUMMARY OF 270 DEGREE PROBE ORIENTATION

AVERAGE	1297.74	668.29	1194.53	211.17	1907.11	20584.33	49233.79		
MINIMUM	1292.15	643.11	1186.59	134.07	1570.53	17013.32	30633.38		
MAXIMUM	1302.41	685.14	1202.23	354.29	2440.61	26244.87	85591.25		
STD DEV	2.22	10.10	3.60	54.24	210.05	2228.62	13353.30		

TEST: TEST-11A
PROBE ORIENTATION
PORT: D1
1 FEBRUARY 1989

BOILER LOAD: 60 MW
COAL: MED SULF
SORBENT: NONE
DATA TIME: 5 SEC

PROBE TEMP: 1300 F
GAS TEMPERATURE: 1840

TEST: TEST-11A
PROBE ORIENTATION
PORT: D1
1 FEBRUARY 1989

BOILER LOAD: 60 MW
COAL: MED SULF
SORBENT: NONE
DATA TIME: 5 SEC

PROBE TEMP: 1300 F
GAS TEMPERATURE: 1840

TEST: TEST-11A
PROBE ORIENTATION
PORT: D1
1 FEBRUARY 1989

BOILER LOAD: 60 MW
COAL: MED SULF
SORBENT: NONE
DATA TIME: 5 SEC

PROBE TEMP: 1300 F
GAS TEMPERATURE: 1840

TEST: TEST-11A
PROBE ORIENTATION
PORT: D1
1 FEBRUARY 1989

BOILER LOAD: 60 MW
COAL: MED SULF
SORBENT: NONE
DATA TIME: 5 SEC

PROBE TEMP: 1300 F
GAS TEMPERATURE: 1840

TEST: TEST-11A
PROBE ORIENTATION
PORT: D1
1 FEBRUARY 1989

BOILER LOAD: 60 MW
COAL: MED SULF
SORBENT: NONE
DATA TIME: 5 SEC

PROBE TEMP: 1300 F
GAS TEMPERATURE: 1840

FOULING PROBE FIELD TEST
RICHMOND POWER & LIGHT
WHITWATER VALLEY STATION
UNIT 2: PORT E2

TEST 10A - 31 JANUARY 1989
BOILER LOAD: 64 MW
PROBE TEMPERATURE: 1100 F
GAS TEMPERATURE: 1439
DATA TIME: 30 SECONDS

HEAT FLUX METER ORIENTATION

TEST TIME HR	PROBE TEMP [F	AIR-IN TEMP [F	AIR-OUT TEMP [F	AIR-FLOW RATE LB/HR	HF-METER OUTPUT uV	METER-HF CALC B/FT2-HR	AVE-HF CALC B/FT2-HR	AVE-FF CALC	LOC-FF CALC
9.63	1098.12	751.76	1099.5	30.94	134.78	1509.02	4751.02		
9.63	1098.21	754.31	1099	30.98	131.54	1475.39	4715.44		
9.63	1098.66	755.59	1097.5	32.82	158.71	1757.41	4955.21		
9.63	1096.78	749.7	1093.82	36.85	147.07	1636.59	5599.63		
9.64	1097.23	754.16	1094.75	29.58	119.47	1350.10	4448.79		
9.64	1097.93	761.34	1095.07	27.58	118.85	1343.66	4064.44		
9.64	1097.94	765.05	1094.47	27.60	118.36	1338.58	4014.86		
9.64	1097.35	767.31	1095.98	27.71	137.45	1536.73	4021.69		
9.64	1098.53	768.95	1096.91	28.10	127.25	1430.86	4069.48		
9.64	1097.6	770.22	1097.68	28.35	108.47	1235.92	4099.43		
9.64	1097.32	771.3	1096.77	28.09	120.85	1364.42	4037.15		
9.65	1098.95	774.99	1097.35	26.58	114.61	1299.65	3783.62		
9.65	1097.46	771.94	1093.99	31.99	121.44	1370.55	4549.35		
9.65	1099.02	773.69	1097.62	26.87	144.63	1611.26	3843.53		
9.65	1098.53	773.7	1098.22	31.54	139.00	1552.82	4519.75		
9.65	1098.73	771.76	1098.27	32.76	111.15	1263.74	4723.37		
9.65	1098.17	768.47	1096.22	37.23	129.10	1450.06	5388.25		
9.65	1097.19	765.5	1095.22	34.62	137.80	1540.36	5040.62		
9.66	1097.22	770.66	1095.53	31.69	108.23	1233.43	4546.15		
9.66	1098.33	775.62	1095.86	28.58	143.81	1602.75	4041.56		
9.66	1098.23	776.54	1096.26	33.10	140.21	1565.38	4673.15		
9.66	1098.68	773.37	1098.36	36.64	130.86	1468.33	5258.20		
9.66	1096.66	770.07	1098.22	36.15	123.58	1392.76	5238.32		
9.66	1098.24	776.9	1101.64	29.84	140.26	1565.90	4279.04		
9.66	1099.08	780.79	1101.1	32.60	117.73	1332.04	4611.05		
9.66	1097.6	776.51	1097.17	36.39	190.41	2086.46	5152.74		
9.67	1098.54	774.32	1098.37	39.97	146.60	1631.71	5719.50		
9.67	1096.71	769.17	1096.32	40.92	138.60	1548.67	5911.45		
9.67	1098.45	772.1	1095.49	37.39	135.23	1513.69	5339.42		
9.67	1098.27	774.03	1094.16	36.86	136.52	1527.08	5210.67		
9.67	1098.74	774.96	1094.98	38.45	137.54	1537.67	5433.57		
9.67	1098.36	772.45	1094.11	40.92	167.41	1847.72	5812.25		
9.67	1097.35	770.73	1095.67	43.26	145.03	1615.41	6207.28		
9.68	1097.69	771.34	1097.65	39.68	170.51	1879.89	5717.60		
9.68	1097.3	774.42	1099.41	37.60	145.85	1623.92	5395.97		
9.68	1098.63	778.5	1102.83	35.84	162.03	1791.87	5132.95		

SUMMARY OF 0 DEGREE PROBE ORIENTATION

AVERAGE	1097.99	769.51	1096.99	33.50	136.14	1523.10	4841.85		
MINIMUM	1096.66	749.70	1093.82	26.58	108.23	1233.43	3783.62		
MAXIMUM	1099.08	780.79	1102.83	43.26	190.41	2086.46	6207.28		
STD DEV	0.67	7.62	2.15	4.62	17.89	185.71	652.91		

9.71 1096.57 736.99 1033.61 70.86 284.55 3063.63 9281.40
9.71 1097.96 742.24 1034.71 60.70 266.57 3084.60 7839.33

FOULING PROBE FIELD TEST
 RICHMOND POWER & LIGHT
 WHITEWATER VALLEY STATION
 UNIT 2: PORT E2

TEST 10A - 31 JANUARY 1989
 BOILER LOAD: 64 MW
 PROBE TEMPERATURE: 1100 F
 GAS TEMPERATURE: 1439
 DATA TIME: 30 SECONDS

HEAT FLUX METER ORIENTATION

TEST TIME HR	PROBE TEMP [F	AIR-IN TEMP [F	AIR-OUT TEMP [F	AIR-FLOW RATE LB/HR	HF-METER OUTPUT UV	METER-HF CALC B/FT2-HR	AVE-HF CALC B/FT2-HR	AVE-FF CALC	LOC-FF CALC
9.71	1098.93	745.15	1034.03	60.33	266.44	2875.65	7695.95		
9.71	1097.31	742.6	1031.47	70.31	280.77	3024.39	8968.74		
9.72	1097.56	741.1	1030.35	67.11	276.19	2976.85	8571.81		
9.72	1098.37	741.83	1030.47	65.99	262.44	2834.13	8410.97		
9.72	1097.21	742.1	1029.76	65.59	271.09	2923.91	8331.61		
9.72	1097.74	744.71	1030.25	59.01	297.41	3197.12	7440.54		
9.72	1099.3	747.2	1030.88	58.22	285.16	3069.96	7293.11		
9.72	1097.99	743.91	1029	71.14	268.13	2893.19	8955.86		
9.72	1097.15	743.44	1028.71	61.86	264.50	2855.51	7792.52		
9.73	1099.27	747.02	1030.13	60.20	246.29	2666.49	7525.99		
9.73	1097.37	745.38	1028.36	63.14	235.02	2549.51	7889.91		
9.73	1099.27	748.63	1030.45	57.89	270.99	2922.88	7204.22		
9.73	1098.52	746.94	1029.3	64.50	242.45	2626.63	8042.19		
9.73	1096.95	746.52	1028.52	60.59	253.59	2742.26	7545.04		
9.73	1098.53	750.06	1029.85	56.56	331.36	3549.52	6938.01		
9.73	1097.95	749.16	1029.19	62.78	301.05	3234.90	7763.14		
9.74	1098.35	748.23	1029.6	66.26	248.91	2693.69	8232.67		
9.74	1097.1	747.43	1028.78	61.64	274.53	2959.62	7658.10		
9.74	1097.74	747.89	1029.18	66.78	270.26	2915.30	8294.92		
9.74	1098.35	746.62	1028.48	64.06	299.06	3214.24	7973.19		
9.74	1096.97	747.93	1028.14	62.82	234.11	2540.06	7773.08		
9.74	1097.13	751.59	1029.38	54.65	259.08	2799.25	6703.76		
9.74	1099	755.62	1030.63	51.33	240.69	2608.36	6233.49		
9.74	1098	757.99	1030.57	52.55	218.32	2376.16	6325.26		
9.75	1097.84	759.11	1030.59	51.20	229.59	2493.14	6137.90		
9.75	1097.37	760.99	1031.12	50.59	228.76	2484.53	6034.61		
9.75	1098.29	764.2	1032.07	45.84	271.72	2930.45	5422.26		
9.75	1099.7	762.3	1031.77	58.20	245.66	2659.95	6925.40		
9.75	1097.11	756.37	1029.56	65.07	249.84	2703.34	7849.78		
9.75	1100.17	751.39	1029.43	82.61	263.67	2846.89	10142.65		
9.75	1096.23	741.69	1025.28	80.67	257.11	2778.80	10102.17		
9.76	1097.11	744.15	1026.55	71.69	285.08	3069.13	8939.95		
9.76	1098.3	745.1	1027.28	70.68	257.14	2779.11	8807.13		
9.76	1096.96	744.72	1026.62	66.64	256.29	2770.29	8295.48		

SUMMARY OF 90 DEGREE PROBE ORIENTATION

AVERAGE	1097.94	748.29	1029.84	62.78	264.27	2853.15	7816.45		
MINIMUM	1096.23	736.99	1025.28	45.84	218.32	2376.16	5422.26		
MAXIMUM	1100.17	764.20	1034.71	82.61	331.36	3549.52	10142.65		
STD DEV	0.91	6.37	1.93	7.73	23.25	241.33	1050.40		

9.80	1097.4	756.49	1027.56	53.69	370.01	3950.70	6426.68		
9.80	1098.83	763.21	1026.11	55.03	422.50	4495.55	6388.54		
9.80	1097.95	758.73	1022.15	71.15	473.34	5023.27	8276.28		
9.80	1097.87	755.32	1021.05	71.26	445.79	4737.30	8361.77		

FOULING PROBE FIELD TEST
 RICHMOND POWER & LIGHT
 WHITEWATER VALLEY STATION
 UNIT 2: PORT E2

TEST 10A - 31 JANUARY 1989
 BOILER LOAD: 64 MW
 PROBE TEMPERATURE: 1100 F
 GAS TEMPERATURE: 1439
 DATA TIME: 30 SECONDS

HEAT FLUX METER ORIENTATION

TEST TIME HR	PROBE TEMP [F	AIR-IN TEMP [F	AIR-OUT TEMP [F	AIR-FLOW RATE LB/HR	HF-METER OUTPUT uV	METER-HF CALC B/FT2-HR	AVE-HF CALC B/FT2-HR	AVE-FF CALC	LOC-FF CALC
9.81	1098.39	754.67	1019.51	76.71	401.01	4272.48	8971.13		
9.81	1098.13	753.98	1019.26	68.99	410.61	4372.13	8081.69		
9.81	1096.1	755.34	1018.97	67.10	387.03	4127.37	7811.40		
9.81	1099.43	758.23	1020.47	72.33	488.78	5183.54	8375.85		
9.81	1099.63	750.66	1016.41	90.30	501.93	5320.03	10596.75		
9.81	1097.17	745.45	1013.4	83.41	490.23	5198.59	9869.24		
9.81	1098.89	745.41	1012.25	88.08	467.64	4964.10	10378.63		
9.82	1097.2	744.71	1011.15	79.13	465.37	4940.54	9310.06		
9.82	1097.14	747.25	1011.44	71.97	465.02	4936.91	8396.14		
9.82	1096.67	752.62	1013.84	57.23	395.18	4211.97	6601.49		
9.82	1098.95	757.15	1015.03	63.49	463.85	4924.76	7229.94		
9.82	1096.92	752.68	1013.41	78.32	421.43	4464.44	9017.28		
9.82	1098.87	752.9	1014.42	75.93	427.92	4551.81	8768.59		
9.82	1097.17	751.43	1013.73	74.13	408.29	4348.05	8586.26		
9.83	1096.12	756.94	1015.67	55.22	423.46	4505.51	6308.92		
9.83	1097.74	764.42	1017.36	55.87	358.68	3833.10	6240.33		
9.83	1099.1	767.13	1018.59	57.05	384.69	4103.08	6334.85		
9.83	1097.48	765.36	1018.24	59.49	423.36	4504.48	6643.09		
9.83	1097.81	761.89	1017.39	74.04	442.88	4707.09	8353.51		
9.83	1098.08	756.19	1015.49	83.55	485.87	5153.33	9566.67		
9.83	1098.61	752.24	1013.88	82.51	447.26	4752.56	9532.84		
9.83	1097.52	748.7	1012.05	92.69	468.84	4976.56	10778.99		
9.84	1095.86	750.2	1012.62	68.90	435.60	4631.53	7984.13		
9.84	1097.2	758.1	1015.09	59.31	384.19	4097.89	6730.63		
9.84	1097.75	758.08	1014.47	84.36	440.61	4683.53	9551.01		
9.84	1097.53	756.06	1014.56	74.99	432.59	4600.28	8560.04		
9.84	1097.8	758.09	1015.76	63.67	430.63	4579.94	7244.53		
9.84	1097.84	761.57	1016.71	61.61	439.62	4673.26	6941.31		
9.84	1099.13	759.45	1015.66	75.97	486.94	5164.44	8595.08		
9.85	1096.64	753.16	1013.05	81.14	407.52	4340.06	9311.86		
9.85	1096.39	758.01	1015.65	62.60	372.66	3978.21	7121.96		
9.85	1100.83	761.58	1016.72	78.80	460.66	4891.65	8878.03		

SUMMARY OF 180 DEGREE PROBE ORIENTATION

AVERAGE	1097.84	755.65	1016.36	71.39	434.22	4617.22	8225.71		
MINIMUM	1095.86	744.71	1011.15	53.69	358.68	3833.10	6240.33		
MAXIMUM	1100.83	767.13	1027.56	92.69	501.93	5320.03	10778.99		
STD DEV	1.08	5.52	3.70	10.71	37.23	386.45	1287.97		

9.88	1098.94	839.07	1120.17	2.59	340.64	3645.84	321.49		
9.88	1099.4	854.05	1137.06	2.91	348.06	3722.86	363.67		
9.88	1099.54	867.12	1131.67	10.21	400.01	4262.10	1192.74		
9.88	1098.26	871.35	1130.04	16.25	365.25	3901.30	1856.29		
9.89	1098.63	874.31	1132.59	17.42	391.54	4174.19	1986.78		
9.89	1098.68	874.8	1133.98	21.61	397.83	4239.48	2473.25		

FOULING PROBE FIELD TEST
 RICHMOND POWER & LIGHT
 WHITEWATER VALLEY STATION
 UNIT 2: PORT E2

TEST 10A - 31 JANUARY 1989
 BOILER LOAD: 64 MW
 PROBE TEMPERATURE: 1100 F
 GAS TEMPERATURE: 1439
 DATA TIME: 30 SECONDS

HEAT FLUX METER ORIENTATION

TEST TIME HR	PROBE TEMP [F	AIR-IN TEMP [F	AIR-OUT TEMP [F	AIR-FLOW RATE LB/HR	HF-METER OUTPUT uV	METER-HF CALC B/FT2-HR	AVE-HF CALC B/FT2-HR	AVE-FF CALC	LOC-FF CALC
9.89	1099.16	871.43	1134.77	27.12	423.24	4503.23	3153.68		
9.89	1098.6	863.79	1134.66	34.91	485.09	5145.23	4175.63		
9.89	1098.15	851.94	1132.62	46.44	459.13	4875.77	5755.93		
9.89	1097.07	846.41	1131.9	40.84	492.10	5218.00	5148.59		
9.89	1097.58	848.83	1133.02	38.39	481.92	5112.33	4817.69		
9.90	1098.15	849.68	1133.56	38.02	464.81	4934.73	4766.05		
9.90	1098.7	849.42	1130.98	41.49	481.49	5107.87	5158.53		
9.90	1096.48	842.88	1123.63	45.36	441.73	4695.16	5623.47		
9.90	1098.57	846.7	1123.09	36.82	515.49	5460.79	4493.84		
9.90	1098.67	846.45	1121.18	41.11	479.16	5083.68	4987.30		
9.90	1097.23	844.34	1114.4	42.11	474.53	5035.62	5021.77		
9.90	1098.57	843.17	1117.8	42.39	462.75	4913.35	5140.71		
9.91	1099.21	842.25	1116.8	43.34	497.83	5277.48	5254.39		
9.91	1098.2	836.15	1110.09	52.30	479.89	5091.26	6326.58		
9.91	1096.21	833.79	1105.15	45.91	492.57	5222.88	5501.29		
9.91	1097.17	839.57	1108.96	38.00	484.78	5142.02	4520.40		
9.91	1097.76	845.87	1112.32	34.78	501.58	5316.40	4092.20		
9.91	1099.49	849.01	1115.28	36.61	469.97	4988.29	4304.61		
9.91	1096.89	843.36	1108.7	44.67	487.64	5171.70	5233.96		
9.91	1097.11	843.81	1107.65	39.01	464.31	4929.54	4544.94		
9.92	1096.99	850.37	1110.96	32.38	444.91	4728.17	3726.03		
9.92	1098.14	858.31	1114.84	27.59	478.33	5075.07	3125.37		
9.92	1098.89	861.73	1116.55	31.18	465.50	4941.89	3508.50		
9.92	1097.38	858.05	1112.97	35.98	441.09	4688.51	4050.20		
9.92	1097.55	856.12	1114.97	36.97	456.67	4850.23	4225.80		
9.92	1097.74	856.62	1115.63	34.17	451.94	4801.14	3908.17		
9.92	1099.87	859.45	1117.24	35.20	556.32	5884.60	4007.01		
9.93	1098.13	846.22	1108.8	54.01	494.44	5242.29	6262.50		
9.93	1096.6	840.08	1105.53	46.40	494.35	5241.35	5438.92		
9.93	1096.88	847.52	1109.68	34.65	469.45	4982.89	4011.27		

SUMMARY OF 270 DEGREE PROBE ORIENTATION

AVERAGE	1098.07	851.50	1120.26	34.70	459.34	4877.98	4124.43		
MINIMUM	1096.21	833.79	1105.15	2.59	340.64	3645.84	321.49		
MAXIMUM	1099.87	874.80	1137.06	54.01	556.32	5884.60	6326.58		
STD DEV	0.95	10.69	10.03	12.08	45.56	472.96	1479.20		

TEST: TEST-10A
PROBE ORIENTATION
PORT: E2
31 JANUARY 1989

BOILER LOAD: 64 MW
COAL: MED SULF
SORBENT: NONE
DATA TIME: 5 SEC

TEST: TEST-10A
PROBE ORIENTATION
PORT: E2
31 JANUARY 1989

BOILER LOAD: 64 MW
COAL: MED SULF
SORBENT: NONE
DATA TIME: 5 SEC

TEST: TEST-10A
HF METER ORIENTATION
PORT: E2
31 JANUARY 1989

BOILER LOAD: 64 MW
COAL: MED SULF
SORBENT: NONE
DATA TIME: 5 SEC

TEST: TEST-10A
AVE HF ORIENTATION
PORT: E2
31 JANUARY 1989

BOILER LOAD: 64 MW
COAL: MED SULF
SORBENT: NONE
DATA TIME: 5 SEC

FOULING PROBE FIELD TEST
 RICHMOND POWER & LIGHT
 WHITEWATER VALLEY STATION
 UNIT 2: PORT F2

TEST 12A1 - 2 FEBRUARY 1989
 BOILER LOAD: 60 MW
 PROBE TEMPERATURE: 800 F
 GAS TEMPERATURE: 1125
 DATA TIME: 5 SECONDS

HEAT FLUX METER ORIENTATION: PROBE 1

TEST TIME HR	PROBE TEMP [F	AIR-IN TEMP [F	AIR-OUT TEMP [F	AIR-FLOW RATE LB/HR	HF-METER OUTPUT uV	METER-HF CALC B/FT2-HR	AVE-HF CALC B/FT2-HR	AVE-HF CALC B/FT2-HR	LOC-HF CALC B/FT2-HR
8.96	798.8	442.3	654.3	39.56	458.59	3641.91	3702.73		
8.96	799.1	444.6	655.0	39.52	466.35	3699.64	3672.28		
8.96	799.6	446.5	655.8	39.87	467.90	3711.18	3685.97		
8.96	799.2	448.2	656.8	39.87	473.33	3751.58	3671.71		
8.97	800.0	449.8	657.8	41.84	484.98	3838.25	3843.52		
8.97	798.9	450.1	658.0	43.27	474.96	3763.70	3972.78		
8.97	799.3	451.3	658.4	43.33	483.02	3823.67	3962.60		
8.97	798.3	451.7	658.3	46.99	487.77	3859.01	4288.81		
8.97	796.8	452.2	657.9	47.43	480.26	3803.13	4308.86		
8.97	799.8	455.9	658.7	40.29	476.08	3772.04	3608.62		
8.97	800.4	459.0	660.4	40.64	461.80	3665.79	3614.48		
8.98	798.7	459.2	660.9	44.50	457.72	3635.44	3962.90		
8.98	797.5	460.2	661.2	44.61	477.65	3783.72	3959.10		
8.98	798.6	461.6	661.8	43.86	483.08	3824.12	3876.85		
8.98	800.0	464.1	663.5	42.13	478.06	3786.77	3710.54		
8.98	799.6	464.3	664.7	49.32	481.21	3810.20	4363.17		
8.98	797.5	463.8	664.1	51.29	475.29	3766.16	4536.09		
8.98	797.9	465.9	664.0	45.93	483.55	3827.61	4017.64		
8.99	799.3	468.7	664.5	43.90	465.68	3694.66	3795.29		
8.99	799.8	471.0	665.6	43.41	477.19	3780.29	3728.96		
8.99	799.8	472.5	666.3	45.94	457.71	3635.36	3931.69		
8.99	799.3	473.0	666.6	46.89	473.94	3756.11	4007.81		
8.99	797.9	472.7	666.2	52.70	484.72	3836.32	4503.94		
8.99	797.5	472.4	665.7	51.36	483.96	3830.66	4383.30		
8.99	798.2	475.2	666.5	46.24	465.96	3696.74	3905.50		
8.99	799.4	478.6	668.0	43.73	463.45	3678.07	3657.78		
9.00	799.9	481.0	669.3	43.30	468.95	3718.99	3601.16		
9.00	799.8	481.6	670.5	47.74	450.67	3582.98	3981.60		
9.00	799.1	482.0	670.8	48.77	470.52	3730.67	4067.07		
9.00	799.3	482.7	670.9	49.71	469.27	3721.37	4130.75		
9.00	798.7	483.4	671.3	50.21	471.68	3739.30	4166.53		
9.00	764.1	484.5	671.6	50.03	477.41	3781.93	4134.37		
9.00	799.2	485.7	671.8	49.92	465.39	3692.50	4103.89		
9.01	798.7	486.6	672.4	50.99	469.80	3725.31	4185.10		
9.01	798.9	487.6	672.8	50.94	480.19	3802.61	4167.29		
9.01	798.8	488.7	673.4	50.91	472.48	3745.25	4150.66		
9.01	799.3	489.9	673.8	50.67	478.05	3786.69	4115.21		
9.01	798.7	490.6	674.0	52.97	491.63	3887.73	4290.07		
9.01	799.1	491.2	674.6	53.34	481.22	3810.28	4320.51		
9.01	798.2	491.5	675.0	55.78	471.20	3735.73	4521.10		
9.02	797.8	491.9	674.7	56.10	477.46	3782.30	4528.46		
9.02	797.6	493.5	674.9	52.09	462.80	3673.23	4173.95		
9.02	798.8	495.9	675.9	49.52	473.41	3752.17	3935.65		
9.02	799.9	497.9	677.4	48.97	469.48	3722.93	3881.78		
9.02	799.3	499.0	678.3	52.48	464.46	3685.58	4154.68		
9.02	799.3	498.9	678.6	54.24	478.22	3787.96	4303.11		
9.02	799.3	499.4	678.8	54.79	477.55	3782.97	4339.01		

FOULING PROBE FIELD TEST
 RICHMOND POWER & LIGHT
 WHITEWATER VALLEY STATION
 UNIT 2: PORT F2

TEST 12A1 - 2 FEBRUARY 1989
 BOILER LOAD: 60 MW
 PROBE TEMPERATURE: 800 F
 GAS TEMPERATURE: 1125
 DATA TIME: 5 SECONDS

HEAT FLUX METER ORIENTATION: PROBE 1

TEST TIME HR	PROBE TEMP [F	AIR-IN TEMP [F	AIR-OUT TEMP [F	AIR-FLOW RATE LB/HR	HF-METER OUTPUT uV	METER-HF CALC B/FT2-HR	AVE-HF CALC B/FT2-HR	AVE-HF CALC	LOC-HF CALC
9.03	799.1	500.0	678.7	55.31	441.60	3515.50	4364.55		
9.03	797.9	500.8	679.1	55.25	422.05	3370.05	4349.82		
9.03	797.6	501.7	679.3	54.87	468.58	3716.24	4303.67		
9.03	798.4	503.3	680.2	52.87	451.90	3592.14	4129.29		
9.03	798.8	504.7	681.1	52.43	448.68	3568.18	4084.50		
9.03	799.2	505.9	681.7	52.21	461.57	3664.08	4051.00		
9.03	799.6	507.2	682.4	52.01	450.83	3584.18	4024.00		
9.04	799.7	507.7	683.1	55.79	456.04	3622.94	4322.36		
9.04	798.8	507.2	683.0	59.23	451.67	3590.42	4597.25		
9.04	798.2	506.8	682.8	60.45	468.52	3715.79	4696.75		
9.04	798.5	507.1	682.6	60.41	470.38	3729.63	4682.17		
9.04	797.8	507.6	682.6	60.08	455.87	3621.67	4642.27		
9.04	798.7	509.3	683.0	56.04	465.71	3694.88	4299.42		

SUMMARY OF 0 DEGREE PROBE ORIENTATION

AVERAGE	798.28	480.45	670.18	49.31	469.32	3721.77	4107.86		
MINIMUM	764.11	442.29	654.25	39.52	422.05	3370.05	3601.16		
MAXIMUM	800.41	509.29	683.13	60.45	491.63	3887.73	4696.75		
STD DEV	4.51	19.90	8.65	5.59	12.35	91.85	289.27		

9.08	799.5	509.9	655.2	77.61	462.27	3669.29	4982.35		
9.08	799.2	509.3	655.1	82.15	469.91	3726.13	5287.59		
9.08	799.6	508.8	654.6	86.12	476.35	3774.04	5542.36		
9.08	798.6	507.3	653.4	92.95	474.14	3757.60	5993.81		
9.09	797.4	506.9	652.8	86.33	474.14	3757.60	5562.35		
9.09	797.9	508.8	653.7	79.52	462.63	3671.97	5087.41		
9.09	798.9	510.2	654.6	76.97	469.16	3720.55	4907.61		
9.09	800.1	511.4	655.7	76.22	469.34	3721.89	4856.43		
9.09	798.9	510.8	655.1	84.12	474.60	3761.02	5362.01		
9.09	798.7	510.4	655.0	84.91	480.65	3806.04	5420.62		
9.09	799.3	510.5	655.1	84.66	475.56	3768.17	5405.78		
9.10	798.8	510.8	655.4	84.34	471.28	3736.32	5384.60		
9.10	798.5	511.1	655.7	83.77	466.05	3697.41	5350.80		
9.10	797.9	511.4	655.9	82.15	467.01	3704.55	5238.62		
9.10	798.5	513.0	656.6	76.86	470.88	3736.35	4875.14		
9.10	800.2	514.3	657.4	76.07	465.28	3691.68	4808.24		
9.10	799.6	514.0	657.4	82.55	469.28	3721.44	5230.22		
9.10	798.7	512.9	656.6	87.73	468.26	3713.85	5566.55		
9.11	798.0	512.6	656.7	88.13	474.18	3757.90	5605.94		
9.11	798.1	512.8	656.3	84.19	472.56	3745.85	5337.10		
9.11	799.6	513.8	657.0	81.81	468.50	3715.64	5173.58		
9.11	799.8	514.3	657.3	85.12	470.33	3729.26	5375.39		
9.11	799.6	513.8	657.2	86.99	465.15	3690.72	5506.54		
9.11	797.9	513.2	656.7	89.78	471.18	3735.58	5687.89		
9.11	797.7	513.0	656.5	89.17	479.68	3798.82	5649.26		

FOULING PROBE FIELD TEST
 RICHMOND POWER & LIGHT
 WHITEWATER VALLEY STATION
 UNIT 2: PORT F2

TEST 12A1 - 2 FEBRUARY 1989
 BOILER LOAD: 60 MW
 PROBE TEMPERATURE: 800 F
 GAS TEMPERATURE: 1125
 DATA TIME: 5 SECONDS

HEAT FLUX METER ORIENTATION: PROBE 1

TEST TIME HR	PROBE TEMP [F	AIR-IN TEMP [F	AIR-OUT TEMP [F	AIR-FLOW RATE LB/HR	HF-METER OUTPUT uV	METER-HF CALC B/FT2-HR	AVE-HF CALC B/FT2-HR	AVE-HF CALC	LOC-HF CALC
9.11	798.7	514.8	657.4	79.48	466.92	3703.88	5002.72		
9.12	798.9	516.3	658.2	77.98	459.28	3647.04	4887.65		
9.12	799.9	517.2	659.1	77.26	454.24	3609.55	4838.08		
9.12	799.5	516.9	658.8	84.72	458.80	3643.47	5310.85		
9.12	799.0	516.2	658.5	87.63	466.18	3698.38	5506.03		
9.12	798.0	515.5	657.8	89.92	471.80	3740.19	5647.94		
9.12	798.7	515.3	657.6	89.95	479.84	3800.01	5650.61		
9.12	798.8	515.3	657.2	89.77	470.18	3728.14	5625.43		
9.13	798.9	515.4	657.0	89.26	464.21	3683.72	5580.07		
9.13	798.2	515.5	656.9	88.80	464.53	3686.10	5543.47		
9.13	797.8	515.7	656.7	88.45	469.18	3720.70	5509.12		
9.13	797.4	517.6	657.9	78.16	469.81	3725.39	4843.71		
9.13	798.2	520.0	659.5	73.00	455.89	3621.82	4496.53		
9.13	799.3	522.0	661.1	70.20	465.64	3694.51	4311.97		
9.13	799.8	523.6	662.5	73.21	460.60	3656.86	4489.75		
9.14	799.3	522.8	662.3	80.22	469.90	3726.06	4941.61		
9.14	799.6	522.2	662.2	84.28	479.67	3798.74	5211.43		
9.14	798.8	521.2	661.8	86.50	475.06	3764.45	5370.86		
9.14	799.1	520.9	661.7	86.74	477.28	3780.96	5392.28		
9.14	798.9	520.3	661.3	89.58	478.96	3793.46	5573.97		
9.14	798.0	519.9	660.6	89.94	482.35	3818.68	5588.03		
9.14	798.0	520.0	660.6	86.57	477.91	3785.65	5377.12		
9.15	798.2	520.9	660.9	82.91	476.64	3776.20	5126.72		
9.15	799.6	521.9	661.6	80.99	467.17	3705.74	4995.12		
9.15	800.1	522.1	661.8	84.88	472.06	3742.13	5234.67		
9.15	799.2	520.5	660.9	95.32	475.27	3766.01	5910.09		
9.15	798.5	518.7	659.6	97.92	483.59	3827.91	6090.75		
9.15	797.5	517.9	658.4	97.92	478.11	3787.14	6074.75		
9.15	798.1	518.6	658.6	89.88	477.12	3779.77	5554.93		
9.16	799.2	519.4	658.7	88.47	465.75	3695.18	5442.39		
9.16	798.2	519.8	658.8	87.84	470.27	3728.81	5389.67		
9.16	797.4	520.4	658.9	85.78	471.54	3738.26	5249.26		
9.16	798.8	522.0	660.1	79.27	472.16	3742.87	4832.68		
9.16	798.9	523.5	661.2	70.16	475.29	3766.16	4755.35		
9.16	799.9	524.4	662.1	78.98	466.34	3699.57	4800.71		

SUMMARY OF 90 DEGREE PROBE ORIENTATION

AVERAGE	798.79	516.00	658.01	84.34	470.63	3731.50	5289.28
MINIMUM	797.35	506.87	652.78	70.20	454.24	3609.55	4311.97
MAXIMUM	800.21	524.44	662.45	97.92	483.59	3827.91	6090.75
STD DEV	0.75	4.62	2.51	5.80	6.37	47.37	376.49

9.21	799.9	523.7	658.9	91.39	256.73	2140.07	5458.58
9.21	799.0	523.4	658.7	95.67	256.25	2136.50	5715.91
9.21	798.4	522.9	658.2	96.68	259.24	2158.75	5778.39

FOULING PROBE FIELD TEST
 RICHMOND POWER & LIGHT
 WHITEWATER VALLEY STATION
 UNIT 2: PORT F2

TEST 12A1 - 2 FEBRUARY 1989
 BOILER LOAD: 60 MW
 PROBE TEMPERATURE: 800 F
 GAS TEMPERATURE: 1125
 DATA TIME: 5 SECONDS

HEAT FLUX METER ORIENTATION: PROBE 1

TEST TIME HR	PROBE TEMP °F	AIR-IN TEMP °F	AIR-OUT TEMP °F	AIR-FLOW RATE LB/HR	HF-METER OUTPUT uV	METER-HF CALC B/FT2-HR	AVE-HF CALC B/FT2-HR	AVE-FF CALC	LOC-FF CALC
9.21	798.3	523.2	658.5	91.78	251.22	2099.08	5483.90		
9.22	799.4	524.0	659.0	90.11	250.42	2093.12	5372.58		
9.22	799.4	524.6	659.4	90.52	250.34	2092.53	5388.63		
9.22	799.4	524.2	659.4	94.37	250.30	2092.23	5631.99		
9.22	799.3	523.9	659.2	96.29	249.06	2083.01	5755.08		
9.22	798.7	523.7	659.0	96.35	244.53	2049.30	5756.11		
9.22	799.0	523.7	658.9	95.88	253.28	2114.40	5720.41		
9.22	798.7	523.9	658.9	95.54	256.61	2139.18	5694.64		
9.23	798.8	524.1	659.0	94.92	254.88	2126.31	5653.49		
9.23	798.3	524.3	659.0	94.50	252.06	2105.33	5622.22		
9.23	798.7	524.6	659.3	93.95	254.75	2125.34	5587.84		
9.23	799.2	525.0	659.9	93.35	243.99	2045.29	5560.40		
9.23	799.1	525.2	660.0	92.89	251.27	2099.45	5528.48		
9.23	799.6	525.6	660.4	94.91	246.26	2062.17	5649.55		
9.23	799.2	524.8	659.9	99.51	255.84	2133.45	5938.74		
9.24	798.6	524.1	659.2	100.77	267.56	2220.65	6007.71		
9.24	797.7	524.0	658.7	98.57	266.78	2214.84	5864.90		
9.24	799.2	524.5	659.2	95.22	258.73	2154.95	5660.85		
9.24	798.7	524.9	659.3	94.41	255.15	2128.32	5602.27		
9.24	799.1	525.2	659.6	94.05	254.93	2126.68	5578.00		
9.24	799.0	525.5	659.7	93.68	254.29	2121.92	5552.34		
9.24	798.9	525.7	659.9	93.77	247.76	2073.33	5554.77		
9.24	798.7	525.6	659.8	96.02	260.20	2165.89	5691.87		
9.25	798.8	525.4	659.6	96.23	262.07	2179.80	5703.05		
9.25	799.2	525.1	659.5	98.29	259.54	2160.98	5832.08		
9.25	797.9	524.8	659.0	98.68	268.92	2230.76	5850.43		
9.25	798.1	525.1	659.1	93.69	267.90	2223.18	5543.83		
9.25	798.9	526.0	659.8	91.15	253.26	2114.25	5386.69		
9.25	799.3	526.5	660.1	90.49	246.38	2063.07	5336.50		
9.25	799.2	527.0	660.5	90.34	242.80	2036.43	5326.85		
9.26	798.7	526.8	660.5	93.56	243.65	2042.76	5521.26		
9.26	799.0	526.8	660.5	93.76	244.89	2051.98	5536.79		
9.26	798.6	526.9	660.8	93.53	248.89	2081.74	5528.58		
9.26	798.8	527.1	660.9	93.06	259.23	2158.67	5496.69		
9.26	799.2	527.3	661.0	92.66	256.64	2139.40	5470.20		
9.26	799.2	527.3	661.1	94.56	256.77	2140.37	5585.29		
9.26	798.8	526.8	660.9	97.95	258.27	2151.53	5797.63		
9.27	797.8	526.3	660.4	98.31	255.39	2130.10	5819.81		
9.27	798.6	526.6	660.6	94.11	245.31	2055.11	5568.26		
9.27	799.0	527.1	660.8	92.65	253.81	2118.35	5471.24		
9.27	799.2	527.3	661.1	94.77	246.85	2066.56	5595.60		
9.27	799.6	527.0	661.0	96.87	253.42	2115.44	5732.42		
9.27	798.6	526.5	660.5	98.96	250.09	2090.67	5856.10		
9.27	798.5	526.2	660.2	98.60	257.41	2145.13	5831.31		
9.28	798.4	526.3	660.2	97.14	256.55	2138.73	5742.39		
9.28	798.9	526.5	660.2	96.27	245.54	2056.82	5683.31		
9.28	798.6	526.7	660.4	95.86	261.99	2179.21	5656.57		

FOULING PROBE FIELD TEST
 RICHMOND POWER & LIGHT
 WHITWATER VALLEY STATION
 UNIT 2: PORT F2

TEST 12A1 - 2 FEBRUARY 1989
 BOILER LOAD: 60 MW
 PROBE TEMPERATURE: 800 F
 GAS TEMPERATURE: 1125
 DATA TIME: 5 SECONDS

HEAT FLUX METER ORIENTATION: PROBE 1

TEST TIME HR	PROBE TEMP [F	AIR-IN TEMP [F	AIR-OUT TEMP [F	AIR-FLOW RATE LB/HR	HF-METER OUTPUT uV	METER-HF CALC B/FT2-HR	AVE-HF CALC B/FT2-HR	AVE-HF CALC	LOC-HF CALC
9.28	798.7	526.9	660.5	94.39	251.73	2102.87	5564.82		
9.28	798.7	527.4	660.9	93.47	246.47	2063.74	5509.76		
9.28	799.3	527.7	661.1	94.54	247.80	2073.63	5572.83		
9.28	799.0	527.4	660.9	97.34	243.99	2045.29	5737.02		
9.29	799.6	526.8	660.6	102.20	257.05	2142.45	6040.61		
9.29	799.1	525.7	659.8	105.48	259.11	2157.78	6246.12		
9.29	797.7	524.9	658.9	106.02	256.49	2138.29	6272.95		
9.29	798.7	525.2	659.0	99.90	251.03	2097.66	5902.90		
9.29	798.2	525.7	659.0	98.63	253.41	2115.37	5804.78		
9.29	799.2	526.0	659.2	97.78	259.58	2161.28	5751.30		

SUMMARY OF 180 DEGREE PROBE ORIENTATION

AVERAGE	798.85	525.56	659.82	95.61	253.74	2117.86	5668.09		
MINIMUM	797.69	522.85	658.20	90.11	242.80	2036.43	5326.85		
MAXIMUM	799.86	527.65	661.14	106.02	268.92	2230.76	6272.95		
STD DEV	0.46	1.28	0.79	3.25	6.30	46.88	193.02		

9.40	799.0	546.2	689.3	87.17	220.41	1869.85	5505.62		
9.40	798.6	546.3	689.1	86.91	212.86	1813.68	5483.05		
9.40	798.8	546.3	689.2	86.62	218.41	1854.97	5464.38		
9.40	798.5	546.4	689.1	86.17	220.10	1867.54	5428.00		
9.41	798.5	546.6	689.2	85.81	217.69	1849.61	5402.67		
9.41	799.0	546.7	689.4	85.33	213.70	1819.93	5376.21		
9.41	798.7	546.9	689.5	84.95	211.63	1804.53	5347.02		
9.41	799.3	547.1	689.6	84.59	210.79	1798.28	5323.99		
9.41	799.5	547.3	689.9	84.13	212.28	1809.36	5298.01		
9.41	799.0	547.5	690.0	83.97	217.41	1847.53	5284.59		
9.41	799.2	547.2	689.9	86.34	215.53	1833.54	5440.61		
9.42	798.7	547.0	689.7	86.60	208.33	1779.98	5455.85		
9.42	798.8	546.9	689.6	86.22	207.51	1773.87	5433.43		
9.42	798.3	547.0	689.7	85.95	209.48	1788.53	5419.45		
9.42	798.8	547.1	690.0	85.52	204.85	1754.08	5398.76		
9.42	798.6	547.2	690.1	85.28	204.02	1747.91	5379.84		
9.42	798.5	547.4	690.1	84.89	198.36	1705.80	5349.24		
9.42	799.4	547.5	690.3	84.31	200.92	1724.84	5314.55		
9.43	799.5	547.7	690.6	84.13	211.37	1802.59	5308.41		
9.43	799.5	547.6	690.5	87.30	208.97	1784.74	5508.81		
9.43	798.2	546.7	689.7	89.25	212.22	1808.92	5635.80		
9.43	798.4	546.4	689.3	87.68	214.57	1826.40	5532.41		
9.43	798.3	547.2	689.8	83.15	212.85	1813.60	5235.93		
9.43	799.1	548.2	690.5	80.73	208.42	1780.64	5072.13		
9.43	799.3	548.9	691.3	80.16	207.21	1771.64	5041.98		
9.43	799.3	549.0	691.5	82.42	213.30	1816.95	5186.68		
9.44	799.4	548.0	690.7	87.93	210.07	1792.92	5541.97		
9.44	799.4	547.0	690.2	90.09	207.36	1772.76	5695.61		

FOULING PROBE FIELD TEST
 RICHMOND POWER & LIGHT
 WHITEWATER VALLEY STATION
 UNIT 2: PORT F2

TEST 12A1 - 2 FEBRUARY 1989
 BOILER LOAD: 60 MW
 PROBE TEMPERATURE: 800 F
 GAS TEMPERATURE: 1125
 DATA TIME: 5 SECONDS

HEAT FLUX METER ORIENTATION: PROBE 1

TEST TIME HR	PROBE TEMP IF	AIR-IN TEMP IF	AIR-OUT TEMP IF	AIR-FLOW RATE LB/HR	HF-METER OUTPUT UV	METER-HF CALC B/FT2-HR	AVE-HF CALC B/FT2-HR	AVE-HF CALC	LOC-HF CALC
9.44	798.9	545.7	689.3	94.64	207.83	1776.26	5999.57		
9.44	798.1	544.6	688.4	96.51	216.14	1838.08	6124.51		
9.44	797.7	544.2	687.7	92.25	215.35	1832.20	5845.61		
9.44	798.1	545.3	688.2	87.47	207.22	1771.72	5518.77		
9.44	798.5	545.9	688.6	86.23	209.85	1791.28	5432.54		
9.45	798.9	546.6	689.1	82.77	214.36	1824.84	5208.71		
9.45	799.5	547.1	689.7	86.33	214.34	1824.69	5436.17		
9.45	799.1	546.4	689.2	89.53	215.35	1832.20	5647.95		
9.45	798.1	545.9	688.8	90.87	217.21	1846.04	5734.09		
9.45	798.3	545.3	688.2	91.90	220.93	1873.72	5798.27		
9.45	797.8	545.6	688.2	87.91	218.38	1854.75	5537.60		
9.45	798.2	546.0	688.6	86.34	217.13	1845.45	5435.66		
9.46	798.7	546.7	689.0	85.01	207.89	1776.70	5342.91		
9.46	797.8	546.9	689.0	85.49	212.03	1807.50	5364.78		
9.46	798.5	547.1	689.2	85.31	204.04	1748.06	5352.73		
9.46	798.4	547.3	689.5	83.73	207.36	1772.76	5254.33		
9.46	799.0	547.7	689.9	83.92	212.43	1810.48	5270.33		
9.46	799.3	547.7	690.1	84.81	208.28	1779.60	5333.71		
9.46	798.9	547.6	690.2	86.13	212.03	1807.50	5424.34		
9.47	798.4	546.6	689.4	90.85	211.34	1802.37	5730.02		
9.47	797.7	546.1	688.7	87.79	215.85	1835.92	5530.04		
9.47	798.7	547.0	689.4	84.98	206.09	1763.31	5342.90		
9.47	798.9	547.2	689.7	84.84	212.64	1812.04	5338.97		
9.47	799.1	547.2	689.7	87.63	212.13	1808.25	5515.32		
9.47	798.9	546.6	689.3	88.92	213.09	1815.39	5605.94		
9.47	798.7	546.3	688.8	88.93	217.16	1845.67	5594.39		
9.48	798.5	546.3	688.5	88.37	219.53	1863.30	5551.75		
9.48	798.2	546.6	688.6	86.34	220.81	1872.83	5416.97		
9.48	799.6	547.4	689.2	83.28	211.10	1800.58	5213.22		
9.48	799.3	548.0	689.9	83.48	210.98	1799.69	5229.06		
9.48	799.4	547.8	689.5	86.21	217.16	1845.67	5394.35		
9.48	798.2	547.0	689.0	90.22	219.54	1863.38	5658.01		

SUMMARY OF 270 DEGREE PROBE ORIENTATION

AVERAGE	798.74	546.84	689.47	86.54	212.27	1809.29	5450.81		
MINIMUM	797.65	544.20	687.70	80.16	198.36	1705.80	5041.98		
MAXIMUM	799.55	548.99	691.50	96.51	220.93	1873.72	6124.51		
STD DEV	0.49	0.87	0.74	2.98	4.96	36.94	197.68		

TEST: TEST-12A1
PROBE ORIENTATION
PORT: F2
2 FEBRUARY 1989

BOILER LOAD: 60 MW
COAL: MED SULF
SORBENT: NONE
DATA TIME: 5 SEC

PROBE TEMP: 800 F
GAS TEMPERATURE: 1125

TEST: TEST-12A1
PROBE ORIENTATION
PORT: F2
2 FEBRUARY 1989

BOILER LOAD: 60 MW
COAL: MED SULF
SORBENT: NONE
DATA TIME: 5 SEC

PROBE TEMP: 800 F
GAS TEMPERATURE: 1125

TEST: TEST-12A1
PROBE ORIENTATION
PORT: F2
2 FEBRUARY 1989

BOILER LOAD: 60 MW
COAL: MED SULF
SORBENT: NONE
DATA TIME: 5 SEC

PROBE TEMP: 800 F
GAS TEMPERATURE: 1125

TEST: TEST-12A1
PROBE ORIENTATION
PORT: F2
2 FEBRUARY 1989

BOILER LOAD: 60 MW
COAL: MED SULF
SORBENT: NONE
DATA TIME: 5 SEC

PROBE TEMP: 800 F
GAS TEMPERATURE: 1125

TEST: TEST-12A1
PROBE ORIENTATION
PORT: F2
2 FEBRUARY 1989

BOILER LOAD: 60 MW
COAL: MED SULF
SORBENT: NONE
DATA TIME: 5 SEC

PROBE TEMP: 800 F
GAS TEMPERATURE: 1125

FOULING PROBE FIELD TEST
 RICHMOND POWER & LIGHT
 WHITEWATER VALLEY STATION
 UNIT 2: PORT G1

TEST 11C - 1 FEBRUARY 1989
 BOILER LOAD: 60 MW
 PROBE TEMPERATURE: 600 F
 GAS TEMPERATURE: 823
 DATA TIME: 5 SECONDS

HEAT FLUX METER ORIENTATION: PROBE 1

TEST TIME HR	PROBE TEMP [F	AIR-IN TEMP [F	AIR-OUT TEMP [F	AIR-FLOW RATE LB/HR	HF-METER OUTPUT uV	METER-HF CALC B/FT2-HR	AVE-HF CALC B/FT2-HR	AVE-FF CALC	LOC-FF CALC
18.52	596.9	362.9	466.5	132.37	408.95	2652.34	6055.07		
18.52	597.1	363.6	466.7	127.60	410.12	2659.32	5810.39		
18.52	597.8	364.1	467.1	125.38	405.33	2630.77	5700.44		
18.52	598.3	364.5	467.5	125.41	407.44	2643.34	5701.81		
18.53	598.5	364.6	467.6	127.01	407.81	2645.55	5777.35		
18.53	598.8	364.6	467.5	128.69	406.86	2639.89	5846.95		
18.53	598.7	364.5	467.7	130.39	409.30	2654.43	5940.31		
18.53	598.4	364.4	467.6	132.07	408.47	2649.48	6020.93		
18.53	598.0	364.3	467.5	133.94	409.27	2654.25	6107.96		
18.53	598.1	364.0	467.3	135.09	408.11	2647.34	6162.19		
18.53	597.7	364.0	467.1	133.37	410.49	2661.52	6073.13		
18.54	597.9	364.5	467.3	130.22	407.44	2643.34	5911.29		
18.54	597.9	364.8	467.5	128.55	406.70	2638.93	5830.94		
18.54	598.1	365.1	467.8	127.18	404.60	2626.42	5765.43		
18.54	598.4	365.3	467.9	127.34	409.47	2655.44	5767.62		
18.54	598.9	365.4	467.9	128.78	405.17	2629.81	5829.43		
18.54	599.1	365.4	467.9	129.92	404.27	2624.45	5879.89		
18.54	598.4	365.3	467.8	130.95	406.57	2638.16	5924.77		
18.55	598.5	365.4	467.8	130.54	406.78	2639.41	5904.49		
18.55	598.5	365.6	468.1	129.72	406.99	2640.66	5874.28		
18.55	587.9	365.8	468.1	128.76	406.77	2639.35	5818.29		
18.55	599.0	365.9	468.3	127.86	405.42	2631.30	5777.63		
18.55	598.5	366.0	468.4	128.23	406.99	2640.66	5796.61		
18.55	598.8	366.1	468.5	129.74	409.20	2653.83	5868.88		
18.55	598.9	366.0	468.4	131.33	406.55	2638.04	5940.22		
18.55	598.3	366.0	468.6	130.83	406.45	2637.44	5928.01		
18.56	598.1	366.2	468.5	129.93	407.15	2641.61	5871.74		
18.56	598.0	366.5	468.8	126.88	406.69	2638.87	5731.66		
18.56	598.4	366.8	469.0	125.56	407.82	2645.61	5667.60		
18.56	599.1	367.0	469.1	126.60	407.74	2645.13	5708.39		
18.56	600.1	366.6	468.8	134.10	411.47	2667.36	6054.86		
18.56	599.3	365.9	468.4	139.22	413.80	2681.25	6300.17		
18.56	598.3	365.6	468.1	139.91	415.74	2692.81	6333.25		
18.57	598.0	365.4	467.8	139.37	416.01	2694.42	6303.27		
18.57	598.5	366.2	468.1	131.03	410.14	2659.43	5895.99		
18.57	598.7	366.2	468.1	132.12	416.35	2696.45	5945.04		
18.57	598.9	366.3	468.1	131.93	412.91	2675.94	5930.66		
18.57	598.9	366.3	468.1	132.68	414.97	2688.22	5963.20		
18.57	598.8	366.2	468.0	133.56	417.62	2704.02	5998.63		
18.57	598.7	366.1	467.7	134.88	417.47	2703.12	6051.36		
18.58	598.4	366.0	467.6	134.49	421.84	2729.17	6036.24		
18.58	598.0	366.0	467.8	133.96	422.49	2733.04	6017.18		
18.58	598.4	366.1	468.0	133.02	424.11	2742.70	5987.30		
18.58	598.6	366.2	468.0	132.21	428.26	2767.43	5943.25		
18.58	599.1	366.3	468.2	131.67	426.26	2755.51	5925.95		
18.58	598.9	366.3	468.4	132.89	428.48	2768.74	5992.01		
18.58	598.8	366.3	468.3	133.76	429.68	2775.89	6024.15		

FOULING PROBE FIELD TEST
 RICHMOND POWER & LIGHT
 WHITEWATER VALLEY STATION
 UNIT 2: PORT G1

TEST 11C - 1 FEBRUARY 1989
 BOILER LOAD: 60 MW
 PROBE TEMPERATURE: 600 F
 GAS TEMPERATURE: 823
 DATA TIME: 5 SECONDS

HEAT FLUX METER ORIENTATION: PROBE 1

TEST TIME HR	PROBE TEMP [F	AIR-IN TEMP [F	AIR-OUT TEMP [F	AIR-FLOW RATE LB/HR	HF-METER OUTPUT uV	METER-HF CALC B/FT2-HR	AVE-HF CALC B/FT2-HR	AVE-HF CALC B/FT2-HR	LOC-HF CALC B/FT2-HR
18.59	599.0	366.3	468.4	134.30	428.45	2768.56	6053.80		
18.59	599.2	366.3	468.4	134.85	430.16	2778.75	6076.81		
18.59	598.8	366.2	468.4	134.70	428.84	2770.89	6078.38		
18.59	598.6	366.3	468.4	134.29	429.46	2774.58	6054.54		
18.59	598.7	366.5	468.5	133.81	432.97	2795.50	6028.17		
18.59	599.0	366.4	468.4	135.06	428.39	2768.20	6082.10		
18.59	598.5	366.4	468.5	135.72	428.80	2770.65	6119.01		
18.60	598.5	366.5	468.4	135.33	430.34	2779.83	6083.88		
18.60	598.6	366.5	468.4	134.70	429.25	2773.33	6056.96		
18.60	598.2	366.7	468.4	133.32	427.46	2762.66	5990.79		
18.60	598.1	366.9	468.7	132.01	429.21	2773.09	5931.92		
18.60	598.4	367.1	468.8	130.90	423.56	2739.42	5880.31		
18.60	598.8	367.3	469.0	130.11	426.72	2758.25	5843.67		

SUMMARY OF 0 DEGREE PROBE ORIENTATION

AVERAGE	598.33	365.73	468.06	131.67	415.37	2690.60	5949.69		
MINIMUM	587.86	362.86	466.45	125.38	404.27	2624.45	5667.60		
MAXIMUM	600.10	367.28	469.07	139.91	432.97	2795.50	6333.25		
STD DEV	1.45	0.94	0.54	3.33	9.37	55.84	145.12		

18.66	598.2	372.4	482.6	121.67	140.23	1050.77	5920.75		
18.66	598.1	372.6	482.5	120.64	141.29	1057.09	5855.18		
18.66	598.9	372.7	482.7	119.47	137.07	1031.94	5801.03		
18.66	599.2	373.0	482.8	118.88	136.46	1028.30	5767.13		
18.67	599.2	373.1	483.1	119.57	137.66	1035.45	5811.70		
18.67	599.0	372.9	483.1	122.87	141.00	1055.36	5980.23		
18.67	598.9	372.8	483.0	124.22	139.84	1048.45	6047.03		
18.67	599.1	372.5	482.8	125.08	140.15	1050.29	6090.56		
18.67	598.4	372.6	482.6	124.84	143.34	1069.31	6065.09		
18.67	598.0	373.1	483.0	124.97	143.58	1070.74	6065.89		
18.67	598.5	372.7	482.4	124.30	141.75	1059.83	6025.13		
18.68	598.3	372.8	482.6	123.62	141.50	1058.34	5993.81		
18.68	598.7	372.9	482.4	122.90	141.85	1060.43	5942.62		
18.68	599.2	373.1	482.6	122.22	140.92	1054.88	5909.20		
18.68	599.2	373.2	482.9	123.35	137.33	1033.49	5973.09		
18.68	598.5	373.0	482.6	125.72	142.63	1065.07	6085.63		
18.68	598.6	372.9	482.6	125.79	141.87	1060.55	6090.13		
18.68	598.5	372.9	482.5	126.09	142.40	1063.70	6102.43		
18.69	598.3	372.9	482.5	125.66	142.39	1063.64	6081.62		
18.69	598.3	373.0	482.2	125.08	142.12	1062.04	6032.56		
18.69	598.2	373.1	482.4	123.42	140.81	1054.23	5956.86		
18.69	598.2	373.4	482.4	121.54	138.24	1038.91	5853.24		
18.69	598.4	373.6	482.6	120.67	138.41	1039.92	5809.74		
18.69	598.9	373.8	482.8	120.11	135.98	1025.44	5781.19		
18.69	599.2	374.0	483.2	120.51	136.50	1028.54	5811.62		

FOULING PROBE FIELD TEST
 RICHMOND POWER & LIGHT
 WHITEWATER VALLEY STATION
 UNIT 2: PORT G1

TEST 11C - 1 FEBRUARY 1989
 BOILER LOAD: 60 MW
 PROBE TEMPERATURE: 600 F
 GAS TEMPERATURE: 823
 DATA TIME: 5 SECONDS

HEAT FLUX METER ORIENTATION: PROBE 1

TEST TIME HR	PROBE TEMP IF	AIR-IN TEMP IF	AIR-OUT TEMP IF	AIR-FLOW RATE LB/HR	HF-METER OUTPUT uV	METER-HF CALC B/FT2-HR	AVE-HF CALC B/FT2-HR	AVE-HF CALC	LOC-HF CALC
18.69	598.9	373.9	483.2	122.77	139.56	1046.78	5928.74		
18.70	599.0	373.7	483.1	124.28	139.31	1045.29	6004.95		
18.70	598.6	373.7	483.1	124.44	139.00	1043.44	6012.68		
18.70	598.4	373.6	482.5	124.04	138.46	1040.22	5967.61		
18.70	598.7	373.6	482.6	123.58	139.71	1047.67	5946.03		
18.70	598.5	373.7	482.5	124.01	138.66	1041.41	5959.05		
18.70	598.7	373.7	482.5	124.39	140.88	1054.64	5981.16		
18.70	598.5	373.7	482.6	124.36	141.32	1057.27	5982.46		
18.71	598.3	373.7	482.6	123.30	138.20	1038.67	5927.11		
18.71	599.1	373.8	482.7	123.45	137.32	1033.43	5937.05		
18.71	598.9	373.7	482.8	124.33	138.13	1038.25	5989.25		
18.71	599.1	373.6	482.8	125.08	140.15	1050.29	6028.69		
18.71	599.5	373.7	482.7	125.50	138.78	1042.13	6041.18		
18.71	598.9	373.5	482.7	126.20	137.82	1036.41	6084.35		
18.71	599.0	373.5	482.6	126.22	137.94	1037.12	6082.53		
18.72	598.9	373.5	482.6	126.32	138.03	1037.66	6087.35		
18.72	598.9	373.5	482.6	127.10	139.16	1044.39	6122.69		
18.72	598.4	373.3	482.4	129.84	143.38	1069.54	6257.55		
18.72	598.2	372.9	482.0	132.30	142.77	1065.91	6377.27		
18.72	597.2	372.5	481.7	133.31	145.90	1084.56	6425.37		
18.72	596.9	372.6	481.4	130.15	144.62	1076.94	6255.25		
18.72	597.5	372.9	481.4	127.54	141.25	1056.85	6112.91		
18.73	597.8	373.1	481.7	125.70	140.30	1051.19	6027.49		
18.73	598.2	373.3	481.7	124.94	138.73	1041.83	5980.57		
18.73	598.4	373.5	481.8	123.13	139.57	1046.84	5890.67		
18.73	598.4	373.8	482.0	122.05	139.79	1048.15	5833.07		
18.73	598.3	373.9	482.1	122.27	139.97	1049.22	5839.26		
18.73	598.7	374.0	482.5	121.62	135.93	1025.14	5822.72		
18.73	598.8	374.1	482.5	122.96	138.02	1037.60	5883.08		
18.74	598.2	373.9	482.4	124.49	140.44	1052.02	5966.17		
18.74	598.2	374.1	482.4	123.78	136.35	1027.65	5922.31		
18.74	598.6	374.0	482.4	124.98	137.37	1033.73	5983.04		
18.74	598.6	373.9	482.5	126.56	137.87	1036.71	6070.97		
18.74	598.5	373.5	482.4	127.96	139.37	1045.65	6148.86		
18.74	598.3	373.5	482.3	127.89	141.00	1055.36	6143.24		

SUMMARY OF 90 DEGREE PROBE ORIENTATION

AVERAGE	598.55	373.32	482.51	124.40	139.84	1048.44	5997.94
MINIMUM	596.87	372.35	481.39	118.88	135.93	1025.14	5767.13
MAXIMUM	599.52	374.12	483.21	133.31	145.90	1084.56	6425.37
STD DEV	0.48	0.47	0.40	2.80	2.21	13.16	132.91

18.77	598.7	389.3	495.3	93.38	282.73	1900.07	4370.08
18.77	598.7	389.8	496.0	93.75	287.62	1929.22	4396.50
18.77	598.8	389.9	496.6	94.50	289.38	1939.70	4451.29

FOULING PROBE FIELD TEST
 RICHMOND POWER & LIGHT
 WHITEWATER VALLEY STATION
 UNIT 2: PORT G1

TEST 11C - 1 FEBRUARY 1989
 BOILER LOAD: 60 MW
 PROBE TEMPERATURE: 600 F
 GAS TEMPERATURE: 823
 DATA TIME: 5 SECONDS

HEAT FLUX METER ORIENTATION: PROBE 1

TEST TIME HR	PROBE TEMP [F	AIR-IN TEMP [F	AIR-OUT TEMP [F	AIR-FLOW RATE LB/HR	HF-METER OUTPUT UV	METER-HF CALC B/FT2-HR	AVE-HF CALC B/FT2-HR	AVE-FF CALC	LOC-FF CALC
18.77	598.4	390.2	497.0	95.55	293.54	1964.50	4503.70		
18.78	598.5	390.4	497.5	96.46	292.29	1957.05	4561.08		
18.78	598.6	390.5	497.9	98.17	294.80	1972.01	4654.07		
18.78	598.6	390.5	497.9	99.54	297.66	1989.05	4722.10		
18.78	598.8	390.4	498.2	101.11	298.85	1996.15	4809.52		
18.78	598.5	390.3	498.4	103.38	297.12	1985.84	4933.94		
18.78	598.4	390.2	498.4	103.71	299.62	2000.74	4953.35		
18.78	598.1	390.4	498.7	103.27	300.89	2008.30	4940.54		
18.79	598.2	390.6	498.8	102.04	301.48	2011.82	4879.00		
18.79	598.1	391.0	499.4	100.25	300.06	2003.36	4798.72		
18.79	598.8	391.4	499.8	99.23	298.96	1996.80	4752.09		
18.79	599.0	391.8	500.2	98.45	298.10	1991.68	4716.47		
18.79	599.3	391.8	500.4	100.55	298.64	1994.89	4821.07		
18.79	598.7	391.7	500.4	103.50	301.37	2011.17	4967.54		
18.79	598.6	391.5	500.3	104.72	302.27	2016.53	5028.87		
18.80	598.9	391.4	500.7	104.90	303.48	2023.74	5061.60		
18.80	598.5	391.6	501.0	104.60	304.57	2030.24	5050.36		
18.80	598.9	391.6	501.1	104.82	302.73	2019.27	5070.70		
18.80	598.8	391.6	501.2	105.55	303.58	2024.34	5107.88		
18.80	598.7	391.7	501.3	105.58	304.03	2027.62	5111.66		
18.80	598.5	391.7	501.3	106.55	305.04	2033.04	5158.63		
18.80	598.4	391.6	501.7	106.33	306.04	2039.00	5166.76		
18.80	598.3	391.8	502.2	105.83	302.68	2018.97	5163.13		
18.81	598.2	391.9	502.8	105.08	304.65	2030.71	5146.39		
18.81	598.3	392.2	503.3	103.11	305.68	2036.85	5058.10		
18.81	598.5	392.6	503.8	102.18	302.77	2019.51	5018.80		
18.81	598.8	392.9	504.3	101.71	301.32	2010.87	5003.35		
18.81	599.1	393.1	504.9	102.93	303.81	2025.71	5082.90		
18.81	599.0	392.7	504.9	106.58	300.23	2004.37	5270.68		
18.81	598.8	392.5	505.4	107.33	303.52	2023.98	5352.79		
18.82	598.2	392.5	505.7	107.12	302.40	2017.30	5353.20		
18.82	598.1	392.5	505.9	106.76	300.73	2007.35	5346.05		
18.82	598.1	392.7	506.4	105.46	301.14	2009.79	5297.25		
18.82	598.6	393.0	506.8	104.21	301.83	2013.91	5237.69		
18.82	598.5	393.1	507.1	103.44	298.28	1992.75	5203.56		
18.82	598.4	393.4	507.5	102.85	296.41	1981.60	5183.41		
18.82	598.3	393.6	507.6	102.52	297.51	1988.16	5162.25		
18.83	598.3	393.8	508.4	101.18	296.18	1980.23	5119.80		
18.83	598.3	394.2	508.9	99.97	294.84	1972.25	5065.20		
18.83	599.2	394.4	509.6	99.26	298.92	1996.56	5047.19		
18.83	599.4	394.7	510.1	99.49	297.21	1986.37	5069.43		
18.83	599.3	394.5	510.2	102.87	298.78	1995.73	5252.56		
18.83	599.0	394.1	509.9	105.65	300.15	2003.89	5404.30		
18.83	598.3	393.8	509.5	107.45	300.17	2004.01	5492.58		
18.84	598.3	393.5	509.1	107.64	301.38	2011.22	5492.79		
18.84	598.5	393.5	509.3	107.27	304.45	2029.52	5486.22		
18.84	598.5	393.5	509.2	106.82	299.11	1997.70	5459.91		

FOULING PROBE FIELD TEST
 RICHMOND POWER & LIGHT
 WHITewater VALLEY STATION
 UNIT 2: PORT G1

TEST 11C - 1 FEBRUARY 1989
 BOILER LOAD: 60 MW
 PROBE TEMPERATURE: 600 F
 GAS TEMPERATURE: 823
 DATA TIME: 5 SECONDS

HEAT FLUX METER ORIENTATION: PROBE 1

TEST TIME HR	PROBE TEMP °F	AIR-IN TEMP °F	AIR-OUT TEMP °F	AIR-FLOW RATE LB/HR	HF-METER OUTPUT uV	METER-HF CALC B/FT2-HR	AVE-HF CALC B/FT2-HR	AVE-HF CALC	LOC-HF CALC
18.84	598.1	393.6	509.3	106.39	304.14	2027.67	5435.11		
18.84	598.2	393.6	509.2	105.83	303.11	2021.54	5403.23		
18.84	598.2	393.8	509.4	105.27	302.04	2015.16	5373.24		
18.84	598.5	394.0	509.5	104.89	300.57	2006.40	5352.00		
18.85	598.7	394.0	509.7	104.21	301.63	2012.71	5322.82		
18.85	598.7	394.2	509.8	104.37	300.18	2004.07	5329.15		
18.85	598.3	394.1	509.5	105.69	301.28	2010.63	5388.15		
18.85	598.3	393.9	509.4	106.90	304.91	2032.26	5455.03		
18.85	598.1	393.7	509.3	107.45	302.50	2017.90	5483.57		
18.85	597.9	393.7	509.3	106.92	301.49	2011.88	5455.10		

SUMMARY OF 180 DEGREE PROBE ORIENTATION

AVERAGE	598.54	392.36	504.11	103.21	300.01	2003.08	5096.04		
MINIMUM	597.85	389.34	495.32	93.38	282.73	1900.07	4370.08		
MAXIMUM	599.38	394.70	510.16	107.64	306.04	2039.00	5492.79		
STD DEV	0.34	1.42	4.68	3.60	4.34	25.85	290.81		

18.87	598.9	392.9	507.7	108.73	474.31	3041.89	5512.88		
18.87	599.3	392.8	507.4	109.98	473.85	3039.15	5565.57		
18.87	598.6	392.3	506.9	115.63	481.59	3085.28	5852.52		
18.87	598.7	391.9	505.4	117.70	484.91	3105.06	5899.08		
18.88	598.6	391.5	505.0	119.41	488.64	3127.29	5983.73		
18.88	598.0	391.2	504.3	119.45	482.85	3092.79	5962.52		
18.88	597.9	391.4	503.4	114.98	481.26	3063.31	5683.67		
18.88	598.1	392.1	503.6	109.48	476.83	3056.91	5387.99		
18.88	598.4	392.7	503.5	107.15	474.33	3042.01	5239.72		
18.88	598.7	393.3	503.2	105.42	473.52	3037.18	5112.76		
18.88	599.2	393.6	503.2	104.62	472.06	3028.48	5061.03		
18.89	599.4	393.6	502.8	108.60	476.47	3054.76	5236.78		
18.89	598.8	393.0	502.5	112.33	477.38	3060.18	5430.53		
18.89	599.1	392.6	502.1	113.72	479.42	3072.34	5494.72		
18.89	598.6	392.5	501.8	114.31	476.67	3055.95	5518.68		
18.89	598.3	392.2	501.2	113.98	477.51	3060.96	5483.12		
18.89	598.1	392.2	500.9	112.99	479.96	3075.56	5421.03		
18.89	598.2	392.4	501.1	111.72	481.37	3083.97	5363.55		
18.90	598.7	392.6	501.2	109.46	483.28	3095.35	5250.70		
18.90	599.1	392.9	501.6	108.36	483.39	3096.00	5201.76		
18.90	599.4	392.9	501.7	109.51	479.96	3075.56	5257.93		
18.90	598.9	392.6	500.8	111.70	475.34	3048.03	5337.92		
18.90	598.5	392.5	500.3	111.81	474.41	3042.48	5325.90		
18.90	598.4	392.4	499.8	111.14	477.34	3059.95	5268.96		
18.90	598.4	392.5	499.6	110.70	477.19	3059.05	5237.83		
18.90	598.4	392.5	499.6	110.16	474.79	3044.75	5211.31		
18.91	598.7	392.7	499.7	109.38	477.37	3060.13	5168.61		
18.91	598.9	392.8	499.7	108.72	472.99	3034.02	5131.18		

FOULING PROBE FIELD TEST
 RICHMOND POWER & LIGHT
 WHITEWATER VALLEY STATION
 UNIT 2: PORT G1

TEST 11C - 1 FEBRUARY 1989
 BOILER LOAD: 60 MW
 PROBE TEMPERATURE: 600 F
 GAS TEMPERATURE: 823
 DATA TIME: 5 SECONDS

HEAT FLUX METER ORIENTATION: PROBE 1

TEST TIME HR	PROBE TEMP [F	AIR-IN TEMP [F	AIR-OUT TEMP [F	AIR-FLOW RATE LB/HR	HF-METER OUTPUT uV	METER-HF CALC B/FT2-HR	AVE-HF CALC B/FT2-HR	AVE-HF CALC B/FT2-HR	LOC-HF CALC
18.91	598.4	392.8	499.5	108.33	472.71	3032.35	5104.17		
18.91	598.5	392.8	499.1	109.94	472.26	3029.67	5163.03		
18.91	598.5	392.7	499.8	110.04	473.81	3038.91	5204.66		
18.91	598.8	392.5	499.8	111.12	476.15	3052.85	5265.06		
18.91	598.5	392.3	499.7	112.03	475.91	3051.42	5313.13		
18.92	598.8	392.2	500.0	112.73	483.17	3094.69	5364.74		
18.92	598.9	392.1	499.9	113.74	486.39	3113.88	5417.83		
18.92	598.6	392.0	498.4	113.95	480.57	3079.20	5353.36		
18.92	598.2	391.9	497.7	113.36	477.51	3060.96	5298.62		
18.92	598.5	391.9	498.4	112.15	481.65	3085.63	5275.73		
18.92	598.5	392.1	498.4	111.02	482.58	3091.18	5209.83		
18.92	598.4	392.1	498.1	110.47	477.92	3063.40	5167.92		
18.93	598.4	392.3	497.5	109.88	476.52	3055.06	5103.93		
18.93	598.4	392.4	497.0	109.36	477.95	3063.58	5049.35		
18.93	598.7	392.5	497.2	108.86	475.77	3050.59	5030.59		
18.93	599.0	392.4	496.5	109.96	475.82	3050.89	5057.15		
18.93	598.5	392.3	496.6	110.78	475.69	3050.11	5099.75		
18.93	598.8	392.4	497.6	110.90	480.07	3076.22	5151.80		
18.93	598.8	392.2	497.3	112.92	479.68	3073.89	5241.15		
18.94	598.7	391.9	496.6	113.27	478.65	3067.75	5235.89		
18.94	598.4	391.9	496.2	112.93	476.01	3052.02	5199.73		
18.94	597.9	391.8	496.2	112.32	478.82	3068.77	5177.59		
18.94	598.0	392.0	496.4	110.06	474.43	3042.60	5074.87		
18.94	598.4	392.3	496.9	108.65	477.23	3059.29	5028.69		
18.94	598.7	392.5	497.0	107.84	474.51	3043.08	4978.22		
18.94	599.4	392.6	498.0	107.30	474.41	3042.48	4994.51		
18.95	599.2	392.9	498.7	108.16	480.78	3080.45	5054.13		
18.95	599.5	392.5	498.9	111.77	483.11	3094.34	5253.91		
18.95	598.9	392.1	497.8	114.21	484.04	3099.88	5326.24		
18.95	598.7	391.8	496.7	115.21	482.99	3093.62	5332.69		
18.95	598.4	391.6	495.6	115.10	480.32	3077.71	5282.87		
18.95	598.4	391.6	494.7	114.73	479.05	3070.14	5225.86		

SUMMARY OF 270 DEGREE PROBE ORIENTATION

AVERAGE	598.63	392.37	499.96	111.41	478.26	3065.42	5293.98		
MINIMUM	597.87	391.23	494.72	104.62	472.06	3028.48	4978.22		
MAXIMUM	599.49	393.60	507.74	119.45	488.64	3127.29	5983.73		
STD DEV	0.37	0.48	3.01	2.96	3.74	22.28	223.68		

TEST: TEST-11C
PROBE ORIENTATION
PORT: G1
1 FEBRUARY 1989

BOILER LOAD: 60 MW
COAL: MED SULF
SORBENT: NONE
DATA TIME: 5 SEC

PROBE TEMP: 600 F
GAS TEMPERATURE: 823

TEST: TEST-11C
PROBE ORIENTATION
PORT: G1
1 FEBRUARY 1989

BOILER LOAD: 60 MW
COAL: MED SULF
SORBENT: NONE
DATA TIME: 5 SEC

PROBE TEMP: 600 F
GAS TEMPERATURE: 823

TEST: TEST-11C
PROBE ORIENTATION
PORT: G1
1 FEBRUARY 1989

BOILER LOAD: 60 MW
COAL: MED SULF
SORBENT: NONE
DATA TIME: 5 SEC

PROBE TEMP: 600 F
GAS TEMPERATURE: 823

TEST: TEST-11C
PROBE ORIENTATION
PORT: G1
1 FEBRUARY 1989

BOILER LOAD: 60 MW
COAL: MED SULF
SORBENT: NONE
DATA TIME: 5 SEC

PROBE TEMP: 600 F
GAS TEMPERATURE: 823

TEST: TEST-11C
PROBE ORIENTATION
PORT: G1
1 FEBRUARY 1989

BOILER LOAD: 60 MW
COAL: MED SULF
SORBENT: NONE
DATA TIME: 5 SEC

PROBE TEMP: 600 F
GAS TEMPERATURE: 823

APPENDIX C
TEST 13 TEST DATA

FOULING PROBE FIELD TEST
 RICHMOND POWER & LIGHT
 WHITEWATER VALLEY STATION
 NIT 2: PORT E2

TEST 13 - 3 FEBRUARY 1989
 BOILER LOAD: 60 MW
 PROBE TEMPERATURE: 950 F
 GAS TEMPERATURE: 1439
 DATA TIME: 5 MINUTES

PROBE #1 @ 180 DEGREE ORIENTATION
 NEW HEAT FLUX METER CALIBRATION

TEST TIME HR	PROBE TEMP IF	AIR-IN TEMP IF	AIR-OUT TEMP IF	AIR-FLOW RATE LB/HR	HF-METER OUTPUT uV	METER-HF CALC B/FT2-HR	AVE-HF CALC B/FT2-HR	AVE-FF CALC	LOC-FF CALC
9.40	949.6	557.9	728.7	71.08	620.44	2784.01	5360.34	0.0056	0.0020
9.48	946.9	551.9	723.7		631.25	2808.88		0.0019	0.0013
9.57	949.9	553.2	725.0	72.61	667.52	2892.30	5510.30	0.0005	-0.0008
9.65	949.3	553.8	726.2		661.48	2878.40		0.0000	-0.0005
9.73	949.5	560.7	729.3	66.12	716.05	3003.92	4924.18	0.0097	-0.0034
9.82	948.3	560.3	729.1		615.44	2772.51		0.0102	0.0023
9.90	946.7	557.4	729.0	57.41	657.90	2870.17	4350.29	0.0028	-0.0003
9.98	948.8	558.1	727.6		597.96	2732.31		0.0069	0.0035
10.07	949.9	551.8	724.0	62.70	676.96	2914.01	4769.38	-0.0020	-0.0013
10.15	946.6	545.0	715.8		651.79	2856.12		-0.0040	0.0001
10.23	948.4	545.7	716.1	63.56	664.91	2886.29	4782.72	-0.0004	-0.0007
10.32	949.9	544.5	718.1		665.65	2888.00		-0.0048	-0.0007
10.40	948.5	543.6	716.5	72.61	678.20	2916.86	5546.21	-0.0057	-0.0014
10.48	948.5	541.6	714.7		687.33	2937.86		-0.0082	-0.0019
10.57	950.2	547.0	717.0	67.32	666.58	2890.13	5053.97	-0.0017	-0.0008
10.65	948.9	542.8	716.7		663.48	2883.00		-0.0068	-0.0006
10.73	948.9	540.5	711.5	80.98	676.31	2912.51	6114.85	-0.0036	-0.0013
10.82	948.3	540.7	711.4		662.79	2881.42		-0.0032	-0.0006
10.90	950.7	534.3	706.4	80.47	752.63	3088.05	6114.88	-0.0112	-0.0051
10.98	946.9	534.6	705.3		710.09	2990.21		-0.0084	-0.0031
11.07	945.7	540.1	708.6	77.40	641.11	2831.55	5756.44	-0.0032	0.0007
11.15	947.4	546.6	712.7		664.84	2886.13		0.0013	-0.0007
11.23	949.1	547.0	712.8	71.08	641.93	2833.44	5205.30	-0.0019	0.0007
11.32	948.2	546.0	711.5		639.36	2827.53		-0.0043	0.0008
11.40	949.2	544.7	709.3	73.30	652.48	2857.70	5327.50	-0.0037	0.0000
11.48	940.2	537.3	703.6		718.91	3010.49		-0.0089	-0.0035
11.57	949.9	553.2	715.9	73.81	651.64	2855.77	5301.20	0.0065	0.0001
11.65	948.0	549.4	714.9		670.45	2899.04		-0.0025	-0.0010
11.73	950.7	547.0	711.2	68.51	645.04	2840.59	4968.29	-0.0048	0.0005
11.82	947.6	549.3	714.6		648.57	2848.71		-0.0034	0.0003
11.90	949.2	550.6	716.3	68.68	659.12	2872.98	5026.18	-0.0022	-0.0004
11.98	948.2	551.8	718.1		632.08	2810.78		0.0054	0.0013
12.07	948.8	548.3	713.7	68.85	676.08	2911.98	5030.16	-0.0011	-0.0013
12.15	952.0	559.3	721.7		600.36	2737.83		0.0084	0.0033
12.23	949.7	550.5	714.2	65.95	698.96	2964.61	4766.72	-0.0036	-0.0025
12.32	948.4	555.9	719.9		620.26	2783.60		0.0054	0.0020
12.40	948.0	553.9	719.1	65.95	626.81	2798.66	4810.69	-0.0010	0.0016
12.48	951.5	553.4	717.7		650.60	2853.38		-0.0017	0.0001
12.57	947.6	543.1	709.6	70.22	660.29	2875.67	5163.82	-0.0046	-0.0004
12.65	950.3	543.4	709.0		628.78	2803.19		-0.0027	0.0015
12.73	952.3	539.5	703.4	75.52	692.12	2948.88	5466.27	-0.0065	-0.0021
12.82	947.5	529.8	692.5		737.33	3052.86		-0.0100	-0.0044
13.00	951.8	535.7	702.1	70.56	735.05	3047.62	5182.71	-0.0110	-0.0043
13.08	947.9	541.5	708.9		672.96	2904.81		-0.0054	-0.0011
13.17	948.6	542.4	709.6	71.08	675.31	2910.21	5249.24	-0.0031	-0.0013
13.25	951.2	536.6	701.8		715.78	3003.29		-0.0128	-0.0034

FOULING-PROBE FIELD TEST
 RICHMOND POWER & LIGHT
 WHITEWATER VALLEY STATION
 NIT 2: PORT E2

TEST 13 - 3 FEBRUARY 1989
 BOILER LOAD: 60 MW
 PROBE TEMPERATURE: 950 F
 GAS TEMPERATURE: 1439
 DATA TIME: 5 MINUTES

PROBE #1 @ 180 DEGREE ORIENTATION
 NEW HEAT FLUX METER CALIBRATION

TEST TIME HR	PROBE TEMP IF	AIR-IN TEMP IF	AIR-OUT TEMP IF	AIR-FLOW RATE LB/HR	HF-METER OUTPUT uV	METER-HF CALC B/FT2-HR	AVE-HF CALC B/FT2-HR	AVL FF CALC	LOC-FF CALC
13.33	947.8	539.7	705.5	78.93	666.02	2888.85	5780.88	-0.0085	-0.0007
13.42	948.0	534.3	701.2		724.80	3024.04		-0.0133	-0.0038
13.50	946.7	540.8	706.0	76.88	683.53	2929.12	5609.34	-0.0052	-0.0017
13.58	948.7	547.2	711.7		665.66	2888.02		0.0005	-0.0007
13.67	948.4	544.4	709.3	75.86	677.67	2915.64	5524.50	-0.0035	-0.0014
13.75	948.5	541.4	706.9		687.00	2937.10		-0.0065	-0.0019
13.83	961.3	444.0	609.1	72.10	1649.30	5150.39	5256.81	-0.0285	-0.0240
13.92	946.3	464.6	652.5		823.58	3251.23		-0.0183	-0.0081
14.00	958.1	416.9	592.0	91.92	1506.02	4820.85	7109.34	-0.0303	-0.0226
14.08	953.5	423.3	604.9		1440.10	4669.23		-0.0286	-0.0219
14.17	950.2	418.2	608.9	145.23	1526.61	4868.20	12228.15	-0.0284	-0.0232
14.25	948.6	442.9	641.6		988.67	3630.94		-0.0141	-0.0134
14.33	950.3	512.3	709.7	151.89	547.35	2615.90	13242.61	-0.0078	0.0072
14.42	948.3	524.5	702.2		581.51	2694.47		-0.0040	0.0046
14.50	947.9	542.8	716.7	84.57	536.76	2591.55	6493.32	-0.0071	0.0081
14.58	949.0	545.0	717.6		579.09	2688.91		-0.0141	0.0048
14.67	944.4	503.6	669.8	38.78	887.06	3397.24	2845.19	-0.0257	-0.0104
14.75	948.9	575.6	741.6		416.10	2314.03		0.0194	0.0203
14.83	946.4	576.5	747.7	53.14	433.62	2354.33	4016.99	0.0122	0.0183
14.92	949.3	577.6	747.8		418.55	2319.67		0.0177	0.0200
15.00	949.7	579.8	751.6	58.26	436.93	2361.94	4419.15	0.0126	0.0178
15.08	950.4	574.1	747.4		466.98	2431.05		0.0029	0.0145
15.17	948.2	574.9	748.2	57.24	460.01	2415.02	4379.81	0.0089	0.0153
15.25	948.4	576.6	748.2		447.99	2387.38		0.0177	0.0166
15.33	947.9	571.8	747.6	61.34	479.47	2459.78	4761.57	0.0007	0.0133
15.42	948.7	566.1	742.4		461.75	2419.03		0.0046	0.0151
15.50	949.4	566.6	744.8	70.05	481.12	2463.58	5514.72	0.0001	0.0130
15.58	948.7	559.6	740.2		516.16	2544.17		-0.0040	0.0098
15.67	948.2	553.6	732.9	65.10	553.07	2629.06	5153.97	-0.0051	0.0067
15.75	947.9	559.0	738.3		529.54	2574.94		-0.0048	0.0087
15.83	950.1	560.3	735.5	67.15	505.21	2518.98	5192.95	-0.0018	0.0107
15.92	946.6	553.4	728.4		515.40	2542.42		-0.0019	0.0099
16.00	947.1	551.9	728.8	71.59	548.05	2617.52	5592.15	-0.0081	0.0072
16.08	949.0	565.4	736.7		492.24	2489.15		0.0040	0.0120
16.17	949.1	565.2	737.6	72.61	482.79	2467.42	5527.29	0.0008	0.0129
16.25	950.6	565.0	736.3		490.64	2485.47		-0.0006	0.0121
16.33	949.5	563.6	736.3	66.12	549.86	2621.66	5041.85	-0.0029	0.0070
16.42	948.3	556.1	730.1	66.80	559.01	2642.72	5133.19	-0.0062	0.0063

APPENDIX D
TEST 15 TEST DATA

FOULING PROBE FIELD TEST
 RICHMOND POWER & LIGHT
 WHITEWATER VALLEY STATION
 UNIT 2: PORT F2

TEST 15 - 1 MARCH 1989
 BOILER LOAD: 60 MW
 PROBE TEMPERATURE: 200°F
 GAS TEMPERATURE: 1169°F
 DATA TIME: 5 MINUTES

TEST TIME HR	PROBE TEMP °F	AIR-IN TEMP °F	AIR-OUT TEMP °F	AIR-FLOW RATE LB/HR	HF-METER OUTPUT UV	METER-HF CALC B/FT2-HR	AVE-HF CALC B/FT2-HR	AVE-HF CALC	LOC-HF CALC
8.26	798.9	498.1	626.2	58.67	380.35	1827.00	3319.03	0.0028	0.0004
8.44	799.1	498.3	626.4	58.31	381.08	1828.67	3299.18	0.0035	0.0003
8.53	799.8	498.2	626.4	59.59	383.98	1835.31	3371.60	0.0011	-0.0001
8.61	799.7	500.4	627.6	56.97	369.38	1801.88	3199.96	0.0069	0.0019
8.69	798.7	497.4	626.1	59.82	386.90	1842.00	3398.08	0.0003	-0.0005
8.78	799.5	496.7	625.8	57.96	393.62	1857.39	3304.97	0.0033	-0.0014
8.86	798.9	495.5	626.0	60.30	386.71	1841.57	3475.68	-0.0021	-0.0005
8.94	798.7	495.2	626.2	60.77	381.28	1829.13	3515.11	-0.0033	0.0002
9.03	799.7	497.3	626.6	58.12	394.22	1858.76	3318.45	0.0028	-0.0015
9.11	798.6	495.8	625.6	61.34	397.20	1865.59	3516.66	-0.0033	-0.0019
9.19	798.4	497.5	627.2	60.66	397.85	1867.08	3473.39	-0.0020	-0.0020
9.28	798.7	497.2	627.5	60.07	396.86	1864.81	3455.26	-0.0015	-0.0018
9.36	799.2	495.9	626.4	60.09	382.55	1832.04	3462.25	-0.0017	0.0001
9.44	798.4	495.3	626.2	60.47	385.97	1839.87	3494.02	-0.0027	-0.0004
9.53	798.8	493.7	625.1	61.56	408.30	1891.01	3571.14	-0.0049	-0.0033
9.61	799.3	494.5	625.5	59.11	412.16	1899.85	3419.35	-0.0004	-0.0038
9.69	798.3	492.0	623.6	61.09	406.54	1886.98	3543.46	-0.0043	-0.0031
9.78	797.7	491.3	623.4	62.08	385.56	1838.93	3620.49	-0.0063	-0.0004
9.86	799.0	492.7	623.7	59.57	370.02	1803.35	3445.96	-0.0012	0.0018
9.94	799.7	493.7	624.5	58.66	393.14	1856.29	3387.11	0.0006	-0.0014
10.03	800.3	492.3	623.7	59.31	372.76	1809.62	3442.18	-0.0011	0.0014
10.11	799.2	491.0	623.0	60.79	377.53	1820.54	3543.65	-0.0041	0.0007
10.19	798.4	490.7	622.8	58.99	371.06	1805.73	3440.54	-0.0010	0.0016
10.28	799.6	494.0	624.7	57.52	361.81	1784.54	3320.01	0.0028	0.0029
10.36	799.5	494.8	624.4	59.16	357.77	1775.29	3384.10	0.0007	0.0035
10.44	798.9	494.8	624.2	59.66	366.14	1794.46	3409.54	-0.0001	0.0023
10.53	799.0	492.2	621.7	58.19	363.96	1789.47	3326.56	0.0026	0.0026
10.61	800.0	492.4	621.9	57.92	378.27	1822.24	3313.68	0.0030	0.0006
10.69	799.3	490.7	622.4	62.02	393.65	1857.46	3606.04	-0.0059	-0.0014
10.78	799.0	492.9	623.6	61.11	390.07	1849.26	3525.60	-0.0036	-0.0009
10.86	798.1	491.2	621.7	61.89	390.98	1851.34	3565.96	-0.0048	-0.0011
10.94	798.6	490.6	621.1	62.66	399.51	1870.88	3611.98	-0.0061	-0.0022
11.03	799.1	492.3	621.8	59.80	403.43	1873.85	3420.98	-0.0004	-0.0027
11.11	798.8	493.1	622.6	61.49	382.71	1832.41	3517.66	-0.0034	0.0000
11.19	799.5	494.7	623.3	58.80	392.94	1855.83	3339.10	0.0022	-0.0013
11.28	799.5	494.4	623.3	59.92	378.56	1822.90	3410.64	-0.0001	0.0006
11.36	798.6	489.1	616.3	59.21	359.25	1778.68	3323.69	0.0027	0.0033
11.44	799.0	495.0	624.0	61.00	362.98	1787.22	3474.54	-0.0021	0.0028
11.53	799.0	494.2	623.4	58.84	387.39	1843.12	3356.45	0.0016	-0.0006
11.61	798.6	492.2	621.9	61.84	409.47	1893.69	3540.41	-0.0040	-0.0035
11.69	799.9	494.2	622.9	59.86	384.72	1837.01	3402.74	0.0001	-0.0002
11.78	798.4	493.6	622.6	60.85	370.13	1803.60	3466.00	-0.0018	0.0018
11.92	798.3	392.9	550.1	84.02	245.63	1518.49	5832.77	-0.0445	0.0224
12.00	797.1	369.7	527.3	110.57	327.78	1706.62	7695.92	-0.0598	0.0080
12.09	803.4	355.9	519.5	155.34	498.61	2097.82	11227.01	-0.0735	-0.0135
12.17	793.6	375.6	549.0	100.32	329.49	1710.53	7678.44	-0.0603	0.0078
12.25	805.1	387.6	557.6	70.10	220.84	1461.72	5262.96	-0.0370	0.0270

FOULING PROBE FIELD TEST
 RICHMOND POWER & LIGHT
 WHITEWATER VALLEY STATION
 UNIT 2: PORT F2

TEST 15 - 1 MARCH 1989
 BOILER LOAD: 60 MW
 PROBE TEMPERATURE: 800 F
 GAS TEMPERATURE: 1169
 DATA TIME: 5 MINUTES

TEST TIME HR	PROBE TEMP °F	AIR-IN TEMP °F	AIR-OUT TEMP °F	AIR-FLOW RATE LB/HR	HF-METER OUTPUT UV	METER-HF CALC B/FT2-HR	AVE-HF CALC B/FT2-HR	AVE-FF CALC	LOC-FF CALC
12.34	795.8	349.5	513.3	157.35	369.66	1802.52	11382.01	-0.0755	0.0018
12.42	800.1	354.6	521.2	141.98	419.83	1917.41	10445.76	-0.0718	-0.0047
12.50	803.7	364.0	533.8	109.84	389.44	1847.82	8233.94	-0.0618	-0.0009
12.59	798.0	460.7	616.6	48.54	330.95	1713.88	3341.84	0.0021	0.0075
12.67	798.8	488.2	631.0	48.83	323.53	1696.88	3079.98	0.0113	0.0087
12.75	799.0	502.4	637.3	53.89	341.73	1738.56	3208.53	0.0066	0.0059
12.84	799.2	511.3	642.1	53.73	329.15	1709.75	3104.10	0.0104	0.0078
12.92	799.7	514.1	641.9	54.63	346.08	1748.52	3082.76	0.0112	0.0052
13.00	798.7	514.5	642.1	57.10	326.93	1704.67	3215.84	0.0064	0.0081
13.09	799.3	516.1	642.7	55.43	320.44	1689.81	3098.53	0.0106	0.0091
13.17	800.2	517.2	644.8	57.35	322.91	1695.46	3232.45	0.0057	0.0087
13.25	798.9	521.4	648.8	52.82	309.72	1665.26	2969.43	0.0158	0.0109
13.34	798.8	521.0	646.2	53.09	316.50	1680.79	2934.91	0.0172	0.0098
13.42	799.4	524.5	648.9	53.10	284.09	1606.57	2915.76	0.0180	0.0152
13.50	797.9	521.0	646.5	54.56	294.39	1630.15	3024.12	0.0136	0.0135
13.59	797.7	518.5	645.7	56.68	271.86	1578.56	3183.92	0.0075	0.0175
13.67	798.4	518.8	645.4	53.94	299.44	1641.72	3015.96	0.0139	0.0126
13.75	799.0	519.2	645.0	51.12	297.33	1636.89	2839.77	0.0213	0.0129
13.84	799.1	516.3	643.7	54.90	307.60	1660.40	3088.54	0.0110	0.0112
13.92	797.9	511.2	641.1	57.97	303.45	1650.90	3325.50	0.0026	0.0119
14.00	799.3	513.6	642.8	54.20	298.42	1639.38	3093.68	0.0108	0.0127
14.09	799.2	514.4	643.4	54.51	302.52	1648.77	3104.87	0.0104	0.0120
14.17	798.7	512.7	641.7	56.09	317.22	1682.43	3194.13	0.0071	0.0097
14.25	799.6	514.2	642.9	55.38	314.72	1676.71	3146.11	0.0088	0.0100
14.34	799.8	513.4	641.4	56.41	317.53	1683.14	3189.18	0.0073	0.0096
14.42	798.9	512.4	641.4	56.95	337.17	1728.12	3244.11	0.0054	0.0065
14.50	799.7	511.7	640.1	54.95	329.53	1710.62	3116.10	0.0100	0.0077
14.59	798.1	509.3	639.0	57.74	321.11	1691.34	3308.49	0.0032	0.0091
14.67	798.2	508.3	638.8	56.89	300.54	1644.24	3280.13	0.0041	0.0124
14.75	798.1	509.6	639.9	56.38	283.34	1604.85	3243.75	0.0054	0.0154
14.84	798.1	507.0	638.3	57.06	303.74	1651.56	3309.84	0.0031	0.0119
14.92	798.4	509.9	639.8	53.95	281.83	1601.39	3095.61	0.0108	0.0156
15.00	797.7	510.1	639.7	57.53	299.64	1642.18	3293.40	0.0037	0.0126
15.09	798.2	511.8	640.8	57.51	303.08	1650.05	3276.77	0.0043	0.0120
15.17	798.6	510.2	639.4	57.10	307.64	1660.50	3257.69	0.0049	0.0112
15.25	799.6	513.1	640.8	54.27	311.96	1670.39	3060.29	0.0121	0.0105
15.34	799.9	512.9	641.5	54.47	308.06	1661.46	3093.46	0.0108	0.0111

END

DATE FILMED

01 / 29 / 91