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Thermal Performance of the ABB GT24 Combustion Turbine

Peaking Service Experience at GPU Gilbert Station

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Peaking Service Experience at GPU Gilbert Station

TR-113978

Interim Report, December 1999

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REPORT SUMMARY

EPRI's Durability Surveillance (DS) program—in place since 1991—is producing the first in-service performance and operating data on the newest high-efficiency gas turbines. This detailed investigation of the ABB GT24 installed at GPU Genco's Gilbert Station in Milford, New Jersey, is providing plant personnel and the manufacturer with valuable information for solving initial problems. Study results will help all power producers specify, operate, and maintain a new generation of high-performance gas turbines.

Background

Gas turbine manufacturers now offer large, heavy-frame models with advanced features that allow firing temperatures approaching 2400°F (1315°C). These very high firing temperatures have helped boost thermal efficiency to about 38% in simple-cycle applications, while combined-cycle efficiencies are approaching 60% (LHV). To resolve uncertainties about performance, reliability, and component life of new models, the DS team—composed of EPRI, utilities, and gas turbine manufacturers—installed instrumentation for monitoring blade temperature, vibration, and other parameters in initial units. The current study investigated the ABB GT24, which features sequential combustion (reheat), a high compression ratio, and air-cooled blades.

Objective

To collect and trend data from the DS project's on-line integrated monitoring and analysis system; to establish valid baseline data for performance comparisons to be made over the life of the unit; to investigate any data anomalies and identify potential or emerging problems; and, to generate guidelines for durability evaluation of an ABB GT24 advanced gas turbine (which would also apply to the 50-Hz sister model, the GT26).

Approach

The DS project team used optical pyrometers, vibration sensors, and Efficiency-MAP™ performance software to record operating data over approximately 10 months of initial commercial service. The team analyzed early data to establish baseline performance characteristics of the ABB GT24. To allow for proactive problem-solving, they provided the manufacturer with data on operating issues uncovered during the roll-out period.

Results

Data monitoring, storage, and analysis systems performed well, providing information needed to develop baseline operating characteristics for the ABB GT24 advanced gas turbine. Findings to date on blade temperatures, vibration levels, and hot-gas-path part condition show that, overall, the ABB GT24 advanced gas turbine is operating as expected. Early data enabled the DS project team to solve problems experienced during roll-out and commissioning. In some cases, the

findings prompted the manufacturer to adopt new quality control measures that will benefit future purchasers. EPRI report TR-108608 (November 1997) covers startup and site testing during mid-1997. TR-111644 covers initial commercial service from December 1997 to September 1998. This report covers operational data from September 1998 to August 1999. EPRI guidelines for monitoring an ABB GT24, under development, will be published in a later EPRI report.

EPRI Perspective

Regardless of manufacturer, EPRI's DS program has uncovered the types of engine faults and performance issues that are expected during early operation of advanced gas turbines. Undetected operational problems can lead to lower-than-expected turbine fleet reliability and availability. By providing manufacturers and power producers with detailed information on such problems now, the DS program can help avoid costly downtime and repeated problems in subsequent installations of a given model.

The DS studies support the broader objective of assisting power generators making combustion turbine (CT) technology selection decisions with risk assessments, early field experience, and fleet reliability data. Other related reports include *Performance of Siemens V84.3A Combustion Turbine: Peaking Service Experience at Kansas City Power and Light Hawthorn Station* (TR-113986*), Gas Turbine Design Evolution and Risk* (TR-114081), and *Technology Risk Assessment in CT-based Power Plants* (TR-113988). In addition, the SOAPP CT Workstation provides rapid, virtual plant design and costing to support proposal preparation and evaluation.

TR-113978

Keywords

Combustion turbines
Durability surveillance
Project risk

EXECUTIVE SUMMARY

The ABB GT24 is an advanced-design machine that employs sequential combustion (reheat), a 30:1 pressure ratio, and high rotor inlet (or firing) temperature of approximately 2250°F (1232°C) at the high-pressure (HP) turbine, enabling the unit to achieve a simple-cycle efficiency of about 38% (LHV). Because most superalloys begin to melt at about 2200°F (1204°C), hot gas components (including turbine blades) must be cooled to maintain temperatures well below this level. As a result, the blades in the single-stage HP turbine and the first and second stage of the low-pressure (LP) four stage turbine are air cooled to ensure survival at these harsh conditions.

As a host unit for EPRI's durability surveillance (DS) program, the ABB GT24, located at GPU Genco's Gilbert Station, was instrumented with the following monitoring and diagnostic systems:

- Blade temperature monitoring system (BTMS) with data evaluations and display system (DEDS)
- Efficiency-MAP™ performance data collection and analysis software
- Vibration monitoring system

Installation

The GT24 was installed at Gilbert Station in mid-1995. It was subsequently selected by EPRI for durability surveillance, including on-line monitoring and periodic hot-gas-path component inspection. The unit was brought on line for site commissioning tests with natural gas in September 1995, and with fuel oil in October 1996.

Fired Hours and Number of Starts from Startup to September 1999

	Startup to December 1997	Startup to May 1998	Startup to September 1998	Startup to August 99
Fired Hours: Natural Gas	994 Hours	1096 Hours	1464 Hours	1831 Hours
Fired Hours: Liquid Fuel	195 Hours	219 Hours	219 Hours	219 Hours
Number of Starts: Natural Gas	207	227	271	322
Number of Starts: Liquid Fuel	40	44	44	44
Total Fired Hours	1189	1315	1683	2050
Total Starts	247	271	315	366

The ABB GT24 at Gilbert Station had a rather lengthy commissioning period, primarily due to extensive field testing conducted at the site. Because the GT24 at Gilbert Station represented the fleet-leading unit for the 60 Hz model and ABB did not perform a factory test at Baden, Switzerland, field testing at the site was performed instead.

As noted, testing of Gilbert Station's ABB GT24 began on September 12, 1995, with the first motor roll, and the first fire occurred on natural gas on September 16, 1995. The order of subsequent tests followed the turbine's startup and commissioning procedure from standstill to full load: igniting the EV combustor on pilot gas, running up to idle speed, synchronizing, increasing load to about 21%, switching to premix gas, running up in load to approximately 25% by increasing turbine inlet temperature (EV combustor fuel input), igniting the SEV combustor, and increasing load to 100% by increasing turbine inlet (SEV fuel input) and inlet guide vane settings.

Compressor mapping runs were conducted at idle speed, while varying inlet guide vane position and rotational speed. Although not at load, aerodynamic conditions varied and a good calibration and indication of design calculations was obtained. Instruments measured a slightly higher inlet mass flow than predicted at lower aerodynamic speeds (which simulate warmer ambient conditions). Under higher aerodynamic speeds, instruments measured a slightly lower mass flow than expected. This behavior was confirmed by full load testing at different ambient temperatures.

Before the January 1996 outage, the SEV combustor was fired for the first time. The combustion was not optimal, due to the uneven circumferential temperature distribution at the SEV inlet resulting from the EV combustor. However, testing after the outage showed marked improvement, and the gas turbine and SEV both ran as expected. The ignition of the SEV was done first with minimum fuel flow; and it went so smoothly that gas turbine full-load was reached three runs later. Emissions measured at full load were less than 25 ppm NO_x (dry basis) at 15% excess O_2, less than 10 ppm CO_2, and less than 1 ppm of volatile organic compounds. Part-load emissions were also met within guaranteed limits, with further optimization ongoing to minimize emissions.

Once the gas turbine was at full load, measurements were made to assess performance. The turbine reached 169 MW with 37.4% efficiency (LHV) at slightly reduced turbine inlet temperatures. Performance and emission measurements indicated that Gilbert Station's ABB GT24 performed better than expected on output, slightly below expectations for efficiency, but with a substantial margin over the values required for the provisional acceptance certificate. Efficiency is expected to meet expectations when operating without prototype instrumentation.

Results and Conclusions

Project results and conclusions focus primarily on turbine blade temperature, baseline performance and performance degradation.

Turbine Blade Temperature

Pyrometer readings recorded by BTMS equipment provide a "thermal fingerprint" or "blade thermal signature" (sometimes referred to as a "blade scan" or "pyrometer trace"), which show the blade temperature as the blade crosses the pyrometer's line of sight.

This report provides turbine rotating blade surface temperature scans from two pyrometers installed on the ABB GT24 at Gilbert Station (pyrometers installed in the second and third stage of the turbine correlate to the first and second stage LP turbine blades, respectively. The ABB GT24 has a one-stage HP turbine that does not have a pyrometer installed**)**. The readings from the pyrometer system (see Chapter 7) provide data on average blade peak temperatures (ABPT) and blade thermal signatures for the first and second stages of the LP turbine rotating blades.

A baseline was developed from blade scans taken on December 16, 1997, for natural gas and on December 18, 1997, for fuel oil to predict future performance and provide a reference for maintenance activities.

The typical ABPT, as measured by the optical pyrometers, range from 1590°F (866°C) to 1600°F (871°C) for the second-stage blades (LP first stage), and 1540°F (838°C) to 1560°F (848°C) for the third-stage blades (LP second stage), at comparable operating conditions.

Baseline Performance

The Efficiency-MAP data taken from December 1996 to September 1997 were considered to be startup and initial test data, and were not used to develop the turbine baseline characteristics. Performance data collected from December 1997 and during the summer peaking season from July 27, 1998, to early September 1998 were analyzed and used to establish the gas turbine performance baseline.

Turbine operational data from September 1998 to August 1999 was compared to the baseline data to evaluate the gas turbine degradation.

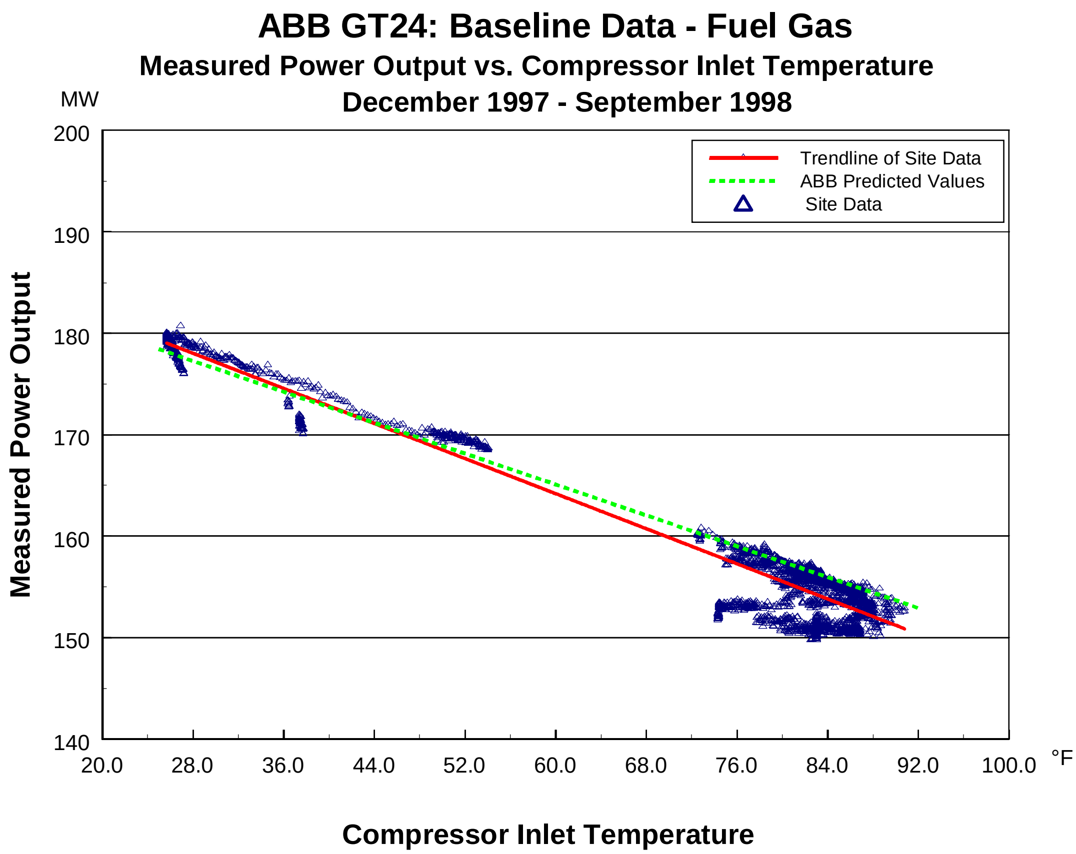

Figure 1
Baseline - Measured Power Output vs. Compressor Inlet Temperature

Figure 1 shows the measured power output as a function of compressor inlet temperature (CIT) for data taken from December 1997 to September 1998. Because the turbine is used as a peaking unit, it did not operate during periods when ambient temperatures ranged from 55°–70°F (13°–21°C) and the curve shows no data for these CITs. The trendline appears linear, as illustrated by the curve fit, even though there was data missing over a range of temperatures. The design power output values given by ABB engineers are superimposed over actual values reported by EPRI and show good overlap, although some divergence from the design values is evident at the high and low extremes of the temperature range. The ABB value for Gilbert's power output, corrected to ISO conditions is 165.5 MW.

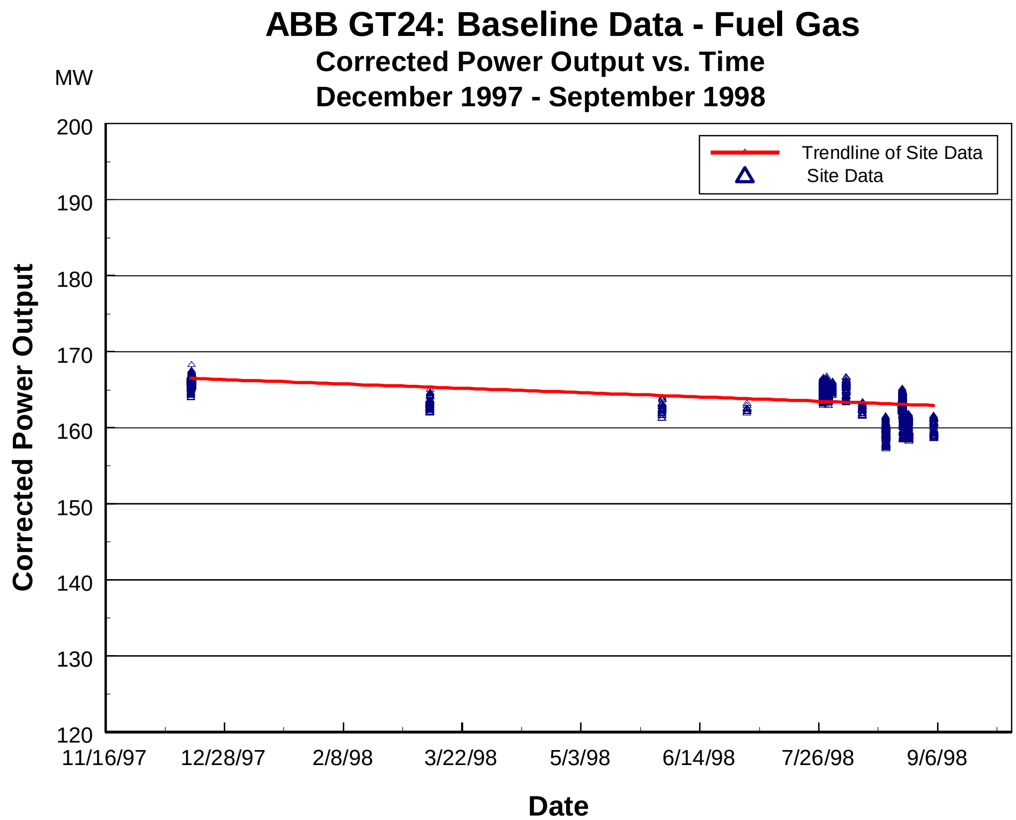

Figure 2
Baseline - Corrected Power Output vs. Time

The power output data were corrected for compressor inlet temperature (CIT) using the ABB correction curves. As shown in Figure 2, the corrected output at the start of the baseline is approximately 167 MW and decreases to 165 MW at the end of the baseline period.

The ABB value for Gilbert's power output corrected to ISO conditions is 165.5 MW. Baseline data corrected to ISO conditions as shown above is very close to the ABB- design value. This confirms the validity of the ABB correction curves and validates data taken from December 1997 to September 1998 as baseline performance data.

Operating Data – Power Output

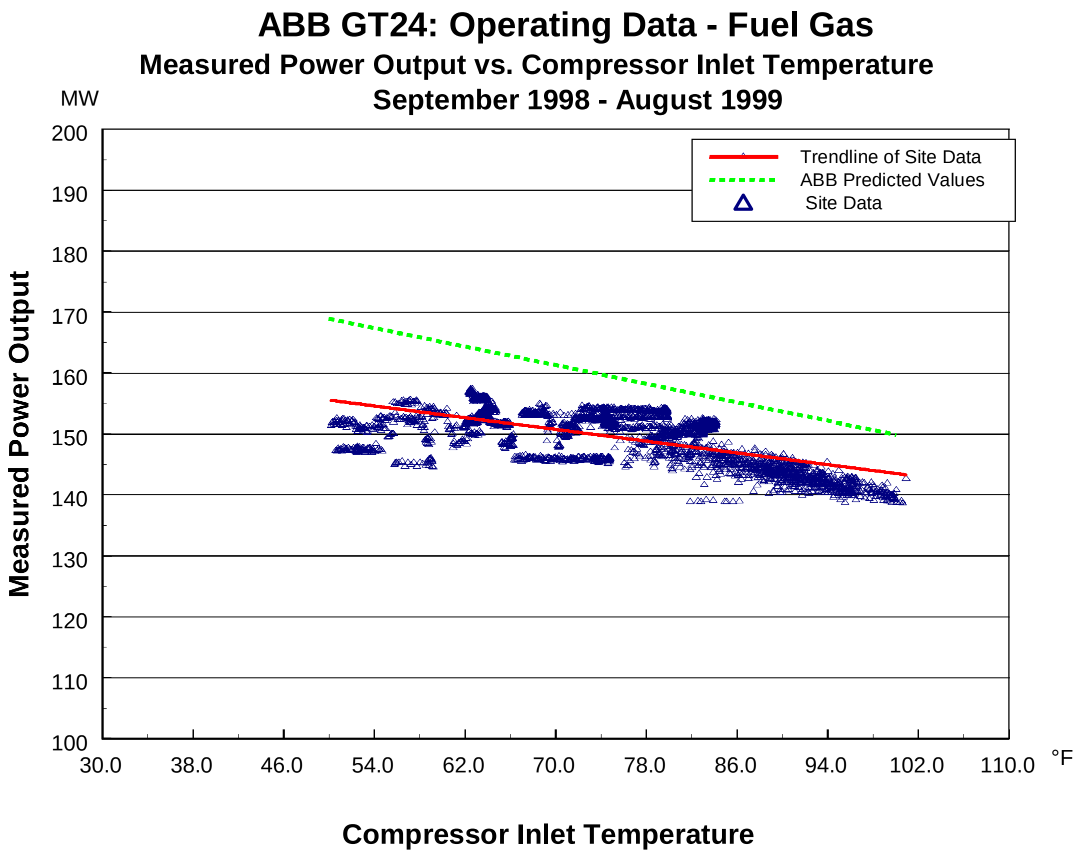

Figure 3
Operating Data Measured Power Output vs. Compressor Inlet Temperature

Figure 3 plots the measured power output (MW) from September 1998 to August 1999 as a function of compressor inlet temperature (CIT).

Power trended is below ABB predicted values.

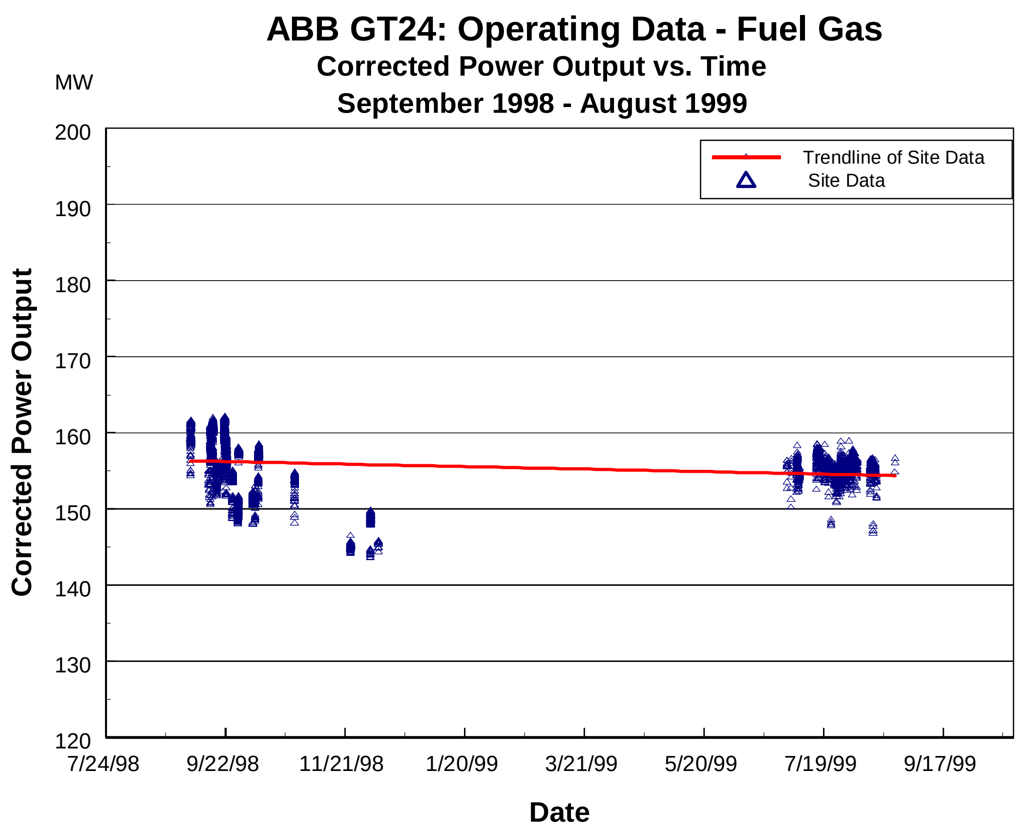

Figure 4
Operating Data Corrected Power Output vs. Time

Figure 4 shows the power output (MW), corrected for compressor inlet temperature (CIT), using the ABB correction curves.

Performance Degradation

As of early September 1998, the ABB GT24 at Gilbert Station had accumulated a total of 1683 firing hours with 315 starts on gas and oil. Because the turbine primarily operates during the summer and winter seasons to meet peak power demands, it does not accumulate many running hours over the course of a year. Therefore, performance data taken from December 1997 to June 1998 were included with data taken through early September 1998 to establish an accurate baseline for determining performance degradation.

An accurate degradation signature for this gas turbine cannot be established until the turbine accumulates additional running hours. In reviewing the baseline data for corrected power output vs. time, a slight degradation in the magnitude of 1%, or less than 2 MW, can be detected (see Figure 5).

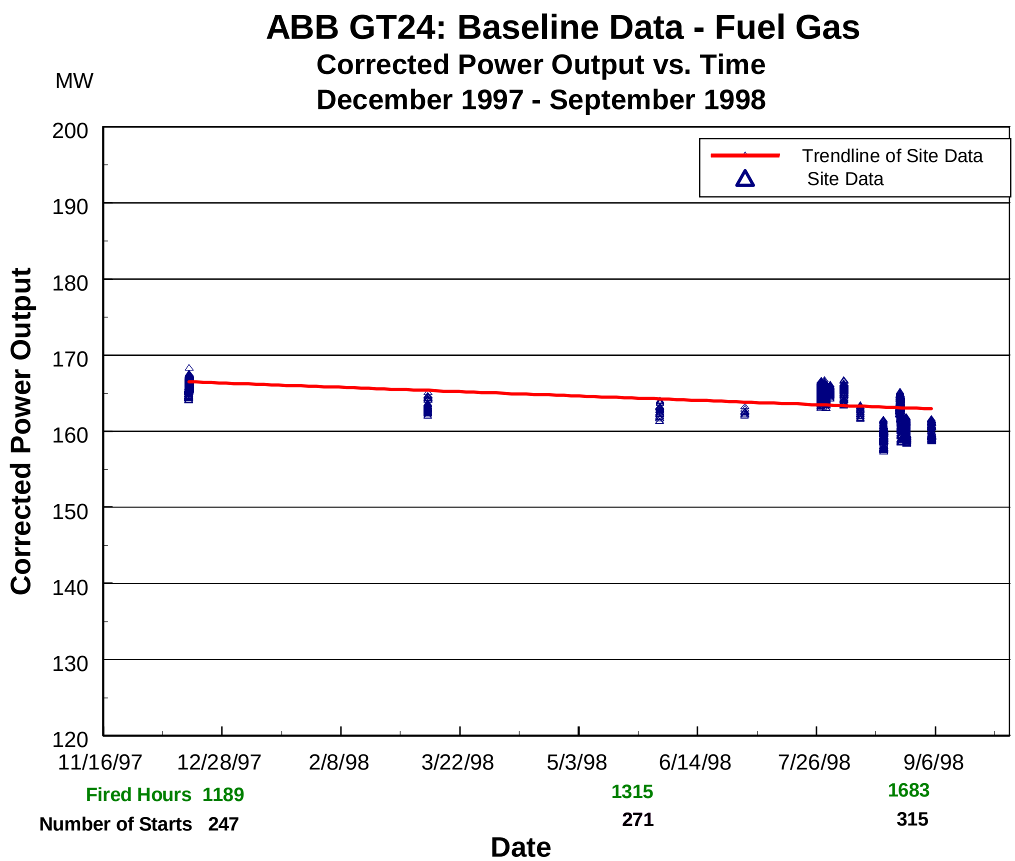

Figure 5
Degradation - Corrected Power Output vs. Time

In reviewing the data from September 1998 to August 1999 for corrected power output vs. time, a small degradation in the magnitude of 3 MW can be detected (see Figure 6). Note that the gas turbine is operating approximately 10 MW below the baseline

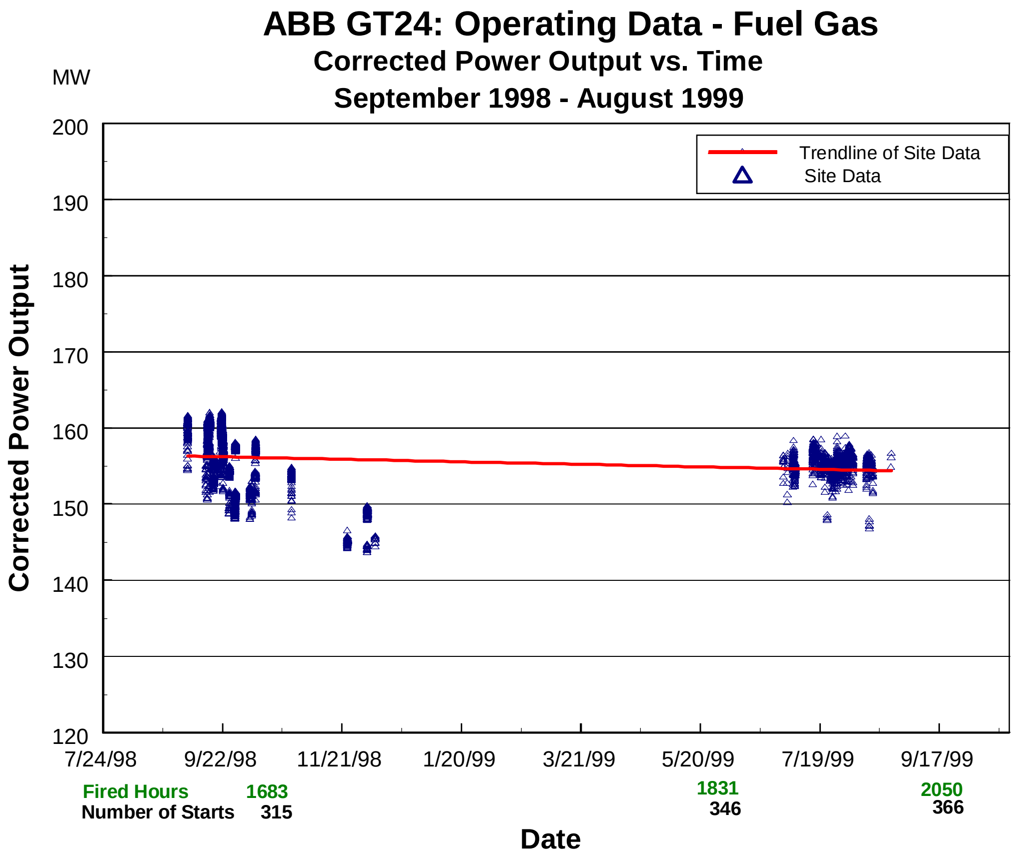

Figure 6
Degradation Corrected Power Output vs. Time

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1 INTRODUCTION

EPRI, in alliance with utilities and major gas turbine manufacturers, initiated the Durability Surveillance (DS) program in 1991 for monitoring advanced gas turbines. The program objective is to subject early production, advanced technology industrial gas turbines to intense field surveillance in an effort to uncover potential problems or deficiencies, enabling the manufacturer to take corrective action that will result in a more durable and efficient fleet.

An additional objective is to establish benchmarks for output, heat rate, availability, mechanical characteristics, maintenance costs, and component life for these new machines. This information will help power producers specify, operate, and maintain advanced gas turbines in simple- and combined-cycle applications. Advanced gas turbine units monitored under the EPRI DS program include engines from ABB, GE, and Siemens.

This report focuses on the durability surveillance findings for the ABB GT24 at GPU Genco's Gilbert Station. Report information is based on data collected by EPRI's data acquisition system (DAS) from the time of turbine startup in 1995 to September 1998.

The unit's baseline performance was established with data taken from December 1997 to September 1998. Over that time, the ambient temperature varied from 25°F to 90°F (-4°C to 32°C), and this spread enabled temperature correction curves to be developed for several performance variables. As indicated by the baseline curves, performance remained constant during this period.

Overview of EPRI Systems

Following are brief descriptions of each EPRI system used to monitor the ABB GT24 gas turbine. A system block diagram illustrating the EPRI durability surveillance monitoring and analysis systems at Gilbert Station is shown in Figure 1-1. The location of the pyrometers and other key monitoring systems are shown in Figure 1-2.

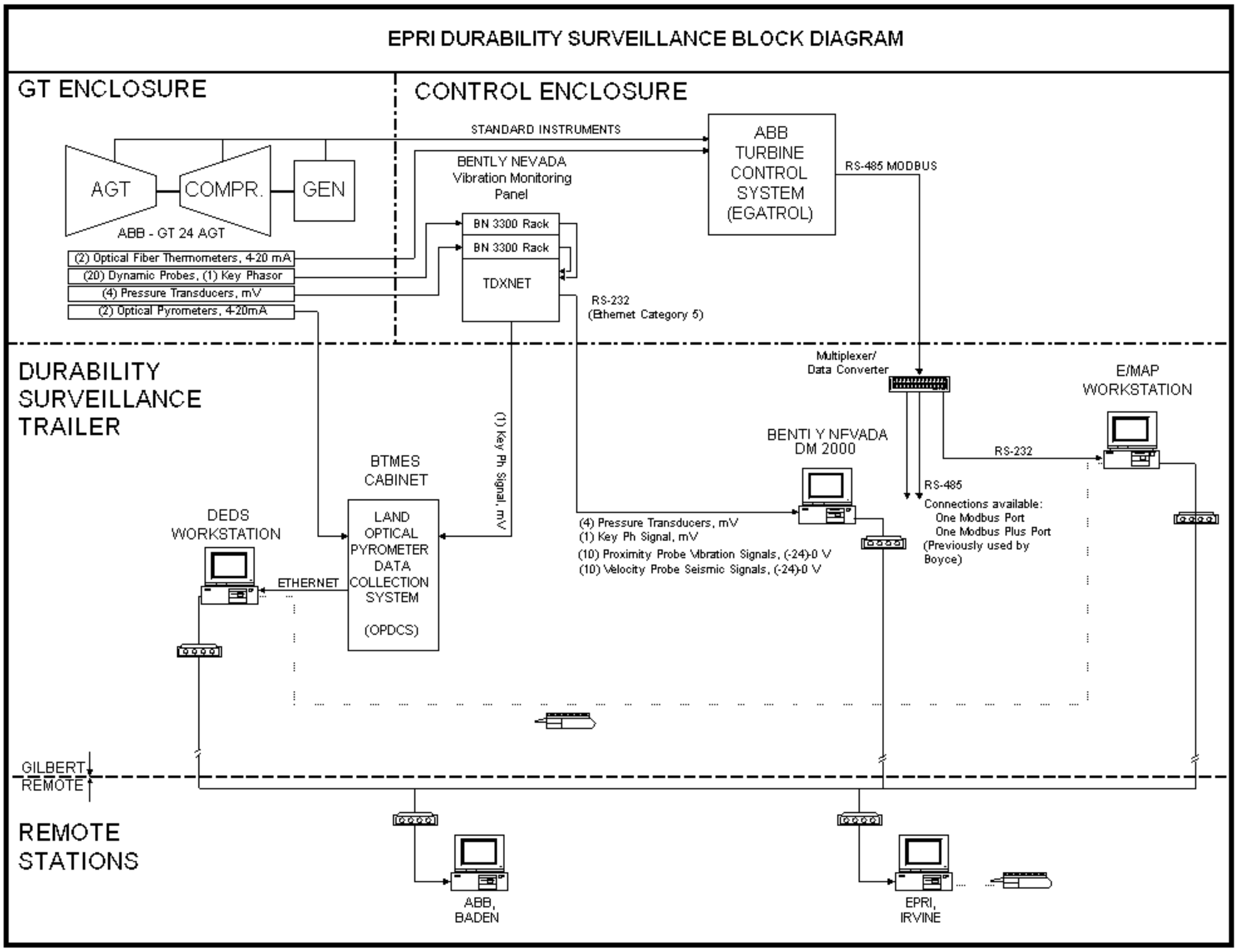

Figure 1-1
EPRI Durability Surveillance Monitoring and Analysis Systems

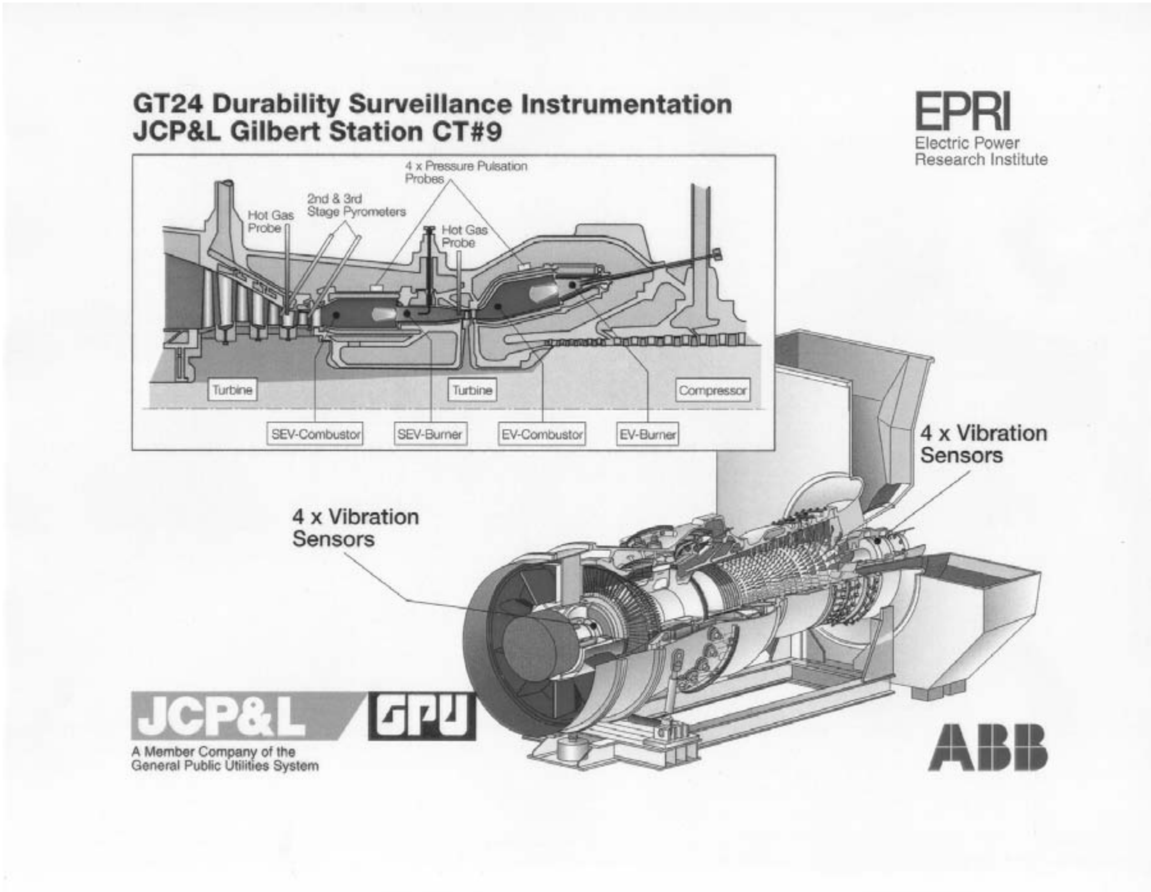

Figure 1-2
Location of Pyrometers and Other Key Monitoring Systems

Optical Pyrometer – Blade Temperature Monitoring System (BTMS)

The optical pyrometer system at Gilbert Station is responsible for collecting, monitoring, and evaluating temperature data on the second and third stage turbine blades (the second and third stage pyrometers correlate to the first and second stage LP turbine blades, respectively). The ABB GT24 has a one-stage HP turbine that does not have a pyrometer installed. Two optical pyrometers, designed by Land Infrared, Inc., are installed in these stages with the pyrometers in the forward view.

These pyrometers detect thermal radiation emitted by the blade surface and convert it to a 4-20 ma high frequency signal, which is sent to the blade temperature monitoring system (BTMS) for processing. The signal contains 30 to 40 temperature samples, taken uniformly along the blade surface for each blade. High-speed signal processing electronics extract the individual temperature samples and correlate them with the calibrated temperature range. A temperature "profile" can be displayed for visual interpretation. The acquisition system gathers about 3000 turbine blade temperature readings at five minute intervals throughout the day. Figure 1-3 depicts schematically the pyrometer system.

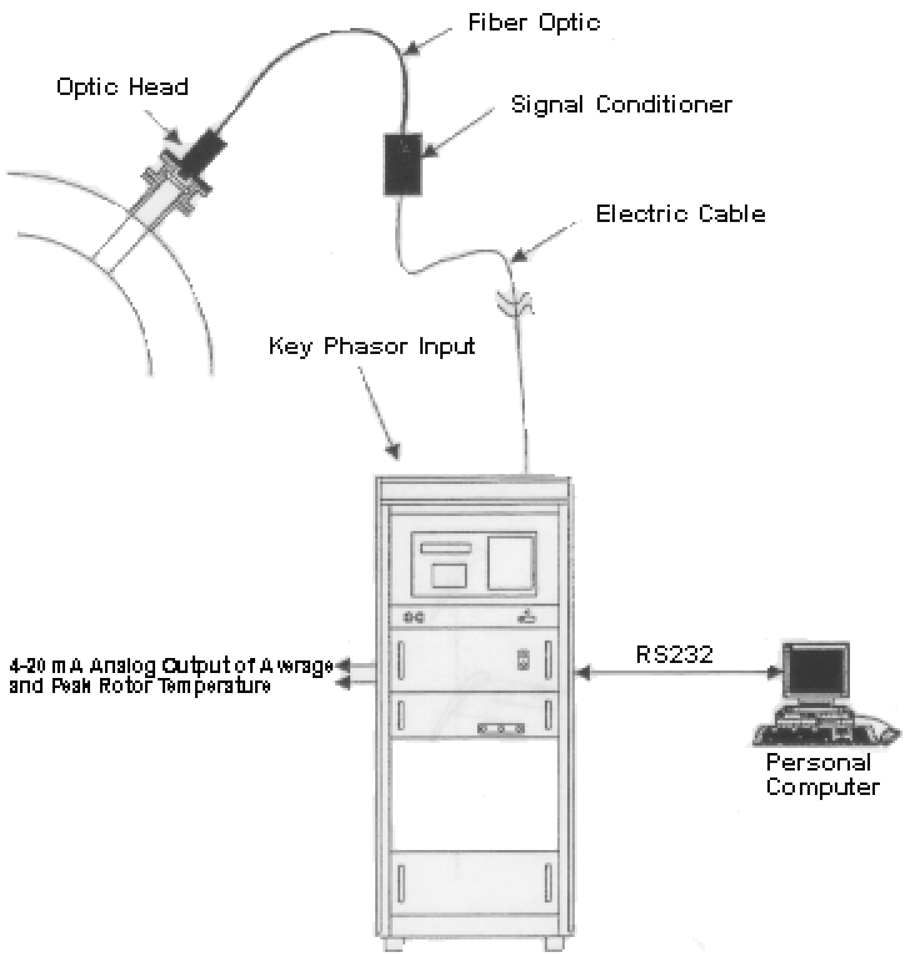

Figure 1-3
BTMS Schematic Diagram

Vibration Monitoring System

The vibration monitoring system, supplied by Bently Nevada, is a stand-alone, advanced, flexible data acquisition and display package. Vibration data at Gilbert Station are collected using Bently Nevada 3300 series monitoring equipment. A communication processor (TDXnet) is used to transmit data to the data acquisition station via standard Ethernet connection. The data acquisition station consists of a Pentium computer with Windows NT.

The data acquisition software is capable of acquiring data from up to twelve Bently Nevada communication processors and can collect process data via NetDDE. In addition, the data acquisition software is capable of collecting startup and shutdown data based on input from the Keyphasor®.

Data collected from communication processors or NetDDE can be viewed using Data Manager® 2000 display software, which allows users to display machinery data in a user-definable manner (i.e., plots, lists, and reports).

Efficiency-MAP™

Efficiency-MAP™ performs detailed steady-state design and non-ISO heat balances of gas turbine power systems. Analysis tasks include:

- Overall cycle balance of the ABB GT 24 to generate information on operating performance at major points throughout the compressor-turbine cycle, including overall cycle efficiency
- Simulating performance of the gas turbine cycle at part-load operating conditions, which aids the operator in "fine tuning" to boost performance
- Predicting the effects of proposed changes or enhancements to the gas turbine cycle

The Efficiency-MAP™ workstation receives its inputs via serial connection with the ABB Egatrol turbine control system. Efficiency-MAP™ initially collects data on all major components of the gas turbine to establish a baseline model of the "entire" gas turbine cycle, which shows the energy and flow balances throughout the cycle. Reports can be analyzed and compared with the baseline condition to get an accurate picture of the state of the gas turbine and to gauge degradation over time. "What-if" scenarios can be simulated to determine what measures could be taken to improve the turbine's performance.

Measurement Units

Both English units and SI units (in parenthesis) are used throughout this document. Table 1-1 lists conversion factors.

Table 1-1
Unit Conversions

Measure	English Units	SI Units	Conversion
Length	Foot	Meter	1 ft = 0.304 m
Area	square foot	Square Meter	1 ft^2 = 0.092 m^2
Volume	Cubic foot	Cubic Meter	1 ft^3 = 0.028 m^3
	U.S. gallon	Liter	1 gal = 3.785 L
Temperature	° Fahrenheit (°F)	° Celsius (°C)	°F = (°C*9/5)+32°
	° Fahrenheit (°F)	° Celsius (°C)	Δ°F = Δ°C*9/5
Torque	ft-lb	N-m	1 ft-lb = 1.355 N-m
Energy (Work)	ft-lb	J	1 ft-lb = 1.355 J
Energy (Heat)	Btu	kJ	1 Btu = 1.055 kJ
Energy (Electricity)	kWh	kJ	1 kWh = 3600 kJ
Pressure	psi	kPa	1 psi = 6.894 kPa
	Bar	kPa	1 Bar = 100 kPa
Power	hp	kW	1 hp = 0.745 kW
Heat Rate	Btu/kWh	kJ/kWh	1 Btu/kWh = 1.0548 kJ/kWh

2
ABB GT24 TURBINE DESIGN FEATURES

Characteristics of Advanced Industrial Gas Turbines

In the past, turbine advancements were incremental, with new units being little more than uprated versions of existing designs. In contrast, today's gas turbines rely heavily on an assortment of cutting-edge technologies.

Materials and manufacturing advancements have led to higher-strength alloys, advanced coatings, and higher quality components. Turbine design has improved significantly as well—a result of powerful computational tools that have led to more accurate aerodynamic, fluid flow, heat transfer, structural, and dynamic analyses. In addition, enhanced cooling techniques for hot-gas-path components have been incorporated into new designs, enabling firing temperatures to reach 2300°F (1260°C) and higher. Other key advancements include improved combustor designs that have significantly reduced NO_x emissions associated with the higher firing temperatures.

ABB GT24

The GT24 represents the first commercial application of the thermodynamic principle of reheat. Its sequential combustion system features two stages of annular combustors—an innovative, yet proven, ABB technology. This unique design results in higher simple- and combined-cycle efficiencies for a given turbine inlet temperature.

Because the GT24 has a single-stage high-pressure (HP) turbine and a four-stage low-pressure (LP) turbine, the following nomenclature is used throughout this report when referring to various turbine stages:

- 1st overall stage of turbine blades - 1st stage HP turbine blades
- 2nd overall stage of turbine blades - 1st stage LP turbine blades
- 3rd overall stage of turbine blades - 2nd stage LP turbine blades

Sequential combustion in the GT24 initiates in the first (EV) combustor using ABB's "vortex breakdown technology". After expansion in the turbine's HP stage, the gases undergo an additional mixing/ignition cycle in the second (SEV) combustor, and are expanded in the remaining four LP turbine stages.

The GT24 employs a high pressure ratio (PR = 30) compressor to support this sequential combustion system, which enables it to achieve a simple-cycle efficiency of 38.3% (LHV). The sequential combustors limit NO_x to 25 ppmvd (for natural gas) without water or steam injection.

Another key feature of the GT24 is the use of advanced cooling techniques. Because it uses a rotor inlet (firing) temperature of approximately 2250°F (1232°C), turbine blades are exposed to temperatures well above their operating limit. Most superalloys begin to melt at about 2200°F (1204°C), mandating that hot gas components (including turbine blades) be cooled. Accordingly, the single-stage HP turbine and the first stage of the LP turbine employ advanced air cooling.

Other key design features of the GT24 include:

- two bearing, single-shaft construction
- cold-end-driven generator
- axial exhaust
- monolithic rotor, welded from forged disks
- 22-stage subsonic axial compressor (PR=30:1), utilizing controlled-diffusion airfoil (CDA) blade design
- three rows of variable guide vanes
- compact annular combustor design for the 30 EV burners and the 24 SEV burners
- single-stage HP turbine, with cooled blade and vane rows
- four-stage LP turbine, with the first stage air cooled, and blade rows 2-4 shrouded
- horizontal split casing

Table 2-1 lists key performance data for the GT24 and GT26.

Table 2-1
ABB GT24 (60 Hz) and GT26 (50 Hz) Performance Data

Characteristics	GT24 (60 Hz)	GT26 (50 Hz)
Baseload output, MW	185	270
Heat rate, Btu/kWh (LHV) Heat rate, (kJ/kWh)	8915 (9405)	8867 (9355)
Efficiency, % (LHV)	38.3	38.5
Mass flow rate, lb/sec Mass flow rate, (kg/sec)	864 (392)	1243 (564)
Exhaust temperature, °F Exhaust temperature, (°C)	1190 (643)	1190 (643)
Combustor system	EV Low NO_x SEV	EV Low NO_x SEV
Number of combustors	2 (30, 24 burners)	2 (30, 24 burners)

Notes:

1. *Data reflect ISO conditions.*
2. *Rated values are for machines fired with natural gas.*

Figures 2-1 and 2-2 depict some of the advanced operating concepts of the GT24 engine and combustor. Figure 2-3 shows an external view of a GT24 turbine.

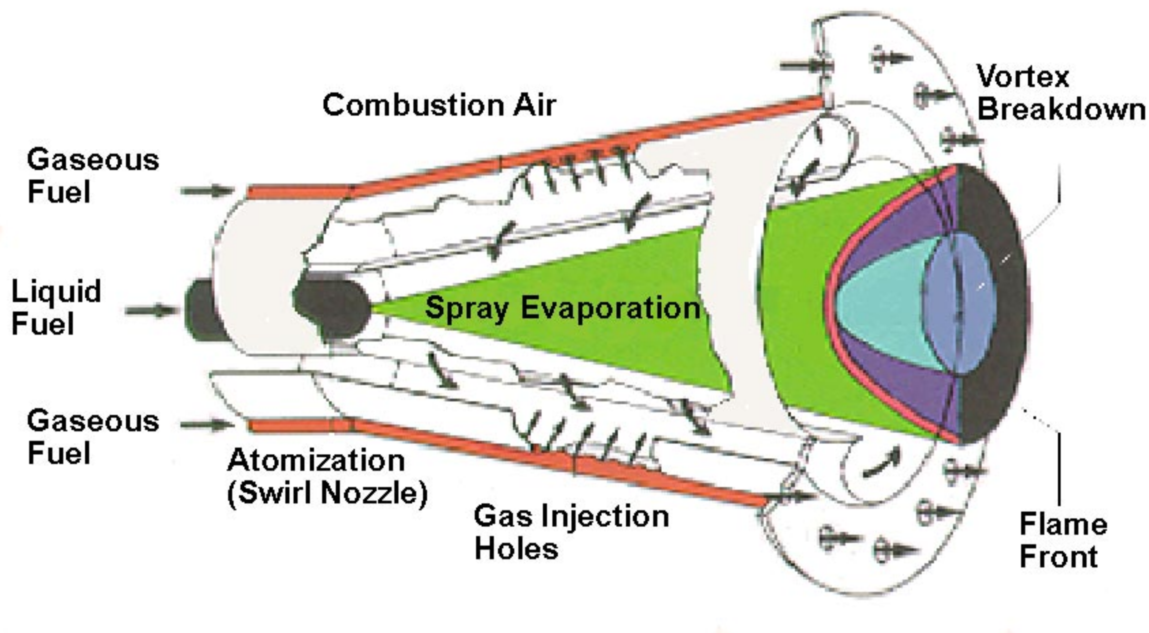

Figure 2-1
ABB EV Burner Design: Dual Fuel, Double Cone Burner

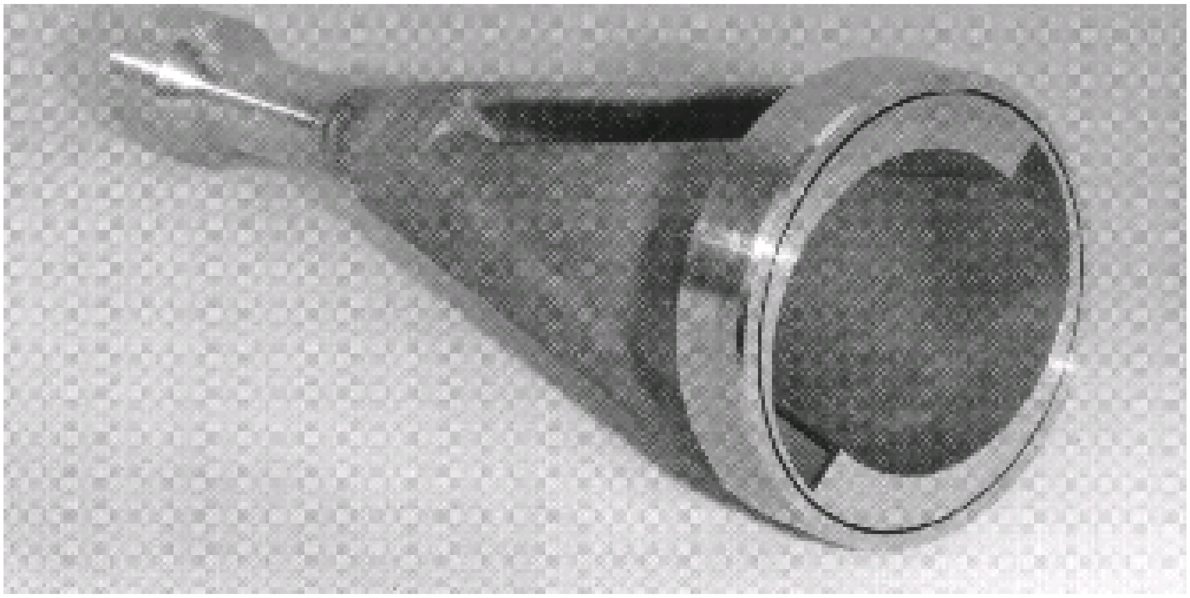

Figure 2-2
The EV Burner

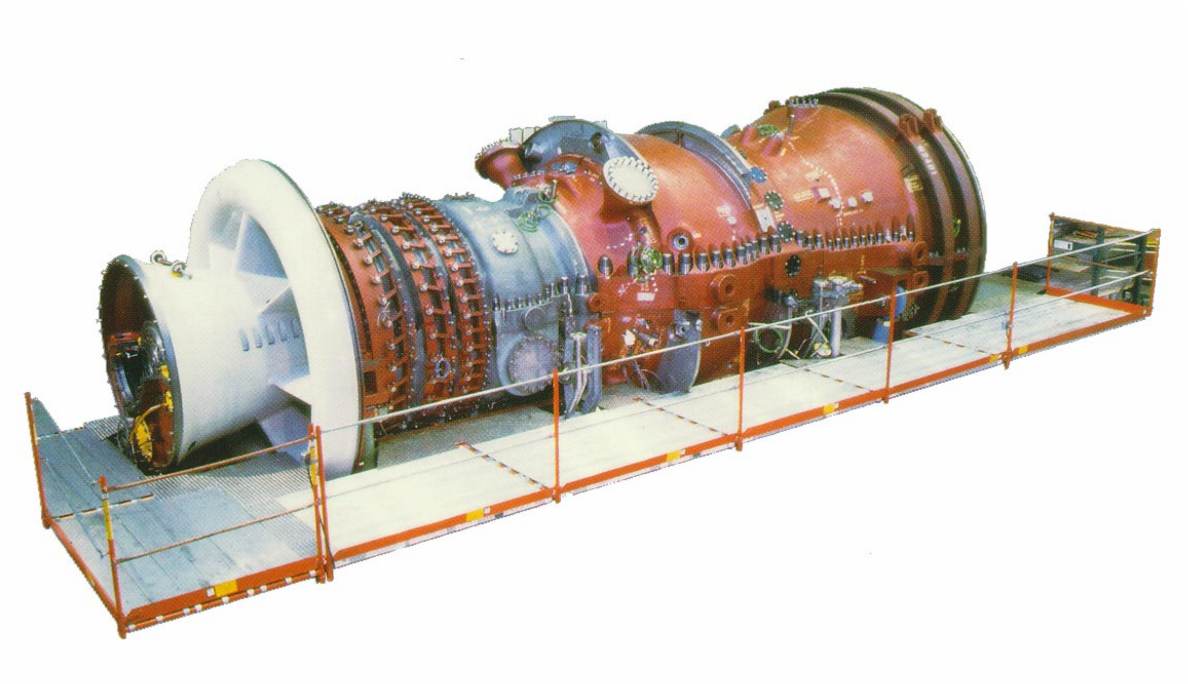

Figure 2-3
ABB GT24 Advanced Industrial Gas Turbine

3
ABB GT24 AND GT26 FLEET HISTORY

Technology advancements have led to unprecedented performance for today’s gas turbines. But questions and concerns arise when considering these turbines for traditional utility peaking or cycling applications. Power producers worldwide are closely watching cutting-edge units such as ABB’s GT24. Several of these units have now been shipped and installed, and are accumulating service hours. Others are on order or are in the installation and commissioning process.

In an environment of regulatory uncertainty, planners and developers perceive near-term opportunities for high-efficiency power plants, and are trying to position themselves to take advantage of these opportunities. Yet reports of design problems and extended commissioning periods are forcing many to step back and reevaluate the situation.

Typical concerns include:

- Have the advertised advantages been realized?
- What surprises have occurred?
- What problems are apparent?
- What is the status of manufacturer problem resolution?
- What are the projections for life-cycle cost?
- How many units are actually running?
- How many service hours have been accumulated?
- Has the market fully accepted these units?

This report provides a starting point for answering these and other questions. Obviously, some questions will take a long time to answer fully, but an accurate summary of the current findings should help those who must make decisions in the short term.

Advertised Advantages

The primary attraction of advanced gas turbines lies primarily in their higher thermal efficiency. Higher efficiency translates to lower fuel consumption, and fuel is by far the largest single cost element in a plant’s operation and maintenance expenditures. If advertised efficiency gains are not realized in the field, then the economic advantages of advanced technology gas turbines drop off sharply.

During project team discussions with plant personnel, no complaints regarding output or efficiency for the GT24 were voiced.

Surprises

As with any new technology, surprises were expected. Plant personnel knew that these high-efficiency gas turbines were pushing the technical envelope, and they recognized some inherent level of risk. Therefore, when technical issues arose, they were prepared to deal with them constructively. This approach led to strong team work between ABB and GPU.

Some personnel were surprised, however, by the length of the commissioning cycles. Significant variability was apparent, and some cycles were commendably short. The commissioning cycle extends to full commercial acceptance, not just first-fire, synchronization, and full-load operation, and includes extended testing phases for through understanding of the machine. Most of the longer commissioning periods included test phases in which several parameter variations were made. Other machines in the fleet have been commissioned within three months.

Technical Problems—General Fleet

Although it was not observed at Gilbert Station, users of some other GT24 units have reported compressor blade distress in the form of cracking. ABB launched a changeout campaign, resulting in several outages. Sites also reported that starting reliability was an issue. Sites logged numerous failures to start, but in many cases the causes of the starting failures were not known. Sites were sometimes unwilling to discuss technical issues and directed us to ABB for information. Some sites refused to offer any information at all.

Problem Resolution

Sites that provided information for this introductory snapshot indicated they were satisfied with the manufacturer's efforts to resolve the technical issues. They credited ABB with a high level of attention to the problems and with a high level of effort regarding problem resolution.

Life-Cycle Costs

It is far too early to offer any judgment with respect to the life cycle costs of the GT24 and GT26 turbines. As a class, these units have accumulated very few service hours. Most, if not all, of the units are still under the manufacturer's warranty umbrella. At this stage of maturity, life cycle-cost projections cannot be validated.

Because components for high-efficiency turbines can be very expensive, any abbreviation of life can have serious consequences in higher life-cycle costs.

Most of the technical problems observed to date have been addressed, and the power producers interviewed generally felt that the manufacturer will be successful in resolving these issues. Respondents believed that monitoring efforts such as the EPRI durability surveillance program will provide the best insight into life-cycle cost expectations.

Running Units

As of September 1999, very few GT24 or GT26 units have actually seen service. Figure 3-1 shows the operating experience for GT24. Figure 3-2 shows the operating experience for GT26.

GT24 - Operating Experience **Status: June-99**

Plant	*Customer*	*Coun-try*	*Fuel*	*First Ignition*	*No. Starts*	*Fired Hours*
Gilbert	JCP&L	US	NG, Oil	Sep-95	346	1'831
Poryong GT11	KEPCO	KR	NG, Oil	May-97	130	664
Poryong GT12	KEPCO	KR	NG, Oil	Jun-97	121	612
Poryong GT21	KEPCO	KR	NG, Oil	Jun-97	146	594
Poryong GT22	KEPCO	KR	NG, Oil	Jul-97	117	581
Poryong GT31	KEPCO	KR	NG, Oil	Jul-97	57	310
Poryong GT32	KEPCO	KR	NG, Oil	Jul-97	48	295
Poryong GT41	KEPCO	KR	NG, Oil	Oct-98	38	228
Poryong GT42	KEPCO	KR	NG, Oil	Nov-98	46	261
Total					**1'049**	**5'376**

ABB Power Generation
PGTM: Gregor Gnädig 10/2/99

ABB

Figure 3-1
GT24 Operating Experience

GT26 - Operating Experience

Status: June-99

Plant	Customer	Coun-try	Fuel	First Ignition	No. Starts	Fired Hours
BIRR	ABB	CH	NG, Oil	Nov-96	149	400
RDK4	Badenwerk	DE	NG, Oil	Sep-97	222	2'142
ROCKSAVAGE-A	Intergen	UK	NG	Oct-97	139	7'237
ROCKSAVAGE-B	Intergen	UK	NG	Nov-97	148	7'233
TARANAKI	Transalta	NZ	NG	Feb-98	115	7'192
Total					**773**	**24'204**

ABB Power Generation

PGTM: Gregor Gnädig 10/2/99

Figure 3-2
GT26 Operating Experience

4
OPERATING HISTORY OF THE ABB GT24 AT GILBERT STATION

Commissioning History at Gilbert Station

The following chronology summarizes the ABB GT 24 installation milestones and commissioning cycle at Gilbert Station:

September 1995	Gas turbine generator erection
September 16, 1995	Natural gas firing
October 23, 1995	Synchronization
November 15, 1995	Second combustor (SEV) ignited for first time
December 1995 to March 1996	Outage
May 21, 1996	Unit reached full load for first time
June 20, 1996	Provisional acceptance and commercial dispatch
October 1996	Fuel oil firing
November 1996 to March 1997	Outage
June 10, 1997	Natural gas field testing
December 20, 1997	Performance acceptance

Fired Hours and Number of Starts from Startup to June 99

	Startup to December 1997	Startup to May 1998	Startup to September 1998	Startup to August 99
Fired Hours: Natural Gas	994 Hours	1096 Hours	1464 Hours	1831 Hours
Fired Hours: Liquid Fuel	195 Hours	219 Hours	219 Hours	219 Hours
Number of Starts: Natural Gas	207	227	271	322
Number of Starts: Liquid Fuel	40	44	44	44
Total Fired Hours	1189	1315	1683	2050
Total Starts	247	271	315	366

The ABB GT24 at Gilbert Station had a rather lengthy commissioning period, primarily due to extensive field testing conducted at the site. Because the GT24 at Gilbert Station represented the fleet-leading unit for the 60 Hz model and ABB did not perform a factory test at Baden, Switzerland, field testing at the site was performed instead.

As noted, testing of Gilbert Station's ABB GT24 began on September 12, 1995, with the first motor roll, and the first fire occurred on natural gas on September 16, 1995. The order of subsequent tests followed the turbine's startup and commissioning procedure from standstill to full load: igniting the EV combustor on pilot gas, running up to idle speed, synchronizing, increasing load to about 21%, switching to premix gas, running up in load to approximately 25% by increasing turbine inlet temperature (EV combustor fuel input), igniting the SEV combustor, and increasing load to 100% by increasing turbine inlet (SEV fuel input) and inlet guide vane settings.

Compressor mapping runs were conducted at idle speed, while varying inlet guide vane position and rotational speed. Although not at load, aerodynamic conditions varied and a good calibration and indication of design calculations was obtained. Instruments measured a slightly higher inlet mass flow than predicted at lower aerodynamic speeds (which simulate warmer ambient conditions). Under higher aerodynamic speeds, instruments measured a slightly lower mass flow than expected. This behavior was confirmed by full load testing at different ambient temperatures.

Before the January 1996 outage, the SEV combustor was fired for the first time. The combustion was not optimal, due to the uneven circumferential temperature distribution at the SEV inlet resulting from the EV combustor. However, testing after the outage showed marked improvement, and the gas turbine and SEV both ran as expected. The ignition of the SEV was done first with minimum fuel flow; and it went so smoothly that gas turbine full load was reached three runs later. Emissions measured at full load were less than 25 ppm NO_x (dry basis) at 15% excess O_2, less than 10 ppm CO_2, and less than 1 ppm of volatile organic compounds. Part-load emissions were also met within guaranteed limits, with further optimization ongoing to minimize emissions.

Once the gas turbine was at full load, measurements were made to assess performance. The turbine reached 169 MW with 37.4% efficiency (LHV) at slightly reduced turbine inlet temperatures. Performance and emission measurements indicated that Gilbert Station's ABB GT24 performed better than expected on output, slightly below expectations for efficiency, but with a substantial margin over the values required for the provisional acceptance certificate. Efficiency is expected to meet expectations when operating without prototype instrumentation.

Technical Problems at Gilbert Station

In the early stages of startup optimization at Gilbert, it was discovered that the embedded acceleration set point and the set point provided by the static frequency converter were mismatched. The control system compensated for this difference by providing more fuel. This caused the first turbine rotor stage to overheat, for less than one minute. Because of limited damage and the ease of inspecting the affected components, testing continued with no further temperature incidents. Acceleration is now temperature-controlled and smooth.

The EV combustor ignited as expected on pilot gas, in a complete annulus and with pulsation below limits. Pulsation and temperature mapping was done to facilitate the switchover from pilot to premix gas. The final setting has a high margin on both pulsation and temperature level. The switchover runs smoothly, within 10 seconds. While running with the EV combustor alone, with both pilot and premix gas, an unexpected circumferential temperature spread of 180°F (100°C) was observed at the high-pressure turbine exit. This led to rig test investigations into fuel pressure losses in the fuel distribution system, burners, and lances—individually by component and in combination. These investigations were conducted on actual engine hardware at ABB facilities in Mannheim, Germany. New, optimized hardware was built and installed in Gilbert Station's GT24 during a January 1996 outage. The combustor fuel flow system and the components were matched for optimal fuel distribution, and an orifice was installed in the piping to the thermal block to ensure upper and lower half symmetry. A component matching procedure for the fuel distribution system is now standard for ABB GT24 and GT26 units.

During the initial startup optimization just after ignition, operators noticed a short phase of rotation stall in the compressor. This led to the addition of a third blow-off stage to the compressor and a subsequent smooth run-up. Further optimization of the original two blow-off stages resulted in a complete three-stage compatible blow-off system. This new blow-off system is also now standard for all ABB GT24 and GT26 units.

5
THERMAL PERFORMANCE MONITORING IN GAS TURBINE POWER PLANTS

Performance Degradation

Long-term gas turbine performance depends on how well individual components maintain their original condition. Unit thermal performance degrades over time, as components in the turbine flow path become fouled, eroded, corroded, and covered with products of combustion—which occurs even when using a good inlet air filtration system and a clean fuel such as natural gas.

The result is a progressive reduction in the ability of the compressor to convert mechanical energy into potential energy of the working fluid, or of the turbine to extract mechanical energy from the working fluid. The mass flow of the working fluid through the engine may also be reduced as a result of component deterioration. Thus, the original gas turbine output and heat rate are not fully retained over time.

Overall turbine performance degradation is defined as either recoverable or non-recoverable. Recoverable performance degradation is caused by fouling and deposits in the compressor and turbine, which can be recovered by washing or cleaning the compressor and turbine. It may still be possible to restore turbine performance lost through non-recoverable degradation with a major overhaul or engine upgrade. During hot-gas-path inspections, the upper shell of the turbine and/or compressor is removed and the turbine flow path is accessible for thorough cleaning and for replacement of worn or defective parts.

The performance lost through true non-recoverable or permanent degradation may be difficult to restore through conventional hot gas path inspection or major inspection**.** An overall gas turbine uprate may be required to restore original performance and will typically result in a performance increase beyond that of the original equipment in new condition.

The following sections provide background on the various mechanisms responsible for performance degradation in gas turbine components.

Degradation—Recoverable by Washing/Cleaning

Even with an excellent air filtration system, the compressor and turbine are still susceptible to accumulation of ingested particulate matter such as dust, pollen, and other impurities. Over a period of time, this leads to significant fouling of the flow path and air filter blockage. Lubricating oil leaks into the compressor, and when heavy hydrocarbons are present in the atmosphere this combination can act like glue, attaching the dust particles to the compressor airfoil and shroud, which exacerbates fouling problems.

Fuel oil also leaves deposits. When heavy oil is burned in a gas turbine, the hot end of the turbine is subjected to deposits originating from the metals contained in the oil or in fuel additives.

The buildup of these materials result in fouling, which changes the inlet angle, increases surface roughness, and decreases the throat opening of the airfoil. Compressor fouling is common. Because as much as half of the power developed in the turbine is consumed by the compressor, the effect on overall performance can be substantial. Accordingly, advanced gas turbines such as the ABB GT24 employ coatings on the compressor airfoil surfaces that keep the blades smoother, reduce the fouling rate, and make cleaning easier.

Thus, fouling of the compressor and turbine flow path surfaces cause varying degrees of individual component performance degradation (such as decreases in the efficiency and gas flow rate), resulting in overall gas turbine output and heat rate degradation. Fouling is the major cause for gas turbine performance deterioration—typically representing 70–80% of the loss.

The compressor surge margin may also be reduced as a consequence of flow path fouling.

The compressor and turbine may, however, be cleaned to remove the deposits by various "washing" techniques, without having to disassemble the engine. Three techniques for washing are described below:

1. **On-Line Dry Cleaning**: This technique introduces abrasive material such as rice husks or pecan shells into the suction of the compressor of the gas turbine. This method has been used in the past on gas turbines with uncooled blades and is not recommended for advanced gas turbines with intricate cooling schemes and channels, which could be plugged by the abrasive materials.

2. **On-Line Wet Cleaning**: Water mixed with a nontoxic and nonflammable detergent is used to wash the compressor. In areas with a high concentration of ambient particulates, methods employing a fine spray of de-mineralized pure water (without detergent) have been successfully used in a daily on-line water wash. This method allows operators to maintain performance with the gas turbine running.

3. **Soak Wash**: This method is employed with the engine shut down and results in the most thorough cleaning of the compressor and the hot-end components.

Degradation—Recoverable from Icing

Another form of recoverable degradation is icing of the air filter or the front end of the compressor. The resulting performance deterioration could be more severe than that associated with fouling, but it is usually temporary unless the compressor is damaged by ice particles breaking loose or by a severe reduction in air flow through the compressor, leading to compressor surge.

Degradation—Non-recoverable by Washing/Cleaning

Deterioration that is non-recoverable by washing or cleaning can be caused by erosion of the blade surfaces by ingested particulate matter or by damage to the compressor and turbine flow path due to corrosion caused by ingestion of substances such as salt and airborne chemicals, including smog.

Particles greater than 20 microns are usually responsible for erosion and may cause changes in the inlet angle, profile, and throat opening of the airfoils; increased blade tip and seal clearances; and increased surface roughness.

The hot end of the turbine (i.e., the combustion system, turbine, and exhaust diffuser) is also subject to erosion and corrosion caused by metals such as alkalis, vanadium, and lead—or their compounds—that can come from fuel additives or fuel oil. Even with a clean gaseous fuel such as natural gas, hot–end component corrosion may exhibit in the form of a rough scale, caused by surface oxidation.

Gas turbine performance may be recovered during an overhaul by thoroughly cleaning the flow path, replacing damaged parts, recoating airfoil surfaces when necessary, restoring tip and seal clearances where feasible, and sealing any obvious leakage paths.

Degradation—Non-recoverable

Gas turbine performance is not always restored to its original level, even after a major overhaul. The causes of non-recoverable degradation are varied:

- Distortion of the cylinder can cause an eccentricity in clearances and corresponding increases in the leakage path
- Erosion or corrosion of the compressor disks and annulus surfaces can cause roughness of the flow path
- Distortion of the platforms can result in increased leakage and a decrease in aerodynamic performance

Although the extent of non-recoverable deterioration is typically quite small, there are methods available to recover the turbine performance lost through this permanent degradation. Because of their high cost, it is generally not economical to replace the parts that are subject to this type degradation. However, it is possible to uprate the entire machine with the state-of-the-art components. Such an approach, although costly, may allow a higher firing temperature and justify the expense through improved performance relative to the original equipment. These upgrades are typically performed after several years of operation, when the new materials and technologies (such as improved blade cooling) generate enough commercial and financial benefits to justify a major plant uprate.

Miscellaneous Degradation

If leakage from the bleed valve or the flange and horizontal joint occurs, gas turbine performance will drop off. Components such as the gearbox, generator, and auxiliaries will also lose their initial performance over time and contribute to the overall loss in gas turbine performance. The contribution of these miscellaneous components toward overall gas turbine performance deterioration is generally small.

Turbine Blade Duty

Gas turbine blades (particularly the first and second stages) are the most burdened components of the gas turbine due to high heat, intense stress, and the harsh environment. The first-stage turbine blades—which must withstand the most severe combination of temperature, stress, and environment—are generally the limiting components. They must be designed to withstand thermal fatigue (cracking), hot corrosion, high-temperature oxidation, blocked cooling passages or loss of cooling, and loss of material.

Turbine Blade Cooling

Modern gas turbines, such as the ABB GT24, achieve improved efficiency through higher inlet gas temperature, which has been made possible by the introduction of blade cooling. If not properly cooled, these blades are exposed to temperatures well above their operating limit—most superalloys begin to melt at about 2200°F (1204°C). Therefore, blade cooling is critical for effective operation of advanced combustion turbines with turbine inlet temperature above 2250°F (1232°C).

Blade quality problems (cooling air restriction) result from some operating degradation attributable to loss of coating, blade cracks, loss of material, cooling air starvation due to gradual deposits, or other causes. Because blade-related problems often result in changes in surface temperatures, on-line monitoring and analysis can be highly effective in identifying and troubleshooting blade-related degradation or failure.

6
BASELINE PERFORMANCE / DEGRADATION

Performance monitoring as part of a gas turbine durability surveillance program involves evaluation of various measured and calculated performance parameters over the first few years of a unit’s operation. A foundation for such a program is the collection of performance data during the first several hundred hours of operation, to characterize the baseline performance of the unit.

Identifying parameters that indicate overall performance degradation in key gas turbine components is the first step in conducting a performance analysis. Typically used parameters include:

Power output (MW)	Heat rate (HR)
Exhaust gas temperatures (EGT)	Heat consumption
Compressor discharge temperature (CDT) depression	Compressor intake
Compressor discharge pressure (CDP)	Air flow rate (AF)
Compressor adiabatic efficiency (EFF)	EGT spread
Wheel space temperatures	Blade metal temperatures
Compressor inlet temperature (CIT) pressures	Combustor dynamic
Bearing metal temperatures	Lube oil temperatures

Raw data should be reviewed carefully to identify and eliminate corrupted samples. Data corruption can arise from various factors, such as operational problems, sensor malfunctions, or problems with the data acquisition system. Variables such as speed, compressor discharge pressure, power output, fuel flow, exhaust gas temperature, and compressor inlet temperature can all be reviewed, individually or in combination, to spot corrupted samples.

For this performance analysis, data were collected under similar operating conditions (i.e., same firing temperature and fuel gas operation). The DS project team established a method to filter out data that were acquired under full load or gas firing conditions. Segregating data for alternate fuel operation from gas operation is important for accurate comparison. This was accomplished by monitoring the fuel gas flow meter and filtering data input for gas flow only.

To evaluate performance degradation accurately, parameters measured under different conditions must be corrected to the same reference conditions. The correction procedures used by the project team are described below. Data were not corrected for ambient pressure, inlet pressure loss, and exit pressure loss.

ISO Conditions and ISO-Rated Values of Performance Parameters

To compare performance data taken at different ambient conditions, parameters were corrected to the following standard ISO (International Standard Organization) conditions:

- Ambient Temperature (Compressor Inlet Temperature): 59°F (15°C)
- Barometric Pressure: 14.7 psia (101.4 kPa)
- Relative Humidity: 60%
  (specific humidity: 0.0064 lb water vapor/lb dry air)
- Inlet Duct Loss: 0
- Exhaust Duct Loss: 0

In general, gas turbine manufacturers provide ISO-rated values (nominal ratings) for key performance parameters, such as generator power output, heat rate, exhaust gas temperature, heat consumption, air flow rate, and exhaust gas flow rate.

Table 6-1 summarizes the ISO performance parameters provided by ABB for the GT24 at Gilbert Station. Note that these ratings are for both natural gas and distillate fuels, and that they include inlet and exhaust duct pressure losses. For the baseline performance and turbine degradation comparisons, only the natural gas data were used.

Table 6-1
ABB Nominal Ratings for the Gilbert Station GT24

Performance at 59°F (15°C)	Natural Gas	Distillate Fuels
Power output	165.5 MW	176.7 MW
Heat rate (LHV)	9592 Btu/kWh (10,120 kJ/kWh)	9708 Btu/kWh (10,242 kJ/kWh)
Exhaust gas temperature	1095°F (590°C)	1035°F (557°C)
Pressure ratio	30:1	30:1
Exhaust gas flow	828.9 lb/sec (376 kg/sec)	866.7 lb/sec (393 kg/sec)
Firing temperature	2255°F (1235°C)	2200°F (1204°C)

Procedure to Correct Performance Parameters to Standard Conditions

The measured performance parameters were corrected to standard conditions at 59°F (15°C) using correction curves provided by the gas turbine manufacturer in conjunction with commonly accepted methods. Figures 6-1 through 6-3 show the ABB correction curves.

Corrected Power Output (MW)

The corrected (to 59°F) value of MW is given as:

MW_{59} = $(MW_t)*(MWCF_t)$
MW_{59} = MW corrected to 59°F
MW_t = MW measured (average)
$MWCF_t$ = Correction factor MW changes due to compressor inlet temperature, °F from ABB correction curve (Figure 6-1)

Corrected Exhaust Gas Temperature (EGT)

The corrected (to 59°F) value of EGT is given as:

EGT_{59} = $(EGT_t) + (\Delta EGT_t)$
EGT_{59} = EGT corrected to 59°F
EGT_t = EGT measured (average) in °F
ΔEGT_t = Correction factor EGT changes due to compressor inlet temperature, °F from ABB correction curve (Figure 6-2)

Corrected Air Mass Flow Rate (Exhaust)

Air mass flow corrected to 59°F is given as:

AF_{59} = $(AF_t)*(AFCF_t)$
AF_{59} = Air mass flow corrected to 59°F in lb/s
Af_t = Air mass flow measured/calculated using the Efficiency-MAP model at ambient temperature in lb/s
$AFCF_t$ = Correction factor AF changes due to compressor inlet temperature, °F from ABB correction curve (Figure 6-3)

Corrected Compressor Efficiency (%)

The corrected (to 59°F) value of EFF is given as:

EFF_{59} = $(EFF_t)*(EFFCF_t)$
EFF_{59} = EFF corrected to 59°F
EFF_t = EFF measured (average)
$EFFCF_t$ = Correction factor EFF changes due to compressor inlet temperature, °F from ABB correction curve (Figure 6-1)

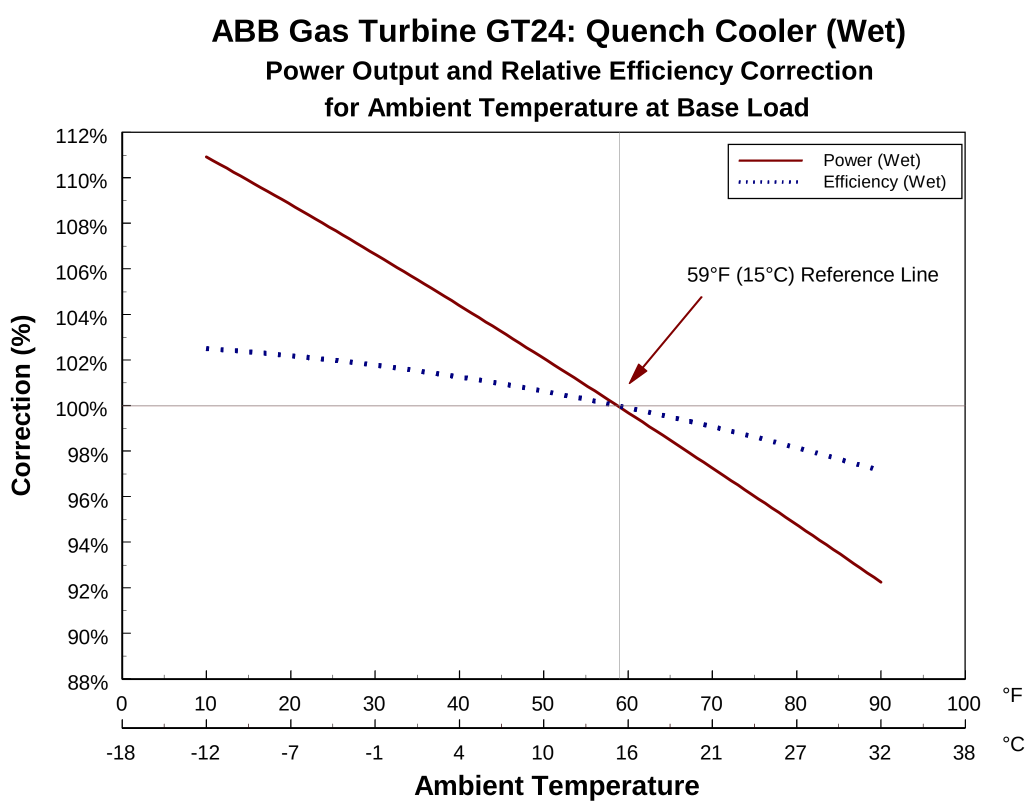

Figure 6-1
ABB Correction Curve - Power Output and Relative Efficiency Correction for Ambient Temperature at Baseload

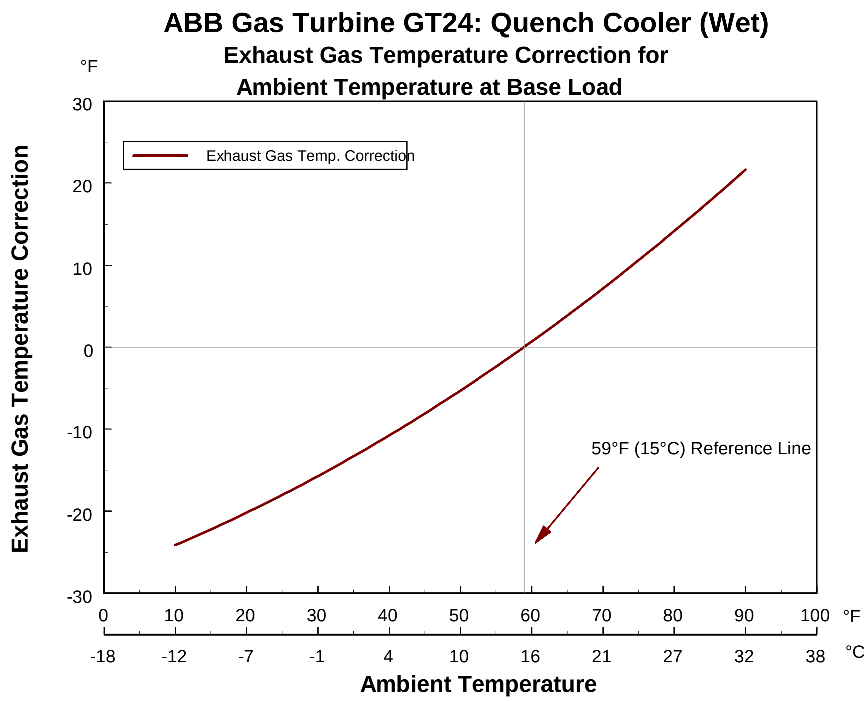

Figure 6-2
ABB Correction Curve - Exhaust Gas Temperature Correction for Ambient Temperature at Baseload

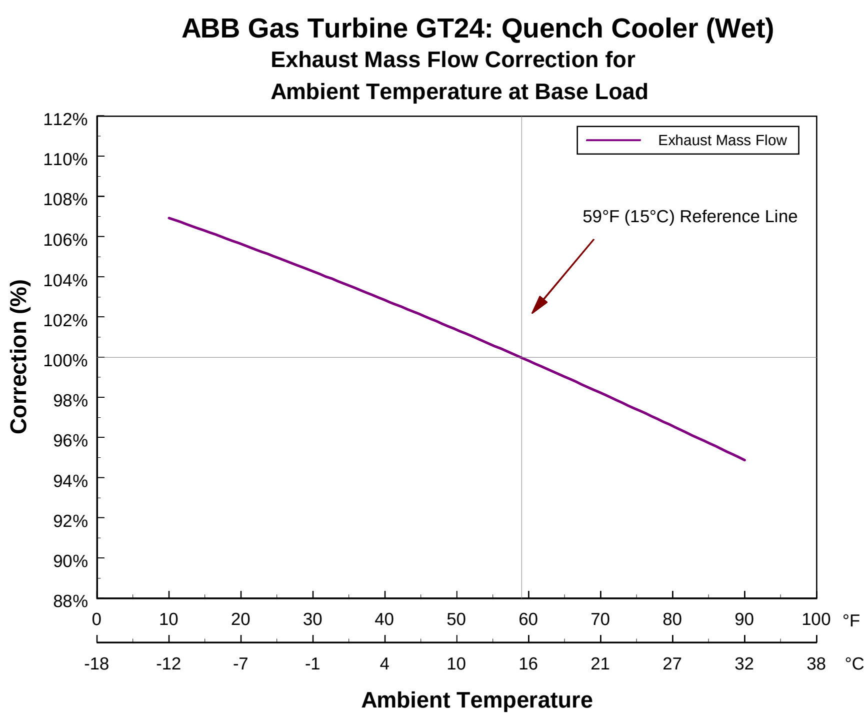

Figure 6-3
ABB Correction Curve - Exhaust Mass Flow Correction for Ambient Temperature at Baseload

Filtering of Non-Full Load Operating Conditions

The EPRI data acquisition system provides operational data for the monitored variables at all operating conditions, including no-load, part-load, and full-load.

Segregation of the data points load level is necessary for an accurate evaluation of performance retention, and can be accomplished by filtering out the data points that are recorded for non-baseload operating conditions. Near-baseload operation is defined by the following conditions:

- EGT is higher than 1057°F (569°C)
- Power output is higher than 150 MW
- Inlet guide vane >90%

Estimation of gas turbine performance degradation requires examination of the following parameters:

- Compressor Fouling or Foreign Object Damage (FOD):
  - Compressor Discharge Pressure (CDP)
  - Air Flow Rate (AFR)
  - Compressor Discharge Temperature (CDT)
  - Compressor Adiabatic Efficiency (EFF)
- Combustor Performance
  - Exhaust Gas Temperature (EGT)
  - Combustion Temperature
- General Degradation
  - Power Output (MW)
- Turbine Blade FOD
  - Exhaust Gas Temperature (EGT)

Turbine Baseline Performance and Degradation

Evaluating gas turbine performance degradation requires establishing baseline performance (over a range of ambient temperatures) and “new and clean” turbine condition for comparison with future performance measurements.

EPRI’s Efficiency-MAP™ model was used to collect data for developing the performance baseline. The data taken from December 1996 to September 1997 are considered startup and initial test data, and are not used for establishing baseline performance. The data collected from December 1997, to early September 1998 represent the summer peaking data and have been used to establish the baseline performance of the ABB GT24.

This section uses the manufacturer's curves to correct the measured data and determine a performance baseline. Power output (MW), exhaust gas temperature (EGT), air mass flow rate (AMFR), and heat rate (HR) were the key performance parameters chosen to characterize baseline performance.

Each measured parameter was first compared with compressor inlet temperature (CIT) and then with time. Parameters plotted against time have been corrected to 59°F (15°C) compressor inlet temperature where applicable. The data shown in Figures 6-4 through 6-12 were not corrected for ambient pressure, inlet pressure loss, and exit pressure loss.

Baseline Performance – Power Output

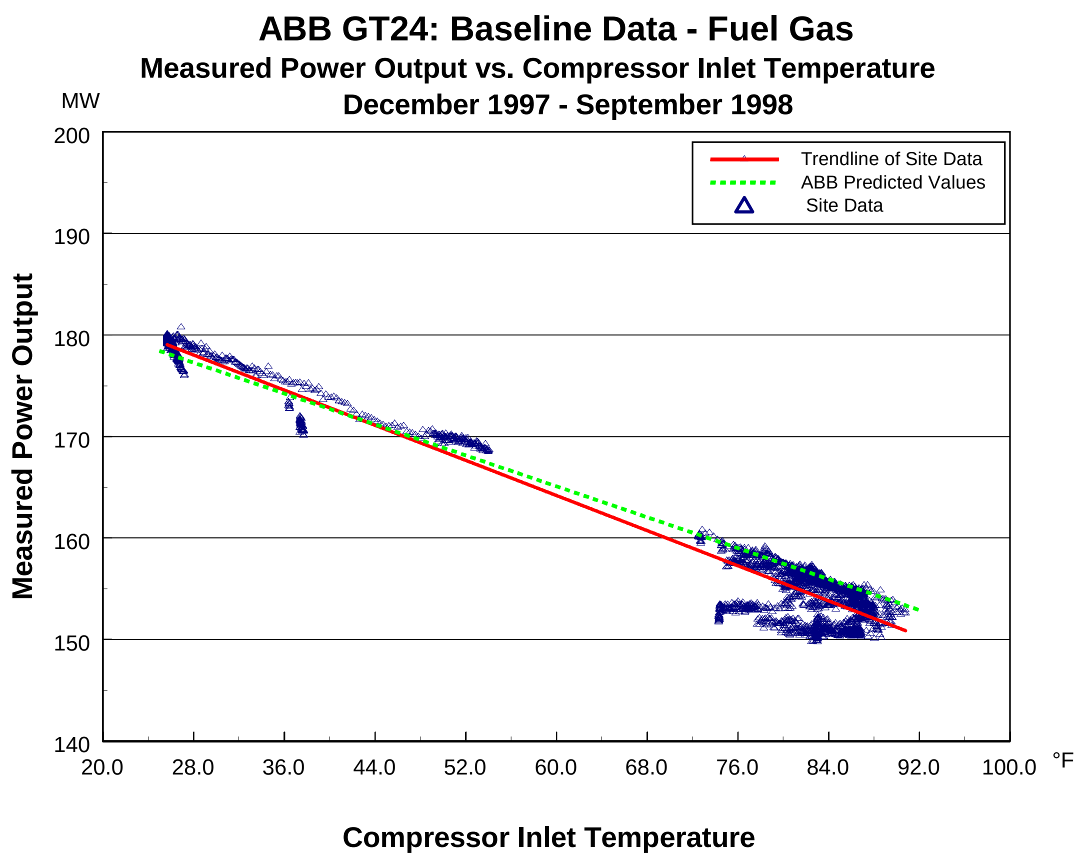

Figure 6-4
Baseline Measured Power Output vs. Compressor Inlet Temperature

Figure 6-4 plots the measured power output (MW) from December 1997 to September 1998 as a function of compressor inlet temperature (CIT).

The ABB values for Gilbert's power output are superimposed and show good overlap between the EPRI (actual) and ABB (design) data. Some divergence from the design values is evident at the high and low extremes of the temperature range, which is partly a result of comparing data taken under slightly different operating conditions (within the near-baseload range). The ABB value for Gilbert's power output**,** corrected to ISO conditions, is 165.5 MW.

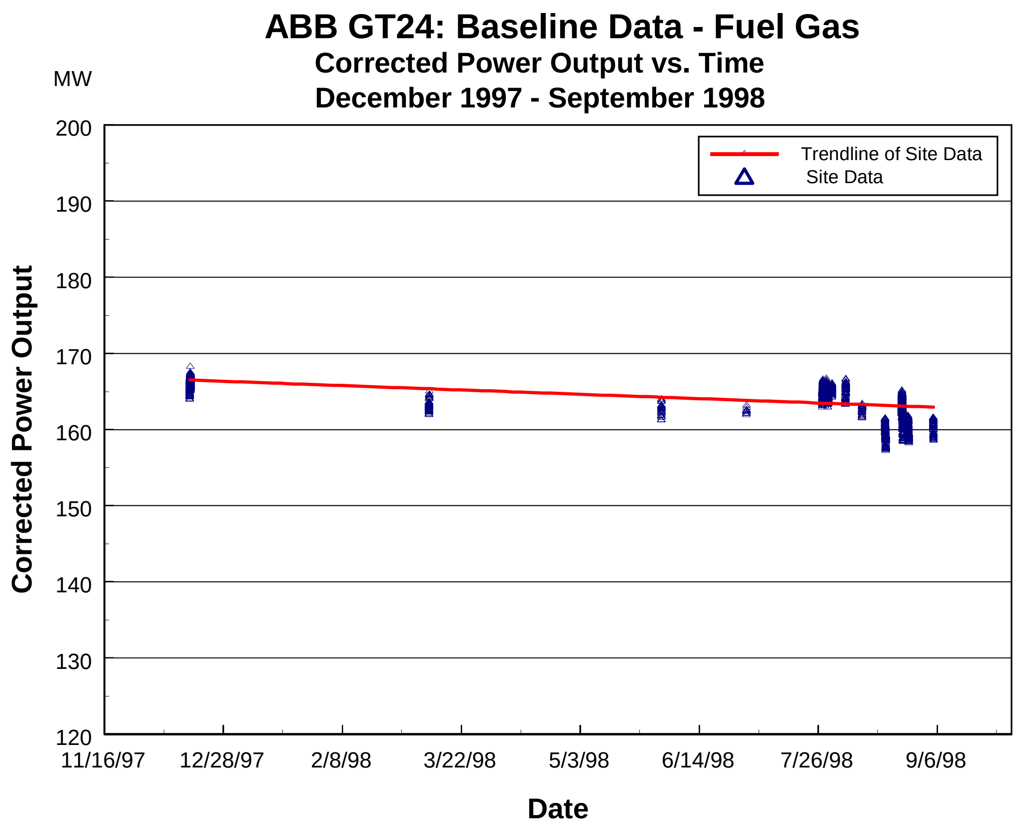

Figure 6-5
Baseline Corrected Power Output vs. Time

Figure 6-5 shows the power output (MW), corrected for compressor inlet temperature (CIT), using the ABB correction curves. The corrected output at the start of the baseline is approximately 167 MW and decreases to 165 MW at the end of the baseline period.

The ABB value for Gilbert's power output corrected to ISO conditions is 165.5 MW. Baseline data corrected to ISO conditions, as shown in Figure 6-5, are very close to the ABB design value. This confirms the accuracy of the ABB correction curves and validates the data taken from December 1997 to September 1998 as representative baseline data.

Baseline Performance – Exhaust Gas Temperature

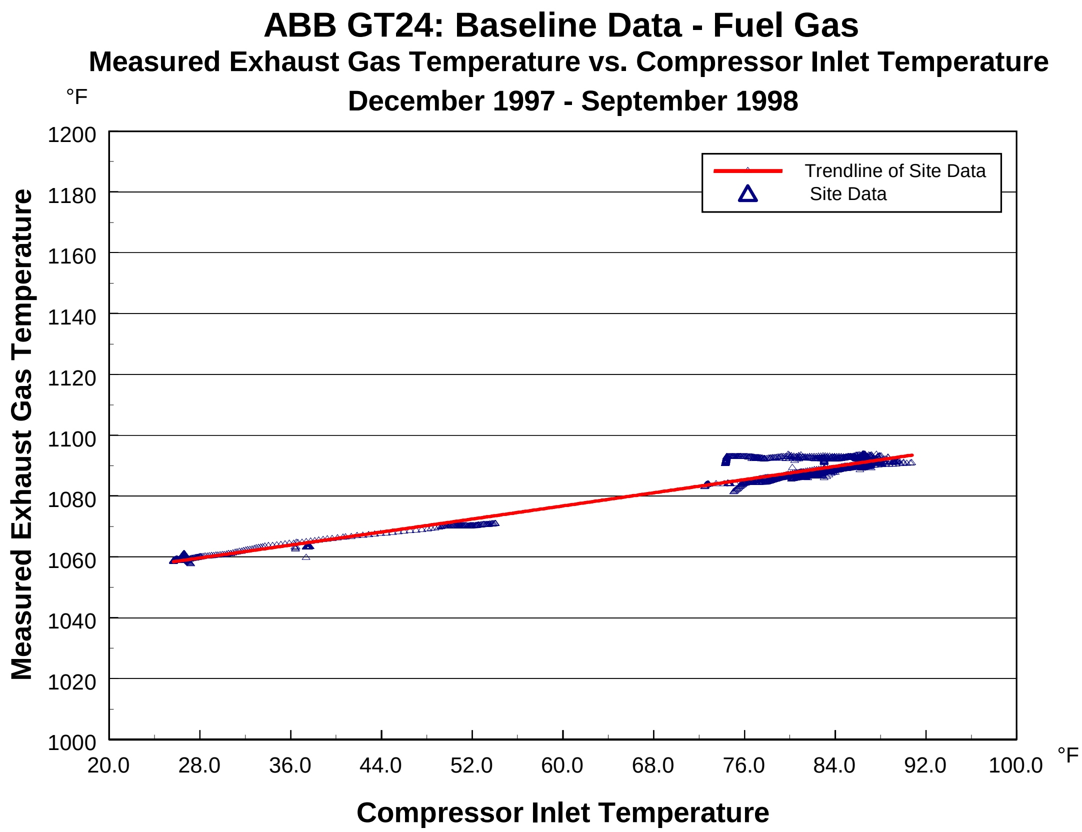

Figure 6-6
Baseline Measured Exhaust Gas Temperature vs. Compressor Inlet Temperature

Figure 6-6 plots the measured exhaust gas temperature (EGT) from December 1997 to September 1998 as a function of compressor inlet temperature (CIT). As noted previously, because the turbine did not operate when ambient temperatures ranged from 55° to 70°F (13° to 21°C), the plot shows no data for these temperatures. The trendline appears linear, as illustrated by the curve fit.

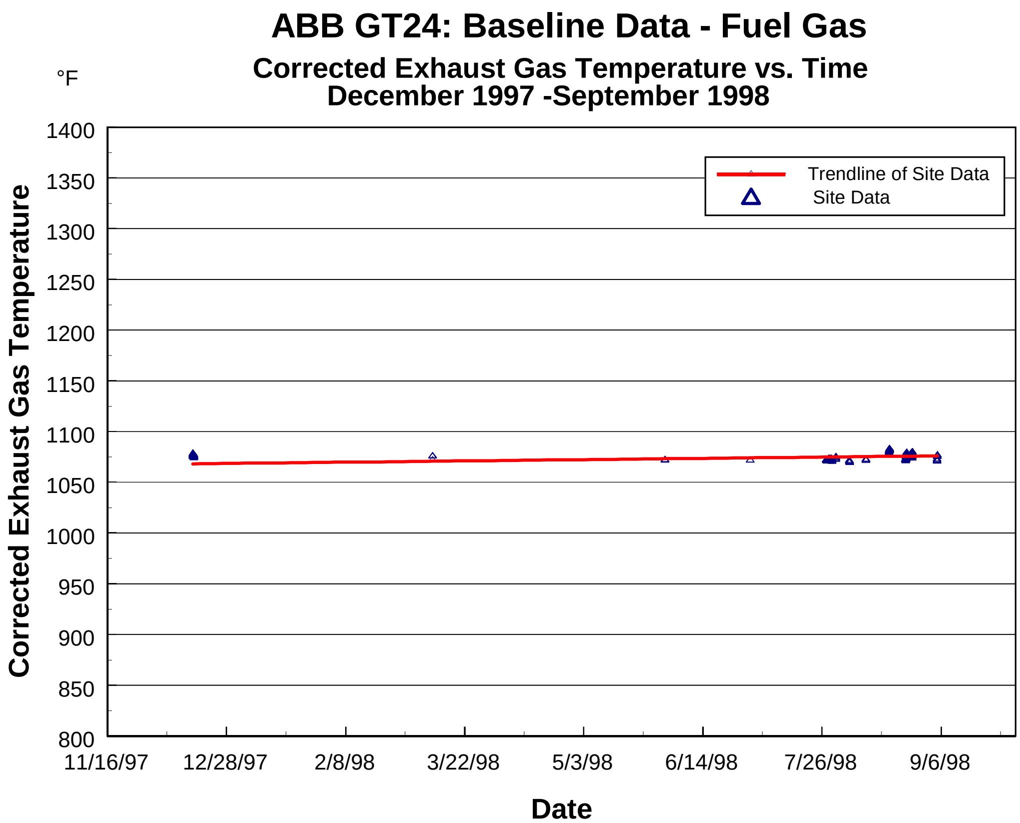

Figure 6-7
Baseline Corrected Exhaust Gas Temperature vs. Time

Figure 6-7 plots the exhaust gas temperatures (EGT) corrected for compressor inlet temperature (CIT) using ABB's correction curves. There appears to be a very slight increase in temperatures over time. The ABB value for Gilbert's exhaust gas temperature, corrected to ISO conditions, is 1095°F (591°C). The curve fit shown for the site data, corrected to ISO conditions, is slightly lower than the ABB value.

Baseline Performance – Air Mass Flow Rate

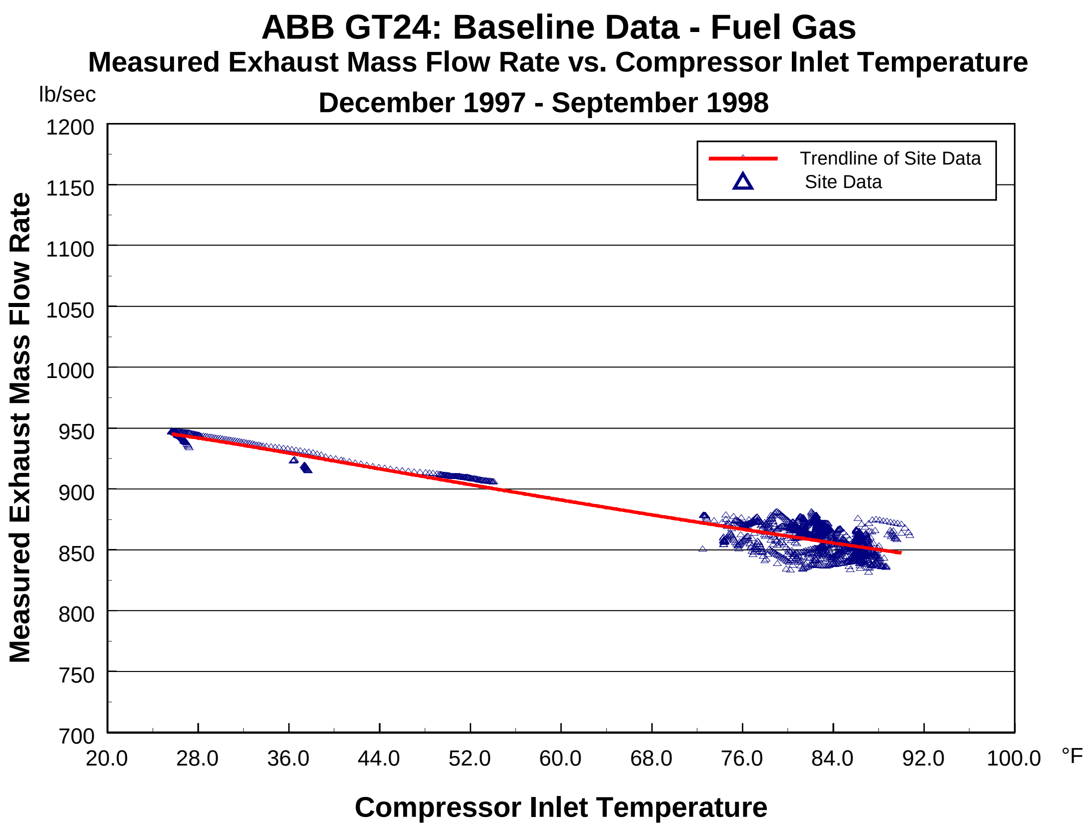

Figure 6-8
Baseline Measured Exhaust Mass Flow Rate vs. Compressor Inlet Temperature

Figure 6-8 plots the measured exhaust mass flow rate from December 1997 to September 1998 as a function of compressor inlet temperature (CIT). As noted previously, because the turbine did not operate when ambient temperatures ranged from 55°F to 70°F (13°C to 21°C), the curve shows no data for these times. The graph also shows that many data points were collected for the temperature range of 70° to 90°F (21° to 32°C), which is attributable to longer and more frequent runs during the peaking season of July and August 1998.

The trendline illustrated by the curve fit for mass flow as a function of CIT is nonlinear. It is logarithmic.

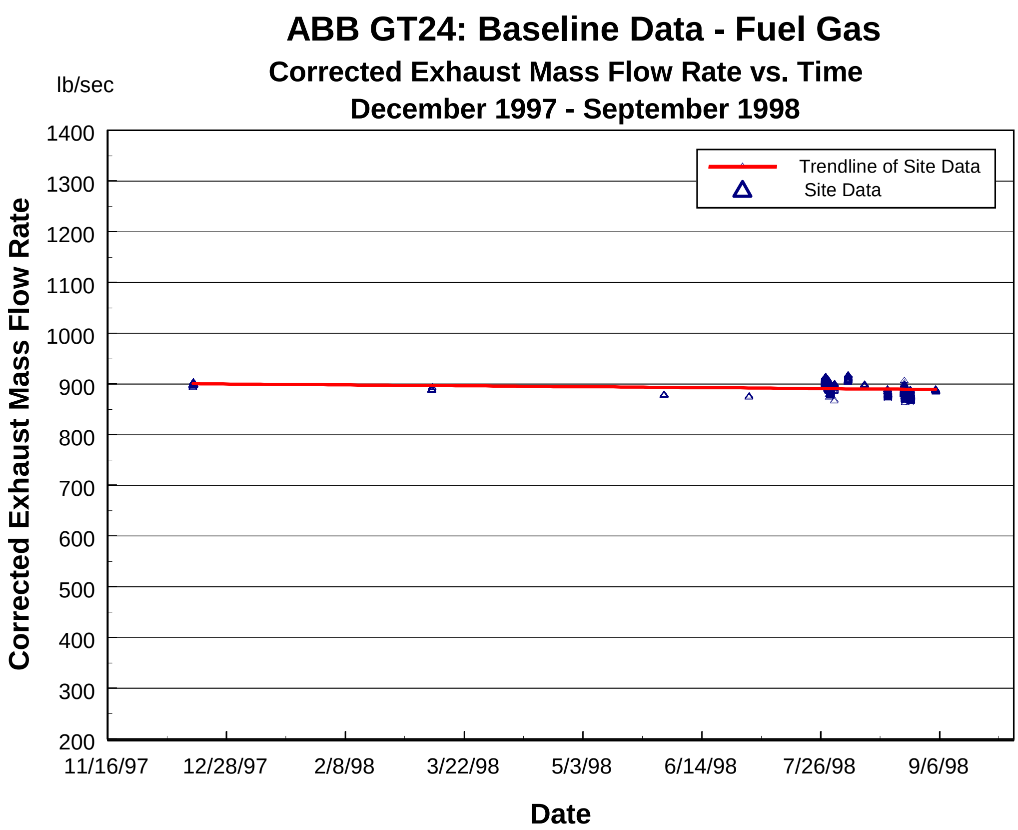

Figure 6-9
Baseline Corrected Exhaust Mass Flow Rate vs. Time

Figure 6-9 shows the exhaust mass flow rate, corrected for compressor inlet temperature (CIT), using ABB's correction curves. There appears to be a decrease in flow over time. As of October 1998, the design value for exhaust mass flow rate corrected to ISO conditions was not available. The curve fit of the baseline data corrected to ISO conditions, as shown in Figure 6-9, is about 900 lb/sec (409 kg/sec).

Baseline Performance – Heat Rate

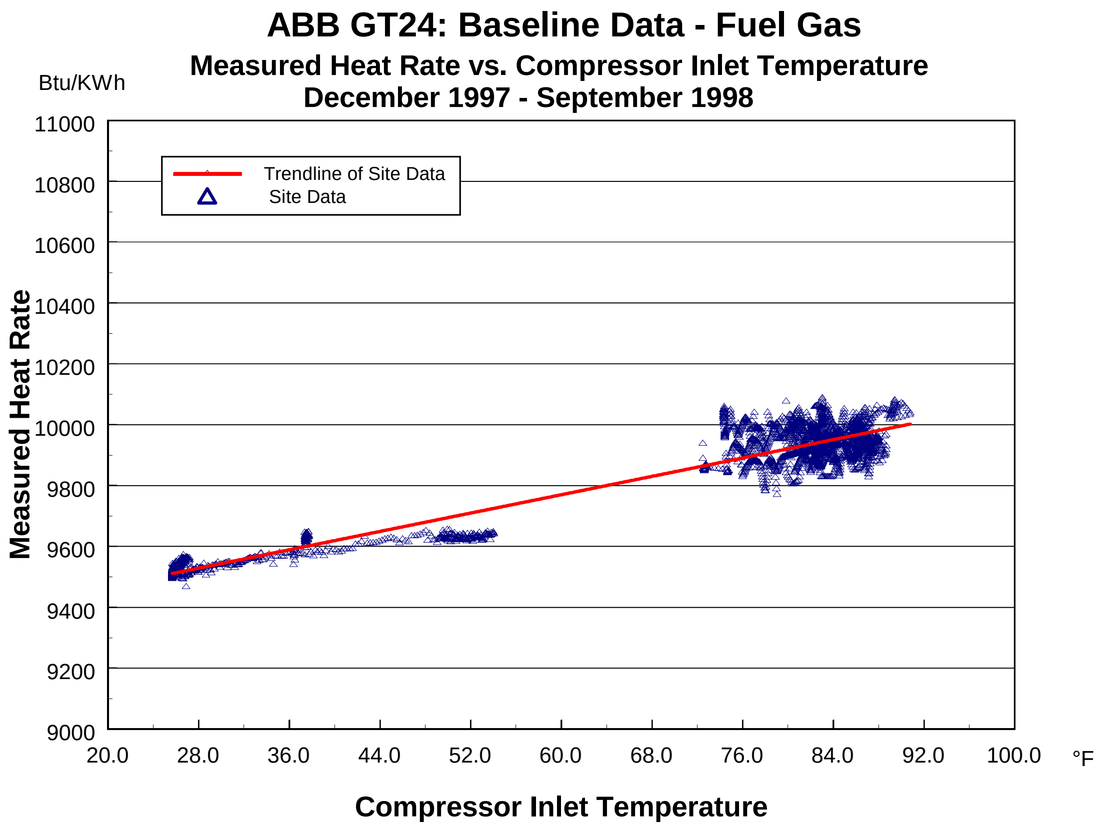

Figure 6-10
Baseline Measured Heat Rate vs. Compressor Inlet Temperature

Figure 6-10 plots the measured heat rate (HR) from December 1997 to September 1998, as a function of compressor inlet temperature (CIT). As noted previously, because the turbine did not operate when ambient temperatures ranged from 55°F to 70°F (13°C to 21°C), no data are shown for these temperatures. The graph also shows that many data points were collected for the temperature range of 70°F to 90°F (21°C to 32°C), which is attributable to longer and more frequent runs during the peaking season of July and August 1998.

The trendline illustrated by the curve fit for heat rate as a function of CIT is linear.

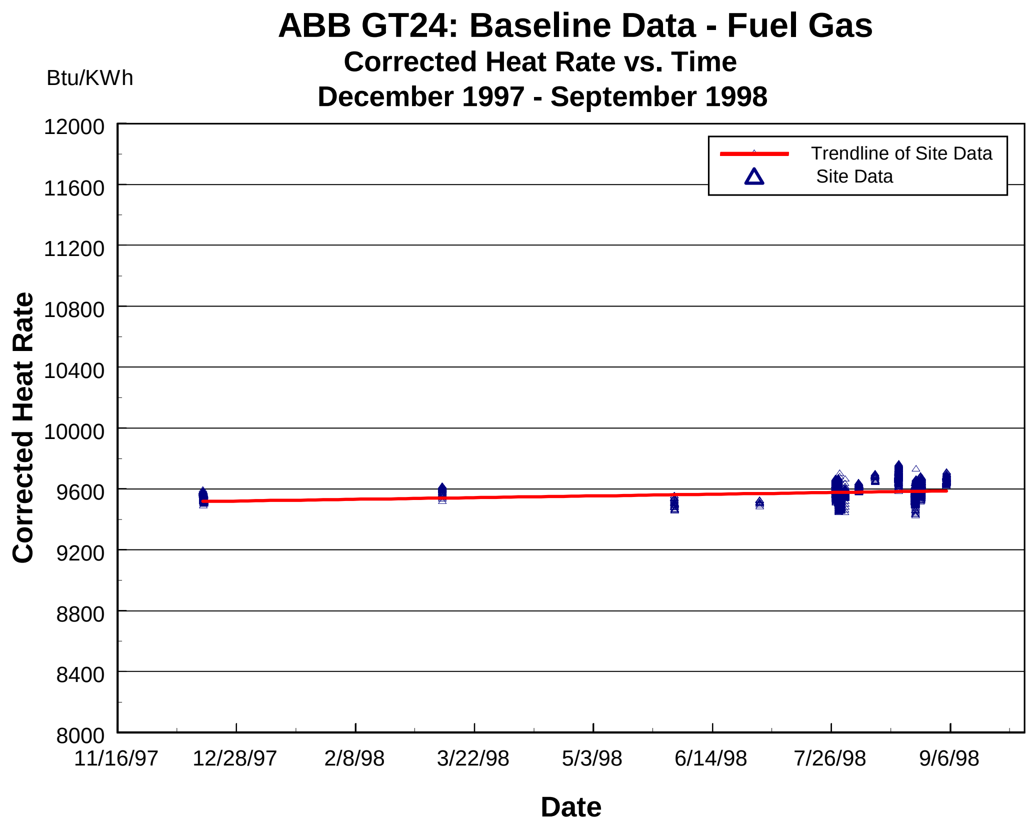

Figure 6-11
Baseline Corrected Heat Rate vs. Time

Figure 6-11 shows the heat rate (HR), corrected for compressor inlet temperature (CIT) using ABB's correction curves. The ABB value for Gilbert's heat rate, corrected to ISO conditions, is 9592 Btu/kWh (10,120 kJ/kWh).

Heat rate is calculated as follows: $HeatRate = \frac{FuelFlow * LHV}{PowerOutput}$.

The curve fit shown for the site data in Figure 6-11, corrected to ISO conditions, is very close to the ABB value.

Operating Data – Power Output

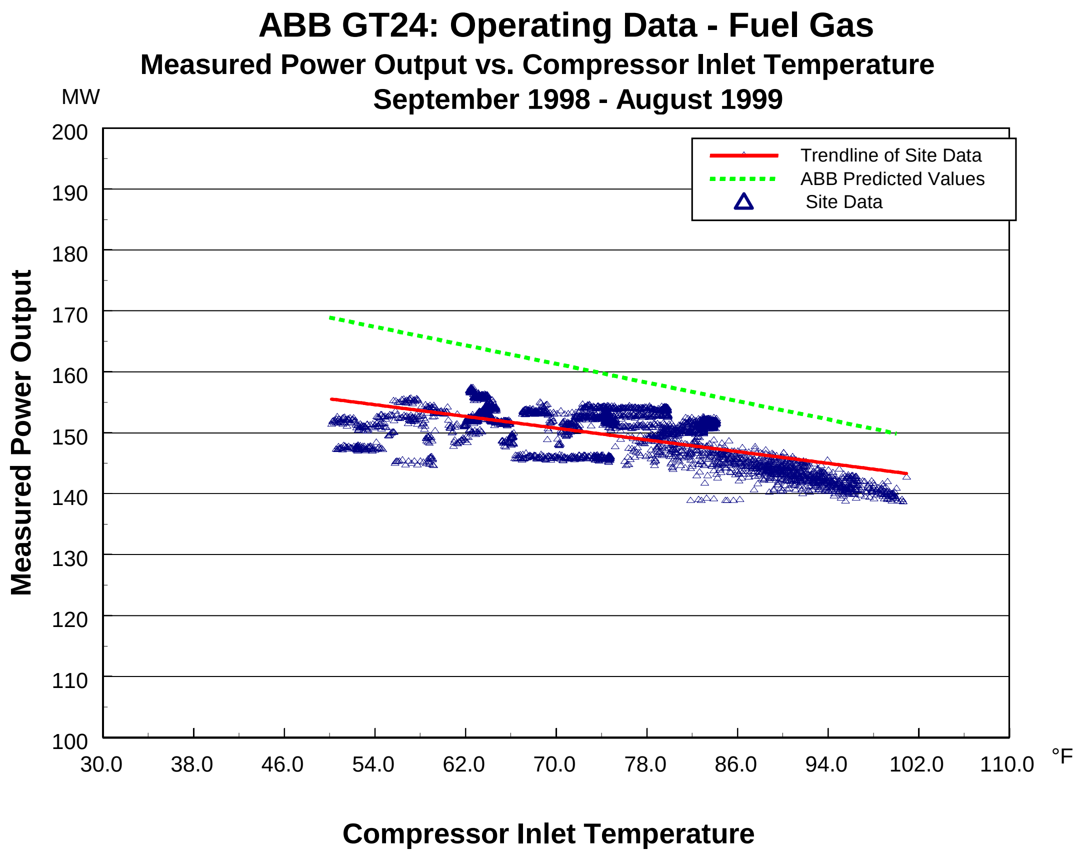

Figure 6-12
Operating Data Measured Power Output vs. Compressor Inlet Temperature

Figure 6-12 plots the measured power output (MW) from September 1998 to August 1999 as a function of compressor inlet temperature (CIT).

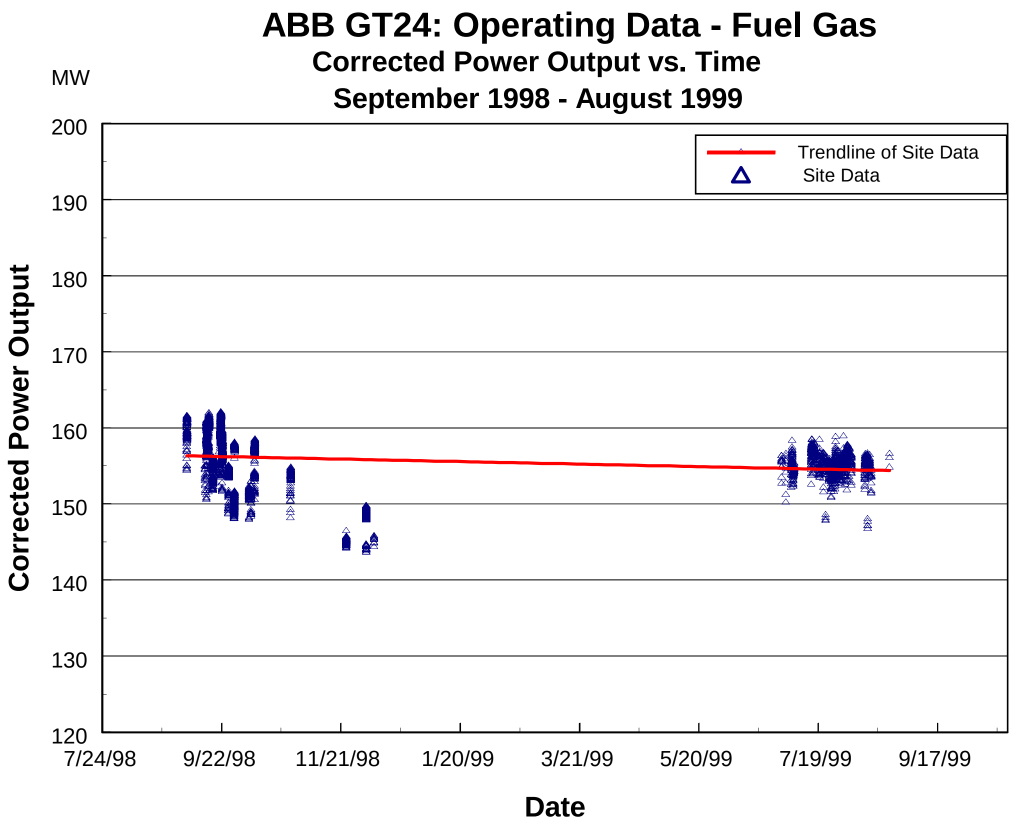

Figure 6-13
Operating Data Corrected Power Output vs. Time

Figure 6-13 shows the power output (MW), corrected for compressor inlet temperature (CIT), using the ABB correction curves.

Operating Data – Exhaust Gas Temperature

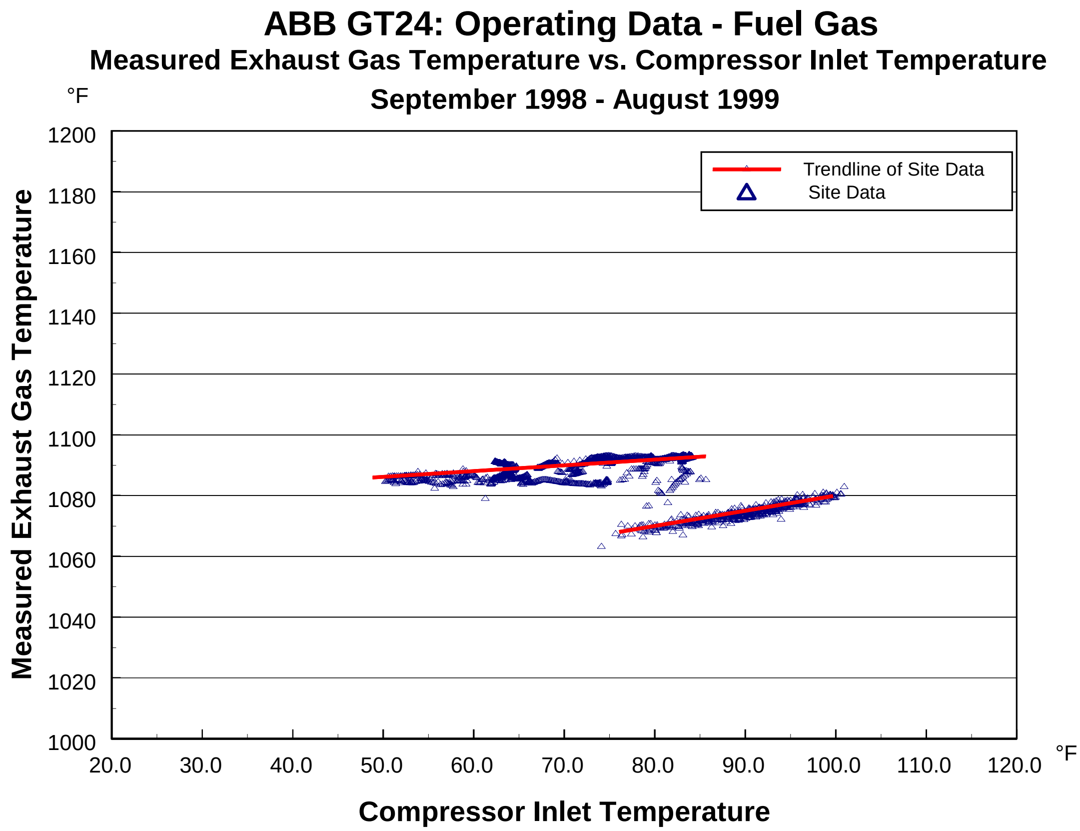

Figure 6-14
Operating Data Measured Exhaust Gas Temperature vs. Compressor Inlet Temperature

Figure 6-14 plots the measured exhaust gas temperature (EGT) from September 1998 to August 1999 as a function of compressor inlet temperature (CIT)

Two different trends are shown: prior and after turbine refurbishing.

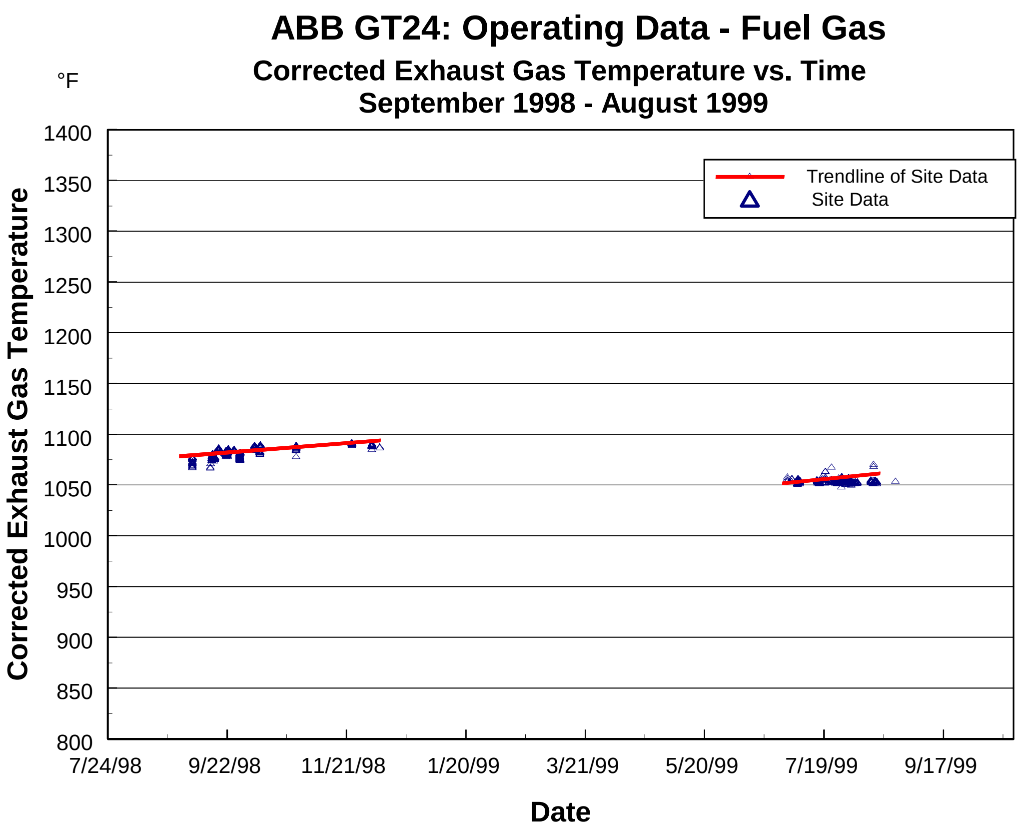

Figure 6-15
Operating Data Corrected Exhausted Gas Temperature vs. Time

Figure 6-15 plots the exhaust gas temperatures (EGT) corrected for compressor inlet temperature (CIT) using ABB's correction curves

Two different trends are shown: prior and after turbine refurbishing.

Performance Degradation Baseline / 1999 Operations

As of September 1999, the ABB GT24 at Gilbert Station had accumulated a total of approximately 2050 firing hours with 366 starts on gas and oil as reflected in Figures 6-16 and 6-17. The turbine primarily operates during the summer and winter seasons to meet peak power demands, it does not accumulate many running hours over the course of a year.

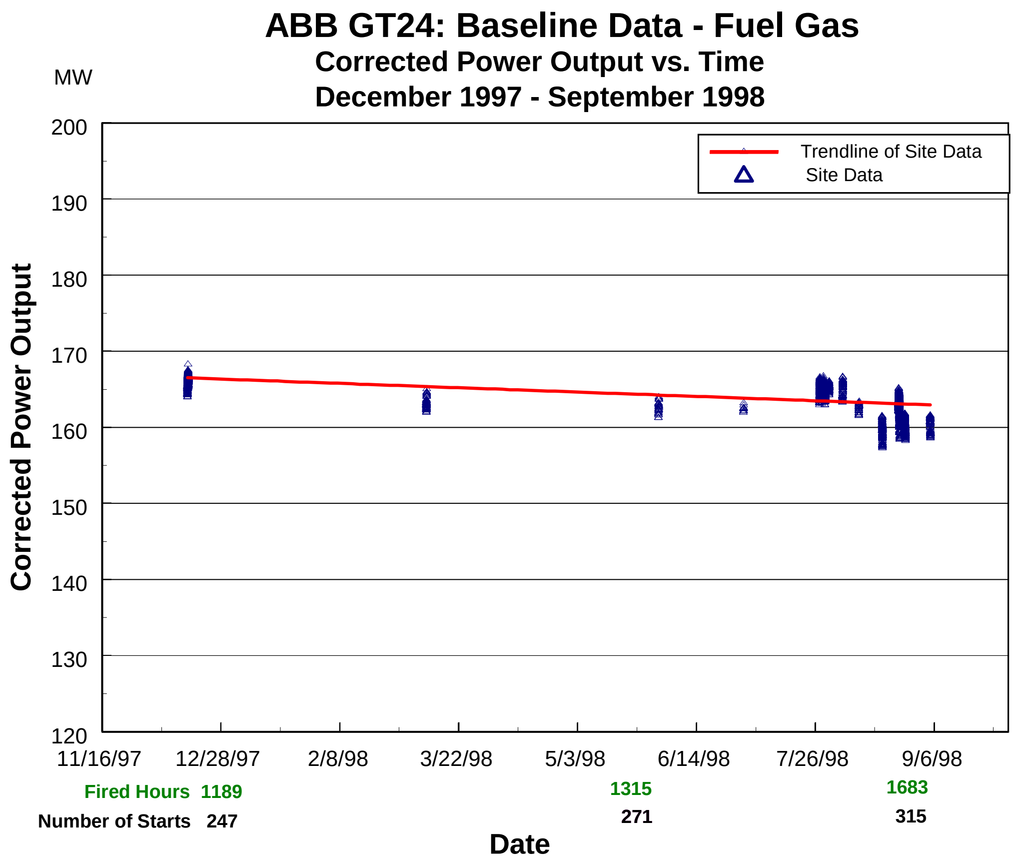

Figure 6-16
Degradation Corrected Power Output vs. Time

In reviewing the data from September 1998 to August 1999 for corrected power output vs. time, a small degradation in the magnitude of 3 MW can be detected **(**see Figure 6-17). Note that the gas turbine is operating approximately 10 MW below the baseline.

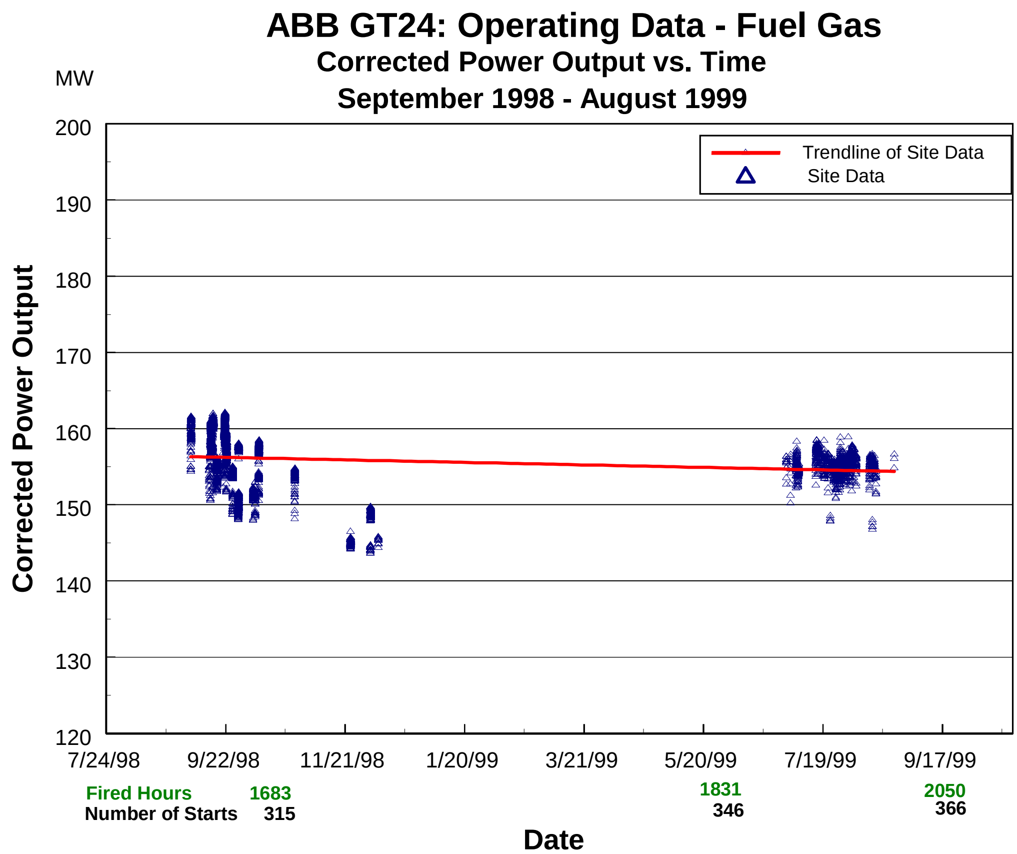

Figure 6-17
Degradation Corrected Power Output vs. Time

Future Combined Cycle Performance

The GT24 at Gilbert is a candidate for repowering with addition of a heat recovery steam generator. Table 6-1 shows performance estimates of the Gilbert unit in simple and combined cycle configuration along with similar estimates for the uprated GT24B, which is expected to enter service in late 1999. The uprating of the GT24B includes increasing the LP-cooling air temperature from 644°F (340°C) to 698°F (370°C), increasing the LP turbine inlet temperature by 108°F (60°C), increasing exhaust temperature from 1130°F (610°C) to 1184°F (640°C), use of TBC on the low pressure turbine vanes and blade platforms, modified blading and heat shield cooling design for the low pressure turbine, modified seal design and single crystal vanes in the high pressure turbine and the first row of blades in the low pressure turbine.

Table 6-2
Comparison of Nominal Performance Estimates

	Gilbert GT24 Simple Cycle	GT24B Simple Cycle	Gilbert GT24 Combined Cycle*	GT24B Combined Cycle*
Plant Net Output, MW	165	185	240	270
Unit Heat Rate (HHV, net)				
Btu/kWh	10,650	9,895	7,280	6,810
KJ/kWh	11,235	10,440	7,680	7,185
Total Plant Cost, $/kW (1999)	N/A	390	N/A	455

* Performance estimates at ISO conditions based on 3 pressure reheat steam cycle using SOAPP-CT workstation V5.0

N/A – Not Available

7 PYROMETER DATA COLLECTION AND ANALYSIS

Blade Temperature Measurement System (BTMS) Data Collection

This section provides pyrometer scans of the second- and third-stage (LP first- and second-stage) rotating blades in the ABB GT24 at GPU Genco's Gilbert Station. Data taken on December 16, 1997, for natural gas and December 18, 1997, for fuel oil provide a baseline from which to analyze and predict future turbine performance and maintenance activities.

Traces from 1998 operation are compared to the baseline data to analyze turbine blade status. The unit was overhauled in 1999 and the pyrometer was removed. Discussions on re-installation are currently underway.

Blade Temperature Scans

The pyrometer readings provide a "thermal fingerprint" (also known as a "blade thermal signature," "blade scan," or "pyrometer trace") that shows the temperature of each blade as it crosses the pyrometer's line of sight. The DS project team used blade scan displays to demonstrate data storage capabilities, blade surface temperature record and analysis upon demand, and status of the blade surface temperature for the plant operator.

Peak Blade Surface Temperature

The peak of the blade surface temperature profile is important, because it represents the maximum temperature detected by the pyrometer. However, because the pyrometer scan area does not cover the blade's entire surface, this peak temperature may not represent the maximum surface temperature on the blade. Nonetheless, the peak surface temperature is a significant indication of blade health when compared with scans from other blades in the same turbine stage (wheel) or peak surface scans from other units (of the same model gas turbine) operating at the same load level and conditions.

Difference in Peak Blade Surface Temperature within a Stage

Some blades yield evidence of higher peak temperatures than the rest of the blades in the same stage. Comparison of "hot" or "warm" blades with the rest of the blades in the stage indicates that a cooling deficiency or other blade-related problem may exist. Close monitoring of these hot or warm blades may be required.

Valley of Blade Surface Temperature

The valley of the blade surface temperature profile is the minimum temperature scanned by the pyrometer. This measurement is taken as the blade passes out of the pyrometer's line of sight. This minimum blade surface temperature as observed by the pyrometer serves for reference purposes only.

Typical Plant Operating Modes

This section presents BTMS data for both full-load and part-load operating conditions. Although many factors can affect the blade temperature traces and average blade peak temperature (ABPT) values, general trends are evident. The purpose of this section is to characterize the typical operating modes at Gilbert Station and to correlate the turbine operating parameters with BTMS temperature traces and ABPT values. Data from EPRI's Efficiency-MAP™ is used to illustrate the operating modes of the gas turbine units.

Blade Temperature Monitoring at Gilbert Station

EPRI BTMS equipment used for monitoring blade temperatures at GPU's Gilbert Station includes two (2) pyrometers. The pyrometer locations are identified as second- and third-stage pyrometers and are indicated on all graphics as such. The second-stage pyrometer correlates to the first-stage LP turbine blades and the third-stage pyrometer correlates to the second-stage LP turbine blades. The ABB GT24 has a single-stage HP turbine that does not have a pyrometer installed due to the lack of available penetration into the turbine case.

Confirmation of Blade Temperature Uniformity between Gas Turbine Stages

The pyrometer data show that each turbine stage contains blades with consistently lower or higher temperatures than other blades in that stage. The positions of the blade peaks relative to one another constitute the "thermal signature" of the turbine stage, which provides information on individual blades and their cooling circuits.

A wide variation in blade metal temperatures of a particular stage may indicate variable cooling effectiveness within the stage. Blades with elevated temperatures should be closely monitored. BTMS equipment has the ability to store blade temperature data over long periods. By trending blade temperatures over time, increases in blade temperatures taken under similar operating conditions can help identify problems early. These temperature increases can indicate blade degradation and may also point to quality improvement steps that the manufacturer should adopt.

Baseline Pyrometer Data

The turbine operated on a regular basis and under varying ambient conditions from August 1997 through December 1997 and from June 1998 to September 1998, providing a valid baseline for data analysis.

The turbine data contained in this report was obtained from two separate sources. The operational data was obtained from Efficiency-MAP™ acquisition software, and the pyrometer data was obtained from data evaluation and display system (DEDS).

Table 7-1
Second- and Third-Stage Baseline Traces

Figure No.	Subject	Comments
7-1	Second-Stage Forward Pyrometer - Fuel Gas	Data Taken on 12/16/97 at 12:08 Hours
7-2	Second-Stage Forward Pyrometer - Fuel Oil	Data Taken on 12/18/97 at 12:11 Hours
7-3	Third-Stage Forward Pyrometer - Fuel Gas	Data Taken on 12/16/97 at 12:08 Hours
7-4	Third-Stage Forward Pyrometer - Fuel Oil	Data Taken on 12/18/97 at 12:11 Hours

Second-Stage Pyrometer Traces

EPRI and ABB agreed to establish two pyrometer traces to represent baseline conditions of the Gilbert GT24. The two traces (see Figure 7-1 through 7-4) were taken on December 16, 1997, 12:08 Hours, for fuel gas, and December 18, 1997 12:11 Hours, for fuel oil. These traces were compared with baseline data taken with the Land Pyrometer system for the entire day and filtered to include only full-load conditions. These comparative traces can be viewed in Figures 7-1 to 7-4.

The pyrometer data display clear traces, which indicate proper pyrometer operation and a high degree of repeatability. A pyrometer trace from December 16, 1997, at 12:08 Hours (see Figure 7-1) has been overlaid on an average baseline trace from the same day to show that the 12:08 trace is valid as baseline pyrometer trace. The 12:08 trace has a minimum-to-maximum peak temperature differential of 115°F (64°C), and the baseline data shows a differential of 114°F (63°C). It should be noted that this differential is considered to be high. The ABPT for this baseline trace is 1654°F (901°C).

The pyrometer trace from December 18, 1997, at 12:11 Hours (see Figure 7-2) has also been compared to a baseline trace created from that day. The minimum peak to maximum peak characteristics of the fuel oil traces show a differential of 125°F (70°C), while the baseline data shows a differential of 117°F (65°C). It should be noted that the delta temperature values are high and should be monitored on a regular basis to check for possible deterioration of the blade cooling systems. The ABPT for this baseline trace is 1636°F (891°C).

The high temperature differential between blades in both gas and oil baseline cases indicates non-uniform air cooling. In reviewing the manufacturing process, ABB determined that these variations were caused by tolerances in the through-flow air cooling characteristics of the blades. These variations were determined by ABB to be acceptable for maintaining cooling and life expectancy of the rotor blades. Thanks to this lesson learned, the through-flow characteristics of every blade are measured by the manufacturer as a quality assurance step during the machine assembly to prevent similar occurrences.

The following turbine operational data correspond to the pyrometer baseline data:

Parameter	December 16, 1997 (12:08 Hours) Fuel Gas	December 18, 1997 (12:11 Hours) Fuel Oil
Power Output (MW)	169.83	185.78
Compressor Inlet Temperature	52°F (11°C)	42°F (6°C)
Exhaust Gas Temperature	1070°F (577°C)	1025°F (552°C)
Average Blade Peak Temperature	1654°F (901°C)	1636°F (891°C)

The baseline pyrometer data show a high variation in peak blade temperatures, which indicate non-uniform cooling characteristics. These results clearly warrant closer monitoring of pyrometer traces to ensure immediate identification of any additional increases in peak blade temperatures.

Third-Stage Pyrometer Traces

The third-stage pyrometer data display clear traces, which indicate proper pyrometer operation and a high degree of repeatability. As with the second-stage pyrometer trace, a trace from December 16, 1997, at 12:08 Hours (see Figure 7-3) has been plotted as the baseline data for blade temperature measurements taken under fuel gas operation. The trace has a minimum-to-maximum peak temperature differential of 71°F (39°C). The ABPT for this baseline trace is 1515°F (824°C).

In a similar manner, the pyrometer trace from December 18, 1997, at 12:11 Hours (see Figure 7-4) has been plotted to be used as baseline data for blade temperature measurements under oil operation. This trace’s minimum-to-maximum peak has also been plotted for analysis. The baseload minimum peak to maximum peak characteristics of the fuel oil traces show a differential of 70°F (39°C). The ABPT for this baseline trace is 1472°F (800°C).

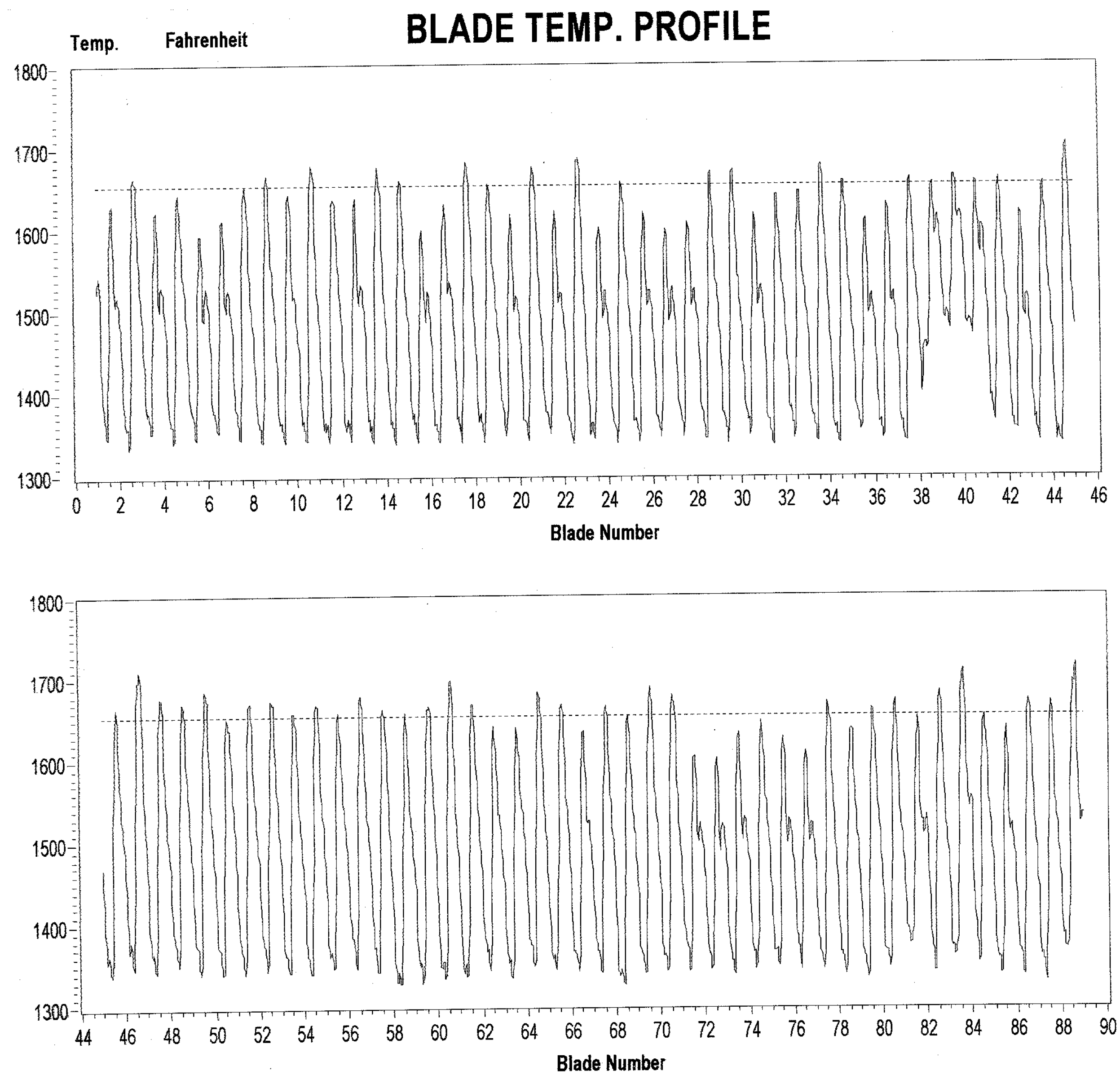

Figure 7-1
Second-Stage Forward Pyrometer Trace - Fuel Gas Baseline 12/16/97 12:08 Hours

Output:	169.8 MW	# Blades:	88	ABPT:	1654°F (901°C)
CIT:	52°F (11°C)	Max Blade #:	46	Max T:	1717°F (936°C)
EGT:	1070°F (577°C)	Min Blade #:	5	Min T:	1595°F (868°C)

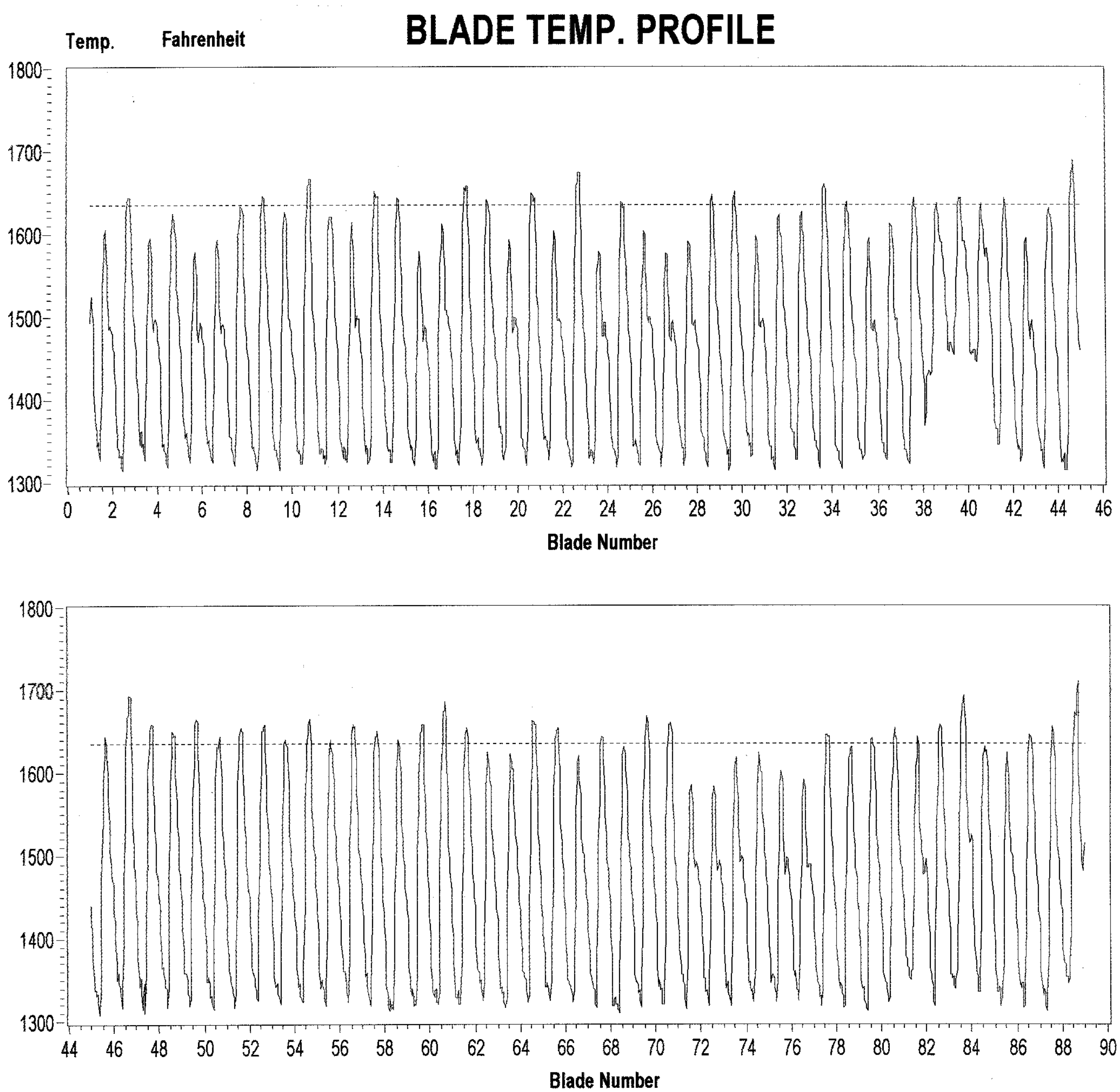

Figure 7-2
Second-Stage Forward Pyrometer Trace - Fuel Oil Baseline 12/18/97 12:11 Hours

Output:	185.8 MW	# Blades:	88	ABPT:	1636°F (891°C)
CIT:	42°F (6°C)	Max Blade #:	46	Max T:	1710°F (932°C)
EGT:	1025°F (552°C)	Min Blade #:	5	Min T:	1583°F (862°C)

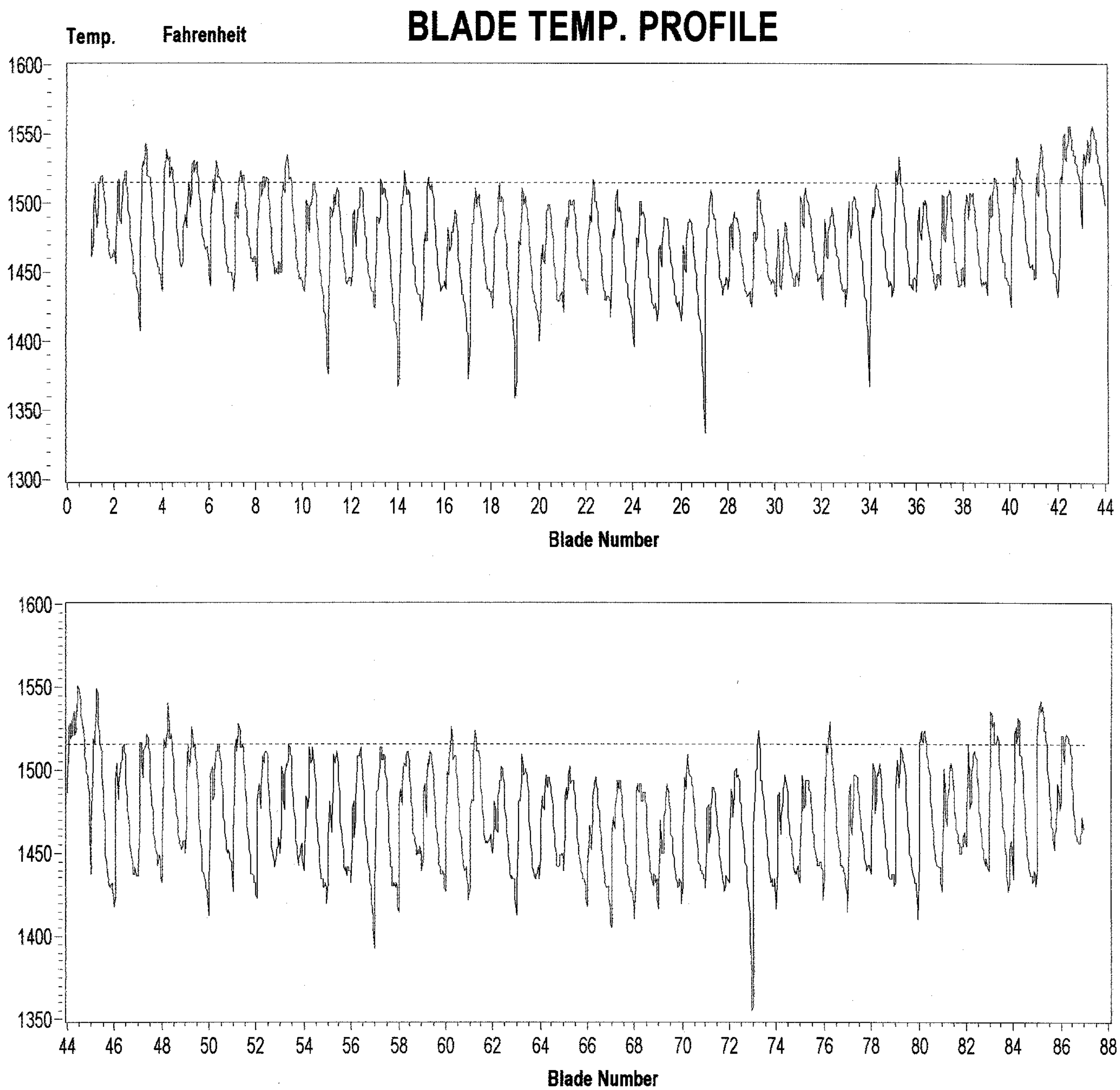

Figure 7-3
Third-Stage Forward Pyrometer Trace - Fuel Gas Baseline 12/16/97 12:08 Hours

Output:	169.8 MW	# Blades:	86	ABPT:	1515°F (824°C)
CIT:	52°F (11°C)	Max Blade #:	42	Max T:	1557°F (847°C)
EGT:	1070° (577°C)	Min Blade #:	30	Min T:	1477°F (803°C)

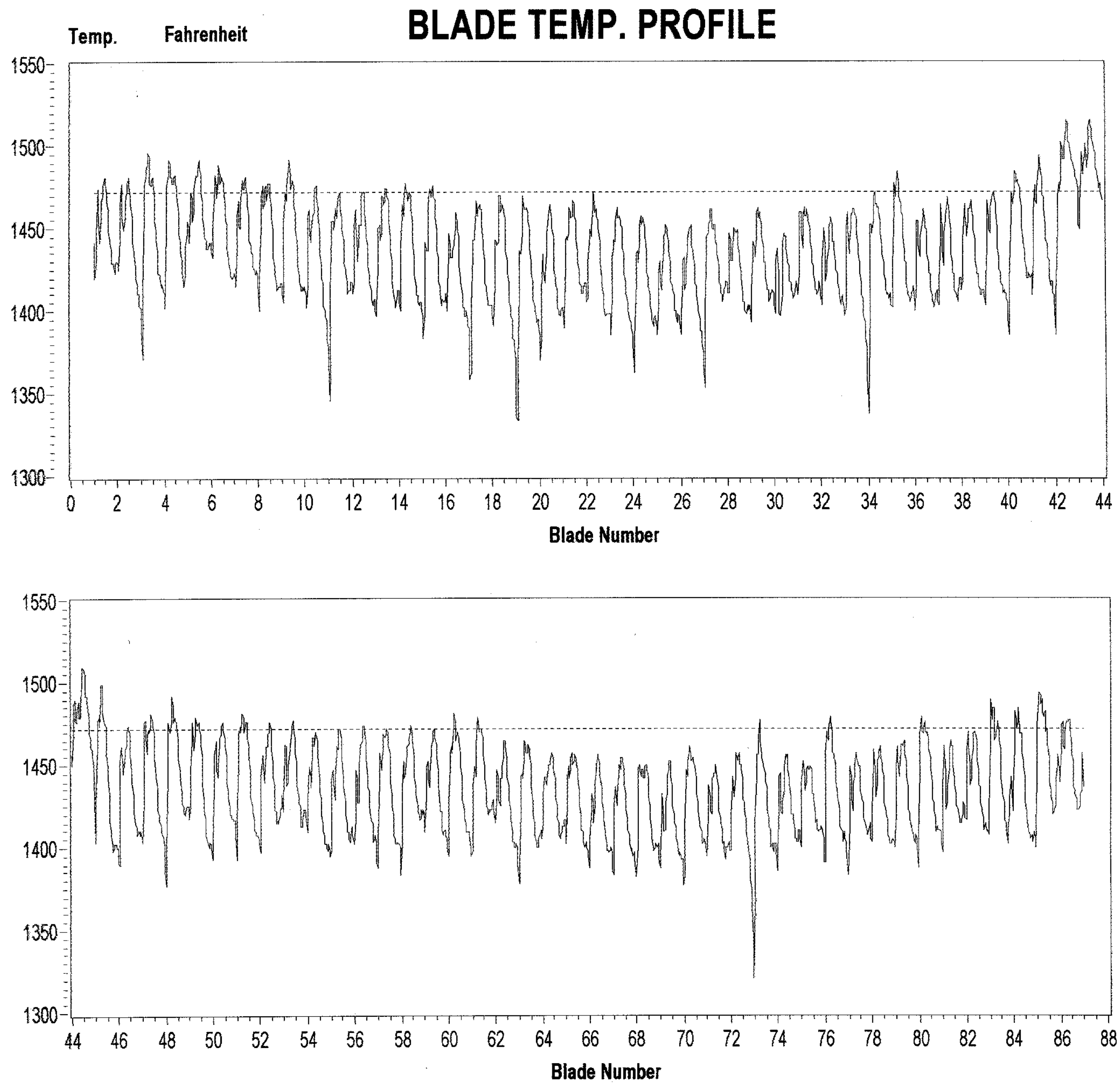

Figure 7-4
Third-Stage Forward Pyrometer Trace - Fuel Oil Baseline 12/18/97 12:11 Hours

Output:	185.8 MW	# Blades:	86	ABPT:	1472°F (800°C)
CIT:	42°F (6°C)	Max Blade #:	44	Max T:	1515°F (824°C)
EGT:	1025° (552°C)	Min Blade #:	30	Min T:	1440°F (782°C)

Winter and Summer Peaking Data

Second-Stage Pyrometer Traces

The pyrometer traces shown in Figures 7-5 through 7-11 provide pyrometer data from the winter and summer peaking seasons. Data were taken from February 26, 1998, to September 4, 1998. The pyrometer data display clear traces, which indicate proper pyrometer operation and a high degree of repeatability. The traces have similar profiles, which can be verified by observing that the higher temperature blades and the lower temperature blades are consistent for all traces.

Table 7-2
Second-Stage Forward Pyrometer Figures for Winter and Summer Peaking Data

Figure No.	Subject	Comments
7-5	Second-Stage Forward Pyrometer - Fuel Oil	Data Taken on 2/26/98 at 21:05 Hours
7-6	Second-Stage Forward Pyrometer - Fuel Gas	Data Taken on 7/10/98 at 15:01 Hours
7-7	Second-Stage Forward Pyrometer - Fuel Gas	Data Taken on 7/27/98 at 15:05 Hours
7-8	Second-Stage Forward Pyrometer - Fuel Gas	Data Taken on 8/04/98 at 15:50 Hours
7-9	Second-Stage Forward Pyrometer - Fuel Gas	Data Taken on 8/16/98 at 19:00 Hours
7-10	Second-Stage Forward Pyrometer - Fuel Gas	Data Taken on 8/26/98 at 17:00 Hours
7-11	Second-Stage Forward Pyrometer - Fuel Gas	Data Taken on 9/04/98 at 15:40 Hours

For example, in the pyrometer trace from July 10, 1998, shown in Figure 7-6, analysis of the maximum and minimum peak blade surface temperatures shows that some blades operate at higher temperature levels than other blades of the same stage:

- Blades No. 17, 22, 44, 46, 60, 83, and 88 operate at higher temperature levels in the 1655°F–1679°F (902°C–915°C) range.
- Blades No. 5, 15, 23, 26, 71, 72, and 76 operate at lower temperature levels in the 1551°F–1570°F (844°C–854°C) range.

There is a temperature differential of 106°F (59°C) between the highest (#83) and the lowest (#26), indicating non-uniform cooling characteristic of the blades. In reviewing the manufacturing process, ABB determined that these variations were caused by tolerances in the through-flow air cooling characteristics of the blades. These variations were determined by ABB to be acceptable for maintaining cooling and life expectancy of the rotor blades.

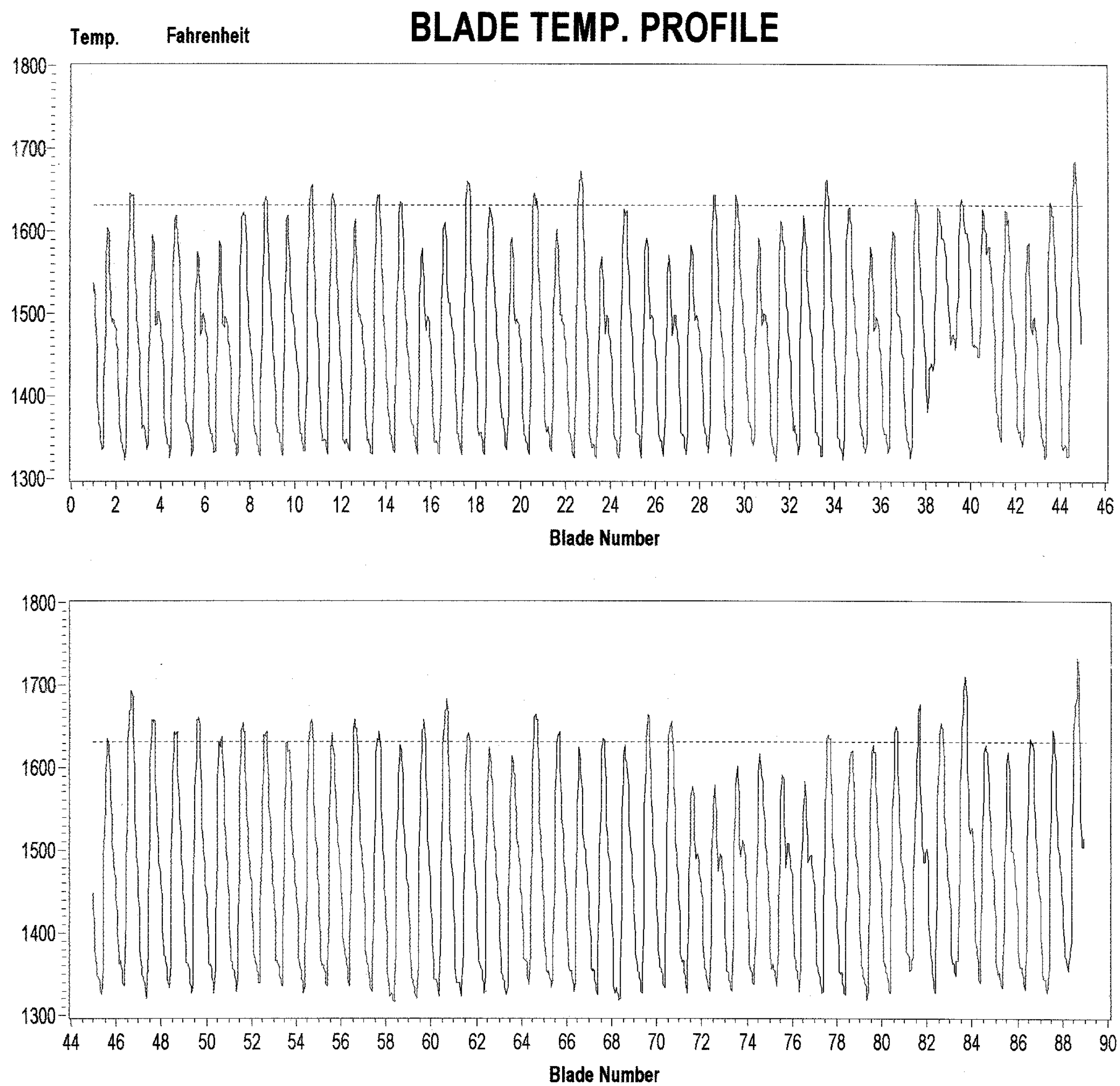

Figure 7-5
Second-Stage Forward Pyrometer Trace - Fuel Oil - 2/26/98 21:05 Hours

Output:	183.0 MW	# Blades:	88	ABPT:	1630°F (888°C)
CIT:	45°F (7°C)	Max Blade #:	88	Max T:	1733°F (945°C)
EGT:	1025°F (552°C)	Min Blade #:	23	Min T:	1564°F (851°C)

Figure 7-5 shows a differential of 169°F (94°C) between the maximum (#88) and minimum (#23) blade temperatures. The temperature variation between blades is high, indicating non-uniform air cooling characteristic of the blades. Thanks to this lesson learned, the through-flow characteristics of every blade are measured by the manufacturer as a quality assurance step during the machine assembly to prevent similar occurrences. This blade temperature trace represents the turbine running on oil and should be compared to the oil baseline trace from December 18, 1997, shown in Figure 7-2. These variations were determined by ABB to be acceptable for maintaining cooling and life expectancy of the rotor blades.

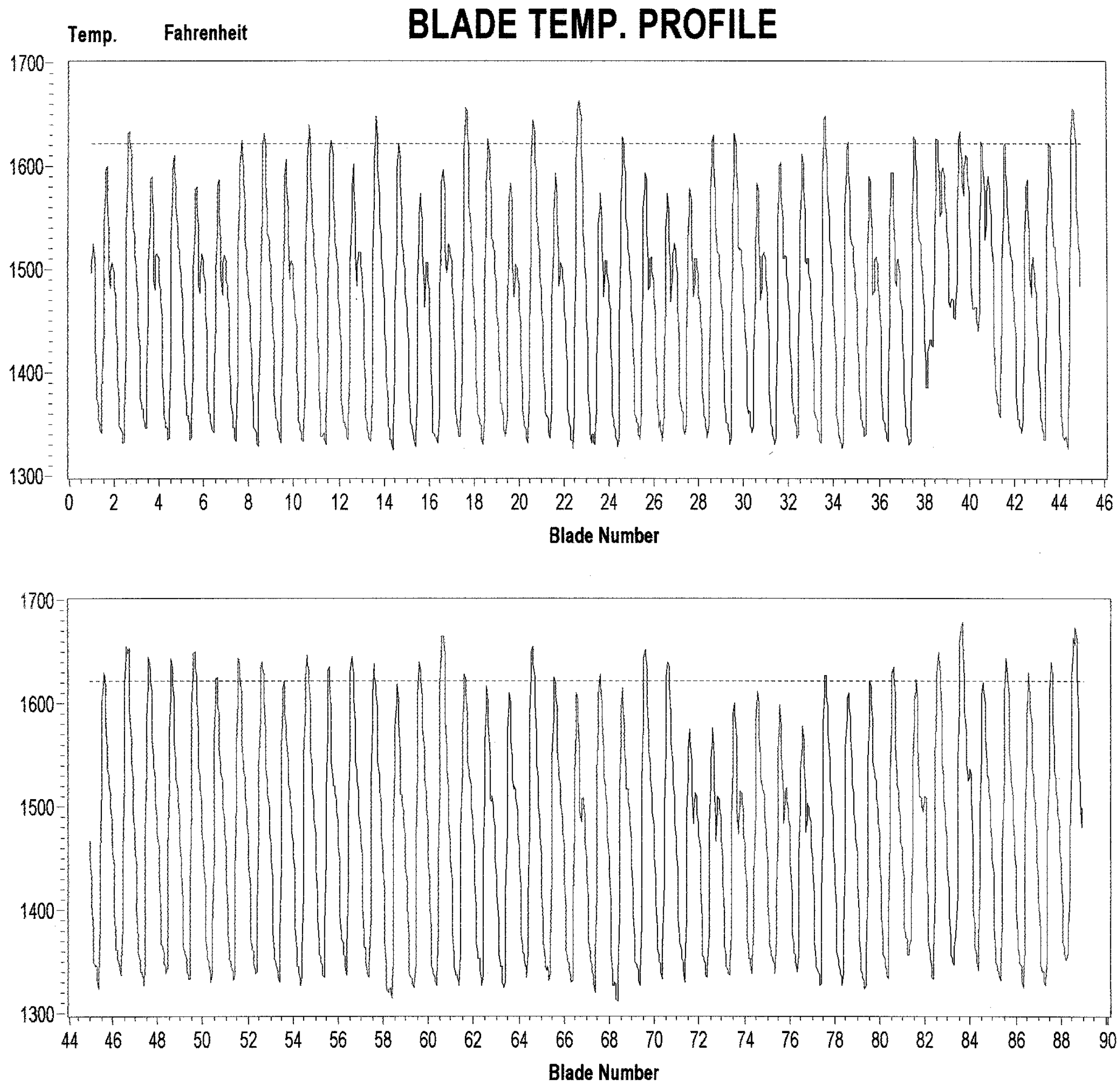

Figure 7-6
Second-Stage Forward Pyrometer Trace - Fuel Gas - 7/10/98 15:01 Hours

Output:	155.8 MW	# Blades:	88	ABPT:	1621°F (883°C)
CIT:	82°F (28°C)	Max Blade #:	83	Max T:	1679°F (915°C)
EGT:	1086°F (586°C)	Min Blade #:	26	Min T:	1573°F (856°C)

Figure 7-6 shows a differential of 106°F (59°C) between the maximum (#83) and minimum (#26) blade temperatures. The temperature variation between blades is high, indicating non-uniform air cooling characteristic of the blades. These variations were determined by ABB to be acceptable for maintaining cooling and life expectancy of the rotor blades.

This blade temperature trace represents the turbine running on gas and should be compared to the gas baseline trace from December 16, 1997, shown in Figure 7-1.

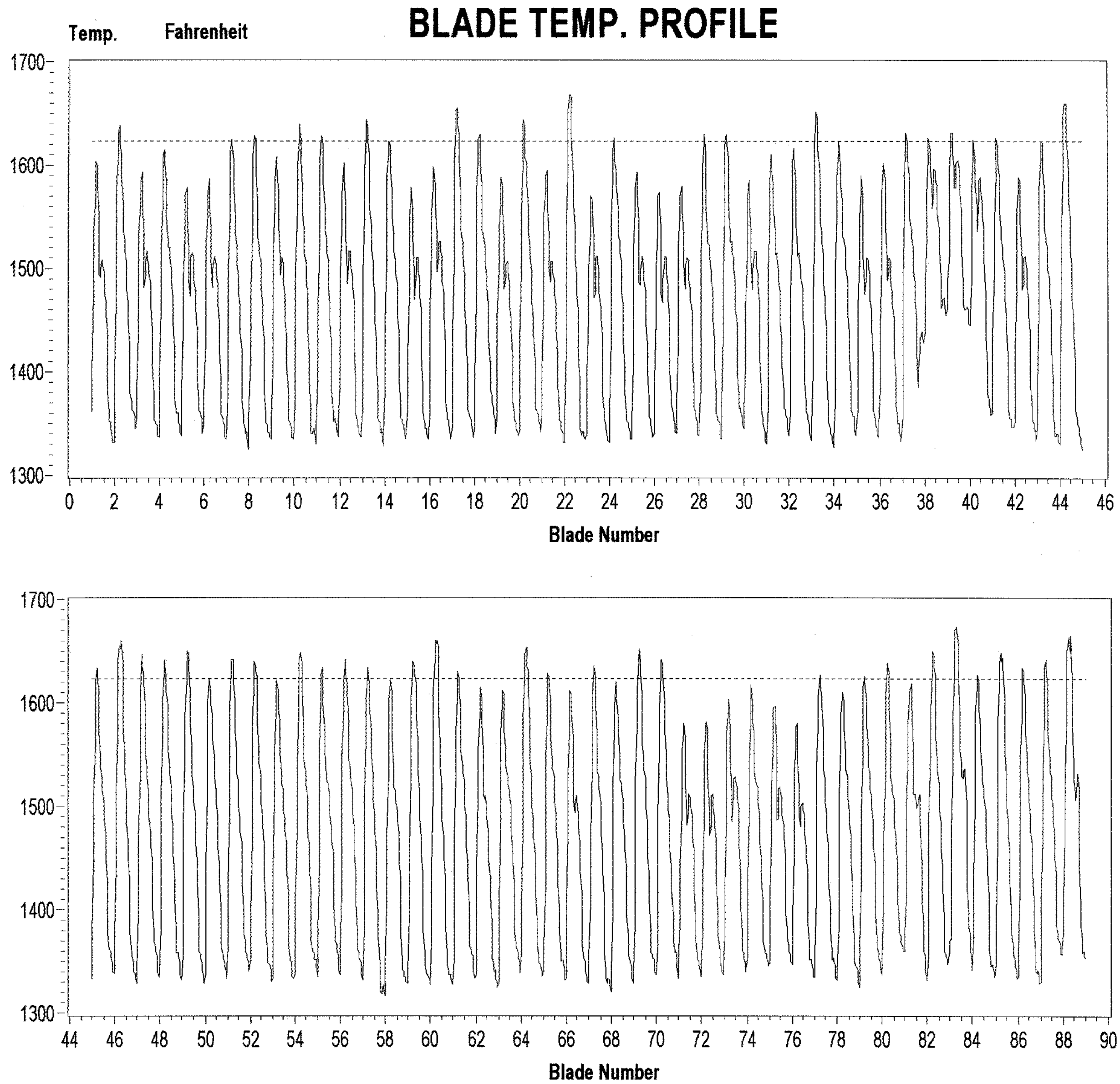

Figure 7-7
Second-Stage Forward Pyrometer Trace - Fuel Gas - 7/27/98 15:05 Hours

Output:	156.5 MW	# Blades:	88	ABPT:	1623°F (884°C)
CIT:	83°F (28°C)	Max Blade #:	83	Max T:	1674°F (912°C)
EGT:	1088°F (587°C)	Min Blade #:	23	Min T:	1570°F (854°C)

Figure 7-7 shows a differential of 104°F (58°C) between the maximum (#83) and minimum (#23) blade temperatures. The temperature variation between blades is high, indicating non-uniform air cooling characteristic of the blades. These variations were determined by ABB to be acceptable for maintaining cooling and life expectancy of the rotor blades.

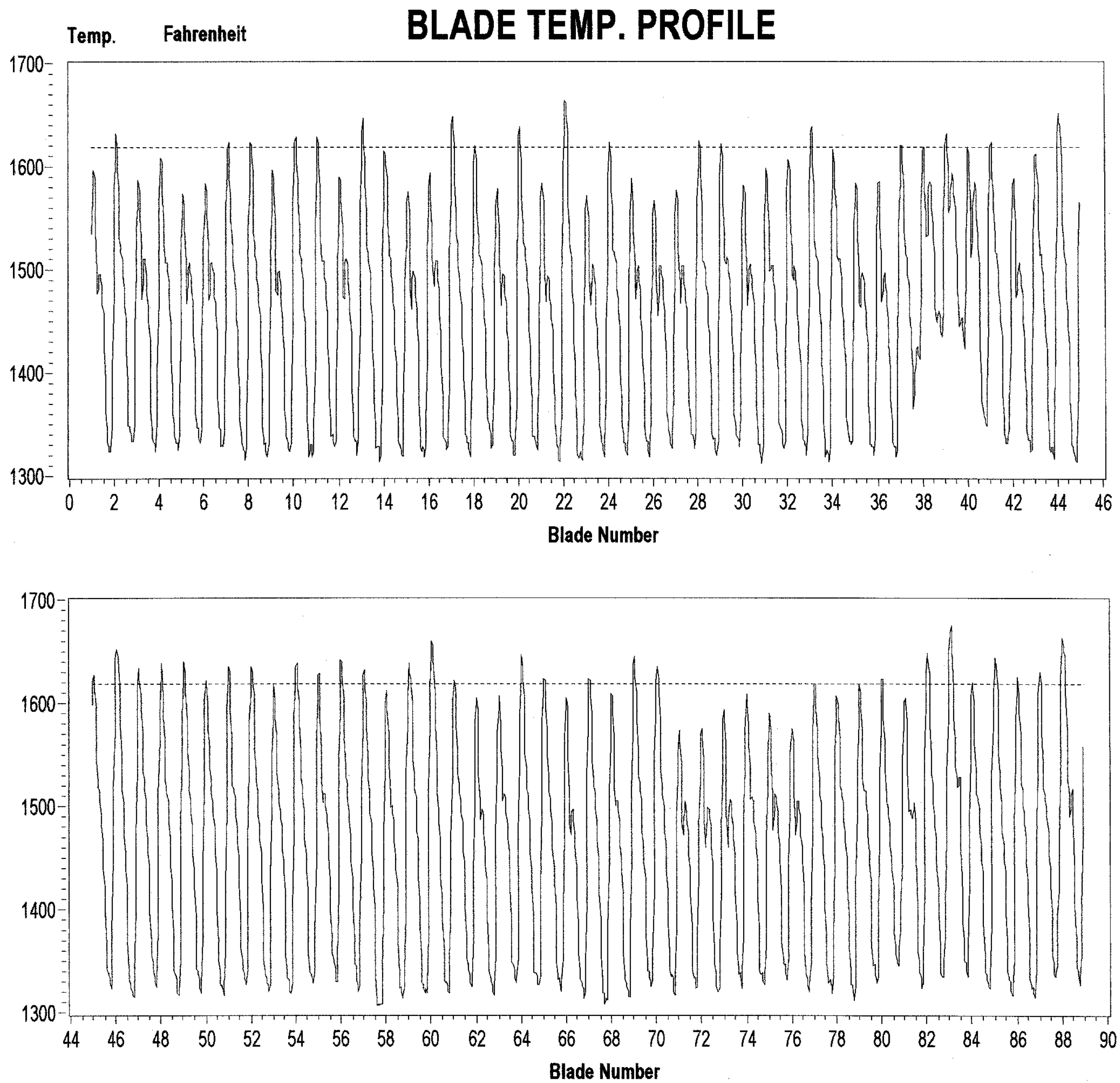

Figure 7-8
Second-Stage Forward Pyrometer Trace - Fuel Gas - 8/04/98 15:50 Hours

Output:	151.0 MW	# Blades:	88	ABPT:	1618°F (881°C)
CIT:	89°F (32°C)	Max Blade #:	82	Max T:	1675°F (913°C)
EGT:	1091°F (588°C)	Min Blade #:	26	Min T:	1570°F (854°C)

Figure 7-8 shows a differential of 105°F (58°C) between the maximum (#82) and minimum (#26) blade temperatures. The temperature variation between blades is high, indicating non-uniform air cooling characteristic of the blades. These variations were determined by ABB to be acceptable for maintaining cooling and life expectancy of the rotor blades.

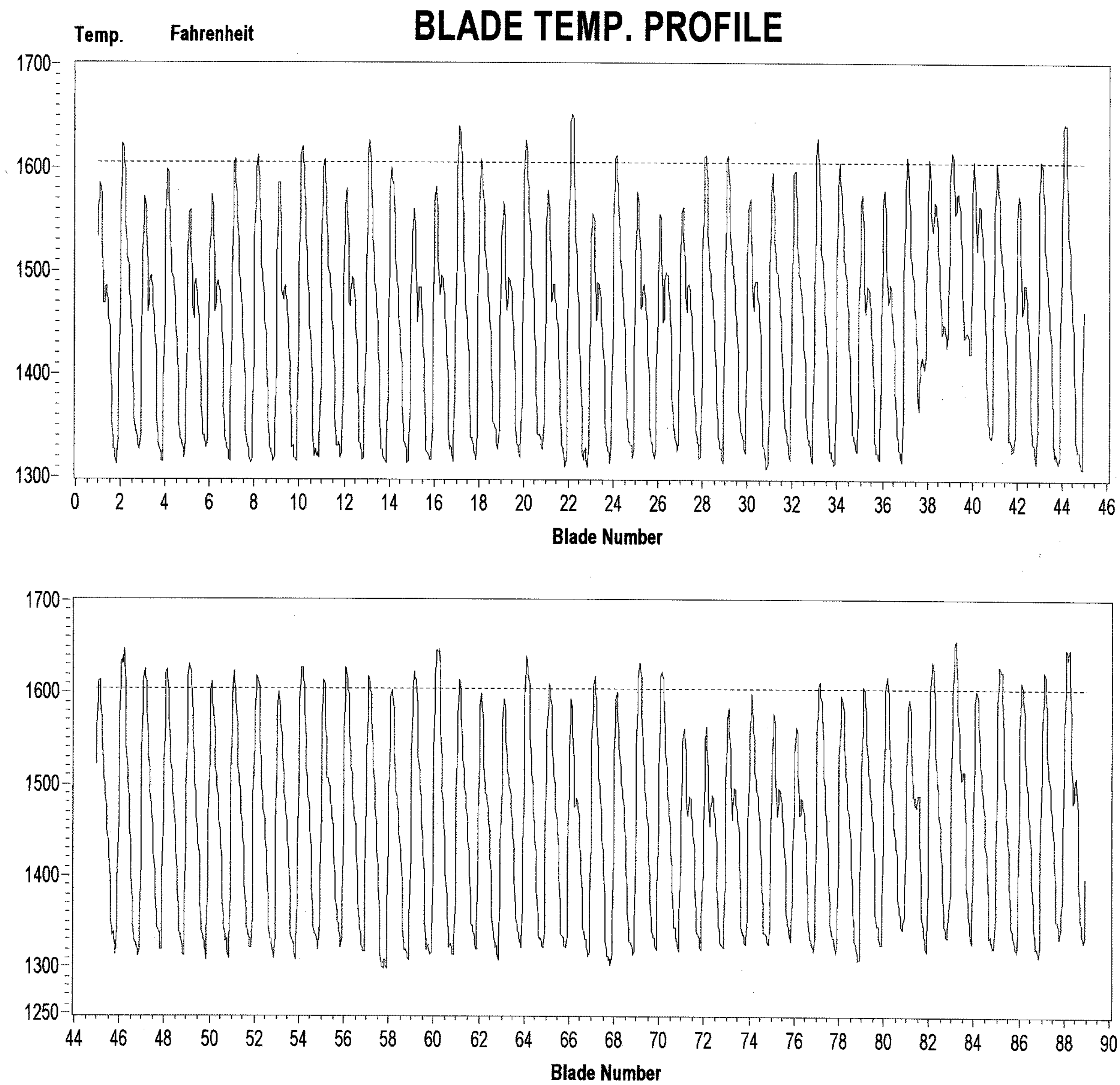

Figure 7-9
Second-Stage Forward Pyrometer Trace - Fuel Gas - 8/16/98 19:00 Hours

Output:	143.7 MW	# Blades:	88	ABPT:	1605°F (874°C)
CIT:	84°F (29°C)	Max Blade #:	22	Max T:	1657°F (903°C)
EGT:	1085°F (585°C)	Min Blade #:	26	Min T:	1554°F (846°C)

Figure 7-9 shows a differential of 103°F (57°C) between the maximum (#22) and minimum (#26) blade temperatures. The temperature variation between blades is high, indicating non-uniform air cooling characteristic of the blades. These variations were determined by ABB to be acceptable for maintaining cooling and life expectancy of the rotor blades.

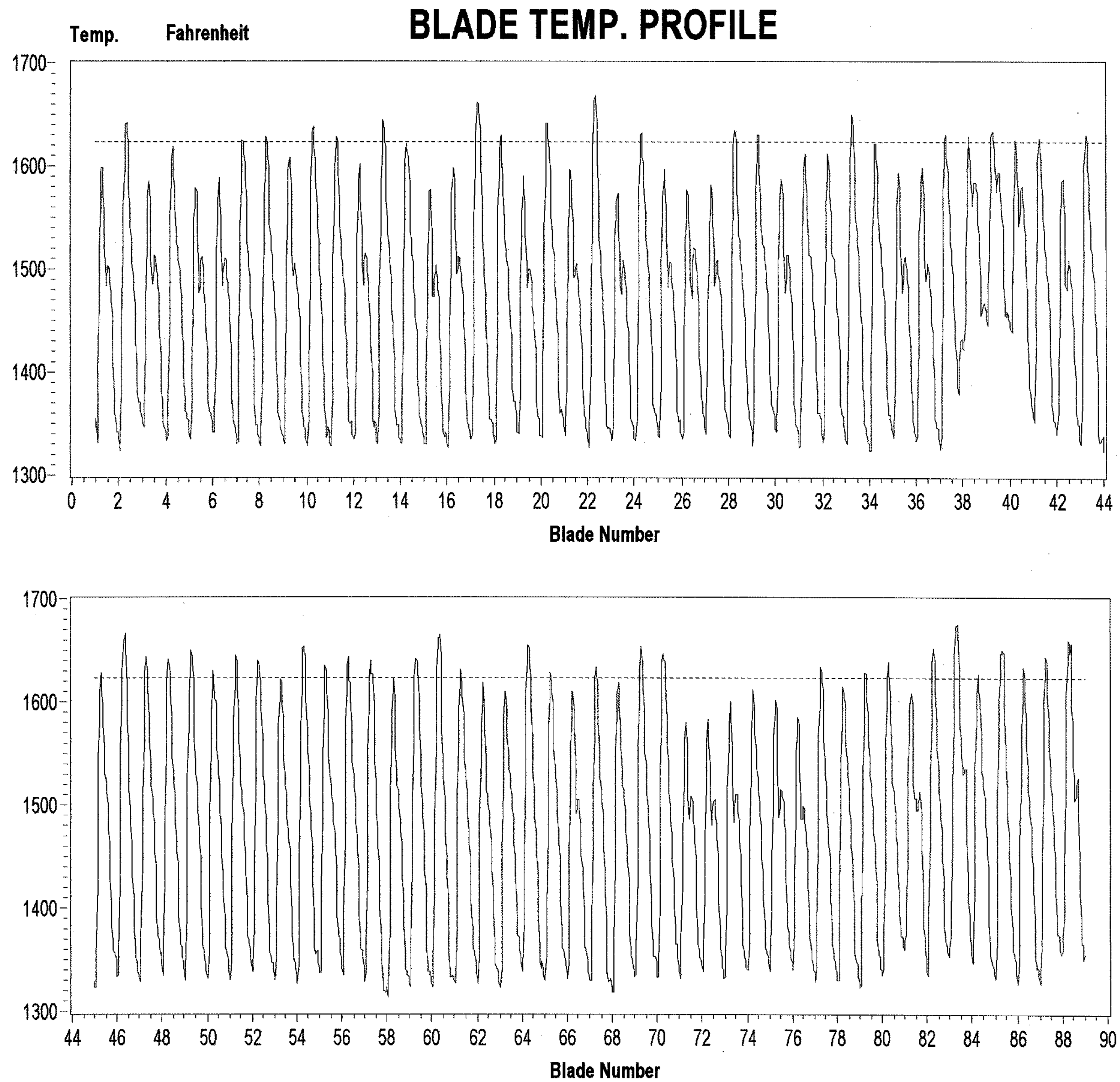

Figure 7-10
Second-Stage Forward Pyrometer Trace - Fuel Gas - 8/26/98 17:00 Hours

Output:	150.8 MW	# Blades:	88	ABPT:	1623°F (884°C)
CIT:	87°F (31°C)	Max Blade #:	83	Max T:	1675°F (913°C)
EGT:	1092°F (589°C)	Min Blade #:	23	Min T:	1570°F (854°C)

Figure 7-10 shows a differential of 105°F (58°C) between the maximum (#83) and minimum (#26) blade temperatures. The temperature variation between blades is high, indicating non-uniform air cooling characteristic of the blades. These variations were determined by ABB to be acceptable for maintaining cooling and life expectancy of the rotor blades.

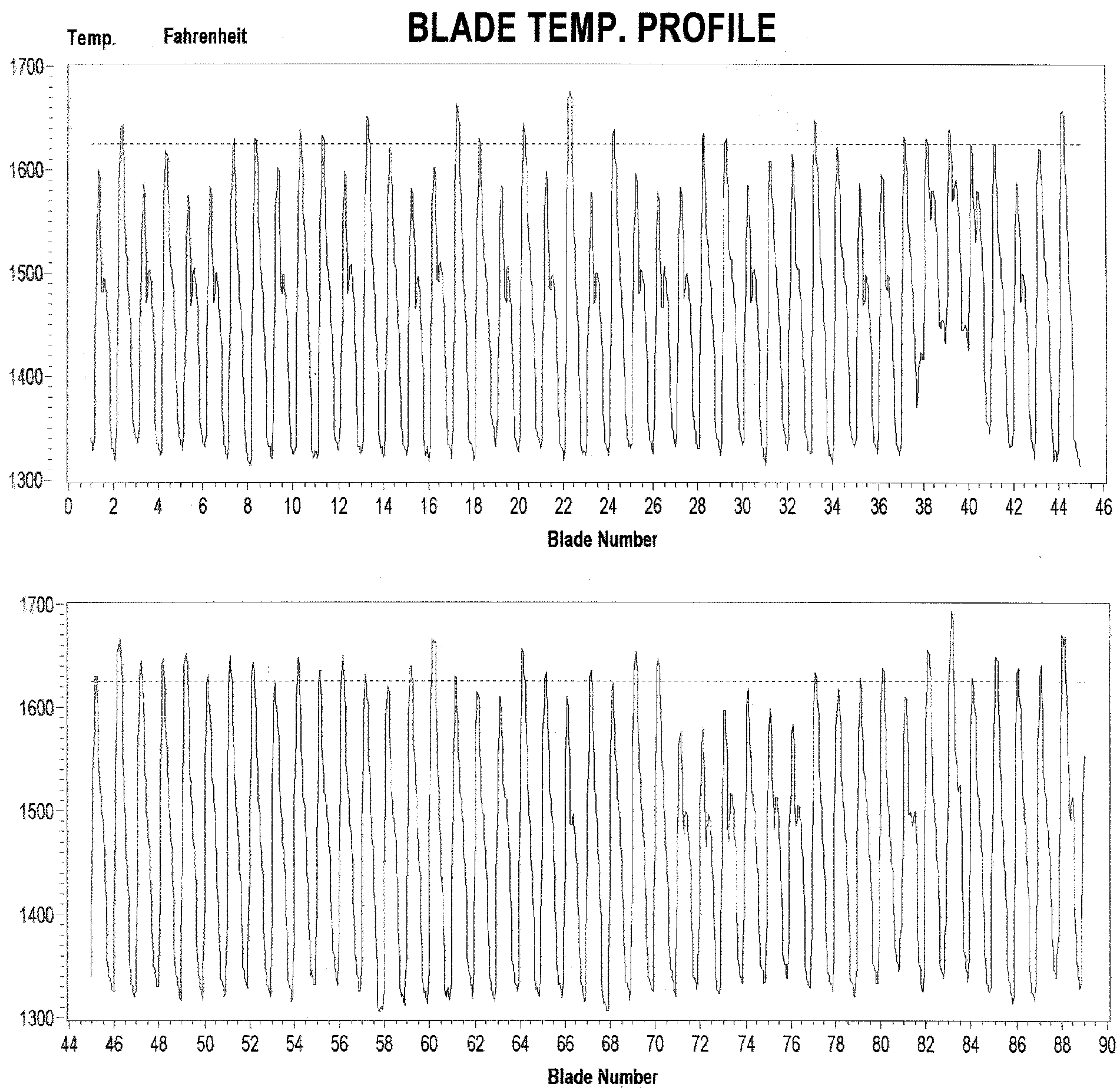

Figure 7-11
Second-Stage Forward Pyrometer Trace - Fuel Gas - 9/04/98 15:40 Hours

Output:	151.5 MW	# Blades:	88	ABPT:	1625°F (885°C)
CIT:	83°F (28°C)	Max Blade #:	83	Max T:	1693°F (923°C)
EGT:	1088°F (587°C)	Min Blade #:	5	Min T:	1576°F (858°C)

Figure 7-11 shows a differential of 117°F (65°C) between the maximum (#83) and minimum (#5) blade temperatures. The temperature variation between blades is high, indicating non-uniform air cooling characteristic of the blades. These variations were determined by ABB to be acceptable for maintaining cooling and life expectancy of the rotor blades.

Third-Stage Pyrometer Traces

The pyrometer traces shown in Figures 7-12 through 7-18 provide additional pyrometer data from February 26, 1998, to September 4, 1998. The pyrometer data display clear traces, which indicate proper pyrometer operation and a high degree of accuracy. The traces have similar profiles, which can be verified by observing that the higher temperature blades and the lower temperature blades are consistent for all the traces.

Table 7-3
Third-Stage Forward Pyrometer Figures for Winter and Summer Peaking Data

Figure No.	Subject	Comments
7-12	Third-Stage Forward Pyrometer - Fuel Oil	Data Taken on 2/26/98 at 21:05 Hours
7-13	Third-Stage Forward Pyrometer - Fuel Gas	Data Taken on 7/10/98 at 15:01 Hours
7-14	Third-Stage Forward Pyrometer - Fuel Gas	Data Taken on 7/27/98 at 15:05 Hours
7-15	Third-Stage Forward Pyrometer - Fuel Gas	Data Taken on 8/04/98 at 15:50 Hours
7-16	Third-Stage Forward Pyrometer - Fuel Gas	Data Taken on 8/16/98 at 19:00 Hours
7-17	Third-Stage Forward Pyrometer - Fuel Gas	Data Taken on 8/26/98 at 17:00 Hours
7-18	Third-Stage Forward Pyrometer - Fuel Gas	Data Taken on 9/04/98 at 15:40 Hours

For example, in the pyrometer trace from July 10, 1998, shown in Figure 7-13, analysis of the maximum and minimum peak blade surface temperatures shows that some blades operate at slightly higher temperature levels than other blades of the same stage:

- Blades No. 3, 4, 42, 43, 44, 45, 83, and 85 operate at higher temperature levels in the 1535°F–1560°F (835°C–849°C) range.
- Blades No. 26, 28, 30, 66, 67, 69, 71, and 75 operate at lower temperature levels in the 1486°F–1497°F (808°C–814°C) range.

The differential of 74° F (41°C) between the highest (#42) and the lowest (#30) blade temperatures is normal and indicates uniform cooling of the blades.

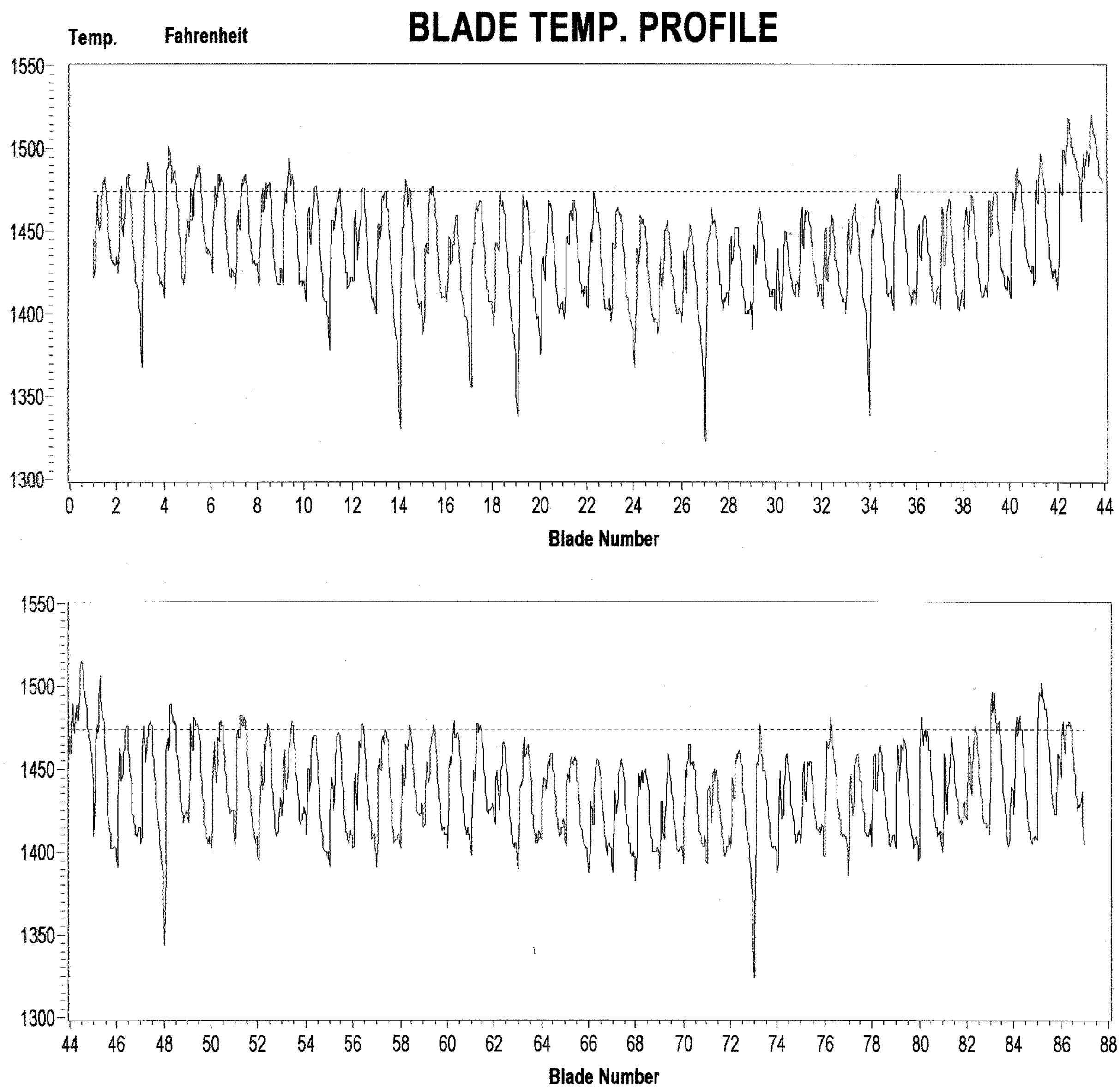

Figure 7-12
Third-Stage Forward Pyrometer Trace - Fuel Oil - 2/26/98 21:05 Hours

Output:	183.0 MW	# Blades:	86	ABPT:	1474°F (801°C)
CIT:	45°F (7°C)	Max Blade #:	43	Max T:	1521°F (827°C)
EGT:	1025°F (552°C)	Min Blade #:	30	Min T:	1451°F (788°C)

Figure 7-12 shows a differential of 70°F (39°C) between the maximum (#43) and minimum (#30) blade temperatures. This temperature variation is normal and indicates uniform cooling of the turbine blades.

This blade temperature trace was taken when the turbine was running on fuel oil and has similar characteristics as the oil baseline trace from December 18, 1997 (Figure 7-4).

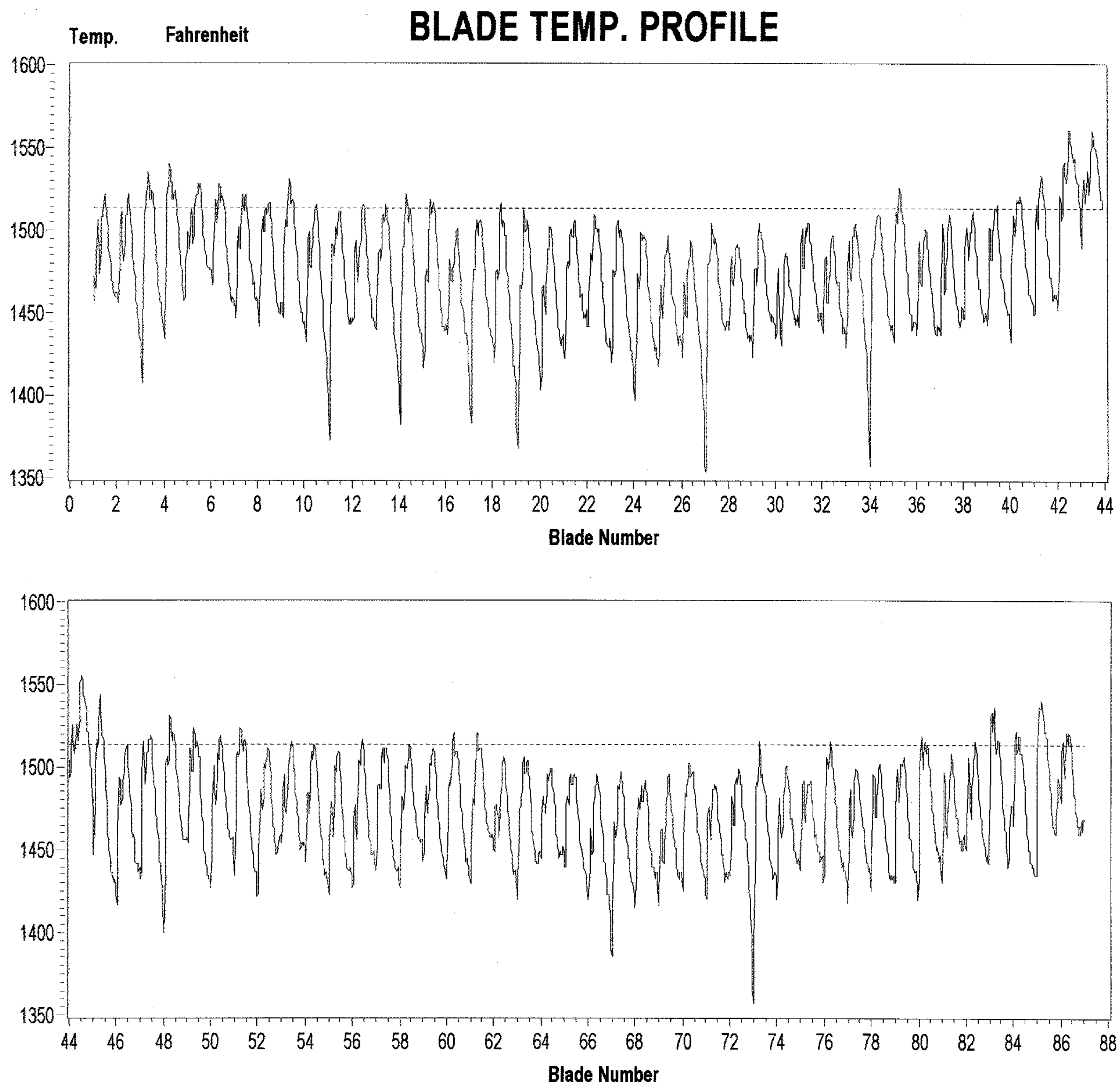

Figure 7-13
Third-Stage Forward Pyrometer Trace - Fuel Gas - 7/10/98 15:01 Hours

Output:	155.8 MW	# Blades:	86	ABPT:	1513°F (828°C)
CIT:	82°F (28°C)	Max Blade #:	42	Max T:	1560°F (849°C)
EGT:	1086°F (586°C)	Min Blade #:	30	Min T:	1486°F (808°C)

Figure 7-13 shows a differential of 74°F (41°C) between the maximum (#42) and minimum (#30) blade temperatures. This temperature variation is normal and indicates uniform cooling of the turbine blades.

This blade temperature trace represents the turbine running on gas and has similar characteristics as the gas baseline trace from December 16, 1997 (Figure 7-3).

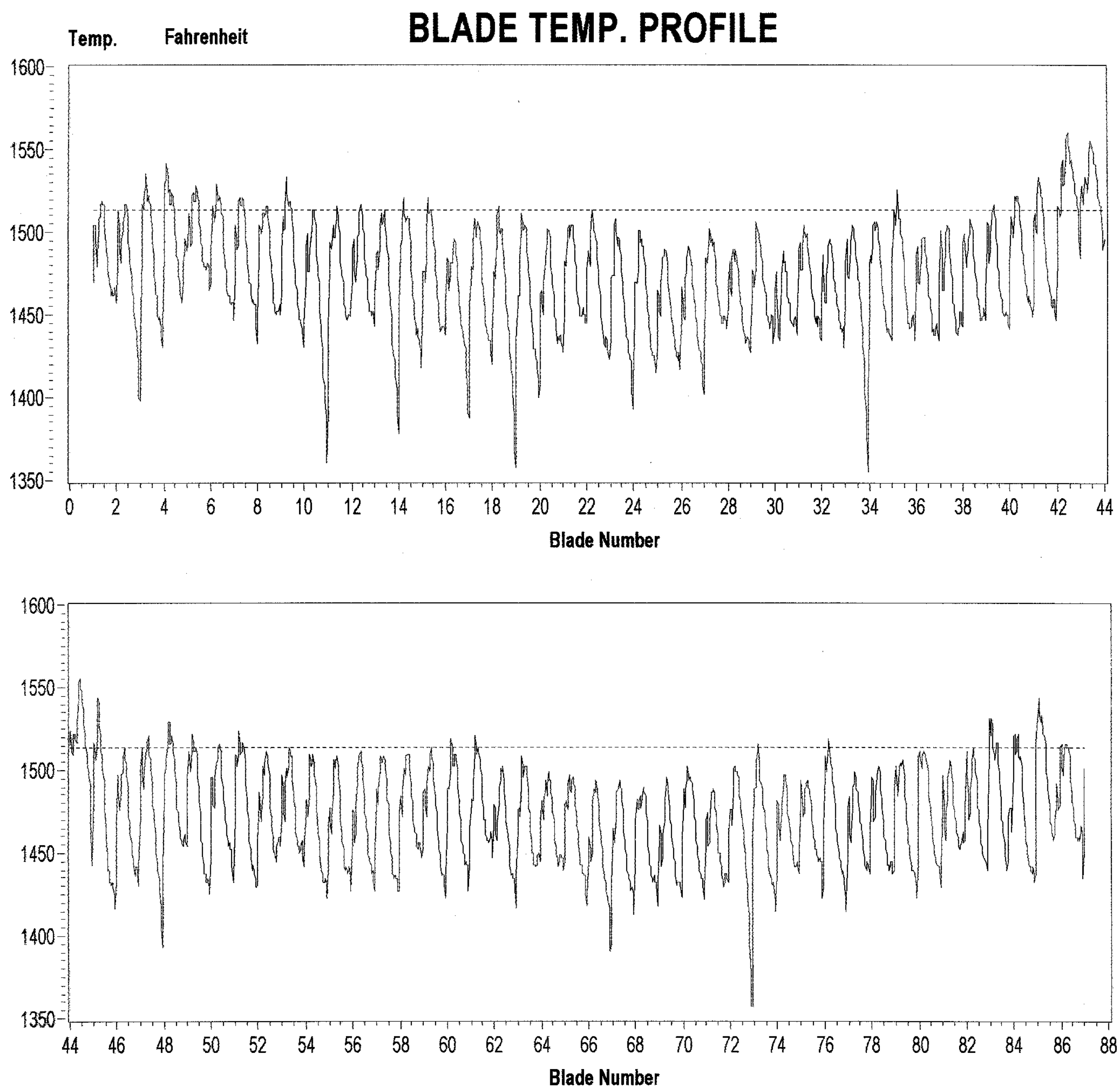

Figure 7-14
Third-Stage Forward Pyrometer Trace - Fuel Gas - 7/27/98 15:05 Hours

Output:	156.5 MW	# Blades:	86	ABPT:	1513°F (823°C)
CIT:	83°F (28°C)	Max Blade #:	43	Max T:	1560°F (849°C)
EGT:	1088°F (587°C)	Min Blade #:	30	Min T:	1488°F (809°C)

Figure 7-14 shows a differential of 72°F (40°C) between the maximum (#43) and minimum (#30) blade temperatures. This temperature variation is normal and indicates uniform cooling of the turbine blades.

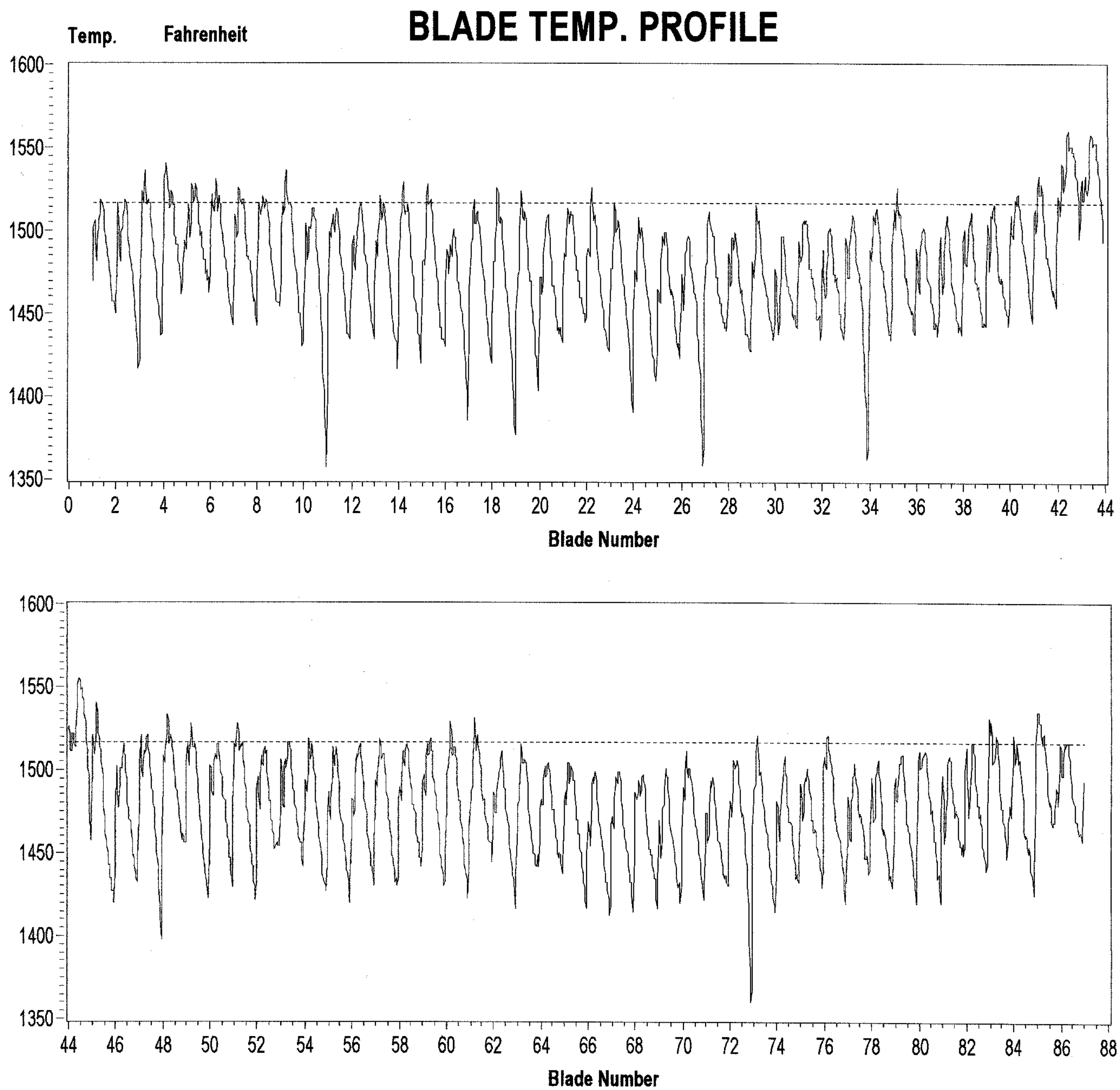

Figure 7-15
Third-Stage Forward Pyrometer Trace - Fuel Gas - 8/04/98 15:50 Hours

Output:	151.0 MW	# Blades:	86	ABPT:	1517°F (825°C)
CIT:	89°F (32°C)	Max Blade #:	43	Max T:	1560°F (849°C)
EGT:	1091°F (588°C)	Min Blade #:	30	Min T:	1497°F (814°C)

Figure 7-15 shows a differential of 63°F (35°C) between the maximum (#43) and minimum (#30) blade temperatures. This temperature variation is normal and indicates uniform cooling of the turbine blades.

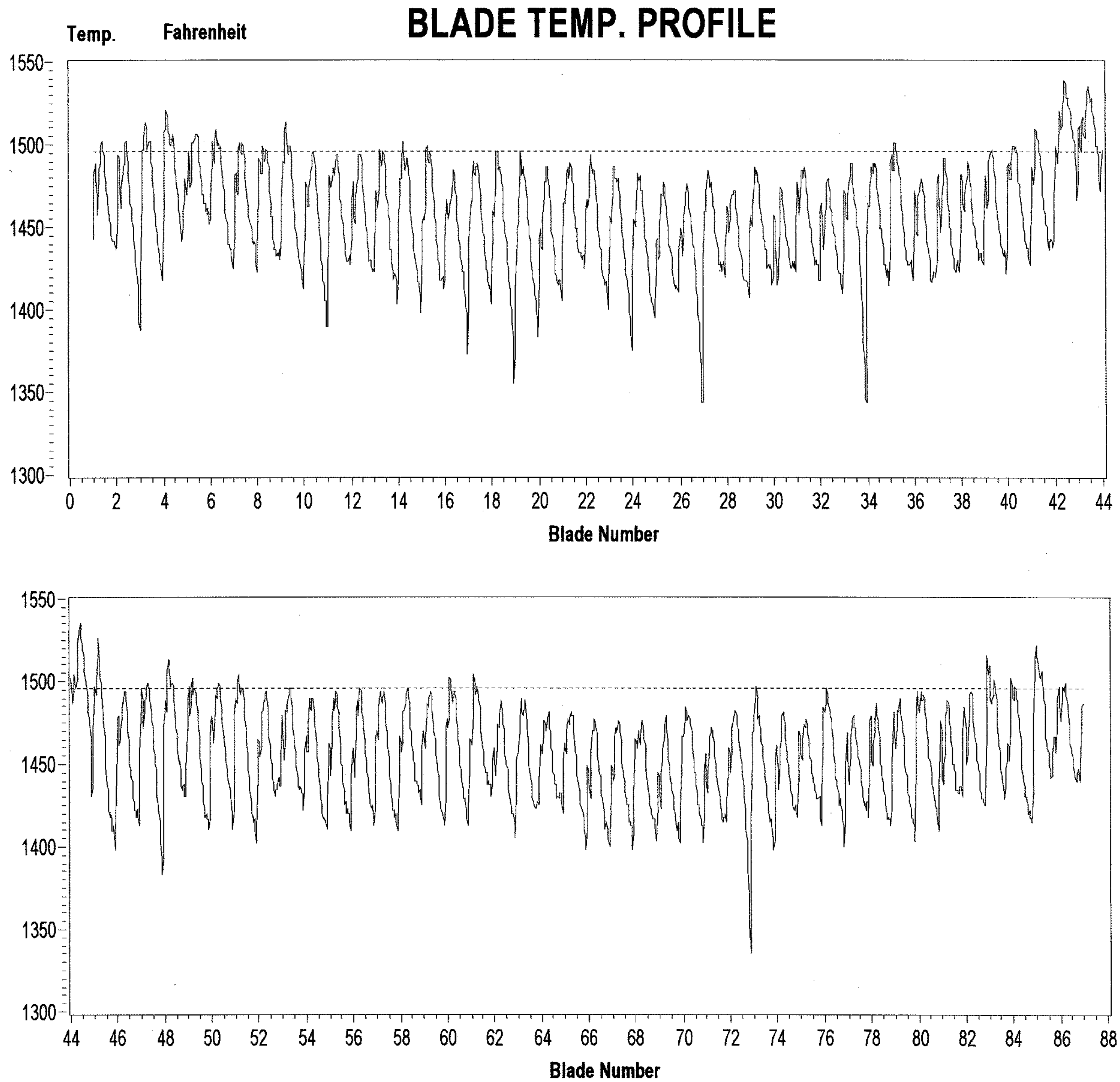

Figure 7-16
Third-Stage Forward Pyrometer - Fuel Gas - 8/16/98 19:00 Hours

Output:	143.7 MW	# Blades:	86	ABPT:	1495°F (813°C)
CIT:	84°F (29°C)	Max Blade #:	42	Max T:	1539°F (837°C)
EGT:	1085°F (585°C)	Min Blade #:	30	Min T:	1472°F (800°C)

Figure 7-16 shows a differential of 67°F (37°C) between the maximum (#42) and minimum (#30) blade temperatures. This temperature variation is normal and indicates uniform cooling of the turbine blades.

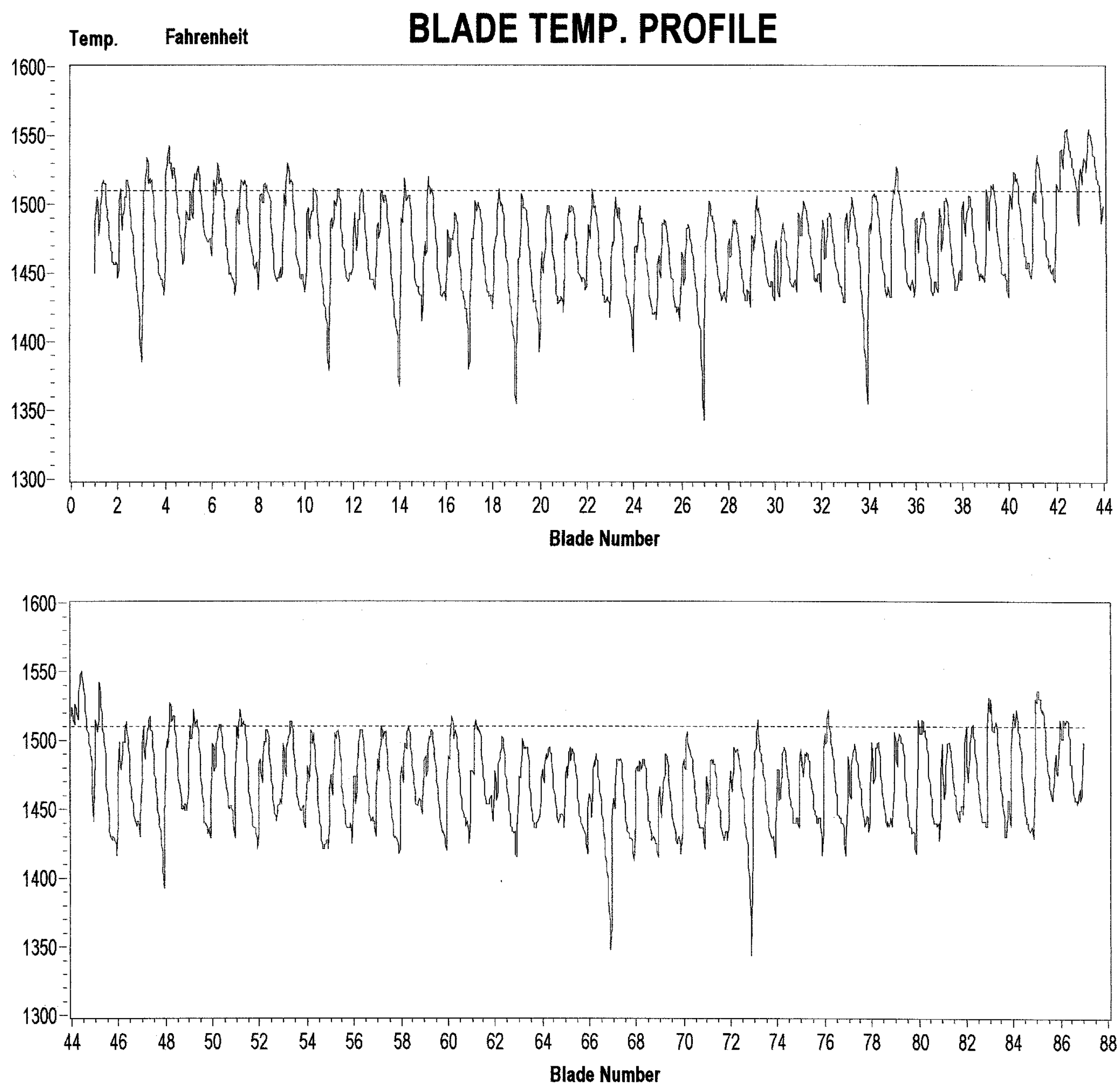

Figure 7-17
Third-Stage Forward Pyrometer - Fuel Gas - 8/26/98 17:00 Hours

Output:	150.8 MW	# Blades:	86	ABPT:	1510°F (821°C)
CIT:	87°F (31°C)	Max Blade #:	42	Max T:	1555°F (846°C)
EGT:	1092°F (589°C)	Min Blade #:	30	Min T:	1485°F (807°C)

Figure 7-17 shows a differential of 70°F (39°C) between the maximum (#42) and minimum (#30) blade temperatures. This temperature variation is normal and indicates uniform cooling of the turbine blades.

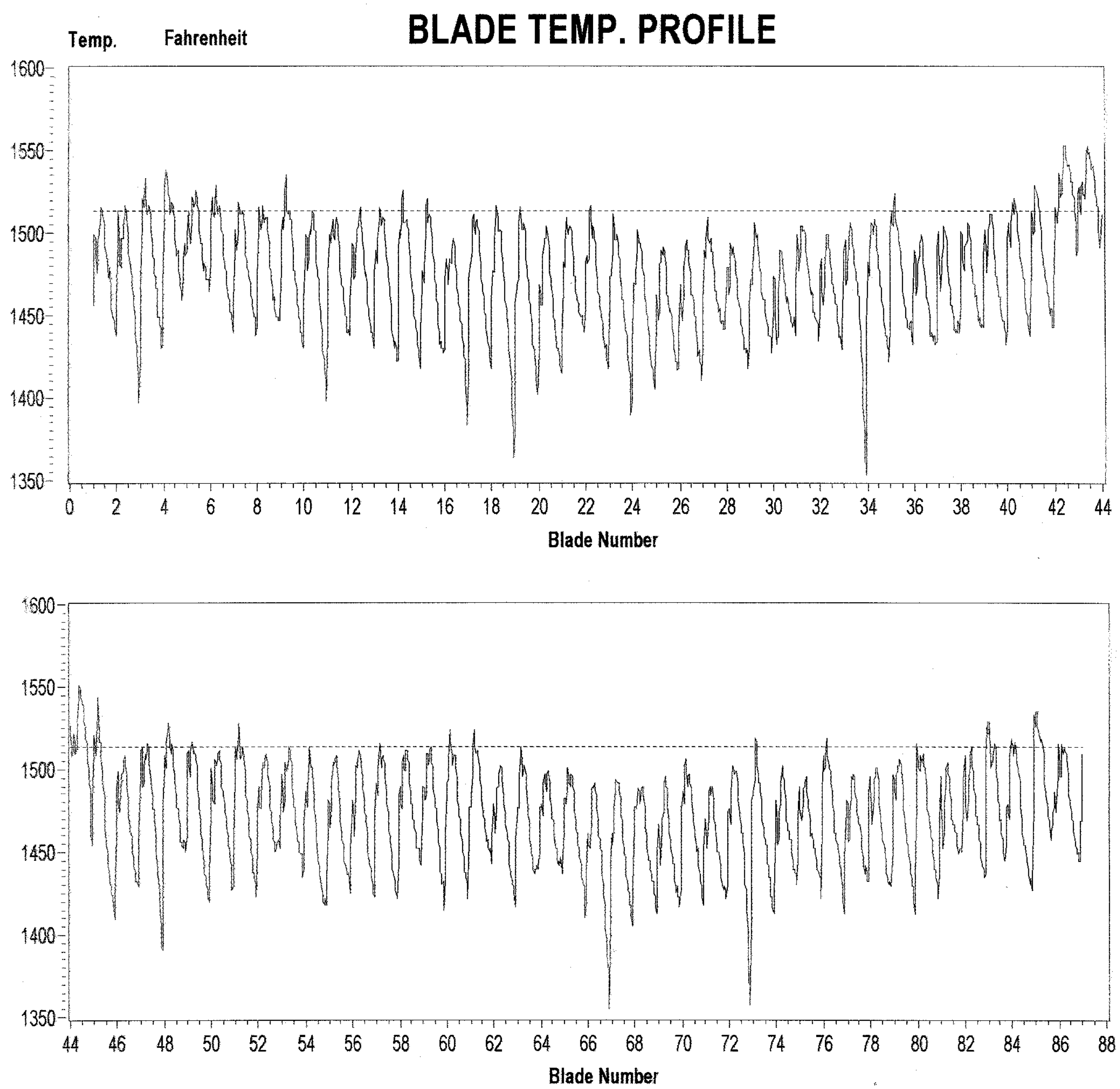

Figure 7-18
Third-Stage Forward Pyrometer - Fuel Gas - 9/04/98 15:40 Hours

Output:	151.5 MW	# Blades:	86	ABPT:	1513°F (823°C)
CIT:	83°F (28°C)	Max Blade #:	43	Max T:	1553°F (845°C)
EGT:	1088°F (587°C)	Min Blade #:	25	Min T:	1491°F (811°C)

Figure 7-18 shows a differential of 62°F (34°C) between the maximum (#43) and minimum (#25) blade temperatures. This temperature variation is normal and indicates uniform cooling of the turbine blades.

Pyrometer Data Analysis Summary

Pyrometer data collected to date have yielded important information regarding blade temperature trends in the ABB GT24 at GPU Genco's Gilbert Station. These trends are summarized below:

For the second-stage turbine blades, the 1997 baseline data (December, 16 1997) for gas-firing show a minimum-to-maximum peak temperature differential of 114°F (63°C). The ABPT for this baseline trace is 1654°F (901°C). Approximately one year later, the 1998 data (September 4, 1998) for gas firing show a differential of 117°F (65°C) between the maximum (#83) and minimum (#5) blade temperatures. ABPT for this trace is 1625°F (885°C). Over this nine-month period the differential showed little change. Initially, ABB determined that these variations were caused by tolerances in the through-flow air cooling characteristics of the blades and were determined by ABB to be acceptable for maintaining cooling and life expectancy of the rotor blades. The decrease in ABPT reflects a difference in ambient temperature for the two periods. In conclusion, the minimum-to-maximum peak temperature differential that had been observed during baseline testing appears to be unchanged and consistent with OEM's blade life profile.

A
APPENDIX – LISTING OF EPRI DS GUIDELINES AND STUDIES

The EPRI DS Project included other studies which had examined a FE 7FA advanced gas turbine at Florida Power and Light's Martin plant (combined-cycle, baseload duty) and a GE 7F at Potomac Electric Power Company's Station H (simple-cycle, peaking duty). The following is a list of published guidelines and studies:

TR-103895 Advanced Gas Turbine Guidelines: Rotating Turbine Blade Temperature Measurement System ("BTMS")

TR-103937 Advanced Gas Turbine Guidelines: Data Acquisition System ("DAS") and Baseline Data

TR-104019 Advanced Gas Turbine Guidelines: Performance, Operation and Maintenance Management System ("POMMS")

TR-104101 Advanced Gas Turbine Guidelines: Hot Gas Path Parts Condition Assessment and Remaining Life Assessment for Peaking Operation

TR-104100 Advanced Gas Turbine Guidelines: Vibration Analysis at Station H - GE 7F

TR-105069 Advanced Gas Turbine Guidelines: Blade Temperature Measurement at Martin CC

TR-105856 Advanced Gas Turbine Guidelines: Performance Retention for General Electric 7F Unit in Peaking Operation

TR-106329 Advanced Gas Turbine Guidelines: Hot Gas Path Conditions and Remaining Life Assessment for GE 7FA in Baseload operation

TR-106330 Advanced Gas Turbine Guidelines: Performance Retention for General Electric 7FA in Baseload Operation

TR-108607 Advanced Gas Turbine Guidelines: Summary of Overall Operating History and Experience from GE7F in Peaking Operation

Additional EPRI Published DS Studies

TR-111644 Thermal Performance of the ABB GT24 Gas Turbine in Peaking Service at Gilbert Station of GPU Energy

TR-111645 Testing and Performance of the Siemens V84.3A Gas Turbine in Peaking Service at Hawthorn Station at KCPL