ERDC/CERL TR-06-19

US Army Corps of Engineers®
Engineer Research and Development Center

Detailed Fuel Cell Demonstration Site Summary Report

Edwards Air Force Base, CA

J. Michael Torrey, John F. Westerman, William R. Taylor, Franklin H. Holcomb, and Joseph Bush

August 2006

Construction Engineering Research Laboratory

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Final Report

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Prepared for U.S. Army Corps of Engineers
Washington, DC 20314-1000

Abstract: Fuel cells are an environmentally clean, quiet, and a highly efficient method for generating electricity and heat from natural gas and other fuels. In fiscal year 1993 (FY93), the Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL) was assigned the mission of managing the DOD Fuel Cell Demonstration Program. Specific tasks included developing turnkey PAFC packages, devising site criteria, screening candidate DOD installation sites based on selection criteria, evaluating viable applications at each candidate site, coordinating fuel cell site designs, installation and acceptance of the PAFC power plants, and performance monitoring and reporting.

CERL selected and evaluated 30 application sites, supervised the design and installation of fuel cells, actively monitored the operation and maintenance of fuel cells, and compiled “lessons learned” for feedback to fuel cell manufacturers. At the conclusion of the demonstration period, each of the demonstration fuel cell sites was given the choice to either have the fuel cell removed or to keep the fuel cell power plant. This report presents a detailed review of a 200 kW fuel cell installed at Edwards Air Force Base (AFB) and operated between July 1997 and July 2002.

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Preface

In fiscal years 93 and 94, Congress provided funds for natural gas utilization equipment, part of which was specifically designated for procurement of natural gas fuel cells for power generation at military installations. The purchase, installation, and ongoing monitoring of 30 fuel cells provided by these appropriations has come to be known as the "DOD Fuel Cell Demonstration Program." Additional funding was provided by: the Office of the Deputy Under Secretary of Defense for Industrial Affairs & Installations, ODUSD (IA&I)/HE&E; the Strategic Environmental Research & Development Program (SERDP); the Assistant Chief of Staff for Installation Management (ACSIM); the U.S. Army Center for Public Works (CPW); the Naval Facilities Engineering Service Center (NFESC); and Headquarters (HQ), Air Force Civil Engineer Support Agency (AFCESA).

The work was performed by the Energy Branch (CF-E), of the Facilities Division (CF), Construction Engineering Research Laboratory (CERL). The CERL Principal Investigator was Franklin H. Holcomb. Part of this work was done by Science Applications International Corporation (SAIC) under General Services Administration (GSA) contract No. 5TS5703C166. J. Michael Torrey and John F. Westerman are associated with SAIC. Dr. Thomas Hartranft is Chief, CEERD-CF-E, and L. Michael Golish is Chief, CEERD-CF. The associated Technical Director was Gary W. Schanche, CEERD-CVT. The Director of CERL is Dr. Ilker R. Adiguzel.

CERL is an element of the U.S. Army Engineer Research and Development Center (ERDC), U.S. Army Corps of Engineers. The Commander and Executive Director of ERDC is COL Richard B. Jenkins, and the Director of ERDC is Dr. James R. Houston.

Unit Conversion Factors

Multiply	By	To Obtain
acres	4,046.873	square meters
cubic feet	0.02831685	cubic meters
cubic inches	0.00001638706	cubic meters
degrees (angle)	0.01745329	radians
degrees Fahrenheit	(5/9) x (°F – 32)	degrees Celsius
degrees Fahrenheit	(5/9) x (°F – 32) + 273.15.	kelvins
feet	0.3048	meters
gallons (U.S. liquid)	0.003785412	cubic meters
horsepower (550 ft-lb force per second)	745.6999	watts
inches	0.0254	meters
kips per square foot	47.88026	kilopascals
kips per square inch	6.894757	megapascals
miles (U.S. statute)	1.609347	kilometers
pounds (force)	4.448222	newtons
pounds (force) per square inch	0.006894757	megapascals
pounds (mass)	0.4535924	kilograms
square feet	0.09290304	square meters
square miles	2,589,998	square meters
tons (force)	8,896.443	newtons
tons (2,000 pounds, mass)	907.1847	kilograms
yards	0.9144	meters

1 Introduction

1.1 Background

In fiscal year 1993 (FY93), the U.S. Congress appropriated $18 million to advance the use of phosphoric acid fuel cells (PAFCs) at Department of Defense (DOD) installations. An additional $18.75 million was appropriated in FY94 to expand the program. The Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL) was assigned the mission of managing the DOD Fuel Cell Demonstration Program. Specific tasks included developing turnkey PAFC packages, devising site criteria, screening candidate DOD installation sites based on selection criteria, evaluating viable applications at each candidate site, coordinating fuel cell site designs, installation and acceptance of the PAFC power plants, and performance monitoring and reporting.

Thirty DOD fuel cell sites were selected based on the following criteria:

1. Geographic diversity
2. Application diversity
3. Fuel cell utilization at site
4. Energy cost savings.

The first two criteria are related more to overall program goals; the last are typical criteria for most fuel cell evaluations. It was important for the DOD Fuel Cell Program sites to represent a cross section of both "base" (including climate) and "building" applications. It was also important to identify applications where a high percentage of the fuel cell thermal and electrical output could be used at the site to demonstrate the greatest benefits.

Energy savings were less important in this Program than is typical with commercial applications since fuel cells purchased by the DOD were given to the Program sites. The economic criteria for each application was to generate at least $25,000 per year in energy savings, which would essentially cover annual maintenance costs. This would enable the fuel cell to pay for itself once the responsibility for maintenance was turned over to the base (after approximately 5 years).

The program followed a consistent approach for selecting sites, designing and reviewing installation plans, installing and maintaining the fuel cells, collecting fuel cell performance data and project decommissioning. This involved:

1. *Preliminary Screening*. Base energy data from the Defense Energy Information System (DEIS) were used to rank DOD sites by utility rates and potential fuel cell energy savings. DOD base personnel were contacted to identify their interest in hosting a fuel cell demonstration unit and identify a preliminary list of potential building applications. The Navy and Air Force provided an initial list of candidate sites for consideration.
2. *Site Visits*. ERDC/CERL and Science Applications International Corporation (SAIC) representatives visited each base, evaluated potential fuel cell application sites and discussed possibilities with site personnel. Data on energy consumption and rates, hours of operation, availability of space, etc. were collected during the site visit.
3. *Site Evaluation Reports*. SAIC prepared a site evaluation report* documenting site information, presenting conceptual fuel cell installation plans, estimation of electrical and thermal energy savings, and projected fuel cell energy savings. Based on the viability of the proposed fuel cell application, the base was accepted as a program site.
4. *Kick-off Meetings*. ERDC/CERL, SAIC, United Technologies Corp. (UTC) Fuel Cells (formerly ONSI Corp. and International Fuel Cells) and site personnel met to review the site evaluation report, discuss relevant issues, schedules, and any other concerns. UTC Fuel Cells collected site data for use in preparing the detailed site installation drawings.
5. *Design Review Meetings*. Detailed design drawings were submitted by UTC Fuel Cells for review by ERDC/CERL, SAIC, and site personnel. Specific issues related to the design were discussed and UTC Fuel Cells would incorporate changes to the drawings based on the input received.
6. *Acceptance Tests*. Installation of the fuel cells was the responsibility of UTC Fuel Cells. After the fuel cell installation was completed, a series of tests were performed to validate fuel cell performance. On successful completion, the fuel cell was turned over to the base, but operation and maintenance remained the responsibility of UTC Fuel Cells for approximately 5 years. Appendix A includes a copy of the acceptance test report.

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* Michael J. Binder, Franklin H. Holcomb, and William R. Taylor. (March 2001). *Site Evaluation for Application of Fuel Cell Technology: Edwards AFB,* ERDC/CERL Technical Report (TR) 01-60/ ADA395031, paa. Champaign, IL: Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL).

7. *Dedication Ceremonies*. Many of the fuel cell sites held a fuel cell dedication ceremony as part of their program participation. Often, dignitaries such as Generals and State Governors were in attendance.
8. *Fuel Cell Operations*. The fuel cells operated for 3 to 5 years. UTC Fuel Cells was responsible for maintenance of the power plant as well as collection of fuel cell performance data.
9. *Fuel Cell Decommissioning*. At the conclusion of the demonstration period, UTC Fuel Cells was responsible for removing the fuel cell and returning the site to the its condition before to the fuel cell installation. Each of the FY93 fuel cell sites, including Edwards AFB was given the opportunity to keep the fuel cell power plant at the end of the demonstration and take responsibility for all costs and issues related to operation, performance, and decommissioning.

This report presents a detailed review of a 200 kW fuel cell installed at Edwards Air Force Base (AFB). The base is located in near Palmdale, CA, approximately 60 mi north of Los Angeles. The fuel cell was installed at the hospital as part of the DOD Fuel Cell Demonstration Program. The fuel cell operated between July 1997 and July 2002.

1.2 Objectives

The overall objectives of the Fuel Cell Demonstration Program were to:

- demonstrate fuel cell capabilities in real-world situations
- stimulate growth and economies of scale in the fuel cell industry
- determine the role of fuel cells in DOD's long-term energy strategy.

The specific objective of this part of the program was to give a detailed review of the PAFC fuel cell demonstration at Edwards AFB.

1.3 Approach

The review process involved:

1. Collecting data from stage of the Fuel Cell Demonstration Program at Edwards AFB
2. Analyzing the data in terms of the technology's capabilities, performance, and potential for a continuing role in the DOD's long-term energy strategy
3. Compiling lessons learned from the demonstration experience
4. Making recommendations for continued/improved use of the technology at DOD installation.

1.4 Mode of Technology Transfer

Results of this work will be forwarded directly to the funding sponsor and to the participating installation. This report will be made publicly accessible through the World Wide Web (WWW) at URLs:

http://www.cecer.army.mil
http://www.dodfuelcell.com

2 Project Overview and Participants

2.1 Project Timeline

The first formal activity related to the fuel cell demonstration unit at Edwards AFB was a site evaluation meeting held in August 1996. (Appendix B contains notes from this meeting and from the meeting of 25 March 1997.) The fuel cell was started up in June 1997 and, over the next 5 years, it operated for over 28,000 hours and generated more than 5 million kWh of electricity. The demonstration unit remains at the Edwards AFB, although it is not currently operational. Table 1 lists the major events and milestones for this fuel cell demonstration unit.

Table 1. Time line of major events and milestones.

Date			Event
15-16	August	1996	Site Evaluation Meeting held at Edwards AFB
29	January	1997	Site Evaluation Report submitted by SAIC
5	February	1997	Project Kick-off Meeting held at Edwards AFB
18	February	1997	Draft design drawings submitted by UTC Fuel Cells
25	March	1997	Fuel Cell Design Review meeting held at Edwards AFB
25	April	1997	ERDC/CERL authorizes UTC Fuel Cells to commence construction.
23-25	June	1997	Acceptance testing performed
16	July	1997	Acceptance Test Meeting; Form DD250 signed by Edwards AFB
25	October	1997	1,000 hours of operation milestone
26	October	1997	Fuel cell shut down due to failed cooling coil and cell sub-stacks. Cell stack removed and sent back to UTC Fuel Cells for repair.
4	February	1998	Repaired cell stack installed
11	March	1998	Power plant restarted after 3,203 outage hours.
12	October	1998	5,000 hours of operation milestone
4	July	1999	10,000 hours of operation milestone
17	February	2000	15,000 hours of operation milestone
3	November	2000	20,000 hours of operation milestone
1	July	2002	Fuel cell shut down for final time

Chapter 4 of this report gives a more detailed analysis of the fuel cell operation and performance history.

There was an approximately 10-month period between the initial site evaluation meeting and the fuel cell acceptance test. It took approximately

3 months to install the fuel cell following acceptance of the installation design. UTC Fuel Cell was responsible for the installation of all 30 fuel cells installed as part of this program. GBC Electrical Services installed the fuel cell at Edwards AFB as a subcontractor to UTC Fuel Cells.

2.2 Project Participants

The successful demonstration of this fuel cell unit required the efforts of several organizations and individuals:

- *ERDC/CERL* had overall responsibility for the DOD Fuel Cell Demonstration Program unit installed at the Naval Hospital. ERDC/CERL was responsible for contracting with the fuel cell manufacturer, identifying all sites, managing all site evaluations, and overseeing all design, installation, operation, and maintenance activities.
- *UTC Fuel Cells* manufactured the PC25B and PC25C fuel cells used at the bases. They were responsible for manufacturing the fuel cell as well as the detailed design drawings, fuel cell installation, operation/maintenance and, if necessary, fuel cell removal.
- *SAIC* was responsible for evaluating potential building applications at each site, developing fuel cell conceptual designs, performing a preliminary economic analysis and submitting the site evaluation report for review by all parties. In addition, SAIC was involved in the detailed design reviews and participating in the design review meetings. For this demonstration unit, SAIC also conducted independent performance monitoring of the fuel cell.
- *GBC Electrical Services* was the installation contractor for this fuel cell. In addition, they performed the maintenance on the fuel cell and were involved in its removal.
- *Edwards AFB Hospital* was directly involved in the review and approval of the fuel cell project.
- *Edwards AFB Personnel* provided review and approval for various aspects of the project including fire and utilities interfaces.

Table 2 lists the individuals involved in this demonstration project at the Hospital. Figure 1 shows the fuel cell installation.

Table 2. Principal project participants.

Organization	Name	Project Role
ERDC/CERL	Dr. Michael Binder	Manager, Fuel Cell Demonstration Program
ERDC/CERL	Franklin Holcomb	Fuel Cell Project Manager
ERDC/CERL	William Taylor	Fuel Cell Project Manager
UTC Fuel Cells	Joseph Staniunis	Installation Designer
UTC Fuel Cells	Douglas Young	Technical Representative
UTC Fuel Cells	Thomas Pompa	Installation/Maintenance Coordinator
Science Applications Int'l Corp.	Gerry Merten	Principal Technical Manager
Science Applications Int'l Corp.	Mike Torrey	Project Manager
Edwards AFB	Ken Munson	Base Point of Contact
Edwards AFB	Lt. Matt Sufnar	95CEG/CEO
Edwards AFB	Jose DeLavega	95CEG/CECV
Edwards AFB	F.P. Woodland	95MG/SGAF
GBC Electrical Services	George Collard	Installation/Maintenance Contractor

Figure 1. Fuel cell installation.

3 Fuel Cell Design and Installation

3.1 Fuel Cell Building Application

The Hospital, built in 1955, is a 65,000 sq ft building with an emergency room, several clinic facilities, and 30 hospital beds. Additions were made to the hospital in 1966. The average occupancy for inpatients was approximately 10 beds per night. Two back-up generators, rated at 300 kW and 500 kW, provide backup power to the facility. Space heating and domestic hot water is provided by the two steam boilers located inside the mechanical room. The steam distribution system operates throughout the year and provides for instrument sterilization and also to control building humidity levels. For space cooling requirements, there are two 200 ton chillers that operate throughout the year to provide space cooling and to control humidity. More details about the site can be obtained from ERDC/CERL TR-01-60, available through URL:

http://www.cecer.army.mil/techreports/Hol_SE_Edwards/Hol_SE_Edwards_TR.pdf

3.2 Conceptual Installation Design

A preliminary conceptual design for the fuel cell installation was prepared. based on the initial site evaluation meeting in August of 1996. Figure 2 shows the layout of the mechanical room, fire system pump room, existing chillers, and the proposed fuel cell location, including proposed fuel cell interface connections.

The proposed fuel cell location was adjacent to the fire system pump room and the mechanical room at the end of an asphalt driveway. This location was close to the facility steam lines located inside the pump room, and approximately halfway between the electric transformer and main natural gas line for the hospital.

Initial plans were to connect the fuel cell electrical interface into the low voltage side of the 12,000/480V transformer (1,000 kVA) that supplied electricity to the hospital facility. This connection would allow the electrical wiring distance to be approximately 60 ft. No grid-independent mode operation was proposed for this application.

The proposed thermal interface was to take the fuel cell's high grade heat exchanger (a fuel cell option) and tie into the space heating loop to add heat on the return side. Figure 3 shows the proposed fuel cell thermal interface where 180 °F return water is heated up by the fuel cell prior to entering the steam heat exchanger. The thermal piping distance was estimated to be approximately 15 ft.

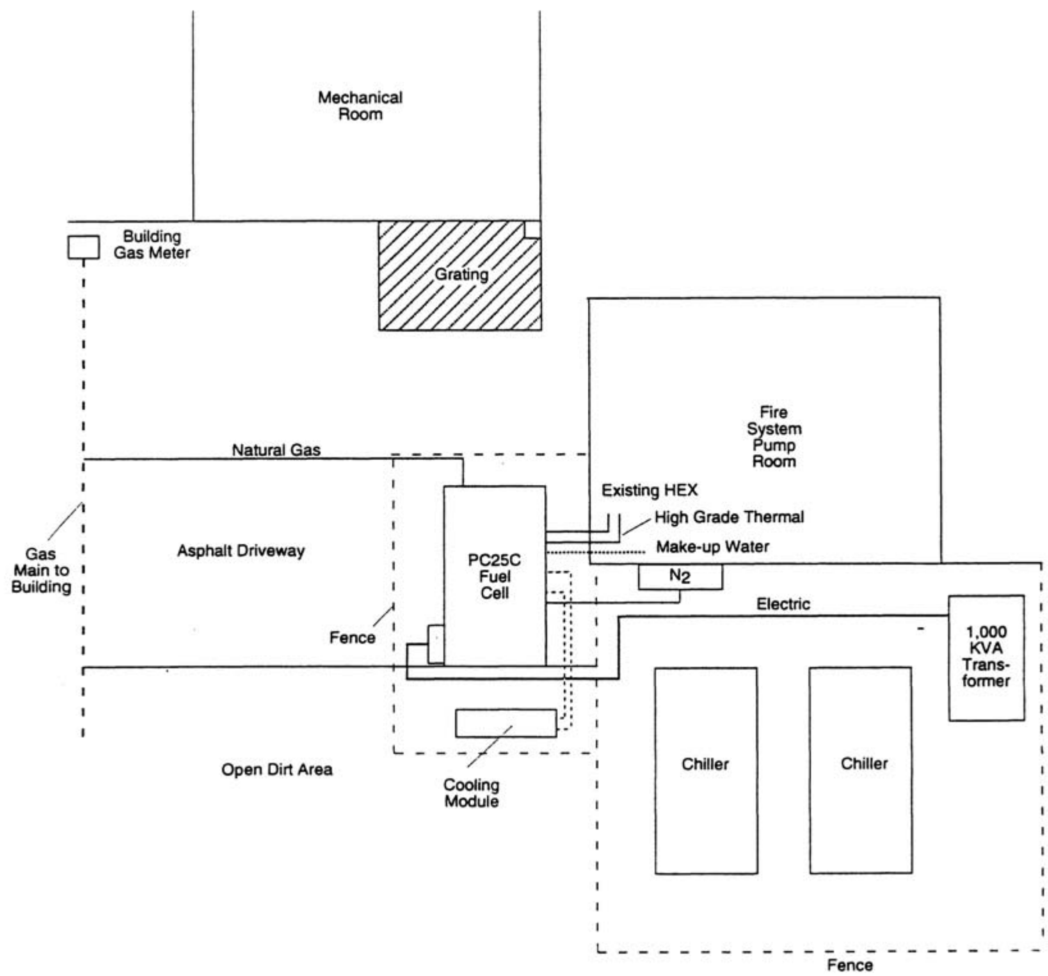


Figure 2. Conceptual design fuel cell location and interfaces.

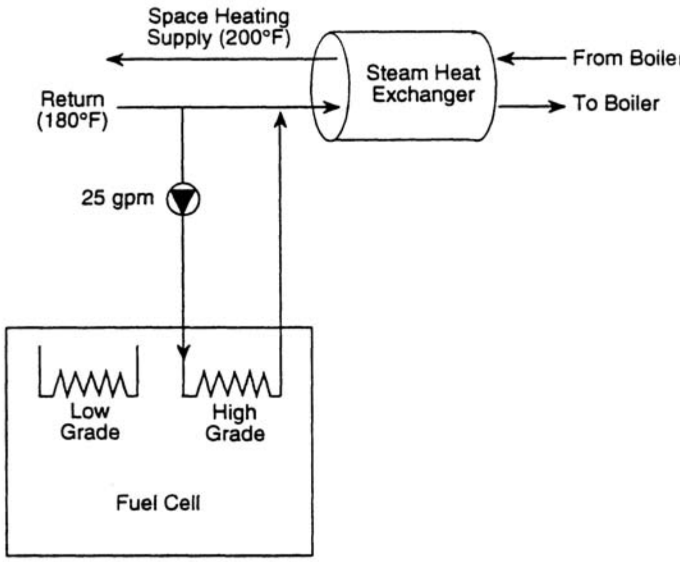


Figure 3. Conceptual design fuel cell thermal interface.

3.3 Detailed Design Drawings

UTC Fuel Cells submitted an original set of design drawings on 18 February 1997. The drawings were reviewed by base personnel, ERDC/CERL, and SAIC. A design review meeting was held 25 March 1997 at Edwards AFB, at which the following drawings were submitted:

S-1: Site Foundation Plan
ME-1: Mechanical/Electrical Layout Plan
M-1: Mechanical Piping and Instrumentation Diagram
M-2: Mechanical Piping Details
E-1: Electrical Wiring Diagrams
E-2: Electrical Details.

The orientation of the fuel cell was rotated 90 degrees from the initial conceptual design layout to accommodate maintenance activities. Thermal piping was run above ground on the new fuel cell cement pad located inside the fenced area. Reviewers submitted comments based on the initial drawings. (Appendix C includes copies of these comments.) Table 3 lists the changes made to the detailed site drawings, both before and after the design review meeting. Figures 4 through 10 show the final installation drawings.

Table 3. Changes to design drawings based on comments.

Drawing		Changes
S-1	1.	Provide standard wall penetration detail.
	2.	Note that equipment pad will have #4 rebar on 2-ft centers instead of 1-ft centers.
	3.	Provide dimension of power module frame wide, fence width (short side) and clearance between fuel cell fence and open grate area.
ME-1	1.	Extend arrow for #7 polygon (electrical connection) note to indicate the make-up water line.
	2.	Add “boxed M” to symbol list.
	3.	Note the #3 and #5 mechanical connections are not used.
	4.	Move the nitrogen bottles 2 ft closer to hospital (Bldg. 5500) so that it is fully supported by the wall of Building 5700.
	5.	Disconnect labels changed (reversed grid-connected and grid-independent.
M-1	1.	Correct the note for the source of natural gas to indicate the interface is at the existing gas piping under the parking lot (as noted in Drawing ME-1)
	2.	Indicate the gas meter should be installed with a bypass (as noted on M-2, gas piping detail.
	3.	In the Equipment Schedule List, change the P1 pump specification to 1-1/2AA, 1/2 HP. (This was incorrectly listed as 1-1/2A, 1/2 HP).
M-2		No changes.
E-1	1.	Change the conduit size for the telephone conductors to 1-in. to match power module interface opening size.
E-2		No changes.

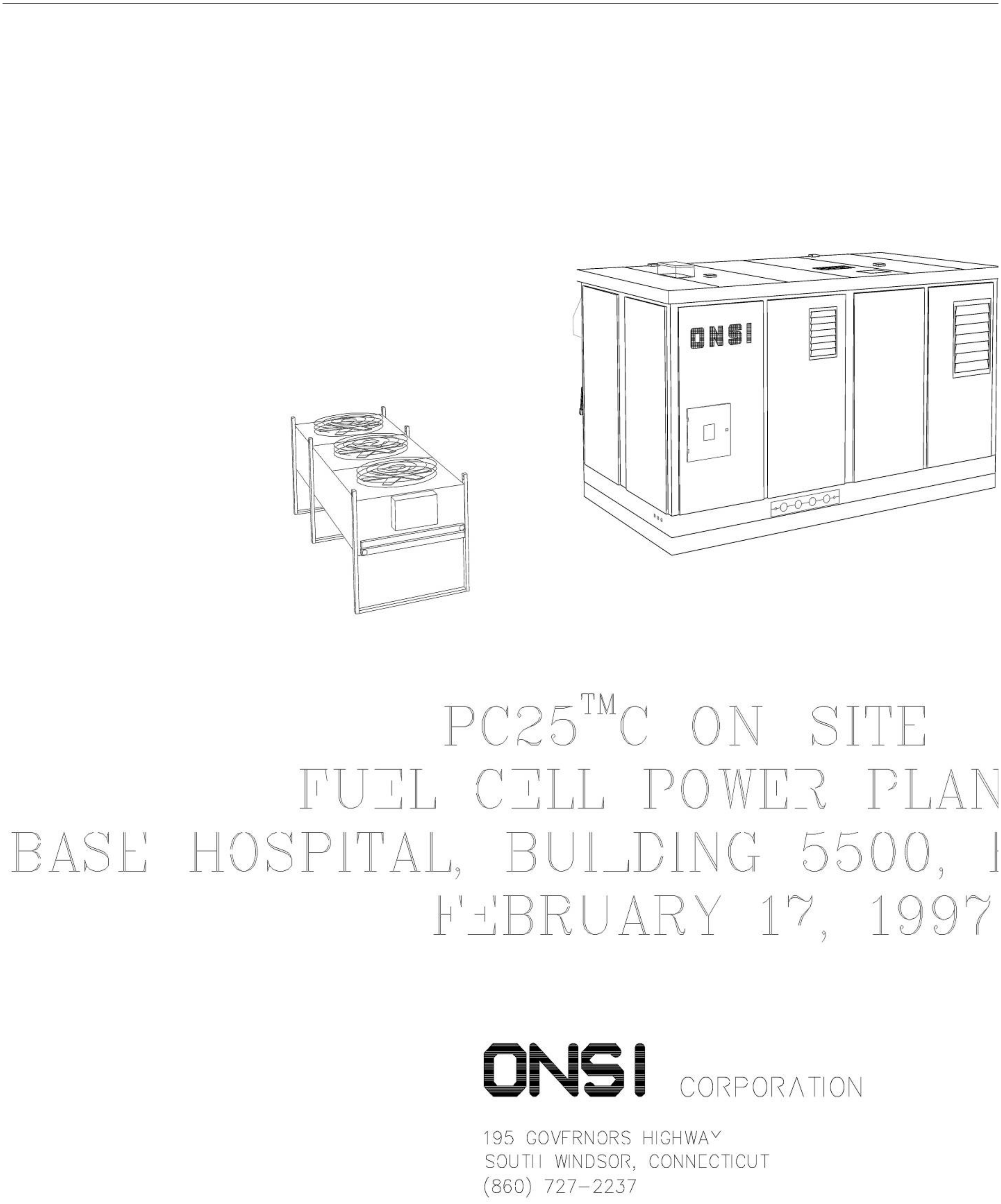


Figure 4. Final installation drawings – cover page with code information.

DRAWING LIST

NO.	TITLE
S-1	SITE FOUNDATION PLAN
ME-1	MECHANICAL/ELECTRICAL LAYOUT PLAN
M 1	MECHANICAL PIPING AND INSTRUMENTATION DIAGRAM
M-2	MECHANICAL PIPING DETAILS
E 1	ELECTRICAL WIRING DIAGRAMS
E 2	ELECTRICAL DETAILS

CODE INFORMATION

INSTALLATION SHALL COMPLY WITH THE FOLLOWING CODES:

THE BOCA NATIONAL BUILDING CODE 1990
THE BOCA NATIONAL MECHANICAL CODE 1990
THE BOCA NATIONAL PLUMBING CODE 1990
THE NATIONAL ELECTRICAL CODE 1993
THE NATIONAL FIRE PROTECTION CODE 1993

T INSTALLATION
EDWARDS AFB, CALIFORNIA

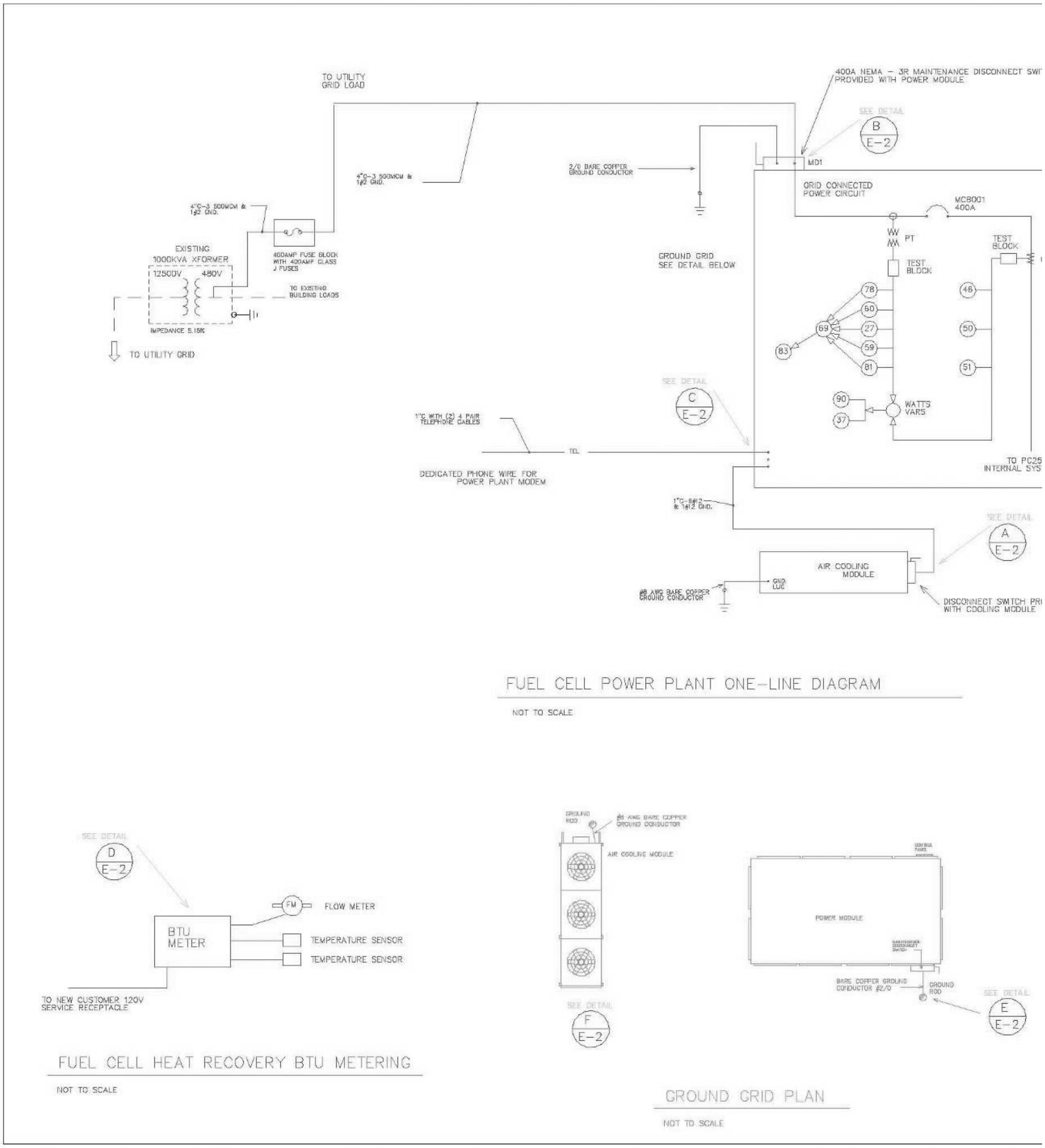
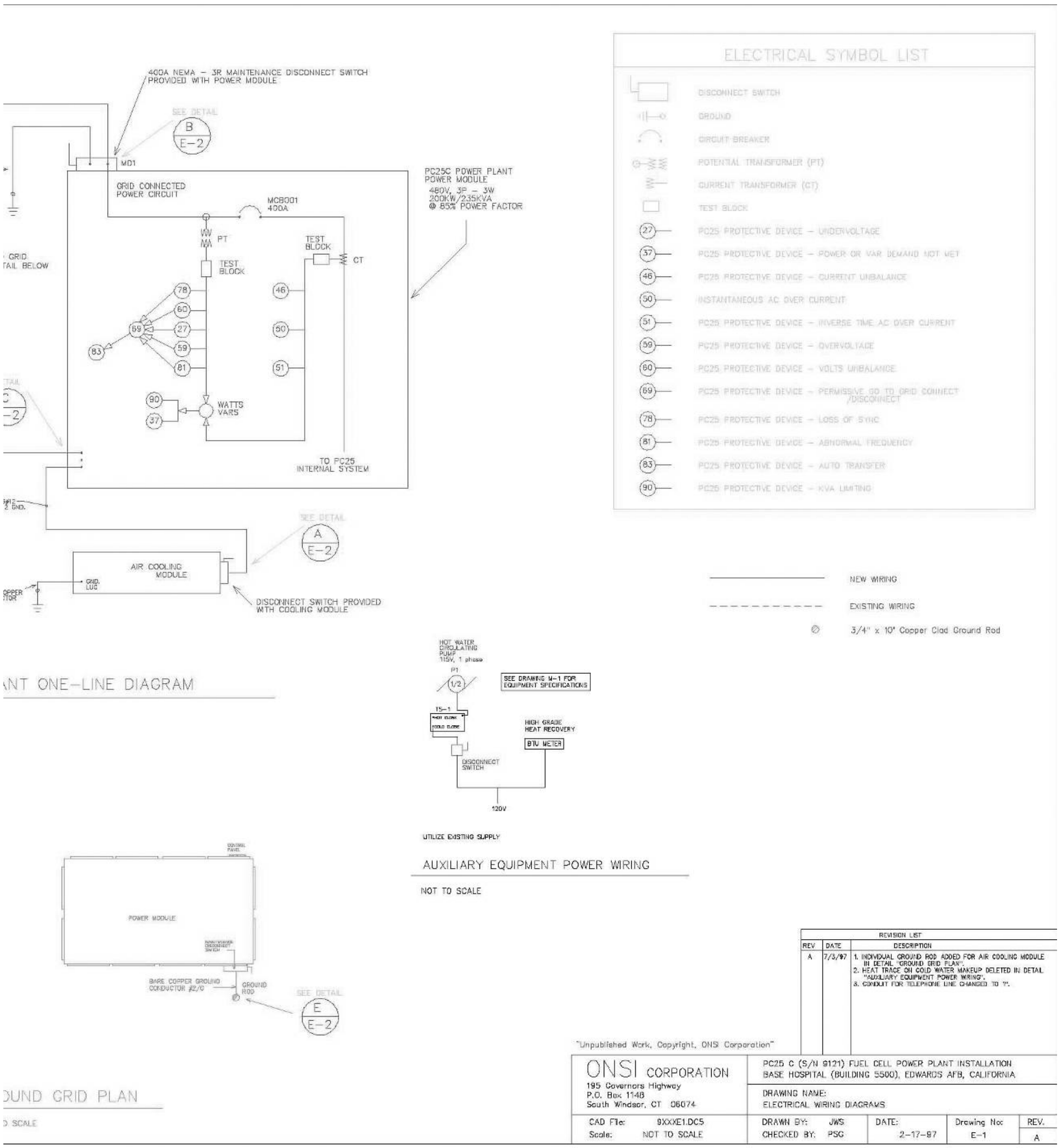


Figure 5. Final installation drawings – auxiliary equipment power wiring.


ELECTRICAL SYMBOL LIST
400A NEMA – 3R MAINTENANCE DISCONNECT SWITCH PROVIDED WITH POWER MODULE
PC25C POWER PLANT POWER MODULE
480V, 3P – 3W
200KW/235KVA
@ 85% POWER FACTOR
GRID CONNECTED POWER CIRCUIT
MCB001 400A
TEST BLOCK
TO PC25 INTERNAL SYSTEM
AIR COOLING MODULE
DISCONNECT SWITCH PROVIDED WITH COOLING MODULE
NEW WIRING
EXISTING WIRING
3/4" x 10' Copper Clad Ground Rod
ANT ONE-LINE DIAGRAM
AUXILIARY EQUIPMENT POWER WIRING
NOT TO SCALE
UTILIZE EXISTING SUPPLY
HIGH GRADE HEAT RECOVERY
BTU METER
SEE DRAWING M-1 FOR EQUIPMENT SPECIFICATIONS
POWER MODULE
BARE COPPER GROUND CONDUCTOR #2/0
OUND GRID PLAN
"Unpublished Work, Copyright, ONSI Corporation"
ONSI CORPORATION
195 Governors Highway
P.O. Box 1148
South Windsor, CT 06074
PC25 C (S/N 9121) FUEL CELL POWER PLANT INSTALLATION
BASE HOSPITAL (BUILDING 5500), EDWARDS AFB, CALIFORNIA
DRAWING NAME:
ELECTRICAL WIRING DIAGRAMS
CAD File: 9XXXE1.DC5
Scale: NOT TO SCALE
DRAWN BY: JWS
CHECKED BY: PSG
DATE: 2-17-97
Drawing No: E-1
REV. A

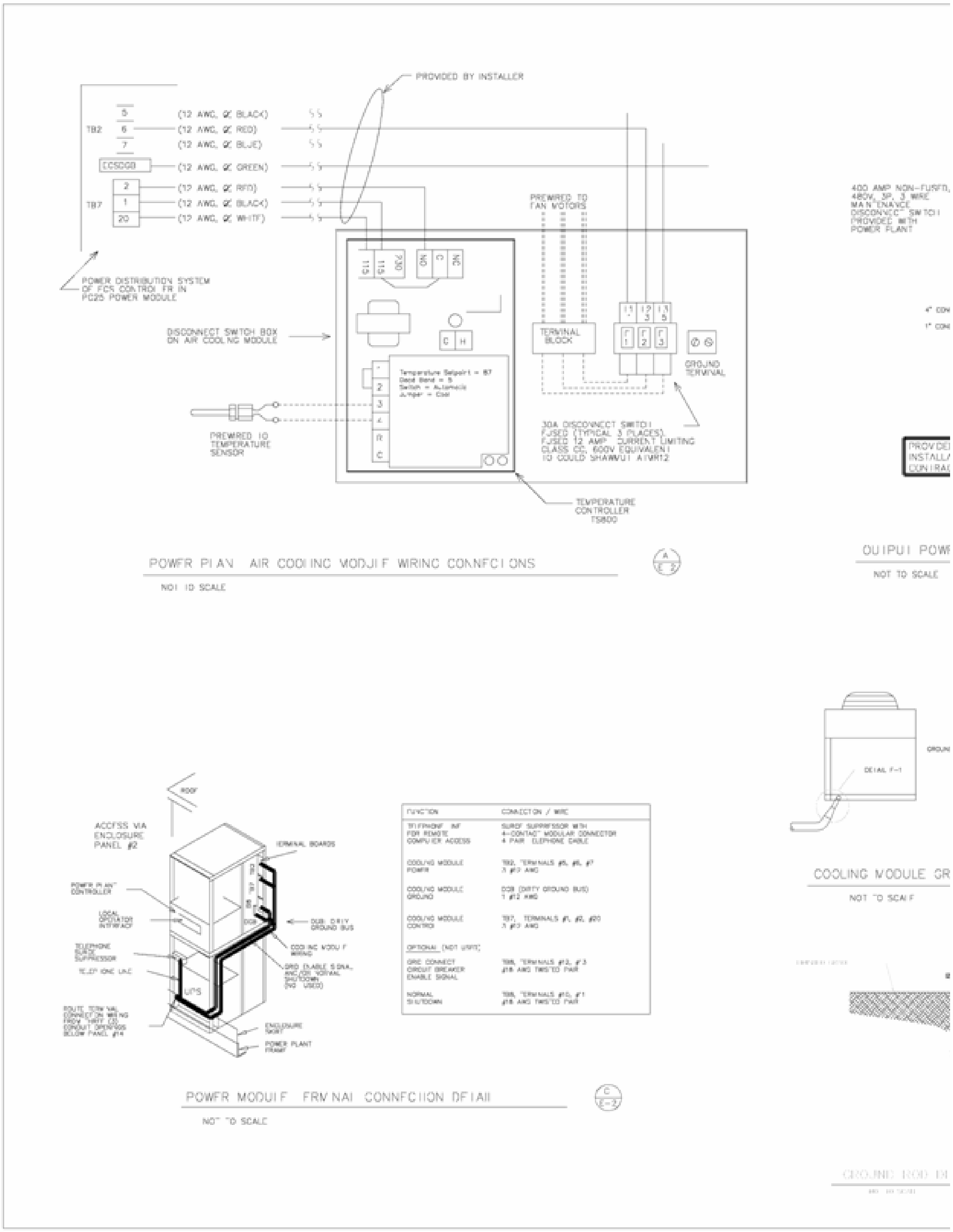
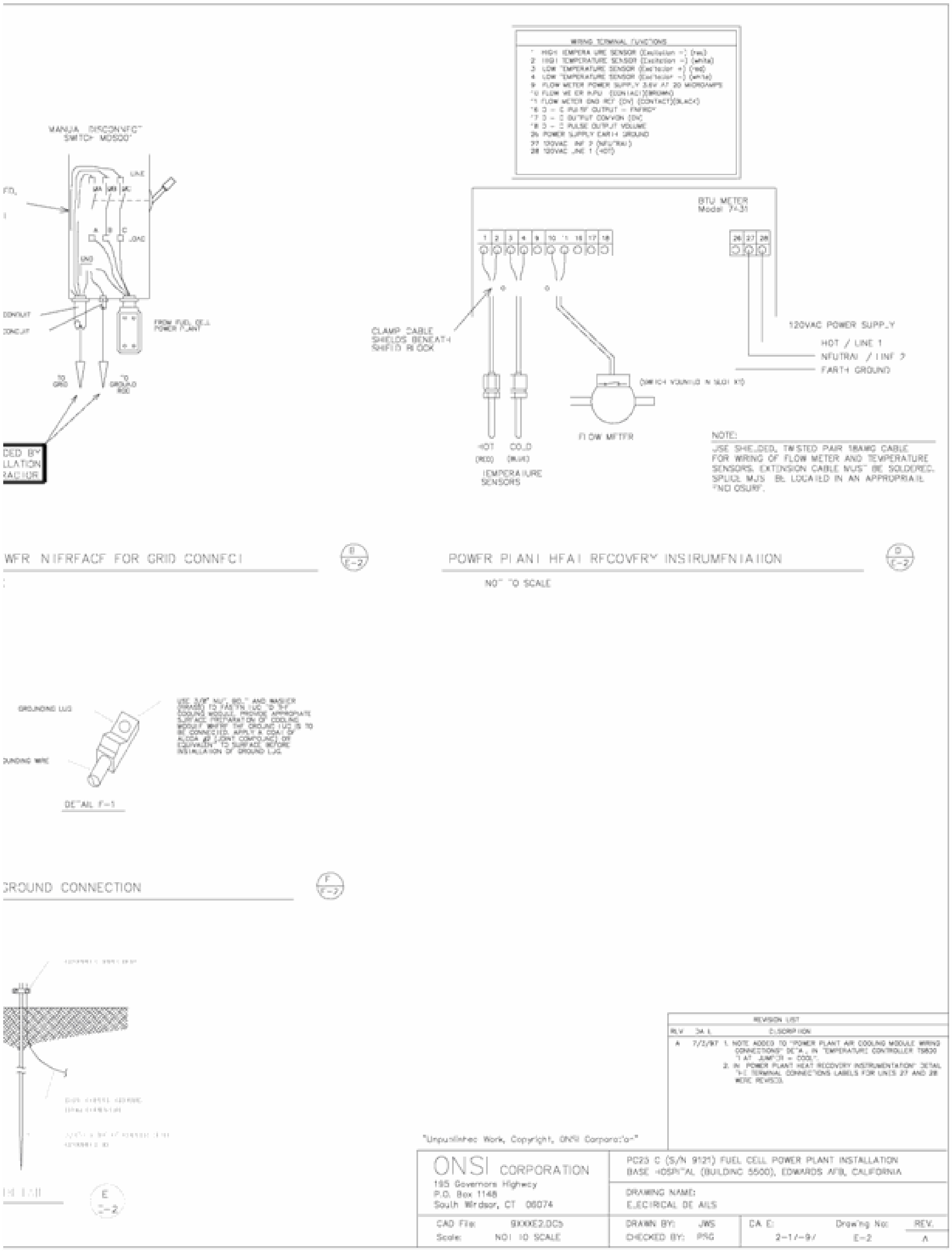


Figure 6. Final installation drawings – electrical details.


WIRING TERMINAL FUNCTIONS
MANUAL DISCONNECT SWITCH MD500
BTU METER Model 74-31
CLAMP CABLE SHIELDS BENEATH SHIELD BLOCK
120VAC POWER SUPPLY
HOT / LINE 1
NEUTRAL / LINE 2
EARTH GROUND
FLOW METER
HOT (RED)
COLD (BLUE)
TEMPERATURE SENSORS
NOTE:
USE SHIELDED, TWISTED PAIR 18AWG CABLE FOR WIRING OF FLOW METER AND TEMPERATURE SENSORS. EXTENSION CABLE MUST BE SOLDERED. SPLICE MUST BE LOCATED IN AN APPROPRIATE ENCLOSURE.
POWER PLANT HEAT RECOVERY INSTRUMENTATION
NOT TO SCALE
GROUNDING LUG
DETAIL F-1
GROUND CONNECTION
REVISION LIST
"Unpublished Work, Copyright, ONSI Corporation"
ONSI CORPORATION
195 Governors Highway
P.O. Box 1148
South Windsor, CT 06074
PC25 C (S/N 9121) FUEL CELL POWER PLANT INSTALLATION
BASE HOSPITAL (BUILDING 5500), EDWARDS AFB, CALIFORNIA
DRAWING NAME:
ELECTRICAL DETAILS
CAD File:
Scale: NOT TO SCALE
DRAWN BY: JWS
CHECKED BY: PRG
Drawing No: E-2
REV. A

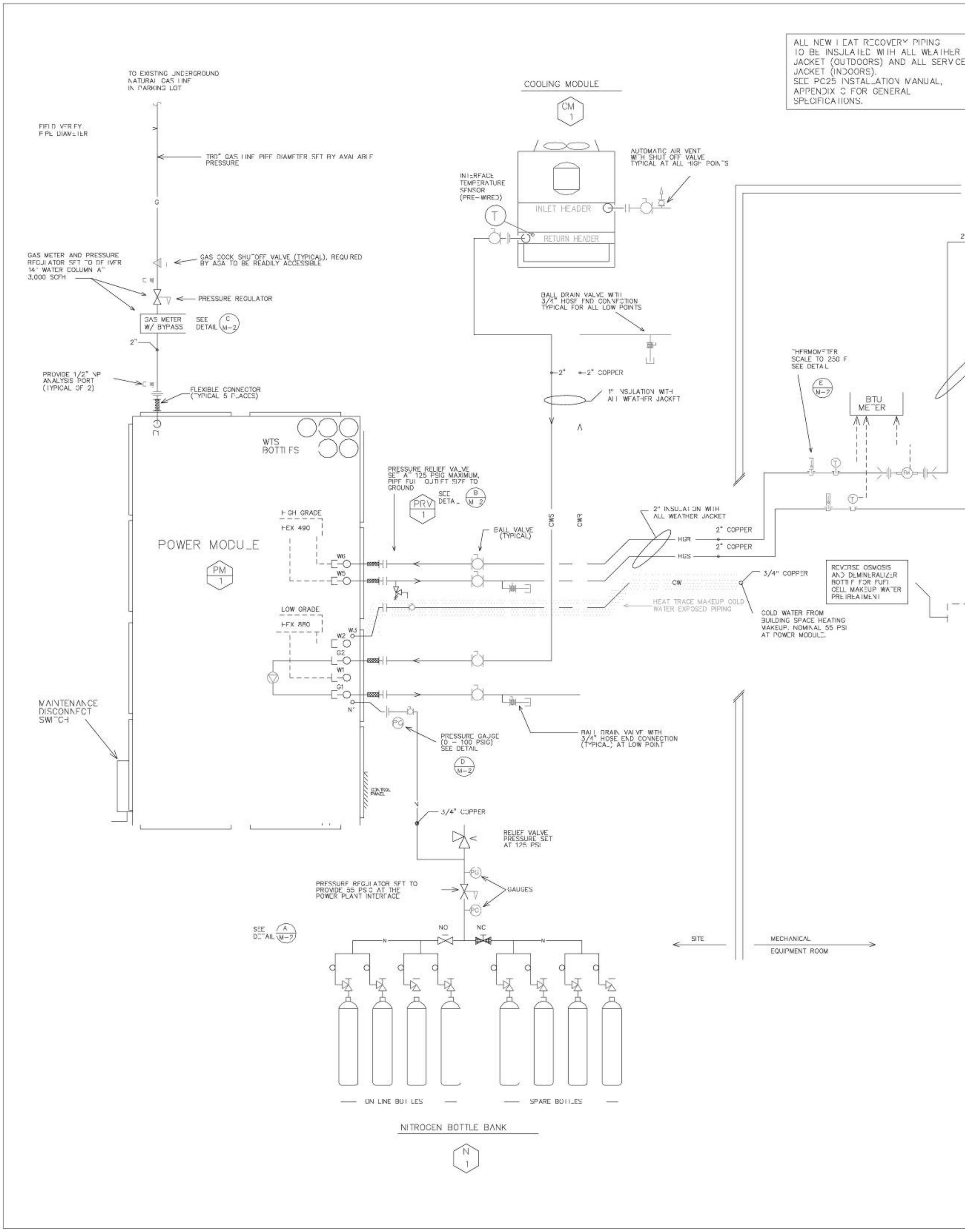
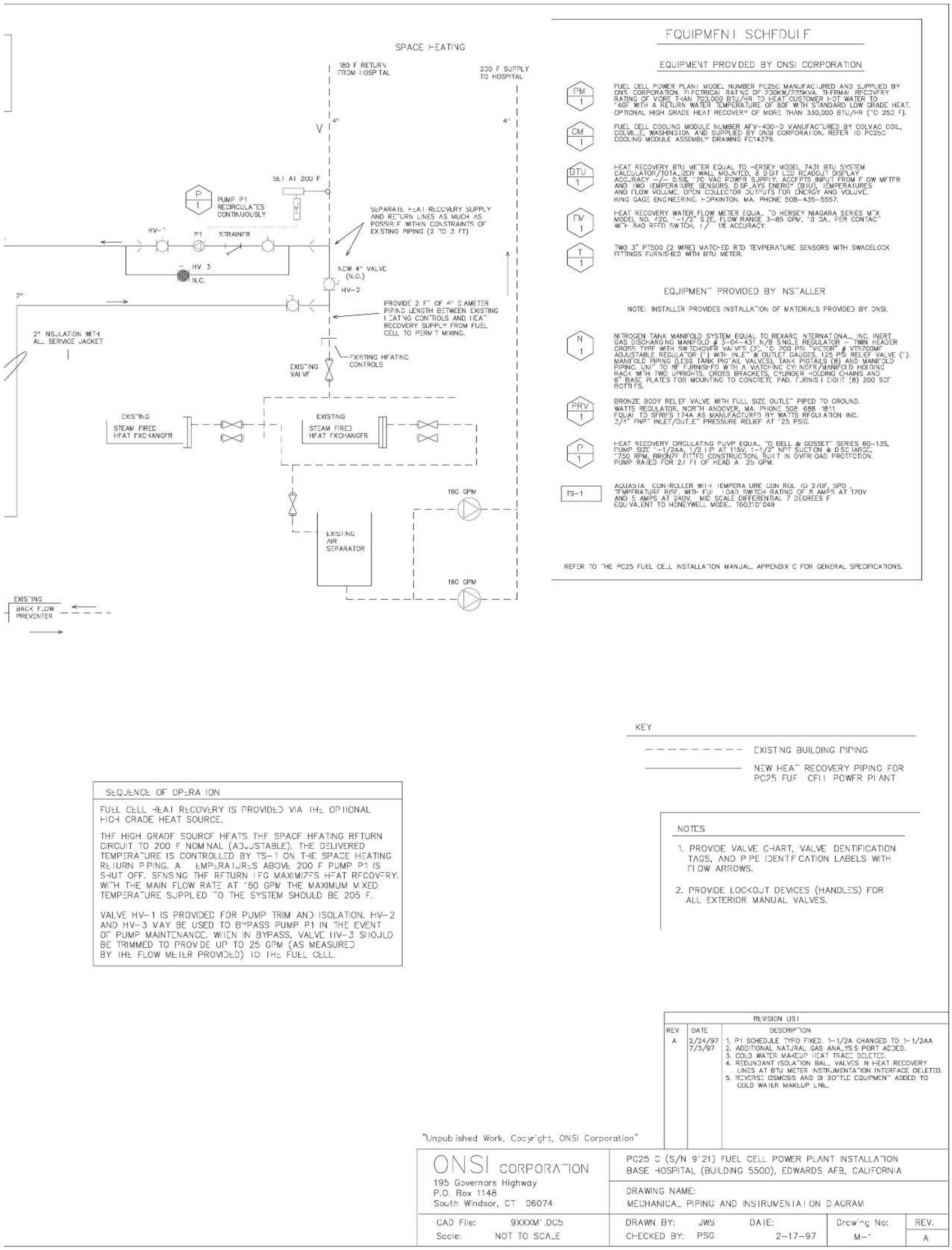


Figure 7. Final installation drawings – mechanical piping and instrumentation diagram.


SPACE HEATING
180 F RETURN FROM HOSPITAL
200 F SUPPLY TO HOSPITAL
SET AT 200 F
PUMP P1 RECIRCULATES CONTINUOUSLY
SEPARATE HEAT RECOVERY SUPPLY AND RETURN LINES AS MUCH AS POSSIBLE WITHIN CONSTRAINTS OF EXISTING PIPING (2 TO 3 FT)
HV-1
P1
STRAINER
HV-3
N.C.
NEW 4" VALVE (N.O.)
HV-2
PROVIDE 2 FT OF 4" DIAMETER PIPING LENGTH BETWEEN EXISTING HEATING CONTROLS AND HEAT RECOVERY SUPPLY FROM FUEL CELL TO PERMIT MIXING.
2" INSULATION WITH ALL SERVICE JACKET
EXISTING HEATING CONTROLS
EXISTING VALVE
EXISTING STEAM FIRED HEAT EXCHANGER
EXISTING STEAM FIRED HEAT EXCHANGER
160 GPM
EXISTING AIR SEPARATOR
160 GPM
EXISTING BACK FLOW PREVENTER
EQUIPMENT SCHEDULE
EQUIPMENT PROVIDED BY ONSI CORPORATION
PM 1 — FUEL CELL POWER PLANT MODEL NUMBER PC25C MANUFACTURED AND SUPPLIED BY ONSI CORPORATION. ELECTRICAL RATING OF 200KW/235KVA. THERMAL RECOVERY RATING OF MORE THAN 700,000 BTU/HR TO HEAT CUSTOMER HOT WATER TO 140F WITH A RETURN WATER TEMPERATURE OF 80F WITH STANDARD LOW GRADE HEAT. OPTIONAL HIGH GRADE HEAT RECOVERY OF MORE THAN 330,000 BTU/HR (TO 250 F).
CM 1 — FUEL CELL COOLING MODULE NUMBER AFV-400-D MANUFACTURED BY COLVAC COIL, COLVILLE, WASHINGTON AND SUPPLIED BY ONSI CORPORATION. REFER TO PC25C COOLING MODULE ASSEMBLY DRAWING FC14379.
BTU 1 — HEAT RECOVERY BTU METER EQUAL TO HERSEY MODEL 7431 BTU SYSTEM CALCULATOR/TOTALIZER WALL MOUNTED, 8 DIGIT LCD READOUT DISPLAY ACCURACY +/- 0.5%, 120 VAC POWER SUPPLY. ACCEPTS INPUT FROM FLOW METER AND TWO TEMPERATURE SENSORS. DISPLAYS ENERGY (BTU), TEMPERATURES AND FLOW VOLUME. OPEN COLLECTOR OUTPUTS FOR ENERGY AND VOLUME. KING GAGE ENGINEERING, HOPKINTON, MA. PHONE 508-435-5557.
FM 1 — HEAT RECOVERY WATER FLOW METER EQUAL TO HERSEY NIAGARA SERIES MTX MODEL NO. 420, 1-1/2" SIZE, FLOW RANGE 3-85 GPM, 10 GAL PER CONTACT WITH 840 REED SWITCH, +/- 1% ACCURACY.
T 1 — TWO 3" PT500 (2 WIRE) MATCHED RTD TEMPERATURE SENSORS WITH SWAGELOCK FITTINGS FURNISHED WITH BTU METER.
EQUIPMENT PROVIDED BY INSTALLER
NOTE: INSTALLER PROVIDES INSTALLATION OF MATERIALS PROVIDED BY ONSI.
N 1 — NITROGEN TANK MANIFOLD SYSTEM EQUAL TO REXARC INTERNATIONAL, INC. INERT GAS DISCHARGING MANIFOLD # 3-04-431 N/B SINGLE REGULATOR - TWIN HEADER CROSS TYPE WITH SWITCHOVER VALVES (2), 10 200 PSI "VICTOR" # VTS700MF ADJUSTABLE REGULATOR (1) WITH INLET & OUTLET GAUGES, 125 PSI RELIEF VALVE (1). MANIFOLD PIPING (LESS TANK PIGTAIL VALVES), TANK PIGTAILS (8) AND MANIFOLD PIPING. UNIT TO BE FURNISHED WITH A MATCHING CYLINDER/MANIFOLD HOLDING RACK WITH TWO UPRIGHTS, CROSS BRACKETS, CYLINDER HOLDING CHAINS AND 6" BASE PLATES FOR MOUNTING TO CONCRETE PAD. FURNISH EIGHT (8) 200 SCF BOTTLES.
PRV 1 — BRONZE BODY RELIEF VALVE WITH FULL SIZE OUTLET PIPED TO GROUND. WATTS REGULATOR, NORTH ANDOVER, MA. PHONE 508 688 1811 EQUAL TO SERIES 174A AS MANUFACTURED BY WATTS REGULATION INC. 3/4" FNPT INLET/OUTLET PRESSURE RELIEF AT 125 PSIG.
P 1 — HEAT RECOVERY CIRCULATING PUMP EQUAL TO BELL & GOSSETT SERIES 60-135, PUMP SIZE 1-1/2AA, 1/2 HP AT 115V, 1-1/2" NPT SUCTION & DISCHARGE, 1750 RPM, BRONZE FITTED CONSTRUCTION, BUILT IN OVERLOAD PROTECTION. PUMP RATED FOR 27 FT OF HEAD AT 25 GPM.
TS-1 — AQUASTAT CONTROLLER WITH TEMPERATURE CONTROL TO 270F, SPDT, TEMPERATURE RISE, WITH FULL LOAD SWITCH RATING OF 8 AMPS AT 120V AND 5 AMPS AT 240V. MID SCALE DIFFERENTIAL 7 DEGREES F EQUIVALENT TO HONEYWELL MODEL T6031D1049
REFER TO THE PC25 FUEL CELL INSTALLATION MANUAL, APPENDIX C FOR GENERAL SPECIFICATIONS.
KEY
EXISTING BUILDING PIPING
NEW HEAT RECOVERY PIPING FOR PC25 FUEL CELL POWER PLANT
SEQUENCE OF OPERATION
FUEL CELL HEAT RECOVERY IS PROVIDED VIA THE OPTIONAL HIGH GRADE HEAT SOURCE.
THE HIGH GRADE SOURCE HEATS THE SPACE HEATING RETURN CIRCUIT TO 200 F NOMINAL (ADJUSTABLE). THE DELIVERED TEMPERATURE IS CONTROLLED BY TS-1 ON THE SPACE HEATING RETURN PIPING. AT TEMPERATURES ABOVE 200 F PUMP P1 IS SHUT OFF. SENSING THE RETURN LEG MAXIMIZES HEAT RECOVERY. WITH THE MAIN FLOW RATE AT 160 GPM THE MAXIMUM MIXED TEMPERATURE SUPPLIED TO THE SYSTEM SHOULD BE 205 F.
VALVE HV-1 IS PROVIDED FOR PUMP TRIM AND ISOLATION. HV-2 AND HV-3 MAY BE USED TO BYPASS PUMP P1 IN THE EVENT OF PUMP MAINTENANCE. WHEN IN BYPASS, VALVE HV-3 SHOULD BE TRIMMED TO PROVIDE UP TO 25 GPM (AS MEASURED BY THE FLOW METER PROVIDED) TO THE FUEL CELL.
NOTES
1. PROVIDE VALVE CHART, VALVE IDENTIFICATION TAGS, AND PIPE IDENTIFICATION LABELS WITH FLOW ARROWS.
2. PROVIDE LOCKOUT DEVICES (HANDLES) FOR ALL EXTERIOR MANUAL VALVES.
REVISION LIST
REV DATE DESCRIPTION
A 2/24/97 7/3/97 1. P1 SCHEDULE TYPO FIXED. 1-1/2A CHANGED TO 1-1/2AA
2. ADDITIONAL NATURAL GAS ANALYSIS PORT ADDED.
3. COLD WATER MAKEUP HEAT TRACE DELETED.
4. REDUNDANT ISOLATION BALL VALVES IN HEAT RECOVERY LINES AT BTU METER INSTRUMENTATION INTERFACE DELETED.
5. REVERSE OSMOSIS AND DI BOTTLE EQUIPMENT ADDED TO COLD WATER MAKEUP LINE.
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ONSI CORPORATION
195 Governors Highway
P.O. Box 1148
South Windsor, CT 06074
PC25 C (S/N 9121) FUEL CELL POWER PLANT INSTALLATION BASE HOSPITAL (BUILDING 5500), EDWARDS AFB, CALIFORNIA
DRAWING NAME:
MECHANICAL PIPING AND INSTRUMENTATION DIAGRAM
CAD File: 9XXXM1.DC5
Scale: NOT TO SCALE
DRAWN BY: JWS
CHECKED BY: PSG
DATE: 2-17-97
Drawing No: M-1
REV. A

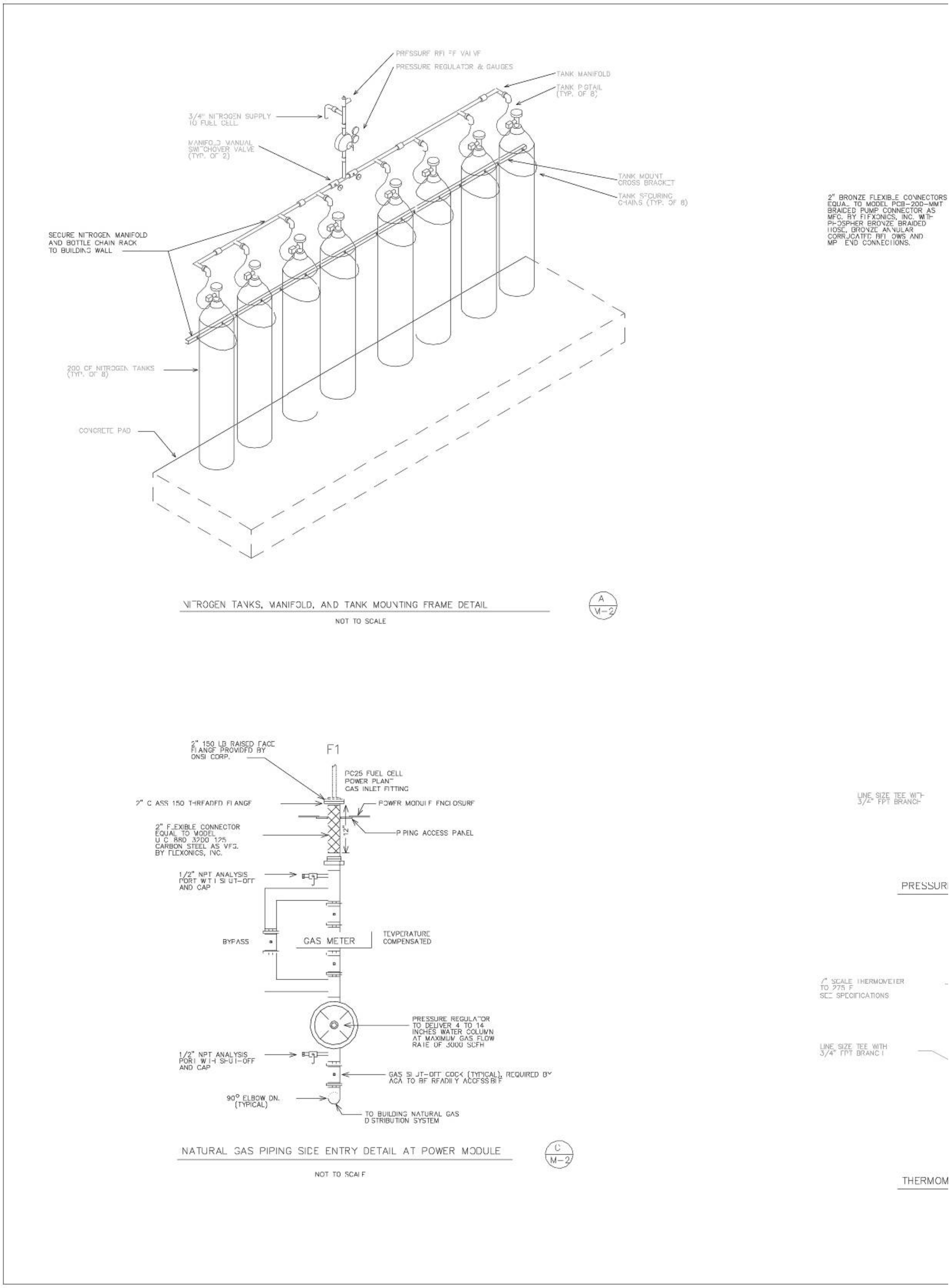
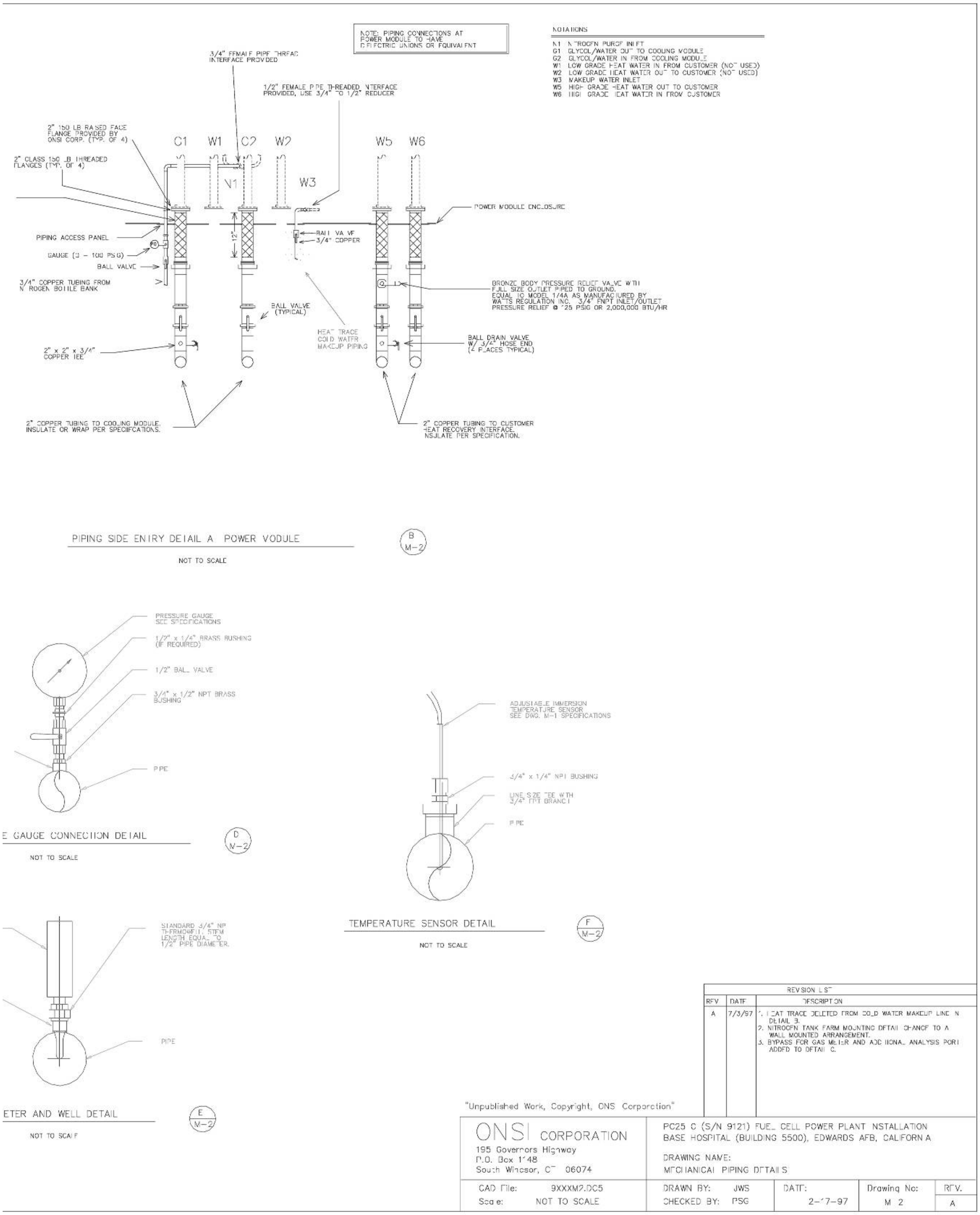


Figure 8. Final installation drawings – mechanical piping details.


NOTE: PIPING CONNECTIONS AT POWER MODULE TO HAVE DIELECTRIC UNIONS OR EQUIVALENT
NOTATIONS
N1 NITROGEN PURGE INLET
G1 GLYCOL/WATER OUT TO COOLING MODULE
G2 GLYCOL/WATER IN FROM COOLING MODULE
W1 LOW GRADE HEAT WATER IN FROM CUSTOMER (NOT USED)
W2 LOW GRADE HEAT WATER OUT TO CUSTOMER (NOT USED)
W3 MAKEUP WATER INLET
W5 HIGH GRADE HEAT WATER OUT TO CUSTOMER
W6 HIGH GRADE HEAT WATER IN FROM CUSTOMER
3/4" FEMALE PIPE THREAD INTERFACE PROVIDED
1/2" FEMALE PIPE THREADED INTERFACE PROVIDED, USE 3/4" TO 1/2" REDUCER
2" 150 LB RAISED FACE FLANGE PROVIDED BY ONSI CORP. (TYP. OF 4)
2" CLASS 150 LB THREADED FLANGES (TYP. OF 4)
C1 W1 C2 W2 W5 W6
N1 W3
POWER MODULE ENCLOSURE
PIPING ACCESS PANEL
GAUGE (0 - 100 PSIG)
BALL VALVE
3/4" COPPER TUBING FROM NITROGEN BOTTLE BANK
12"
BALL VALVE
3/4" COPPER
BRONZE BODY PRESSURE RELIEF VALVE WITH FULL SIZE OUTLET PIPED TO GROUND. EQUAL TO MODEL 174A AS MANUFACTURED BY WATTS REGULATION INC. 3/4" FNPT INLET/OUTLET PRESSURE RELIEF @ 125 PSIG OR 2,000,000 BTU/HR
BALL VALVE (TYPICAL)
HEAT TRACE COLD WATER MAKEUP PIPING
BALL DRAIN VALVE W/ 3/4" HOSE END (4 PLACES TYPICAL)
2" x 2" x 3/4" COPPER TEE
2" COPPER TUBING TO COOLING MODULE. INSULATE OR WRAP PER SPECIFICATIONS.
2" COPPER TUBING TO CUSTOMER HEAT RECOVERY INTERFACE. INSULATE PER SPECIFICATION.
PIPING SIDE ENTRY DETAIL A POWER MODULE
NOT TO SCALE
B M-2
PRESSURE GAUGE SEE SPECIFICATIONS
1/2" x 1/4" BRASS BUSHING (IF REQUIRED)
1/2" BALL VALVE
3/4" x 1/2" NPT BRASS BUSHING
PIPE
E GAUGE CONNECTION DETAIL
NOT TO SCALE
D M-2
ADJUSTABLE IMMERSION TEMPERATURE SENSOR SEE DWG. M-1 SPECIFICATIONS
3/4" x 1/4" NPT BUSHING
LINE SIZE TEE WITH 3/4" FPT BRANCH
PIPE
TEMPERATURE SENSOR DETAIL
NOT TO SCALE
F M-2
STANDARD 3/4" NPT THERMOWELL, STEM LENGTH EQUAL TO 1/2" PIPE DIAMETER.
PIPE
ETER AND WELL DETAIL
NOT TO SCALE
E M-2
REVISION LIST
REV DATE DESCRIPTION
A 7/3/97 1. HEAT TRACE DELETED FROM COLD WATER MAKEUP LINE IN DETAIL 3.
2. NITROGEN TANK FARM MOUNTING DETAIL CHANGE TO A WALL MOUNTED ARRANGEMENT.
3. BYPASS FOR GAS METER AND ADDITIONAL ANALYSIS PORT ADDED TO DETAIL C.
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ONSI CORPORATION
195 Governors Highway
P.O. Box 1148
South Windsor, CT 06074
PC25 C (S/N 9121) FUEL CELL POWER PLANT INSTALLATION BASE HOSPITAL (BUILDING 5500), EDWARDS AFB, CALIFORNIA
DRAWING NAME: MECHANICAL PIPING DETAILS
CAD File: 9XXXM2.DC5
Scale: NOT TO SCALE
DRAWN BY: JWS
CHECKED BY: PSG
DATE: 2-17-97
Drawing No: M 2
REV. A

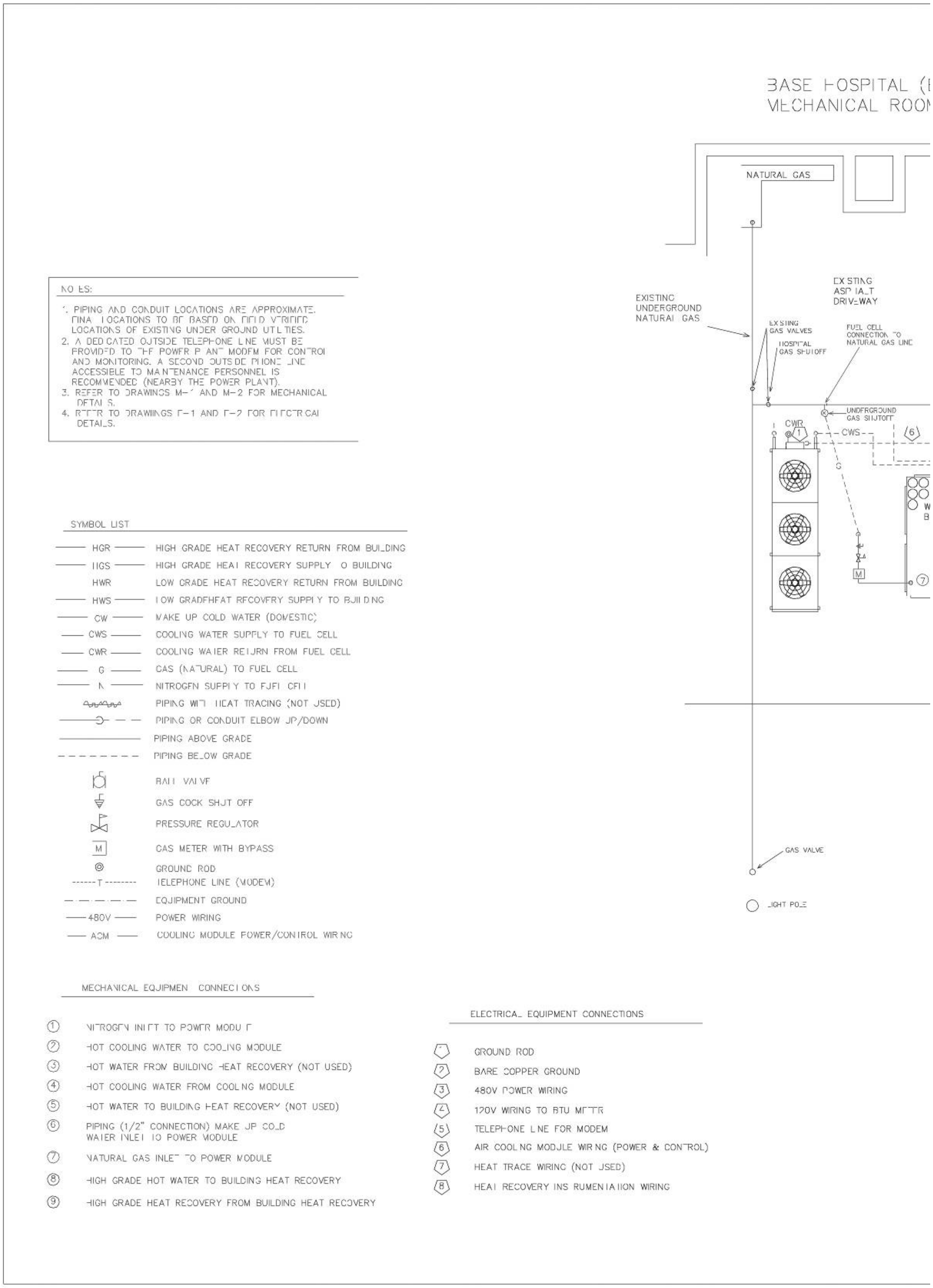
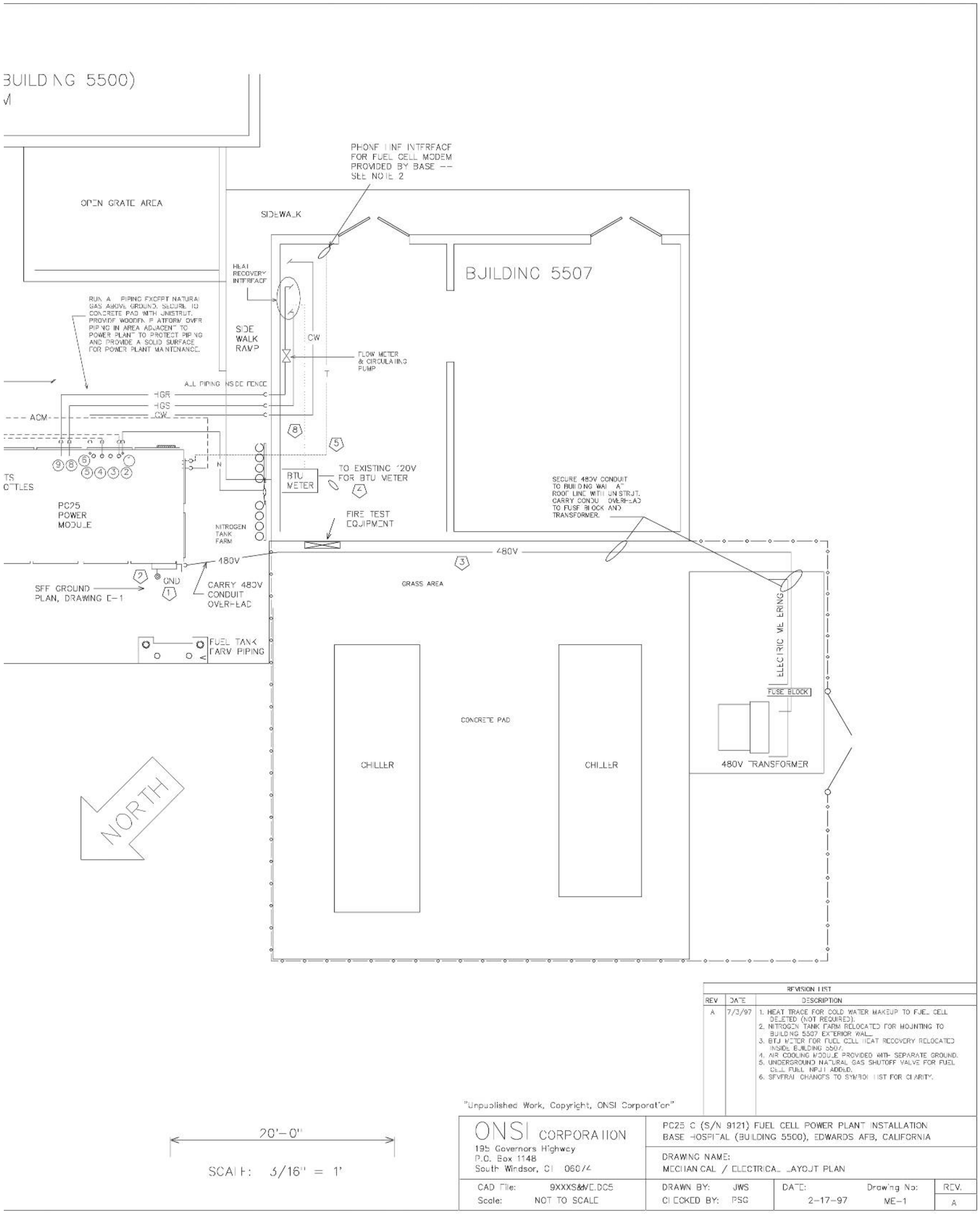


Figure 9. Final installation drawings – mechanical / electrical layout plan.


BUILDING 5500)
OPEN GRATE AREA
PHONE LINE INTERFACE FOR FUEL CELL MODEM PROVIDED BY BASE -- SEE NOTE 2
SIDEWALK
BUILDING 5507
HEAT RECOVERY INTERFACE
RUN ALL PIPING EXCEPT NATURAL GAS ABOVE GROUND. SECURE TO CONCRETE PAD WITH UNISTRUT. PROVIDE WOODEN PLATFORM OVER PIPING IN AREA ADJACENT TO POWER PLANT TO PROTECT PIPING AND PROVIDE A SOLID SURFACE FOR POWER PLANT MAINTENANCE.
SIDE WALK RAMP
CW
FLOW METER & CIRCULATING PUMP
ALL PIPING INSIDE FENCE
HGR
HGS
CW
ACM
PC25 POWER MODULE
BTU METER
TO EXISTING 120V FOR BTU METER
SECURE 480V CONDUIT TO BUILDING WALL AT ROOF LINE WITH UNISTRUT. CARRY CONDUIT OVERHEAD TO FUSE BLOCK AND TRANSFORMER.
NITROGEN TANK FARM
FIRE TEST EQUIPMENT
480V
GND
SEE GROUND PLAN, DRAWING E-1
CARRY 480V CONDUIT OVERHEAD
GRASS AREA
ELECTRIC METERING
FUEL TANK FARM PIPING
FUSE BLOCK
CONCRETE PAD
CHILLER
CHILLER
480V TRANSFORMER
NORTH
REVISION LIST
REV
DATE
DESCRIPTION
A
7/3/97
1. HEAT TRACE FOR COLD WATER MAKEUP TO FUEL CELL DELETED (NOT REQUIRED).
2. NITROGEN TANK FARM RELOCATED FOR MOUNTING TO BUILDING 5507 EXTERIOR WALL.
3. BTU METER FOR FUEL CELL HEAT RECOVERY RELOCATED INSIDE BUILDING 5507.
4. AIR COOLING MODULE PROVIDED WITH SEPARATE GROUND.
5. UNDERGROUND NATURAL GAS SHUTOFF VALVE FOR FUEL CELL FUEL INPUT ADDED.
6. SEVERAL CHANGES TO SYMBOL LIST FOR CLARITY.
"Unpublished Work, Copyright, ONSI Corporation"
20'-0"
SCALE: 3/16" = 1'
ONSI CORPORATION
195 Governors Highway
P.O. Box 1148
South Windsor, CT 06074
PC25 C (S/N 9121) FUEL CELL POWER PLANT INSTALLATION
BASE HOSPITAL (BUILDING 5500), EDWARDS AFB, CALIFORNIA
DRAWING NAME:
MECHANICAL / ELECTRICAL LAYOUT PLAN
CAD File: 9XXXS&VE.DC5
Scale: NOT TO SCALE
DRAWN BY: JWS
CHECKED BY: PSG
DATE: 2-17-97
Drawing No: ME-1
REV. A

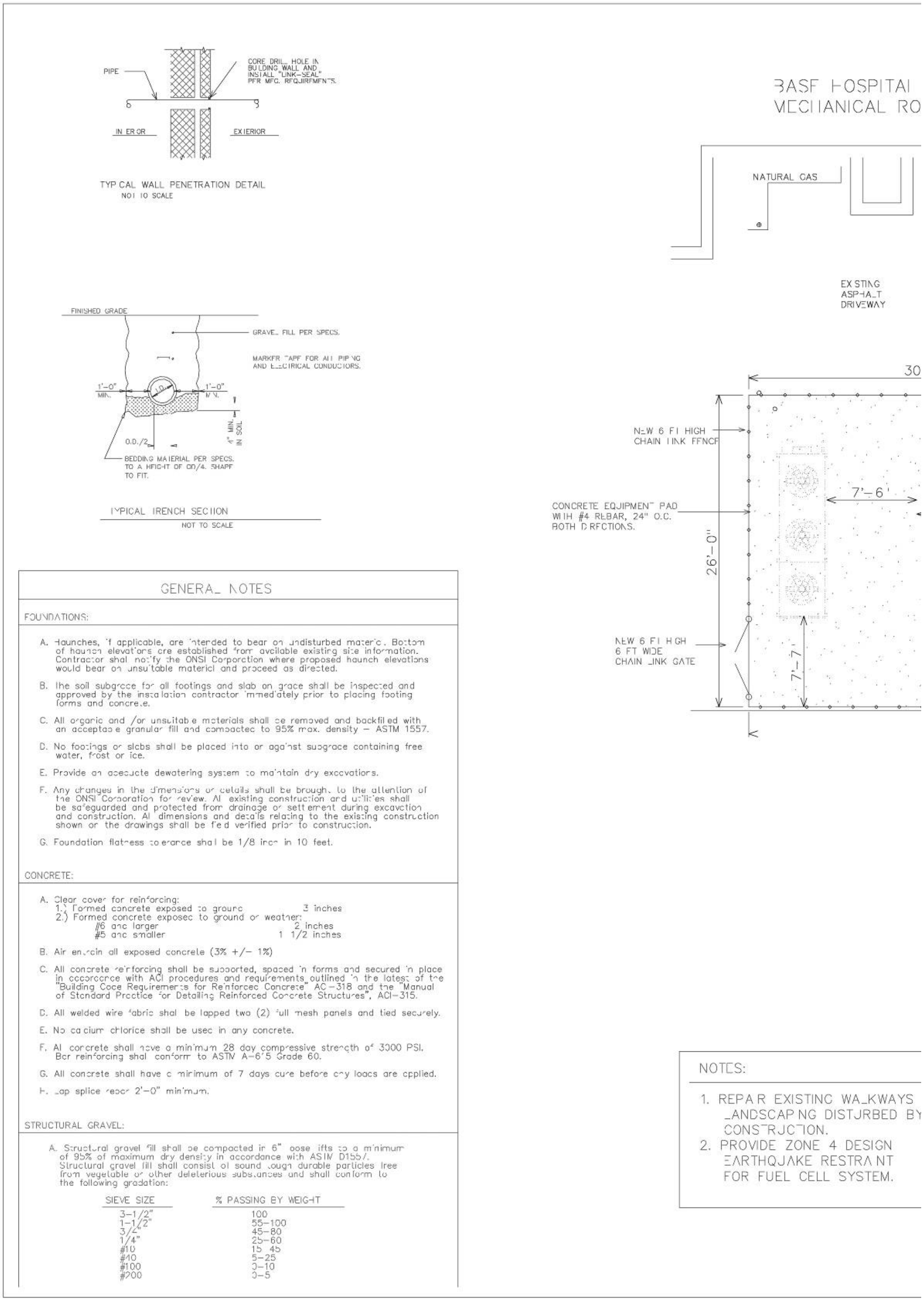
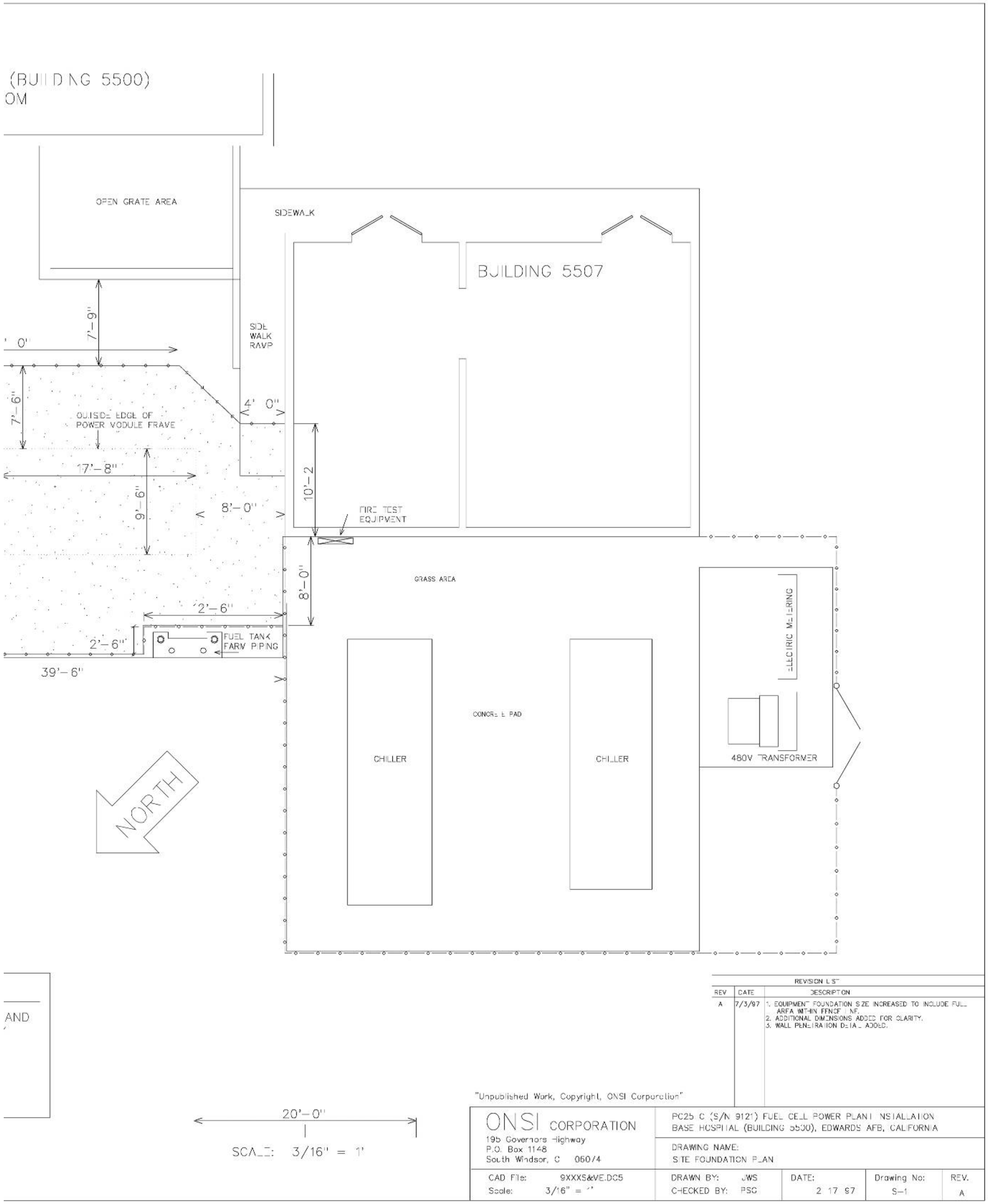


Figure 10. Final installation drawings – site foundation plan.


(BUILDING 5500)
OPEN GRATE AREA
SIDEWALK
BUILDING 5507
SIDE WALK RAMP
7'-9"
7'-6"
OUTSIDE EDGE OF POWER MODULE FRAME
17'-8"
9'-6"
8'-0"
4'-0"
10'-2
FIRE TEST EQUIPMENT
GRASS AREA
8'-0"
2'-6"
2'-6"
FUEL TANK FARM PIPING
39'-6"
CONCRETE PAD
CHILLER
CHILLER
ELECTRIC METERING
480V TRANSFORMER
NORTH
REVISION LIST
REV
DATE
DESCRIPTION
A
7/3/97
1. EQUIPMENT FOUNDATION SIZE INCREASED TO INCLUDE FULL AREA WITHIN FENCE LINE.
2. ADDITIONAL DIMENSIONS ADDED FOR CLARITY.
3. WALL PENETRATION DETAIL ADDED.
"Unpublished Work, Copyright, ONSI Corporation"
20'-0"
SCALE: 3/16" = 1'
ONSI CORPORATION
195 Governors Highway
P.O. Box 1148
South Windsor, C 06074
PC25 C (S/N 9121) FUEL CELL POWER PLANT INSTALLATION
BASE HOSPITAL (BUILDING 5500), EDWARDS AFB, CALIFORNIA
DRAWING NAME:
SITE FOUNDATION PLAN
CAD File: 9XXXS&VE.DC5
Scale: 3/16" = 1'
DRAWN BY: JWS
CHECKED BY: PSC
DATE: 2 17 97
Drawing No: S-1
REV. A

4 Fuel Cell Performance, Outage History and Maintenance Activities

4.1 Operating History

The fuel cell was started up in mid-June 1997. Acceptance tests were done between 23–25 June. (Appendix A includes the Acceptance Test Report.) Official data recording for the demonstration began on 17 July. The formal acceptance test meeting was held on 16 June, with title to the fuel cell transferred to the Edwards AFB using Form DD250. The power plant continued to operate until an event on 18 July 1997. A total of 27 power plant shutdowns were recorded between 17 July 1997 and the final shutdown on 1 July. 2002. There were 16 forced outages and 11 non-forced outages.

Performance data were collected via UTC Fuel Cells' RADAR data acquisition system. Using a modem and telephone line, the power plant was called daily to retrieve a "snapshot" of the current status. Included in the metrics collected were cumulative totals for hot time, load time, MWHrs, input fuel, etc. Thermal heat recovery was not monitored. These data records were then used to generate the various performance parameters discussed in this report.

A total of 28,358 operating load hours were recorded for the Hospital fuel cell. Of the 27 separate operating periods, eight had continuous fuel cell operating hours of more than 1,000 hours. The longest continuous operating period was 4,507 hours (~ 6 months) and occurred between 21 July 1999 and 25 January 2000. Table 4 lists the distribution of continuous periods of operation for this fuel cell.

Table 4. Distribution of continuous hours of operation.

Hours of Operation	Occurrences
Over 3,000 hours	3
2,001 – 3,000 hours	3
1,001 – 2,000 hours	2
751 – 1,000 hours	1
501 – 750 hours	5
250 – 500 hours	6
Less than 250 hours	7

Figure 11 shows the hours of operation and outages on a monthly basis for the entire demonstration period.

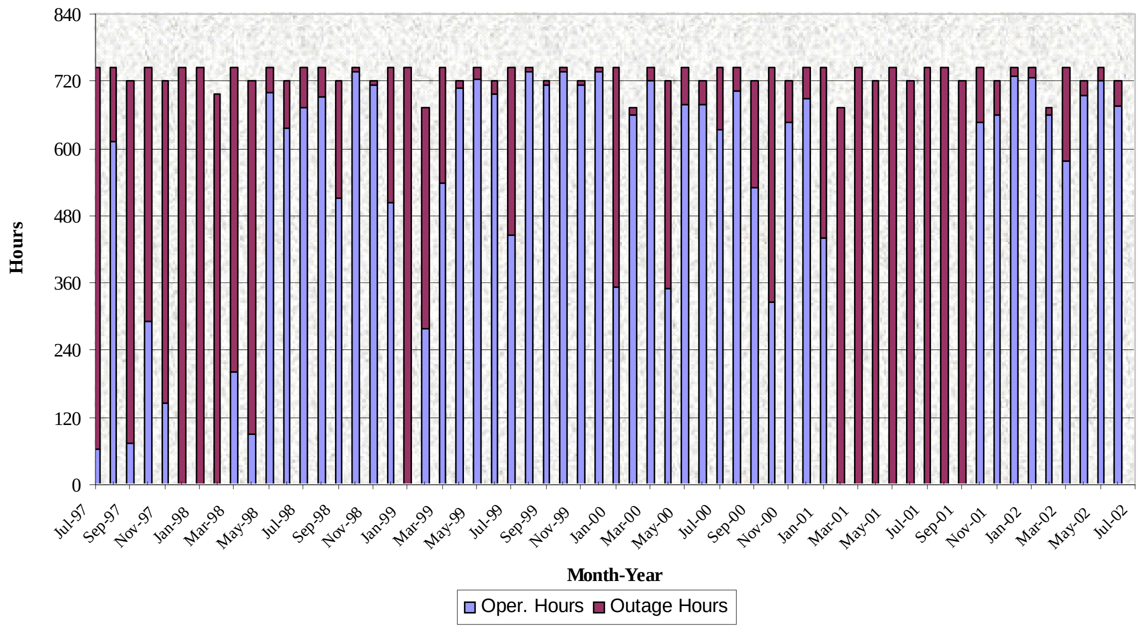


Figure 11. Fuel cell operating hours by month.

The fuel cell generated over 5.1 million kWh of electricity for the Hospital during the demonstration period. Average output of the fuel cell during operation was 179 kW over the 5+ year period. Table 5 lists data related to annual fuel cell electrical operation during the demonstration. The average output represents the fuel cell's average rate of electrical generation while the fuel cell was operating. The average rate of generation through 1999 was 194 kW, 97.2 percent of the fuel cell's nominally rated electrical output of 200 kW. For the period of 2000 to the end of the demonstration, the average generation rate was 164 kW, 82 percent of the fuel cell's nominally rated electrical output.

Table 5. Fuel cell electrical performance characteristics.

Year	Operating Hours	Generation (MWh)	Average Generation. (kW)
1997	1,024	192.8	188
1998	5,630	1,100.3	195
1999	7,340	1,426.5	194
2000	7,326	1,243.7	170
2001	2,823	447.2	158
2002	4,215	670.9	159
Total/Avg.	28,358	5,081.4	179

The RADAR system did not measure thermal utilization. Table 6 lists the input fuel data. The fuel cell consumed natural gas at an average rate of 1,744.3 cu ft/hour of operation or 9.7 cu ft/kW during the course of the demonstration.

Table 6. Fuel cell input fuel characteristics.

Year	Input Fuel (cu ft)	Input Fuel (cubic ft/hr)
1997	1,200,000	1,788.4
1998	9,811,327	1,742.7
1999	13,824,858	1,883.5
2000	12,845,496	1,753.4
2001	4,713,880	1,669.8
2002	7,068,103	1,677.1
Total/Avg.	49,463,664	1,744.3

Table 7 lists the fuel cell electrical efficiency based on higher heating value (HHV) for each year of operation. The average electrical efficiency over the course of the demonstration was 34.0 percent (HHV).

Table 7. Fuel cell electric efficiency.

Year	Generation (MWh)	Input Fuel (cu ft)	Electrical Efficiency (% -HHV)*
1997	192.8	1,200,000	34.9
1998	1,100.3	9,811,327	37.2
1999	1,426.5	13,824,858	34.2
2000	1,243.7	12,845,496	32.1
2001	447.2	4,713,880	31.4
2002	670.9	7,068,103	31.5
Total/Avg.	5,081.4	49,463,664	34.0
*Higher Heating Value (HHV) is based on a natural gas heating value of 1,030 Btu/cubic foot. Efficiency =([MWhrs x 1,000,000 Watt-hrs/MWhrs x 3.413 Btu/Watt] / [cu ft x 1,030 Btu/cu ft]) x 100			

4.2 Fuel Cell Outage Summary

Between 17 July 1997 and 1 July 2002 (43,419 hours), the fuel cell had 27 outages resulting in 15,061.5 hours of down time. The fuel cell's availability was 65.3 percent:

$$65.3\% = ([43,419 - 15,061.5] / [43,419]) \times 100$$

Figure 12 shows the fuel cell's monthly availability.

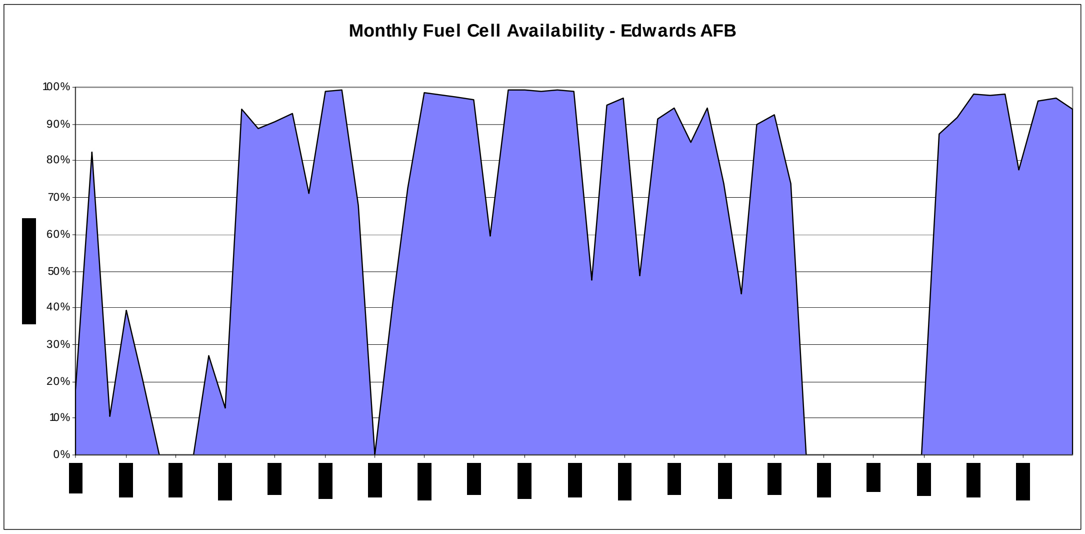


Figure 12. Monthly fuel cell availability.

The outages were identified from the RADAR performance monitoring system data. Because data records are collected on average once per day, outage times had to occasionally be interpolated. Sometimes the modem did not respond or the phone line was down, which prevented collection of a full complement of data records.

The longest outage was for 6,193 hours and occurred between 19 January and 14 October 2001. The next longest outage period occurred between 19 October 1997 and 12 February 1998 (2,556 hours). Table 8 lists the distribution of outage periods by hours of duration.

Table 8. Distribution of non-operational hours by duration.

Outage Hours	Occurrences
Over 3,000 hours	1
2,001 – 3,000 hours	1
1,001 – 2,000 hours	1
751 – 1,000 hours	1
501 – 750 hours	1
250 – 500 hours	7
Less than 250 hours	15

Table 9 lists, in chronological order, the start and end dates/times, the outage duration hours, and the outage type for the 27 individual events. Appendix D has the complete list of outage codes for the PC25C fuel cell.

Table 9. Fuel cell outage periods.

Outage No.	Off Date Stamp	On Date Stamp	Total Outage Hours	Hours to Next Outage	Type	System	Part
		7/17/97 09:34		25.93			
1	7/18/97 11:30	7/31/97 07:00	307.50	630.40	N		
2	8/26/97 13:24	9/13/97 16:00	434.60	5.00	N		
3	9/13/97 21:00	9/22/97 12:58	207.97	70.53	F	TMS	
4	9/25/97 11:30	10/15/97 18:45	487.25	323.97	F	TMS	TCV830
5	10/29/97 06:43	2/12/98 18:35	2,555.87	269.00	F	TMS	
6	2/23/98 23:35	3/11/98 18:35	379.00	56.03	F	TMS	
7	3/14/98 02:37	4/21/98 17:13	926.60	91.70	N		
8	4/25/98 12:55	5/2/98 14:23	169.47	1,344.87	N		
9	6/27/98 15:15	7/1/98 15:00	95.75	243.57	F	WTS	LT450
10	7/11/98 18:34	7/13/98 21:00	50.43	881.28	N		
11	8/19/98 14:17	8/21/98 11:50	45.55	473.75	F	OTR	
12	9/10/98 05:35	9/18/98 15:15	201.67	2,264.75	F	OTR	
13	12/22/98 00:00	2/16/99 17:03	1,361.05	3,326.38	F	FPS	REF300
14	7/5/99 07:26	7/6/99 17:50	34.40	96.67	N		
15	7/10/99 18:30	7/21/99 12:00	257.50	4,507.42	F	OTR	CRL
16	1/25/00 07:25	2/1/00 23:00	183.58	656.33	F	APS	FCV140
17	2/29/00 07:20	2/29/00 16:47	9.45	708.72	N		
18	3/30/00 05:30	3/30/00 14:30	9.00	328.67	N		
19	4/13/00 07:10	4/27/00 21:21	350.18	636.00	F	TMS	TE431
20	5/24/00 09:21	5/26/00 13:00	51.65	2,953.67	N		
21	9/26/00 14:40	10/17/00 21:25	510.75	327.05	F	WTS	LT450
22	10/31/00 12:28	11/1/00 16:30	28.03	259.08	N		
23	11/12/00 11:35	11/14/00 19:30	55.92	520.50	F	OTR	CRL
24	12/6/00 12:00	12/8/00 15:30	51.50	1,007.25	F	NPS	CV720
25	1/19/01 14:45	10/4/01 16:07	6,193.37	4,189.30	N		
26	3/28/02 05:25	4/3/02 11:48	150.38	2,137.20	F	OTR	CRL
27	7/1/02 13:00	Final Shutdown			F	WTS	LT450

Table 10. Forced outage categories.

Category	Description
APS	Air Processing System
CVS	Cabinet Ventilation System
ES	Electrical System
FPS	Fuel Processing System
NPS	Nitrogen Purge System
OTR	Other
PSS	Power Section System
TMS	Thermal Management System
WTS	Water Treatment System

Table 11. Forced outage statistics.

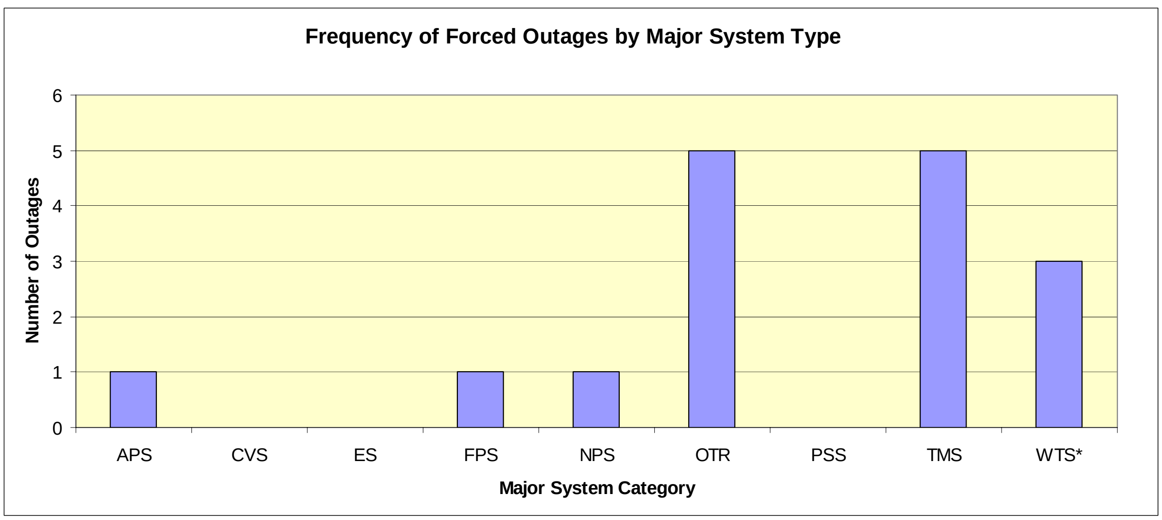
Category	Number of Occurrences	Total Outage Time	Min. Outage Time per Occurrences	Max. Outage Time per Occurrences	Avg. Outage Time per Occurrence
APS	1	183.6	183.6	183.6	183.6
CVS	0	0	0	0	0
ES	0	0	0	0	0
FPS	1	1,361.1	1,361.1	1,361.1	1,361.1
NPS	1	51.5	51.5	51.5	51.5
OTR	5	711.0	45.6	257.5	142.2
PSS	0	0	0	0	0
TMS	5	3,980.3	208.0	2,55.99	796.1
WTS*	3	606.5	N/A	510.8	303.3
	16	6,893.9			430.9
*Includes the final outage which has no time associated it.					

The fuel cell experienced a total of 15,061.5 hours of outage time consisting of 16 forced outages (F) and 11 non-forced (N) outages. Table 10 lists the forced outages, broadly classified by the major fuel cell sub-systems. Table 11 lists the forced outages by major system category, along with statistics related to frequency of occurrence and time duration.

Most of the forced outages were classified as Other (OTR) or Thermal Management System (TMS). (Each had five occurrences.) The most frequent number of Other outages were three, which were attributed to the controller (CRL) for a total of 463.8 hours of outage. The longest outage in the TMS category was 2,555.87 hours between October 1997 and February 1998 due to a problem with the sub stack. This occurred early on in the demonstration. Similar characteristics were also observed in other fuel cells installed in the southwestern region of the country, which included

Camp Pendleton, Twentynine Palms, Davis-Monthan AFB, and Fort Huachuca. It was concluded that the hard water characteristics of the water supply was contributing to the water conductivity in the fuel cell. Hard water is water that contains a high level of dissolved minerals, most notably calcium and magnesium. The degree of hardness increases with increased levels of calcium and magnesium. When hard water is heated, the dissolved minerals come out of solution (precipitate) and attach to plumbing and heat exchangers. Water treatment systems were installed to control the water chemistry of these systems.

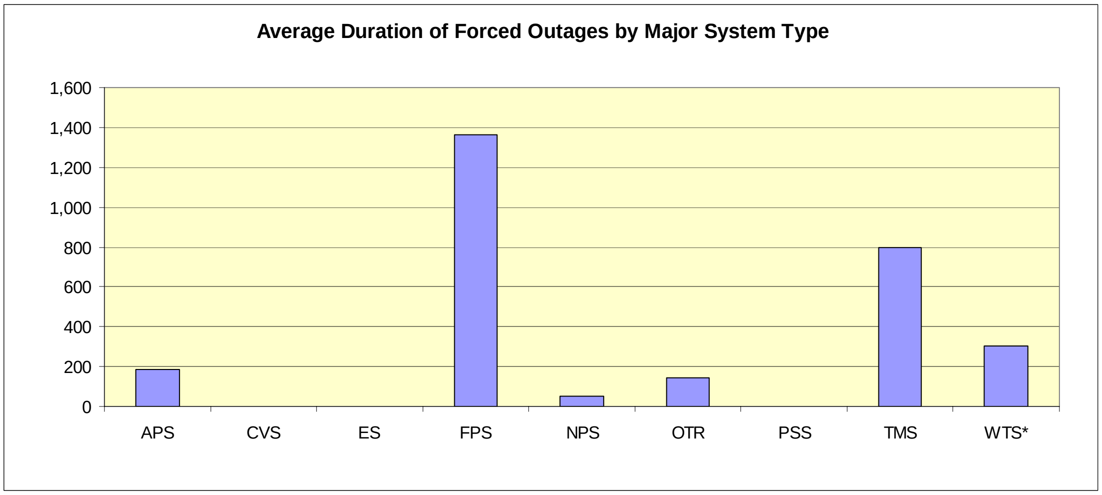
Figure 13 shows a graph of force outage occurrences. The cabinet ventilation system, electrical system, and power section system did not contribute to any forced outages during the demonstration. An outage associated with the water treatment system was the final outage in July 2002, which was not resolved.



* Includes final forced outage that was never resolved.

Figure 13. Forced outage occurrences by major system types.

Figure 14 shows the average duration of forced outage hours by major system category. The fuel processing system was associated with the highest average duration per outage (1,361.1 hours). (Note that this represents just one outage.) The next highest average duration per outage was associated with the thermal management system, with an average of 796.1 hours per occurrence over a total of five outages. The longest TMS outage was attributed to problems with the cooling-side of the fuel cell stack and occurred for 2,555.87 hours. The shortest duration TMS outage lasted for 208 hours and was attributed to a failure of a steam ejector.



* Includes final forced outage that was never resolved.

Figure 14. Average forced outage durations by major system types.

The outages that occurred most frequently for a specific fuel cell component were due to an alarm triggered by the water level transmitter (LT450). The three outages associated with this were for 95.75 hours in June 1998, 510.75 hours in September 2000 and for final outage in July 2002.

These data show that forced outages have a significant impact on the availability of the fuel cell. The shortest duration outage lasted for 45.6 hours. Five of the outages had a duration between 1 and 7 days. There were two outages that had a duration longer than 30 days, of which one was greater than 90 days. Figure 15 shows the outages by duration, which demonstrates that there is a high risk of not achieving the monthly demand savings in the economics for the fuel cell due to forced outages.

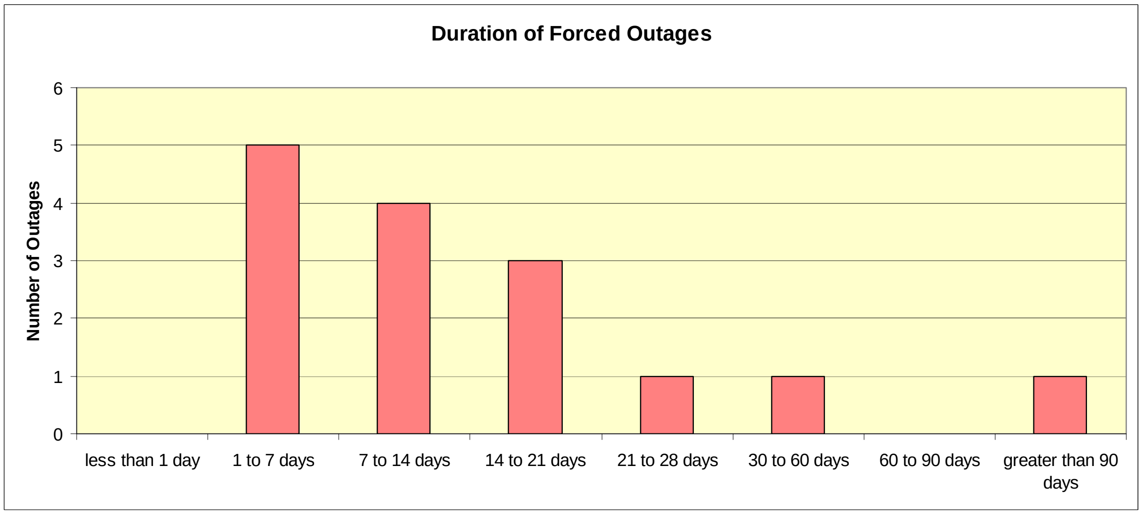


Figure 15. Number of forced outages by outage duration.

Figure 16 shows the distribution of forced outages by major system categories. The major system category contributing to most of the outage hours was the thermal management system (57.7 percent). The next highest category was the fuel processing system with 19.7 percent of the forced outage time.

Typical non-forced outages were due to the natural gas supply being turned off, site operator error, or scheduled maintenance activities. The longest non-forced outage occurred between January and October 2001 for a total of 6,193.37 hours. This outage was due to site personnel shutting off the natural gas supply to the fuel cell and opening the maintenance disconnect switch. This resulted in a hot shutdown of the fuel cell. UTC Fuel Cells informed Edwards AFB that this event could have a permanent negative impact on the fuel cell performance, specifically affecting the fuel cell stack. This outage occurred with approximately 22,000 stack load hours of the total 28,358 load hours for the fuel cell. Fuel cell electric efficiency as shown in Figure 17 shows a variation in efficiency occurring around 22,000 hours, but not a significant step change in the performance of the fuel cell after the time of the event.

4.3 Fuel Cell Stack Degradation

The trend of the fuel cell electrical efficiency based on the lower heating value of natural gas was analyzed based on the hours of fuel cell operation. The data were acquired through the UTC Fuel Cells' RADAR system. Data records are for fuel cell operation when the electrical output was greater than 50 kW to eliminate data from fuel cell testing and startup operation.

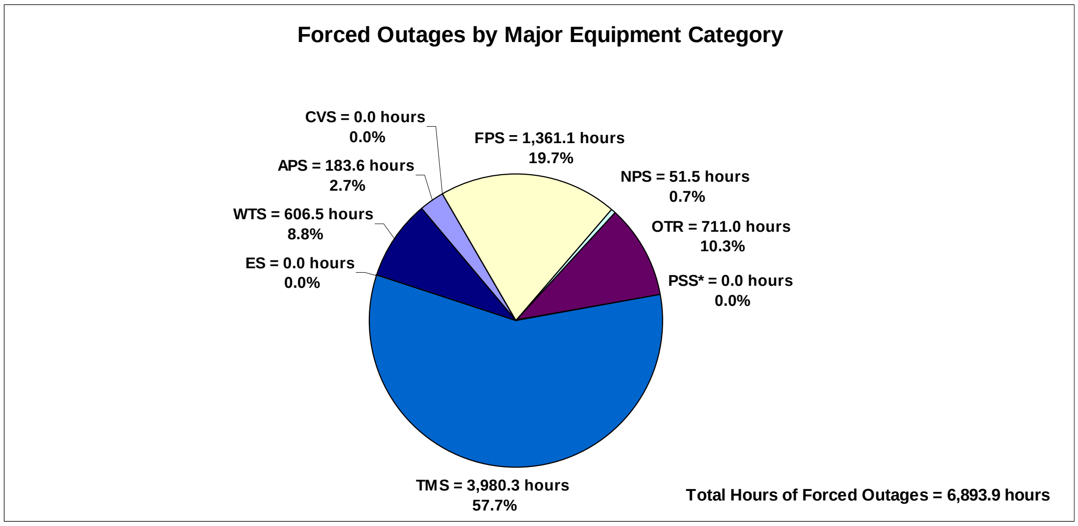


Figure 16. Total forced outage hours by major system types.

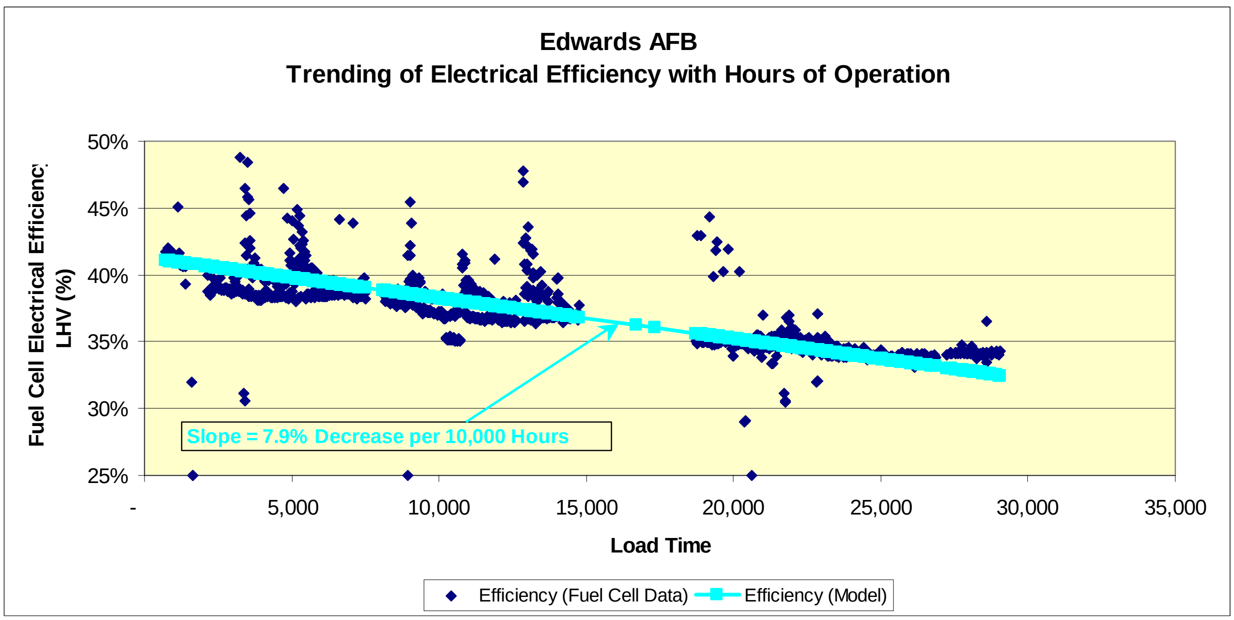


Figure 17. Fuel cell stack electrical efficiency degradation over time.

Note that the data records were not recorded on regular intervals and 1,435 data points were used for this analysis. The individual data points are plotted with hours of operation in an X-Y plot (Figure 17). The average electrical efficiency for the data is 37.2 percent.

A linear regression was conducted on the data to characterize average efficiency trends for the fuel cell. The regression equation is:

Electric Efficiency % (LHV) = ([Load Hours] x [-3.03424×10^{-4}]) + 41.28840 Eq 1

The linear curve fit shows that the trend is a reduction in electrical efficiency with increasing hours of operation. Table 12 lists the resulting efficiencies at 5,000 load hour intervals.

Table 12. Trend of electrical efficiency with fuel cell load hours.

Load Hours	Electrical Efficiency (%)
0	41.3%
5,000	39.8%
10,000	38.3%
15,000	36.7%
20,000	35.2%
25,000	33.7%

The data in Table 12 show that the fuel cell electrical efficiency decreased 1.5 basis points for every 10,000 hours of operation. The regression shows that the average initial electrical efficiency of the fuel cell was approximately 41.3 percent and that it decreased at a rate of approximately 7.9 percent per 10,000 hours of operation. For example, the average decrease between 10,000 hours (38.3 percent) and 20,000 hours (35.2 percent) is:

$$7.9\% = ([38.3\% - 35.2\%] / 38.3\%).$$

The R Square statistic for the above regression is 0.22. This means that 22 percent of the variation seen in the trend of electrical efficiency can be attributed to load hours. Thus other factors in the system are significantly affecting the changes observed in electrical efficiency. The efficiency data (as shown in Figure 9) indicate sub-trends in electrical efficiency within the life of the fuel cell's operation. Figure 10 shows the outages and identification of major system changes. Each of the 27 outages is represented as a circle on the 45 percent efficiency line. The figure identifies regions of operational trends that are attributed to a major change to the system or lack of data. The number identifier presented for the change corresponds to the outage number listed in Table 8. The most significant changes were the installation of a new cell stack and the installation of an external reverse osmosis (RO) water treatment system (#5), and the installation of a new reformer (#13). For a period of approximately 4,000 load hours, the natural gas meter failed which resulted in the inability to determine the efficiency during this period.

The five operational regions shown in Figure 18 were analyzed to determine the electrical efficiency trend by major system change. The trend in efficiency for each region was determined by a linear regression and the slope is reported in terms of percent change per 10,000 hours of operation. Note that the unit of percent change per 10,000 is presented for consistency and only one of the regions evaluated (E) consists of 10,000 hours of data. Table 13 lists the dates, fuel cell load hours, system changes and electric efficiency trends for each of the time frames. For the regions analyzed, the R Square statistic is less than the 0.22 for the entire data set (B=0.05, C=0.02 and E=0.02). This indicates that the major system changes identified did not have a significant impact on the fuel cell performance and that this approach does not improve on the original efficiency trend model.

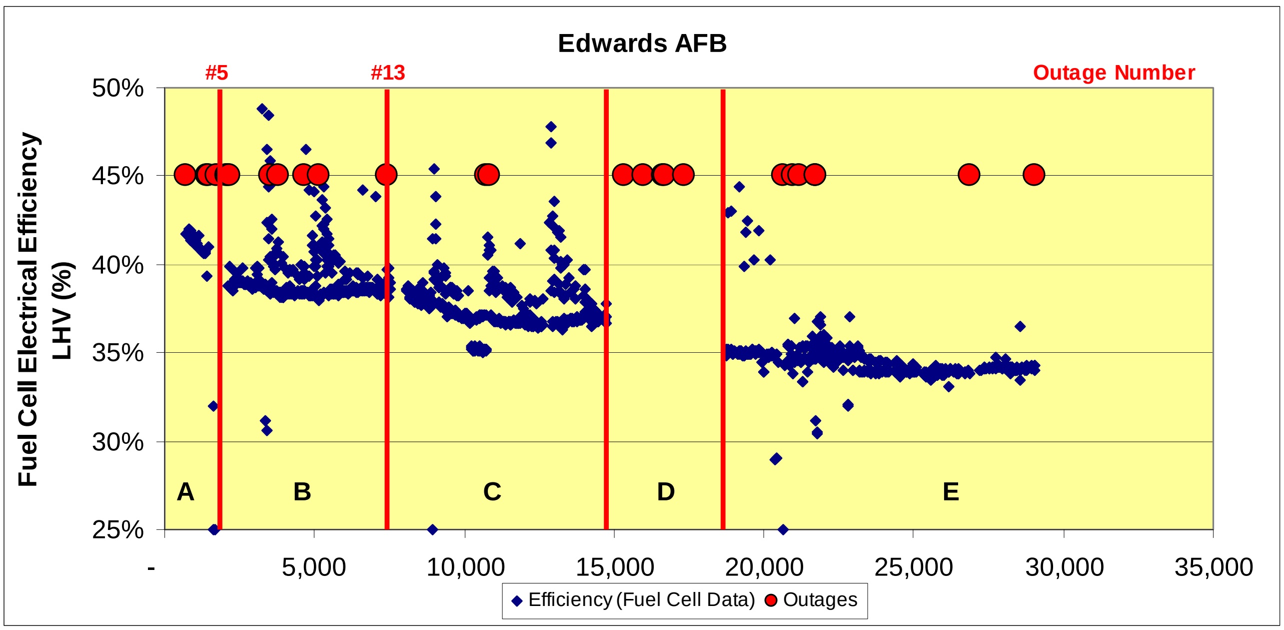


Figure 18. Electric efficiency trends with major system changes.

Table 13. Major system changes and electrical efficiency trends.

Range	Date	Fuel Cell Load Hours at End of Period	Change to System at Start of Period	Slope (% / 10000 hrs)
A	7/17/97 – 2/12/98	1,769	Initial system	-41.8%
B	1/12/98 – 2/16/99	7,407	Install new reformer	-15.0%
C	2/16/99 – 12/31/99	14,747	Install new cell stack and Install RO water treatment	-4.9%
D	12/31/99 – 6/29/00	18,168	Gas meter failure	No data
E	6/29/00 – 7/1/02	29,055	Gas meter repaired	-3.1%

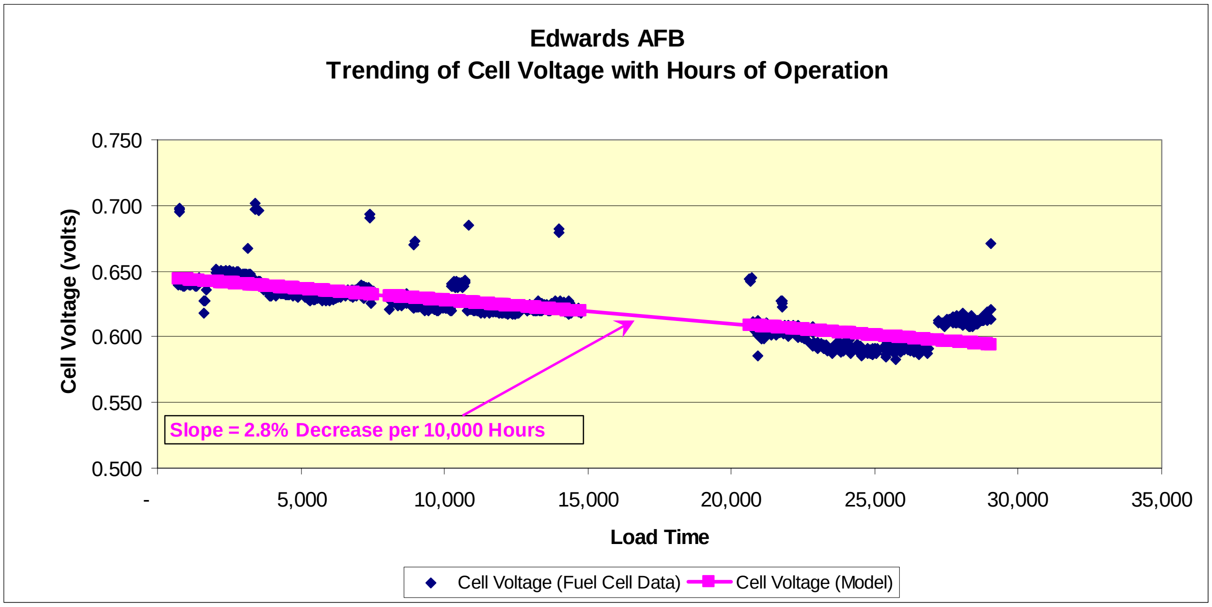


Figure 19. Fuel cell stack cell voltage degradation over time.

The trend of the fuel cell stack cell voltage based on the lower heating value of natural gas was analyzed based on the hours of fuel cell operation. The data are based on the same readings acquired through the UTC Fuel Cells RADAR system as the electrical efficiency data in the previous section. The individual data points are plotted with hours of operation in an X-Y plot. Figure 19 shows that the data fall into the typical operating range of 0.55 to 0.70 volts. The average cell voltage for the data is 0.623 volts. A linear regression was conducted on the data to characterize average cell voltage trends for the fuel cell. The resulting equation is:

Cell volts = ([Load Hours] x [-1.7694 x 10-6]) + 0.645519 Eq 2

The regression shows a reduction in cell voltage with increased hours of operation. Table 14 lists the resulting cell voltages at 5,000 load hour intervals.

Table 14. Trend of cell voltage with fuel cell load hours.

Load Hours	Cell Voltage (%)
0	0.646
5,000	0.637
10,000	0.628
15,000	0.619
20,000	0.610
25,000	0.601

The linear curve fit shows that the average initial cell voltage was approximately 0.646 volts and that it generally decreased at a rate of 2.8 percent per 10,000 hours of operation. For example, the average decrease between 10,000 hours (0.628) and 20,000 hours (0.610) is:

$$2.8\% = ([0.628 - 0.610] / 0.628)$$

This is equal to a cell voltage reduction rate of 0.018 volts per 10,000 hours of operation. The R Square statistic for the above regression is 0.61. This means that 61 percent of the variation seen in the trend of cell voltage can be attributed to load hours. Thus, other factors in the system are affecting the changes observed in cell voltage. The cell voltage data shown in Figure 11 indicate sub-trends in cell voltage during the life of the fuel cell's operation. Since the cell voltage is affected by the electrical output of the fuel cell, an additional analysis was conducted. The data were sorted by the fuel cell electrical output for the most frequent operating levels of 200 kW, 175 kW, and 150 kW. Then a linear regression was conducted for load hours greater than 5,000 hours (i.e., for the fuel cell after the stack was replaced). Table 15 lists the results of the analysis.

Table 15. Cell voltage analysis by electrical output.

Fuel Cell Output	200 kW	175 kW	150 kW
Data points	950	256	110
R Square statistic	0.54	0.95	0.42
Slope (%/10,000 hrs)	-3.41%	-5.44%	-2.67%

The analysis shows that the curve fit was very good for the 175 kW regression with an R Squared value of 0.95. This indicates that 95 percent of the decrease in cell voltage can be attributed to load hours for this data set. The 200 kW and 150 kW regressions have R Squared values that are lower than the original regression model, indicating that this approach does not improve the model for these two data sets. The slopes of the lines for the three power levels range from –2.67 percent to –5.44 percent per 10,000 load hours. Figure 20 shows the regression lines of the analysis for each data set projected over the entire fuel cell operating range.

While the efficiency remains relatively constant along the various fuel cell power levels, power plant cell voltages tend to increase at lower electrical output levels. This is most evident for fuel cell operation between 10,000 and 20,000 load hours. There is no data to indicate why the slope of the data varies at the different power levels.

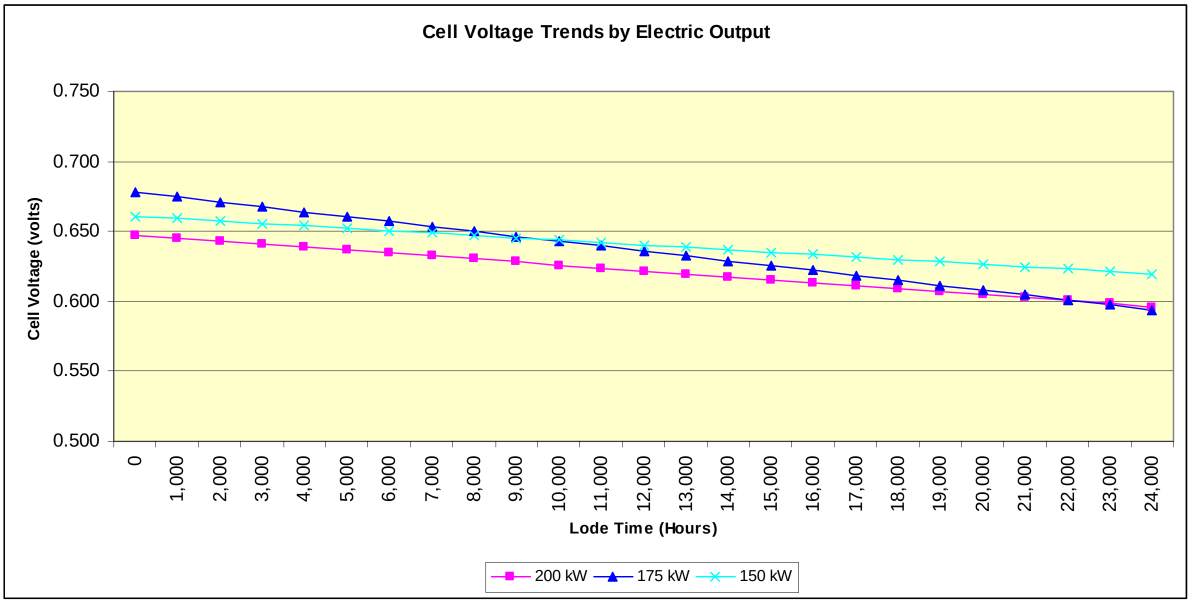


Figure 20. Cell voltage trends by electrical output.

4.4 Fuel Cell Maintenance Activities

UTC Fuel Cells had overall responsibility for maintenance on the fuel cell during the 5-year demonstration period. GBC Electrical Services, as the maintenance contractor, performed most maintenance activities under the guidance of UTC Fuel Cells. Invoices from GBC Electrical Services were obtained to assess maintenance activity levels. Table 16 lists the number of maintenance days at the site and total labor hours by year. No maintenance records were available for 2002.

Table 16. Maintenance days and labor hours by year.

Year	Days at Site	Labor Hours
1997	39	323
1998	42	344
1999	21	193
2000	29	222
2001	9	30
Total	140	1,112

Tables 17 through 21 present the date, labor hours, and a brief description of the maintenance activities that were billed between the years 1997 and 2001. Appendix E includes detailed cost and maintenance summary information.

Table 17. Maintenance activities in 1997.

1997	Labor Hrs	Description of Activity
10-Jun	10.0	Worked with UTC Fuel Cells at site.
11-Jun	9.0	Worked with UTC Fuel Cells at site.
12-Jun	11.5	Worked with UTC Fuel Cells at site.
13-Jun	2.5	Worked with UTC Fuel Cells at site.
16-Jun	8.0	Worked with UTC Fuel Cells at site.
17-Jun	10.0	Worked with UTC Fuel Cells at site.
18-Jun	10.0	Worked with UTC Fuel Cells at site.
19-Jun	8.0	Worked with UTC Fuel Cells at site.
20-Jun	3.0	Worked with UTC Fuel Cells at site.
23-Jul	8.0	Worked with UTC Fuel Cells at site.
24-Jul	5.0	Worked with UTC Fuel Cells at site.
25-Jul	6.0	Worked with UTC Fuel Cells at site.
27-Aug	9.0	Changed nitrogen bottles.
5-Sep	6.0	Changed out resin bottles.
8-Sep	2.0	Changed nitrogen bottles.
9-Sep	0.0	Travel
20-Sep	13.0	Changed ejector assembly.
22-Sep	7.5	Restarted power plant.
26-Sep	3.5	Troubleshot ancillary cooling loop.
29-Sep	9.5	Replaced TVC830.
30-Sep	9.5	Started power plant.
6-Oct	16.0	Installed new controller. Restarted power plant and installed retrofits.
13-Oct	1.0	Worked with UTC Fuel Cells at site.
14-Oct	7.5	Worked with UTC Fuel Cells at site.
15-Oct	12.5	Worked with UTC Fuel Cells at site.
16-Oct	12.5	Worked with UTC Fuel Cells at site.
27-Oct	3.0	Worked with UTC Fuel Cells at site.
28-Oct	9.0	Worked with UTC Fuel Cells at site.
29-Oct	8.5	Worked with UTC Fuel Cells at site.
7-Nov	9.0	Worked with UTC Fuel Cells at site.
8-Nov	2.5	Worked with UTC Fuel Cells at site.
11-Nov	6.0	Worked with UTC Fuel Cells at site to go over wet-up procedure.
13-Nov	2.0	Worked with UTC Fuel Cells at site.
14-Nov	9.5	Started wet-up process.
17-Nov	9.5	Started wet-up process.
18-Nov	12.0	Started wet-up process.
19-Nov	7.0	Started wet-up process.
7-Dec	12.5	Prepared cell stack assembly for removal.
8-Dec	32.0	Removed and shipped cell stack assembly.

Table 18. Maintenance activities in 1998.

1998	Labor Hrs	Description of Activity
10-Jan	22.0	Worked with UTC Fuel Cells on retrofits
12-Jan	7.5	Worked with UTC Fuel Cells on retrofits
13-Jan	5.0	Worked with UTC Fuel Cells on retrofits
2-Feb	4.0	Installed new strainer.
4-Feb	24.0	Installed new cell stack assembly.
5-Feb	9.0	Worked with UTC Fuel Cells at site.
10-Feb	3.5	Worked with UTC Fuel Cells to trouble shoot short in inverter.
11-Feb	9.0	Troubleshot, disassembled and re-assembled inverter.
12-Feb	2.0	Started power plant.
22-Feb	6.5	Worked with UTC Fuel Cells personnel on phone. Restarted power plant.
24-Feb	6.0	Checked ejector and FCV012 for proper movement. Started power plant.
5-Mar	3.0	Took measurements on old inverter drawer.
6-Mar	8.0	Removed and replaced inverter drawer No. 3 and attempted to start power plant.
11-Mar	6.0	Removed and replaced FCV110 and restarted power plant.
7-Apr	15.0	Worked on high grade heat exchanger skid retrofit.
8-Apr	17.0	Worked on high grade heat exchanger skid retrofit.
9-Apr	5.5	Worked on high grade heat exchanger skid retrofit.
13-Apr	18.0	Worked on high grade heat exchanger skid retrofit.
14-Apr	23.0	Worked on high grade heat exchanger skid retrofit.
15-Apr	20.0	Worked on high grade heat exchanger skid retrofit.
16-Apr	27.0	Worked on high grade heat exchanger skid retrofit.
17-Apr	5.5	Troubleshot and repaired short in power conditioning system.
20-Apr	2.0	Replaced pop out fuse for UPS.
21-Apr	8.0	Started power plant.
28-Apr	3.0	Worked with UTC Fuel Cells at site.
29-Apr	6.5	Worked with UTC Fuel Cells at site.
30-Apr	6.5	Worked with UTC Fuel Cells at site.
30-Apr	1.0	Travel
18-Jun	3.0	Tested water, burner air and cathode air. Completed new checklist.
30-Jun	6.0	Plugged reverse osmosis unit back in. Replaced fuse in cooling towers.
1-Jul	5.0	Restarted power plant.
8-Jul	3.5	Took amp readings on cooling tower.
13-Jul	4.5	Took override off LCV452. Changed nitrogen bottles. Started power plant.
10-Sep	4.0	Tested fuses in the cooling tower.
11-Sep	5.0	Troubleshot tripped breaker No. 33.
12-Sep	5.0	Put in new Ground Fault Interrupter (GFI) and new breaker. Breaker still tripped.
17-Sep	6.5	Tested circuit breaker No. 33.
18-Sep	8.5	Installed six temperature testers. Started fuel cell and left running at 200 kW.

1998	Labor Hrs	Description of Activity
12-Oct	5.0	Changed resin and charcoal bottles.
11-Dec	6.0	Recorded water treatment system and pump 400 data. Cleaned filters 100 & 150.
22-Dec	5.5	Took stack voltage readings. Fixed leak on water bottles. Removed humidity sensor. Checked pump 451 on/off times. Checked R/O unit power on.
28-Dec	3.0	Tested TE's on reformer.

Table 19. Maintenance activities in 1999.

1999	Labor Hrs	Description of Activity
8-Jan	2.0	Reset lockout relay. Filled accumulator. Filled tank 450 to 30 in.. Left power plant in P30-S30.
12-Jan	24.0	Prepared reformer for removal.
13-Jan	10.0	Completed reformer preparations.
24-Jan	2.0	Started taking doors and frame apart.
26-Jan	12.0	Removed old reformer and put in new reformer.
28-Jan	5.0	Began quarterly maintenance on power plant.
1-Feb	16.0	Started annual maintenance. Set up for welders.
2-Feb	16.0	Continued with annual service. Assisted/supervised welders. Installed retrofit.
3-Feb	16.0	Insulated reformer piping. Continued annual service.
4-Feb	13.0	Completed piping insulation and annual maintenance activities. Did hydro test.
9-Feb	10.0	Conducted hydro test on ancillary loop.
10-Feb	6.0	Completed site cleanup, seals on door and changed fans.
15-Feb	4.0	Worked with UTC Fuel Cells in troubleshooting ejector.
16-Feb	10.5	Installed ejector. Started power plant while doing reduction on reformer.
17-Feb	8.0	Conducted gas analysis and brought power plant up to 200 kW.
15-Apr	3.0	Built rack for nitrogen bottles.
6-Jul	6.0	Changed nitrogen bottles and tested all three legs of electricity coming into P/T. Started power plant.
12-Jul	4.0	Updated controller software to 4.1 and attempted to start power plant.
20-Jul	8.0	Started power plant. Updated software on Base's laptop computer and explained to site coordinator.
21-Jul	8.0	Traveled to site to retrieve data.
1-Sep	10.0	Changed out water treatment system bottles.

Table 20. Maintenance activities in 2000.

2000	Labor Hrs	Description of Activity
1-Jan	11.0	Changed brake on FT140 and I/O modules for FT140.
3-Feb	2.5	Flushed charcoal bottle out and troubleshot pump 450.
29-Feb	8.0	Replaced pump 451 & fan 800 motor. Started power plant, left running at 150 kW.
30-Mar	8.0	Replaced Multi Source Discovery Protocol (MSDP) card & microchips for another MSDP card.
18-Apr	6.0	Changed out electronic card underneath inverter and boost cards on white panel. Removed #3 motor from cooling tower.

2000	Labor Hrs	Description of Activity
20-Apr	11.0	Removed #2 and #1 fan blades and motors from cooling tower. Replaced relay card.
26-Apr	6.0	Installed new motors and fan blades back into cooling tower.
27-Apr	6.0	Replaced relay card again with correct relay card. Started power plant and left running at 125 kW.
10-May	3.0	Changed master Digital Signal Processing (DSP) card and restarted power plant.
12-May	4.0	Changed slave DSP and CB rating module. Restarted power plant.
3-Jul	3.0	Back flushed charcoal bottle.
21-Sep	4.0	Troubleshot long feed water cycle and tried to repair leak.
28-Sep	6.0	Tri-annual maintenance.
29-Sep	5.0	Tri-annual maintenance.
2-Oct	18.0	Tri-annual cleaning.
3-Oct	20.0	Tri-annual cleaning.
4-Oct	16.0	Tri-annual cleaning.
5-Oct	14.0	Tri-annual cleaning.
6-Oct	8.0	Cleaned condenser and attempted to start power plant.
11-Oct	7.0	Replaced air conditioner.
12-Oct	10.0	Rewired air conditioner. Attempted to start power plant.
16-Oct	6.0	Attempted to start power plant.
17-Oct	10.0	Troubleshot failed attempted to start power plant. Purchased UPS battery.
18-Oct	4.0	Installed UPS battery. Started power plant.
23-Oct	4.0	Tuned up power plant.
24-Oct	2.0	Changed brake.
1-Nov	6.5	Troubleshot process flame off and restarted power plant.
14-Nov	6.0	Installed new controller and started power plant. Left running at 175 kW.
8-Dec	7.0	Restarted power plant and took sub stack readings.

Table 21. Maintenance activities in 2001.

2001	Labor Hrs	Description of Activity
23-Jan	1.0	Turned power on and put power plant in water conditioning.
5-Mar	5.0	Checked thermal management system and water treatment system for leaks. Preformed pressure test on TMS loop.
6-Jun	1.0	Checked on modem - no communication.
8-Jun	2.0	Applied power to power plant. Extended TE350 to CSA. Cleaned heaters 310A & 310B.
16-Jul	2.0	Reset motor controllers for pumps 400, 450 and 830. Put power plant back in water conditioning. Rewired TE350.
4-Oct	7.0	Checked and started power plant.
5-Oct	7.0	Changed WTS bottles. Tuned power plant at all power levels, checked heat recovery system.
9-Oct	4.0	Rebuilt circulating pump for heat recovery system. Reset parameters for heat recovery system.
15-Nov	1.0	Removed and replaced TCV400.

4.5 Fuel Cell Retrofits

As part of the fuel cell demonstration and overall fuel cell development, UTC Fuel Cells refined the fuel cell design based on operational experience gained through the operation of the fleet of fuel cells. These improvements and modifications were classified as retrofits. Once a retrofit was developed, it would be incorporated into the production of new fuel cells or retrofit in the field for installed fuel cells. The details of the retrofits are considered proprietary information by UTC Fuel Cells and are not available for this report. The data in Tables 17 through 21 indicate that five retrofits (Table 22) were added to the fuel cell in the field.

Table 22. Summary of fuel cell retrofits.

Date of Retrofit	Retrofit Description
Oct. 1997	Install new controller and software
Jan. 1998	Upgrade base drive in inverter
Jan. 1998	Install strainer and filter in TMS
Apr. 1998	Replace high grade heat exchangers (redesign)
Feb. 1999	Replace breakers with higher grade version

Fuel Cell Operation and Outage Summary

Figure 12 shows the operational and outage periods for each hour within the 62 months that the fuel cell was active (June 1997 to July 2002). The outage times are highlighted in gray along with a listing of the outage number, duration in hours and minutes, and a brief description of the shutdown. Days where on-site maintenance was performed is shown graphically by an 8 hour box. GBC Electrical Services, the maintenance contractor, provided maintenance activity records.

5 Fuel Cell Economics

5.1 Hospital Energy Costs

The Base purchases electricity from Southern California Edison (SCE) under a time of use rate schedule, TOU-8. This rate has summer and winter seasons consisting of on-peak, mid-peak and off-peak time periods with associated demand and energy charges. The Base also purchases electricity from the Western Area Power Administration (WAPA) for a percentage of its total electricity requirements. Because the WAPA portion of the electricity was assumed to be significantly smaller than the SCE portion as discussed in ERDC/CERL TR-01-60, the focus of the economics will be based on the SCE TOU-8 rates. This rate has a summer and winter season consisting of on-peak, mid-peak, and off-peak time periods. Table 23 summarizes the structure of the TOU-8 tariff.

Table 23. SCE TOU-8 rate structure.

	Summer	Winter
Months	June – September	October – May
On Peak Period	Noon – 6:00 pm	None
Mid-Peak Period	8:00 am – Noon 6:00 pm – 11:00 pm	8:00 am – 9:00 pm
Off-Peak Period	All other hours and holidays	All other hours and holidays
Charges	Facility Charge ($/meter) Energy Charge ($/kWh) Facility Related Demand Charge ($/kW) Time Related Demand Charge ($/kW) Excess Transformer Capacity ($/kVA) Power Factor Adjustment ($/kVA)	Facility Charge ($/meter) Energy Charge ($/kWh) Demand Charge ($/kW) Excess Transformer Capacity ($/kVA) Power Factor Adjustment ($/kVA)

The Base purchases the natural gas commodity from the Defense Fuel Supply Center (DFSC) and the natural gas transportation is provided by the Pacific Gas and Electric Company (PG&E).

The Base did not provide Base-wide or Hospital energy usage or cost information for the fuel cell demonstration time period. To estimate the fuel cell economics, the average electric and natural gas rates used from another customer involved in the DoD Fuel Cell Demonstration Program (Twentynine Palms, CA) were used to approximate cost savings. Both facilities purchase electricity from SCE under the same rate schedule, but purchase natural gas through different suppliers. Table 24 lists the annual average electric and natural costs used for the fuel cell economics analysis.

Table 24. Annual electric and natural gas costs.

Average Energy Costs	1997	1998	1999	2000	2001	2002
Electricity ($/kWh)	$0.1040	$0.1017	$0.1017	$0.1017	$0.1500	$0.1500
Natural Gas ($/therm)	$0.5800	$0.4080	$0.4080	$0.4810	$0.9500	$0.7000

Note that electric and natural gas costs were extremely volatile and high during the years of 2001 and 2002 when California was experiencing the energy crisis brought on by deregulation.

5.2 Fuel Cell Maintenance Costs

Table 25 lists maintenance costs from GBC Electrical Services between 1997 through the end of the 2001. Although the fuel cell was restarted once in 2002, invoices for that service call and others were not available for this report.

Table 25. Summary of fuel cell maintenance costs.

Category	1997	1998	1999	2000	2001	Totals
Labor Hours	323	342	193.5	218	30	1,107
Labor Costs	$16,788	$18,025	$9,970	$12,208	$2,020	$59,010
Nitrogen Costs	$2,072	$2,128	$836	$885	$135	$6,057
Charcoal (cu ft)	0	2	2	2	2	8
Charcoal Costs	$0	$186	$206	$186	$186	$764
Resin (cu ft)	24	8	9	8	8	57
Resin Costs	$6,490	$1,808	$2,420	$2,160	$2,240	$15,118
Other Costs	$9,512	$6,217	$4,752	$2,079	$1,721	$24,282
Travel Costs	$6,413	$8,238	$4,868	$9,141	$3,934	$32,594
Shipping Costs	$309	$205	$25	$23	$0	$562
Totals	$41,583	$36,808	$23,077	$26,682	$10,237	$138,386
Note:. Maintenance data was not available for 2002.						

The cost of maintenance over the entire operating period is estimated at $138,386. Again, the maintenance costs for 2002 are not included as the information was not available. These costs correspond to an average maintenance cost of $27,677/year or 2.72 cents/kWh ($138,386/ 5,081,500 kWh) for all the electricity supplied to the Hospital. *Note that the maintenance costs presented do not include the cost of any parts or labor provided by UTC Fuel Cells to repair or modify the fuel cell.*

Figure 21 shows that labor was the highest cost category at $59,010, representing 42.6 percent of total maintenance costs. Labor hours averaged 221 man-hours per calendar year. The highest number of man-hours in a calendar year was 342 in 1998. Nitrogen costs totaled $6,057 and represents only 4.4 percent of the total maintenance costs. Spread across the 27 outages that occurred, the average cost of nitrogen was $224 per outage. While charcoal used in the water treatment system was a relatively minor cost (~$150/year), resin was a moderate program cost totaling approximately $15,000 or 10.9 percent of the maintenance costs. Resin costs were $533 per 1000 operating hours. The second highest cost category behind labor was travel costs, at 23.6 percent. Appendix E presents maintenance costs by invoice date.

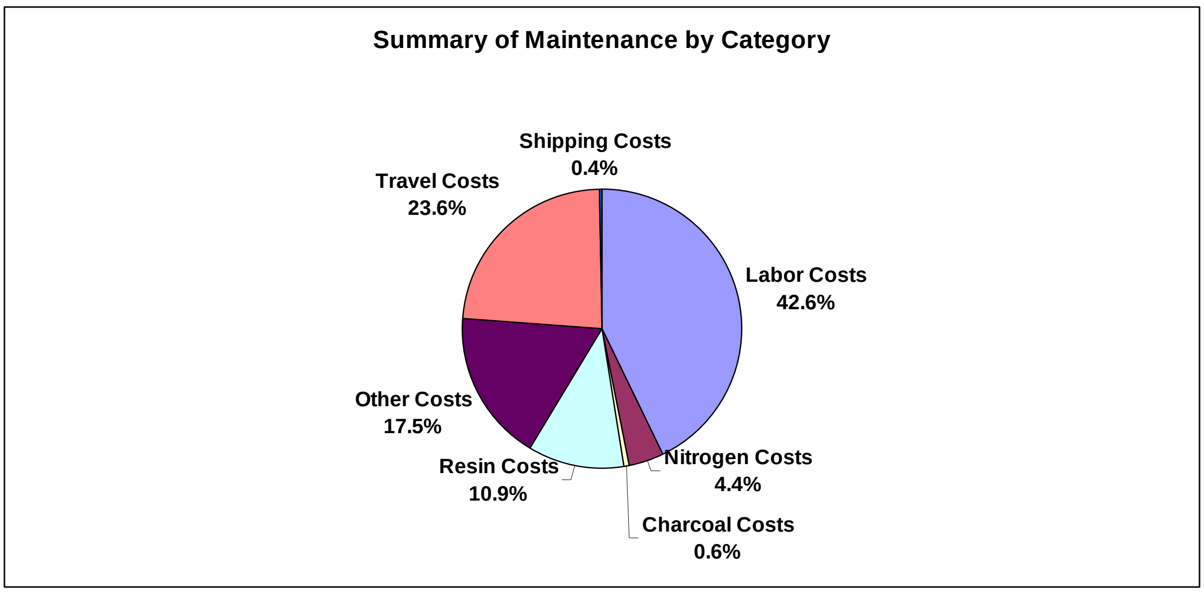


Figure 21. Summary of maintenance costs by category

Figure 22 presents the trend in annual maintenance costs for the fuel cell. Note that the costs for 1997 are for less than 6 months of the demonstration as the fuel cell data collection started on 17 July 1997. The fuel cell concluded operation on 1 July 2002. The high costs on 1997 and 1998 are attributed to the hard water problems which resulted in the replacement of the cell stack and the installation of an external water treatment system.

Fuel cell maintenance costs for the 5-year demonstration period were included in the original purchase contract with the fuel cell manufacturer. First year maintenance costs were included in the original fuel cell purchase price. The final 4 years of contract maintenance paid by ERDC/CERL was $98,223, at an average of $24,556 per year.

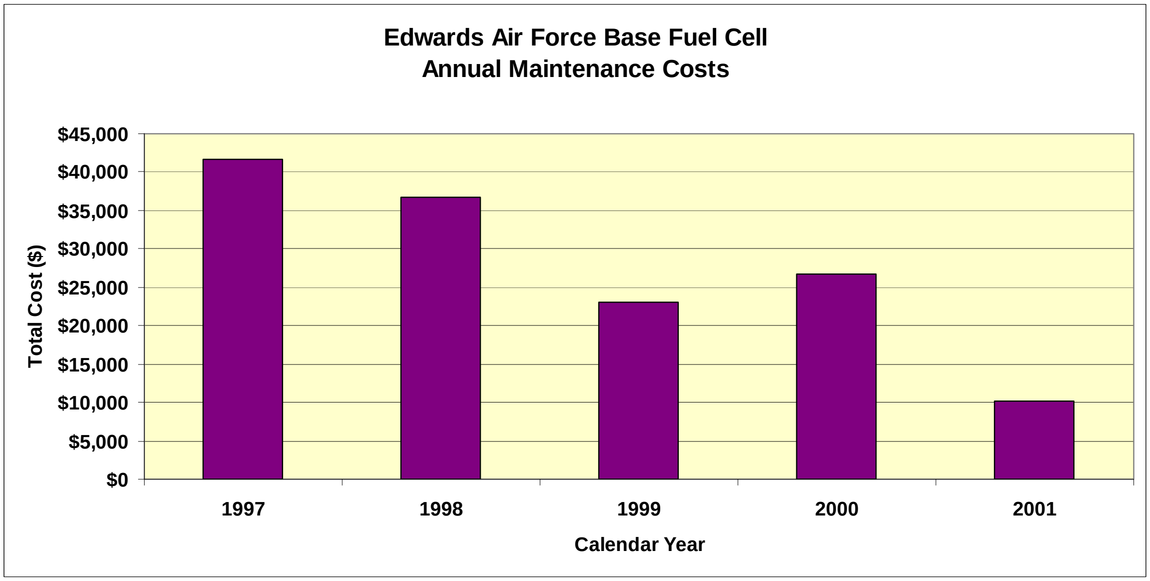


Figure 22. Annual trend in fuel cell maintenance costs.

5.3 Fuel Cell Energy Savings

Energy savings from the fuel cell were calculated based the annual performance data collected through the UTC Fuel Cells RADAR system and the assumed electric and natural gas costs presented in Table 25. Note that the RADAR system did not monitor the thermal heat recovery loop on the fuel cell. Therefore, no data are available to estimate the value of the heat recovered by the Hospital from the fuel cell. Notes from the fuel cell acceptance test indicate that an artificial thermal load had to be established to demonstrate the heat recovery functionality because there was insufficient load at the Hospital. It is inferred that the level of heat recovery was not significant. Table 26 lists the fuel cell energy savings. Net energy savings without heat recovery over the entire program were $304,145.

Table 26. Annual energy savings at hospital.

	1997	1998	1999	2000	2001	2002	Total
Electric Savings Thermal Savings*	$20,053	$111,896	$145,079	$126,488	$67,076	$100,640	$571,232
Total Savings	$20,053	$111,896	$145,079	$126,488	$67,076	$100,640	$571,232
Natural Gas Costs	$7,169	$41,191	$58,041	$63,601	$46,125	$50,961	$267,087
Net Savings	$12,884	$70,706	$87,038	$62,888	$20,950	$49,678	$304,145
*Thermal heat recovery data was not monitored by UTC Fuel Cells' RADAR system.							

Overall electric savings were $571,232 with a maximum annual savings of $145,079 occurring in 1999. The cost of natural gas to operate the fuel cell totaled $267,087 over the course of the demonstration and corresponds to a fuel cost for electrical generation of $0.0526/kWh ($267,087/ 5,081,400 kWh). Figure 23 shows the trend in annual energy savings.

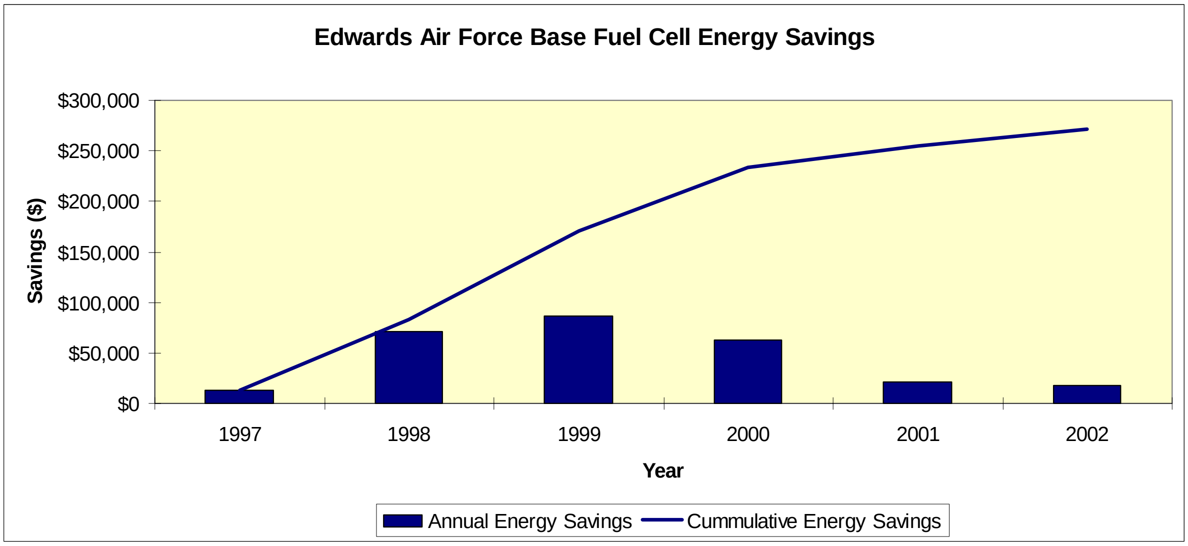


Figure 23. Annual fuel cell energy savings.

5.4 Fuel Cell Lifecycle Costs

The fuel cell lifecycle cost analysis is presented for the operational life of the fuel cell at Edwards AFB. The installed cost of the fuel cell was $1,260,727. The lifecycle cost analysis uses the utility rates presented in Section 5.1, the maintenance costs presented in Section 5.2 and the savings presented in Section 5.3. Note that the analysis is based on the average cost of electricity that the Hospital is charged. That is to say that demand savings are not calculated separately in the analysis. A review of the data shows that demand savings would have been realized in only 20 of the 59 full months of operation and that the average demand reduction for the 20 months would have been 184.8 kW. In 1999, demand savings could have been realized in 9 of the 12 months. In 1998 and 2001, demand savings could have been realized in 2 of the 12 months. The criterion for determining demand savings is that the fuel cell was operational during all hours of the peak period hours for the calendar month. Table 27 lists the months in which demand savings could have been attributed to the fuel cell and the average output of the fuel cell during the month.

Table 27. Fuel cell demand savings.

Month of Demand Savings	Fuel Cell Demand Savings
Oct 1998	200
Nov 1998	200
Mar 1999	200
Apr 1999	196
May 1999	200
Jun 1999	186
Aug 1999	200
Sep 1999	197
Oct 1999	200
Nov 1999	199
Dec 1999	200
Jun 2000	125
Jul 2000	200
Aug 2000	200
Nov 2001	175
Dec 2001	175
Jan 2002	173
Feb 2002	170
May 2002	150
Jun 2002	150
Average Demand:	184.8
Number of Months:	20

The data listed in Table 28 summarize the lifecycle cost analysis. The analysis allocates the capital cost of the fuel cell in the 1997 calendar year. In addition, values are actual costs and are not adjusted to a base year. The analysis shows that the operational costs exceeded the savings in 2001 and that the cumulative operational savings were $158,545.

Table 28. Lifecycle cost analysis.

	1997	1998	1999	2000	2001	2002
HOURS OF OPERATION						
Operation Hrs/Yr	1,024	5,630	7,340	7,326	2,823	4,215
Total Operation Hours	1,024	6,654	13,995	21,320	24,123	28,358
Hours Since Overhaul	1,024	6,654	13,995	21,320	24,123	28,358
OPERATION VALUES						
Electrical Eff (%)	34.9%	37.2%	34.2%	32.1%	31.4%	31.5%
Thermal Eff (%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Demand Disp. (kW)	0	400	1,778	525	350	643
Electrical Output (MWh)	192.8	1100.3	1426.5	1243.7	447.2	670.9
Thermal Displ. (MMBTU)	0.00	0.00	0.00	0.00	0.00	0.00
Fuel Input (MMBTU)	1,236.0	10.105.7	14,239.6	13,320.9	4,855.3	7,280.1
AVERAGE ENERGY RATES						
Demand Rate ($/kW)	—	—	—	—	—	—
Electrical Rate ($/kW)	0.1040	0.1017	0.1017	0.1017	0.1500	0.1500
Facility Gas Rate ($/MMBTU)	5.80	4.08	4.08	4.81	9.50	7.00
Generator Gas Rate ($/MMBTU)	5.80	4.08	4.08	4.81	9.50	7.00
GENERATOR SAVINGS / ENERGY SAVINGS						
Demand	—	—	—	—	—	—
Energy	$20.051	$111,901	$145,075	$126,484	$67,080	$100,635
Displaced Fuel	$0	$0	$0	$0	$0	$0
Subtotal ($)	$20.051	$111,901	$145,075	$126,484	$67,080	$100,635
COSTS						
Fuel Cost	$7,169	$41,231	$58,098	$63,641	$46,125	$50,961
Maintenance	$2,222	$53,823	$27,428	$28,485	$26,470	$7.029
Generator Overhaul	$0	$0	$0	$0	$0	$0
Subtotal ($)	$9,391	$95,054	$85,526	$92,126	$72,595	$57,990
Annual Savings	$10660	$16,846	$59,549	$34,359	($5,515)	$42,645
Cumulative Savings	$10660	$27,507	$87,056	$121,415	$115,899	$158,545
Installed Cost	$1,260,727					
Net Cash Flow	($1,250,067)	$16,846	$59,549	$34,359	($5,515)	$42,645
Cumulative Cash Flow	($1,250,067)	($1,233,220)	($1,173,671)	($1,139,312	($1,144,828)	($1,102,182)

6 Summary and Conclusions

6.1 Review of Fuel Cell Demonstration at Edwards AFB

The 200 kW phosphoric acid fuel cell operated for 28,357.9 hours which corresponds to an availability of 65.3 percent. A total of 27 outages were recorded, 16 of which were classified as a “Forced Outage(s).” The fuel cell delivered more than 5,081 MWh of electricity to the Hospital facility at an average rate of 179 kW. The fuel cell electrical efficiency averaged 34.0 percent (HHV) over the course of the demonstration. Thermal heat recovery was not monitored for this fuel cell. The data listed in Table 29 summarizes the performance of the fuel cell operation.

Table 29. Summary of fuel cell performance.

	1997	1998	1999	2000	2001	2002	Totals
Fuel Cell Operation							
Hours in the Period	3.998.4	8,760.0	8,760.0	8,784.0	8,760.0	4,357.0	43,419.4
Fuel Cell Operation Hours	1,024.3	5,630.0	7,340.2	7,325.9	2,823.0	4,214.6	28,357.9
Fuel Cell Outage Hours	2,974.2	3,130.0	1,419.9	1,458.1	5,937.0	142.4	15,061.5
Availability	25.6%	64.3%	83.8%	83.4%	32.2%	96.7%	65.3%
Electrical Generation							
Total Generation (MWh)	192.8	1,100.3	1,426.5	1,243.7	447.2	670.9	5,081.5
Average Rate of Generation (KW)	188.2	195.4	194.3	169.8	158.4	159.2	179.2
Natural Gas Consumption	1,236.0	10,105.7	14,239.6	13,230.9	4,855.3	7,280.1	
Total Consumption (cu ft/hr)	1,200,000.0	9,811,327.0	13,824,858.0	12,845,496.0	4.713,880.0	7,068,103.0	49,463,664.0
Average Rate of Generation (cu ft/hr)	1,788.4	1,742.7	1,883.5	1,753.4	1,669.8	1,677.1	1,744.3
Heat Recovery							
Total Heat Recovered (MMBTU)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average Rate of Recovery (MMBTU)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Efficiencies							
Electrical (%)	34.9%	37.2%	34.2%	32.1%	31.4%	31.5%	34.0%
PURPA* (%)	34.9%	37.2%	34.2%	32.1%	31.4%	31.5%	34.0%

* Public Utility Regulatory Policy Act (PURPA).

The longest continuous period of operation was 4,507.4 hours, or about 6 months. The fuel cell stack had to be replaced once during the demonstration period and an external water treatment system had to be retrofit to the fuel cell due to high conductivity of the water. In addition, five fuel cell design retrofits were installed on the fuel cell which included a new controller and software as well as a new high grade heat exchanger system.

At the completion of the demonstration, the fuel cell was down due to a forced outage associated with the water treatment system. Edwards AFB has elected to keep the fuel cell and plans to restore operation at the current facility or to move it to another facility.

6.2 Lessons Learned

Based on the experience of installing, and operating the fuel cell, the following lessons learned can be considered:

- High conductivity of water, particularly due to the hardness of the water in the Southwest region of the U.S., must be addressed to prevent negatively impacting the performance of the fuel cell stack.
- Installation of the fuel cell is a relatively straightforward process with no major concerns at this site. The installation took 2 months from the authorization to commence construction to the completion of the acceptance testing (25 April 1997 to 25 June 1997).
- During the course of the demonstration, the fuel cell operation resulting an a cumulative savings of $158,545 or $31,700/yr. The level of energy savings was less than the anticipated $72,500/yr to $108,400/yr due to the following:
    - The average fuel cell electrical output was 179 kW and not the anticipated 200 kW
    - The fuel cell availability was only 65.3 percent instead of 95 percent.
    - The level of heat recovery was not measured and therefore not included in the savings values.
    - The fuel cell was able to potentially reduce the demand of the Hospital in only 20 of the 59 months of the demonstration.
- The fuel cell experienced a total of 8,167.6 hours of non-forced outages attributed to due to the natural gas supply being turned off, site operator error or scheduled maintenance activities. The longest non-forced outage occurred in January to October 2001 for a duration of 6,193.37 hours due to site personnel shutting off the natural gas supply to the fuel cell and opening the maintenance disconnect switch.
- Most of the forced outages were categorized as Other and Thermal Management System issues. The total duration of forced outages was 6,893.9 hours or 46 percent of all outages.
- The average duration of a forced outage was 430.9 hours, or approximately 18 days.
- The maintenance costs averaged $27,677/year, which represents an average cost of 2.72 cents/kWh. This does not include the equipment cost of the replacement cell stack, the reverse osmosis system, the re-

design high grade heat exchanger system, or the other hardware provided by UTC Fuel Cells.

- The average fuel cost to generate electricity was 5.26 cents/kWh. ($267,087 / 5,081,500 kWh).
- The average operating and maintenance costs to generate electricity was 7.98 cents/kWh (5.26 cents/kWh [fuel cost] + 2.72 cents/kWh [O&M costs]). Note that this does not include the value of the heat recovered from the fuel cell. Over the same period of time, the average cost of electricity purchased from SCE is estimated to be 11.8 cents/kWh.

6.3 Issues for Further Analysis

The review and analysis of the 200 kW phosphoric acid fuel cell that was installed at Edwards AFB. resulted in the identification of several issues appropriate for further analysis:

- **Water Quality Requirements.** UTC Fuel Cells has identified through the demonstration that the hardness of the water impacts the fuel cell operation. The Edwards AFB fuel cell required the installation of a reverse osmosis water treatment system. The hardness level at which the fuel cell will require an RO system should be identified.
- **Fuel Cell Electrical Efficiency Trends.** The analysis of the electrical efficiency trends showed that in addition to the number of load hours, other factors affect the efficiency degradation. The secondary analysis that was conducted based on evaluating the trends between major system changes did not substantially improve on the ability to better quantify the electrical efficiency degradation. Further evaluation of trends of other demonstration fuel cells might provide more insight.
- **Cell Voltage Trends.** The analysis of the cell voltage trend showed that the trend for operation at the 175 kW output had the best regression with an R Squared value of 0.95. The 200 kW and 150 kW regressions have R Squared values that are lower than the original regression model indicating that this approach does not improve the model for these two data sets. The slopes of the lines for the three power levels range from –2.67 percent to –5.44 percent per 10,000 load hours. These trends should be further analyzed with additional C models to see if better characterizations can be developed.
- **System Design Improvements.** As part of the fuel cell demonstration and overall fuel cell development, UTC Fuel Cells refined the fuel cell design based on operational experience gained through the operation of the fleet of fuel cells. These improvements and modifications were classified as retrofits. The details of the retrofits are considered

proprietary information by UTC Fuel Cells and are not available for inclusion in this report. Investigation of maintenance activities for a larger number of C type fuel cells may provide greater insight into the modifications to the fuel cell design that can be attributed to the demonstration program.

Acronyms and Abbreviations

Term	Spellout
ACSIM	Assistant Chief of Staff for Installation Management
AFB	Air Force Base
AFCESA	Air Force Civil Engineer Support Agency
ANSI	American National Standards Institute
CEO	corporate executive officer
CERL	Construction Engineering Research Laboratory
CPW	U.S. Army Center for Public Works
CVS	Cabinet Ventilation System
DEIS	Defense Energy Information System
DFSC	Defense Fuel Supply Center
DOD	Department of Defense
DSP	Digital Signal Processing
ERDC	Engineer Research and Development Center
FPS	Fuel Processing System
GFI	Ground Fault Interrupter
HHV	Higher Heating Value
HPLC	high performance low chromatography
HQ	headquarters
I/O	input/output
ILIR	In-house Laboratory Independent Research
kW	Kilowatt
LHV	lower heating value
MSDP	Multi Source Discovery Protocol
N/A	not applicable
NFESC	Naval Facilities Engineering Service Center
NPS	National Park Service
ODUSD	Office of the Deputy Under Secretary of Defense
OMB	Office of Management and Budget
PAFC	Phosphoric Acid Fuel Cell
PG&E	Pacific Gas and Electric Company
PO	purchase order
PSS	Power Section System

Term	Spellout
PURPA	Public Utility Regulatory Policy Act
RO	reverse osmosis
RADAR	Radio Detection And Ranging
SAIC	Science Applications International Corporation
SCE	Southern California Edison
SERDP	Strategic Environmental Research and Development Program
SI	Systeme Internationale
TMS	Thermal Management System
TOC	Table of Contents
TOU	time-of-use
UPS	Uninterruptible Power Supply
URL	Universal Resource Locator
UTC	United Technologies Corp.
WAPA	Western Area Power Administration
WTS	Water Treatment System
WWW	World Wide Web

Appendix A: Fuel Cell Acceptance Test Report

ONSI CORPORATION

ON SITE ACCEPTANCE TEST REPORT

POWER PLANT:	S/N 9061
LOCATION:	NAVAL HOSPITAL MCAGCC TWENTY NINE PALMS, CALIFORNIA
TEST DATES:	JUNE 16 THROUGH JUNE 21, 1995

ONSI CORPORATION

01/23/95

DoD ACCEPTANCE TEST OF PC25™ POWER PLANT INSTALLATION

- Following a normal power plant start-up, operate at IDLE for one hour. At the completion of the one hour, obtain prints of the following five (5) display screens.

  - KEY PARAMETERS (screen 09)
  - REACTANT SUPPLY SYSTEM (screen 10)
  - STACK LOOP, ANC LOOP, & WTS (screen 11)
  - ELECTRICAL OVERVIEW (screen 14)
  - POWER CONDITIONER SYSTEM (screen 25)

- In the grid connect mode with unity power factor and no heat recovery, operate at each of the following powers for one hour. After one hour obtain prints of the five (5) screen displays outlined above. Also perform the additional demonstrations at 100 KW and 200 KW listed below which are accomplished after the one hour hold. The required display screen prints for verification are shown in brackets {}.

  * 50 KW
  * 100 KW
    - demonstrate leading and lagging power factor for 5 minutes
      - max leading power factor up to 0.85 within limitiations imposed by the grid {screen 14}
      - 0.85 lagging power factor {screen 14}
  * 150 KW
  * 200 KW (Rated Power)
    - demonstrate < 3% harmonic distortion [using THD meter across the output power breaker)
    - demonstrate 60 Hz ± 3 Hz frequency [using a Fluke Model 87 True RMS Multimeter or equivalent]
    - demonstrate leading and lagging power factors for 5 minutes
      - max leading power factor up to 0.85 within limitiations imposed by the grid {screen 14}
      - 0.85 lagging power factor {screen 14}
    - demonstrate minimum of 2 hours of heat recovery at time of normal site heat usage and consistent with site design
      - {screen 09 at beginning and end of demonstration plus screen 11 at beginning and every hour until heat recovery demonstration completed}
      - confirmation of 1900 SCFH ± 100 SCFH natural gas consumption during this two hour hold

- Grid Independent operation will be demonstrated at those sites where such capability is installed, at power conditions consistent with normal site demand. After one hour of grid independent operation, each of the five (5) screens displays noted above shall be printed as verification.
  - demonstrate 60 Hz ± 3 Hz frequency [using a Fluke Model 87 True RMS Multimeter or equivalent]
  - demonstrate 480 volts ± 3%

```
                         STACK LOOP, ANC LOOP, & WTS
06/16/95  IDC=   239.2  VDC= 237  KWACNET=     2  VT310DEL= -0.91  EVENTS  0
0656:41   FT012ACT=  21.2  TE400FT= 370.1  TE012FT=   1495        OVERRIDE  0
P/P  9061 P 150 R 160 S 60  W 20  A 30  N 40  C 30  L 10  I 26

TE400     SEPARATOR TEMP (PRIMARY) 370.2  DEGF  SETPOINT:                370.0
TE400R    SEPARATOR TEMP (BACKUP)  369.8  DEGF  SEP TEMP FACTOR(DEGF)      1.0
TE400DEL  SEP TEMP DELTA             0.4  DEGF
LS450     WATER TANK LEVEL SWITCH    On         STK FLOW SW (FS400)       On
TE451     POLISHER TEMP             75.7  DEGF  F/W TEMP SW (TS451)       On
TE810     CONDENSOR EXIT TEMP      138.8  DEGF
TE820     CUST HEX HOT IN TEMP     153.3  DEGF  CUMHEATREC(MMBTU)      0.689
TE880     CUST HEX COLD IN TEMP     90.0  DEGF  FT880 FLOW (PPH)       21940
TE881     CUST HEX COLD EX TEMP    102.3  DEGF  HEAT REC (MBTU/HR)       270
TE401     STACK COOLANT INLET TEMP 361.2  DEGF
LT400     SEPARATOR LEVEL           11.2  IN

PMP451    WTS FEEDWATER PUMP         Off        ON TIME, MIN.(FWPUMP):     0
STARTTEMP TEMP FOR REF HEATUP      350.0  DEGF
IDCNET    NET DC CURRENT           -42.6  AMPS

HTR400    ELEMENT "A"                On         ELEMENT "C"               On
          ELEMENT "B"                On         ELEMENT "D"               Off
```

```
                     KEY PARAMETERS (ENGLISH UNITS)
P/P  9061    06/16/95     0658:39          EVENTS:   0          OVERRIDE:   0
P 150 R 160 S 60  W 20  A 30  N 40  C 30  L 10  I 26
POWER OUTPUT (NET)         2.5  KWAC   OPERATING TIME          66.7  HRS
POWER OUTPUT (GROSS)      56.3  KWAC   POWER FACTOR            0.90
STACK CURRENT            239.1  AMPS   CUMULATIVE POWER       0.839  MWHR
STACK VOLTAGE            237.4  VOLTS  HALF STACK VOLTAGE     -0.09  VOLTS
VOLUMETRIC FUEL FLOW     461.2  SCFH   FUEL FLOW SETPOINT     457.6  SCFH
ACTUAL FUEL FLOW          20.7  PPH
ZT010 EJECTOR POSITION    18.9  %      ZT010 SETPOINT          18.1  %
PHI MONITOR               1.03         TOTAL FUEL CONS        32622  SCF
FT140 BURNER AIR FLOW    206.7  PPH    FT140 SETPOINT         210.0  PPH
TE012 REFORMER TEMP     1492.7  DEGF   ZT110 POSITION          41.9  %
TE012R BACKUP REF TEMP  1436.1  DEGF   TE012 SETPOINT        1495.0  DEGF

TE002 HDS TEMP           499.7  DEGF   TE350 ANODE INLET TEMP 395.6  DEGF

TE400FT STEAM SEP TEMP   371.9  DEGF   TE400 SETPOINT         370.0  DEGF
TE881 TEMP TO CUST       102.3  DEGF   RECOVERED HEAT           289  MBTU/HR
                                       TE451 POLISHER TEMP     75.7  DEGF
LT400 SEPARATOR LEVEL     10.5  IN     TE810 GLYCOL TEMP      140.8  DEGF
PMP451 STATUS              Off         TE160 MOTOR COMP AIR    68.7  DEGF
                                       TE150 MOT COMP AIR IN   62.7  DEGF
ELECTRICAL EFFICIENCY      2.0  %      press <NEXT PAGE> key to view RM data
```

```
                        REACTANT SUPPLY SYSTEM
06/16/95  IDC=   243.5  VDC= 237  KWACNET=     2   VT310DEL= -0.91  EVENTS  0
0655:38   FT012ACT=  21.4  TE403FT=  370  TE012FT=  1494           OVERRIDE  0
P/P  9061 P 150 R 160 S 60  W 20  A 30  N 40  C 30  L 10  I 26

TE012      REF TUBE TEMP (PRIMARY) 1494.4  DEGF  SETPOINT:                1497.3
TE012B     REF TUBE TEMP (BACKUP)  1487.4  DEGF  REF/FUEL CONT OUTPUT:     1.13
TE012DEL   REF TUBE TEMP DELTA        7.0  DEGF
FT012ACT   ACTUAL MASS FUEL FLOW     21.4  PPH   SETPOINT:                 21.0
FT012      UNCORR. MASS FUEL FLOW    22.6  PPH   TE011 FUEL TEMP(DEGF)     56.9
SCFH       ACTUAL VOLUME FUEL FLOW  475.9  CFH   SETPOINT:                468.0
FUELTOT    TOTAL FUEL CONSUMED      22637  SCF   PT012 VENTURI(PSIA)       7.88

ZT010      EJECTOR POSITION          19.0  %     SETPOINT:                 18.3
PHIMON     PHI MONITOR               1.02        STEAM FLOW S.P.(PPH):    105.0
TE350      ANODE INLET TEMP         397.5  DEGF


TE002      HDS BED TEMP             499.3  DEGF  HTR002 STATUS:             On


EFFREF    REFORMER EFFICIENCY        77.6  %
```

```
                        ELECTRICAL OVERVIEW
06/16/95  IDC=   239  VDC= 237  KWACNET=    2.5   VT310DEL= -0.91  EVENTS  0
0657:53   FT012ACT=  21.1  TE430FT=  369  TE012FT=  1498      OVERRIDES   0
P/P  9061 P 150 R 160 S 60  W 20  A 30  N 40  C 30  L 10  I 26

LOADTIME   TOTAL LOAD TIME             66  HR
HOTTIME    TOTAL HOT TIME             120  HR
CELV       AVG VOLTS PER CELL        .741  V/C
ASF        CURRENT DENSITY             42  ASF
KWDC       DC KILOWATTS              56.7  KW
VT310DEL   DELTA HALF STK VOLT      -0.91  V     VT310 HALF STK VOLT     -0.08
           INSTANTANEOUS STK AMPS     239  A
EFFINV     INVERTER EFFICIENCY       99.3  %     CELL EFFICIENCY (%)      59.3
EFFMECH    MECHANICAL EFFICIENCY      4.4  %     REF EFFICIENCY (%)       75.5
EFFELEC    ELECTRICAL EFFICIENCY      1.9  %     HEAT RATE (BTU/KWHR)   190563

KWACNET    NET AC POWER               2.5  KWAC  DISPATCHED POWER:         0.0
PFACT      ACTUAL POWER FACTOR       0.90  -     DISPATCHED P.F.:         1.00
KVARNET    NET KVAR                   1.1  KVAR  DISPATCHED KVAR:          0.0
KVANET     NET KVA                    2.7  KVA
PARPOWER   PARASITE POWER            53.7  KW
KWACGROS   GROSS AC POWER            56.3  KW
MWHRSGR    GROSS AC MW HRS          2.369  MWHR
MWHRSNET   NET AC MW HOURS          0.840  MWHR
```

```
                         POWER CONDITIONER SYSTEM
06/16/95   IDC=  239   VDC= 237     KWACNET=    2.5   VT310DEL= -0.92   EVENTS  0
0658:49    FT012ACT=  21.1  TE400FT= 370.0  TE012FT= 1500.6          OVERRIDE  0
P/P  9061 F 150 R 160 S 60  W 20  A 30  N 40  C 30  L 10  I 26

PT001A     INV AC VOLTAGE,PHASE A    483.7  V
PT001B     INV AC VOLTAGE,PHASE B    480.6  V
PT001C     INV AC VOLTAGE,PHASE C    476.5  V
CT001A     INV AC CURRENT,PHASE A      0.5  A
CT001B     INV AC CURRENT,PHASE B      0.0  A
CT001C     INV AC CURRENT,PHASE C      0.1  A   CURRENT UNBAL (%)        0.0

PT003A     NET AC VOLTAGE,PHASE A    494.5  V
PT003B     NET AC VOLTAGE,PHASE B    492.0  V
PT003C     NET AC VOLTAGE,PHASE C    489.2  V   VOLTAGE UNBAL (%)        1.0
LINKVDC    LINK VOLTAGE              600.3  V

PERCFUND   PERCENT FUNDAMENTAL        83.8  %
PSREQ      PHASE SHIFT REQUEST         2.0  DEG
MCB001     G/I BREAKER STATUS          Off
MCB002     G/C BREAKER STATUS          Off
MCB003     INTER-TIE BREAKER STAT      On
INTCOUNT   INTERRUPT COUNT               0


                 KEY PARAMETERS (ENGLISH UNITS)
P/P  9061    06/16/95     0837:02          EVENTS:   0          OVERRIDE:    0
P 150 R 160 S 60  W 20  A 30  N 40  C 30  L 10  I 50
POWER OUTPUT (NET)           50.7  KWAC   OPERATING TIME          68.4  HRS
POWER OUTPUT (GROSS)        102.9  KWAC   POWER FACTOR           -1.00
STACK CURRENT               459.8  AMPS   CUMULATIVE POWER       0.915  MWHR
STACK VOLTAGE               223.0  VOLTS  HALF STACK VOLTAGE      0.05  VOLTS
VOLUMETRIC FUEL FLOW        900.9  SCFH   FUEL FLOW SETPOINT     850.7  SCFH
ACTUAL FUEL FLOW             40.5  PPH
ZT010 EJECTOR POSITION       24.7  %      ZT010 SETPOINT          23.7  %
PHI MONITOR                  0.98         TOTAL FUEL CONS        24035  SCF
FT140 BURNER AIR FLOW       282.3  PPH    FT140 SETPOINT         283.1  PPH
TE012 REFORMER TEMP        1523.4  DEGF   ZT110 POSITION          45.7  %
TE012R BACKUP REF TEMP     1522.1  DEGF   TE012 SETPOINT        1514.4  DEGF

TE002 HDS TEMP              500.1  DEGF   TE350 ANODE INLET TEMP 396.4  DEGF

TE400FT STEAM SEP TEMP      357.7  DEGF   TE400 SETPOINT         360.6  DEGF
TE881 TEMP TO CUST          129.8  DEGF   RECOVERED HEAT             0  MBTU/HR
                                          TE421 POLISHER TEMP     74.6  DEGF
LT400 SEPARATOR LEVEL        11.4  IN     TE813 GLYCOL TEMP      139.3  DEGF
PMP451 STATUS                 Off         TE160 MOTOR COMP AIR    64.9  DEGF
                                          TE150 MOT COMP AIR IN   67.6  DEGF
ELECTRICAL EFFICIENCY        20.5  %      press <NEXT PAGE> key to view RM data
```

```
                           REACTANT SUPPLY SYSTEM
06/16/95  IDC=   457.6  VDC= 226  KWACNET=    48  VT310DEL= -0.58  EVENTS  0
0839:24   FT012ACT=  38.3  TE400FT=  358  TE012FT=  1524            OVERRIDE  0
P/P  9061 P 160 R 160 S 60  W 20  A 30  N 40  C 30  L 10  I 50

TE012      REF TUBE TEMP (PRIMARY) 1524.3  DEGF  SETPOINT:                1514.4
TE012R     REF TUBE TEMP (BACKUP)  1522.5  DEGF  REF/FUEL CONT OUTPUT:      1.06
TE012DEL   REF TUBE TEMP DELTA        1.7  DEGF
FT012ACT   ACTUAL MASS FUEL FLOW     38.3  PPH   SETPOINT:                  37.0
FT012      UNCORR. MASS FUEL FLOW    42.0  PPH   TE011 FUEL TEMP(DEGF)      71.1
SCFH       ACTUAL VOLUME FUEL FLOW  851.7  CFH   SETPOINT:                 900.4
FUELTOT    TOTAL FUEL CONSUMED      34064  SCF   PT012 VENTURI(PSIA)        7.29

ZT010      EJECTOR POSITION          24.5  %     SETPOINT:                  23.3
PHIMON     PHI MONITOR               1.13        STEAM FLOW S.P.(PPH):     143.8
TE350      ANODE INLET TEMP         396.6  DEGF


TE002      HDS BED TEMP             500.1  DEGF  HTR002 STATUS:               On


EFFREF   REFORMER EFFICIENCY         80.7  %
```

```
                         STACK LOOP, ANC LOOP, & WTS
06/16/95  IDC=   459.9  VDC= 223  KWACNET=    49  VT310DEL= -0.78  EVENTS  0
0849:06   FT012ACT=  41.2  TE400FT= 359.9  TE012FT=   1511         OVERRIDE  0
P/P  9061 P 160 R 160 S 60  W 20  A 30  N 40  C 30  L 10  I 50

TE400      SEPARATOR TEMP (PRIMARY) 359.9  DEGF  SETPOINT:                358.3
TE400R     SEPARATOR TEMP (BACKUP)  359.5  DEGF  SEP TEMP FACTOR(DEGF)      1.0
TE400DEL   SEP TEMP DELTA             0.4  DEGF
LS450      WATER TANK LEVEL SWITCH     On        STK FLOW SW (FS400)         On
TE431      POLISHER TEMP             74.6  DEGF  F/W TEMP SW (TS451)         On
TE810      CONDENSOR EXIT TEMP      139.9  DEGF
TE820      CUST HEX HOT IN TEMP     173.8  DEGF  CUMHEATREC(MMBTU)        1.056
TE880      CUST HEX COLD IN TEMP    172.9  DEGF  FT880 FLOW (PPH)             0
TE881      CUST HEX COLD EX TEMP    123.6  DEGF  HEAT REC (MBTU/HR)        0  0
TE401      STACK COOLANT INLET TEMP 339.0  DEGF
LT400      SEPARATOR LEVEL           11.2  IN

PMP451     WTS FEEDWATER PUMP         Off        ON TIME, MIN.(FWPUMP):       0
STARTTEMP  TEMP FOR REF HEATUP      350.0  DEGF
IDCNET     NET DC CURRENT           224.3  AMPS

HTR400     ELEMENT "A"                Off        ELEMENT "C"                 On
           ELEMENT "B"                On         ELEMENT "D"                Off
```

```
                                 ELECTRICAL OVERVIEW
06/16/95   IDC=   473  VDC= 224  KWACNET=   50.2   VT310DBL= -0.85  EVENTS  0
0845:35    FT012ACT=  37.7  TE400FT=  362  TE012FT=  1507        OVERRIDES   0
P/P  9061 P 160 R 160 S 60  W 20  A 30  N 40  C 30  L 10  I 50

LOADTIME   TOTAL LOAD TIME               68   HR
HOTTIME    TOTAL HOT TIME               122   HR
CELV       AVG VOLTS PER CELL          .700   V/C
ASF        CURRENT DENSITY               84   ASF
KWDC       DC KILOWATTS               106.2   KW
VT319DBL   DELTA HALF STK VOLT        -0.85   V     VT310 HALF STK VOLT     -0.01
           INSTANTANEOUS STK AMPS       465   A
EFFINV     INVERTER EFFICIENCY         99.0   %     CELL EFFICIENCY (%)      56.0
EFFMECH    MECHANICAL EFFICIENCY       48.0   %     REF EFFICIENCY (%)       86.6
EFFELEC    ELECTRICAL EFFICIENCY       23.0   %     HEAT RATE (BTU/KWHR)    16506

KWACNET    NET AC POWER                50.2   KWAC  DISPATCHED POWER:        50.0
PFACT      ACTUAL POWER FACTOR        -1.00   -     DISPATCHED P.F.:         1.00
KVARNET    NET KVAR                    -1.1   KVAR  DISPATCHED KVAR:          0.0
KVANET     NET KVA                     49.7   KVA
PARPOWRR   PARASITE POWER              55.0   KW
KWACGROS   GROSS AC POWER             105.2   KW
MWHRSGR    GROSS AC MW HRS            2.549   MWHR
MWHRSNET   NET AC MW HOURS            0.922   MWHR
```

```
                                 POWER CONDITIONER SYSTEM
06/16/95  IDC=  462  VDC= 224   KWACNET=  49.9  VT310DEL= -0.80  EVENTS  0
0846:35   FT012ACT=  40.4  TE400FT= 361.5  TE012FT= 1511.1       OVERRIDE  0
P/P  9061 P 160 R 160 S 60  W 20  A 30  N 40  C 30  L 10  I 50

PT001A     INV AC VOLTAGE,PHASE A    497.5  V
PT001B     INV AC VOLTAGE,PHASE B    494.2  V
PT001C     INV AC VOLTAGE,PHASE C    493.2  V
CT001A     INV AC CURRENT,PHASE A     53.7  A
CT001B     INV AC CURRENT,PHASE B     56.9  A
CT001C     INV AC CURRENT,PHASE C     58.2  A   CURRENT UNBAL (%)        7.5

PT003A     NET AC VOLTAGE,PHASE A    497.6  V
PT003B     NET AC VOLTAGE,PHASE B    495.3  V
PT003C     NET AC VOLTAGE,PHASE C    492.3  V   VOLTAGE UNBAL (%)        1.0
LINKVDC    LINK VOLTAGE              599.7  V

PERCFUND   PERCENT FUNDAMENTAL        86.5  %
PSREQ      PHASE SHIFT REQUEST         4.8  DEG
MCB001     G/I BREAKER STATUS          Off
MCB002     G/C BREAKER STATUS          On
MCB003     INTER-TIE BREAKER STAT      On
INTCOUNT   INTERRUPT COUNT               0
```

```
                         KEY PARAMETERS (ENGLISH UNITS)
P/P  9061    06/16/95      1027:37            EVENTS:    0         OVERRIDE:    0
P 160 R 160 S 60  W 20  A 30  N 40  C 30  L 10  I 50
POWER OUTPUT (NET)          101.0  KWAC   OPERATING TIME            70.3  HRS
POWER OUTPUT (GROSS)        117.7  KWAC   POWER FACTOR              0.99
STACK CURRENT               539.5  AMPS   CUMULATIVE POWER         1.084  MWHR
STACK VOLTAGE               220.9  VOLTS  HALF STACK VOLTAGE        0.03  VOLTS
VOLUMETRIC FUEL FLOW        993.2  SCFH   FUEL FLOW SETPOINT      1002.5  SCFH
ACTUAL FUEL FLOW             44.7  PPH
ZT010 EJECTOR POSITION       26.9  %      ZT010 SETPOINT            25.9  %
PHI MONITOR                  1.05         TOTAL FUEL CONS          35819  SCF
FT140 BURNER AIR FLOW       315.1  PPH    FT140 SETPOINT           319.3  PPH
TE012 REFORMER TEMP        1521.2  DEGF   ZT110 POSITION            48.7  %
TE012R BACKUP REF TEMP     1519.0  DEGF   TE012 SETPOINT          1520.5  DEGF

TE002 HDS TEMP              510.7  DEGF   TE350 ANODE INLET TEMP 397.3  DEGF

TE400FT STEAM SEP TEMP      355.3  DEGF   TE400 SETPOINT           356.8  DEGF
TE851 TEMP TO CUST          102.5  DEGF   RECOVERED HEAT             0  0  MBTU/HR
                                          TE431 POLISHER TEMP       82.3  DEGF
LT400 SEPARATOR LEVEL        11.1  IN     TE810 GLYCOL TEMP        140.6  DEGF
PMP451 STATUS                 Off         TE160 MOTOR COMP AIR      74.4  DEGF
                                          TE150 MOT COMP AIR IN     69.8  DEGF
ELECTRICAL EFFICIENCY        37.3  %      press <NEXT PAGE> key to view RM data
```

```
                          REACTANT SUPPLY SYSTEM
06/15/95  IDC=   521.3  VDC= 222  KWACNET=  101  VT310DEL= -0.80  EVENTS  0
1028:43   FT012ACT=  44.4  TE400FT=  357  TE012FT=  1522          OVERRIDE  0
P/P  9061 P 160 R 150 S 60  W 20  A 30  N 40  C 30  L 10  I 50

TE012      REF TUBE TEMP (PRIMARY) 1522.1  DEGF  SETPOINT:                1519.6
TE012R     REF TUBE TEMP (BACKUP)  1520.4  DEGF  REF/FUEL CONT OUTPUT:      1.09
TE012DEL   REF TUBE TEMP DELTA        1.7  DEGF
FT012ACT   ACTUAL MASS FUEL FLOW     44.4  PPH   SETPOINT:                  43.5
FT012      UNCORR. MASS FUEL FLOW    50.7  PPH   TE011 FUEL TEMP(DEGF)      75.0
SCFH       ACTUAL VOLUME FUEL FLOW  986.9  CFH   SETPOINT:                 957.6
FUELTOT    TOTAL FUEL CONSUMED      35836  SCF   PT012 VENTURI(PSIA)        6.85

ZT010      EJECTOR POSITION          26.3  %     SETPOINT:                  25.3
PHIMON     PHI MONITOR               1.02        STEAM FLOW S.P.(PPH):     161.9
TE350      ANODE INLET TEMP         398.2  DEGF

TE002      HDS BED TEMP             510.2  DEGF  HTR002 STATUS:               On


EFFREF     REFORMER EFFICIENCY       78.9  %
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                          STACK LOOP, ANC LOOP, & WTS
06/16/95  IDC=   542.1  VDC= 221  KWACNET=    99  VT310DEL= -0.81  EVENTS  0
1029:48   FT012ACT=  44.6  TE400FT= 356.9  TE012FT=   1524        OVERRIDE  0
P/P  9061 P 160 R 160 S 60  W 20  A 30  N 40  C 30  L 10  I 50

TE400      SEPARATOR TEMP (PRIMARY) 357.3  DEGF  SETPOINT:                356.7
TE400R     SEPARATOR TEMP (BACKUP)  357.3  DEGF  SEP TEMP FACTOR(DEGF)    1.0
TE400DEL   SEP TEMP DELTA             0.0  DEGF
LS450      WATER TANK LEVEL SWITCH    On         STK FLOW SW (FS400)      On
TE431      POLISHER TEMP             81.6  DEGF  F/W TEMP SW (TS451)      On
TE810      CONDENSOR EXIT TEMP      139.9  DEGF
TE820      CUST HEX HOT IN TEMP     160.6  DEGF  CUMHEATREC(MMBTU)       1.055
TE880      CUST HEX COLD IN TEMP    150.0  DEGF  FT880 FLOW (PPH)            0
TE881      CUST HEX COLD EX TEMP    103.4  DEGF  HEAT REC (MBTU/HR)      0   0
TE401      STACK COOLANT INLET TEMP 329.1  DEGF
LT400      SEPARATOR LEVEL           10.8  IN

PMP451     WTS FEEDWATER PUMP         On         ON TIME, MIN.(FWPUMP):      0
STARTTEMP  TEMP FOR REF HEATUP      350.0  DEGF
IDCNET     NET DC CURRENT           544.5  AMPS

HTR400     ELEMENT "A"                Off        ELEMENT "C"             Off
           ELEMENT "B"                Off        ELEMENT "D"             Off


                          ELECTRICAL OVERVIEW
06/16/95  IDC=    535  VDC= 222  KWACNET=   99.1  VT310DEL= -0.84  EVENTS  0
1031:21   FT012ACT=  44.4  TE400FT=  356  TE012FT=  1524        OVERRIDES  0
P/P  9061 P 160 R 160 S 60  W 20  A 30  N 40  C 30  L 10  I 50

LOADTIME   TOTAL LOAD TIME             70  HR
HOTTIME    TOTAL HOT TIME             123  HR
CELV       AVG VOLTS PER CELL        .695  V/C
ASF        CURRENT DENSITY             96  ASF
KWDC       DC KILOWATTS             119.3  KW
VT310DEL   DELTA HALF STK VOLT      -0.84  V     VT310 HALF STK VOLT     -0.01
           INSTANTANEOUS STK AMPS     539  A
EFFINV     INVERTER EFFICIENCY       98.0  %     CELL EFFICIENCY (%)     55.5
EFFMECH    MECHANICAL EFFICIENCY     86.9  %     REF EFFICIENCY (%)      79.6
EFFELEC    ELECTRICAL EFFICIENCY     37.5  %     HEAT RATE (BTU/KWHR)    10093

KWACNET    NET AC POWER             100.3  KWAC  DISPATCHED POWER:       100.0
PFACT      ACTUAL POWER FACTOR      -1.00  -     DISPATCHED P.F.:         1.00
KVARNET    NET KVAR                  -0.5  KVAR  DISPATCHED KVAR:          0.0
KVANET     NET KVA                  100.4  KVA
PARPOWER   PARASITE POWER            16.3  KW
KWACGROS   GROSS AC POWER           116.6  KW
MWHRSGR    GROSS AC MW HRS          2.754  MWHR
MWHRSNET   NET AC MW HOURS          1.091  MWHR
```

```
                              POWER CONDITIONER SYSTEM
06/16/95  IDC=  539  VDC= 221    KWACNET= 100.2  VT310DEL= -0.80  EVENTS  0
1032:46   FT012ACT=  44.5  TE400FT= 356.8  TE012FT= 1523.9         OVERRIDE  0
P/P  9061 P 160 R 160 S 60  W 20  A 30  N 40  C 30  L 10  I 50

PT001A    INV AC VOLTAGE,PHASE A   492.8  V
PT001B    INV AC VOLTAGE,PHASE B   490.1  V
PT001C    INV AC VOLTAGE,PHASE C   490.5  V
CT001A    INV AC CURRENT,PHASE A   108.0  A
CT001B    INV AC CURRENT,PHASE B   126.2  A
CT001C    INV AC CURRENT,PHASE C   121.3  A    CURRENT UNBAL (%)       12.3

PT003A    NET AC VOLTAGE,PHASE A   493.1  V
PT003B    NET AC VOLTAGE,PHASE B   490.8  V
PT003C    NET AC VOLTAGE,PHASE C   488.4  V    VOLTAGE UNBAL (%)        1.0
LINKVDC   LINK VOLTAGE             599.8  V

PERCFUND  PERCENT FUNDAMENTAL       86.3  %
PSREQ     PHASE SHIFT REQUEST        6.5  DEG
MCB001    G/I BREAKER STATUS         Off
MCB002    G/C BREAKER STATUS         On
MCB003    INTER-TIE BREAKER STAT     On
INTCOUNT  INTERRUPT COUNT              0
```

```
                         ELECTRICAL OVERVIEW
06/16/95  IDC=  546  VDC= 221  KWACNET=  100.1  VT310DEL= -0.80  EVENTS  0
1041:36   FT012ACT=  45.0  TE400FT=  356  TE012FT=  1529        OVERRIDES  0
P/P  9061 P 160 R 160 S 60  W 20  A 30  N 40  C 30  L 10  I 50

LOADTIME  TOTAL LOAD TIME               70  HR
HOTTIME   TOTAL HOT TIME               124  HR
CELV      AVG VOLTS PER CELL          .591  V/C
ASF       CURRENT DENSITY               98  ASF
KWDC      DC KILOWATTS               121.1  KW
VT310DEL  DELTA HALF STK VOLT        -0.80  V    VT310 HALF STK VOLT     0.02
          INSTANTANEOUS STK AMPS       542  A
EFFINV    INVERTER EFFICIENCY         97.9  %    CELL EFFICIENCY (%)     55.4
EFFMECH   MECHANICAL EFFICIENCY       84.5  %    REF EFFICIENCY (%)      77.6
EFFELEC   ELECTRICAL EFFICIENCY       35.5  %    HEAT RATE (BTU/KWHR)   10669

KWACNET   NET AC POWER               100.1  KWAC DISPATCHED POWER:      100.0
PFACT     ACTUAL POWER FACTOR         0.90  -    DISPATCHED P.F.:        0.85
KVARNET   NET KVAR                    45.9  KVAR DISPATCHED KVAR:        61.9
KVANET    NET KVA                    110.6  KVA
PARPOWER  PARASITE POWER              18.3  KW
KWACGROS  GROSS AC POWER             118.4  KW
MWHRSGR   GROSS AC MW HRS            2.773  MWHR
MWHRSNET  NET AC MW HOURS            1.107  MWHR
```

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                          ELECTRICAL OVERVIEW
05/16/95  IDC=   542  VDC= 221  KWACNET=  100.9  VT310DEL= -0.80  EVENTS  0
1051:11   FT012ACT=  45.6  TE400FT=  356  TE012FT=  1531        OVERRIDES  0
P/P  9061 P 160 R 160 S 60  W 20  A 30  N 40  C 30  L 10  I 50

LOADTIME  TOTAL LOAD TIME               70  HR
HOTTIME   TOTAL HOT TIME               124  HR
CELV      AVG VOLTS PER CELL          .690  V/C
ASF       CURRENT DENSITY               97  ASF
KWDC      DC KILOWATTS               120.1  KW
VT310DEL  DELTA HALF STK VOLT        -0.80  V     VT310 HALF STK VOLT      0.02
          INSTANTANEOUS STK AMPS       544  A
EFFINV    INVERTER EFFICIENCY         97.7  %     CELL EFFICIENCY (%)      55.2
EFFMECH   MECHANICAL EFFICIENCY       85.9  %     REF EFFICIENCY (%)       78.5
EFFELEC   ELECTRICAL EFFICIENCY       36.3  %     HEAT RATE (BTU/KWHR)    10415

KWACNET   NET AC POWER               100.9  KWAC  DISPATCHED POWER:       100.0
PFACT     ACTUAL POWER FACTOR        -0.85  -     DISPATCHED P.F.:        -0.85
KVARNET   NET KVAR                   -59.0  KVAR  DISPATCHED KVAR:        -61.9
KVANET    NET KVA                    116.8  KVA
PARPOWER  PARASITE POWER              18.1  KW
KWACGROS  GROSS AC POWER             119.0  KW
MWHRSGR   GROSS AC MW HRS            2.793  MWHR
MWHRSNET  NET AC MW HOURS            1.124  MWHR


                    KEY PARAMETERS (ENGLISH UNITS)
P/P  9061    06/16/95     1201:57          EVENTS:   0         OVERRIDE:   0
P 160 R 160 S 60  W 20  A 30  N 40  C 30  L 10  I 50
POWER OUTPUT (NET)          150.1  KWAC   OPERATING TIME          71.9  HRS
POWER OUTPUT (GROSS)        166.0  KWAC   POWER FACTOR           -1.00
STACK CURRENT               802.5  AMPS   CUMULATIVE POWER       1.295  MWHR
STACK VOLTAGE               212.1  VOLTS  HALF STACK VOLTAGE      0.16  VOLTS
VOLUMETRIC FUEL FLOW       1457.4  SCFH   FUEL FLOW SETPOINT    1458.7  SCFH
ACTUAL FUEL FLOW             65 6  PPH
ZT010 EJECTOR POSITION       43.2  %      ZT010 SETPOINT          42.1  %
PHI MONITOR                  1.05         TOTAL FUEL CONS        37925  SCF
FT140 BURNER AIR FLOW       438.9  PPH    FT140 SETPOINT         435.2  PPH
TE012 REFORMER TEMP        1587.6  DEGF   ZT110 POSITION          63.1  %
TE012R BACKUP REF TEMP     1592.0  DEGF   TE012 SETPOINT        1596.6  DEGF

TE202 HDS TEMP              537.1  DEGF   TE350 ANODE INLET TEMP 399.5  DEGF

TE400FT STEAM SEP TEMP      349.1  DEGF   TE400 SETPOINT         348.4  DEGF
TE881 TEMP TO CUST           94.6  DEGF   RECOVERED HEAT           0  0  MBTU/HR
                                          TE431 POLISHER TEMP     86.5  DEGF
LT400 SEPARATOR LEVEL        11.3  IN     TE810 GLYCOL TEMP      155.5  DEGF
PMP451 STATUS                 OFF         TE160 MOTOR COMP AIR    74.2  DEGF
                                          TE150 MOT COMP AIR IN   73.5  DEGF
ELECTRICAL EFFICIENCY        38.6  %      press <NEXT PAGE> key to view RM data
```

```
                              REACTANT SUPPLY SYSTEM
06/16/95  IDC=   800.6  VDC= 212  KWACNET=  150   VT310DEL= -0.67  EVENTS  0
1203:45   FT012ACT=  66.5  TE400FT=  349  TE012FT=  1599          OVERRIDE  0
P/P  9061 P 160 R 160 S 60  W 20  A 30  N 40  C 30  L 10  I 50

TE012     REF TUBE TEMP (PRIMARY) 1599.9  DEGF  SETPOINT:               1597.1
TE012R    REF TUBE TEMP (BACKUP)  1605.6  DEGF  REF/FUEL CONT OUTPUT:     1.07
TE012DEL  REF TUBE TEMP DELTA        5.7  DEGF
FT012ACT  ACTUAL MASS FUEL FLOW     66.5  PPH   SETPOINT:                 65.6
FT012     UNCORR. MASS FUEL FLOW    71.1  PPH   TE011 FUEL TEMP(DEGF)     76.8
SCFH      ACTUAL VOLUME FUEL FLOW 1477.0  CFH   SETPOINT:               1460.1
FUELTOT   TOTAL FUEL CONSUMED      37950  SCF   PT012 VENTURI(PSIA)       7.85

ZT010     EJECTOR POSITION          42.1  %     SETPOINT:                 41.2
PHIMON    PHI MONITOR               1.01        STEAM FLOW S.P.(PPH):    242.2
TE350     ANODE INLET TEMP         399.3  DEGF


TS002     HDS BED TEMP             537.9  DEGF  HTR002 STATUS:             Off


EFFREF   REFORMER EFFICIENCY        80.6  %
```

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                              STACK LOOP, ANC LOOP, & WTS
06/16/95  IDC=   806.7  VDC= 212  KWACNET=   151  VT310DEL= -0.67  EVENTS  0
1205:01   FT012ACT=  66.2  TE400FT= 349.0  TE012FT=   1606         OVERRIDE  0
P/P  9061 P 160 R 160 S 60  W 20  A 30  N 40  C 30  L 10  I 50

TE400     SEPARATOR TEMP (PRIMARY) 349.6  DEGF  SETPOINT:                348.5
TE400R    SEPARATOR TEMP (BACKUP)  348.7  DEGF  SEP TEMP FACTOR(DEGF)      0.9
TE400DEL  SEP TEMP DELTA             0.6  DEGF
LS450     WATER TANK LEVEL SWITCH    On         STK FLOW SW (FS400)        On
TE431     POLISHER TEMP             84.5  DEGF  F/W TEMP SW (TS451)        On
TE810     CONDENSOR EXIT TEMP      157.5  DEGF
TE820     CUST HEX HOT IN TEMP     189.8  DEGF  CUMHEATREC(MMBTU)        1.055
TE880     CUST HEX COLD IN TEMP    156.8  DEGF  FT880 FLOW (PPH)             0
TE881     CUST HEX COLD EX TEMP     95.0  DEGF  HEAT REC (MBTU/HR)        0  0
TE401     STACK COOLANT INLET TEMP 308.0  DEGF
LT400     SEPARATOR LEVEL           10.8  IN

PMP451    WTS FEEDWATER PUMP         On         ON TIME, MIN.(FWPUMP):       0
STARTTEMP TEMP FOR REF HEATUP      350.0  DEGF
IDCNET    NET DC CURRENT           809.4  AMPS

HTR400    ELEMENT "A"                Off        ELEMENT "C"                Off
          ELEMENT "B"                Off        ELEMENT "D"                Off
```

```
                              ELECTRICAL OVERVIEW
06/15/95   IDC=   797  VDC= 212  KWACNET=  148.8   VT310DEL= -0.65  EVENTS  0
1206:00    PTC12ACT=  64.1  TE400FT=  350  TE012FT=  1607        OVERRIDES  0
P/P  9061 P 160 R 160 S 60  W 20  A 30  N 40  C 30  L 10  I 50

LOADTIME   TOTAL LOAD TIME              71   HR
HOTTIME    TOTAL HOT TIME              125   HR
CELV       AVG VOLTS PER CELL         .664   V/C
ASF        CURRENT DENSITY             142   ASF
KWDC       DC KILOWATTS              168.9   KW
VT310DEL   DELTA HALF STK VOLT       -0.65   V     VT310 HALF STK VOLT      0.18
           INSTANTANEOUS STK AMPS      802   A
EFFINV     INVERTER EFFICIENCY        97.6   %     CELL EFFICIENCY (%)      53.1
EFFMECH    MECHANICAL EFFICIENCY      90.1   %     REF EFFICIENCY (%)       82.0
EFFELEC    ELECTRICAL EFFICIENCY      38.2   %     HEAT RATE (BTU/KWHR)     9919

KWACNET    NET AC POWER              148.8   KWAC  DISPATCHED POWER:       150.0
PFACT      ACTUAL POWER FACTOR       -1.00   -     DISPATCHED P.F.:         1.00
KVARNET    NET KVAR                   -1.3   KVAR  DISPATCHED KVAR:          0.0
KVANET     NET KVA                   149.3   KVA
PARPOWER   PARASITE POWER             15.8   KW
KWACGROS   GROSS AC POWER            164.7   KW
MWHRSGR    GROSS AC MW HRS           2.996   MWHR
MWHRSNET   NET AC MW HOURS           1.307   MWHR
```

```
                                 POWER CONDITIONER SYSTEM
06/15/95   IDC=  801   VDC= 212    KWACNET= 150.1  VT310DEL= -0.65   EVENTS  0
1206:59    PT012ACT=  64.0  TE400FT= 348.6  TE012FT= 1599.5        OVERRIDE  0
P/P  9061 P 160 R 160 S 60  W 20  A 30  N 40  C 30  L 10  I 50

PT001A     INV AC VOLTAGE,PHASE A    498.2   V
PT001B     INV AC VOLTAGE,PHASE B    496.3   V
PT001C     INV AC VOLTAGE,PHASE C    496.5   V
CT001A     INV AC CURRENT,PHASE A    164.0   A
CT001B     INV AC CURRENT,PHASE B    176.0   A
CT001C     INV AC CURRENT,PHASE C    179.5   A   CURRENT UNBAL (%)          9.1

PT003A     NET AC VOLTAGE,PHASE A    497.1   V
PT003B     NET AC VOLTAGE,PHASE B    495.8   V
PT003C     NET AC VOLTAGE,PHASE C    491.9   V   VOLTAGE UNBAL (%)          1.0
LINKVDC    LINK VOLTAGE              599.6   V

PERCFUND   PERCENT FUNDAMENTAL        88.8   %
PSREQ      PHASE SHIFT REQUEST         6.9   DEG
MCB001     G/I BREAKER STATUS          Off
MCB002     G/C BREAKER STATUS          On
MCB003     INTER-TIE BREAKER STAT      On
INTCOUNT   INTERRUPT COUNT               0
```

```
                     KEY PARAMETERS (ENGLISH UNITS)
/P  9061     06/20/95      1746:14          EVENTS:    0          OVERRIDE:    0
 160 R 160 S 60  W 20  A 30  N 40  C 30  L 10  I 50
OWER OUTPUT (NET)         199.9  KWAC   OPERATING TIME          150.1  HRS
OWER OUTPUT (GROSS)       216.1  KWAC   POWER FACTOR            -1.00
TACK CURRENT             1084.4  AMPS   CUMULATIVE POWER       11.584  MWHR
TACK VOLTAGE              207.0  VOLTS  HALF STACK VOLTAGE       0.49  VOLTS
OLUMETRIC FUEL FLOW      1975.1  SCFH   FUEL FLOW SETPOINT     1992.6  SCFH
CTUAL FUEL FLOW            88.9  PPH
T010 EJECTOR POSITION      66.7  %      ZT010 SETPOINT           66.2  %
HI MONITOR                 1.00         TOTAL FUEL CONS        139496  SCF
T140 BURNER AIR FLOW      555.9  PPH    FT140 SETPOINT          533.3  PPH
E012 REFORMER TEMP       1663.2  DEGF   ZT110 POSITION           64.0  %
E012R BACKUP REF TEMP    1676.0  DEGF   TE012 SETPOINT         1655.6  DEGF

E002 HDS TEMP             581.9  DEGF   TE350 ANODE INLET TEMP  407.8  DEGF

E400FT STEAM SEP TEMP     350.8  DEGF   TE400 SETPOINT          350.1  DEGF
E881 TEMP TO CUST         177.1  DEGF   RECOVERED HEAT            254  MBTU/HR
                                        TE431 POLISHER TEMP     119.0  DEGF
T400 SEPARATOR LEVEL       11.2  IN     TE810 GLYCOL TEMP       153.3  DEGF
MP451 STATUS                Off         TE160 MOTOR COMP AIR    113.1  DEGF
                                        TE150 MOT COMP AIR IN    99.2  DEGF
LECTRICAL EFFICIENCY       36.2  %      press <NEXT PAGE> key to view RM data
```

```
                          REACTANT SUPPLY SYSTEM
06/20/95  IDC=  1085.5  VDC= 207  KWACNET=  200  VT310DEL= -0.36  EVENTS  0
1746:55   FT012ACT=  88.3  TE400FT=  351  TE012FT=  1656        OVERRIDE  0
P/P  9061 P 160 R 160 S 60  W 20  A 30  N 40  C 30  L 10  I 50

TE012      REF TUBE TEMP (PRIMARY) 1657.1  DEGF  SETPOINT:               1655.2
TE012R     REF TUBE TEMP (BACKUP)  1670.2  DEGF  REF/FUEL CONT OUTPUT:     1.08
TE012DEL   REF TUBE TEMP DELTA       14.5  DEGF
FT012ACT   ACTUAL MASS FUEL FLOW     88.3  PPH   SETPOINT:                 89.8
FT012      UNCORR. MASS FUEL FLOW    91.7  PPH   TE011 FUEL TEMP(DEGF)     99.0
SCFH       ACTUAL VOLUME FUEL FLOW 1962.2  CFH   SETPOINT:               1996.0
FUELTOT    TOTAL FUEL CONSUMED     139496  SCF   PT012 VENTURI(PSIA)       8.70

ZT010      EJECTOR POSITION          65.8  %     SETPOINT:                 65.7
PHIMON     PHI MONITOR               1.02        STEAM FLOW S.P.(PPH):    322.3
TE350      ANODE INLET TEMP         407.4  DEGF


TE002      HDS BED TEMP             582.8  DEGF  HTR002 STATUS:             Off


EFFREF   REFORMER EFFICIENCY        81.2  %
```

```
                              STACK LOOP, ANC LOOP, & WTS
06/20/95   IDC=  1089.6  VDC= 207  KWACNET=    200  VT310DEL= -0.37   EVENTS  0
1747:41    FT012ACT=  90.8  TE400FT= 351.5  TE012FT=   1651          OVERRIDE  0
P/P  9061  P 150 R 160 S 60  W 20  A 30  N 40  C 30  L 10  I 50

TE400      SEPARATOR TEMP (PRIMARY) 351.1  DEGF  SETPOINT:                  350.4
TE400R     SEPARATOR TEMP (BACKUP)  350.7  DEGF  SEP TEMP FACTOR(DEGF)        0.9
TE400DEL   SEP TEMP DELTA             0.4  DEGF
LS450      WATER TANK LEVEL SWITCH    On         STK FLOW SW (FS400)          On
TE431      POLISHER TEMP            119.0  DEGF  F/W TEMP SW (TS451)          On
TE810      CONDENSOR EXIT TEMP      153.3  DEGF
TE820      CUST HEX HOT IN TEMP     177.5  DEGF  CUMHEATREC(MMBTU)          1.210
TE880      CUST HEX COLD IN TEMP    105.4  DEGF  FT880 FLOW (PPH)            2763
TE881      CUST HEX COLD EX TEMP    178.5  DEGF  HEAT REC (MBTU/HR)           202
TE401      STACK COOLANT INLET TEMP 316.6  DEGF
LT400      SEPARATOR LEVEL           10.8  IN

PMP451     WTS FEEDWATER PUMP         On         ON TIME, MIN.(FWPUMP):         0
STARTTEMP  TEMP FOR REF HEATUP      350.0  DEGF
IDCNET     NET DC CURRENT          1092.8  AMPS

HTR400     ELEMENT "A"                Off        ELEMENT "C"                  Off
           ELEMENT "B"                Off        ELEMENT "D"                  Off
```

```
                              ELECTRICAL OVERVIEW
06/20/95   IDC=  1092   VDC= 207  KWACNET=  199.7   VT310DEL= -0.36   EVENTS   0
1748:44    FT012ACT=  92.6  TE400FT=  351  TE012FT=  1658          OVERRIDES   0
P/P  9061  P 160 R 160 S 60  W 20  A 30  N 40  C 30  L 10  I 50

LOADTIME   TOTAL LOAD TIME            150  HR
HOTTIME    TOTAL HOT TIME             210  HR
CELV       AVG VOLTS PER CELL        .646  V/C
ASF        CURRENT DENSITY            194  ASF
KWDC       DC KILOWATTS             224.5  KW
VT310DEL   DELTA HALF STK VOLT      -0.36  V     VT310 HALF STK VOLT         0.46
           INSTANTANEOUS STK AMPS    1078  A
EFFINV     INVERTER EFFICIENCY       96.0  %     CELL EFFICIENCY (%)         51.7
EFFMECH    MECHANICAL EFFICIENCY     92.4  %     REF EFFICIENCY (%)          79.2
EFFELEC    ELECTRICAL EFFICIENCY     36.3  %     HEAT RATE (BTU/KWHR)       10435

KWACNET    NET AC POWER             199.9  KWAC  DISPATCHED POWER:          200.0
PFACT      ACTUAL POWER FACTOR      -1.00  -     DISPATCHED P.F.:            1.00
KVARNET    NET KVAR                  -0.7  KVAR  DISPATCHED KVAR:             0.0
KVANET     NET KVA                  200.2  KVA
PARPOWER   PARASITE POWER            16.8  KW
KWACGROS   GROSS AC POWER           216.2  KW
MWHRSGR    GROSS AC MW HRS         14.718  MWHR
MWHRSNET   NET AC MW HOURS         11.591  MWHR
```

```
                              POWER CONDITIONER SYSTEM
06/20/95  IDC= 1086  VDC= 207    KWACNET= 199.3  VT310DEL= -0.35  EVENTS  0
1749:30   PT012ACT=  89.7  TE400PT= 351.2  TE012PT= 1659.3        OVERRIDE  0
P/P  9061 P 160 R 160 S 60  W 20  A 30  N 40  C 30  L 10  I 50

PT001A    INV AC VOLTAGE,PHASE A   491.2  V
PT001B    INV AC VOLTAGE,PHASE B   489.9  V
PT001C    INV AC VOLTAGE,PHASE C   489.8  V
CT001A    INV AC CURRENT,PHASE A   225.1  A
CT001B    INV AC CURRENT,PHASE B   242.1  A
CT001C    INV AC CURRENT,PHASE C   239.5  A   CURRENT UNBAL (%)        7.1

PT003A    NET AC VOLTAGE,PHASE A   489.5  V
PT003B    NET AC VOLTAGE,PHASE B   486.3  V
PT003C    NET AC VOLTAGE,PHASE C   484.2  V   VOLTAGE UNBAL (%)        1.1
LINKVDC   LINK VOLTAGE             599.9  V

PERCFUND  PERCENT FUNDAMENTAL       85.8  %
PSREQ     PHASE SHIFT REQUEST        8.8  DEG
MCB001    G/I BREAKER STATUS         Off
MCB002    G/C BREAKER STATUS         On
MCB003    INTER-TIE BREAKER STAT     On
INTCOUNT  INTERRUPT COUNT              0
```

ONSI CORPORATION

TOTAL HARMONIC DISTORTION

DEMONSTRATED:	1.27 %
REQUIRED:	< 3.00 %
RESULT:	PASS

```
06/30/95   13:04:46

   VOLTS = 483.7
   AMPS  =   0.04
   WATTS =     17
   F.F.  = +1.00

HARM PWR =      0
Approx TDF = 0.95
```

	VOLTS	AMPS
TIF	6	77
THD	1.27%	17.39%
F	474.3V	0.04A
2	0.46%	13.04%
3	0.40%	4,35%
4	0.06%	4.35%
5	0.84%	4.35%
6	0.04%	0.00%
7	0.32%	4.35%
8	0.04%	0.00%
9	0.06%	0.00%
10	0.08%	4.35%
11	0.48%	4.35%
12	0.02%	0.00%
13	0.38%	4.35%
14	0.02%	0.00%
15	0.02%	0.00%
16	0.02%	0.00%
17	0.04%	0.00%
18	0.02%	0.00%
19	0.02%	0.00%
20	0.02%	0.00%
21	0.00%	0.00%
22	0.02%	0.00%
23	0.04%	4.35%
24	0.00%	0.00%
25	0.00%	0.00%

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OUTPUT FREQUENCY
(GRID CONNECT)

DEMONSTRATED: 60.00 HZ
REQUIRED: 60±.3 HZ

RESULT: PASS

```
                              ELECTRICAL OVERVIEW
06/20/95   IDC=  1093  VDC= 207  KWACNET=  200.1   VT310DEL= -0.40  EVENTS   0
1822:17    FT012ACT=  90.1  TE400FT=  351  TE012FT=  1661         OVERRIDES   0
P/P  9061 F 160 R 160 S 60  W 20  A 30  N 40  C 30  L 10  I 50

LOADTIME   TOTAL LOAD TIME              150   HR
HOTTIME    TOTAL HOT TIME               211   HR
CELV       AVG VOLTS PER CELL          .646   V/C
ASF        CURRENT DENSITY              196   ASF
KWDC       DC KILOWATTS               226.7   KW
VT310DEL   DELTA HALF STK VOLT        -0.40   V     VT310 HALF STK VOLT      0.43
           INSTANTANEOUS STK AMPS      1091   A
EFFINV     INVERTER EFFICIENCY         95.6   %     CELL EFFICIENCY (%)      51.7
EFFMECH    MECHANICAL EFFICIENCY       92.2   %     REF EFFICIENCY (%)       81.1
EFFELEC    ELECTRICAL EFFICIENCY       36.5   %     HEAT RATE (BTU/KWHR)    10268

KWACNET    NET AC POWER               200.2   KWAC  DISPATCHED POWER:       200.0
PFACT      ACTUAL POWER FACTOR         0.99   -     DISPATCHED P.F.:         0.85
KVARNET    NET KVAR                    25.1   KVAR  DISPATCHED KVAR:        123.9
KVANET     NET KVA                    202.0   KVA
PARPOWER   PARASITE POWER              16.1   KW
KWACGROS   GROSS AC POWER             216.4   KW
MWHRSGR    GROSS AC MW.HRS           14.841   MWHR
MWHRSNET   NET AC MW HOURS           11.704   MWHR
```

```
                         ELECTRICAL OVERVIEW
06/20/95  IDC=  1110  VDC= 206  KWACNET=  200.1   VT310DEL= -0.39  EVENTS   0
1829:02   FT012ACT=  88.8  TE400FT=  351  TE012FT=  1656        OVERRIDES   0
P/P  9061 P 160 R 160 S 60  W 20  A 30  N 40  C 30  L 10  I 50

LOADTIME  TOTAL LOAD TIME            150  HR
HOTTIME   TOTAL HOT TIME             211  HR
CELV      AVG VOLTS PER CELL        .645  V/C
ASF       CURRENT DENSITY            198  ASF
KWDC      DC KILOWATTS             229.1  KW
VT310DEL  DELTA HALF STK VOLT      -0.39  V     VT310 HALF STK VOLT      0.43
          INSTANTANEOUS STK AMPS    1113  A
EFFINV    INVERTER EFFICIENCY       95.2  %     CELL EFFICIENCY (%)      51.6
EFFMECH   MECHANICAL EFFICIENCY     92.4  %     REF EFFICIENCY (%)       82.0
EFFELEC   ELECTRICAL EFFICIENCY     37.1  %     HEAT RATE (BTU/KWHR)    10198

KWACNET   NET AC POWER             199.7  KWAC  DISPATCHED POWER:       200.0
PFACT     ACTUAL POWER FACTOR      -0.85  -     DISPATCHED P.F.:        -0.85
KVARNET   NET KVAR                -122.6  KVAR  DISPATCHED KVAR:       -123.9
KVANET    NET KVA                  234.8  KVA
PARPOWER  PARASITE POWER            17.4  KW
KWACGROS  GROSS AC POWER           217.2  KW
MWHRSGR   GROSS AC MW HRS         14.866  MWHR
MWHRSNET  NET AC MW HOURS         11.724  MWHR
```

```
                     KEY PARAMETERS (ENGLISH UNITS)
P/P  9061     06/20/95      1834:08          EVENTS:   0        OVERRIDE:   0
P 160 R 160 S 60  W 20  A 30  N 40  C 30  L 10  I 50
POWER OUTPUT (NET)          200.2  KWAC   OPERATING TIME           150.9  HRS
POWER OUTPUT (GROSS)        214.3  KWAC   POWER FACTOR             -1.00
STACK CURRENT              1077.0  AMPS   CUMULATIVE POWER        11.744  MWHR
STACK VOLTAGE               207.2  VOLTS  HALF STACK VOLTAGE        0.44  VOLTS
VOLUMETRIC FUEL FLOW       1943.4  SCFH   FUEL FLOW SETPOINT      1963.9  SCFH
ACTUAL FUEL FLOW             87.5  PPH
ZT010 EJECTOR POSITION       64.8  %      ZT010 SETPOINT            64.3  %
PHI MONITOR                  1.02         TOTAL FUEL CONS         141110  SCF
FT140 BURNER AIR FLOW       536.8  PPH    FT140 SETPOINT           519.6  PPH
TE012 REFORMER TEMP        1660.1  DEGF   ZT110 POSITION            84.4  %
TE012R BACKUP REF TEMP     1672.9  DEGF   TE012 SETPOINT          1656.3  DEGF

TE002 HDS TEMP              595.5  DEGF   TE350 ANODE INLET TEMP   409.8  DEGF

TE400FT STEAM SEP TEMP      351.1  DEGF   TE400 SETPOINT           350.2  DEGF
TE881 TEMP TO CUST          134.0  DEGF   RECOVERED HEAT             912  MBTU/HR
                                          TE431 POLISHER TEMP      119.0  DEGF
LT400 SEPARATOR LEVEL        11.0  IN     TE810 GLYCOL TEMP        150.2  DEGF
PMP451 STATUS                  On         TE160 MOTOR COMP AIR     119.0  DEGF
                                          TE150 MOT COMP AIR IN    101.9  DEGF
ELECTRICAL EFFICIENCY        37.4  %      press <NEXT PAGE> key to view RM data
```

```
                          STACK LOOP, ANC LOOP, & WTS
06/20/95  IDC=  1066.4  VDC= 208  KWACNET=   199  VT310DEL= -0.37  EVENTS  0
1834:53   FT012ACT=  87.5  TE400FT= 350.7  TE012FT=   1656         OVERRIDE  0
P/P  9061 F 160 R 160 S 60  W 20  A 30  N 40  C 30  L 10  I 50

TE400     SEPARATOR TEMP (PRIMARY) 350.7  DEGF  SETPOINT:                 350.2
TE400R    SEPARATOR TEMP (BACKUP)  350.0  DEGF  SEP TEMP FACTOR(DEGF)       0.9
TE400DEL  SEP TEMP DELTA             0.2  DEGF
LS450     WATER TANK LEVEL SWITCH    On         STK FLOW SW (FS400)        On
TE431     POLISHER TEMP            119.0  DEGF  F/W TEMP SW (TS451)        On
TE810     CONDENSOR EXIT TEMP      149.4  DEGF
TE820     CUST HEX HOT IN TEMP     176.6  DEGF  CUMHEATREC(MMBTU)         1.350
TE880     CUST HEX COLD IN TEMP     92.6  DEGF  FT880 FLOW (PPH)          22075
TE881     CUST HEX COLD EX TEMP    130.2  DEGF  HEAT REC (MBTU/HR)         840
TE401     STACK COOLANT INLET TEMP 239.7  DEGF
LT400     SEPARATOR LEVEL           11.2  IN

PMP451    WTS FEEDWATER PUMP         Off        ON TIME, MIN.(FWPUMP):       0
STARTTEMP TEMP FOR REF HEATUP      350.0  DEGF
IDCNET    NET DC CURRENT          1064.1  AMPS

HTR400    ELEMENT "A"                Off        ELEMENT "C"                Off
          ELEMENT "B"                Off        ELEMENT "D"                Off
```

```
                          STACK LOOP, ANC LOOP, & WTS
06/20/95  IDC=  1088.1  VDC= 207  KWACNET=   200  VT310DEL= -0.45  EVENTS  0
1934:51   FT012ACT=  91.6  TE400FT= 351.0  TE012FT=   1651         OVERRIDE  0
P/P  9061 F 160 R 160 S 60  W 20  A 30  N 40  C 30  L 10  I 50

TE400     SEPARATOR TEMP (PRIMARY) 351.1  DEGF  SETPOINT:                 350.4
TE400R    SEPARATOR TEMP (BACKUP)  351.1  DEGF  SEP TEMP FACTOR(DEGF)       0.9
TE400DEL  SEP TEMP DELTA             0.0  DEGF
LS450     WATER TANK LEVEL SWITCH    On         STK FLOW SW (FS400)        On
TE431     POLISHER TEMP            119.5  DEGF  F/W TEMP SW (TS451)        On
TE810     CONDENSOR EXIT TEMP      152.2  DEGF
TE820     CUST HEX HOT IN TEMP     180.6  DEGF  CUMHEATREC(MMBTU)         1.942
TE880     CUST HEX COLD IN TEMP    146.1  DEGF  FT880 FLOW (PPH)              0
TE881     CUST HEX COLD EX TEMP    179.9  DEGF  HEAT REC (MBTU/HR)            0
TE401     STACK COOLANT INLET TEMP 303.4  DEGF
LT400     SEPARATOR LEVEL           10.8  IN

PMP451    WTS FEEDWATER PUMP         On         ON TIME, MIN.(FWPUMP):       0
STARTTEMP TEMP FOR REF HEATUP      350.0  DEGF
IDCNET    NET DC CURRENT          1087.2  AMPS

HTR400    ELEMENT "A"                Off        ELEMENT "C"                Off
          ELEMENT "B"                Off        ELEMENT "D"                Off
```

```
                    KEY PARAMETERS (ENGLISH UNITS)
P/P  9061    06/20/95      2034:51          EVENTS:   0          OVERRIDE:   0
P 160 R 160 S 60  W 20  A 30  N 40  C 30  L 10  I 50
POWER OUTPUT (NET)         200.2  KWAC   OPERATING TIME          152.9  HRS
POWER OUTPUT (GROSS)       215.7  KWAC   POWER FACTOR             1.00
STACK CURRENT             1086.0  AMPS   CUMULATIVE POWER        12.144  MWHR
STACK VOLTAGE              206.7  VOLTS  HALF STACK VOLTAGE       0.39  VOLTS
VOLUMETRIC FUEL FLOW      1994.2  SCFH   FUEL FLOW SETPOINT     1997.0  SCFH
ACTUAL FUEL FLOW            89.8  PPH
ZT010 EJECTOR POSITION      66.9  %      ZT010 SETPOINT           66.2  %
PHI MONITOR                 1.01         TOTAL FUEL CONS        145086  SCF
FT140 BURNER AIR FLOW      517.7  PPH    FT140 SETPOINT          517.8  PPH
TE012 REFORMER TEMP       1652.2  DEGF   ZT110 POSITION           85.2  %
TE012R BACKUP REF TEMP    1661.9  DEGF   TE012 SETPOINT         1657.1  DEGF

TE002 HDS TEMP             603.9  DEGF   TE350 ANODE INLET TEMP  409.8  DEGF

TE400FT STEAM SEP TEMP     350.9  DEGF   TE400 SETPOINT          350.2  DEGF
TE881 TEMP TO CUST         180.4  DEGF   RECOVERED HEAT           101  MBTU/HR
                                         TE431 POLISHER TEMP     121.9  DEGF
LT400 SEPARATOR LEVEL       11.0  IN     TE810 GLYCOL TEMP       153.3  DEGF
PMP451 STATUS                Off         TE160 MOTOR COMP AIR    107.6  DEGF
                                         TE150 MOT COMP AIR IN    93.1  DEGF
ELECTRICAL EFFICIENCY       37.4  %      press <NEXT PAGE> key to view RM data
```

ONSI CORPORATION

FUEL CONSUMPTION

TIME	CUMULATIVE FUEL CONSUMED
1834:08	141,110 SCF
2034:51	145,086 SCF

ELAPSED TIME:	2.012 HRS
INCREMENTAL FUEL CONSUMED:	3,976 SCF
AVG. VOLUMETRIC FUEL FLOW RATE:	1976 SCFH
REQUIRED FUEL FLOW RATE:	1900 ± 100 SCFH

RESULT: PASS

```
                         STACK LOOP, ANC LOOP, & WTS
06/20/95   IDC=  1086.1  VDC= 207  KWACNET=    199  VT310DEL= -0.44  EVENTS  0
2035:32    FT012ACT=  89.9  TE400FT= 350.8  TE012FT=    1555       OVERRIDE  0
P/P  9061 F 160 R 160 S 60  W 20  A 30  N 40  C 30  L 10  J 50

TE400      SEPARATOR TEMP (PRIMARY) 350.9  DEGF  SETPOINT:                350.1
TE400R     SEPARATOR TEMP (BACKUP)  350.9  DEGF  SEP TEMP FACTOR(DEGF)      0.9
TE400DEL   SEP TEMP DELTA             0.0  DEGF
LS450      WATER TANK LEVEL SWITCH    On         STK FLOW SW (FS400)        On
TE431      POLISHER TEMP            121.9  DEGF  F/W TEMP SW (TS451)        On
TE810      CONDENSOR EXIT TEMP      154.0  DEGF
TE825      CUST HEX HOT IN TEMP     188.0  DEGF  CUMHEATREC(MMBTU)       1.997
TE880      CUST HEX COLD IN TEMP    150.7  DEGF  FT880 FLOW (PPH)         2591
TE881      CUST HEX COLD EX TEMP    182.0  DEGF  HEAT REC (MBTU/HR)         83
TE401      STACK COOLANT INLET TEMP 316.8  DEGF
LT400      SEPARATOR LEVEL           10.8  IN

PMP451     WTS FEEDWATER PUMP         Off        ON TIME, MIN.(FWPUMP):      0
STARTTEMP  TEMP FOR REF HEATUP      350.0  DEGF
IDCNET     NET DC CURRENT          1081.8  AMPS

HTR400     ELEMENT "A"                Off        ELEMENT "C"               Off
           ELEMENT "B"                Off        ELEMENT "D"               Off
```

ONSI CORPORATION

HEAT RECOVERY

TIME	CUMULATIVE HEAT RECOVERY
1834:50	1,350,000 BTU
2035:32	1,997,000 BTU

ELAPSED TIME: 2.012 HRS
INCREMENTAL HEAT RECOVERY: 647,000 BTU
AVERAGE RATE OF HEAT RECOVERY: 321,570 BTU/HR.

```
                     KEY PARAMETERS (ENGLISH UNITS)
P/P  9061    06/21/95     0935:15           EVENTS:   0          OVERRIDE:   0
P 161 R 160 S 60  W 20  A 30  N 40  C 30  L 10  I 80
POWER OUTPUT (NET)          38.1  KWAC  OPERATING TIME           166.0  HRS
POWER OUTPUT (GROSS)        90.3  KWAC  POWER FACTOR              0.95
STACK CURRENT              410.4  AMPS  CUMULATIVE POWER        14.561  MWHR
STACK VOLTAGE              227.9  VOLTS HALF STACK VOLTAGE       -0.00  VOLTS
VOLUMETRIC FUEL FLOW       711.9  SCFH  FUEL FLOW SETPOINT       717.6  SCFH
ACTUAL FUEL FLOW            32.0  PPH
ZT010 EJECTOR POSITION      23.2  %     ZT010 SETPOINT            21.8  %
PHI MONITOR                 1.07        TOTAL FUEL CONS         169280  SCF
FT140 BURNER AIR FLOW      250.4  PPH   FT140 SETPOINT           253.7  PPH
TE012 REFORMER TEMP       1515.5  DEGF  ZT110 POSITION            45.5  %
TE012R BACKUP REF TEMP    1510.2  DEGF  TE012 SETPOINT          1527.3  DEGF

TE002 HDS TEMP             603.0  DEGF  TE350 ANODE INLET TEMP  406.7  DEGF

TE400PT STEAM SEP TEMP     364.0  DEGF  TE400 SETPOINT           363.4  DEGF
TE881 TEMP TO CUST         162.1  DEGF  RECOVERED HEAT             237  MBTU/HR
                                        TE431 POLISHER TEMP      105.2  DEGF
LT400 SEPARATOR LEVEL       10.9  IN    TE810 GLYCOL TEMP        151.3  DEGF
PMP451 STATUS                On         TE160 MOTOR COMP AIR     100.8  DEGF
                                        TE150 MOT COMP AIR IN     84.0  DEGF
ELECTRICAL EFFICIENCY       18.4  %     press <NEXT PAGE> key to view RM data
```

```
                         REACTANT SUPPLY SYSTEM
06/21/95  IDC=   398.5  VDC= 229  KWACNET=   31   VT310DEL= -0.83  EVENTS  0
0936:14   FT012ACT=  32.0  TE400PT=  363  TE012PT=  1518           OVERRIDE  0
P/P  9061 P 161 R 160 S 60  W 20  A 30  N 40  C 30  L 10  I 80

TE012     REF TUBE TEMP (PRIMARY) 1518.2  DEGF  SETPOINT:                   1526.8
TE012R    REF TUBE TEMP (BACKUP)  1511.6  DEGF  REF/FUEL CONT OUTPUT:         1.04
TE012DEL  REF TUBE TEMP DELTA        6.5  DEGF
FT012ACT  ACTUAL MASS FUEL FLOW     32.0  PPH   SETPOINT:                     31.7
FT012     UNCORR. MASS FUEL FLOW    36.1  PPH   TE011 FUEL TEMP(DEGF)         85.4
SCFH      ACTUAL VOLUME FUEL FLOW  710.9  CFH   SETPOINT:                    700.5
FUELTOT   TOTAL FUEL CONSUMED     169292  SCF   PT012 VENTURI(PSIA)           7.15

ZT010     EJECTOR POSITION          22.9  %     SETPOINT:                     21.6
PHIMON    PHI MONITOR               1.04        STEAM FLOW S.P.(PPH):        134.4
TE350     ANODE INLET TEMP         406.7  DEGF

TE002     HDS BED TEMP             602.1  DEGF  HTR002 STATUS:                 Off

EFFREF   REFORMER EFFICIENCY       83.7  %
```

```
                         STACK LOOP, ANC LOOP, & WTS
06/21/95  IDC=   490.8  VDC= 223 KWACNET=     54  VT310DEL= -0.80  EVENTS  0
0937:07   FT012ACT=  40.4  TE400FT= 362.5  TE012FT=    1520        OVERRIDE  0
P/P  9061 P 161 R 160 S 60  W 20  A 30  N 40  C 30  L 10  I 80

TE400     SEPARATOR TEMP (PRIMARY) 362.5  DEGF  SETPOINT:               358.8
TE400R    SEPARATOR TEMP (BACKUP)  362.1  DEGF  SEP TEMP FACTOR(DEGF)     1.0
TE400DEL  SEP TEMP DELTA             0.4  DEGF
LS450     WATER TANK LEVEL SWITCH    On         STK FLOW SW (FS400)       On
TE431     POLISHER TEMP            105.2  DEGF  F/W TEMP SW (TS451)       On
TE810     CONDENSOR EXIT TEMP      153.3  DEGF
TE820     CUST HEX HOT IN TEMP     186.1  DEGF  CUMHEATREC(MMBTU)       3.231
TE880     CUST HEX COLD IN TEMP    150.5  DEGF  FT880 FLOW (PPH)        22247
TE881     CUST HEX COLD EX TEMP    160.6  DEGF  HEAT REC (MBTU/HR)        224
TE401     STACK COOLANT INLET TEMP 346.1  DEGF
LT400     SEPARATOR LEVEL           11.3  IN

PMP451    WTS FEEDWATER PUMP         Off        ON TIME, MIN.(FWPUMP):      0
STARTTEMP TEMP FOR REF HEATUP      350.0  DEGF
IDCNET    NET DC CURRENT           209.3  AMPS

HTR400    ELEMENT "A"                On         ELEMENT "C"               On
          ELEMENT "B"                On         ELEMENT "D"               Off


                          ELECTRICAL OVERVIEW
06/21/95  IDC=   452  VDC= 225  KWACNET=   44.5  VT310DEL= -0.85  EVENTS  0
0938:12   FT012ACT=  35.0  TE400FT=  361  TE012FT=  1526       OVERRIDES  0
P/P  9061 P 161 R 160 S 60  W 20  A 30  N 40  C 30  L 10  I 80

LOADTIME  TOTAL LOAD TIME            166  HR
HOTTIME   TOTAL HOT TIME             226  HR
CELV      AVG VOLTS PER CELL        .704  V/C
ASF       CURRENT DENSITY             81  ASF
KWDC      DC KILOWATTS             102.1  KW
VT310DEL  DELTA HALF STK VOLT      -0.85  V     VT310 HALF STK VOLT     -0.02
          INSTANTANEOUS STK AMPS     452  A
EFFINV    INVERTER EFFICIENCY       97.4  %     CELL EFFICIENCY (%)      56.1
EFFMECH   MECHANICAL EFFICIENCY     50.1  %     REF EFFICIENCY (%)       88.4
EFFELEC   ELECTRICAL EFFICIENCY     23.8  %     HEAT RATE (BTU/KWHR)    16152

KWACNET   NET AC POWER              44.5  KWAC  DISPATCHED POWER:         0.0
PFACT     ACTUAL POWER FACTOR       0.95  -     DISPATCHED P.F.:         1.00
KVARNET   NET KVAR                  14.5  KVAR  DISPATCHED KVAR:          0.0
KVANET    NET KVA                   46.8  KVA
PARPOWER  PARASITE POWER            54.6  KW
KWACGROS  GROSS AC POWER            99.1  KW
MWHRSGR   GROSS AC MW HRS         17.986  MWHR
MWHRSNET  NET AC MW HOURS         14.563  MWHR
```

```
                              POWER CONDITIONER SYSTEM
06/21/95   IDC=  427   VDC= 227    KWACNET=  42.6  VT310DFL= -0.81   EVENTS  0
0939:11    FT012ACT=  35.6   TE400FT= 361.9  TE012FT= 1525.2         OVERRIDE  0
F/P  9061 P 161 R 160 S 60  W 20  A 30  N 40  C 30  L 10  I 80

PT001A     INV AC VOLTAGE,PHASE A   482.9  V
PT001B     INV AC VOLTAGE,PHASE B   480.0  V
PT001C     INV AC VOLTAGE,PHASE C   478.9  V
CT001A     INV AC CURRENT,PHASE A    52.3  A
CT001B     INV AC CURRENT,PHASE B    54.9  A
CT001C     INV AC CURRENT,PHASE C    47.5  A   CURRENT UNBAL (%)        14.3

PT003A     NET AC VOLTAGE,PHASE A   485.4  V
PT003B     NET AC VOLTAGE,PHASE B   482.7  V
PT003C     NET AC VOLTAGE,PHASE C   480.7  V   VOLTAGE UNBAL (%)         1.0
LINKVDC    LINK VOLTAGE             599.9  V

PERCFUND   PERCENT FUNDAMENTAL       85.4  %
PSREQ      PHASE SHIFT REQUEST        2.0  DEG
MCB001     G/I BREAKER STATUS        On
MCB002     G/C BREAKER STATUS        Off
MCB003     INTER-TIE BREAKER STAT    Off
INTCOUNT   INTERRUPT COUNT             0
```

DEMONSTRATED OUTPUT VOLTAGE: 478.9 TO 482.9 VAC
REQUIRED OUTPUT VOLTAGE: 480 ± 3% VAC

RESULT: PASS

ONSI CORPORATION

OUTPUT FREQUENCY
(GRID INDEPENDENT)

DEMONSTRATED:	59.99 HZ
REQUIRED:	60±3 HZ
RESULT:	PASS

Appendix B: Project Meeting Notes

EDWARDS AFB SITE EVALUATION MEETING 14-15 AUG 96

I. OVERALL INBRIEFING TO COLONEL KUKKUK & STAFF

II. POTENTIAL SITES

- SWIMMING POOL
- DINING HALL (with NEIGHBORING DORMITORIES)
- HOSPITAL
- FLIGHT LINE (SPACE HEATING, 3-4 MONTHS ONLY)

- AGING ELECTRICAL INFRASTRUCTURE
  - COULD REPLACE DIESEL GENERATOR AT HOSPITAL WITH GRID-INDEPENDENT OPTION (DOUBLE BACKUP SYSTEM - THEY HAVE UPS ON ALL CRITICAL LOAD ON BASE WITH DIESEL GENERATORS AS 2ND BACKUP).

III. VISIT TO POTENTIAL SITES

- HOSPITAL HAS BEST THERMAL APPLICATION

IV. OUTBRIEFING

- 15-20% THERMAL UTILIZATION
- NEED TO SEE IF FUEL CELL CAN HANDLE 1 of the two 200-ton chillers in grid-independent mode (4 Compressors per chiller). Can switch over occur without compressors shutting down? Can fuel cell start compressors from shut down state? SAIC to check.

V. CAPT FAABORG TO WORK WITH SAIC ON GETTING MORE EXACT RATE STRUCTURE DATA TO BETTER REFINE ECONOMIC SAVINGS.

CHAIN LINK FENCE IS REQUIRED.

Wayne Holfeldt is Edison Electric POC. Capt Faaborg is somewhat concerned about whether "selling" power to the hospital, I don't think that's a concern – We set precedent at 29 Palms. LOCAL AQMD IS KERN COUNTY.

QUESTION OF WHETHER SPACE HEATING or DHW (or both) is best application – WILL GO BACK TO HOSPITAL TO DOUBLE CHECK.

WED, 14 AUG 96 EDWARDS AFB SITE EVALUATION

HANGARS – SPACE HEATING

10 months cooling/year 6 months cooling base average
4 months heating

Hospital – several buildings, do produce steam, run 3 months out of year
Guessing 2500 meals/day

Savings for Edwards	Elec	121,000
	Gas	15,000
	Gas Cost	31,000
		4,05,000

- Get fuel cell serial #'s, etc into database

Hospital has 500 KW + (2) 250 kW generators

*USE KEN MUNSON AS PRIMARY POC.

EDWARDS AFB KICKOFF MEETING 05 Feb 97

I. INTRODUCTIONS / OVERALL PROGRAM (FORSAKE OF NEW POC)
- POSSIBLE PAPERWORK NEEDED BY EDWARDS
- 1391
- ENVIRONMENTAL

II. SITE EVALUATION REPORT SUMMARY (TORREY)
- Pump Room - They're going to put a drain in there because there's a lot of water - Will need to coordinate drain installation with fuel cell design.
- Possibility of removing one of the tanks (fuel) - Needs to be checked out.
- Joe's question. Is 8' Clearance to the grates sufficient - yes.

III. GENERAL DESCRIPTION OF ONSI / FUEL CELL

IV. UPCOMING EVENTS
- 5 Sets of drawings
- 3 weeks

- BASE RESPONSIBILIES
- Log Book
- Photos
- Public Relations

EDWARDS AFB — DESIGN REVIEW — 25 MAR 97

I. PURPOSE OF MEETING – BINDER

II. INITIAL BASE QUESTIONS – BASE
- FORM 332 NEEDS TO BE SUBMITTED BY KEN FOR BASE APPROVAL (COMPREHENSIVE PLANNING FLIGHT & ENVIRONMENTAL MANAGEMENT). Next Meeting is May 5 for Approval – WILL WORK IT INTERNALLY THIS WEEK & MAY BE ABLE TO GET PAPERWORK SIGNED OFF THIS WEEK

III. DESIGN REVIEW – JOE

SAIC Comments (unless otherwise noted)

ME-1
(1) To BE Corrected on AS-BUILT
(2) WILL BE ADDED ON AS-BUILT
(3) Will be Labeled as not used on AS-BUILTS.

BASE QUESTION ON PHONE LINE – Explained Connection is all that's required. (2 Class A lines).

ME-1 (TAYLOR)
(1) Should be adequate as is

ME-1 (Holcomb)
(1) Will move on row so it doesn't

extend past end of Bldg.
(2) BASE WOULD PREFER THAT DIGGING BE AVOIDED IF POSSIBLE. - MIGHT SLOW PROJECT DOWN.
COMMENT IS WITHDRAWN.

M-1 (SAIC)

(1) EQUIV. LENGTH <19' - OK
(2) MUST BE LESS THAN 170 psig ⇒ OK.
(3) FIELD EXPERIENCE HAS SHOWN THAT ONE BLEED LINE IS SUFFICIENT - INSTALLATION MANUAL WILL PROBABLY BE CHANGED.
(4) SEQUENCE OF OPERATION STATEMENT WILL BE REWRITTEN. HV-2 & HV-3 CAN BE USED TO OBTAIN HEAT RECOVERY SHOULD PUMP P-1 FAIL.
(5) WILL BE ADDED TO AS-BUILT.

M-1 (TAYLOR)

(2) M-1 TO BE CHANGED TO INDICATE NEW GAS LINE TO CONNECT TO EXISTING BURIED GAS LINE.

M-2 (SAIC)

(1) By-Pass Valves will be Shown on As-Built.

- 3 -

E-1 (SAIC)

(1) BASE & GEORGE COLLARD WILL DISCUSS AT PRECONSTRUCTION BRIEFING.
(2) Will be changed to 1" on AS-BUILT.

S-1 (SAIC)

(1) TO BE ADDED TO AS BUILT.

S-1 (Holcomb)

(1) Change on AS-BUILT

(2) O/K AS IS

IV. Schedule

(1) Base Memo to Me
(2) My Memo to ONSI
(3) Base to keep log
(4) Base to take photos

George wants to Start construction on 07 Apr - Base will try to get me letter by 31 Mar

-4-

NOTE: BASE SUBMITTED NO COMMENTS FOR THE DESIGN REVIEW

25 MAR 97 EDWARDS AFB DESIGN REVIEW

Base needs to file form 332 to get approval / review for the project. Normally needs to go thru planning + zoning committee. May 6 is when the next P+Z meets. George wants to start a week from monday (7 APR 97).

- JOE - DESIGN COMMENTS
  - Comment by base, they cannot run any phone line. Response from Joe, all they need to do is provide a phone interface, George will run the cable.
  - Joe will move the N_2 bottles back so that they are flush with building.
  - Comment about digging underground, base does not want to do any digging, overhead lines are fine.
  - Grounding of fence and N_2 bottles, George will discuss with base at the preconstruction meeting.

KEN MUNSON - DOESN'T USE EMAIL, USE SAME SYNTAX AS SUFNARS.

EDWARDS AFB ACCEPTANCE TEST 16 JUL 97

KEN MUNSON - EDWARDS AFB
DOUG YOUNG - ONSI
MIKE BINDER - USACERL

KEN MUNSON DIDN'T WANT TO REVIEW ACCEPTANC TEST REPORT OR AS-BUILTS. HE WANTED TO TREAT THE FUEL CELL AS REAL PROPERTY WHICH WOULD REQUIRE THE COMMANDER TO SIGN THE DD250. THIS COULD TAKE A COUPLE WEEKS. KEN CALLED LT MATT SUFNAR IN. THE LT SAID THE FUEL CELL COULD BE TREATED AS ~~REA~~ EQUIPMENT (SAME AS A GENERATOR OR CHILLER) AND THAT KEN COULD SIGN THE DD250. KEN SAID THE HOSPITAL DID NOT WANT A DEDICATION CEREMONY SINCE THEY WERE LOSING MONEY. EDWARDS BILLS THE HOSPITAL AT AN AVERAGE PRICE FOR ELECTRICITY (INCLUDING WAPA) WHICH DOES NOT OFFSET THE NATURAL GAS PRICE. I REMINDED KEN THAT EDWARDS AFB WAS SAVINGS THE HIGH PRICE ELECTRICITY PURCHASED FROM THE UTILITY. HE AGREED BUT SAID THE HOSPITAL DOESN'T SEE THAT SAVINGS. DOUG & I TOURED THE FUEL CELL SITE.

Appendix C: Review Letters for Original Design Drawings

Science Applications International Corporation
An Employee-Owned Company

February 14, 1996

Dr. Mike Binder
USACERL
Energy and Utilities Systems Division
2902 Newmark Drive
Champaign, IL 61821-1076

Subject: Twenty-Nine Palms Final Design Review

Dear Mike:

SAIC and our licensed mechanical and electrical subcontractors have reviewed the fuel cell installation design drawings for the Twenty-Nine Palms Marine Corps. Base. Our comments are presented below.

1. HEAT REJECTION LOOP (COOLING MODULE)

   a. Assumed 30 gpm flow rate.
   b. Total equivalent piping length of 335 feet.
   c. Pressure drop - 30 gpm in 2" pipe = 2'/100'.
   d. Fluid cooler pressure drop - 12' at 30 gpm.
   e. Total pressure drop external to fuel cell is (3.35' x 2') + 12' = 18.7'

   Pipe sizing and velocity are adequate at 2". Discharge head for circulating pump located in fuel cell power module should include the 18.7' piping loop pressure drop.

2. HEAT RECOVERY PIPING - CUSTOMER SIDE

   a. Flow rate - 30 gpm.
   b. Total equivalent piping length - 318 feet.
   c. Pipe size - 3"
   d. Pressure drop - 25 gpm in 3" pipe = 0.8/100'.
   e. Piping pressure loss = 3.18 x 0.8 = 2.8'
   f. Pressure drop through HEX880 (in power module) = 15'
   g. Total pump head required = 2.8' + 15' = 17.7'

   Piping sizing and velocity are adequate at 3"; however, as the velocity is low at 2.3 feet per second, some savings could be realized by utilizing 2" pipe versus 3". A check valve is recommended at the discharge of Recirculating Pump P-2.

3. HEAT RECOVERY PIPING - FUEL CELL SIDE HEX850 TO STORAGE TANK LOOP WP-11

a. Flow rate - 25 gpm
b. Pipe size - assume 2"
c. Total equivalent piping length - 221'
d. Pressure drop - 25 gpm in 2" pipe = 1.5'/100'
e. Piping pressure loss = 2.21 x 1.5 = 3.3'
f. Pressure drop through HEX880 = 15' ±
g. Total pump head required = 3.3' + 15' = 18.3'

Piping sizing and velocity are adequate at 2". The B&G Series 90, size 1-1/2A, 1/2 H.P. pump is adequate.

4. CITY WATER TO FUEL CELL POWER MODULE

a. Flow rate - assume 10 gpm ±
b. Water pressure - assume 50 psig ±
c. Total equivalent piping length - 156'
d. Pressure drop - 10 gpm in 3/4" pipe = 10 psig/100'
e. Pressure drop through HEX880 - assume 15'
f. Total pressure drop then is (1.56 x 10) + (15' x .43) = 22 psig. The 3/4" pipe size is adequate assuming that about 28 psig at the fuel cell inlet is satisfactory.

Should the City water supply not be isolated from the potable system elsewhere in the plant, an approved backflow prevention device should be provided.

5. NATURAL GAS

a. Connected load - 1,900 CFH
b. Pipe size - 3"
c. Pressure at point-of-connection - assume under 14" W.C.
d. Total equivalent piping length - 180'.
e. Maximum delivery capacity of 0.60 specific gravity natural gas per hour with pressure drop at 0.5 inch water column in 3" pipe is 8,257 CFH. Pipe sizing at 3" is adequate.

6. NITROGEN

a. Required flow rate - could not be determined from data provided.
b. Pipe size - 3/4"
c. Total equivalent piping length = 60'.

Assuming a required delivery pressure of 50 psig at the fuel cell power module connection, capacity of a 3/4" pipe is in excess of 1,600 liters per minute. This pipe size should be adequate depending on ONSI's maximum anticipated flow rate

5. ELECTRICAL

a. The plans should be stamped by a registered electrical engineer.
b. More details should be given for the new 400A subpanel: i.e., mounting AIC, breaker sizes, etc.
c. The sizes of conduits and conductors from new sub-panel to "NTH" and "HNH" should be given.
d. The 120V power source to the fuel cell power module should be shown.
e. Show ground grid around fuel cell enclosure and all termination points.
f. Show routing to room F005 along with feeder length and voltage drop.

Based on the 125°F and 140°F supply temperatures for the domestic hot water loops, the 5,000 gallon storage tank appears adequate. The detailed electrical and thermal designs are sufficient. With consideration of the above comments, we believe that the site design is adequate to proceed with construction.

Sincerely,

Gerry Mertes
Division Manager
Advanced Energy Systems

29 PALMS "RECORD DRAWING" CHANGES 6/19/95
J. Steniunas

DRAWING	CHANGE
S-1	Equipment positioning adjustments including nitrogen rack to back side of pad Fence lengthened 1 ft to 52 ft Full concrete pad within fence Drainage accommodations at building end of pad
S-2	Equipment position adjustments
ME-1	Equipment repositioned as on S-1 Gas line repositioned Spare conduit added (emergency power cord) Building wall penetrations noted Disconnect label changed (reversed GC & GI)
M-1	Storage tank dimension typo corrected Mixing valves labeled (inlets B&C, outlet A) Closed valves illustrated
M-2	No changes
E-1	Grounding illustration changed to correspond to ground grid on 9061 E-3 drawing
E-2	No changes
E-3	Ground grid updated.

Appendix D: PC25C Fuel Cell Forced Outage Description Codes

Fleet Log
Model C

page1

FORCED OUTAGE ORIGIN BY POWER PLANT

DESCRIPTION	CODE1	CODE2	CODE3
POWER SECTION SYSTEM	PSS		
FREEZE PREVENTION HEATER A			HTR310A
FREEZE PREVENTION HEATER B			HTR310B
GROUND FAULT DETECTOR			GFD-001
HALF-STACK VOLTAGE MONITOR			VT310
FUEL PROCESSING SYSTEM	FPS		
SHUTOFF VALVE			CV000
SHUTOFF VALVE			CHV100
CHECK VALVE			CV100
FLOW CONTROL VALVE			FCV012
EJECTOR			EJT010
REFORMER			REF300
LOW TEMP SHIFT CONVERTER			SC300
AIR PRE-HEATER			HEX910
BURNER CONTROL			BSC001
INTEGRATED LOW TEMP SYSTEM		ILS	
AIR PROCSSING SYSTEM	APS		
FILTER			FIL100
PROCESS AIR BLOWER			BLO100
CATHODE			FCV100
CATHODE AIR VALVE			FCV110
REFORMER BURNER			FCV140
VALVE POSITION INDICATIOR			ZT110
AIR FLOW TRANSMITTER			FT140
HAND ORIFICE			HO135
FIXED ORIFICE			FO130
REFORMER BURNER SENSOR			BE030
THERMAL MANAGEMENT SYSTEM	TMS		
FLOW SWITCH			FS400
THERMAL TEMP MANAGEMENT CONTROL			TE400
THERMAL TEMP MANAGEMENT CONTROL			TE431
CELL STACK COOLING H20 SUB-SYSTEM		CSCW	
COOLANT ACCUMULATOR			ACC400
COOLANT PUMP			PMP400
THERMAL CONTROL HEAT EXCHANGER			HEX400
FLOW ORIFICE			FO400
FLOW ORIFICE			FO420
BLOWDOWN COOLER			HEX310
BLOWDOWN VALVE			FCV430
MIXED RESIN DEMINERALIZER BED			DMN440
ELECTRIC HEATER			HTR400
MOTORIZED VALVE			TCV400
ANCILLARY COOLANT SUB-SYSTEM		ACS	
PUMP			PMP830
BLOWDOWN COOLER			HEX431
CONDENSER			HEX920
CUSTOMER HEAT EXCHANGER			HEX880
FORCED CONVECTION COOLING MODULE			HEX800
SELF-ACTUATED FLOW CONTROL VALVE			TCV800
MOTORIZED VALVE			TCV830
HAND ORIFICE			HO840

CHANGE IN STATE

DESCRIPTION	CODE
POWER UP	PU
POWER DOWN	PD
IDLE UP	IU
IDLE DOWN	ID
SHUTDOWN	S
NONE	N

FORCED OUTAGE/ UNFORCED OUTAGE

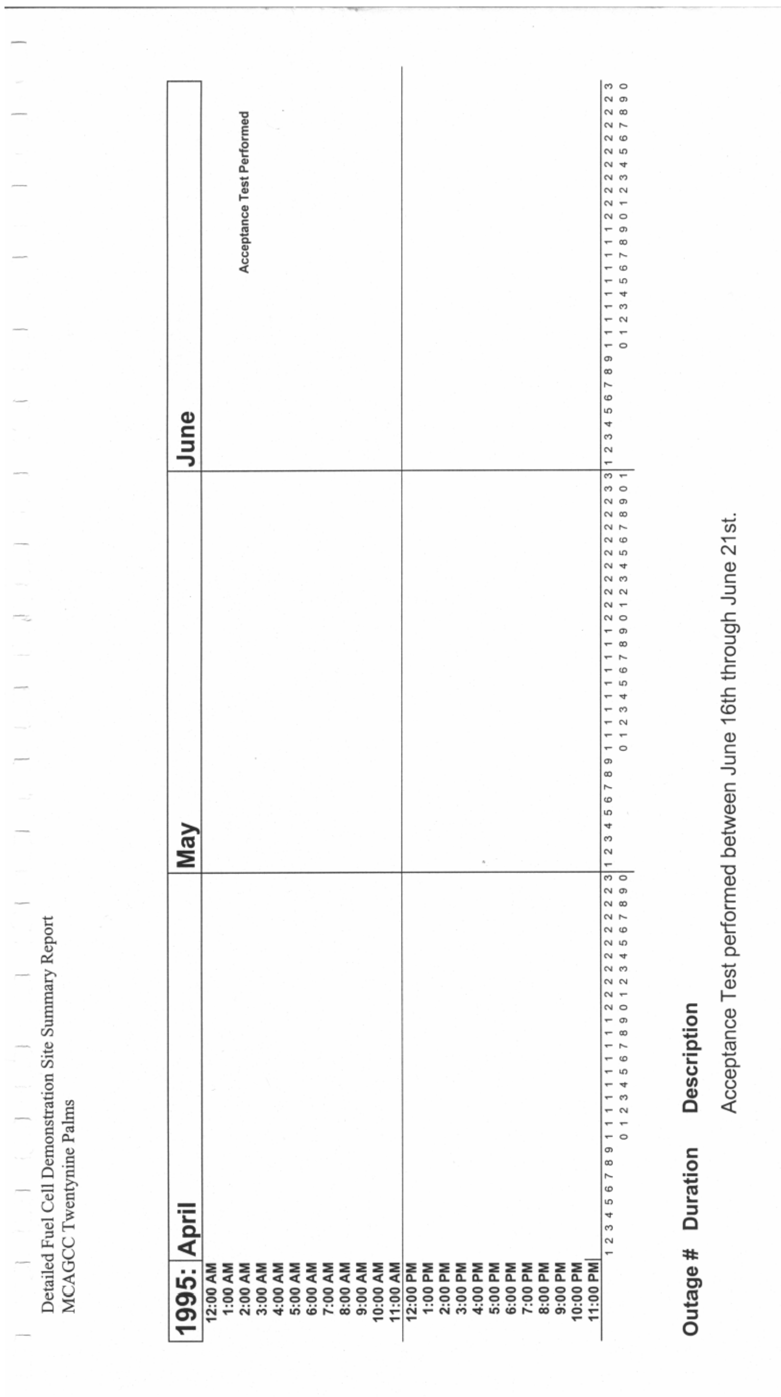
DESCRIPTION	CODE
FORCED	F
UNFORCED	U

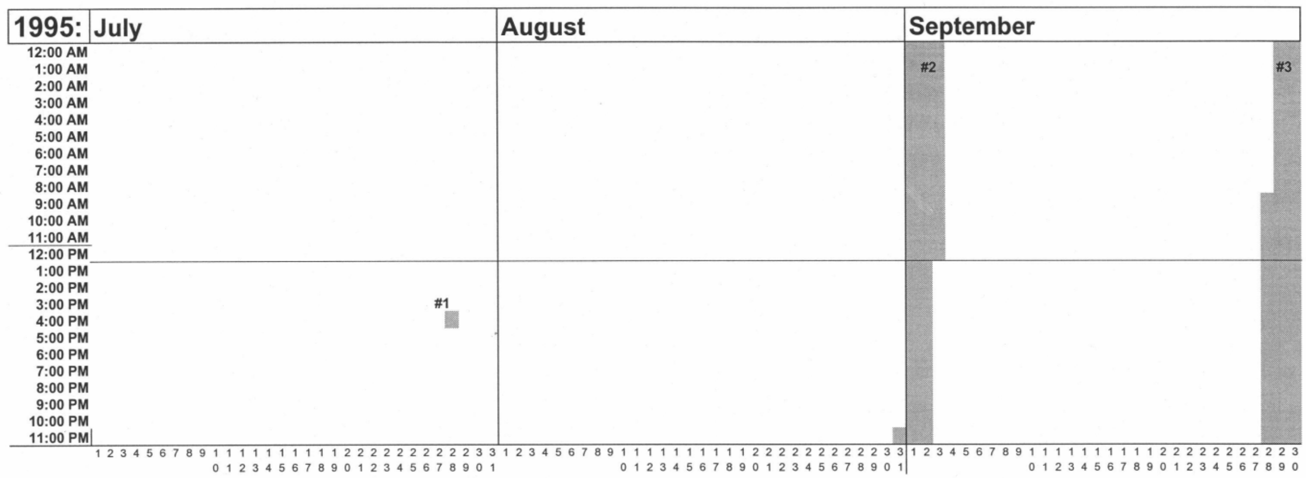
Fleet Log
Model C

page2

WATER TREATMENT SYSTEM	WTS		
WTS PUMP			PMP450
ORGANIC FILTER			ORG450
MIXED RESIN DEMINERALIZER BED			DMN450A
MIXED RESIN DEMINERALIZER BED			DMN450B
MIXED RESIN DEMINERALIZER BED			DMN450C
MIXED RESIN DEMINERALIZER BED			DMN450D
FEEDWATER PUMP			PMP451
ISOLATION HAND VALVE			HV450A
ISOLATION HAND VALVE			HV450B
WATER TANK LEVEL TRANSMITTER			LS450
WATER TANK LEVEL TRANSMITTER			LS451
WATER TANK LEVEL TRANSMITTER			LT450
WATER LEVEL CONTROL VALVE			LCV451
CHECK VALVE			CHV451
NITROGEN PURGE SYSTEM	NPS		
OPEN SOLENOID VALVE			CV720
OPEN SOLENOID VALVE			CV710
FLOW ORIFICE			FO720
AIR EJECTOR			EJT710
CABINET VENTILATION SYSTEM	CVS		
VENTILATION FAN			FAN165
VENTILATION FAN			FAN150
FLOW SWITCH			FS165
FILTER			FIL150
FLOW CONTROL DAMPER			FCD150
EXIT FLOW RATE CONTROL			TE150B
TO PROCESSED STEAM SHUTOFF VALVE			CV500
ELECTRICAL SYSTEM	ES		
POWER CONDITIONING SYSTEM		PCS	
MOTORIZED AC CURCUIT BREAKER			MCB001
MOTORIZED AC CURCUIT BREAKER			MCB002
MOTORIZED AC CURCUIT BREAKER			MCB003
POWER DISTRIBUTION SYSTEM		PDS	
AUXILIARY TRANSFORMER			T005
UNINTERUPTABLE POWER SUPPLY			UPS001
POWER PLANT CONTROL		PPC	
LOCAL OPERATING INTERFACE			LOI
LOCAL DIAGNOSTIC TERMINAL			LDT
ELECTICAL CONTROL SYSYEM		ECS	
OTHER	OTR		
OTHER ELECTRICAL		OTRE	
K001			K001
K002			K002
INVERTER			INV
CSA			CSA
PC CARD			PC
BOOST REGULATOR			BSRG
FUSE			FUSE
POLE FAULT			POLE
BRIDGE FAULT			BRDG
QUAD POWER SUPPLY			QUAD
DUAL POWER SUPPLY			DUAL
RELAY TRIP			RELAY
GROUND FAULT			GRND
CIRCUIT BREAKER			CRB
CONTROLLER			CRL
SUBSTACK			SBSTK
GRID DISTIRBANCE			GRID
OTHER GAS		OTRG	
OTHER WATER		OTRW	

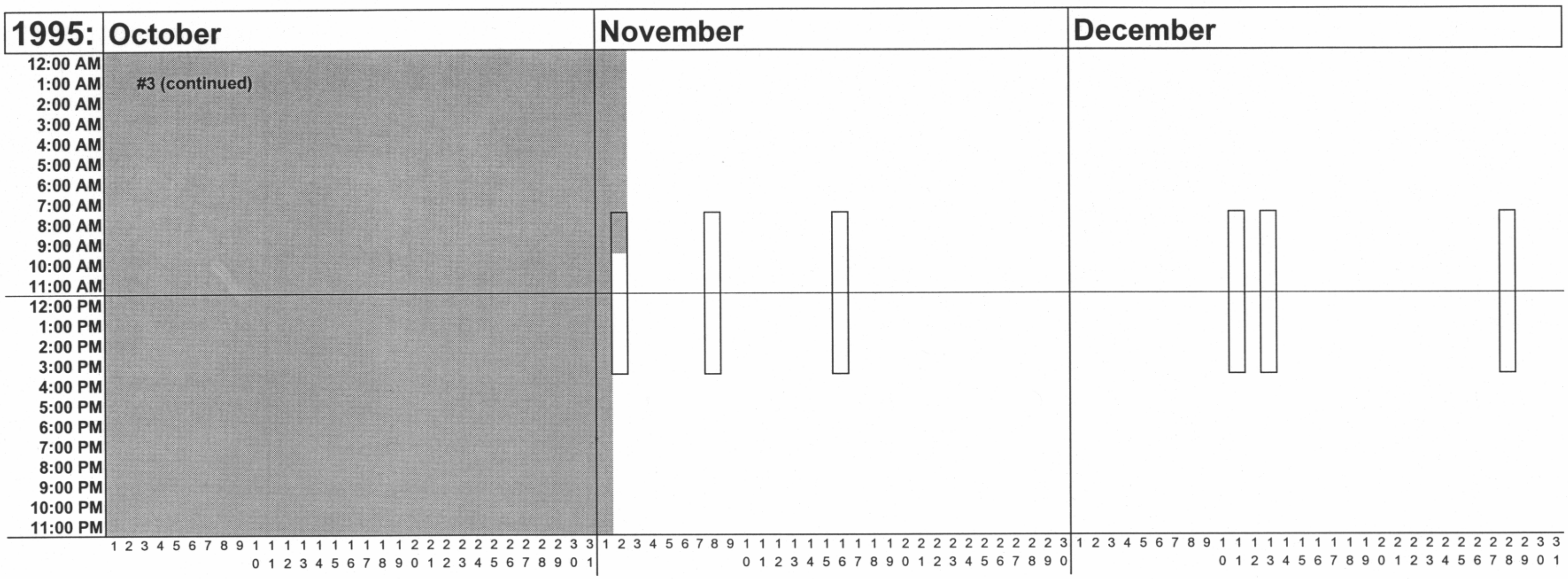
Appendix E: Summary of Maintenance Invoices by Year





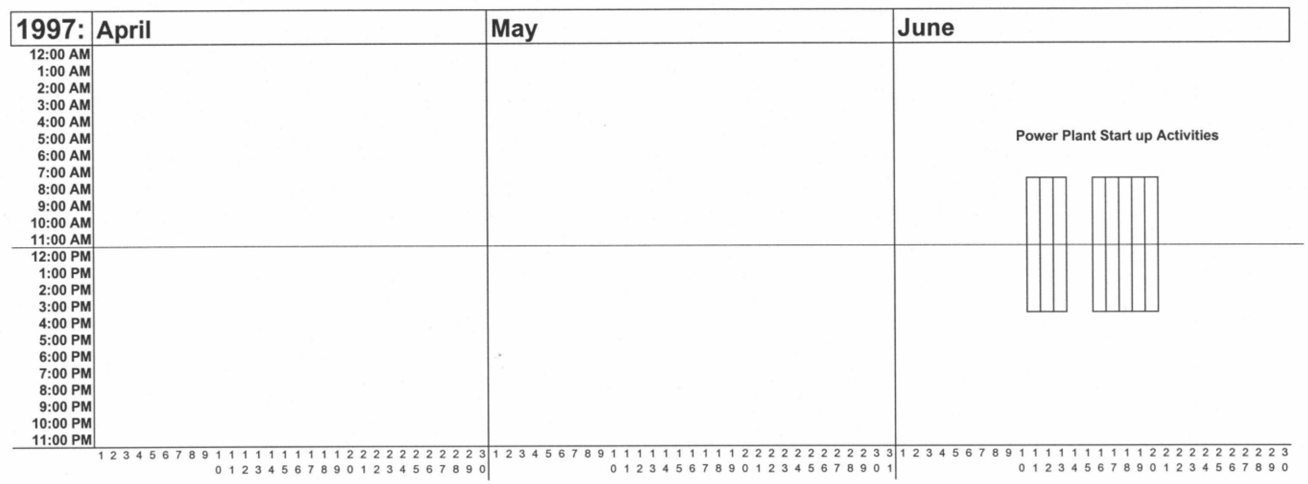
Outage #	Duration	Description
1	00:33	APS: FT140 low in R80-R160 shutdown (while adjusting electro-mechanical brake to prevent unstable FCV1140 operation)
2	60:12	TMS/CSW: Loss of separator control (SEPDEL high for 10min in S60) restarted raised power slowly.
3	840:20	TMS/CSW: Low HDS bed temperature (TE002 low for 60sec in R110-R160). Completed 2000 hour maintenance. Replaced FCV503. Replaced FO002 orifice with 1.1" size. Replaced PMP400 with high flow pump to improve TE401. Replaced PC7 controller card.

Detailed Fuel Cell Demonstration Site Summary Report
MCAGCC Twentynine Palms



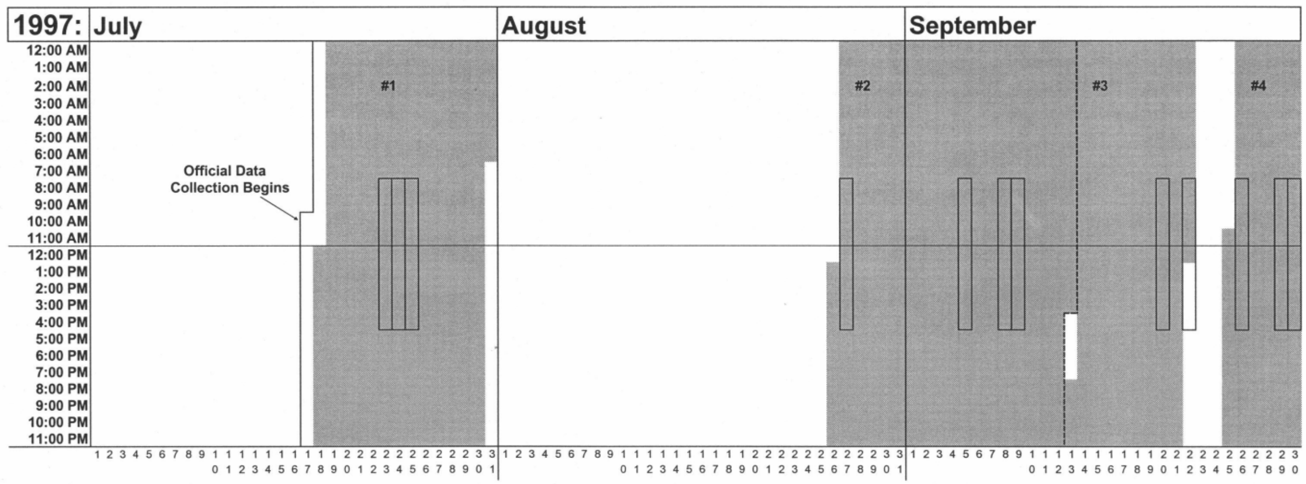
Outage #	Duration	Description
3	840:20	See previous page.

Detailed Fuel Cell Demonstration Site Summary Report
Edwards AFB

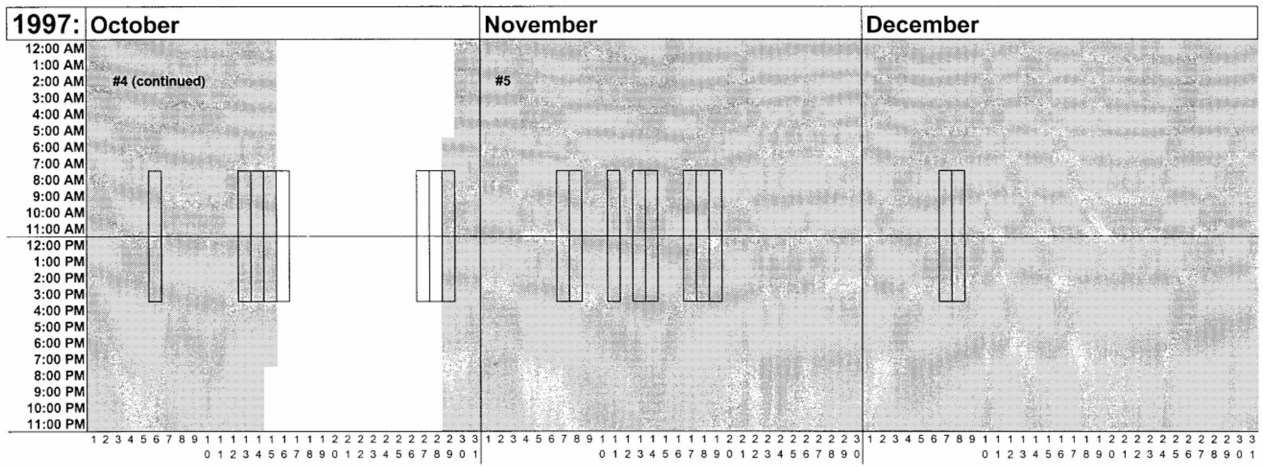


Outage # **Duration** **Description**

Fuel Cell Acceptance Testing was performed June 23-25, 1997

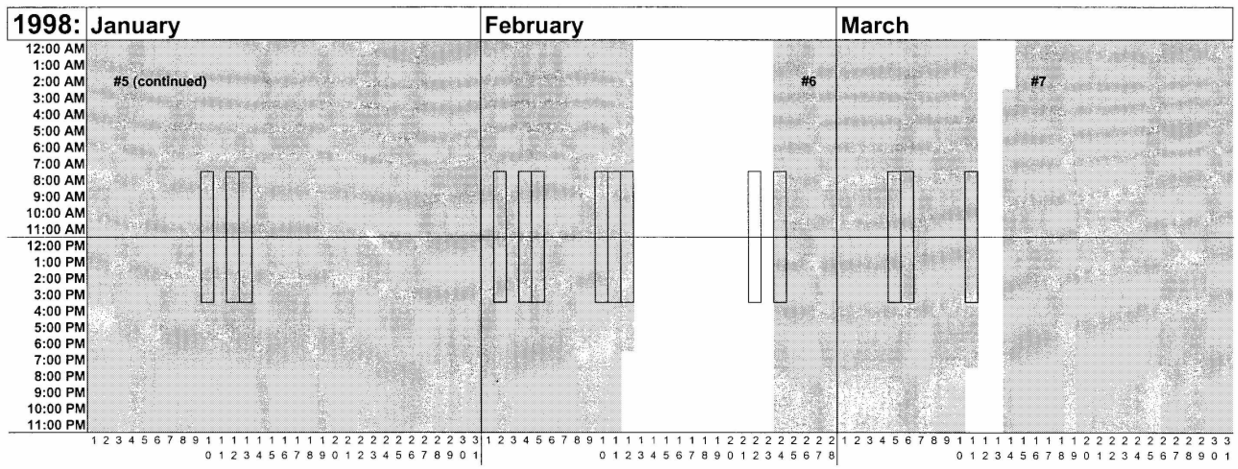


Outage #	Duration	Description
1	307:30	shutdown due to site gas supply; controller hard drive and site gas meter failed and were replaced
2	434:36	shutdown due to operator error
3	207:58	TMS: shutdown due to failed steam ejector
4	487:15	TMS: shutdown due to frozen TCV830

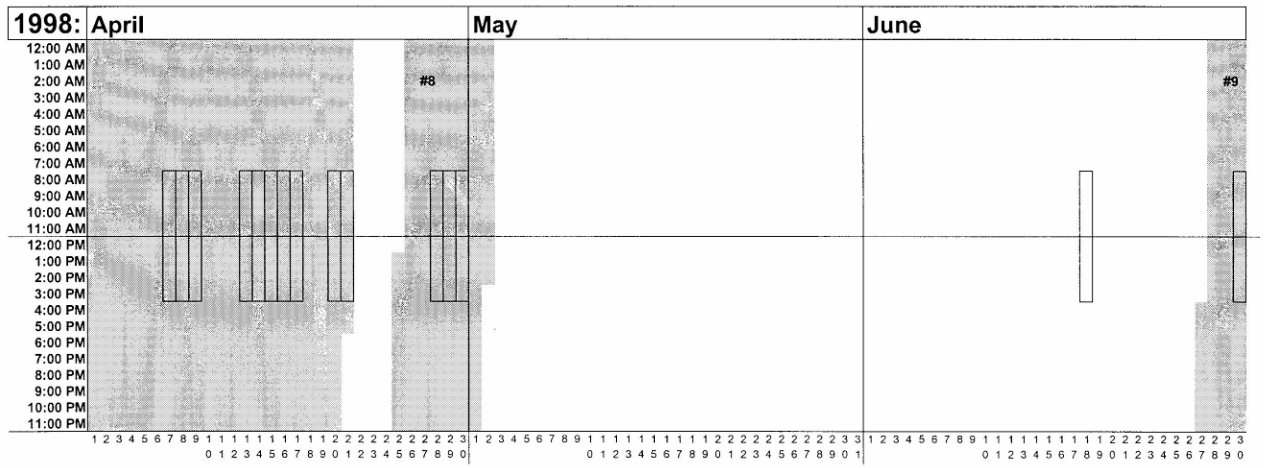


Outage #	Duration	Description
4	487:15	See previous page.
5	2,555:52	TMS: P/P shutdown due to failed cell stack assembly cooler. Foreign restricted cooler coil #17, causing failure of sub stack nos. 16 & 17. The fuel cell stack was removed and sent to UTC Fuel Cells for repair.

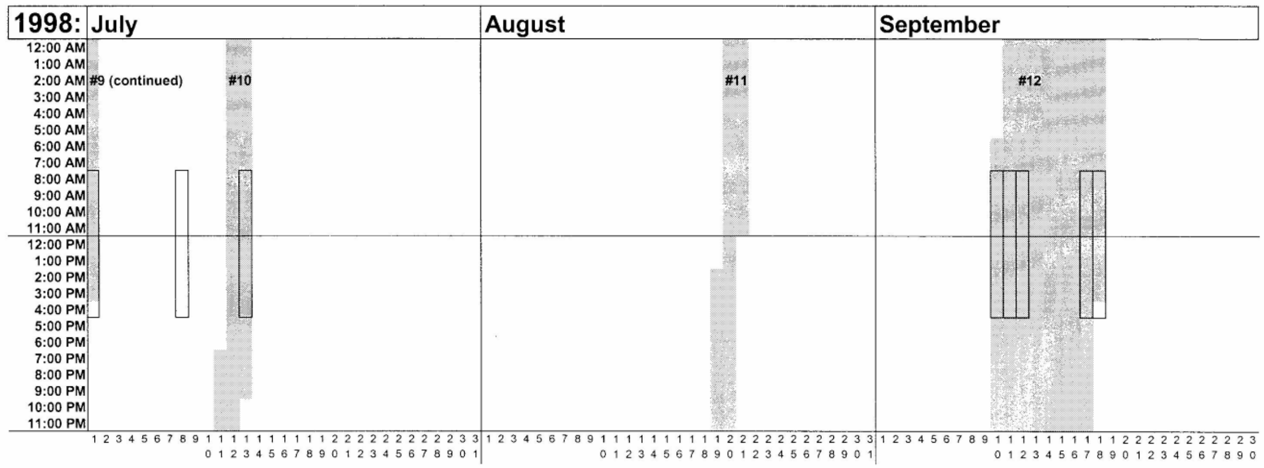
Detailed Fuel Cell Demonstration Site Summary Report
Edwards AFB



Outage #	Duration	Description
5	2,555:52	See previous page.
6	379:00	TMS: Same as #5, but new cell stack assembly operated for 269 hours
7	926:36	Outage not specified. Worked on High Grade Heat Exchanger retrofit.

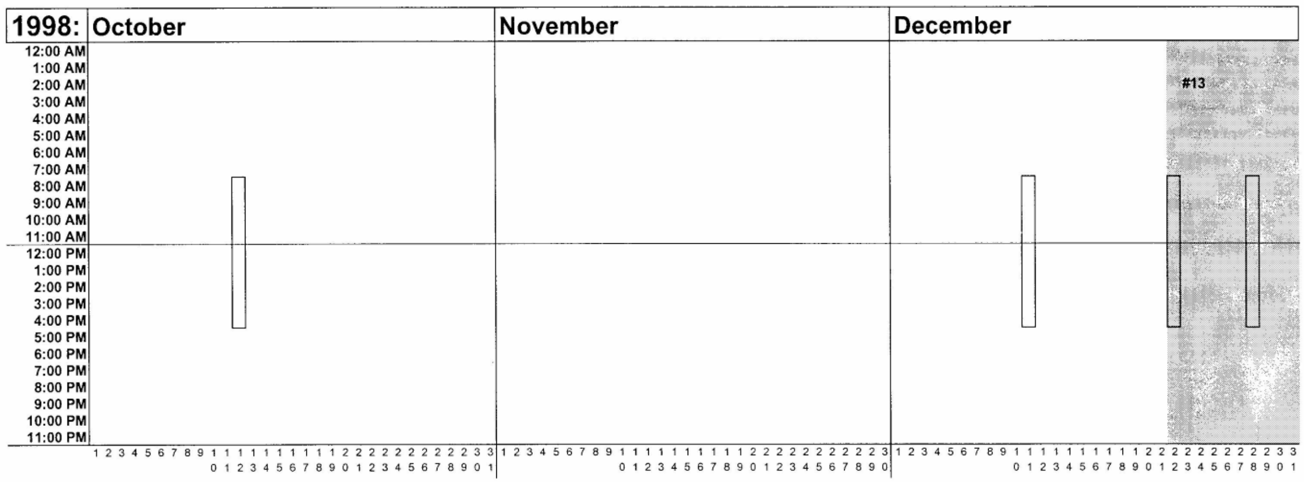


Outage #	Duration	Description
7	926:36	See previous page.
8	169:30	Outage not specified. UTC Fuel Cells worked at site.
9	95:45	WTS: P/P shutdown due to low LT450; customer inadvertently shut off the R/O unit.



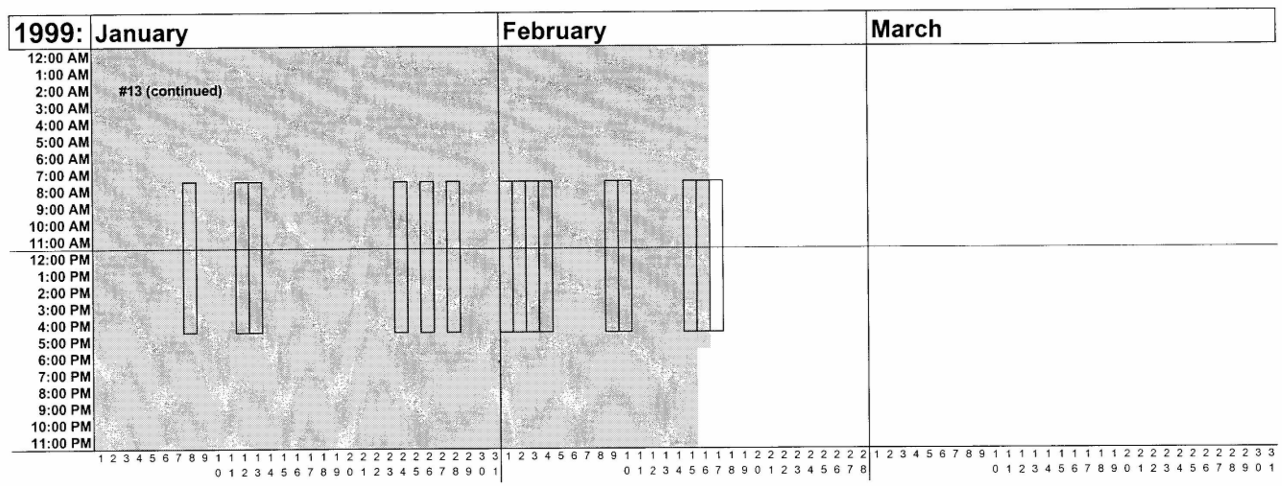
Outage #	Duration	Description
9	95:45	See previous page.
10	50:26	WTS: P/P shutdown due to low LT450; customer inadvertently shut off the R/O unit (Again).
11	45:33	OTR: Base natural gas shutoff by customer.
12	201:40	OTR: Shutdown due to blown cooling module motor fuse; found and repaired cut wire.

Detailed Fuel Cell Demonstration Site Summary Report
Edwards AFB

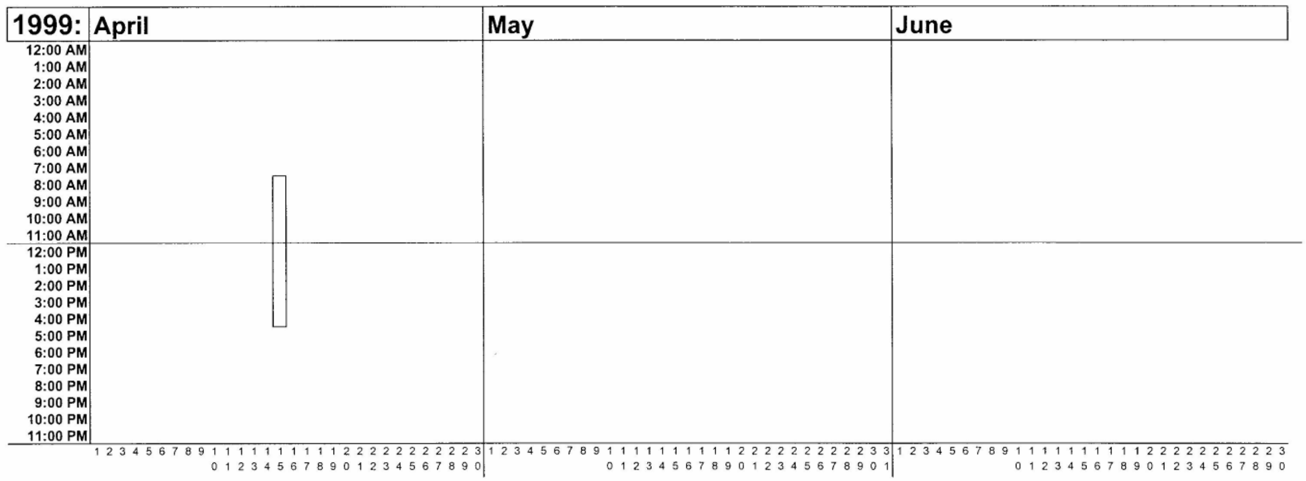


Outage #	Duration	Description
13	1,361:03	FPS: New reformer installed.

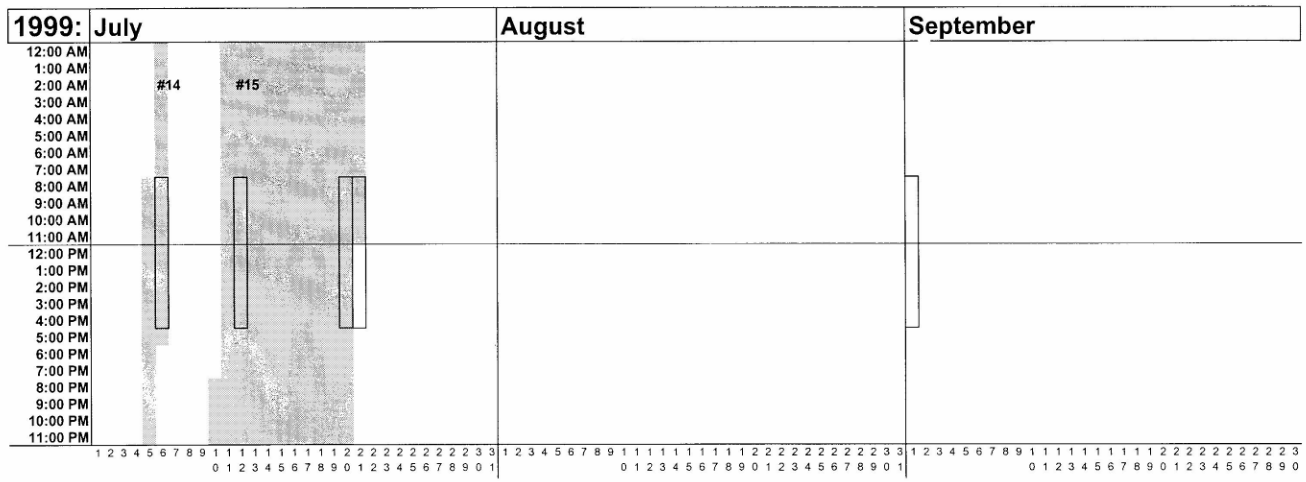
Detailed Fuel Cell Demonstration Site Summary Report
Edwards AFB



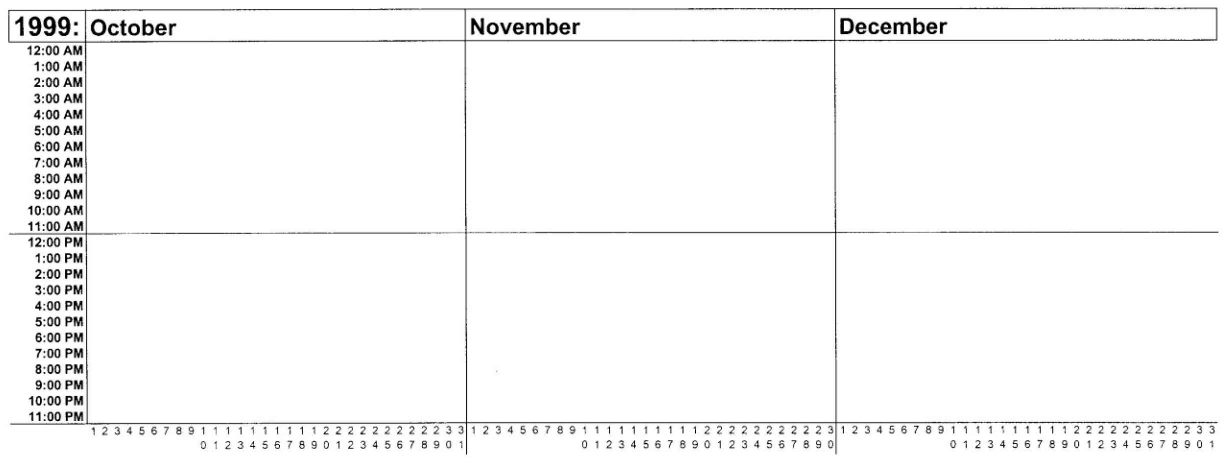
Outage #	Duration	Description
13	1,361:03	See previous page.



Outage # **Duration** **Description**

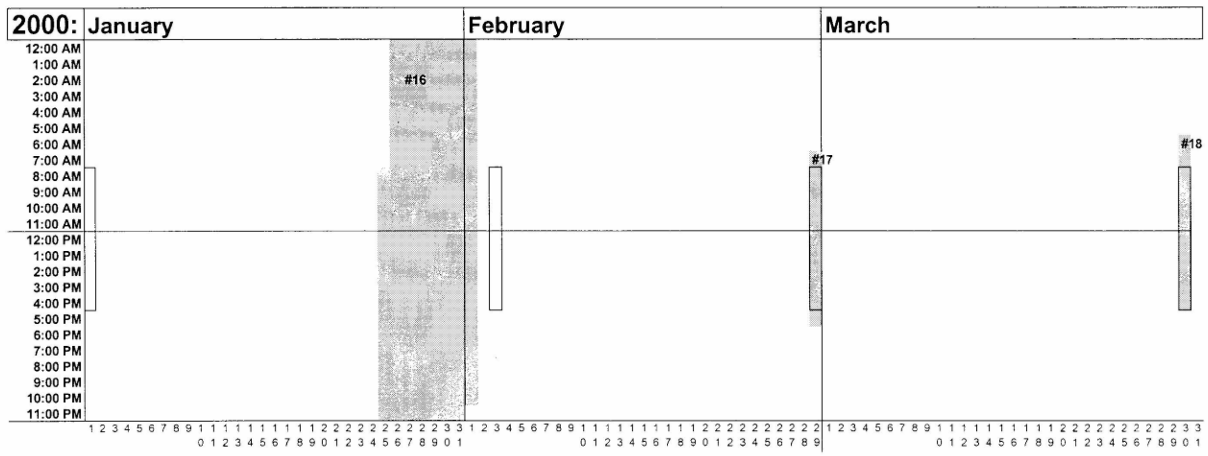


Outage #	Duration	Description
14	34:24	Base transformer fire resulted in loss of grid (major disturbance).
15	257:30	OTR: Grid disturbance. Apparent controller reboot.

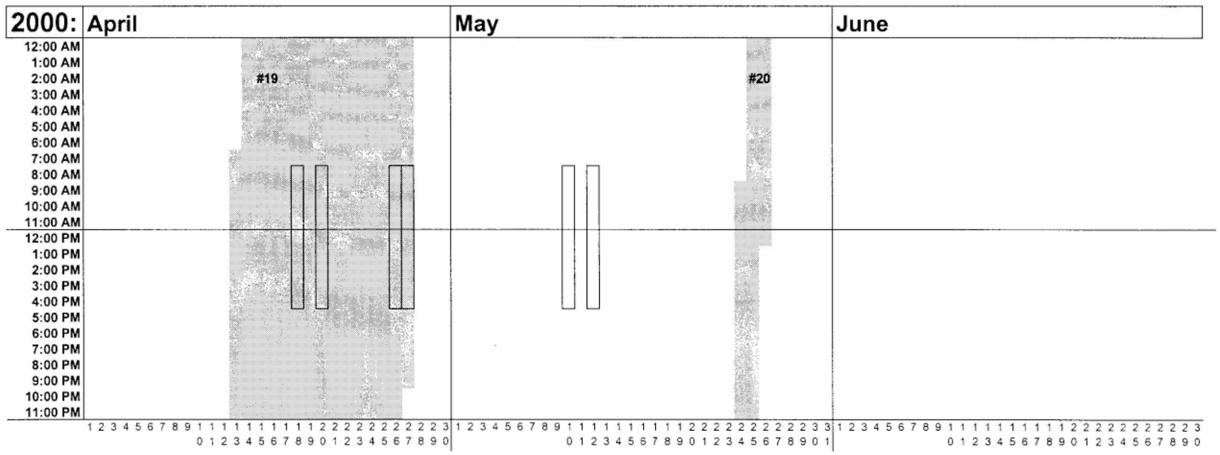


Outage # Duration Description

Detailed Fuel Cell Demonstration Site Summary Report
Edwards AFB

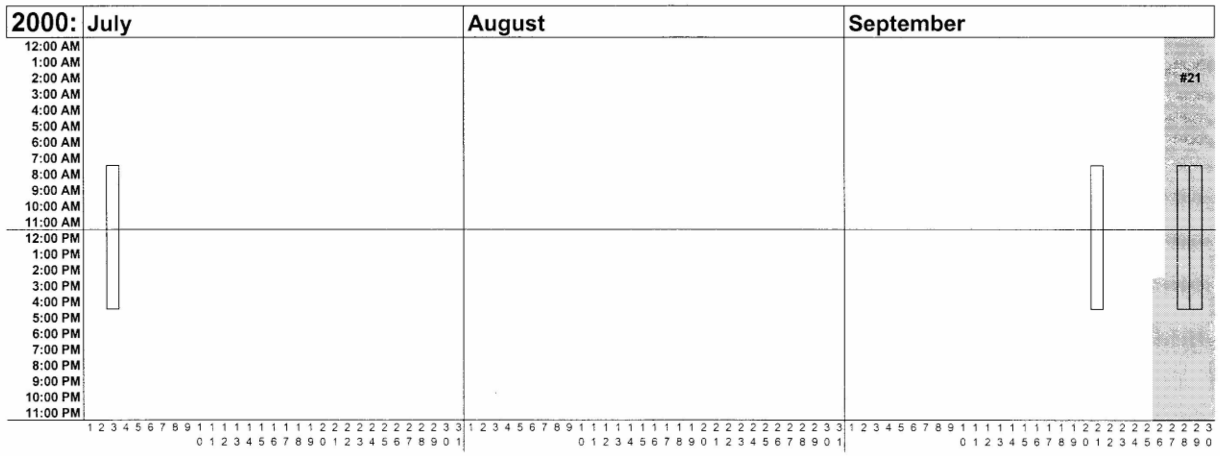


Outage #	Duration	Description
16	183:35	APS: Shutdown on low burner air. Replacement FCV140 and I/O modules sent.
17	9:27	Planned brief shutdown to replace pump 451 and fan 800 motor.
18	9:00	Manual shutdown to replace MSDP card.

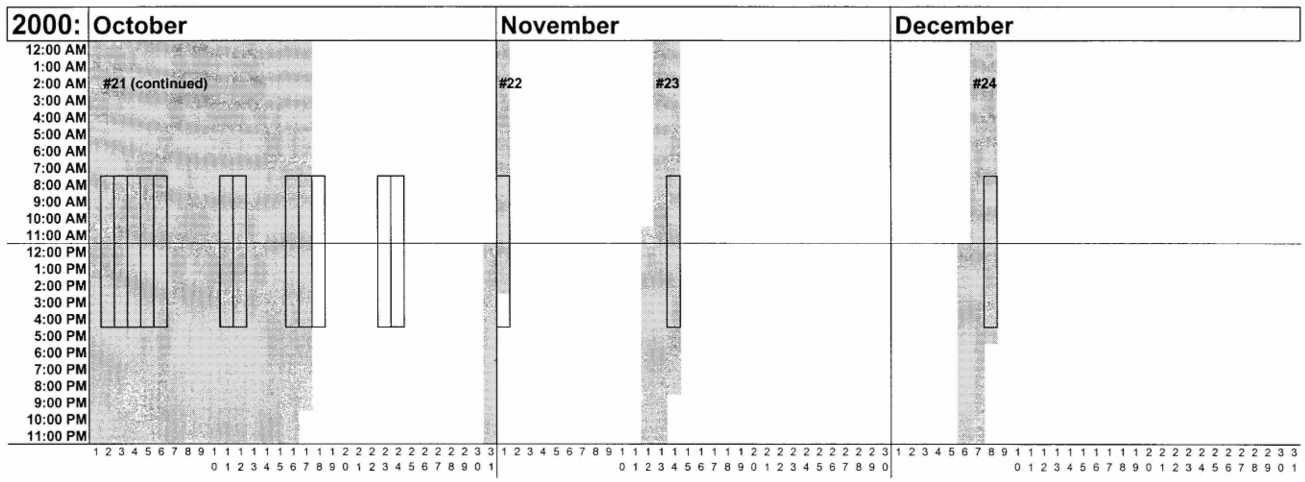


Outage #	Duration	Description
19	350:11	TMS: Replace TE431 thermal temperature management control.
20	51:40	Outage not specified.

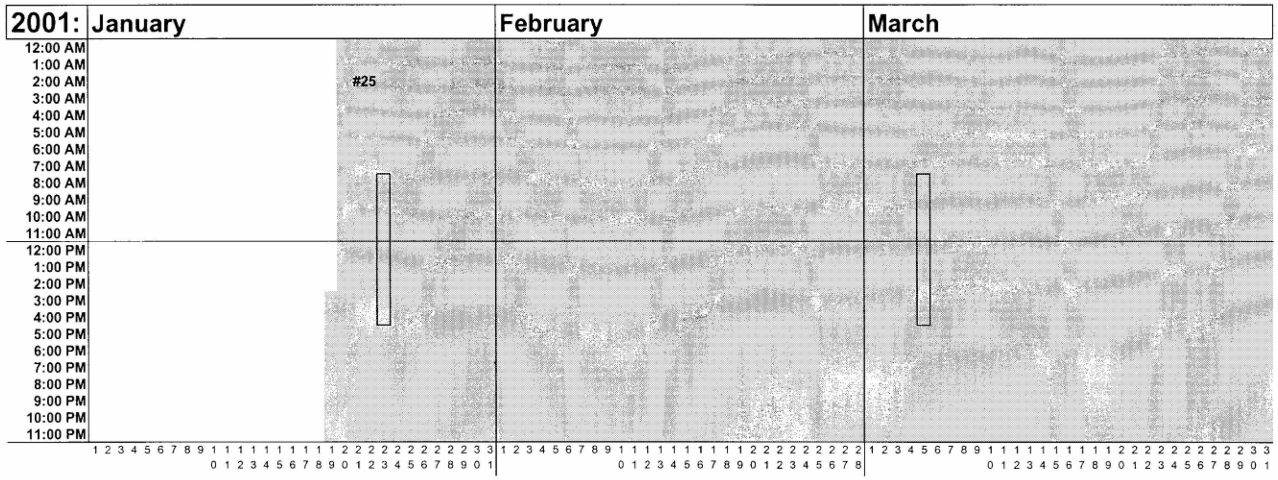
Detailed Fuel Cell Demonstration Site Summary Report
Edwards AFB



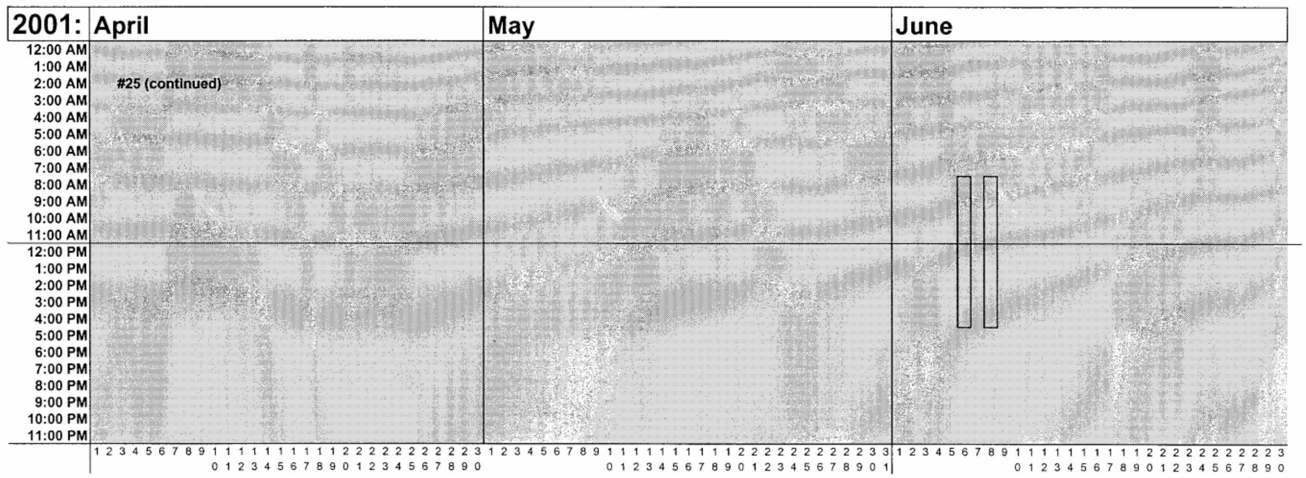
Outage #	Duration	Description
21	510:45	WTS: Shutdown on low tank 450 level.



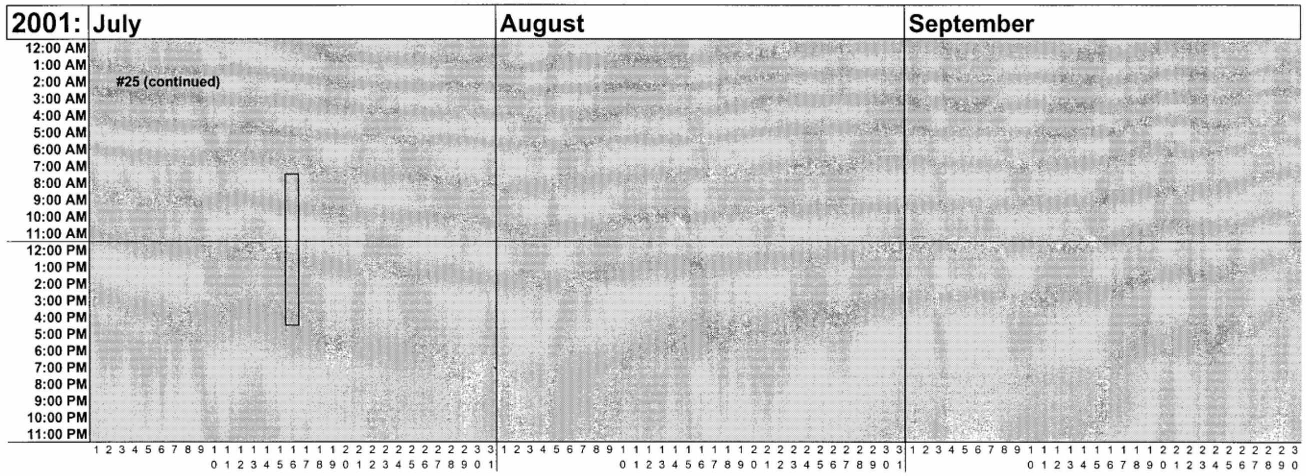
Outage #	Duration	Description
21	510:45	See previous page.
22	28:00	Power plant shutdown when base contractor cut natural gas line.
23	55:55	OTR: Shutdown on controller failure.
24	51:30	NPS: Shutdown due to suspected failure of CV720, solenoid valve.



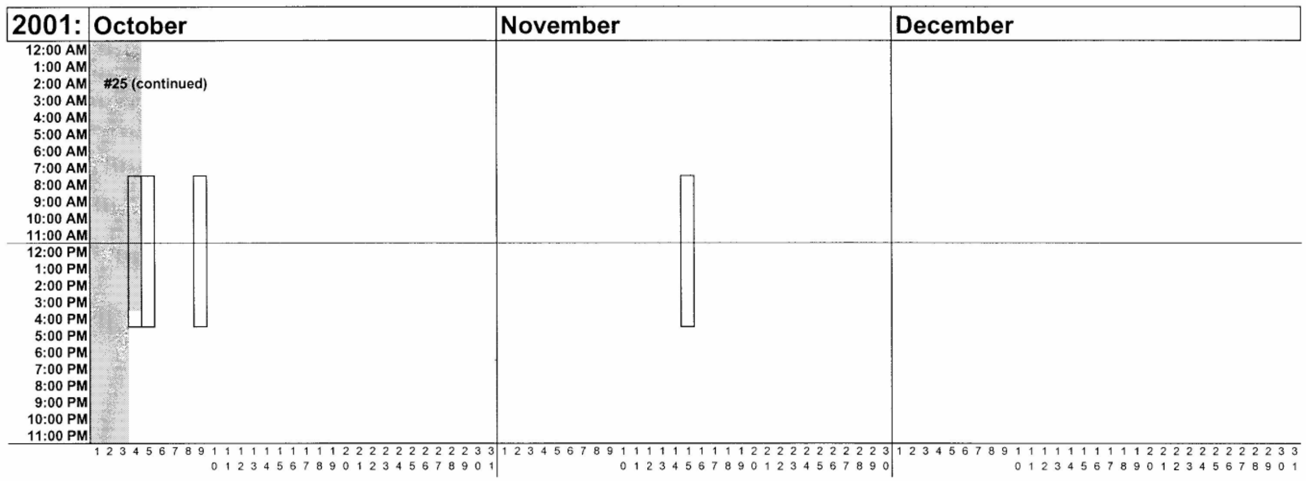
Outage #	Duration	Description
25	6,193:22	Base shut off gas to the power plant and opened the maintenance disconnect switch resulting in a hot shutdown. This will result in a permanent cell stack performance loss.



Outage #	Duration	Description
25	6,193:22	See previous page.

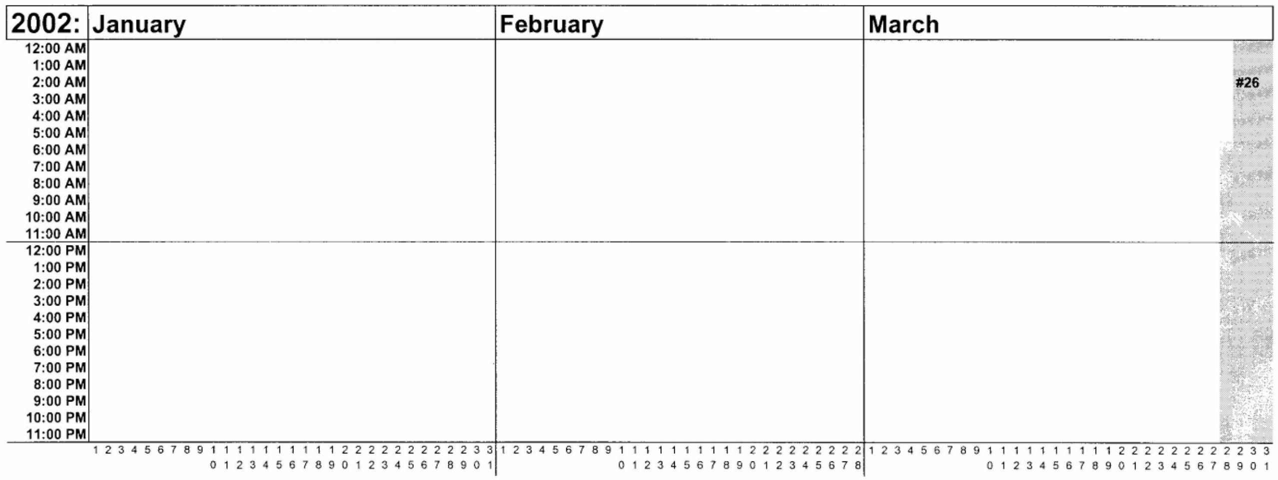


Outage #	Duration	Description
25	6,193:22	See previous page.

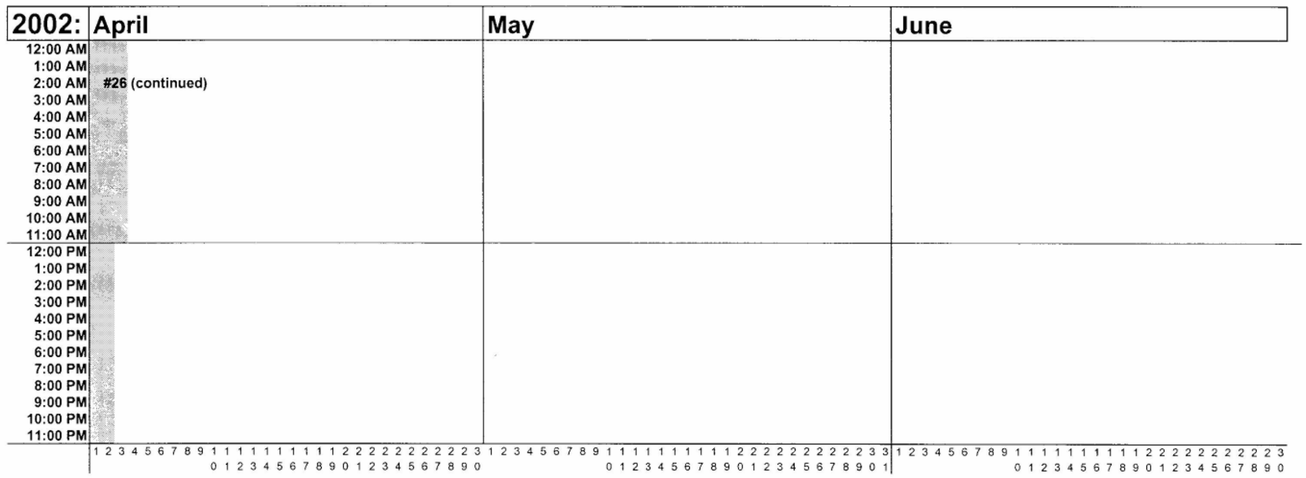


Outage #	Duration	Description
25	6,193:22	See previous page.

Detailed Fuel Cell Demonstration Site Summary Report
Edwards AFB

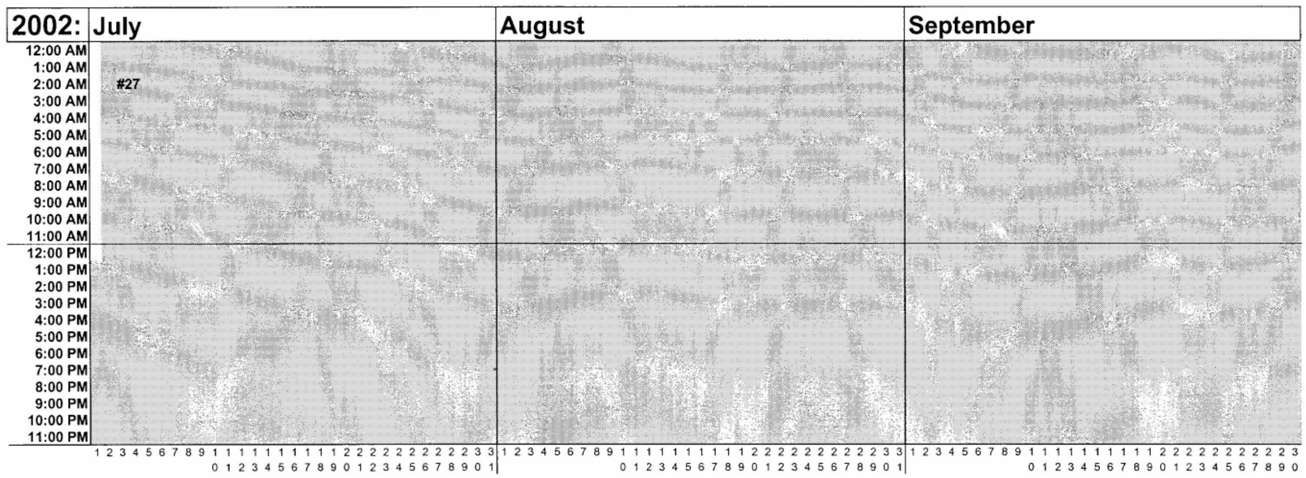


Outage #	Duration	Description
26	150:23	OTR: Shutdown (unknown cause) with controller reboot.



Outage #	Duration	Description
26	150:23	See previous page.

Detailed Fuel Cell Demonstration Site Summary Report
Edwards AFB



Outage #	Duration	Description
27	Final Shutdown	WTS: Low water LT450 shutdown.

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5e. TASK NUMBER

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14. ABSTRACT

Fuel cells are an environmentally clean, quiet, and a highly efficient method for generating electricity and heat from natural gas and other fuels. In fiscal year 1993 (FY93), the Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL) was assigned the mission of managing the DOD Fuel Cell Demonstration Program. Specific tasks included developing turnkey PAFC packages, devising site criteria, screening candidate DOD installation sites based on selection criteria, evaluating viable applications at each candidate site, coordinating fuel cell site designs, installation and acceptance of the PAFC power plants, and performance monitoring and reporting.

CERL selected and evaluated 30 application sites, supervised the design and installation of fuel cells, actively monitored the operation and maintenance of fuel cells, and compiled "lessons learned" for feedback to fuel cell manufacturers. At the conclusion of the demonstration period, each of the demonstration fuel cell sites was given the choice to either have the fuel cell removed or to keep the fuel cell power plant. This report presents a detailed review of a 200 kW fuel cell installed at Edwards Air Force Base (AFB) and operated between July 1997 and July 2002.

15. SUBJECT TERMS
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energy conservation
energy technology alternatives
Edwards AFB, CA

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