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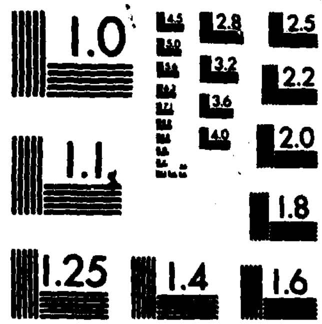

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MEGAWATT FUEL CELL SYSTEMS ANALYSIS

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FEBRUARY 1983

FINAL REPORT FOR THE PERIOD SEPTEMBER 1981 TO JULY 1982

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

Aero Propulsion Laboratory
Air Force Wright Aeronautical Laboratories
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio 45433

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This analysis effort evaluated the operational and economical benefits of utilizing a megawatt fuel cell to provide prime electrical power and thermal energy to an Air Force Logistics Center. Issues motivating this analysis include concerns with the Air Logistics Center's vulnerability to electrical grid and fuel supply disruption, and energy conservation/self sufficiency goals established by the Air Force Logistics Command. This effort determined that megawatt fuel cells can provide an economical alternative for survivable power systems when compared to electrical grid/diesel boiler systems currently used.

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Foreword

This final report is submitted by United Technologies Corporation under Contract F33600-81-C-0582. This effort was sponsored by the Aero Propulsion Laboratory Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio and the Directorate of Operations and Maintenance, Air Force Logistics Command, Wright-Patterson Air Force Base, Ohio. Captain Richard G. Honneywell was the Project Engineer for the Aero Propulsion Laboratory and Major George Kastanos was the Project Manager for the Air Force Logistics Command. Mr. John C. Trocciola, of United Technologies Corporation, was the Principal Investigator.

In order to investigate the feasibility of utilizing a multimegawatt fuel cell at Tinker ALC, a large amount of information relating to the base's energy consumption patterns was required. This information, plus a number of ideas which helped in the study, was supplied by Messrs. Charles Hazelwood, Paul Braid, Dixon Neas, Dale Dalrimple, Robert Koger, Joseph Petrie, Colonel Preston Daniel, Major George Kastanos and Captain Richard Honneywell. The help, encouragement and enthusiasm of these individuals is greatly appreciated.

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Section I
EXECUTIVE SUMMARY

ENERGY VULNERABILITY

Many military installations in the United States have critical mission requirements which necessitate the availability of uninterruptible electrical power. There is a growing concern for the ability of the energy supply system in the United States to provide this needed energy during national emergencies. This national concern focuses on several areas:

(1) Grid-supplied electric power is vulnerable to war, sabotage, accidents, weather and acts of nature. In addition, electromagnetic pulse (EMP) is an additional concern for systems that rely on the electrical grid.

(2) The reliance of the system on imported fuels leads to vulnerability to an energy supply cutoff such as was experienced during the 1974 oil embargo.

(3) The fuel supply system in this country is highly centralized, relying on pipelines and transportation systems for distribution. These distribution systems are vulnerable to interruptions similar to those that can affect the grid.

These issues are discussed more fully in the Federal Energy Management Agency (FEMA) report entitled "Dispersed Decentralized and Renewable Energy Sources: Alternatives to National Vulnerability and War" (Reference 1). Dispersed energy systems are suggested as offering the best potential for survival and recovery of the energy system. In addition, the FEMA report identifies alternative energy systems such as cogeneration systems and fuel cells as technologies which can reduce dependency on imported fuels.

In response to these concerns, the Air Force Logistics Command has established a goal of achieving energy self-sufficiency at its Maintenance Centers by the year 2000. Energy self-sufficiency would enable the Logistics Centers to continue critical maintenance operations after disruption of the normal energy supply mechanisms. In addition to the goal of energy self-sufficiency, the Air Force has energy conservation goals which provide guidelines for reduction in facility energy consumption.

The Air Force Systems Command, in response to these operational requirements, has identified phosphoric acid fuel cell technology as a potentially superior technology to satisfy the requirement for achieving energy self sufficiency while assisting the Air Force to meet its conservation goals.

FUEL CELLS ARE POTENTIAL SOLUTIONS TO ENERGY VULNERABILITY

Fuel cell powerplants have inherent characteristics which can help decrease the vulnerability of the system to energy supply interruption. These characteristics include: the ability to be dispersed and sited in local secure areas, inherent high efficiencies which can reduce dependency on imported hydrocarbon fuels, and the ability to operate independently of the electrical grid which can decrease vulnerability to grid failure because of accidents, sabotage, war or electromagnetic pulse (EMP). In addition, fuel cells are capable of operation on indigenous fuels such as natural gas, biomass or coal-derived products, which also reduces fuel import dependency.

Fuel cell powerplants are not commercial products today. However, United Technologies will be conducting extensive application testing of pre-commercial fuel cell powerplants in the user environment. Over 50 dispersed 40-kilowatt powerplants will be field tested beginning in 1982 in programs sponsored by the Department of Energy (DOE), the Gas Research Institute (GRI) and the Department of Defense (DOD). These powerplants will supply electrical energy to a facility, as well as supply necessary thermal energy which will increase the overall efficiency of the powerplant. Four of these powerplants will be tested by DOD at various Air Force and Army facilities.

Dispersed fuel cell powerplants supplying megawatts of power have also been built. A 1-megawatt pilot plant was successfully tested in late 1976 and demonstrated operational features necessary for dispersed commercial operation. The high efficiency, rapid load response, fuel flexibility and clean emissions characteristics of fuel cells led to the development of two 4.5-MW fuel cell demonstrators which are being installed at two electric utility sites. One unit is being installed by Consolidated Edison Company in New York City. The New York program is jointly funded by DOE, the Electric Power Research Institute (EPRI), United Technologies, Con Ed and other utilities. A second 4.5-MW powerplant was purchased by Tokyo Electric Power Company and is being placed into operation in Goi, Japan.

STUDY RESULTS

This study assessed the feasibility and potential benefits of utilizing megawatt fuel cells located on the base, to provide critical electrical needs and to supplement the thermal requirements of an Air Logistics Center (ALC). The fuel cell option was compared to the option of purchasing electricity from the electrical grid with and without government owned diesel backup. The study focused on the requirements of the Tinker Air Logistics Center, located in Oklahoma City, Oklahoma.

The fuel cell powerplant selected for this application was the FCG-1, whose nominal characteristics are described in "FCG-1 Powerplant Preliminary Specification", prepared for the Electric Power Research Institute, July 1981. The power plant is rated at 11 MW of electrical power and can produce useful thermal energy. The operating approach chosen was to run the fuel cell, sited at the ALC, as the primary power source for the critical electrical needs and to utilize the powerplant's thermal energy in the maintenance operations. The electrical grid would provide power for the less critical needs plus backup power for the fuel cell. The FCG-1 would supply approximately 26% of the peak power requirements and provide supplemental thermal energy for use in maintenance operations.

Depending upon the location of the fuel cell power plant and the degree of thermal integration, up to 100% of its available thermal energy could be utilized. This would result in an overall fuel utilization in excess of 80%.

Since the fuel cell provides prime power to the ALC's critical facilities with the grid as a backup, startup problems which can be experienced with emergency generators are eliminated. In the event of the shutdown of either the grid or the fuel cell, a power system which can supply the base is already in an operating mode.

This study indicates that dispersed fuel cells, operating as described, can increase the energy self-sufficiency of the ALC for the following reasons:

(1) By siting the fuel cell on the base, the center's critical electrical needs are met by a power source that is secure.

(2) In the event of electrical grid loss, the critical power source (the fuel cell) is operating. In an alternative case of the electrical grid plus diesel backup, the diesel generators must be started after a grid loss. The diesel starting characteristics must be considered in assessing the ALC's survivability.

(3) By recovering thermal energy from the fuel cell for base maintenance uses, the total fuel storage requirements for an energy supply interruption are reduced. It is estimated that 12 to 19% less fuel storage would be required with the fuel cell than with diesel emergency generators.

(4) Utilizing a fuel cell to provide power to the critical needs can reduce the vulnerability to the effects on the grid of sabotage, accidents and EMP.

The high fuel utilization achieved with the fuel cell promotes fossil energy conservation. Using criteria specified in the Air Force Facility Energy Plan Vol. II, the conservation measures already instituted at Tinker reduce the specific energy consumption in fiscal year 1981 by 5.7% relative to fiscal year 1975. If one 11-MW fuel cell were installed, the energy consumption would be 16 to 20% less than FY75. With two 11-MW power plants, the energy consumption would be 26 to 35% less than base year consumption. The installation and operation of fuel cell power plants could significantly contribute to an Air Force goal of a 30% reduction in the energy consumption of building operations by fiscal year 1995.

Cost projections have been made for the reference FCG-1 powerplant. The installed cost is a function of production level, degree of technology development, investment in manufacturing facilities and other factors. The range of installed costs of FCG-1 powerplants is projected to be on the order of 800 to 1500 $/kW. Early commercial units will be higher in cost and units modified to military standards could cost more than commercial units.

An economic measurement recommended in the Air Force Facility Energy Plan, Volume II for calculating the merits of an investment in energy conservation equipment is the yearly energy savings divided by the installed cost of the equipment (E/C ratio). Using criteria specified in the plan, it is estimated that fuel cells would have E/C ratios between 34 and 100 for the projected cost range. This ratio would be higher if the fuel cell were compared to the grid-plus-diesel case and the fuel cell cost were reduced by the "avoided" cost of the diesel. The Energy Plan also specifies minimum and average values of E/C. The values specified for FY '84, minimum 17 and average 30, could be satisfied for fuel cell installed costs up to $3250 to $3750/kW and $1750 to $2500/kW respectively.

Life cycle cost analysis indicates that fuel cell powerplants offer the potential for reduced costs when compared to either the grid or to the grid plus diesel backup. For the example of a fuel cell installed cost of $1500/kW and a diesel installed cost of $1000/kW, life cycle costs savings in the range of 9 to 20 million dollars are possible with the fuel cell. The life cycle cost comparisons for a range of alternatives are shown in Figure 1-1. Fuel cells have lower life cycle costs, compared to the grid plus diesel, for installed costs up to 1750 to $3500/kW. Similarly, the fuel cell offers life cycle cost savings, compared to the grid alone, at installed costs up to $1050 to $2050/kW.

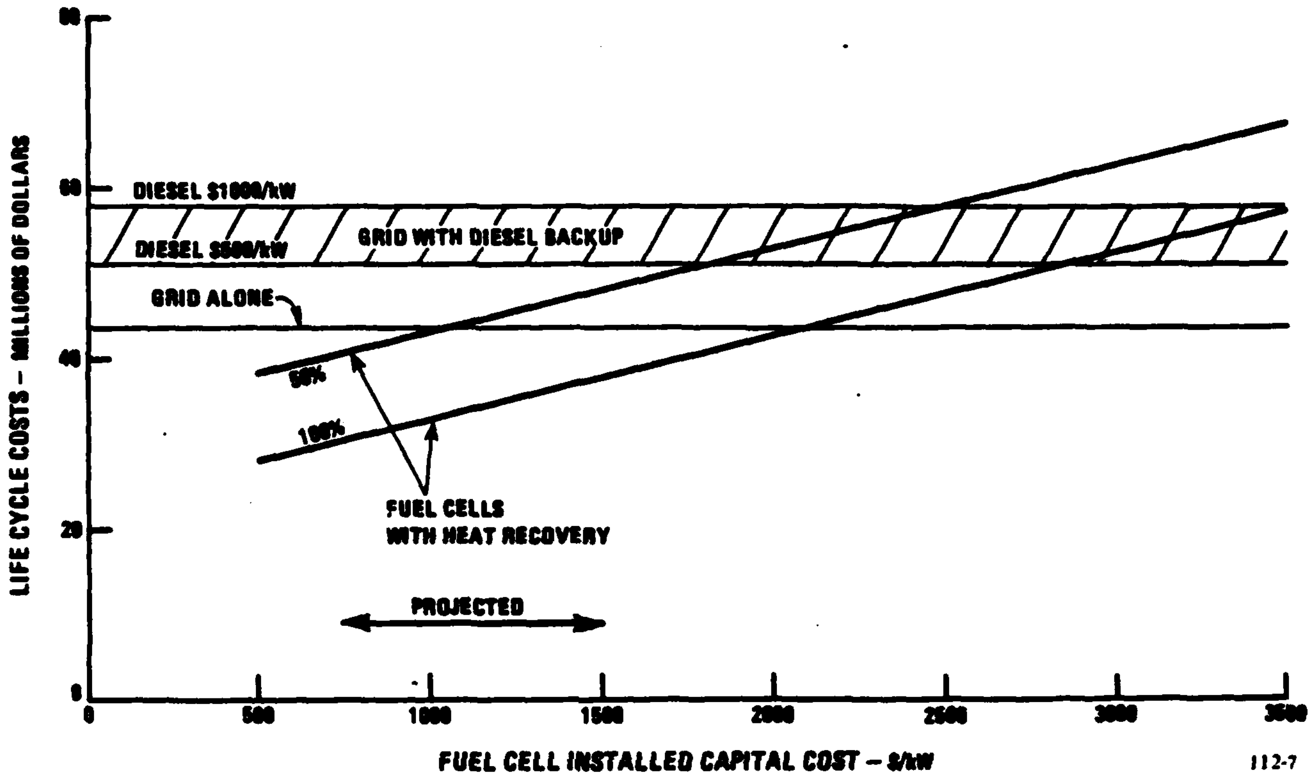

Figure 1-1. Life Cycle Costs of Providing 11 MW's of Electrical Power to Tinker ALC

To determine the effect of energy costs on life cycle costs and to extend the study to other facilities, sensitivity analyses were also conducted. Fuel cell discounted benefit-to-cost ratios were estimated as a function of the cost of electricity and natural gas. In calculating the benefit-to-cost ratio, only direct economic benefits were estimated. Since energy self-sufficiency can be a tactical/strategic issue, its economic benefits are not easily measured and it was not included in the economic benefits. The analysis of benefits to costs is based upon the following assumptions:

75% utilization of fuel cell heat
$1000/kW diesel installed cost
$1500/kW nominal fuel cell installed cost

The impact of energy costs on discounted benefit-to-cost is shown in Figure 1-2. For locations where the combination of gas and electricity costs are in the shaded region, the fuel cell would have lower life cycle costs than the grid plus diesel. The current energy costs for various ALC's as well as two energy cost projections are shown in Figure 1-2. The fuel cell powerplants offer life cycle cost savings to the Air Force at several locations, both at today's energy costs as well as at projected costs.

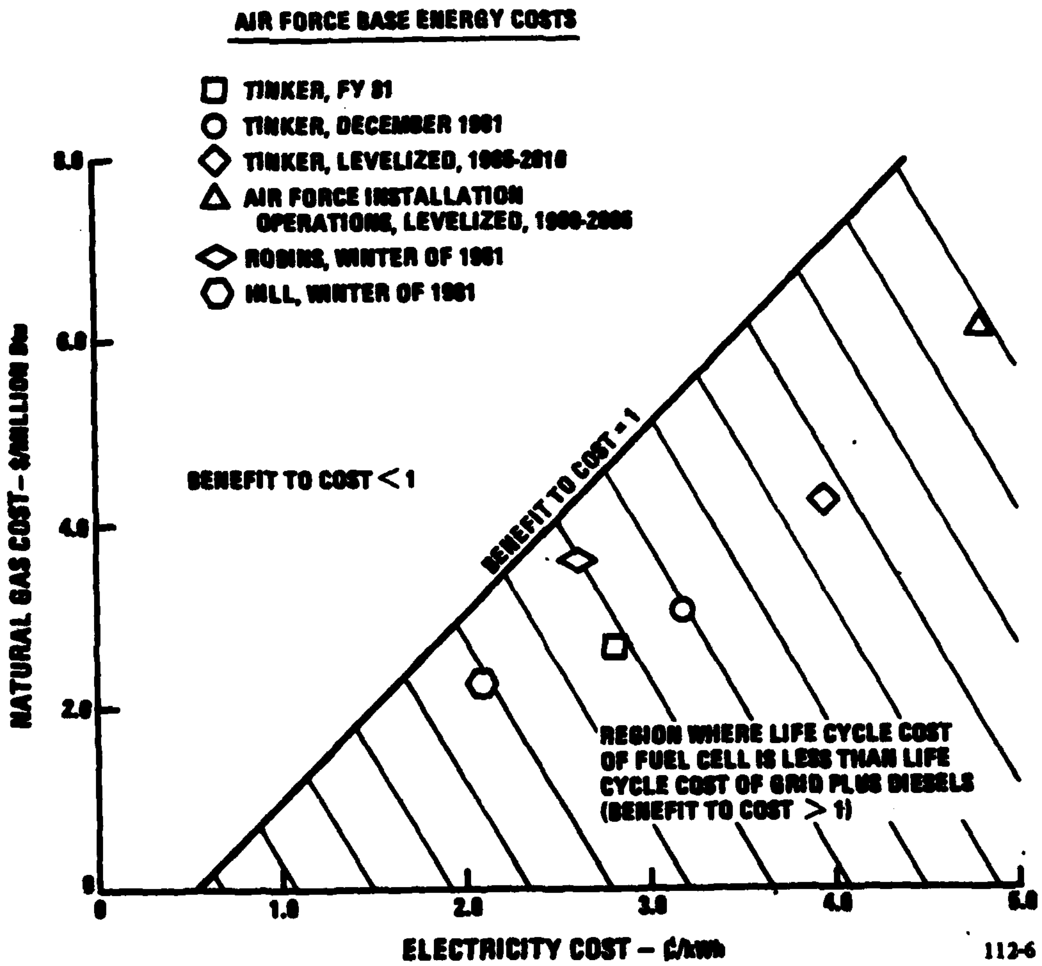

Figure 1-2. Effect of Energy Costs on Discounted Benefit to Cost Ratio

In summary, fuel cells can benefit the Air Force by increasing the energy self-sufficiency of their bases, while reducing specific energy consumption and providing lower life cycle costs than the alternatives considered. As a result of this study, areas for further investigation have been recommended.

SECTION II
INTRODUCTION

Many military installations in the United States have critical mission requirements which necessitate the availability of uninterruptible electrical power. There is a growing concern for the ability of the energy supply system in the United States to provide this needed energy during national emergencies. This national concern focuses on several areas:

(1) Grid supplied electrical power is vulnerable to war, sabotage, accidents, weather and acts of nature. In addition, electromagnetic pulse (EMP) is an additional concern for systems that rely on the electrical grid.

(2) The reliance of the system on imported fuels leads to vulnerability to an energy supply cutoff such as was experienced during the 1974 oil embargo.

(3) The fuel supply system in this country is highly centralized, relying on pipelines and transportation systems for distribution. These distribution systems are vulnerable to interruptions similar to those that can affect the grid.

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In response to these concerns, the Air Force Logistics Command has established a goal of achieving energy self-sufficiency at its Maintenance Centers by the year 2000. Energy self-sufficiency would enable the Logistics Centers to continue critical maintenance operations after disruption of the normal energy supply mechanisms. In addition to the goal of energy self-sufficiency, the Air Force has energy conservation goals which provide guidelines for reduction in facility energy consumption.

The Air Force Systems Command, in response to these operational requirements, has identified phosphoric acid fuel cell technology as a potentially superior technology to satisfy the requirement for achieving energy self sufficiency while assisting the Air Force to meet its conservation goals.

In a fuel cell powerplant, a wide range of existing or planned fuels can be are converted to electricity. The fuel cell process (Figure 2-1) consists of:

- o a chemical transformation of the fuel to hydrogen;
- o an electrochemical conversion of hydrogen and oxygen (from the air) to dc power; and,
- o a power-conditioning step where the dc power is converted to ac power.

Heat generated by the conversion process must be removed from the system. This heat can be rejected to air or water or recovered for cogeneration applications. The possible fuels include light petroleum distillates, natural gas, coal-derived gases and liquids, and gases produced from biomass.

The electrochemical conversion is static and essentially independent of scale. As a result, fuel cell powerplants have several unique features. The fuel cell has a high efficiency over a wide range of power ratings. The emission levels are lower than combustion-based conversion processes. Measured data from experimental powerplants are significantly lower than existing standards (Figure 2-2).

External water is not required for fuel processing or powerplant cooling; only fuel and air need to be available at the powerplant site. This lack of reliance on external water supply is valuable in areas where water is scarce or expensive. Power conditioning incorporating solid state technology is efficient and provides rapid response to changes in load and inherent reactive load control. Each of the major subsystems in the generation process is modular and adaptable to factory assembly. As a result, the powerplant can be designed to minimize on-site construction and reduce lead time.

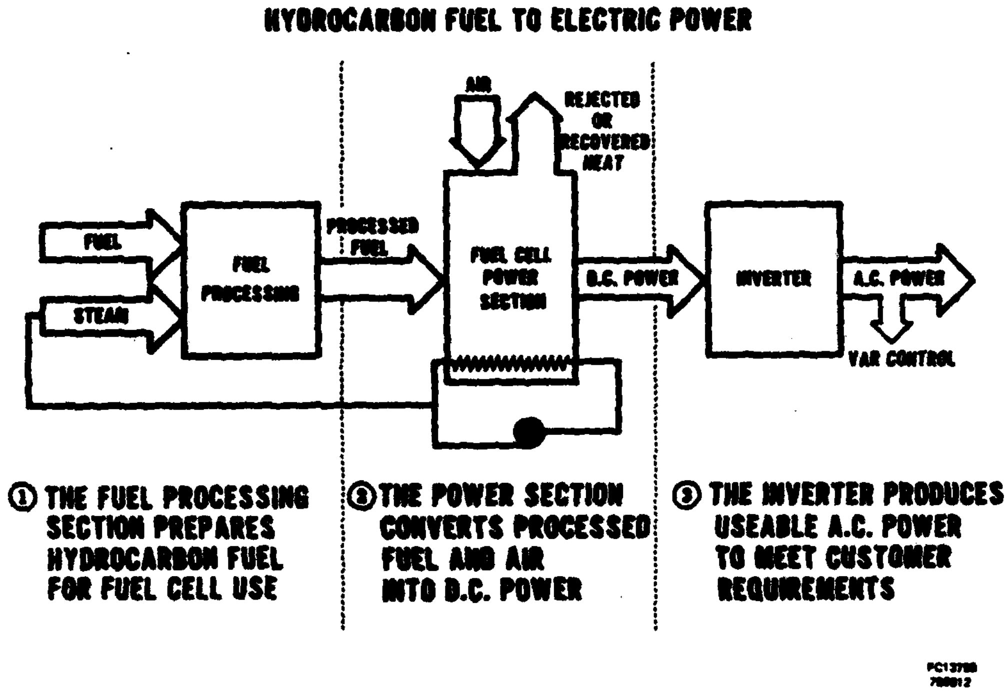

Figure 2-1. The Fuel Cell Powerplant

POUNDS OF POLLUTANTS PER MILLION BTU HEAT INPUT

	FEDERAL STANDARDS*			
	GAS-FIRED CENTRAL STATION	OIL-FIRED CENTRAL STATION	COAL-FIRED CENTRAL STATION	EXPERIMENTAL FUEL CELLS**
PARTICULATES	0.1	0.1	0.1	0.0000029
NO_x	0.2	0.3	0.7	0.013-0.018
SO_2	NO REQUIREMENT	0.8	1.2	0.000023
SMOKE	20% OPACITY	20% OPACITY	20% OPACITY	NEGLIGIBLE

*FEDERAL STANDARDS EFFECTIVE 8-17-71
**YORK RESEARCH CORP., Y-7300 APRIL 1970

Figure 2-2. Fuel Cell Air Emissions

During the past decade, a number of experimental and development fuel cell powerplant programs contributed to the evolution of the technology.

Both a 40-kW and a 1-MW experimental fuel cell powerplant have been designed, fabricated and tested by United Technologies. The 40-kW unit (Figure 2-3) operates automatically, with provisions incorporated for recovery of thermal energy and water for its own use. The powerplant, fueled by natural gas, has demonstrated total energy efficiency of 80 percent (Figure 2-4). The powerplant has operated for more than 18,000 hours with few major component replacements required.

The 1-MW pilot plant represented a major step in scale-up. This powerplant (Figure 2-5) was successfully tested in late 1976, and demonstrated the critical operational features necessary for dispersed utility applications. These include high efficiency, rapid load response, reactive power generation, fuel flexibility and clean emissions.

At present, there are two 4.5-MW experimental fuel cell demonstration units being installed at electric utility sites by electric utility personnel. The first unit is being installed by Consolidated Edison Company in New York City. The powerplant is jointly funded by DOE, EPRI and UTC. The installation and test is jointly funded by DOE, EPRI, Con Ed and other utilities. The second 4.5-MW powerplant was purchased by the Tokyo Electric Power Company and is being installed in Goi, Japan, Figure 2-6. This powerplant incorporates an improved fuel cell power section and produces 50 rather than 60-Hz power. With the experience gained from the first demonstration unit, the fabrication and installation period has been reduced considerably.

The 40-kW and 1-MW testing has confirmed the potential for dispersed siting in constrained areas. The modular construction and installation requirements necessary for short lead time have been demonstrated. The forthcoming tests on the 4.5-MW units should provide substantiation of operational characteristics. However, the cost issues necessary for commercial operation, including initial capital, installation and maintenance costs, require further technology development.

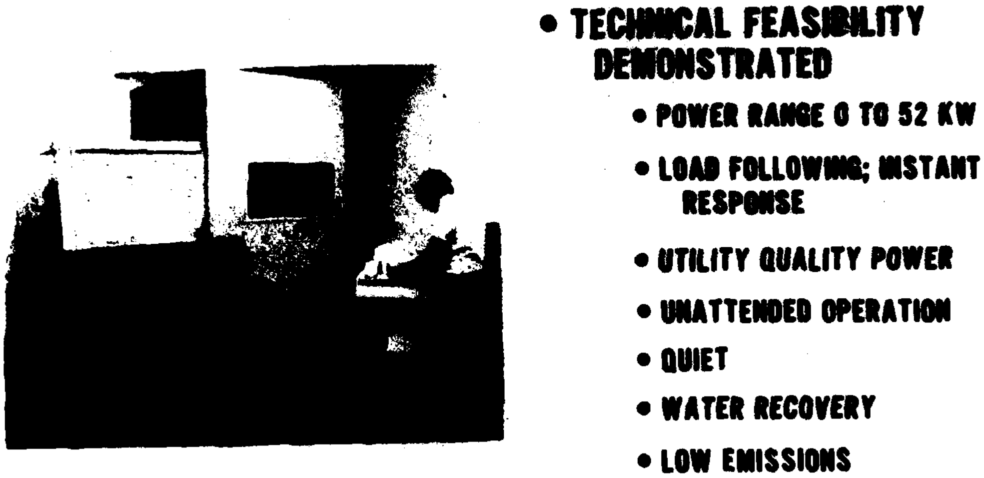

Figure 2-3. The 40-kW Powerplant

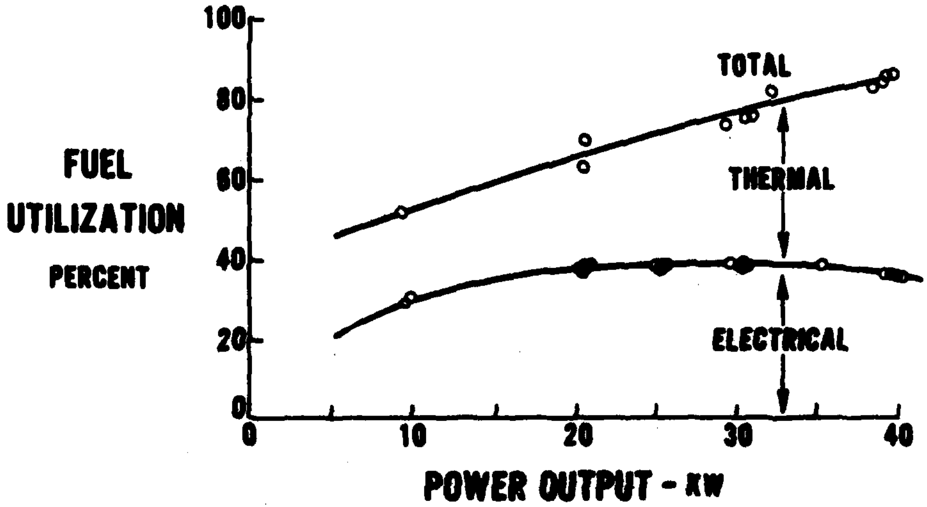

Figure 2-4. The 40-kW Powerplant Performance

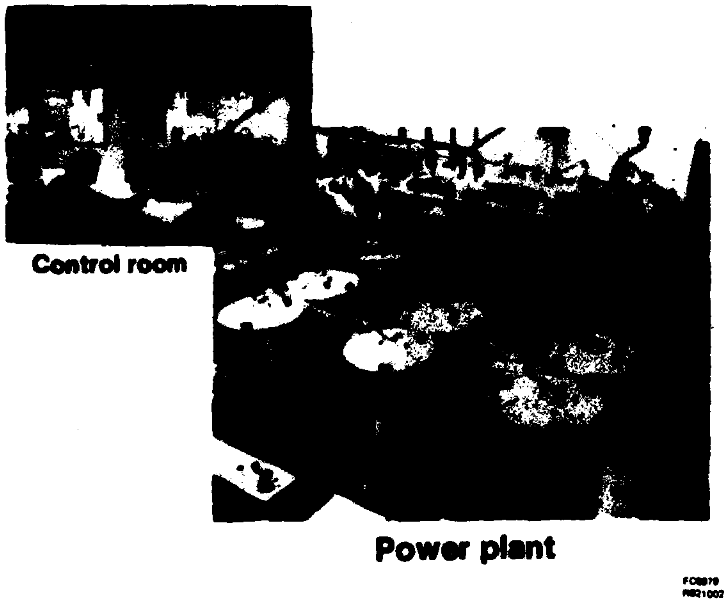

Figure 2-5. One MW Pilot Powerplant

Figure 2-6. Tokyo Electric Powerplant Site'

The Air Force Systems Command, through their own studies, have identified the phosphoric acid fuel cell technology as a superior technology to satisfy the Air Force Logistic Command requirements for improved energy self-sufficiency. The concept entails the fuel cell powerplant, sited on the base in a secure area operating continuously, supplying electrical and thermal energy to the ALC. The powerplant could be sized to provide sufficient power for critical electrical needs with the electrical grid providing backup power for these loads plus power for the other less critical loads. Since the fuel cell operates continuously with the grid as a backup, the necessity to start emergency generators in the event of power loss is eliminated.

The objectives of this contract were to (a) assess the feasibility of utilizing a megawatt-size phosphoric acid fuel cell power system to supply critical electrical and thermal energy requirements of an Air Logistics Center, (b) provide preliminary conceptual designs and performance evaluations for this application, and (c) quantify the potential benefits to the Air Force resulting from the use of dispersed fuel cell powerplants. Tinker Air Force Base was selected to provide a focal point for defining the requirements and establishing the benefits.

In order to achieve these objectives it was necessary to establish the electrical and thermal requirements for the Air Logistics Center at Tinker Air Force Base. This effort was assisted by and coordinated with personnel from Tinker. Based on these requirements, an 11-MW fuel cell powerplant similar to that being studied for electric utility dispersed applications was selected for evaluation. These evaluations included an assessment of energy self-sufficiency, energy consumption reduction and overall life cycle costs. The benefit measures and financial factors used in this study were based upon review of appropriate government documents and discussions with Air Force personnel.

SECTION III
REQUIREMENTS OF TINKER AIR LOGISTICS CENTER

OVERALL REQUIREMENTS

The selection of the fuel cell powerplant configuration and the evaluation of the overall fuel cell impact is dependent upon the specific application requirements. In particular the operational requirements with respect to performance, environmental, logistic, and cost parameters, determine the suitability of the powerplant for the application. The specific requirements for Tinker Air Force Base were determined primarily from a questionnaire completed by Tinker Air Force Base personnel and previously published energy assessments (References 2 and 3). This material was supplemented by data from base boiler "logs", a tour of the ALC and direct communications with Base personnel. The close coordination with Base personnel provided a good mechanism for obtaining current data and constructive suggestions and for ensuring that the key application factors were identified and factored into the analysis.

The application requirements with respect to environmental, logistical, performance, safety, survivability and cost parameters are shown in Tables 3-1, 3-2, and 3-3. The tables list the minimum operational requirements which must be satified to complete the ALC mission. The cost requirements provide the basis for comparing the fuel cell to the other alternatives for providing the ALC operational requirements.

The FY81 thermal and electrical energy requirements consist primarily of grid electricity and natural gas, with a small quantity of fuel oil which is not shown in the tables.

The thermal energy is used primarily for various process heating requirements in the manufacturing buildings, for space heating, and for air conditioning.

Previous studies (Reference 4, 5) have shown that the heat available from the fuel cell powerplant is compatible with these uses. In particular, the fuel cell could provide heat for:

1. Boiler feedwater or furnace air preheat.
2. Building space heating requirements.
3. Moderate temperature manufacturing process use.

The degree to which the available heat is utilized depends upon the temperature level required, and the seasonal variation in thermal use. For this reason information on temperature levels and seasonal variations was developed for the boilers, process heating and space heating requirements. The specific requirements for each of these elements are discussed below.

TABLE 3-1.
AIR LOGISTICS CENTER APPLICATION PERFORMANCE REQUIREMENTS

Parameter	Requirement to Complete ALC Mission
Reliability	must equal diesel-electric generators
Lifetime	25 years minimum
Maintenance	maintenance should be reduced to the level of existing capability
Growth Potential	N/A at present
Startup Time	Less than 1-4 hours if utilized as an off-line emergency back-up
Thermal Energy*	2.14×10^{12} Btu's/yr (FY'81)
Electrical Output*	2.08×10^{8} kW hrs/yr (FY'81) 42 MW peak (calendar '81) 24 MW average (FY'81)

* Total ALC Consumption

TABLE 3-2.
AIR LOGISTICS CENTER APPLICATION
ENVIRONMENTAL/LOGISTICAL REQUIREMENTS

Parameter	Requirements to Complete ALC Mission
Fuel Types(s)	must be able to operate on locally available fuels, natural gas, coal, petroleum derivatives or biomass
Volume/Size	space adjacent to loads is at premium
Weight	not a factor
Environmental	must meet local emission requirements
Safety	design for dispersed siting design consistent w/codes
Survivability	grid connected or isolated operation can be sited in secure areas
EMCS	suitable for computer operation no special requirement on powerplant

TABLE 3-3.
AIR LOGISTICS CENTER APPLICATION COST REQUIREMENTS

Parameter	Requirement to Complete ALC Mission
Acquisition	must pay back during equipment lifetime
Life Cycle	"
Maintenance	to be considered as part of economic analysis
Operation	"

THERMAL REQUIREMENTS

The thermal needs of the Tinker Air Logistics Center are provided by individual boiler plants which are dispersed within the Base. These boiler plants provide heat to three functional areas which contain ALC facilities (Areas A, B and C). Areas B and C are adjacent and are served from a common system. The functional areas and boiler plants are shown in Figure 3-1. The operating characteristics of the individual boilers are as follows:

a. Boiler Plant 3001 operates on a year-round basis, providing steam to the main manufacturing building (3001). This energy is used to provide process heat, space heat and steam for air conditioning.

b. Boiler Plant 2102 supplements 3001 during the heating season. Tinker Civil Engineering indicates that the output of this boiler is used primarily for space heating.

c. Boiler Plant 208 provides service to warehouses and other facilities in Area A. Tinker Civil Engineering indicates that this boiler is primarily used for space heating and will be shut down during the cooling season.

In order to determine seasonal variations, Tinker Civil Engineering supplied data for twelve months for Boiler Plant 3001 and for one heating season month for Boiler Plants 208 and 2102. The data supplied, in the form of boiler "logs", include average monthly steam output, condensate returned temperature, feedwater temperature, amount of makeup water required, flue gas temperature and % O_2 in the flue. Typical boiler logs used in this study are shown in the Appendix. A summary of the data taken from the supplied boiler logs is shown in Table 3-4. Using these data, the energy required for furnace air preheat, feedwater heating and space heating were estimated.

In addition to providing data on the overall thermal requirements, the questionnaire returned by Tinker personnel provided data on the thermal requirements of specific manufacturing processes within the ALC. The data provided are shown in Table 3-5. The average hourly thermal consumption and temperatures of these processes are shown in Figure 3-2. These characteristics were utilized to determine which processes could be serviced by the fuel cell thermal output.

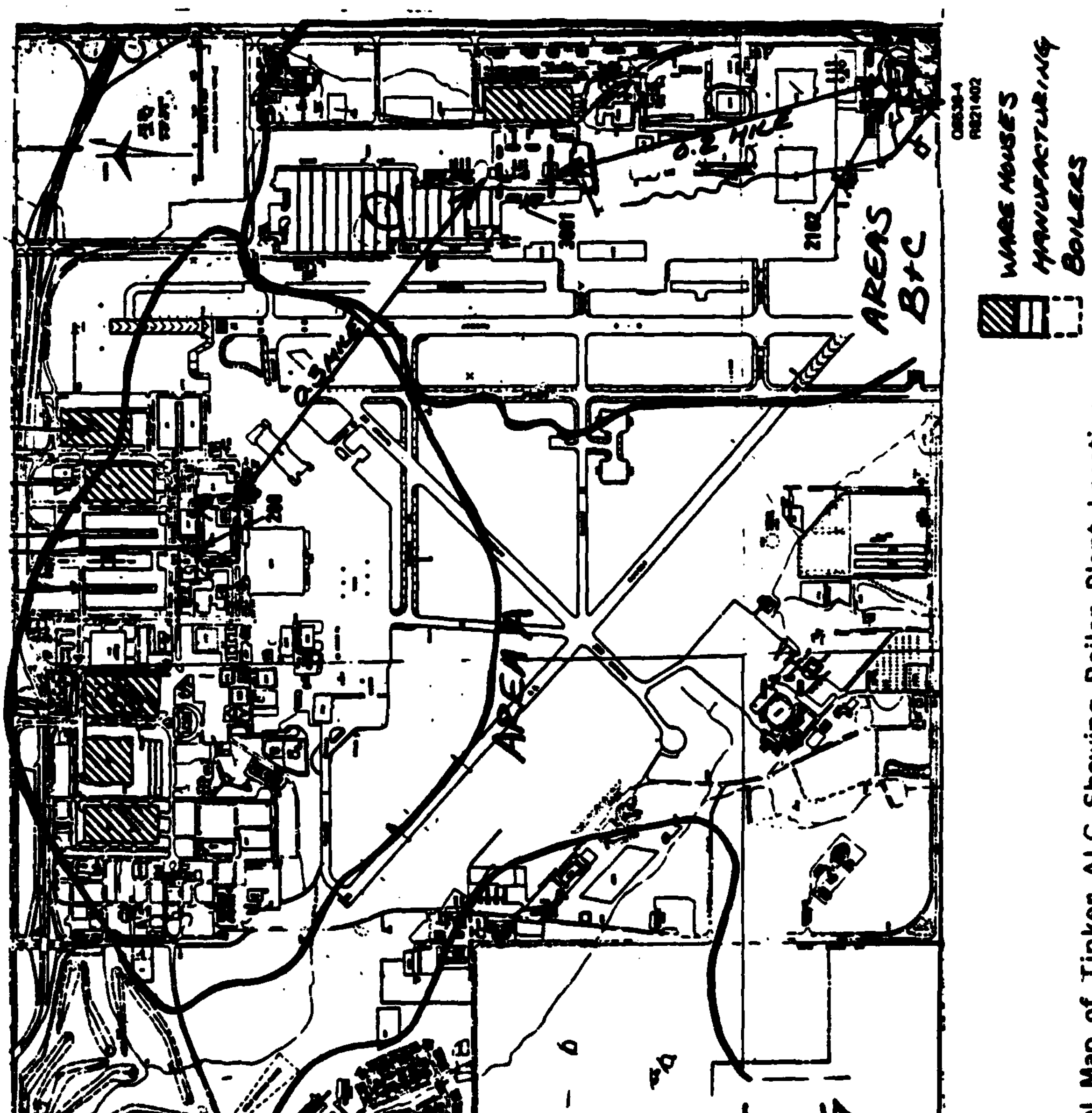

Figure 3-1. Partial Map of Tinker ALC Showing Boiler Plant Locations

TABLE 3-4.
TINKER ALC BOILER LOG DATA SUMMARY

Boiler Plant	Average Daily Output	Condensate Returned Temp	Feedwater Temp	% Makeup Water	Location
3001	87,000-154,000 Lbs Steam/Hour (1981)	135-145°F	240°F	26-54%	B/C
2102	19,000 (Feb. 1981)	161	168	17	B/C
208	98,960 (Dec. 1980)	196	220	11	A

Space heating is a thermal requirement which could be provided by the fuel cell. Since this usage is not directly measured, it had to be estimated from the data provided. The personnel from Tinker Civil Engineering and OC-ALC/XRS indicated that the thermal outputs of Boiler Plants 208 and 2102 are used primarily for space heating during the months of October through April. The thermal output of each of these boilers was provided by Civil Engineering for one month, December and February, respectively.

The space heating requirement provided by Boiler Plants 208 and 2102 for these months was then estimated by reducing the total output to account for the process heating duties of each boiler. Process heating duties included aircraft cleaning and aircraft paint (Boiler Plant 2102) and accessory cleaning and degreasing, parachute drying and fiberglass ovens (Boiler Plant 208). The space heating duties for other heating season months were estimated on the basis of monthly degree days. This analysis results in a conservative estimate of the space heating in that a 25% reduction in degree days was assumed to result in a 25% reduction in building space heating requirements. The actual reduction in space heating would be less due to line steam and thermal losses which would not be reduced directly with degree days. The estimated monthly space heating provided by Boiler Plants 2102 and 208 is shown in Figure 3-3.

TABLE 3-5
OC-ALC/MA THERMAL LOADS

Shop	Bldg.	Type Load	Energy Source	Load MBtu/hr	Temp Required	Time	Other
1 Chem. Clean	3001	tank w/solutions	steam	P-9 A-8	3-130°F 2-140°F	15 hr/dy 7 dy/wk	4-150°F 2-250°F 27-185°F
2 Plating	3001	tank w/solution	steam	A-4.92	2-300°F 3-250°F	24 hr/dy 7dy/wk	8-220°F 74-120°F 27-180°F
3 Manifold Clean	3001	elect. oven tank w/solution	elect. steam	P-0.561 A-0.293	180°F	16 hr/dy 5 dy/wk	
4 Tank & Cooler	3001	tank w/solution	steam	P-0.485 A-0.207	1-250°F 2-150°F	8 hr/dy	
5 Bearing Shop	3001	tank w/solution	steam	P-0.242 A-0.117	135-237°F	8 hr/dy 5 dy/wk	4 tanks
6 Paint Shop	3001	ovens	elect. steam	A-80kW	650°F 180°F	8 hr/dy 8 hr/dy	8 elect. 1 steam 10'x6'x6'
7 In-process Clean	3001	ovens tank w/solution	steam		150°F 180°F	8 hr/dy 8 hr/dy	6'x6'x30' 6'x6'x8' 7 ea.
8 Governor Accy's	3001	tank w/solution	steam		2-120°F 1-200°F		3 tanks
9 Sheet Metal	3001	degreaser	steam	P-0.27 A-0.162	250°F	8 hr/dy 5 dy/wk	
10 Accy's Clean	210	tank w/solution	steam	P-0.102 A-0.1	180°F	8 hr/dy 5 dy/wk	6 tanks
11 Accy's Degreaser	210	tank w/solution	steam	P-0.24 A-0.2	260°F	8 hr/dy 5 dy/wk	
12 Accy's Test	210	hot air	nat. gas	A-7.89	1000°F	continuous	
13 Parachute	229	hot air	steam	P-0.35 A-0.3	120°F	3 hr/dy 5 dy/wk	drying tower
14 Fiberglass	230	ovens	4 elect. 2 steam	P-0.15 P-0.15	225-400°F 140-220°F	8 hr/dy 5 dy/wk	A-0.14 A-0.1
15 Aircraft Clean	2122	hot water	steam	P-.26 A-.094	140°F	24 hr/dy 5 dy/wk	
16 CSD	2210	absorption chiller	steam				from Hazelwood
17 Aircraft Paint	2280	hot water	steam	P-0.35 A-0.083	140°F		24 hr/dy 5 dy/wk

P = Peak Use
A = Avg. Use
M = Millions

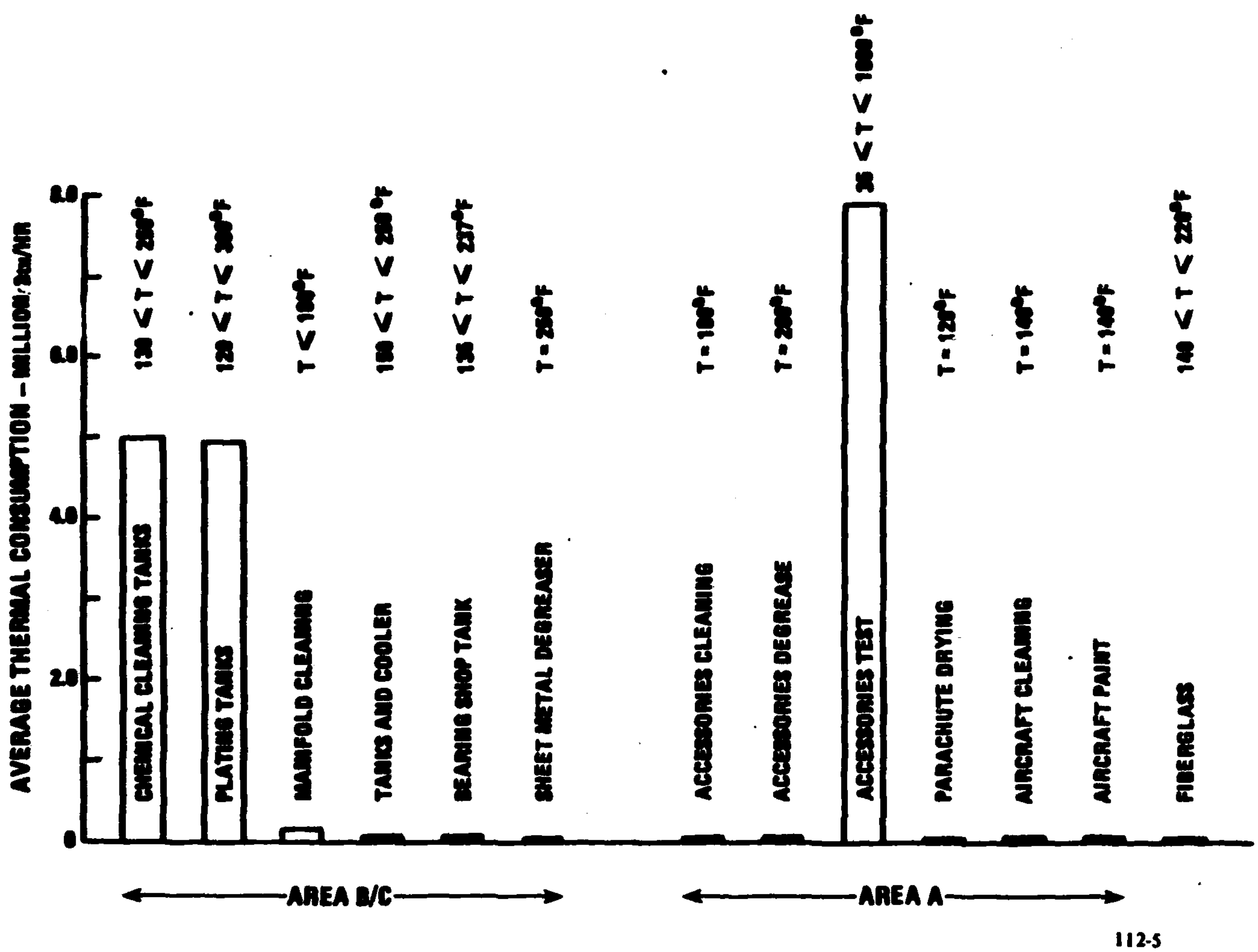

Figure 3-2. Average Thermal Consumptions of Identified Processes at Tinker ALC

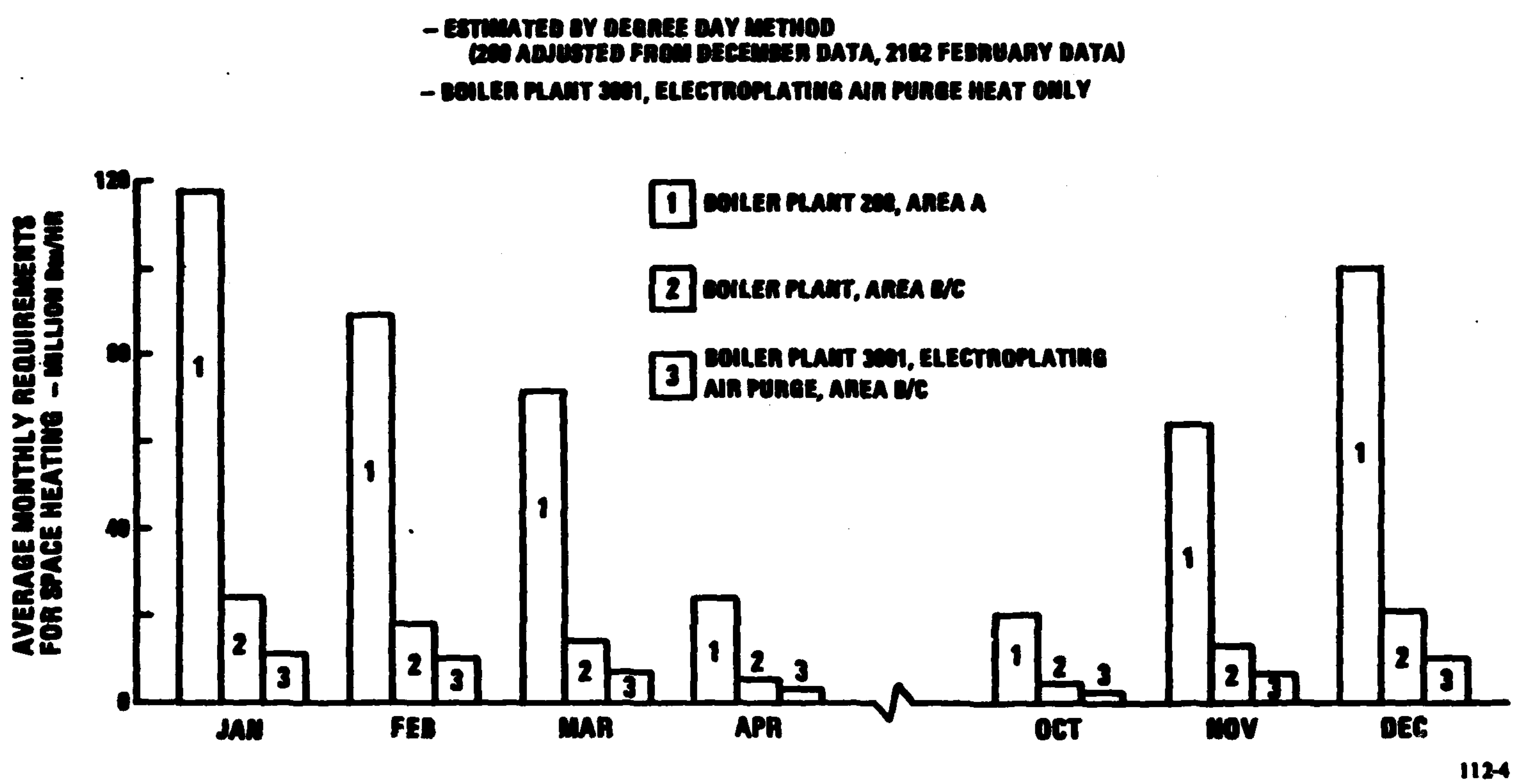

Figure 3-3. Estimate of Tinker ALC Space Heating Requirements by Boiler Location

The total space heating load provided by Boiler Plant 3001 was not determined. However, a portion of this space heat was estimated by the method suggested in Reference 2. This report indicated that a space heating load is associated with the continuous flow of purge air through the electroplating area. This air flow, approximately 343,000 ft^3 per minute, removes heat from Building 3001 during the heating season and represents a space heating load. In estimating this load, it was assumed that the purge air was heated from ambient temperature to the comfort temperature of 65°F. This estimated space heat is also shown in Figure 3-3.

THERMAL REQUIREMENTS COMPATIBLE WITH FUEL CELL

While the overall thermal loads at Tinker are large, the degree to which they can be satisfied depends upon temperature levels, seasonal variations, the location of the fuel cell relative to the loads and the size of the fuel cell installation.

In order to assess the compatibility of the fuel cell with these thermal loads, each of the individual loads was examined in greater detail. Based on the layout of the Air Logistic Center, Area A and Areas B/C were considered individually since fuel cells could be sited to serve each separate area or could be located to serve the combined areas.

The thermal compatibility analysis considered seasonal variation in the thermal requirements of the ALC by utilizing boiler plant output for a month typical of each season:

Winter	January
Spring	April
Summer	July
Fall	October

The thermal output of the boiler plant for any month was the average daily value for that month, as taken from the boiler logs.

In matching the thermal needs to fuel cell thermal output, only that portion with temperatures below the source temperature, i.e., fuel cell stream temperature, was considered. In general, present phosphoric acid fuel cells can provide thermal energy at temperature levels up to approximately 265°F. In addition, if desired some saturated steam can provided up to 372°F, when natural gas is the fuel. Each of the individual thermal uses were examined and then composite thermal requirements, compatible with the fuel cell heat, were developed for each area. These composite requirements account for seasonal variations and are adjusted to avoid double counting of thermal requirements.

Based upon the fuel cell temperature level, it was determined that fuel cell heat is of sufficient quality to provide building space heating requirements. It is estimated that the monthly space heating requirements range from approximately 20 million to 118 million Btu per hour for area A and 6 million to 35 million for the partial requirements of area B/C.

The temperature requirements for the individual manufacturing processes range from 35°F to 1000°F. Since the fuel cell heat has a maximum temperature of approximately 265°F, only that portion of the ALC's thermal requirements with maximum temperature below 240°F were considered to be compatible with the fuel cell available heat. The process heating requirements within this range are approximately 10 million Btu per hour in Area B/C and approximately 2 million Btu per hour in Area A. These requirements do not include other potential uses for fuel cell heat, for which data was not available (i.e., paint shop oven, in-process cleaning and governor accessories - items 6-8, Table 3-5).

In the boilers in Building 3001, condensate is returned to the boiler system, mixed with makeup water and then heated to 240°F in a feedwater heater. The feedwater heating requirements are a function of the condensate return temperature, the percentage makeup water, and the total feedwater flow rate. Since both the total quantity of water and the amount of makeup water varies with season, the amount of feedwater heating required has a seasonal variation. This seasonal variation was utilized in estimating the amount of heat that can be provided by the fuel cell. The boilers in Building 3001 provide both space heat and individual manufacturing processes for which fuel cell heat may be substituted. Therefore, in estimating the feedwater heating requirements, the output of these boilers was reduced to reflect those requirements which would be satisfied directly by the fuel cell. It was determined that the fuel cell heat is of sufficient quality to provide feedwater heating. The boiler feed water requirement heat is estimated to be beween approximately 8 million and 16 million Btu per hour depending on the season.

Since Boiler Plants 208 and 2102 are primarily used for space heat and since fuel cell heat was determined to be capable of direct substitution for this duty, fuel cell heating of the feedwater was not considered.

For similar reasons to those discussed above, fuel/air preheat was only considered in Boiler Plant 3001. This furnace operates at 20% excess air, with a flue gas temperature of approximately 325°F. The difference between the furnace air ambient temperature and the flue gas temperature is a partial measure of the furnace's inefficiency. Using fuel cell heat to raise the temperature of the air/fuel from ambient to 240°F will result in a lowering of the amount of fuel required by the furnace. Seasonal variation of ambient temperature and flue gas composition, as given in the boiler logs, and boiler output were used to determine the amount of fuel cell heat that can be provided. As was done in the feedwater heating case, the output of Boiler Plant 3001 was lowered by the amount of process or space heat provided by the fuel cell. Analyses indicate the fuel cell output is of sufficient quality to preheat air and fuel from ambient temperature to 240°F. The amount of heat for this duty varies between 3 and 5 million Btu per hour depending on season.

As noted above, limited steam at 372°F is also available from the natural gas fuel cell powerplant. From discussions with Tinker Civil Engineering, it was determined that this steam would be useful for a number of applications, such as air conditioning, space heating, or providing additional feedwater or furnace air heating.

Table 3-6 lists the ALC thermal requirements which are compatible with the fuel cell powerplant, identifies the location and indicates the nature of the load. Figure 3-4 summarizes the composite thermal needs which could be satisfied by the fuel cell powerplant with thermal energy at a maximum temperature of approximately 265°F. The requirements are broken out by area and season. The requirements for Area B/C vary from approximately 33 million Btu per hour to 64 million Btu per hour with only moderate variation from season to season. The average requirements in Area A are highly variable, ranging from a low of 7 million Btu per hour in the summer to 120 million Btu per hour in the winter. Using these requirements provided the basis for assessing the feasibility of utilizing the thermal energy from a MW sized fuel cell powerplant.

TABLE 3-6
IDENTIFIED USES FOR FUEL CELL HEAT

Major Category	Specific Use	Location	ALC	Sink Temp Range Initial	Sink Temp Range Final
Boiler/Plant	Feed Water Heat	3001	√	Seasonal	~240°F
Boiler/Plant	Fuel/Air Heat	3001	√	Seasonal	~240°F
Process	Plating Tanks	3001	√	Less than 225°F	
Process	Accy's Test	210	√	35°F	240°F
Process	Chemical Cleaning	3001	√	Less than 190°F	
Process	Misc.	Various in A, B/C	√	Less than 240°F	
Space Heat	Plating Air Purge	3001*	√	Seasonal	~65°F
Space Heat	Space Heat	208/2102**	Partial	Seasonal	~65°F
Direct Steam Input to System	Various	3001/208/2102	√	---	~ 350°F

* Total space heat provided by boilers in Building 3001 not known

** Areas served by these boiler plants

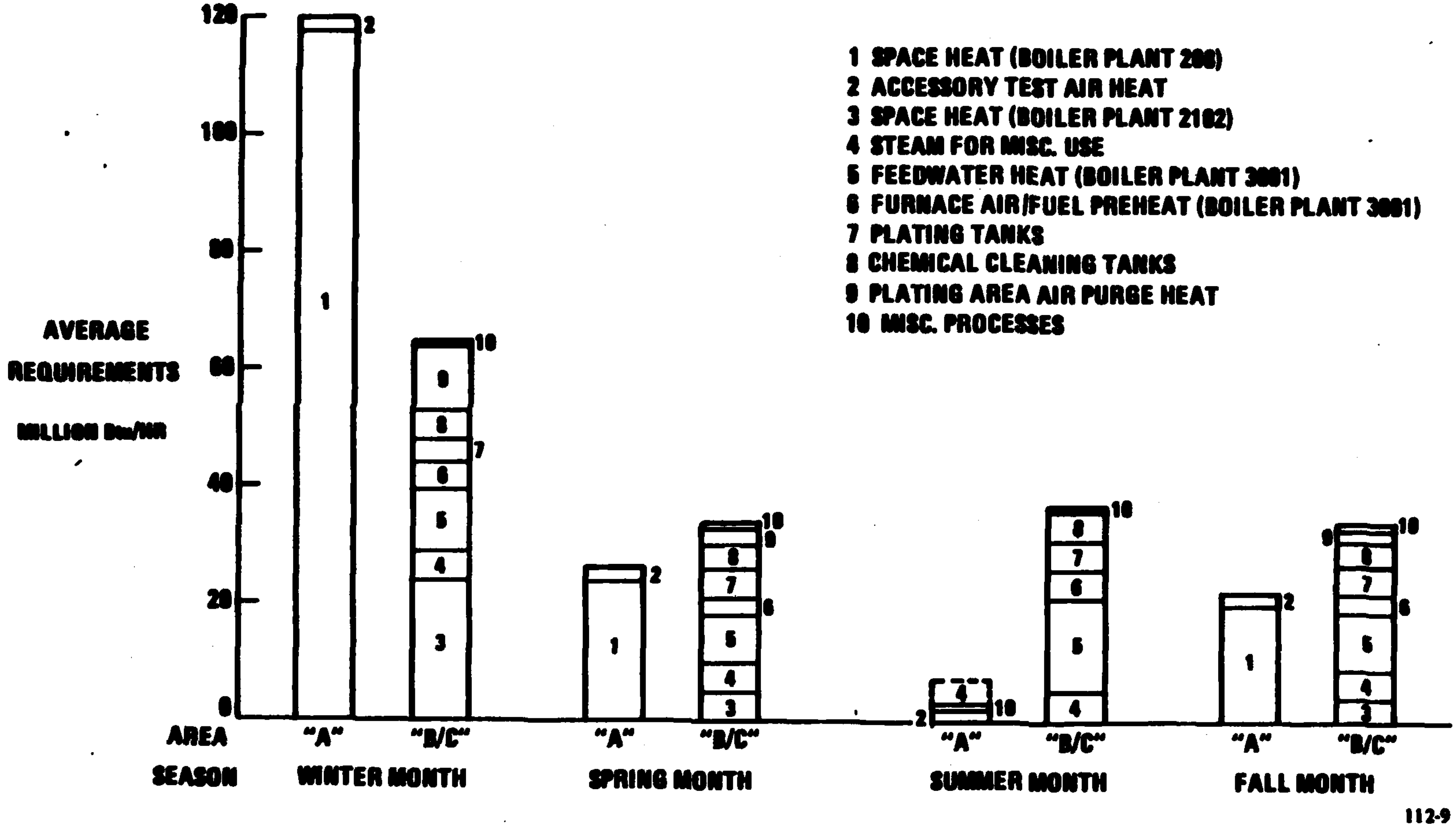

Figure 3-4. Identified Thermal Uses at Tinker AFB

SECTION IV
EVALUATION OF FUEL CELL FEASIBILITY

As mentioned earlier, United Technologies Corporation is developing a range of fuel cell powerplants for commercial applications. At the present time, emphasis is focused on both multi-kW and MW-sized powerplants. A preliminary specification for a MW-sized powerplant has been prepared for the Electric Power Research Institute under contract RP1777-1. The details of this specification are presented in Reference 6. The document also provides data on available options for the powerplant, some of which may be appropriate for ALC applications. The FCG-1 is rated at 11 MW and can operate on a variety of fuels. The standard power plant operates on natural gas, light distillate fuel, synthetic natural gas, liquified natural gas, and propane, and can be configured to operate on a variety of customer-selected fuels derived from coal, petroleum, shale, tar sands, biomass, waste treatment and process by-products. The capability to operate on indigenous fuels such as natural gas and coal-derived products can help reduce vulnerability to a fuel supply interruption. For this application, natural gas was assumed as the primary fuel with light distillate (naphtha) as the alternative. The nominal powerplant characteristics are summarized in Table 4-1. For cogeneration applications, the recoverable thermal energy is approximately 39 million Btu/hr, of which 5 million Btu/hr can be in the form of 372°F steam.

The thermal energy of this powerplant is contained in circulating liquid streams at the temperature levels specified in Table 4-1. While the FCG-1 is not presently configured for heat recovery, the thermal energy contained in these loops would be recoverable by appropriate heat exchange. For example, if it is desired to use the thermal energy to provide boiler feedwater heating, a heat exchanger with the fuel cell liquid stream on one side and the feedwater on the other may be optimum. If contamination is a concern, such as in providing heat to the plating tanks, an intermediate liquid stream may be appropriate.

A comparison of the 11-MW powerplant features to key performance, environmental and logistics requirements is presented in Tables 4-2 and 4-3.

For the most part the operational characteristics of the 11-MW powerplant meet or exceed the requirements for the Air Logistic Centers. Although the unit rating is less than the total base demand, sufficient units could be added to provide for all loads and to have a good balance between the thermal and electrical output. The selection of number of units involves an analysis of both critical loads and operating economics.

TABLE 4-1
NOMINAL FCG-1 FUEL CELL POWERPLANT CHARACTERISTICS

- o Rating: 11MW
- o Fuel:* Natural Gas or Light Distillate
- o Heat Rate: 8340 Btu/kW Hr (Natural Gas)
- o Recoverable Thermal Energy ** ~ 39 million Btu/Hr

  265 to 225°F ~ 31.5% of Heat

  225 to 185°F ~ 31.5% of Heat

  185 to 120°F ~ 37.0% of Heat

* Other fuel capabilities available as options

** Option available with 5 million Btu/hr of 372°F steam (natural gas mode)

TABLE 4-2.
AIR LOGISTICS CENTER APPLICATION ENVIRONMENTAL/
LOGISTICAL REQUIREMENTS COMPARED TO FUEL CELL FEATURES

Parameter	Reqm't to Complete ALC Mission*	Megawatt Fuel Cell Features**
Fuel Type(s)	Must be able to operate on locally available fuels, natural gas, coal, petroleum derivatives or biomass	o Multi-fuel capability o Coal/biomass derived fuels
Volume/Size	Space adjacent to loads is at premium	o Modular in design o Siting flexibility o Truck transportable
Weight	Not a factor	
Environmental	Must meet local emission requirements	o Minimal air emissions/ discharge o No water required o Minimal noise
Safety	Design for dispersed siting	o Designed for rural/urban siting o Design consistent w/codes
Survivability	o Grid connected or isolated operation o Can be sited in secure areas	o Can be adapted for either grid-connected or isola- o Can be sited in secure areas
EMCS	o Suitable for computer operation o No special reqm't on powerplant	o Suitable for computer operation o No special reqm't on powerplant

* Tinker AFB input
** UTC input

TABLE 4-3.
AIR LOGISTICS CENTER APPLICATION PERFORMANCE
REQUIREMENTS COMPARED TO FUEL CELL FEATURES

Parameter	Reqm't to complete ALC Mission*	Megawatt Fuel Cell Features**
Reliability	Must equal diesel-electric generators	o High unit availability o F/C w/grid backup results in high power reliability
Lifetime	25 years minimum	o Design life ~30 years
Maintenance	Maintenance should be reduced to the level of existing capability	o Minimal routine maintenance reqmt's o Modular design simplifies replacements
Startup Time	Less than 1-4 hours if off-line emergency backup	o Startup time 1-4 hours if off-line. Potential for rapid change-over from grid connect to isolated o Concept utilizes grid as backup
Electrical Output	2.08×10^8 kW hrs/yr*** 42 MW peak*** 24 MW average***	o 11 MW rated output power quality and interface compatible with grid

* Tinker AFB input
** UTC input
*** Total electrical consumption, demand of Tinker

The reference powerplant specification provides for grid-connected only operation; however, the unit can be adapted to either grid-connected or isolated operation. Grid-isolated operation can reduce the vulnerability of the ALC to the effects of electromagnetic pulse. The startup time is longer than required for use as an emergency generator. However, it is anticipated that the fuel cell would be operated continuously in parallel with the grid, to maximize fuel savings. With this mode of operation the switchover from grid to isolated operation would be well within the startup requirement for backup power.

The present FCG-1 is designed for operation on both natural gas and light distillate fuels. System options for extending the fuel range to cover a range of coal and biomass derived fuels have been identified. System studies indicate that these changes can be accommodated with minimum impact on cost or performance for fully developed power plants (Reference 7). It is estimated that, for the configuration used in the reference FCG-1 powerplant, the fuel switchover from natural gas to light distillate could be achieved in approximately one hour.

The FCG-1 availability objective is consistent with dispersed application in the electric utility network. The overall availability can be influenced by the level of component redundancy and the approach to spare parts provisioning.

By comparing the quality and quantity of the FCG-1 thermal energy to the requirements of the ALC, an estimate was made of the degree to which this energy is suitable for use. Figure 4-1 compares the compatible thermal requirements with the thermal output of one FCG-1 fuel cell powerplant. Considering all uses, the requirements for Area B/C are close to the FCG-1 thermal output. Area A is primarily space heating, therefore the heat utilization would be low during the summer months. Table 4-4 shows the extent of heat recovery possible as a function of fuel cell location and the type of thermal integration with the base. Three 11-MW powerplant location options were considered for this analysis: one in Area B/C, one in Area A, or one in each area. For each option, it was assumed that the fuel cell would provide space heating only or heat to all of the compatible thermal loads within the area. For the space heat alone option, the overall heat utilization ranged from approximately 30 to 50%. However by proper selection of

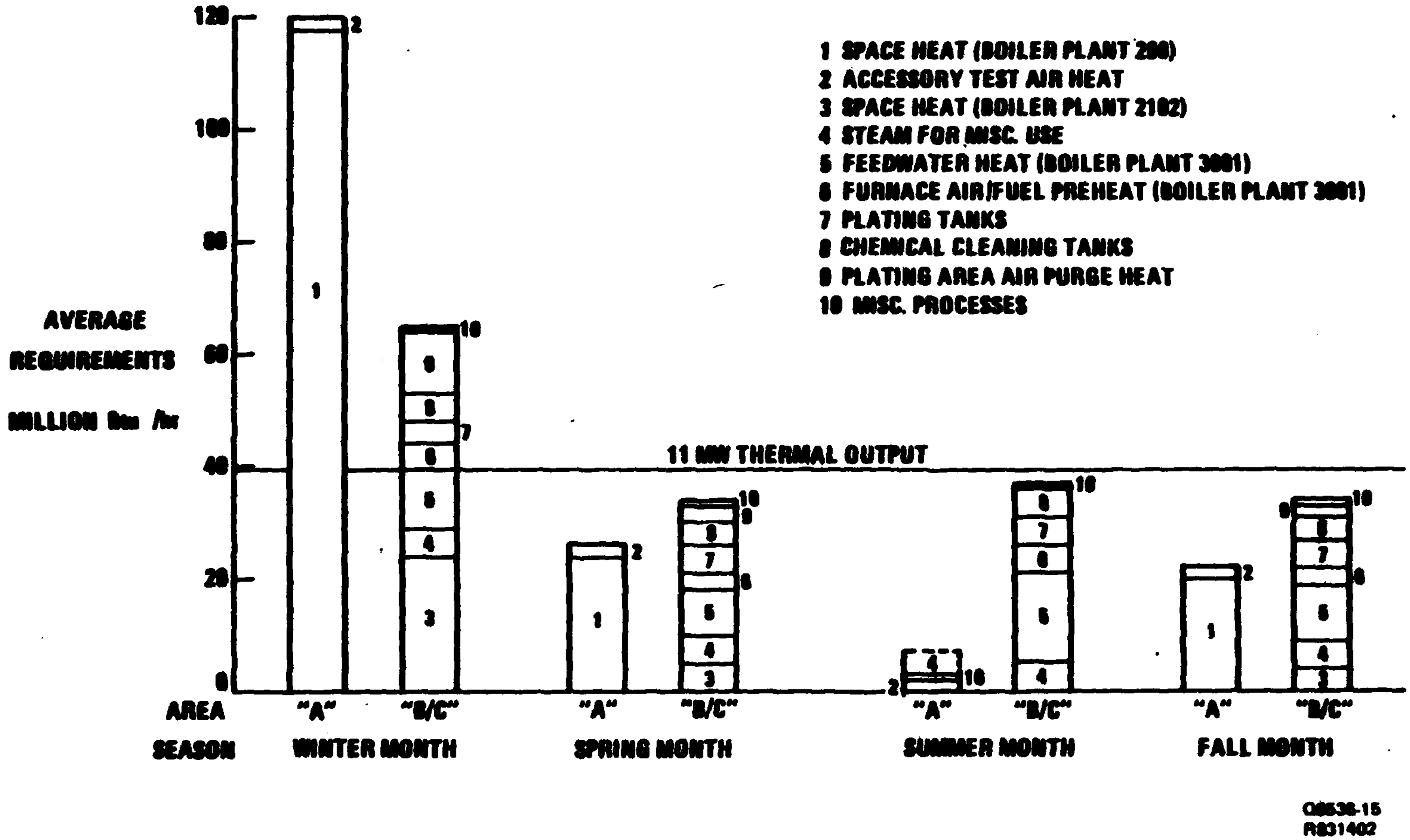

Figure 4-1. Comparison of Thermal Uses at ALC to Fuel Cell Thermal Output

the site and degree of integration, heat utilization of 50 to 90% might be anticipated. For example, the siting of two 11-MW powerplants might consist of one in Area A providing space heating only plus one in Area B/C providing space heat plus selected process heat. This combination could result in utilization in excess of 70%. Heat utilizations of 100% are possible if the powerplant could provide thermal energy to uses which are presently in either location.

Based upon this analysis, it is feasible to operate an 11-MW fuel cell power plant continuously at Tinker ALC and have a high fuel utilization. The potential benefits arising from this application are discussed in the following section.

TABLE 4-4.
HEAT RECOVERY OPTIONS AT TINKER ALC
AND UTILIZATION OF F/C HEAT

	F/C Location		
Thermal Use	One 11-MW Power-Plant in Area A	One 11-MW Power-Plant in Area B/C	One 11-MW Power-Plant in Each Area
Space Heat	~53%	~31%	~42%
All Uses Identified	~57-60	~90	~74-75

* Includes heat associated with plating air purge but not other Building 3001 space heat

SECTION V
POTENTIAL FUEL CELL BENEFITS

The preceding analysis indicates that an 11-MW fuel cell powerplant has the performance, environmental and logistic features suitable for siting within the Air Logistics Center at Tinker Air Force Base. The analysis of the base thermal requirements indicates that high overall fuel utilization could be achieved if the powerplant is operated at rated conditions to supply the ALC's critical electrical requirements plus a portion of the center's thermal requirements. An 11-MW fuel cell sited at Tinker ALC would supply approximately 26% of the 1981 peak electrical demand for 42 MW.

In this section the potential benefits which could result from deploying fuel cell powerplants at Tinker ALC are presented. The specific benefit areas considered include energy self-sufficiency, energy conservation and potentially lower life cycle costs.

ENERGY SELF-SUFFICIENCY BENEFITS

A prime concern of the Air Force Logistics Command is to continue providing critical maintenance functions in the event of disruption in the energy supply system. These disruptions could include loss of grid electric power and/or fuel supply due to natural causes, accidents, or sabotage. In addition, control of foreign oil supplies could seriously compromise the operation of oil-fired thermal equipment. One approach to ensuring a high degree of energy self-sufficiency would be to completely isolate the base's electric supply from the grid and to incorporate extensive fuel storage facilities. An alternative, which is presently employed to a limited extent, is to install government-owned backup diesel generators. These generators would be started and operated in the event of grid failure.

The dispersed fuel cell, operating in the cogeneration mode, offers another alternative. The fuel cell powerplant would operate continuously in parallel with the electric grid supplying electrical power to the ALC's critical needs. The grid would supply less critical needs and supply backup power to the fuel cell. These approaches are illustrated in Figure 5-1. With the fuel cell approach, energy self-sufficiency is enhanced because:

- The fuel cell, which supplies the ALC's critical electrical needs, is located in a secure area, the Air Base. In the alternative, the prime power source, the electrical grid, is vulnerable to loss due to weather, sabotage or accident.

- Both the fuel cell and the grid are operating and are rapidly available in the event of loss of either. In the grid plus diesel case, the backup diesel generators must be started and synchronized to the load when the grid is lost. This reduces both the response time and the overall reliability.

- Since the fuel cell is operating with recovery of thermal energy, high overall thermal efficiency is possible. This minimizes the fuel storage requirements in the event of fuel supply interruptions and provides conservation benefits. The reduction in fuel storage requirements is quantified in the "Conservation Benefits" section.

- By electrically isolating the fuel cell and critical loads from the grid, the effects of electromagnetic pulse on the ALC are reduced.

In addition to improving the overall energy self-sufficiency, the fuel cell powerplant could offer improvements in conservation and operating economics due to the high overall fuel utilization.

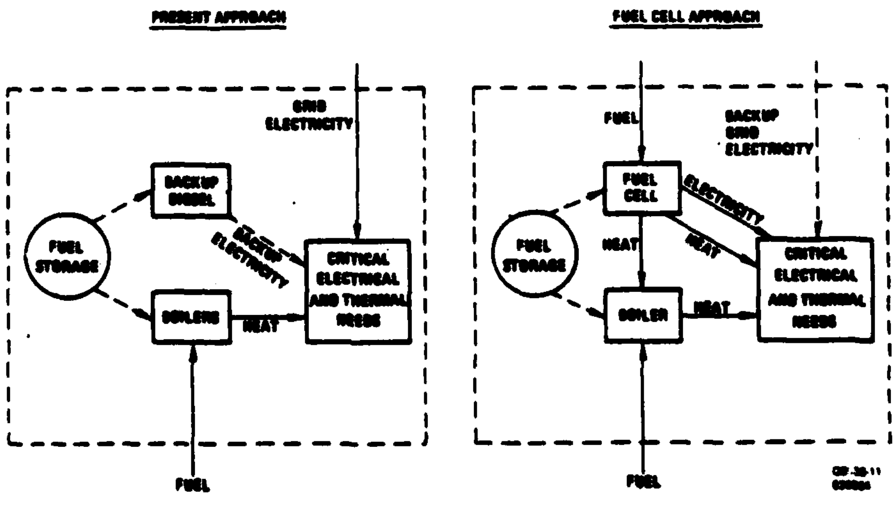

Figure 5-1. Approaches to Supplying ALC Critical Electrical Needs

CONSERVATION BENEFITS

As noted in the previous section, the integration of the 11-MW fuel cell powerplant with the thermal system of the ALC could provide overall fuel cell heat recoveries up to 100% depending upon the location of the fuel cell powerplant and the degree of thermal integration with the ALC. Based upon these results, the overall reduction in energy consumption was estimated for the Tinker Air Logistic Center. These estimates are based upon the procedures specified in the Air Force Energy Plan (Reference 8). In addition to the the degree of fuel cell fuel heat recovery, the following input was used in estimating the reduction in energy consumption:

Fuel cell heat rate ~ 8340 Btu/kWh
Grid electricity heat rate ~ 11,600 Btu/kWh (Ref. 8)
ALC boiler average thermal efficiency ~ 76%

Figure 5-2 shows the relationship between the reduction in ALC specific energy consumption (millions of Btu per square foot of building area) and the overall fuel cell heat recovery. As prescribed by the Air Force Energy Plan, these reductions are relative to the energy consumption in fiscal year 1975. With the conservation measures already instituted at Tinker the specific energy consumption in fiscal year 1981 was 5.7% less than fiscal year 1975. If one 11-MW fuel cell were installed, the energy consumption would be 16 to 20% less than FY75. With two 11-MW power plants, the energy consumption would be 26 to 35% less than base year consumption. The installation and operation of fuel cell powerplants could significantly contribute to an Air Force goal of a 30% reduction in the energy consumption of building operations by fiscal year 1995.

In addition to the conservation savings realized under normal operating conditions, the fuel storage requirements to maintain the ALC operational during emergency operations is also reduced, when compared to diesel backup generators. The magnitude of this savings was estimated assuming a 30-day interruption in both thermal and electrical supply. The storable fuel for the fuel cell was light distillate while the backup diesel used #2 fuel oil. The heat rate of diesel generators was estimated to be 11,040 Btu/kW hr (Reference 9). Figure 5-3 shows the reduced fuel storage for the fuel cell case. For the range of 50-100% heat recovery, 11-MW's of power and Tinker's average thermal load, the fuel cell would require approximately <u>12 to 19%</u> less fuel storage.

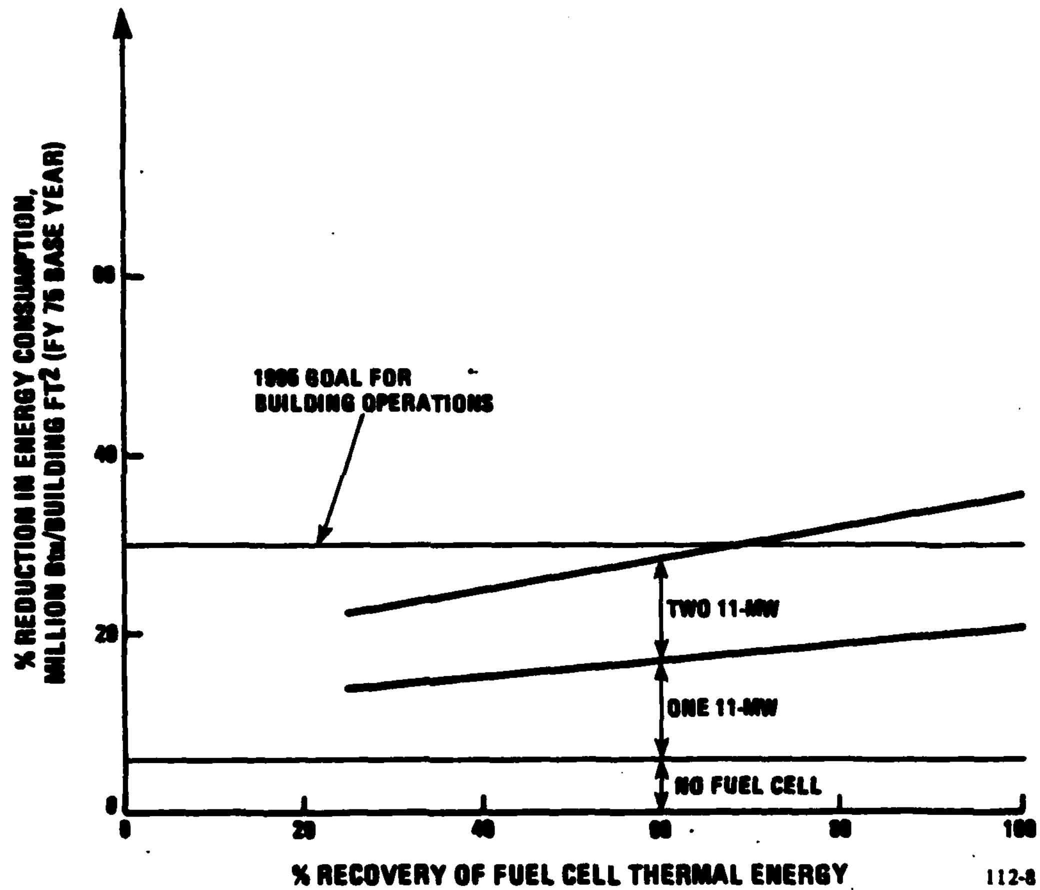

Figure 5-2. Effect of Fuel Cells on Tinker ALC FY'81 Energy Consumption

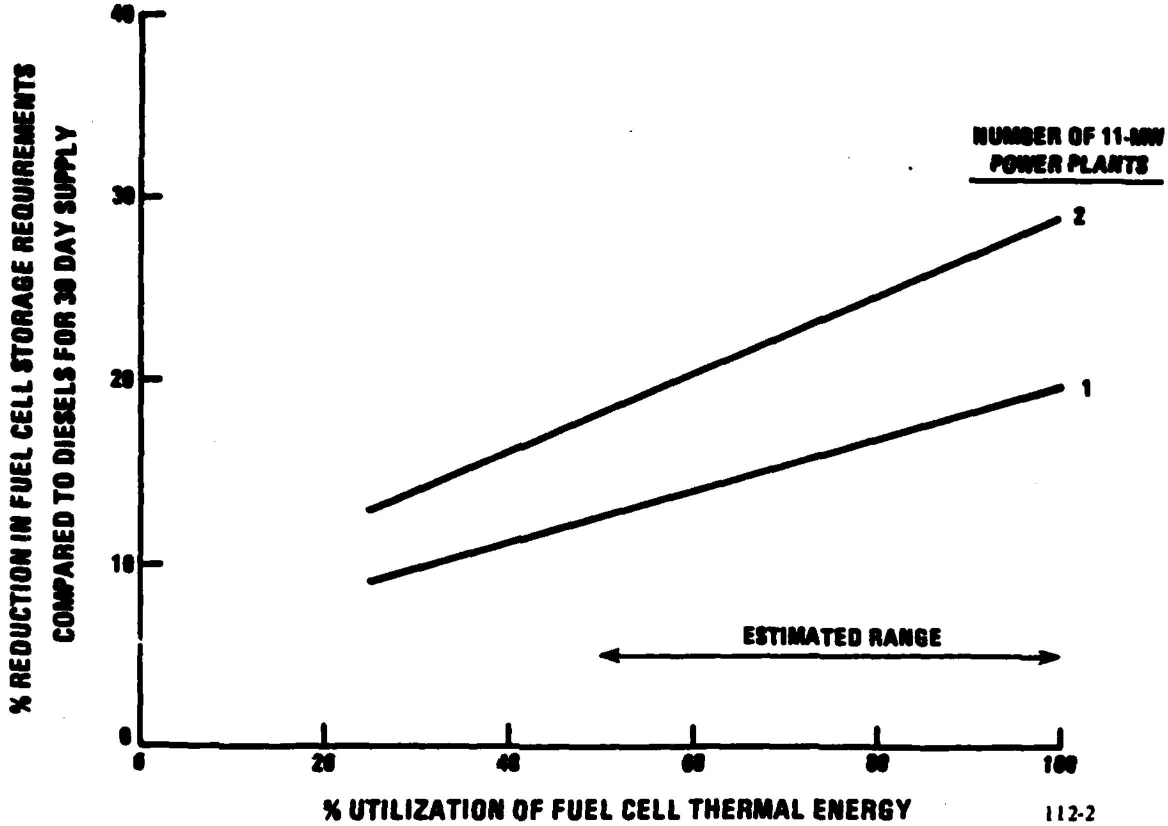

Figure 5-3. Effect of Fuel Cells on Fuel Storage Requirements

ECONOMIC BENEFITS

Economic Assumptions

Several economic measures are used by the Air Force in assessing the value of alternative courses of action. Two applicable measures for this study are the energy savings-to-cost ratio (E/C) and the life cycle cost. The Air Force Facility Energy Plan (Ref. 10) defines the energy savings to cost ratio as:

$$E/C = \frac{\text{Millions of Btu Saved/Year}}{\text{Capital Cost of Equipment (thousand of dollars)}}$$

The Facility Energy Plan also provides goals for E/C ratios for various fiscal years.

Life cycle costs represent the total capital, operating and maintenance expenditures over the entire life of the equipment. In order to account for the time value of money, the annual expenditures are discounted at a specified rate. The methodology used in developing these measures is defined in The Code of Federal Regulations, CFR Part 436 (Ref. 11), the "Life-Cycle Costing Manual for the Federal Energy Management Program" (Ref. 12) and The Federal Register, November 18, 1981 pages 56716-56733 (Ref. 13). Some of the general guidelines for the economic factors are:

Discount rate ~ 7%
Economic life ~ 25 years
Constant 1981 dollars
Energy cost escalation based on real cost increases
Fuel cell cost is 90% of actual

The 7% discount rate and 25-year economic life are specified in the Energy Security Act (Public Law 96-294), Section 405. They are to be used for evaluating potential energy conservation measures for federal buildings. The Code of Federal Regulation, CFR Part 436 (Reference 11) includes cogeneration systems as one of the potential energy conservation measures that are applicable. The use of constant dollars, except where an item is expected to escalate at a rate greater than general inflation (such as energy), and the use of the 90% cost factor are specified in "Life-Cycle Costing Manual For The Federal Energy Management Program", 12/80 (Reference 12).

Cost projections have been made for the reference FCG-1 powerplant. The installed cost is a function of production level, degree of technology development, investment in manufacturing facilities and other factors. The range of installed costs of FCG-1 powerplants is projected to be on the order of 800 to 1500 $/kW.

Early commercial units will be higher in cost and units modified to military standards could cost more than commercial powerplants.

In order to develop the complete life cycle costs for fuel cell cases and to develop similar estimates for the conventional options, additional cost information was also developed.

A projection was made of Tinker's costs for natural gas and grid electricity for the period 1985-2010. Projected energy escalation rates, exclusive of inflation, are provided periodically by the Department of Energy. The escalation rates used in this study are from the Federal Register, November 18, 1981 pages 56716-56733 (Reference 13). The cost of natural gas was estimated from Tinker's FY81 costs using the DOE regional escalation rates for the incremental time periods involved. The projected cost of purchased grid electricity was estimated by escalating the fuel component of the FY81 electricity cost, using DOE regional escalation rates applied to the electric utility's fuel costs. The impact of the utility's escalated fuel costs on the cost of electricity was determined, assuming no change in the cost of other components of the electricity cost (i.e., profit, capital recovery, overhaul and maintenance). A fuel mix of 50% coal/50% natural gas is projected by the electric utility for 1986 and was assumed for the analysis.

The resulting levelized energy costs for Tinker for the period 1985 through 2010 are shown in Table 5-1. Sensitivity analyses were also conducted to determine the effect of energy costs on life cycle costs.

The capital and operating and maintenance costs of diesel emergency electrical generators were determined from discussions with Tinker Civil Engineering and from published data. The installed capital cost was estimated to be between 500 and $1000/kW depending on size and other factors. This range of costs was used for the study. The data sources are shown in Table 5-2.

TABLE 5-1
ESTIMATED LEVELIZED ENERGY COSTS FOR TINKER ALC

- 7% Discount Rate
- 1981 Dollars
- Period 1985-2010

Grid Electricity* (Energy Plus Fuel Adjustment Charges)	3.94¢/kW Hr
Natural Gas*	$4.25/Million Btu

*FY81	2.78¢/kW Hr	Dec. 81	3.17¢/kw Hr
	$2.57/Million Btu		$3.06/Million Btu

TABLE 5-2.
COST OF DIESEL ELECTRIC GENERATORS

Source	Diesel Cost	Size
EPRI Report AP2113 (Reference 9)	$500-700/kW	10-20 MW
Becherer Associates (Reference 14)	650	2.4
Tinker Civil Engineering	1000	0.750

The yearly operating and maintenance costs of diesel emergency generators were taken from data received from Tinker, data contained in the Becherer Associates Report and in the ASME Report on Diesel Generators (Reference 15). The estimated yearly costs for megawatt size emergency diesel generators is $15 to 25/kW/year. These costs are for maintaining a diesel generator in the standby mode. The costs include parts, maintenance and labor for conducting monthly operability testing, but do not include fuel costs. This range was employed in the life cycle costs analyses.

Energy Savings to Cost Ratios

The estimated energy savings to cost ratio as a function of fuel cell installed capital cost is shown in Figure 5-4.

The figure indicates high E/C ratios are possible for fuel cell powerplants. For the projected cost range, the E/C ratio ranges between 34 and 100. The Air Force Facility Energy Plan, Reference 10, provides E/C guidelines for potential energy conservation investments. The guidelines for FY84 specify a minimum of value of 17 with an average value, for all projects, of 30 (see page B-3-1 of Reference 10). Table 5-3 indicates the range of allowable fuel cell costs which would still meet the E/C guidelines.

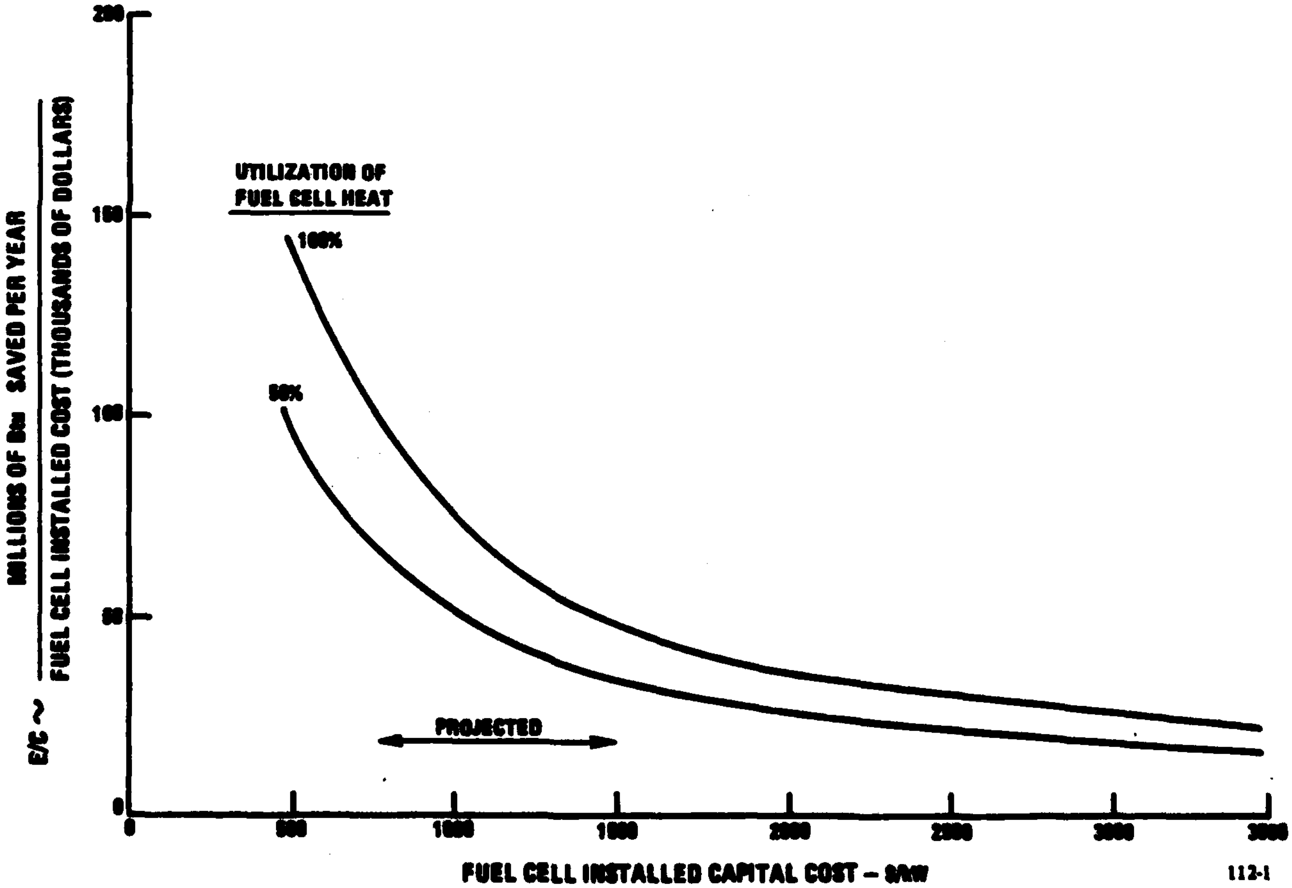

Figure 5-4. Energy Savings-to-Cost Ratio for Fuel Cells Compared to Grid

TABLE 5-3.
ENERGY SAVINGS-TO-COST RATIO FOR FUEL CELLS

E/C Ratio	Value	Fuel Cell Cost
Minimum	17	$3250-3750/kW
Average	30	1750-2500

The lower cost levels correspond to the 50% heat utilization case. The E/C ratios shown would be higher if the fuel cell case were compared to the grid plus diesel backup case and the fuel cell cost were reduced by the "avoided" cost of the diesel (500 to $1000/kW).

Life Cycle Cost Comparisons

The life cycle costs for providing 11 MW's of electrical power to Tinker ALC were estimated and compared to two other cases. In the fuel cell case, the amount of fuel cell heat recovered was taken as a cost credit. The first conventional option is grid electricity plus conventional boiler plants. This configuration would provide the minimum energy self-sufficiency since there would be no electrical back-up in the event of a grid outage. The second case assumes that the grid is backed-up with government-owned diesel emergency generators, thus increasing the energy self-sufficiency.

The estimated life cycle costs of the three alternatives are shown in Figure 5-5. The life cycle costs include the present value of yearly fuel, electricity and other O&M costs plus the capital cost of the fuel cell or diesels in those cases. Fuel cell maintenance is estimated to be 0.5¢/kW hour (Reference 4). In the case of the electrical grid alone, no costs were assigned to the value of lost manufacturing production when the grid is down. For the example of a fuel cell installed cost of $1500/kW and a diesel installed cost of $1000/kW, life cycle cost savings of approximately 9 to 20 million dollars are possible with the fuel cell. Figure 5-5 shows that fuel cells have lower life cycle costs, compared to the grid plus diesel, at fuel cell installed costs up to <u>1750</u> to <u>$3500</u>/kW. Similarly, the fuel cell offers life cycle cost savings, compared to the grid alone, at installed costs up to <u>1050</u> to <u>$2050</u>/kW.

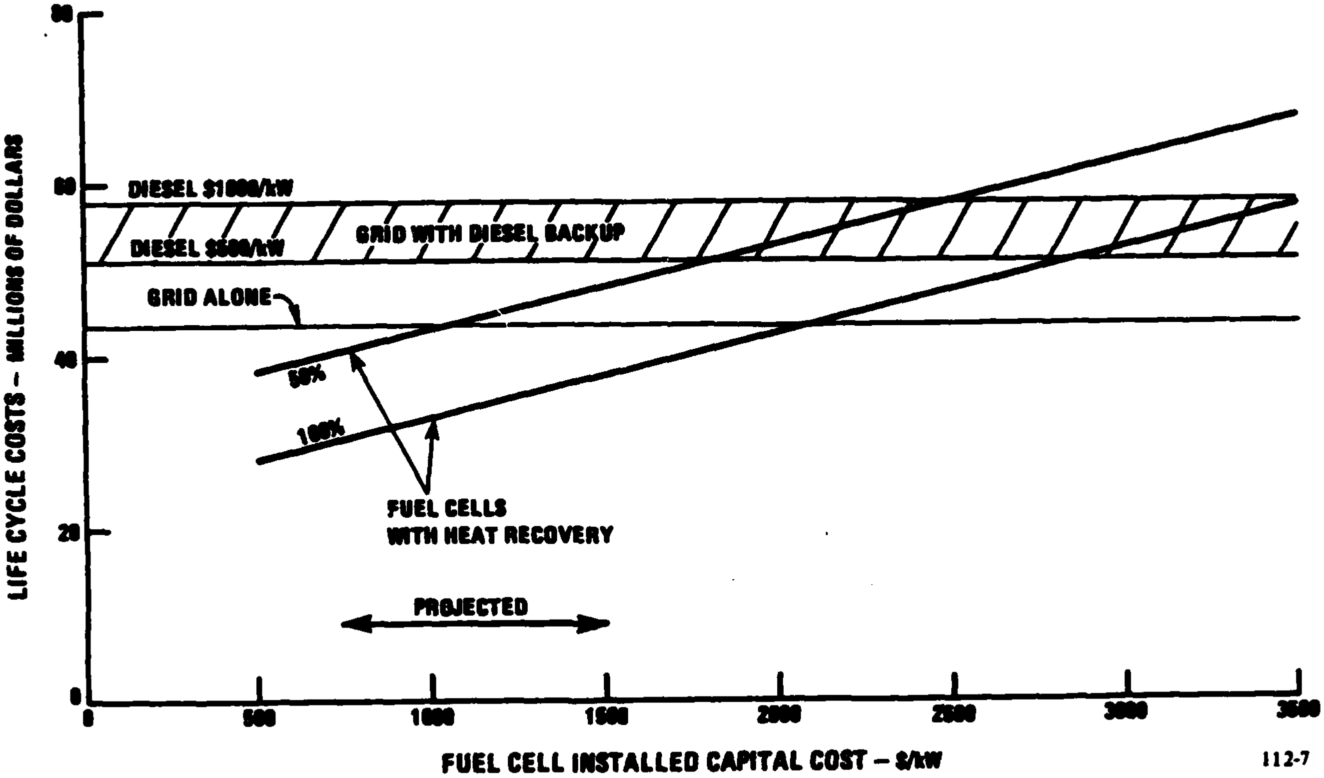

Figure 5-.5 Life Cycle Costs of Providing 11 MW's of Electrical Power to Tinker ALC

Discounted benefit to cost ratios (B/C) for fuel cells were also calculated as a function of the fuel cell installed cost. These ratios are shown in Figure 5-6. In comparing the fuel cell to the grid plus diesel, the fuel cell capital cost was reduced by the avoidance of the diesel capital cost. The figure shows that high B/C ratios are possible with fuel cells, particularly for the range of projected costs. Figure 5-6 also shows that discounted B/C ratios greater than unity are possible for fuel cell installed capital costs in excess of $3000/kW.

The fuel cell installed capital costs for a discounted B/C ratio of unity are shown in Table 5-4. These costs are also shown as "breakeven" costs.

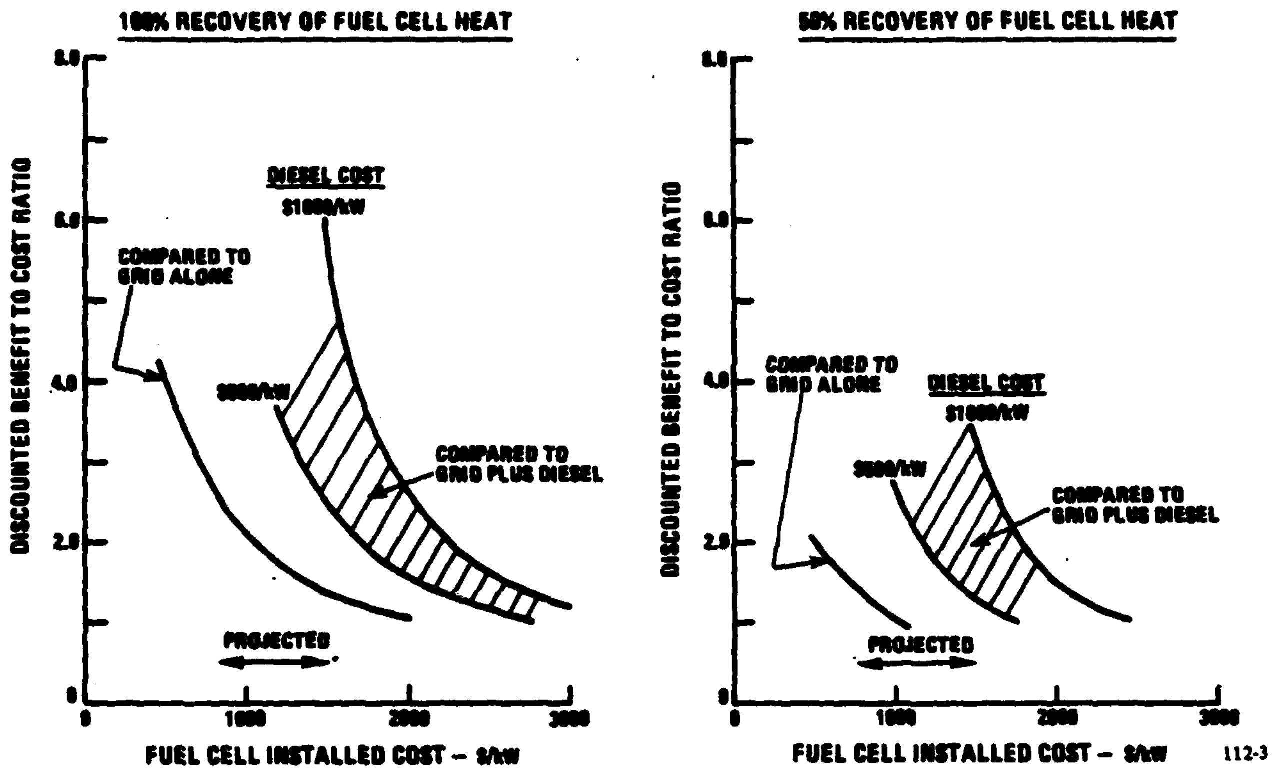

Figure 5-6. Discounted Benefit to Cost Ratio for Fuel Cells

TABLE 5-4.
FUEL CELL INSTALLED CAPITAL COST FOR DISCOUNTED B/C OF UNITY

- Electricity 3.94¢/kW hr.
- Natural Gas $4.25/Million Btu

Case		Percent Recovery of Fuel Cell Heat	Fuel Cell Installed Capital Cost
(1)	Fuel Cells Compared To Grid	50	$1050/kW
		100	2050
(2)	Fuel Cell Compared To Grid With Backup Diesels	50	1750-2500
		100	2750-3500

In calculating the B/C, only direct economic benefits were estimated. Since energy self-sufficiency can be a tactical/strategic issue, its economic benefits are not easily measured and were not quantified or included.

The life cycle cost savings that would be realized in using fuel cells to provide electrical power to an Air Logistics Center are sensitive to the cost of grid electricity and the cost of fuel for the fuel cell. In this study, the life cycle costs for Tinker ALC were estimated using a levelized electricity and fuel costs of 3.94¢/kW hour and $4.25/million Btu respectively. To determine the sensitivity of life costs to fuel and electricity costs and to extend the study to other ALC's where energy costs are different than those at Tinker, the effect of energy costs on the discounted benefit to cost ratio were estimated. In estimating this effect, the following variables were fixed:

Nominal Fuel Cell Installed Cost	- $1500/kW
Diesel Installed Cost	- $1000/kW
Percent of Fuel Cell Heat Recovered	- 75%

Figure 5-7 shows the impact of gas and electricity costs on discounted benefit to cost ratio. The shaded area in the figure corresponds to the combinations of these two costs that result in a B/C of one or greater. If a facility's energy costs, i.e., of gas and electricity, are in the shaded area, fuel cells will have lower life cycle costs than the grid plus diesels.

The present-day energy costs for Tinker, Robbins and Hill ALC's as well as the projected costs for Air Force Installation Operations, as given in the Air Force Energy Plan (Ref. 8), are indicated on the figure. These data show that fuel cells can offer life cycle cost savings when compared to the grid plus diesel.

Based on the life cycle costs and benefit-to-cost ratios, fuel cell powerplants can have life cycle cost advantages for application at Air Force Logistic Centers. In addition, for those situations where additional reliability is required the fuel cell powerplant can be cost effective for installed costs on the order of $3,000/kW when compared to the grid plus diesel backup.

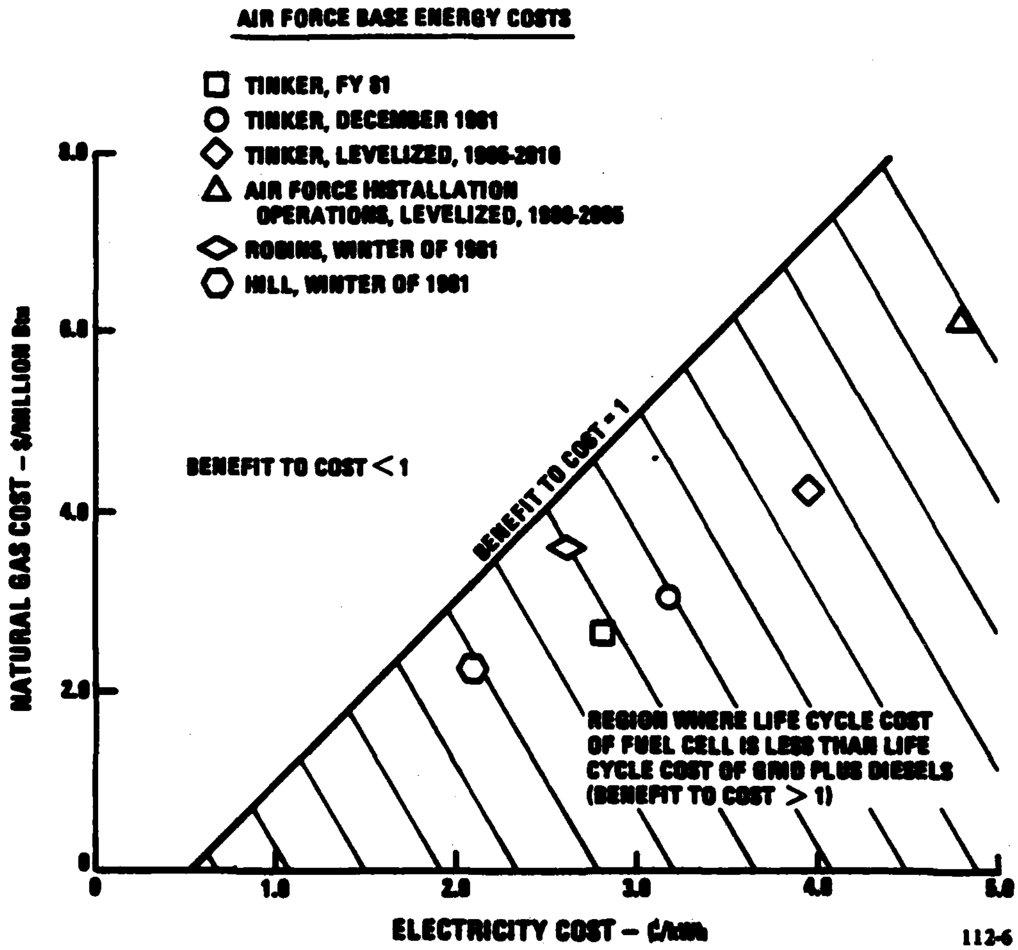

Figure 5-7. Effect of Energy Costs on Discounted Benefit-to-Cost Ratio

Section 6
RECOMMENDATIONS

The FCG-1 power plant discussed in Section 4 is designed for dispersed application within electrical utility systems. Air Force application at Air Logistics Centers can have different technical and operational requirements. Initial studies in conjunction with this and other fuel cell programs have indicated that this commercial power plant can be adapted to meet the specific Air Force requirements. There are several areas were design studies of power plant options could confirm the capabilities for Air Force applications or enhance their potential benefits. These studies would also identify areas requiring further research and technology development to enhance the capability for meeting USAF requirements.

- To satisfy electric utility requirements, the present FCG-1 power plant is designed for gird-connected operation only. In the event of a grid failure the fuel cell power plant disconnects from the grid and shuts down. Grid-independent operation, including provisions for black start capability, is necessary to achieve a high degree of energy self-sufficiency. Several options are available for providing both grid-independent and grid-parallel operations (Reference 16). Additional studies to identify the detailed technical requirements for the electric interface and to select the most effective option for meeting these requirements would be required.

- The FCG-1 is presently configured to provide electric energy only. To meet the Air Force goal for energy conservation, the power plant should provide both electrical and thermal energy. Several liquid streams for recovering thermal energy have been identified and preliminary studies have defined the quality and quantity of the recoverable thermal energy in these streams. The design of the FCG-1 power plant would be modified to incorporate the provisions for heat recovery necessary for the Air Force applications. These design studies could focus on cost effective approaches for maximizing quality and quantity of heat without compromising the electric generation efficiency.

- The availability objective of the FCG-1 meets or exceeds the requirements of a dispersed electric utility generator. The overall energy self-sufficiency of the base can be enhanced if the availability of the fuel cell power plant is further improved. Several approaches for improving the overall availability have been identified in previous studies. These include selective redundancy of critical components and effective spare parts provisioning. These approaches could be further evaluated to define power plant configurations and maintenance approaches which provide higher availability at reasonable costs.

- The FCG-1 can operate on both natural gas and light distillate fuel. Options are available to increase the fuel capability to a range of coal and biomass derived fuels. Additional studies to define the desirable range of fuels and to establish configurations for accommodating these fuels would be desirable. These studies should address cost and performance issues as well as approaches for accommodating rapid switch-over from one fuel to another.

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APPENDIX

TYPICAL BOILER LOGS USED FOR THERMAL REQUIREMENTS STUDY

(Reproduced from best available copies)

MONTHLY STEAM BOILER PLANT OPERATING LOG

1. COMMAND: OC ALC   2. BASE AND LOCATION: TAFB   Jan 1981   3001-1

DATE	A. Average Steam Pressure (PSIG)	B. Steam Produced (1000 LBS) Boiler No. 1	Boiler No. 2	Boiler No. 3	Boiler No. 4	Total	C. Load Factor (%)	D. Fuel Used Oil (Gal) Boiler No. 1	Boiler No. 2	Boiler No. 3	Boiler No. 4	Total
1	225		1314.0	1122.0		2436.0	58.0		1506.0	1411.0		2918.0
2	225		1315.0	1332.0		2640.0	[illegible]		1603.0	1332.0		3331.0
3	225		[illegible]	1122.8		[illegible]	62.0		1640.0	1538.0		3172.0
4	225		1379.0	1340.0		[illegible]	[illegible]		1704.0	1647.0		3351.0
5	225		1611.0	1428.0		[illegible]	71.[illegible]		1496.0	1674.0		2822.0
6	225		1528.0	1900.0		3322.0	62.0		1730.0	1633.0		3383.0
7	225		1250.0	1466.0		2766.0	65.0		1700.0	1611.0		3517.0
8	225		[illegible]	1287.0		2632.0	62.0		[illegible]	1312.0		3401.0
9	225		1374.0	1334.0		2768.0	64.0		1916.0	1544.0		3460.0
10	225		1276.0	1013.0		2289.0	53.0		1660.0	1178.0		2798.0
11	225		1382.0	1015.0		2397.0	60.0		1501.0	1360.0		2861.0
12	225		1732.0	1380.0		3112.0	78.0		1958.0	1720.0		3478.0
13	225		1722.0	1291.0		3013.0	67.0		2084.0	1182.0		3266.0
14	225		1698.0	1385.0		3083.0	74.0		2021.0	1731.0		3752.0
15	225		1791.0	1460.0		3051.0	72.0		2157.0	1779.0		3966.0
16	225		1760.0	1444.0		3204.0	70.0		2160.0	1760.0		3920.0
17	225		1621.0	1449.0		2870.0	74.0		2000.0	1337.0		3337.0
18	225		1766.0	1152.0		2938.0	76.0		2102.0	1494.0		3276.0
19	225		1774.0	1350.0		3124.0	75.5		2096.0	1718.0		3813.0
20	225		1672.0	1380.0		3052.0	66.0		2100.0	1698.0		3798.0
21	225		1701.0	1421.0		3122.0	71.0		2085.0	1782.0		3867.0
22	225		1196.0	1151.0		3147.0	74.0		2106.0	1834.0		3940.0
23	225		1685.0	1254.0		2919.0	65.0		2051.0	1572.0		3623.0
24	225		1635.0	1072.0		2710.0	76.0		1987.0	1384.0		3371.0
25	225		1591.0	1072.0		2663.0	[illegible]		1939.0	1316.0		3255.9
26	225		1577.0	1222.0		2799.0	77.0		1252.0	1872.0		3125.0
27	229		1632.0	1241.0					1510.0	1728.0		3238.0
28	225		1633.0	1250.0					1583.0	[illegible]		
29	225		1206.0	1108.0					1860.0	166[illegible]		
30	225		1114.0	1114.0					1776.0	144[illegible]		
31	225		1152.0	1161.0		5195.0	76.0		1761.0	[illegible]		
TOTAL			45146.0	40222.0		91564.0			52824.0	50472.0		104303.0
MAX.	225		1922.0	1261.0		3184.0	81.0		2157.0	2062.0		4225.0
MIN.	225		1204.0	1011.0		2122.0	52.0		1201.0	1178.0		2298.0
AVG.	225		[illegible]	[illegible]		[illegible]	69.2		1577.[illegible]	1626.1		3235.[illegible]

AVG. DAILY STEAM OUTPUT THOUSAND LBS

AVG. SO_2 IN FLUE

DATE	E. Flue Gas CO_2 (Avg. %) Boiler No. 1	Boiler No. 2	Boiler No. 3	Boiler No. 4	Temp (Avg °F) Boiler No. 1	Boiler No. 2	Boiler No. 3	Boiler No. 4	F. Feedwater Heater Average Press. (PSIG)	Average Temp °F	G. Feedwater Flow (Gallons)	H. Makeup Water Flow (Gallons)	I. Makeup Water (%)	J. Cond. Ret. Temp °F	Remarks
1		3.1	3.0			335	340		11	242	[illegible]	[illegible]	43.[illegible]	142	
2		[illegible]	3.4			330	340		11	242	[illegible]	[illegible]	[illegible]	141	
3		3.0	3.0			335	[illegible]		11	242	[illegible]	[illegible]	[illegible]	142	
4		3.0	3.6			335	340		11	242	[illegible]	[illegible]	[illegible]	[illegible]	
5		3.2	3.4			340	340		10	240	[illegible]	[illegible]	[illegible]	141	
6		3.2	3.4			340	345		10	240	[illegible]	[illegible]	[illegible]	142	
7		2.4	3.4			340	345		10	240	[illegible]	[illegible]	[illegible]	142	
8		3.2	3.4			340	345		10	240	[illegible]	[illegible]	[illegible]	141	
9		3.2	3.4			340	344		10	240	[illegible]	[illegible]	47.0	142	
10		2.9	2.8			335	330		10	240	[illegible]	[illegible]	44.4	143	
11		2.8	2.4			330	310		10	240	[illegible]	[illegible]	47.0	141	
12		2.5	[illegible]			325	320		11	242	[illegible]	[illegible]	[illegible]	142	
13		2.8	3.0			330	310		11	242	[illegible]	[illegible]	47.3	141	
14		3.0	2.6			331	315		11	242	[illegible]	141000	37.0	142	
15		3.3	2.4			310	310		11	242	[illegible]	[illegible]	46.0	141	
16		2.8	2.4			310	310		10	240	[illegible]	[illegible]	18.1	141	
17		3.0	3.4			340	315		10	240	[illegible]	[illegible]	37.3	140	
18		3.0	3.3			342	315		10	240	[illegible]	[illegible]	35.8	140	
19		3.0	3.0			340	340		10	240	[illegible]	[illegible]	41.8	140	
20		3.0	3.4			340	345		10	240	[illegible]	[illegible]	[illegible]	140	
21		3.0	3.4			340	345		10	240	[illegible]	[illegible]	35.3	140	
22		3.0	3.4			345	340		10	240	[illegible]	[illegible]	41.3	141	
23		3.0	3.2			300	330		10	240	[illegible]	[illegible]	[illegible]	140	
24		3.0	3.0			325	345		10	240	[illegible]	[illegible]	[illegible]	140	
25		3.0	3.0			340	323		10	240	[illegible]	[illegible]	[illegible]	140	
26		3.4	3.0			335	325		10	240	[illegible]	[illegible]	26.8	140	
27		3.0	3.0			335	323		10	240	[illegible]	[illegible]	[illegible]	140	
TOTAL											[illegible]	[illegible]			
MAX.		3.3	3.4			360	345		11	242	[illegible]	[illegible]	50.0	143	
MIN.		2.5	2.4			330	[illegible]		10	240	[illegible]	[illegible]	[illegible]	[illegible]	
AVG.		3.1	3.1			330	330		10	240	[illegible]	[illegible]	[illegible]	[illegible]	

AVG. FLUE GAS TEMPERATURE °F

AVG. FEEDWATER EXIT TEMP °F

AVG. % MAKEUP WATER

AVG. CONDENSATE RETURN TEMP °F

MONTHLY STEAM BOILER PLANT OPERATING LOG

1. COMMAND: OCAMC | 2. BASE AND LOCATION: TAFB OKC Apr 1981 | 3. BUILDING NO.: 3001

DATE	A. AVERAGE STEAM PRESSURE (PSIG)	B. STEAM PRODUCED (1000 LBS) BOILER NO. 1	2	3	4	TOTAL	C. PLANT LOAD FACTOR (%)	D. FUEL USED: GAS (MCF) / OIL (GAL) / COAL (TONS) BOILER NO. 1	2	3	4	TOTAL	E. FLUE GAS: CO_2 (Avg. %) BOILER NO. 1	2	3	4	TEMP (Avg °F) BOILER NO. 1	2	3	4	F. DEAERATOR HEATER: AVERAGE PRESS (PSIG)	AVERAGE TEMP °F	G. FEEDWATER FLOW (Gallons)	H. MAKEUP WATER FLOW (Gallons)	I. MAKEUP WATER (%)	J. COND. RETURNED TEMP °F
1	225		1063.0	1122.0		2185.0	51.0		1459.0	1467.0		2928.0		2.2	3.3			330	320		9	235	244492	133.0	56.6	142
2	[illegible]		[illegible]	1621.0		2109.0	51.0		1458.0	1431.0		2889.0		[illegible]	2.4			326	330		9	240	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]		[illegible]	[illegible]		2331.0	60.0		1544.0	1607.0		[illegible]		2.2	2.4			320	330		9	240	[illegible]	[illegible]	[illegible]	
4	[illegible]		[illegible]	[illegible]		1850.0	60.0		1420.0	1632.0		[illegible]		[illegible]	3.1			326	327		9	240	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]		[illegible]	[illegible]		1880.0	60.0		1476.0	1626.0		[illegible]		3.0	3.0			320	310		9	240	[illegible]	129700	51.7	[illegible]
6	[illegible]		1022.0	866.0		1888.0	54.0		1483.0	1096.0		2579.0		[illegible]	3.0			320	310		9	240	[illegible]	[illegible]	[illegible]	[illegible]
7	[illegible]		[illegible]	[illegible]		1937.0	58.2		[illegible]	[illegible]		[illegible]		[illegible]	3.0			316	[illegible]		9	240	[illegible]	[illegible]	[illegible]	[illegible]
8	[illegible]		[illegible]	[illegible]		1891.0	54.0		1467.0	[illegible]		2637.0		[illegible]	3.2			326	310		9	240	[illegible]	[illegible]	[illegible]	[illegible]
9	[illegible]		1050.0	1079.0		2051.0	58.0		1390.0	1437.0		2827.0		3.2	3.2			320	320		9	240	[illegible]	134900	56.0	140
10	[illegible]		1293.0	1112.0		2195.0	64.0		1505.0	1369.0		2874.0		3.2	3.2			320	320		9	240	[illegible]	150900	56.2	140
11				OUT	P.E.																					
12	[illegible]		[illegible]	340.0		532.0	[illegible]		[illegible]	1380		790.0		3.6	3.5			[illegible]	[illegible]		9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
13	[illegible]		[illegible]	[illegible]		2159.0	58.0		1489.0	1486.0		2975.0		3.6	3.6			327	311		9	[illegible]	[illegible]	[illegible]	51.1	[illegible]
14	[illegible]		[illegible]	955.0		1900.0	52.0		1279.0	1331.0		2709.0		3.6	[illegible]			330	326		9	225	[illegible]	15790	40.0	140
15	[illegible]		[illegible]	[illegible]		[illegible]	[illegible]		[illegible]	1259.0		2454.0		3.6	3.0			330	320		9	240	[illegible]	149760	66.6	140
16	[illegible]		[illegible]	[illegible]		2249.0	[illegible]		1369.0	1486.0		2859.0		3.6	3.0			310	320		9	240	271630	[illegible]	58.9	140
17	[illegible]		1150.0	1156.0		2306.0	64.0		1639.0	1486.0		3125.0		3.6	2.9			330	320		9	240	[illegible]	150900	46.1	140
18	[illegible]		[illegible]	1080.0		[illegible]	49.0		1456.0	1377.0		2973.0		3.6	2.5			[illegible]	326		9	240	[illegible]	[illegible]	[illegible]	[illegible]
19	[illegible]		[illegible]	[illegible]		[illegible]	[illegible]		1551.0	[illegible]		2647.0		3.6	2.7			330	320		9	240	[illegible]	[illegible]	46.2	140
20	[illegible]		[illegible]	[illegible]		[illegible]	59.0		[illegible]	[illegible]		[illegible]		3.6	2.7			330	320		9	240	[illegible]	[illegible]	[illegible]	[illegible]
21	[illegible]	[illegible]	[illegible]	[illegible]		2607.0	58.0	[illegible]	1294.0	[illegible]		[illegible]	3.6	3.1	2.7		310	327	320		9	240	[illegible]	[illegible]	[illegible]	[illegible]
22	[illegible]	[illegible]	[illegible]			[illegible]	60.0	1700.0	1320.0			3020.0	2.8	2.4			328	320			9	240	[illegible]	[illegible]	[illegible]	[illegible]
23	[illegible]	[illegible]	[illegible]			[illegible]	56.3	[illegible]	1442.0			[illegible]	4.0	3.6			323	320			9	240	[illegible]	[illegible]	[illegible]	[illegible]
24	[illegible]	[illegible]	[illegible]			1957.0	55.0	[illegible]	1432.0			2545.0	3.0	3.5			[illegible]	320			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
25	[illegible]	770	[illegible]			[illegible]	40.0	768.0	1028.0			1796.0	[illegible]	2.9			[illegible]	[illegible]			9	240	[illegible]	[illegible]	[illegible]	[illegible]
26	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]	1120.0			1872.0	[illegible]	2.8			[illegible]	327			9	240	[illegible]	[illegible]	[illegible]	[illegible]
27	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	1100.0	[illegible]			[illegible]	2.5	3.3			[illegible]	[illegible]			9	240	[illegible]	[illegible]	[illegible]	[illegible]
28	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]	1450			[illegible]	[illegible]	2.6			[illegible]	[illegible]			[illegible]	240	[illegible]	[illegible]	[illegible]	[illegible]
29	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]	1240.0			[illegible]	[illegible]	[illegible]			[illegible]	[illegible]			9	240	[illegible]	[illegible]	[illegible]	[illegible]
30	235	[illegible]	1421.0	330		3167.2	73.0	[illegible]	2102.0	377.0		4362.0	3.8	2.6	2.8		320	320	316		9	[illegible]	[illegible]	[illegible]	[illegible]	
31																										
TOTAL		11275	25779	19926		66445		13897	41199	25619		86650											[illegible]	3787400		
AVG.		1375.6	1420.6	1103.1		2107.0	73	[illegible]	2162.0	1539.0		[illegible]	3.3	3.6	2.6		[illegible]	336	372		9	[illegible]	[illegible]	[illegible]		
MAX.		[illegible]	[illegible]	330.6		557.0	38	752.0	742.0	386		788.0	[illegible]	2.1	2.1		310	307	[illegible]		8	[illegible]		[illegible]	[illegible]	[illegible]
MIN.		[illegible]	[illegible]	[illegible]		[illegible]	4.5	[illegible]	1420	[illegible]		[illegible]	3.3	3.2	3.0		[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

CALORIFIC VALUE OF FUEL USED | 5. BOILER NO.

A-3

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MONTHLY STEAM BOILER PLANT OPERATING LOG

1. COMMAND: OCALC

2. BASE AND LOCATION: TAFB JULY 1981

3. BUILDING NO. AND NAME: 304-[illegible]

DATE	A. AVERAGE STEAM PRESSURE (PSIG)	B. STEAM PRODUCED (1000 LBS) BOILER NO. 1	2	3	4	TOTAL	C. LOAD FACTOR (%)	D. FUEL USED GAS (MCF) / OIL (GAL) / COAL (TON) BOILER NO. 1	2	3	4	TOTAL
1	225	135[illegible]	1455.0	1008.0		3819.0	55.3	1934.0	1996.0	1364.0		5294.0
2	[illegible]	[illegible]	[illegible]	[illegible]		3332.0	56.0	1828.0	1886.[illegible]	1344.0		[illegible]78.2
3	[illegible]	[illegible]	[illegible]	[illegible]		3336.0	50.0	1324.0	1406.0	606.0		3336.0
4	[illegible]	[illegible]	[illegible]			[illegible]	47.0	1294.0	1361.0			[illegible]55.0
5	[illegible]	[illegible]	[illegible]	[illegible]		3200.0	65.5	1676.2	1760.0	102.0		3538.0
6	225	3[illegible]	14[illegible]	902.0		3649.0	57.3	1894.0	1948.0	1191.0		5023.0
7	[illegible]	[illegible]	[illegible]322.0	944.0		3534.0	52.7	1890.0	1952.0	1288.0		5724.0
8	[illegible]	[illegible]	[illegible]	[illegible]		3816.0	58.[illegible]	1960.0	2088.[illegible]	1258.0		5306.0
9	[illegible]	[illegible]	[illegible]	[illegible]		3850.0	58.0	2040.0	2094.0	1348.0		[illegible]82.0
10	[illegible]	[illegible]	1536.0	932.0		3900.0	56.0	2040.0	2072.0	1248.0		5360.0
11	[illegible]	[illegible]	[illegible]	[illegible]		3826.2	55.3	1634.2	1674.2	1132.0		[illegible]44.0
12	[illegible]	[illegible]	[illegible]	[illegible]		3716.0	5[illegible].6	1874.0	1896.0	[illegible]248.0		[illegible]218.0
13	[illegible]	1576.0	[illegible]	990.0		4100.0	6[illegible]	2046.0	2154.0	1304.0		[illegible]501.6
14	225	1706.0	1752.0	878.0		4336.0	[illegible].7	2372.0	2290.0	1172.0		5934.0
15	[illegible]	[illegible]	[illegible]	1026.0		4196.0	[illegible]	[illegible]	[illegible]	[illegible]160.0		5723.0
16	[illegible]	[illegible]	[illegible]	1070.0		4088.0	63.3	2057.0	2038.0	[illegible]		5690.0
17	[illegible]	[illegible]	[illegible]	1114.0		3717.0	5[illegible]	1742.0	1783.0	[illegible]		4926.0
18	225	1265.0	1372.0	1032.0		3669.0	5[illegible].0	1765.0	1817.0	1348.0		4940.0
19	22[illegible]	[illegible]	[illegible]	990.0		3605.0	53.3	1772.0	1831.2	[illegible]332.0		49[illegible]2
20	22[illegible]	1442.6	1567.0	1014.0		4024.0	57.7	2102.0	2096.0	1323.0		5515.0
21	225	1404.0	1536.0	1076.6		4016.0	[illegible]	1951.0	2036.6	1400.0		5388.0
22	[illegible]	[illegible]	1670.0	1196.0		3990.0	61.3	1904.0	1902.0	[illegible]36.0		[illegible]82.0
23	[illegible]	[illegible]	[illegible]320.0	1208.[illegible]		4182.0	60.0	1990.0	1992.0	[illegible]40.0		[illegible]564.0
24	[illegible]	[illegible]	[illegible]	[illegible]		4028.0	58.[illegible]	[illegible]	[illegible]	[illegible]		[illegible]348.[illegible]
25	[illegible]	[illegible]	[illegible]	[illegible]		3710.0	56.0	[illegible]	1906.0	[illegible]		[illegible]778.[illegible]
26	[illegible]	[illegible]	[illegible]	8[illegible]		3754.0	[illegible]	1912.0	1730.6	[illegible]		5074.0
27	[illegible]	1[illegible]	1523.[illegible]	[illegible]		4345.0	57.3	[illegible]	[illegible]	[illegible]		[illegible]47[illegible]
28	[illegible]	[illegible]	[illegible]	[illegible]		3[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		33[illegible]
29	22[illegible]	1318.0	1512.[illegible]	107[illegible]		3873.0	[illegible]	[illegible]4.0	1776.0	14[illegible]		50[illegible]
30	225	1[illegible]	1571.0	1118.6		4108.6	62.0	2038.0	[illegible]	[illegible]		5516.0
31	225	[illegible]	15[illegible]	[illegible]		42[illegible]	6[illegible]	[illegible]	[illegible]	[illegible]		57[illegible]
TOTAL		[illegible]	[illegible]	29[illegible].0		114,[illegible]		[illegible]	[illegible]	[illegible]		161,638.[illegible]
AVG.	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	15[illegible]		[illegible]
MIN.	[illegible]	864.0	[illegible]	[illegible]		[illegible]	[illegible]	115[illegible]	[illegible]	162.[illegible]		[illegible]
MAX.	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]

DATE	E. FLUE GAS CO_2 (Avg. %) BOILER NO. 1	2	3	4	TEMP (Avg °F) BOILER NO. 1	2	3	4	F. FEEDWATER HEATER AVERAGE PRESS (PSIG)	AVERAGE TEMP	G. FEEDWATER FLOW (Gallons)	H. MAKEUP WATER FLOW (Gallons)	I. MAKEUP WATER (%)	J. COND. RETURN TEMP
1	3.2	3.4	2.8		340	340	320		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
2	3.2	3.4	[illegible]		340	[illegible]	320			[illegible]				
3	3.2	3.4	[illegible]		335	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]			
4	[illegible]	3.4			330	[illegible]			[illegible]	[illegible]	[illegible]			
5	1.[illegible]	3.1	2.[illegible]		330	[illegible]	30[illegible]		10	[illegible]	[illegible]			
6	3.8	3.6	2.8		340	340	320		10	240	454298	[illegible]		
7	3.8	3.6	2.8		340	340	320		11	[illegible]	[illegible]	[illegible]		
8	[illegible]	[illegible]	[illegible]		[illegible]	330	320		10	[illegible]	[illegible]			
9	1.8	3.[illegible]	3.[illegible]		333	333	320		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
10	3.[illegible]	3.6	3.[illegible]		340	[illegible]	320		1[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
11	3.8	[illegible]	[illegible]		[illegible]	[illegible]	320		10	240	[illegible]	[illegible]	[illegible]	[illegible]
12	3.8	[illegible]	3.[illegible]		333	333	320		10	240	[illegible]	[illegible]	[illegible]	
13	[illegible]	[illegible]	3.4		330	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
14	4.1	3.7	3.5		330	330	340		10	240	[illegible]	146600	27.6	[illegible]
15	4.0	3.7	2.[illegible]		[illegible]	[illegible]	340		10	240	[illegible]	[illegible]	[illegible]	[illegible]
16	4.2	3.6	3.[illegible]		335	335	320		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
17	3.[illegible]	3.[illegible]	[illegible]		340	340	325		10	240	[illegible]	[illegible]	3.[illegible]	[illegible]
18	3.8	3.8	3.4		342	340	325		10	240	[illegible]	151000	[illegible]	14[illegible]
19	3.[illegible]	3.8	3.[illegible]		[illegible]	[illegible]	330		[illegible]	242	[illegible]	[illegible]	[illegible]	[illegible]
20	[illegible]	3.8	[illegible]		34[illegible]	330	320		9	237	4[illegible]	[illegible]	[illegible]	[illegible]
21	3.8	3.8	[illegible]		34[illegible]	330	320		10	246	500[illegible]	[illegible]	22.2	110
22	[illegible]	3.7	3.[illegible]		[illegible]	333	320		9	237	[illegible]	[illegible]	[illegible]	[illegible]
23	[illegible]6	3.[illegible]	[illegible]		[illegible]	335	320		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
24	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
25	3.6	3.[illegible]	[illegible]		[illegible]	[illegible]	320		10	240	[illegible]	[illegible]	[illegible]	
26	3.6	2.8	3.[illegible]		33[illegible]	33[illegible]	320		9	237	[illegible]	[illegible]	[illegible]	
27	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	320		1[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
28	[illegible]	[illegible]	3.1		[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
29	3.6	4.0	[illegible]		[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
30	[illegible].6	[illegible]	[illegible]		3[illegible]6	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
31	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TOTAL											[illegible]	[illegible]		
AVG.	4.2	[illegible]	3.[illegible]		[illegible]	[illegible]	[illegible]		11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
MIN.	[illegible]	3.1	2.[illegible]		[illegible]	[illegible]	3[illegible]		9	[illegible]	[illegible]	[illegible]	[illegible]	
MAX.	[illegible]	3.[illegible]	3.55		[illegible]	[illegible]	[illegible]		1[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

A-4

MONTHLY STEAM BOILER PLANT OPERATING LOG

1. COMMAND: O.C.A.L.C.

2. BASE AND LOCATION: Tinker Air Force Base Nov-1981

3. BUILDING NO.: 3001-C

DATE	A. AVERAGE STEAM PRESS (PSIG)	B. STEAM PRODUCED (1000 LBS) BOILER NO. 1	B. 2	B. 3	B. 4	B. TOTAL	C. PEAK LOAD FACTOR (%)	D. FUEL USED BOILER NO. 1	D. 2	D. 3	D. 4	D. TOTAL
1	[illegible]	950.0		1152.0		2141.0	46.0	1302.0		1378.0		2685.0
2	235	1125.4		1112.6		2437.0	58.0	1343.0		1377.0		2720.0
3	235	1151.0		1338.0		2489.0	58.0	1532.0		1598.0		3130.0
4	[illegible]	[illegible]		1393.0		2596.0	66.0	1665.0		1683.0		3348.0
5	[illegible]	[illegible]		1320.0		2359.0	60	1534.0		1578.0		3112.0
6	[illegible]	[illegible]		[illegible]		[illegible]	56.5	1449.0		1500.0		2949.0
7	[illegible]	[illegible]		1100.0		2060.0	47.0	1244.0		1335.0		2579.0
8	[illegible]	[illegible]		1133.0		2100.0	51.0	1251.0		1320.0		2571.0
9	[illegible]	[illegible]		[illegible]		2521.0	62.0	1389.0		1574.0		3256.0
10	235	[illegible]		[illegible]		2616.0	64.0	1646.0		1715.0		3361.0
11	[illegible]	[illegible]		1236.0		[illegible]	58.0	1390.0		[illegible]		[illegible]
12	[illegible]	[illegible]		1320.0		2329.0	67.0	1624.0		[illegible]		3130.0
13	[illegible]	[illegible]		1274.0		2499.0	59.0	1513.0		1578.0		3091.0
14	[illegible]	1200.0		1251.0		2451.0	54.0	1480.0		1562.0		[illegible]
15	[illegible]	[illegible]		[illegible]		[illegible]	50.0	1598.0		1494.0		2.992.0
16		[illegible]		[illegible]		[illegible]	55.5	1497.0		[illegible]		[illegible]
17	[illegible]	[illegible]		1329.0		2.671.0	63.0	1606.0		1654.0		3.260.0
18	[illegible]	[illegible]		[illegible]		2.631.0	71.0	1633.0		1590.0		3.126.0
19	[illegible]			[illegible]		[illegible]	66.0	1579.0		[illegible]		[illegible]
20	235	[illegible]	1160.0	[illegible]		2411.7	60.0	1177.0	1124.0	1146.0		2253.0
21	[illegible]	[illegible]	[illegible]			2180.0	54.0	1492.0	1344.0			2836.0
22	230	[illegible]	[illegible]			2152.0	53.0	1336.0	1246.0			[illegible]
23	235	1197.0	1136.0			2333.0	57.0	1457.0	1344.0			2791.0
24	235	[illegible]	1261.0			2558.0	62.0	1520.0	1504.0			3024.0
25	[illegible]	[illegible]	[illegible]			2644.0	64.0	[illegible]	[illegible]			3121.0
26	[illegible]	[illegible]	[illegible]			[illegible]	49.0	1312.0	1186.0			[illegible]
27	[illegible]	[illegible]	[illegible]			[illegible]	47.0	[illegible]	[illegible]			[illegible]
28	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]	[illegible]			[illegible]
29	[illegible]	[illegible]	[illegible]			[illegible]	51.0	1416.0	1568.0			2794.0
30	[illegible]	[illegible]	[illegible]			2856.0	[illegible]	1519.0	1736.0			[illegible]
31												
TOTAL		[illegible]	13230.0	24691.0		73040.0		44325.0	15913.0	29599.0		89517.0
MAX.		1421.?	[illegible]	[illegible]		2856.0	71.0	1677.0	1738.0	1715.0		3348.0
MIN.		[illegible]	[illegible]	[illegible]		2060.0	46.0	1244.0	1132.0	444.0		2498.0
AVG.		1171.9	1203.7	1233.5		2435.3	58.8	1474.1	1424.4	1479.9		2984.7

DATE	E. FLUE GAS CO_2 (Avg. %) BOILER NO. 1	CO_2 2	CO_2 3	CO_2 4	TEMP (Avg °F) BOILER NO. 1	TEMP 2	TEMP 3	TEMP 4	F. FEEDWATER HEATER AVERAGE PRESS (PSIG)	F. AVERAGE TEMP (°F)	G. FEEDWATER FLOW (Gallons)	H. MAKEUP WATER FLOW (Gallons)	I. MAKEUP WATER (%)	J. COND. RETURNED TEMP (°F)
1	3.0		2.8		320		340		10	240	271801	123300	[illegible]	140
2	3.2		2.9		375		321		9	237	313447	[illegible]	45.0	[illegible]
3	3.2		2.5		330		320		10	240	[illegible]	[illegible]	[illegible]	[illegible]
4	3.2		2.9		330		330		10	240	[illegible]	[illegible]	[illegible]	140
5	3.2		3.6		330		[illegible]		10	[illegible]	[illegible]	[illegible]	[illegible]	140
6	3.2		[illegible]		325		[illegible]		10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	3.2		3.4		326		312		10	240	263395	[illegible]	[illegible]	142
8	2.6		3.4		330		310		9	233	260458	127320	39.8	140
9	3.2		3.4		330		322		10	240	[illegible]	116700	120	140
10	4.0		3.8		340		340		10	240	329182	121000	40.1	140
11	4.0		[illegible]		340		[illegible]		10	[illegible]	258940	127210	[illegible]	140
12	3.0		3.6		330		330		10	[illegible]	[illegible]	131900	[illegible]	[illegible]
13	3.0		3.6		335		328		10	239	[illegible]	131000	41.6	140
14	3.0		[illegible]		335		325		9	237	307231	125900	37.6	[illegible]
15	3.0		3.6		330		320		10	240	293149	118100	40.2	140
16	3.0		[illegible]		[illegible]		320		[illegible]	240	[illegible]	[illegible]	[illegible]	[illegible]
17	3.0		3.6		330		320		10	240	335476	116600	33.2	14[illegible]
18	3.2		3.4		330		315		10	240	325116	[illegible]	39.0	[illegible]
19	3.6		[illegible]		320		315		10	[illegible]	315555	[illegible]	[illegible]	14[illegible]
20	3.7	3.4	3.8		[illegible]	340	315		10	240	310580	125700	[illegible]	14[illegible]
21	3.8	3.4			350	340			7	237	345570	[illegible]	[illegible]	[illegible]
22	3.8	3.2			322	331			10	240	[illegible]	[illegible]	[illegible]	[illegible]
23	3.0	2.6			330	330			9	237	294926	118300	40.1	[illegible]
24	3.0	2.8			332	325			9	237	321914	125300	38.9	[illegible]
25	[illegible]	3.0			[illegible]	340			10	240	[illegible]	[illegible]	[illegible]	[illegible]
26	[illegible]	[illegible]			340	350			10	240	[illegible]	[illegible]	[illegible]	[illegible]
27	2.2	[illegible]			340	[illegible]			10	240	[illegible]	[illegible]	[illegible]	[illegible]
28	[illegible]	[illegible]			[illegible]	[illegible]			10	246	[illegible]	[illegible]	[illegible]	[illegible]
29	2.2	2.0			[illegible]	[illegible]			10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
30	3.2	[illegible]			[illegible]	[illegible]			10	240	[illegible]	[illegible]	[illegible]	[illegible]
31														
TOTAL											9,316,115	3,723,100		
MAX.	4.0	3.4	3.8		350	350	340		10	240	357672	141,200	46	14[illegible]
MIN.	2.6	2.0	2.8		320	330	310		7	237	243076	107220	33.[illegible]	[illegible]
AVG.	3.2	2.9	3.4		333	341	322		9.7	239	307837	124103	40.[illegible]	140

9. CALORIFIC VALUE OF FUEL USED	6. BOILER NO.	1	2	3	4	TOTAL	7. BOILER EFFICIENCY (%)

*USGPO: 1983-659-062-932