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Onsite 40-Kilowatt Fuel Cell Power Plant Manufacturing and Field Test Program

United Technologies Power Systems

February 1985

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Lewis Research Center
Under Contract DEN 3-255

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United Technologies Power Systems
South Windsor, Connecticut 06074

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Lewis Research Center
Cleveland, Ohio 44135
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Washington, D.C. 20545
Under Interagency Agreement DE-AI21-80ET17088

CONTENTS

I. SUMMARY

OVERVIEW

A joint Gas Research Institute and U.S. Department of Energy Program was initiated in 1982 to evaluate the use of fuel cell power systems for on-site energy service. Forty-six 40-kW fuel cell power plants were manufactured at the United Technologies Corporation facility in South Windsor, Connecticut, and are being delivered to host utilities and other program participants in the United States and Japan for field testing.

The construction of the 46 fully-integrated power plants was completed in January 1985 within the constraints of the contract plan. The program has provided significant experience in the manufacture, acceptance testing, deployment, and support of on-site fuel cell systems. Initial field test results also show that these experimental power plants meet the performance and environmental requirements of a commercial specification.

Purpose of Program

The 40-kW Power Plant Manufacturing and Field Test Program was initiated to establish the operational feasibility of on-site fuel cell energy service and to provide the participating utilities the opportunity to simulate this concept within their individual service territories. An important objective of the manufacturing phase of this program was to demonstrate the capability to produce a quantity of power plants that would repeatedly meet the requirements of the specification and is a significant step in the overall program to introduce fuel cells into commercial service in the gas industry.

Background

The 40-kW Power Plant Manufacturing and Field Test Program is a part of the joint Gas Industry and U.S. Department of Energy (DOE) program and was sponsored by the Gas Research Institute (GRI) and DOE, with the National Aeronautics and Space Administration Lewis Research Center (NASA) executing and administrating the contract with United Technologies Corporation (UTC) (Reference 1). The contract effort was initiated January 28, 1982, and acceptance testing of the 46th power plant was completed on February 5, 1985.

Previous program activity had demonstrated the technical feasibility of on-site fuel cell power plant energy service. This earlier activity had also provided a level of confidence in the technology sufficient to undertake the more extensive field evaluation planned by GRI and DOE. Initial utility participation was through the Team to Advance Research in Gas Energy Transformation (TARGET). The TARGET program was started in 1967 by 28 gas distribution and transmission companies, combination gas and electric utilities, and UTC to investigate the technical and economic practicality of the on-site fuel cell generation option (Reference 2). The first 40-kW PC18 configuration was built and tested in 1974-1978. Subsequently, the design was improved in programs sponsored principally by DOE and GRI, including the Engineering and Development Program, from August 1977 to February 1982 (Reference 3), and the Field Test Power Plant Program, from September 1980 to October 1983 (Reference 4). At the outset of the present 40-kW Power Plant Manufacturing Program, the basic PC18 configuration had been defined and evaluated in 7320 hours of in-plant testing and limited field testing at two utility sites.

The configuration that evolved from these cooperative programs produces 40-kW power at a nominal 40% electrical efficiency and provides thermal energy such that up to 80% overall efficiency is attained using typical pipeline gas. Maximum noise level 15 feet from the operating power plant is 60 dB(A) and exhaust emissions are a factor of 10 below federal standards. The power plant can operate connected to the electric utility distribution grid or independently.

In preparation for the procurement and fabrication of components and subsystems to manufacture the power plants, UTC undertook an assessment of readiness to proceed and presented results to DOE, GRI, and NASA. No technical deficiencies were noted that might prevent the power plant from functioning properly or cause it not to meet the specification requirement.

NASA-Lewis also prepared a power plant readiness analysis and concluded that the power plant design should be able to achieve the planned field test objectives.

ACCOMPLISHMENTS

Following completion of the UTC assessment, preparation of necessary specifications, drawings, and detailed plans was initiated. Part of this included institution of a configuration control program, which incorporates a formalized design system to provide complete documentation and to maintain control for the incorporation of changes found necessary during the manufacturing and test phases.

These formalized procedures have provided for the orderly incorporation of changes throughout the program. The most significant of these changes affected the water-steam coolant loop and resulted from problems uncovered by the two early field test unit test sites before testing of the power plants produced under this program began.

The 46 power plants were fabricated between June 1983, when the initial assembly began, and January 1985 when the 46th power plant was completed. Delivery pace was temporarily slowed in early 1984 after the initial four units had been delivered, when field experience showed that difficulties involving the inverter and grid connect unit (GCU) required correction. Expanded testing of each inverter coupled with its associated GCU was incorporated and deliveries resumed. During the manufacturing phase, design changes and additional quality assurance testing were instituted based on program experience. The overall assembly phase was extended approximately six months from the schedule established in early 1982. However, the fabrication costs were eight percent below the estimate made at the time the contract was signed in January 1982.

The program has provided valuable experience for the procurement, fabrication, assembly, and acceptance testing of a significant quantity of fuel cell power plants, and for the preparation, shipping, deployment, and field support of the units. Although the total impact of the field test program will not be known until the testing is complete and the results are analyzed, results to date indicate the manufacturing phase was successful.

PURPOSE OF REPORT

This Interim Report encompasses the design and manufacturing phases of the 40-kW Power Plant Manufacturing and Field Test Program. The contract between UTC and NASA also provided UTC field engineering support to the host utilities, training programs and associated manuals for utility operating and maintenance personnel, spare parts support for a defined test period, and testing at UTC of a power plant made available from a preceding program phase. These activities are ongoing and will be reported subsequently.

II. POWER PLANT DESIGN

INTRODUCTION

At the start of the 40-kW Power Plant Manufacturing Program, the basic design of a 40-kW Fuel Cell Power Plant had been established and field test experience had been achieved in limited testing of the early field test power plant configuration at two utility sites.

Prior to the initiation of the manufacture and field testing of the 46 power plants, two studies were conducted. UTC completed an independent assessment of readiness to proceed (Appendix A) and, at DOE request, NASA also prepared a readiness analysis. The UTC assessment reviewed the overall design and procurement status to define shortages and to finalize program plans. The NASA study (Reference 5) reviewed power plant experience to that point and concluded that the field test power plant should be able to meet 8000 hours of operation, although nuisance shutdowns and special maintenance were expected since the power plant was still an experimental unit.

This section of the report first describes the process used at UTC to accomplish the design tasks that defined the power plant configuration, and processes used to record, control, and maintain the design changes anticipated as manufacturing and early field testing proceeded. Next, the available technology base used at the start of this program is briefly described. The major portion of this section describes the three fuel cell power plant configurations that resulted from these inputs for the 40-kW Power Plant Manufacturing Program.

DESIGN CONFIGURATION AND CONTROL PROCESS

The 40-kW power plants were designed and manufactured using a formal configuration control system. This consisted of a documented list of parts and components, and provisions to update the list as changes were made.

For effective field service, it was important that all hardware built to the same part number be interchangeable and, if a part were to be modified or replaced, that it still be compatible with necessary interface components. It was also important that records be maintained to document the specific parts in each power plant. Power plant configuration integrity was necessary in order to accomplish program objectives and operating activities in a cost-effective manner. Some of these objectives/activities included: meeting the power plant performance specification, being able to compare results and accomplishments between power plants, being able to trace hardware for problem identification and solutions, supplying spare parts, and minimizing fabrication and assembly costs by having interchangeable parts and components.

The configuration control system used for this program included a detailed bill-of-material as its main feature. In addition, a formal design change procedure was used to ensure accurate record keeping.

The bill-of-material is the key element in documenting and controlling the power plant configuration. Once the total system has been conceptualized and defined and a preliminary design is established, the design is converted into detailed drawings. These drawings, along with specifications and associated data, provide a formal document defining each of the part numbers in the power plant.

Each hardware item and software procedure is uniquely identified and recorded in an indentured parts list. Figure 2-1 shows a typical page from this list. All listed parts, together with their definition specification and software documents, establish the configuration baseline (bill-of-material). Once the parts list is established, the configuration becomes the responsibility of Change Control. The configuration then can only be modified by a formal change procedure.

G0206 MODEL PC18B-3A(K) CODE RZ HISTORICAL ENGINE PARTS LIST DATE 11/29/83 PAGE 1

FC4300-02

GN = GROUP NUMBER IG = INTERCHANGEABILITY GROUP
ML = MINIMUM LETTER APP = APPLICATION CODE
CL = CONTROLLED LETTER PS = PROCURABILITY,SALEABILITY CODES

ITEM	PART NUMBER	UNITS	ASY	APPL	LV	12345678 NOMENCLATURE	GN	ML CL	START EC	A P P	O R G	IG	PS
000050.01	FC4300-02	1	A	A	1	POWER PLANT ASSY-FUEL CELL(PC18B-3A)		K	83PB534	D	D		
000051.01	FC5840-01	1	A	A	2	.SUPPORT & CABINET ASSY-POWER PLANT		C	83PB420	D	D		
000052.01	FC5783-01	1	A	A	3	..SUPPORT ASSY-POWER PLANT		C	83PB370	D	D		
000053.01	FC5584-01	1	A	A	4	...SUPPORT-POWER PLANT,ASSY OF				D	D		
000054.01	FC5584-02	1		A	5	....SUPPORT-POWER PLANT				D	D		
000100.01	FC5584-03	3		A	5	....PLATE-POWER PLANT SUPPORT				D	D		
000150.01	FCMS0425-01			A	5	....COMPOUND-RED PHENOLIC PRIMER				D	D		
000200.01	FC5376-01	1	A	A	4	...SUPPORT-POWER PLANT,ASSY OF		A	83PB356	D	D		
000201.01	FC5376-02	1		A	5	....SUPPORT-POWER PLANT				D	D		
000250.01	FCSP3398-09	4		A	5	....NUT-RIVET,COUNTERSUNK HEAD,.250-28				D	D		
000300.01	FCSP3399-26	4		A	5	....NUT-RIVET,PLAIN HEAD,.500-13				D	D		
000350.01	FC5376-03	1		A	5	....SUPPORT-POWER PLANT				D	D		
000400.01	FC5376-04	1		A	5	....PLATE-POWER PLANT SUPPORT				D	D		
000450.01	FC5376-05	1		A	5	....PLATE-POWER PLANT SUPPORT				D	D		
000500.01	FC5376-06	1		A	5	....PLATE-POWER PLANT SUPPORT				D	D		
000550.01	FC5376-07	1		A	5	....SUPPORT-POWER PLANT				D	D		
000600.01	FC5376-08	1		A	5	....BRACE-POWER PLANT SUPPORT				D	D		
000650.01	FC5376-09	2		A	5	....RETAINER-POWER PLANT SUPPORT			83PB356	D	D		
000700.01	FCMS0425-01			A	5	....COMPOUND-RED PHENOLIC PRIMER				D	D		
000750.01	FC5381-01	1	A	A	4	...SUPPORT-POWER PLANT,ASSY OF				D	D		
000751.01	FC5381-02	1		A	5	....SUPPORT-POWER PLANT				D	D		
000800.01	FC5381-03	2		A	5	....FLANGE-POWER PLANT SUPPORT				D	D		

Figure 2-1. Typical Page, Historical Engine Parts List

Experience from both manufacturing activities and field testing can suggest a change in power plant design. Based on properly documented and approved requests, the Design Engineer modifies the design, documents changes, conducts a design review, and submits a request to Design Drafting after obtaining approvals from Engineering, Quality Assurance, Product Assurance and Safety, and Project Management. Design Drafting prepares the required new/revised drawings, documents the reason for the change, and prepares the necessary paperwork to incorporate the change into the control system.

AVAILABLE TECHNOLOGY BASE

Introduction

The 40-kW On-Site Field Test power plant is a forerunner of commercial fuel cell power plants. This power plant draws directly on technology established during a decade of on-site research and development activities funded by gas utilities and United Technologies Corporation (UTC).

In 1976 a gas industry/UTC program developed the first 40-kW fuel cell power plant. This pilot unit design (PC18A-1) incorporated features suggested from the earlier field testing of the smaller 12.5-kW units. It demonstrated a broad band 40% electrical efficiency and power plant waste heat availability at useful temperatures. The combined output of electricity and heat exceeded 80% overall pipeline gas utilization.

In mid-1977 the Gas Research Institute (GRI) and the U.S. Department of Energy (DOE) began an engineering and development program with UTC to upgrade this pilot unit design. The objective was to define a configuration that could be used for a utility field test of the fuel cell on-site energy service concept. By early 1980 the pilot unit had been redesigned and a specification written (Reference 6). A single power plant (PC18B-1) was built for verification testing. Testing was conducted from April 1980 to February 1982. During this period many problems were uncovered and design and component changes were made, but most of the specification items were verified. Detailed reports of the Engineering and Development Program may be found in Reference 3.

In anticipation of the field test program, three early field test power plants were built under DOE sponsorship and two were deployed in early 1982. Their configuration (PC18B-3) was essentially the same as the verification power plant with a grid-connect capability added. Results of the 3 Power Plant Program may be found in Reference 4.

The 40-kW Power Plant Manufacturing Program was initiated in early 1982 and the first of 46 power plants delivered in November 1983. This power plant design (PC18B-2A/-3A/-5A) incorporated changes resulting from the field testing experience of the early units. As of the end of 1984, 37 power plants had been delivered for on-site evaluation. The manufacture of all 46 power plants was completed in January 1985.

Pilot Power Plant (PC18A-1)

In 1976 a gas industry/UTC program developed a 40-kW experimental power plant reflecting lessons learned from previous field tests. It successfully demonstrated broad band 40% electrical generating efficiency and the availability of power plant waste heat at useful temperatures. This experimental power plant is shown in Figure 2-2. The combined output of electricity and heat exceeded 80% overall pipeline gas utilization, as shown in Figure 2-3.

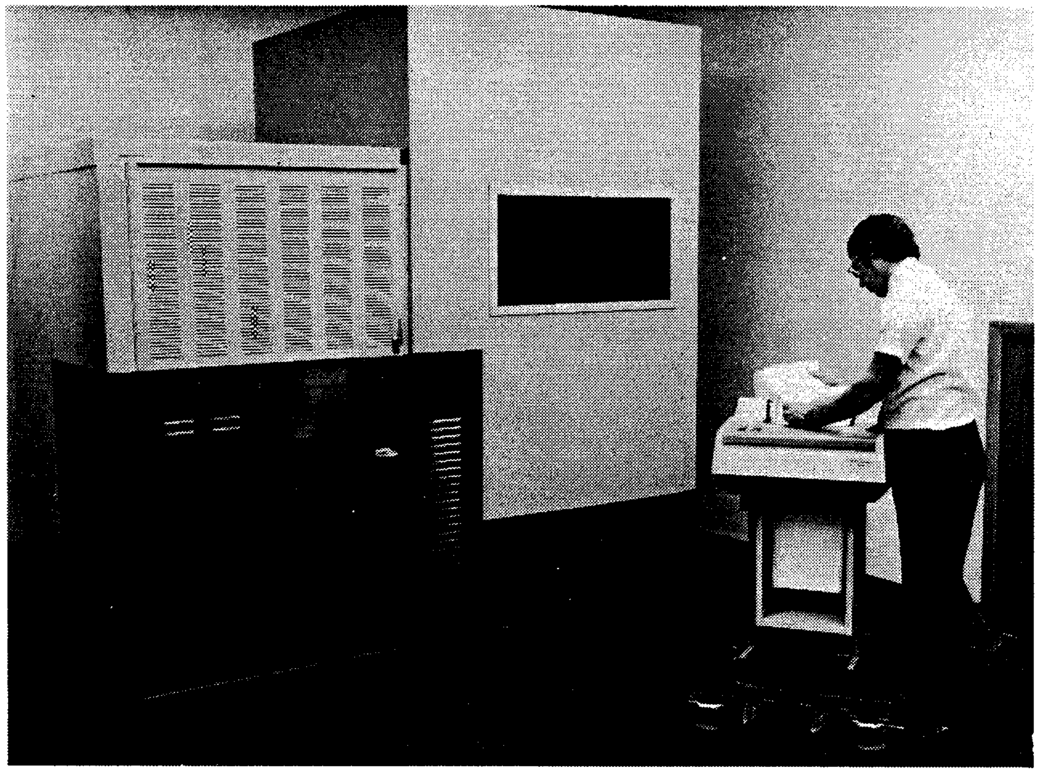

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Figure 2-2. 40-kW Pilot Fuel Cell Power Plant Operating at UTC Facility

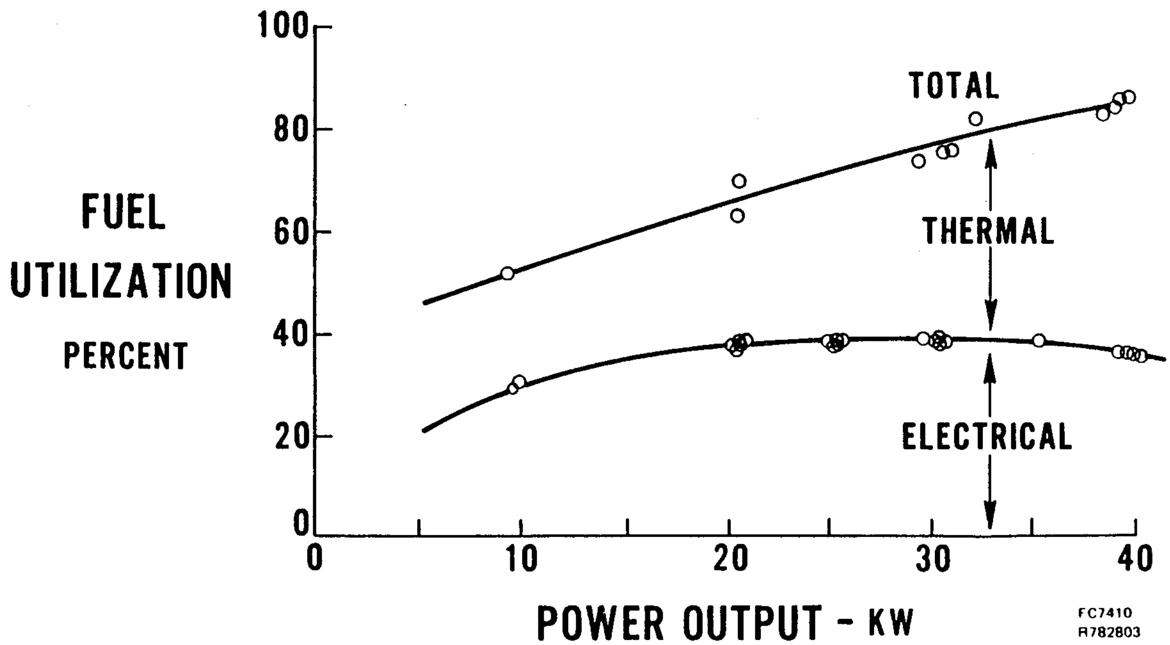

Figure 2-3. 40-kW Pilot Power Plant Performance

Engineering and Verification Power Plant (PC18B-1)

The successful operation of the 40-kW pilot power plant (PC18A-1) resulted in a Gas Research Institute (GRI) and Department of Energy (DOE) sponsored Engineering and Development (E&D) program (The 40-kW Field Test Power Plant Modification and Development Program). The program incorporated technological improvements and customer heat recovery provisions into a 40-kW power plant design (PC18B-1) suitable for a utility field test of the fuel cell on-site energy service concept.

The goals of the E&D program were to further develop on-site fuel cell power plants by: (1) defining the requirements of an on-site power plant, based on previous experience and continuing gas industry input; (2) performing the engineering analysis and developmental activities needed to design a 40-kW power plant and all its components and subsystems; and (3) fabricating and testing a verification power plant.

During this program, safety aspects of the hardware and the power plant were reviewed by the American Gas Association (AGA) and Underwriters Laboratories (UL) (Reference 7).

The 40-kW power plant design (PC18B-1) that emerged from this program was improved over the pilot power plant (PC18A-1). Major improvements made to the power plant are listed below:

The fuel processing subsystem was modified to process virtually all pipeline gases, including peak-shaved gases.

A more active reformer catalyst was incorporated.

The power section was modified to incorporate ribbed-substrate technology and to replace dielectric oil cooling with two-phase water cooling.

The fuel cell electrodes were modified to improve electrochemical efficiency.

The inverter was modified to improve paralleling capability, some of the control functions were changed from electronic to microprocessor circuitry, and an optional grid-connect capability was added.

Byproduct heat recovery was added to permit the power plant to operate in a total energy mode.

An all-weather enclosure was added to permit outside operation in the range -25° to 120°F ambient temperature.

Several other modifications were made to improve the manufacturability, durability, and maintainability of the power plant.

During the time test power plant modifications were being developed, a specification providing a general description and performance characteristics of the field test power plant was completed (Reference 6). The specification includes physical dimensions, thermal and electrical output characteristics, operating and maintenance requirements, efficiency levels, and power rating details.

A power plant (PC18B-1) incorporating the above modifications was built (Figure 2-4) and testing began April 15, 1980. The purpose of the test was to: (1) Evaluate the power plant performance as compared to the specification, (2) Establish a data base of system and component performance, endurance, and maintenance for the Field Test Program, and (3) Identify and, if feasible, incorporate any modifications required to improve reliability, enhance manufacturability, or reduce cost.

Most of the objectives of the test were met by the conclusion of the test program on February 25, 1982, after 7300 hours of operation. All elements of the specification were addressed and most met or bettered the specification (Reference 3D).

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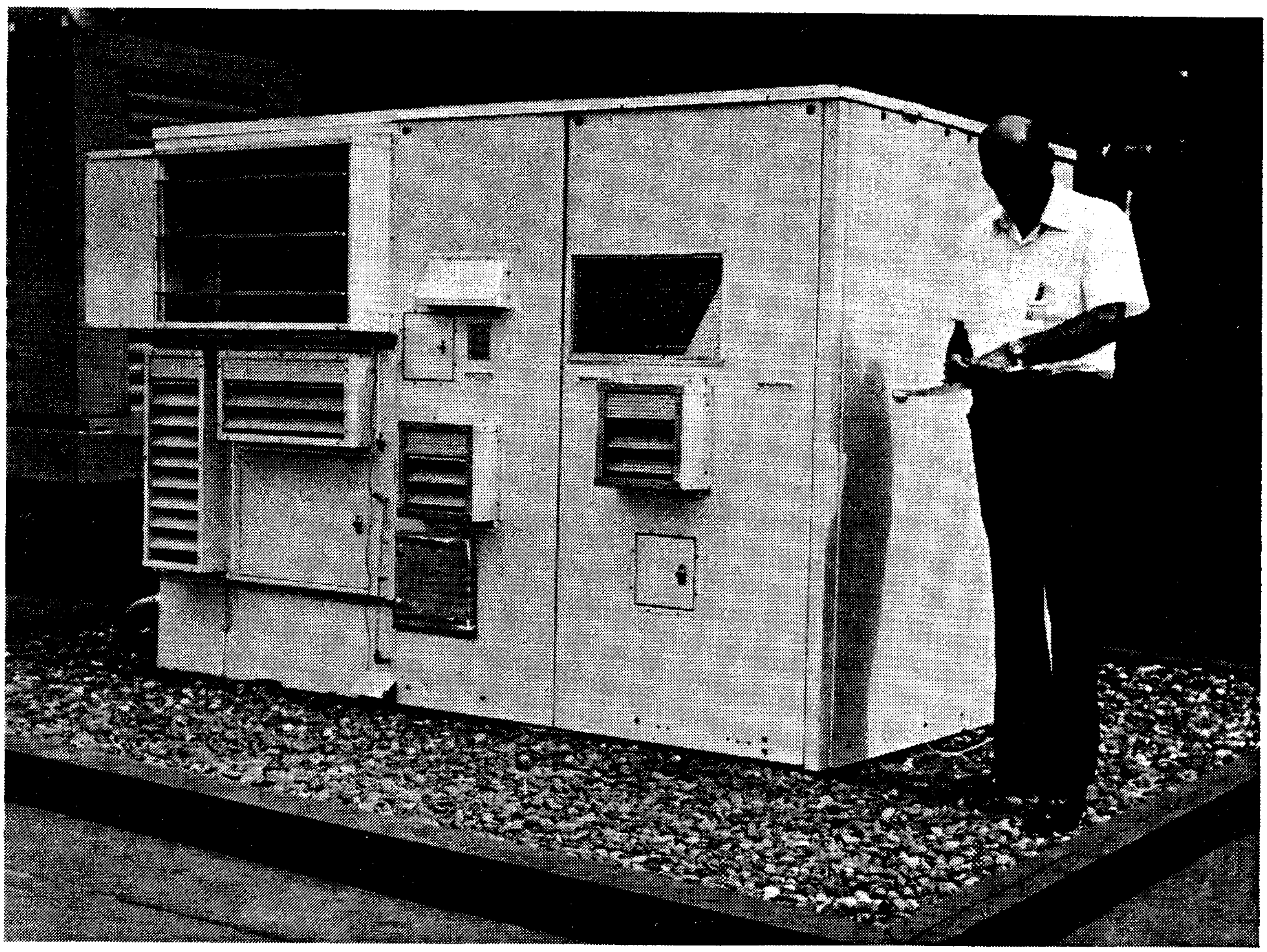

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Figure 2-4. 40-kW Verification Power Plant

Early Field Test Units

In preparation for the anticipated On-Site Field Test Program, DOE sponsored construction of three early field test power plants in 1980 (Reference 4). The design of these early units was designated the PC18B-3 configuration. This design was essentially the same as the verification power plant (PC18B-1), but with a grid connect capability. The grid connect capability was incorporated by adding a separate grid connect unit (GCU) which provided: (1) connection to the utility grid; and (2) protection for both the utility grid and the power plant in case of faults in either. A topical report distributed by UTC under GRI contract 5080-344-0308 (Reference 8) describes the operating and protective functions of the GCU.

The first two power plants were delivered to Northwest Natural Gas in Portland, Oregon, and Northeast Utilities in Vernon, Connecticut, for early field testing. Both of these units were connected to the grid and provided electric and thermal energy to a commercial laundry in Portland (Figure 2-5) and a telephone company switching station in Vernon (Figure 2-6), respectively. These experimental installations accumulated a total of 5900 test hours. The third power plant was held at UTC and subsequently modified to reflect improvements that resulted from the test experience of the two delivered units. This power plant now has the same configuration (PC18B-3A) as the units being delivered for field testing and is being operated at UTC in support of the field test activity.

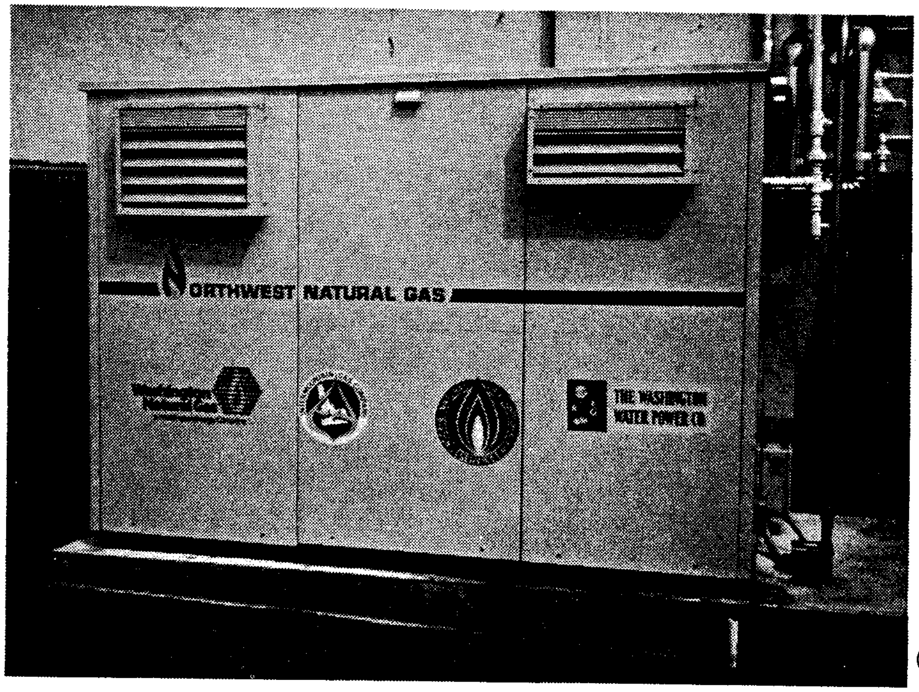

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Figure 2-5. Northwest Natural Gas Installation

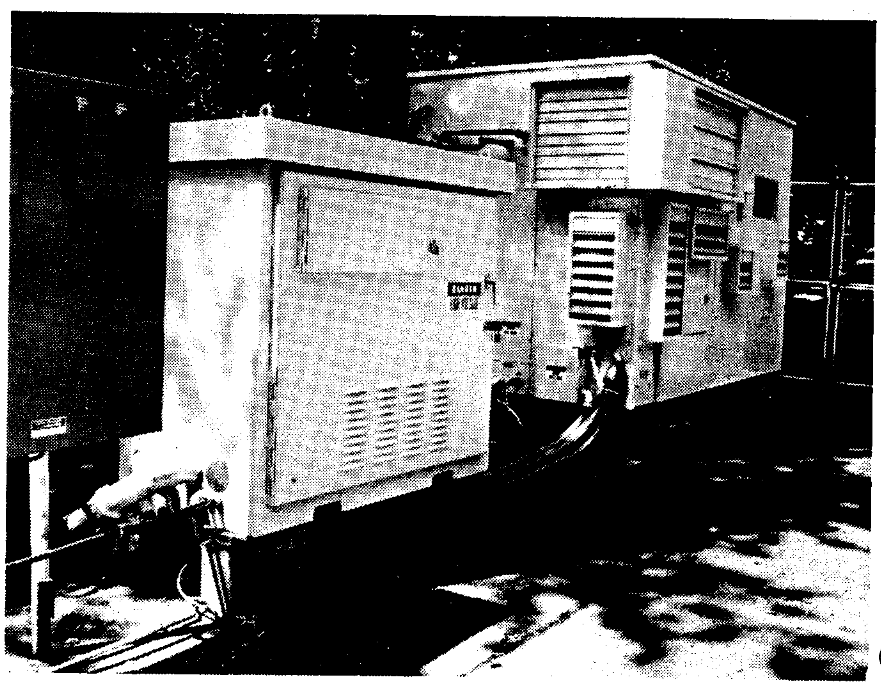

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Figure 2-6. Northeast Utilities Installation

On-Site Field Test Power Plant (PC18B-2A/-3A/-5A)

On July 20, 1981, DOE and GRI signed an agreement to conduct the On-Site 40-kW Fuel Cell Power Plant Manufacturing and Field Test Program. NASA-Lewis Research Center was selected by the sponsors to manage this program, which began in January 1982 and included the manufacture and field test of 46 power plants. The initial design of these 46 power plants incorporated changes resulting from the field testing experience of the PC18B-3 "early" units and includes three specific configurations identified as PC18B-2A, PC18B-3A, and PC18B-5A. These were the basic fuel cell power plant, designed to operate in a grid-isolated (i.e., load-following) mode designated PC18B-2A; the basic power plant plus a grid connect unit designed to operate in the grid-connected mode, designated PC18B-3A; and the basic power plant modified to operate on a 50-Hz frequency grid, which exists in certain overseas areas, designated PC18B-5A.

The major changes from the PC18B-3 design initially were heavy-duty fuel and air control valves, stainless steel elements for condensate preheater HEX 411, coated customer water side of low-grade heat exchanger HEX 513, a commercial condenser HEX 514 with a stainless steel core, and an extended cabinet ("dog house") to provide more room in the areas of the feedwater system, specifically to accommodate the larger coolant pump and condenser that were used.

UTC Readiness Assessment

In preparation for the procurement and fabrication of components and subsystems to manufacture and field test the 46 fuel cell power plants, UTC undertook an assessment of readiness to proceed. An assessment team, representing all relevant disciplines (Design, Materials Control, Project, Production, Engineering, and Quality Control) reviewed all hardware items based on the following criteria. The objective was to identify deficiencies.

Are there any known technical shortcomings?
Are current make/buy decisions valid?
Are there drawing or specification shortages?
Are current vendors adequate?
Are current quality requirements adequate?

This assessment review took place between February 10 and March 16, 1982. (Appendix A provides further information on the review.) The following results were presented to DOE/GRI/NASA in April, 1982:

No technical deficiencies were noted that would prevent the power plant from functioning properly or cause it not to meet the specification requirement.

Several reliability deficiencies were noted and were subsequently corrected by design changes.

HEX 411, 513, and 514 materials
Thermal insulation
Coolant system fittings
Miscellaneous components

Several manufacturing and vendor deficiencies were uncovered. This led to establishing new procedures, new vendors, and some redesigns.

NASA Readiness Assessment

DOE requested NASA-Lewis to prepare a power plant readiness analysis that would explain to field test participants the projected ability of the PC18B-2A/-3A/-5A design to satisfactorily achieve the planned field testing objective of at least 8000 hours of operation per power plant.

As background for this readiness analysis, UTC was requested to prepare a briefing that would cover all details of the verification power plant testing. This presentation was made on March 18, 1982.

NASA-Lewis used the UTC briefing material, combined with their own firsthand knowledge of the testing of the verification power plant, as the basis of their review. Their findings were completed early in 1982 and documented in a Readiness Analysis Report issued in November 1982 (Reference 5).

NASA-Lewis concluded that the field test power plants should be able to meet the desired 8000-hour operation goal. However, they also concluded that nuisance shutdowns and special maintenance should be expected, since the power plant was an experimental unit.

NASA Design Change Review

Operational problems encountered during the field testing of the first field test units produced under this program resulted in the continuous incorporation of design changes to the initial on-site power plant configuration. NASA requested that a limited design review be conducted. The prime objective of this was to review changes that had been incorporated, and to identify uncertainties and risks in the evolved design which might preclude meeting the 8000-hour operation goal.

The design review took place during the August-November 1983 time period. In general, NASA concluded that the design changes were well-founded and engineered (Reference 9). More specific conclusions were as follows.

Numerous technical concerns related to component designs, functional operations, and manufacturing processes were raised. However, with the exception of the power plant coolant system, none of these concerns was deemed serious enough to preclude operation of the power plant for 8000 hours. For the most part, the system failsafe logic was considered adequate to shut down the power plant automatically in the event of a component malfunction, which otherwise could result in a system failure. NASA concluded that the coolant system would require modification or maintenance to achieve 8000 hours of operation.

Design Changes

Many design changes were incorporated into the power plant configuration subsequent to the initial PC18B-2A/-3A/-5A design. Most of these design changes were not significant. Because of the rigorous design process used for this program, any drawing or recording error or any change in vendor part number dictated a corresponding routine design change. These and other routine changes accounted for the overwhelming majority of design changes as the program progressed. Of the 757 changes made, only 61 were considered "major", and the cumulative effect of these modifications was to ensure operation as originally designed, not to enhance performance. Therefore, the power plant specification and description that follow were not affected by these changes, but were confirmed.

A detailed review of these design changes is provided in Section III.

POWER PLANT SPECIFICATION

The specification providing a general description and performance characteristics of the field test power plant was revised in May 1982 (Reference 6B), and a further revision to this specification was issued in July 1983 (Reference 6C).

The following is a summary of the more salient specification criteria:

- Start-up - 4 hours
  - Semi-automatic
  - Gas - 4" H_2O - gas pressure

- Operation on load - Automatic
  - Power Range - 0-40 kW
  - Fuels - Methane
    - Pipeline gas
    - Peak-shave gas
  - Transients - 56 kW for 5 seconds
    - 51 kW (10% imbalance) for 5 seconds
  - Electrical eff. - 40% at 20 to 40 kW (500 hours)
  - Water Recovery - Self-sufficient at 20 kW average load profile at 100°F ambient

- Electrical Characteristics
  - Voltage regulation - ±5%
  - Transient voltage recovery - 2 cycles
  - Fault clearing - 300 amps line-to-line at zero volts for 5 seconds
  - Frequency stability - ± .0002% per year (grid independent)
  - Total harmonic distortion - 8%
  - Electromagnetic characteristics - will not degrade electrical devices at 10 ft.
  - Power factor - 0.85 (40 kW/47 kVA)
  - Noise at 15 ft. - 60 dBA

- Emissions - (pounds/million Btu heat input)

NO_x	0.02
SO_2	0.00003
Particulate	0.000003
Smoke	None
THC	0.02

- High-grade heat - 56,000 Btu/hr at 500 hr at 110°F at rated power
- Low-grade heat - 100,000 Btu/hr at 500 hr at 70°F at rated power
- Shutdown - manual and automatic for safety
- Parallel Operation - Coordinated by a master control unit (MCU)

POWER PLANT CONFIGURATIONS

The fuel cell power plant configurations chosen for the On-Site 40-kW Power Plant Program were identified as PC18B-2A (load following) and PC18B-3A (grid-connect). Both models were manufactured to the design described in UTC Specification FCS-1460, Revision C (Reference 6C). The basic difference between the two models was the addition of a grid connect unit (GCU) in model -3A, which allows the fuel cell power plant to operate at a given dispersed power level connected to the utility grid, independent of customer load requirements. An additional modification to provide 50-Hz output resulted in a third model (PC18B-5A).

Physical Description

A photograph of the 40-kW Fuel Cell Power Plant is shown in Figure 2-7. Exterior dimensions are shown in Figure 2-8. Power plant size permits passage through a standard 6-foot, 8-inch wide double door. Dry weight is approximately 10,000 pounds.

The grid connect unit (GCU) associated with the power plant model PC18B-3A is shown in Figure 2-9. The size of the GCU is shown in Figure 2-10. The GCU weighs approximately 800 pounds and has a weatherized cabinet.

The following functional description is of the basic configuration, PC18B-2A. A description of the differences in the grid connect option, model PC18B-3A, and the 50-Hz option, PC18-5A, is provided at the end of this section.

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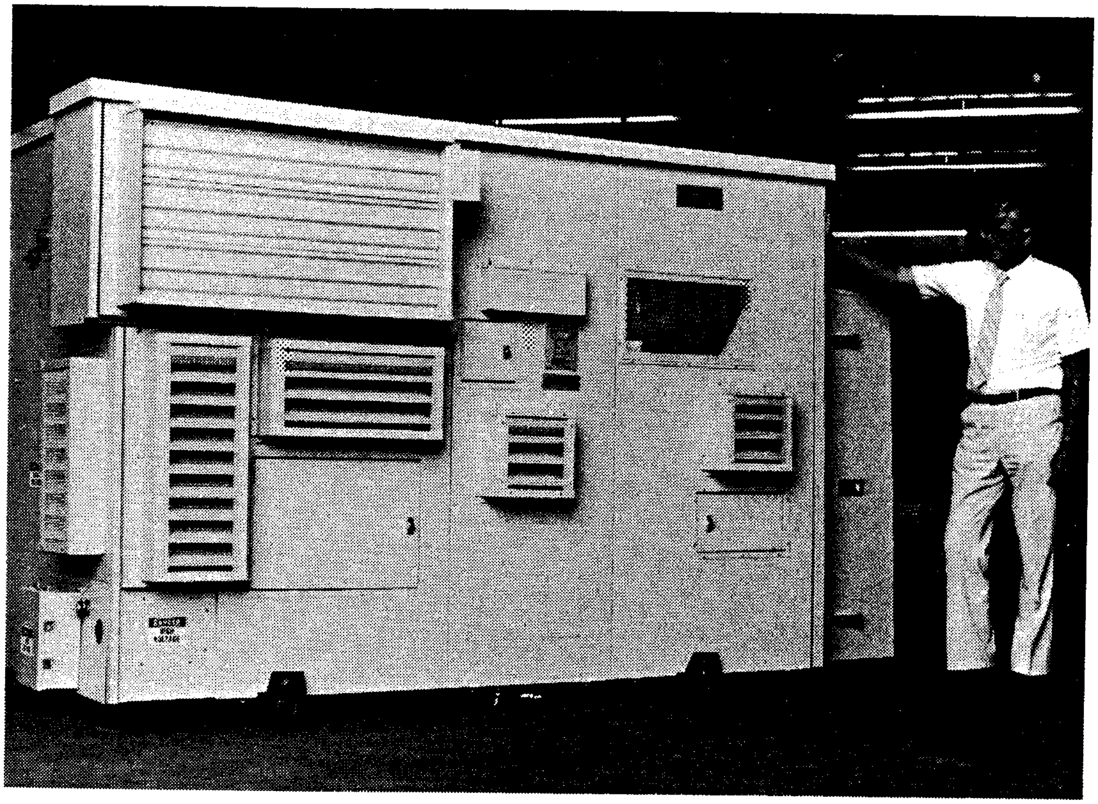

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Figure 2-7. The 40-kW Power Plant

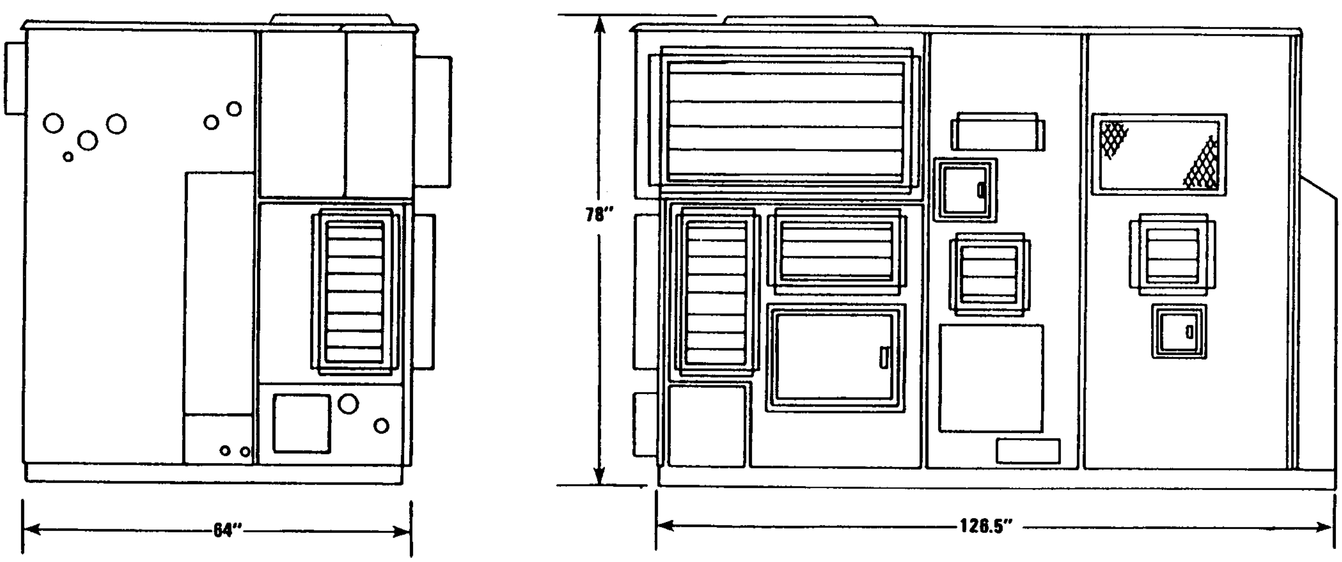

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Figure 2-8. Power Plant Maximum Dimensions

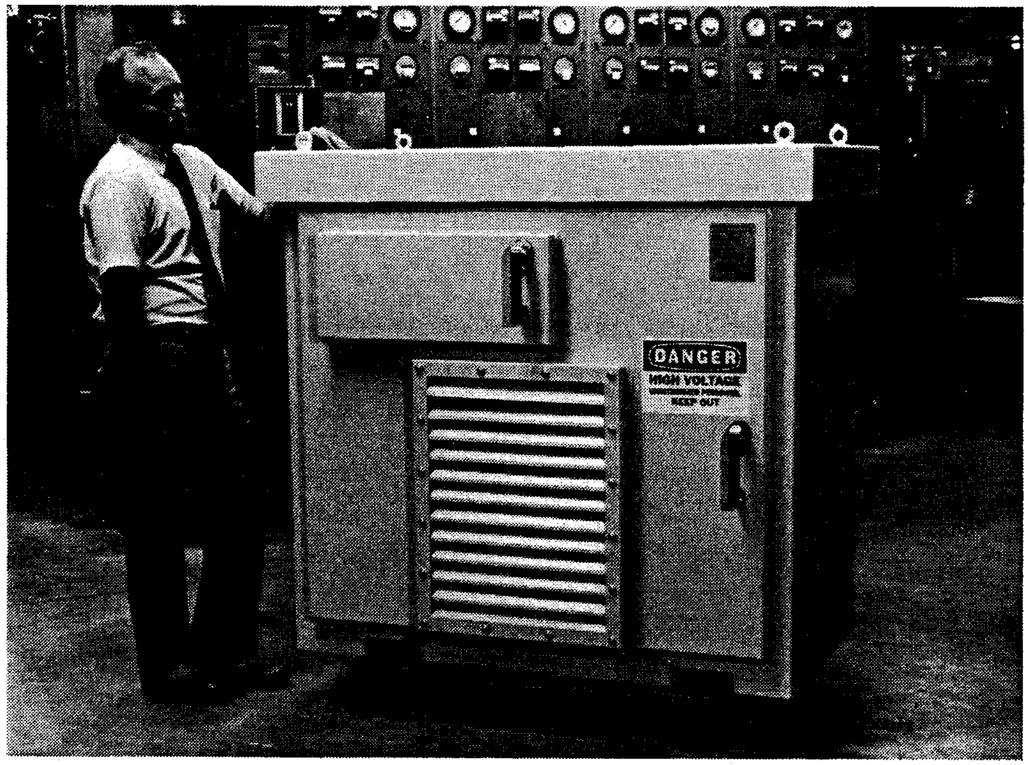

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Figure 2-9. Grid Connect Unit

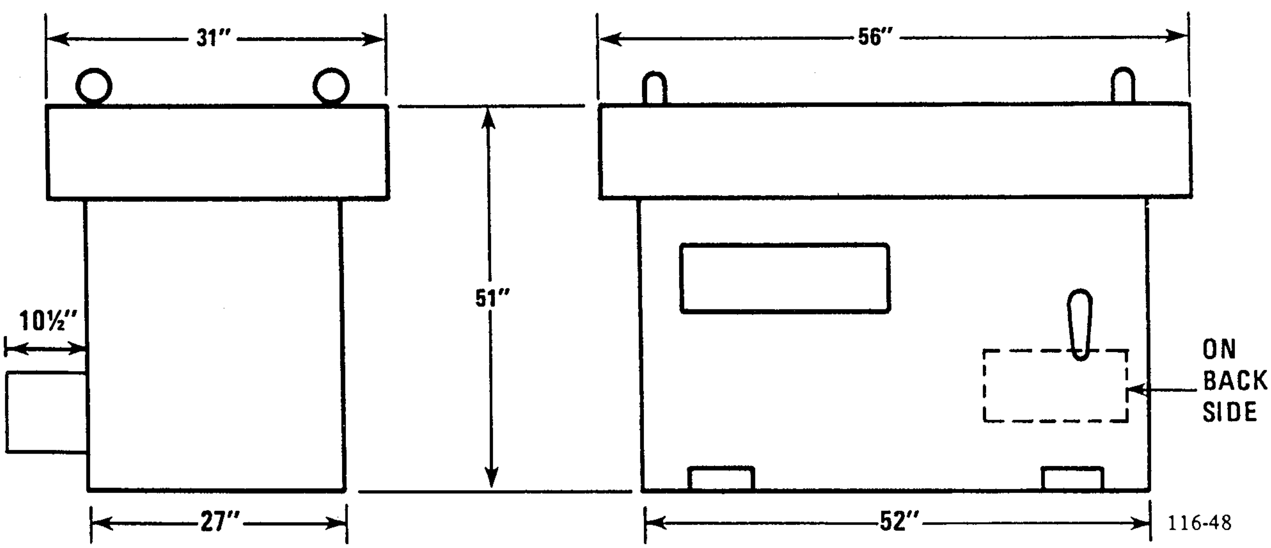

Figure 2-10. Grid Connect Unit Dimensions

Functional Description

The 40-kW Fuel Cell Power Plant consists of the following major subsystems and their associated controls:

- Fuel Processor (including preprocessor)
- Power Section
- Inverter
- Thermal Management (including heat recovery)
- Instrumentation and Control
- Water Treatment

A simplified block diagram of the power plant is shown in Figure 2-11. The location of major components within the power plant is illustrated in Figure 2-12.

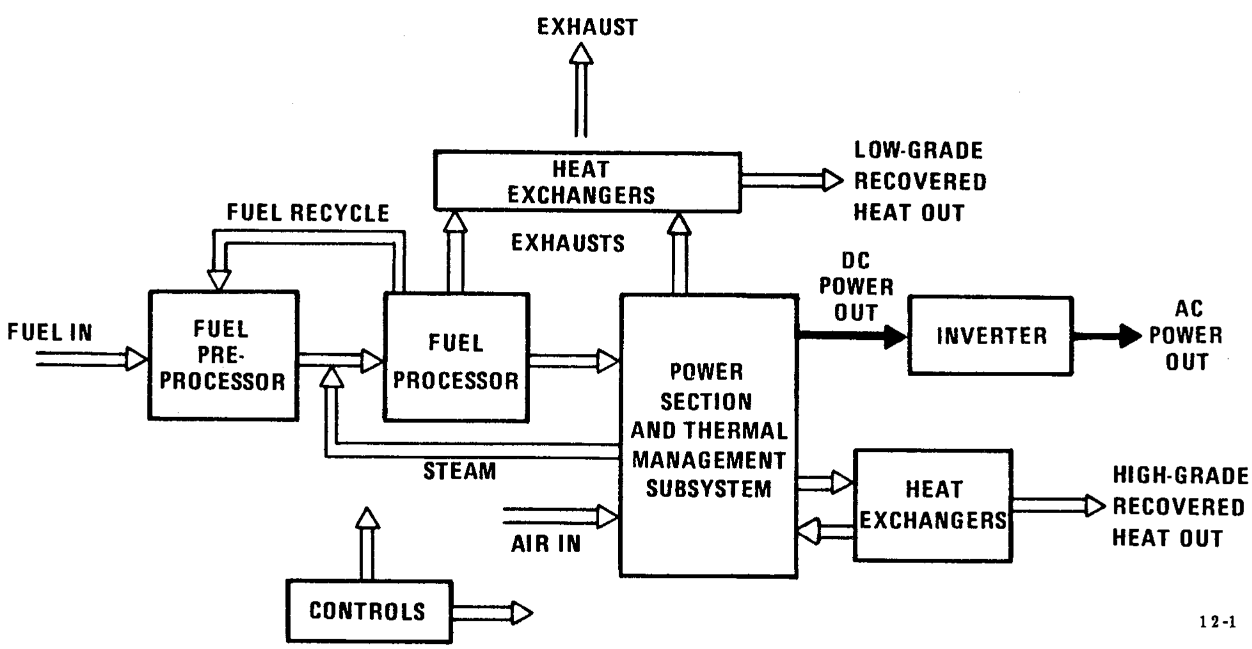

Figure 2-11. Simplified Block Diagram

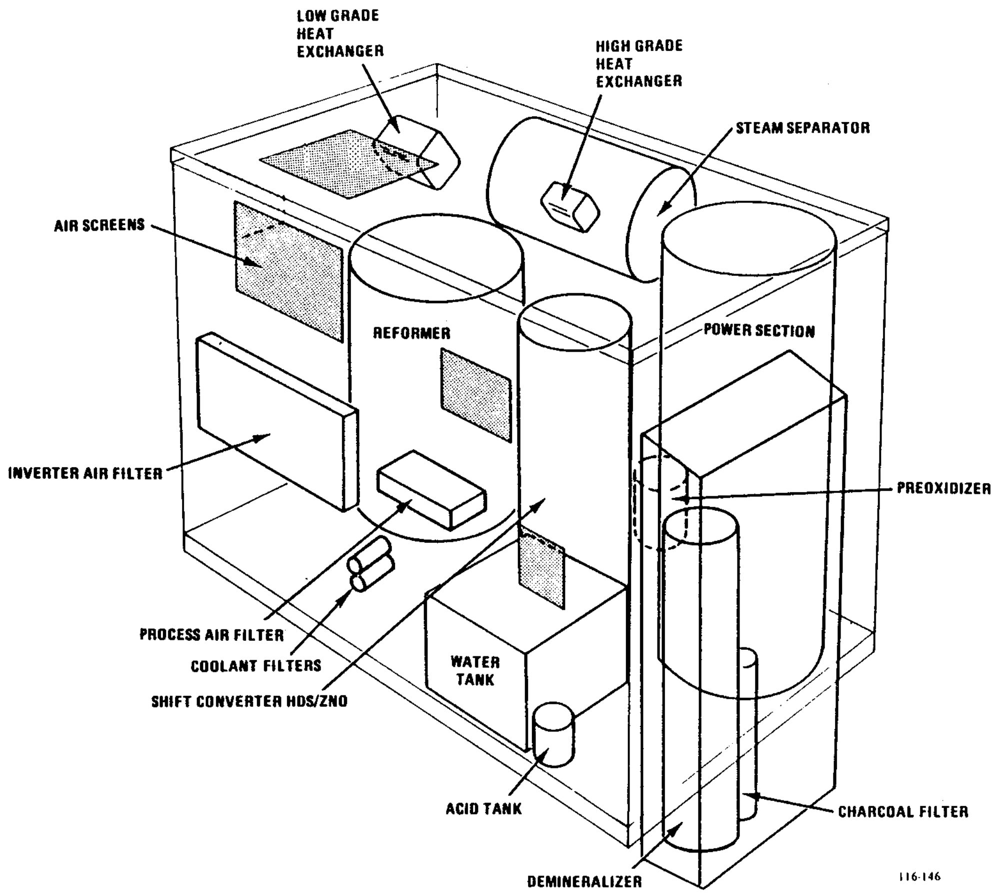

Figure 2-12. Major Component Locations

The function of the 40-kW on-site power plant is to produce utility-grade electricity and to provide recoverable thermal energy. It uses typical pipeline gas fuels. As shown in Figure 2-11, fuel enters the fuel preprocessor subsystem (preoxidizer and hydrodesulfurizer) where it is mixed with a portion of recycled fuel gas that has already been processed. The mixture of fuel and recycled processed fuel flows through the preoxidizer, where oxygen is removed if it is present in a peak-shaved fuel. The fuel stream then enters the hydrodesulfurizer where sulfur is removed. The desulfurized fuel, mixed with steam, enters the fuel processing subsystem (reformer and shift converter) where the fuel and steam are catalytically converted into a hydrogen-rich gas. The hydrogen-rich gas, cooled and filtered, flows to the power section.

The power section electrochemically consumes hydrogen from the hydrogen-rich gas and oxygen from the process air system as it produces direct current. Water is a byproduct of the electrochemical process.

The depleted fuel leaves the power section and flows to the reformer burner where the remaining fuel is consumed with air from the process air system to produce the thermal energy required for the steam reforming process. Reformer burner exhaust combines with depleted air from the power section and flows into the heat exchangers to be cooled for heat and water recovery. The water subsequently is used for fuel processing needs. The thermal management subsystem controls power section temperature by circulating water through the power section. Heat generated in the process of producing power is removed from the power section by changing the circulating water into a two-phase mixture of steam and water. The two-phase mixture flows through heat exchangers, providing customer thermal energy and power plant thermal control. Steam is separated for use in the fuel processing subsystem. The remaining water is recycled through the coolant loop.

DC power from the power section is supplied to the inverter assembly, which converts the unregulated dc output power into voltage-regulated, current-limited ac power with fault-clearing capability. Output power from the inverter assembly is three-phase, 120/208 ± 5% Vac, 4-wire, 60-Hz, and is capable of instantaneous load response.

The heat input required for power plant startup is supplied by two sources: electric resistance heaters in the thermal management subsystem and a burner in the reformer which heats the fuel processor subsystem.

The electrical energy required for power plant start-up is provided by external utility ac power. This also includes the ac power for the separate dc power supply unit needed during start for this design.

A complete schematic showing major power plant components is presented in Figure 2-13.

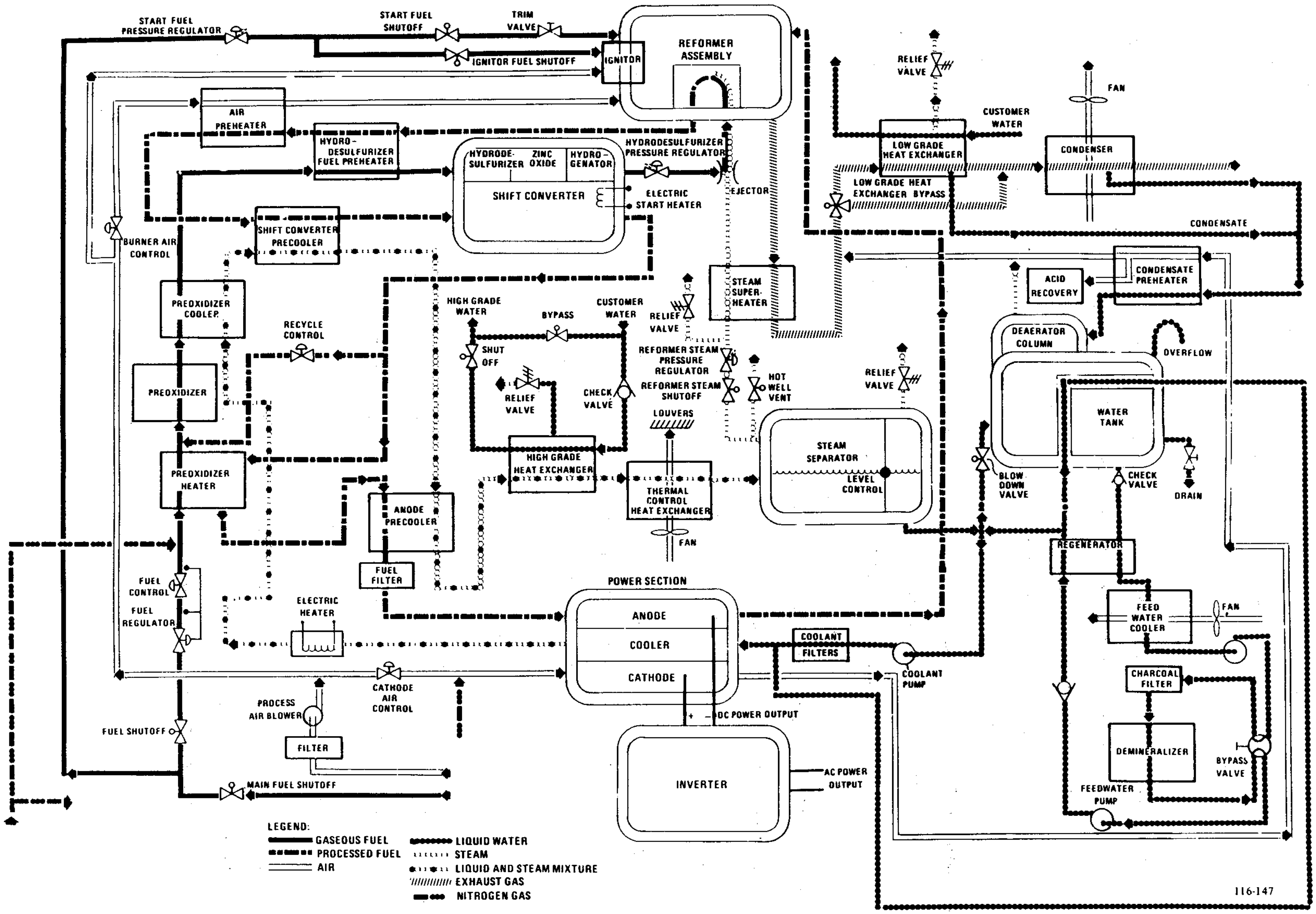

Figure 2-13. Power Plant Schematic Diagram

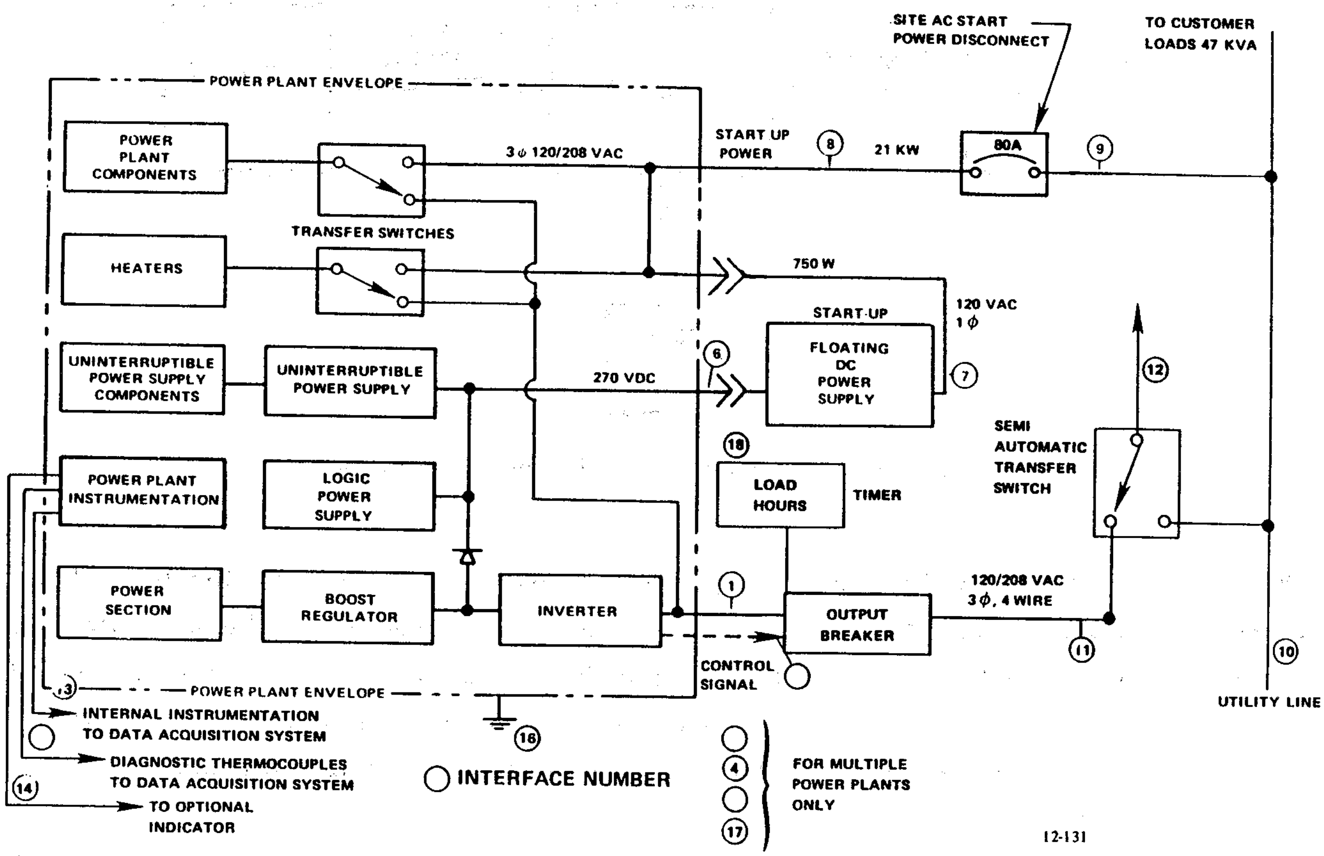

Figure 2-14. Electrical Schematic

Electrical Description - The electrical system and equipment of the power plant is designed, fabricated, and assembled to meet or exceed the requirements and standards of the National Electrical Code, 1978. A simplified schematic is shown in Figure 2-14. The power section converts hydrogen (derived from the fuel) and air into electrical power. The inverter changes the dc power into three-phase alternating current. Following start-up, the inverter and the power section are capable of supplying the power for the power plant components and losses, in addition to the net rated output of 40 kW. The electrical system also provides the means of implementing, monitoring, and controlling the several operating modes (i.e., start, warm-up, on-load operations, shutdown, and standby). A control unit is provided to permit parallel operation of two or more isolated power plants. The power plant electrical system is depicted in block diagram form in Figure 2-15.

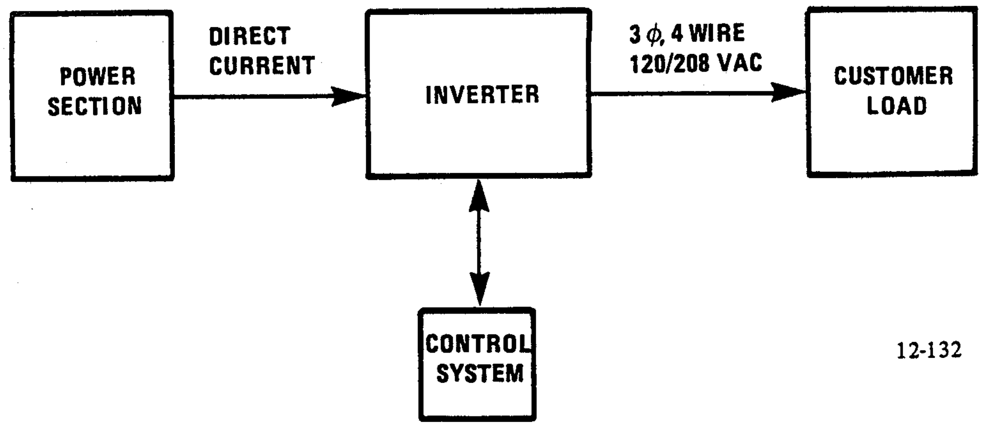

Figure 2-15. Simplified Electrical Diagram

The power section supplies dc voltage to the inverter. The inverter is a three-phase solid-state switch that inverts the dc voltage and regulates the ac voltage at a nominal level of 120/208 volts ac. Single-phase, 120-volt ac is provided through use of a neutral-forming autotransformer. A portion of this power is supplied to the power plant controller, making the power plant electrically self-sufficient.

The inverter provides an uninterruptible power source to maintain operation of critical power plant components during fault-clearing periods of up to 5 seconds. The inverter also provides various ac voltages and a power section output dc current signal for use by the controller.

The power plant controller is a programmed microcomputer which provides the control intelligence for the three basic power plant operating modes: start, run, and shutdown.

A separate master control unit (MCU) is used to parallel power plants in multi-unit installations. The master control unit provides for equal load-sharing among power plants (see Figure 2-16).

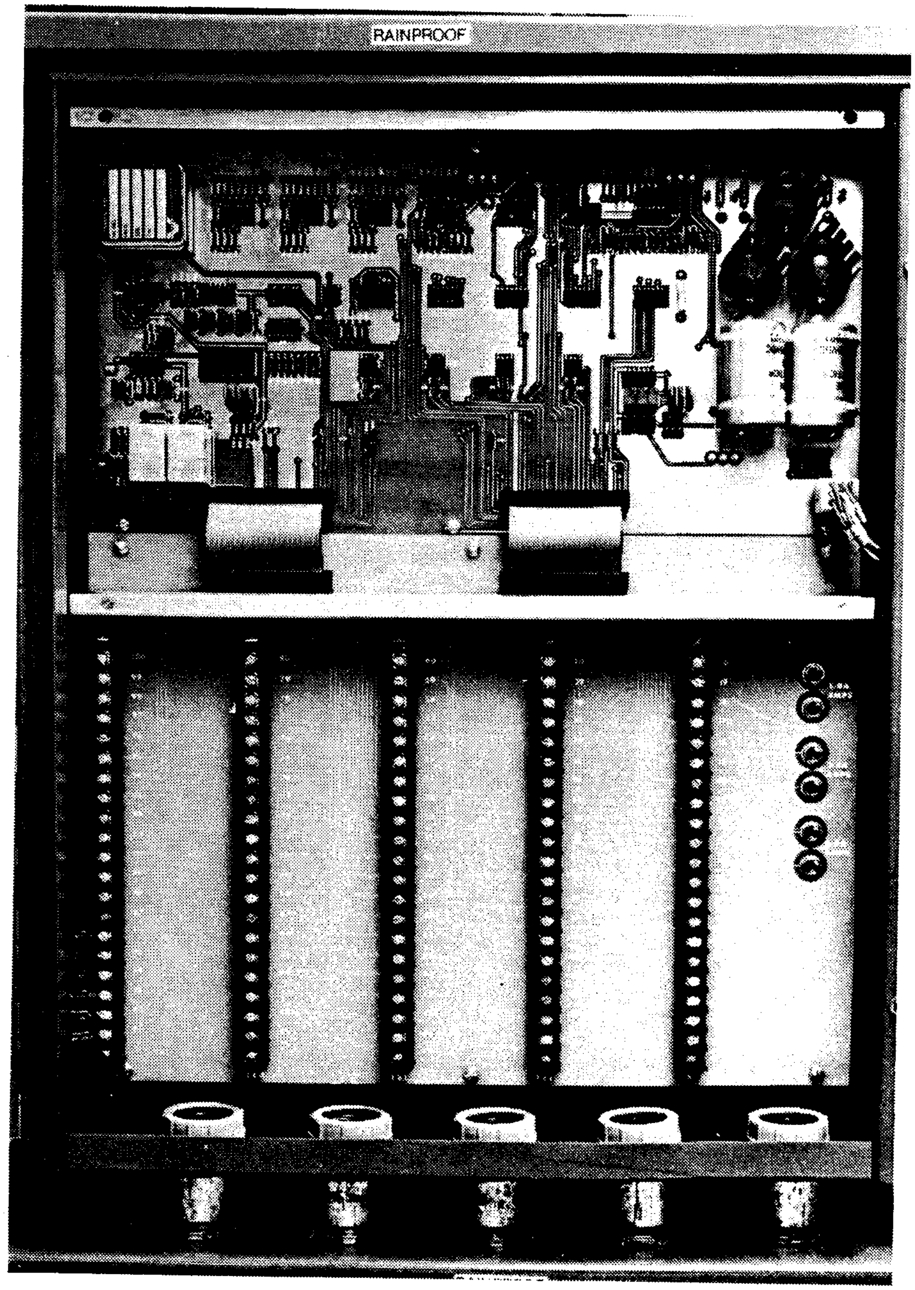

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Figure 2-16. Master Control Unit (MCU)

Heat Recovery System - A schematic of the heat recovery system is shown in Figure 2-17.

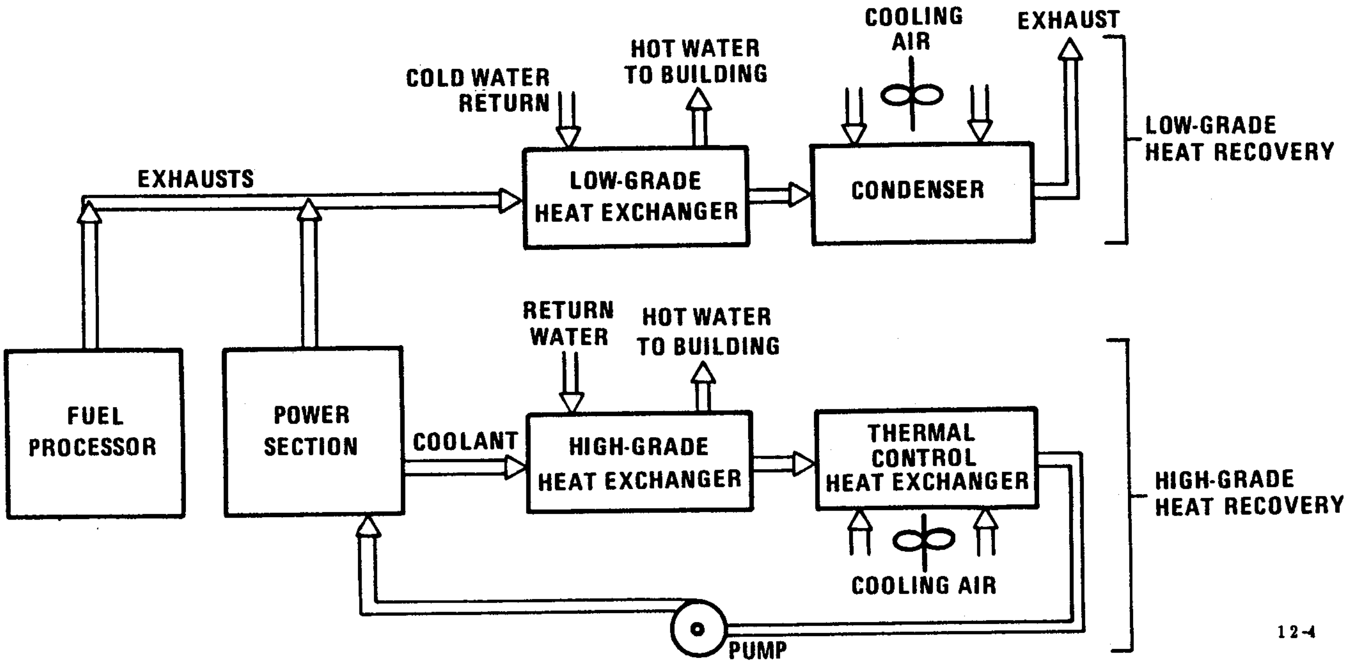

Figure 2-17. Heat Recovery System Schematic

High-grade heat is provided by directing the power section coolant to the high-grade heat exchanger, where water from an external customer loop may be heated to a maximum temperature of 275°F. Low-grade heat is provided by passing the power section and fuel processing exhausts through a low-grade heat exchanger, where heat is transferred to a customer water loop. Under maximum heat recovery conditions a total fuel utilization of approximately 80% is attainable. If either high- or low-grade heat is not required by the customer, air-cooled heat exchangers will automatically provide sufficient cooling for power plant operation.

The heat recovery and thermal management subsystem and equipment of the power plant meet or exceed the intent of the applicable requirements and standards of the following:

ASME Boiler and Pressure Vessel Code, Section VIII, dated 1977.

ANSI B31.1, Code for Pressure Piping, dated 1977.

Operation

Start-up is semi-automatic with a service person present and requires approximately four hours from 70°F ambient conditions. Approximately six hours are required from the minimum startup temperature of 33°F, which is maintained by the auxiliary cabinet heater.

Operation is fully automatic and is load-following. Transient response is within two cycles from zero to rated power output.

Shutdown is either manually initiated or automatically initiated, based on monitoring of critical power plant parameters.

Parallel Operation - Power plant installation may include up to six units with the present master control unit design. Shutdown of any one power plant in a multiple installation will not interfere with the operation of other parallel units.

Environmental Conditions - The power plant has been designed to provide rated power and 5 seconds of overload or current limit operation within an ambient temperature range of -25°F to 110°F. In ambients up to 120°F the power plant will continue to supply rated power, but will have limitations in overload and current limit capacity, as described below (Electrical Characteristics). The power plant is provided with an all-weather cabinet for ease of siting. It has been designed to withstand the environmental conditions specified in Table 2-1. If shutdown occurs at or below an ambient temperature of 32°F, a utility-supplied cabinet heater is used to prevent the water in the power plant from freezing. The power plant is capable of operating at altitudes up to 6,000 feet with some limitation of transient overload capability.

TABLE 2-1. 40-kW POWER PLANT ENVIRONMENT DESIGN PARAMETERS

Ambient Temperature, °F	-25°F to 120°F
Wind (Side Wall), mph	Up to 80
Snow or Ice Roof Load, lb/ft^2	Up to 40
Rain/Wind	1 in/hr/35 mph
Solar Radiation, Btu/ft^2-hr	300
Altitude, ft	Sea Level to 6000
Relative Humidity, %	10 to 100

TABLE 2-2. PIPELINE GAS CONTENT SPECIFICATION

COMPONENT	MAXIMUM ALLOWABLE VOLUME %
Methane	100.0
Ethane	10.0
Propane	5.0
Butane	1.25
Pentanes, Hexanes C_6^+	0.05
CO_2	3.0
O_2	2.5
N_2 (Continuous)	15.0
Total Sulfur	30 PPM_V
Thiophane Sulfur	10 PPM_V
NH_3	1 PPM_V
Chlorine	0.05 PPM_W

Fuel Requirements - Power plant fuel is either pipeline or peak-shaved gas. The allowable range of fuel supply pressure is 4 to 14 inches of water gauge (iwg). Specifications for these fuels, as coordinated with the gas industry, are presented in Tables 2-2 and 2-3.

These specifications encompass virtually all normal gas compositions anticipated for pipeline and peak-shaved gas.

TABLE 2-3. PEAK-SHAVED GAS CONTENT SPECIFICATION

COMPONENT	SPECIFICATION PERCENT OF TOTAL GAS MIX VOLUME
Natural Gas	Minimum 45%
Peak-Shaved Gas Mix	Maximum 55%
Liquified Petroleum (LP) Gas	Maximum 36%
Air	Maximum 23.5%
Propylene	Maximum 10% (Equal to 3.6% in LP Gas)
Maximum Total Sulfur	30 PPM_V
Maximum Thiophane Sulfur	10 PPM_V
Maximum NH_3	1.0 PPM_V
Chlorine	0.05 PPM_W

Design Safety

The power plant is designed so that no single component failure will result in a hazard to personnel or major equipment. The codes and standards presented in Table 2-4 have been selected as applicable and their spirit and intent included in the 40-kW power plant design criteria.

TABLE 2-4. CODES AND STANDARDS FOR POWER PLANT DESIGN CRITERIA

ORGANIZATION AND NUMBER	TITLE
NFPA 70	National Electrical Code
ASME	Boiler and Pressure Vessel Code
ANSI B31	Code for Pressure Piping
UL 795	Commercial-Industrial Gas-Heating Equipment
ANSI Z21.47-1978 (AGA)	American National Standard for Gas-Fired Central Furnaces
U.S. Govt. Title 40	Code of Federal Regulations, Protection of the Environment, Part 60 to 80, dated 1979
U.S. Govt.	Occupational Safety and Health Act

Automatic shutdown controls and sensors are incorporated to prevent unsafe operating conditions and to protect the integrity of the power plant against excessive overloads and faults. The parameters which are detected and cause shutdown include those specified in Tables 2-5 and 2-6.

TABLE 2-5. POWER PLANT AUTOMATIC SHUTDOWN PARAMETERS

Parameter	Limits
Reformer Control T/C Undertemperature	<1250°F
Preoxidizer Exit T/C Overtemperature	>1000°F
Loss of Burner Air Flow (Pressure Sense) or Closed Burner Air Valve	<3" H_2O
Loss of Coolant Flow	<4 GPM for 60 seconds
Steam Separator Coolant Temperature	>392°F
Reformer Control T/C Overtemperature	>1700°F
Cabinet Internal Air Overtemperature	>400°F
Power Section dc Voltage Isolation Breakdown	>2 Amps
Excessive Power Section dc Voltage	≥220 Vdc for 30 seconds
High Anode Exit Temperature	>385°F for 5 minutes
Half-Stack Voltage Out of Limits	>0.75 volts change for 15 minutes
Loss of Inverter Output	0 Vac for 20 seconds
Low Steam Separator Water Level	Separator Empty
Controller Logic Component Failure (Failure of the Analog to Digital Converter)	
Controller Logic Component Failure (Failure of the Timer Module)	

TABLE 2-6. INVERTER AUTOMATIC SHUTDOWN PARAMETERS

Parameter	Limits
Start-up loop failure; program sequence not proper	N/A
Low inverter dc link voltage startup	<260 Vdc
Low power section voltage	<120V
Low inverter dc link voltage	<260V
High inverter dc link voltage	>320V
Phase "A" dc unbalance	I_{dc}>10A
Phase "B" dc unbalance	I_{dc}>10A
Phase "C" dc unbalance	I_{dc}>10A
High inverter ac output voltage	V_{LN}>180V
High inverter ac output voltage	V_{LN}>175V
Abnormal frequency	>66 Hz, <54 Hz
Abnormal volts (high link, low link, low fuel cell) or panel switch "open"	N/A
Blown fuse - inverter pole, blown fuse - boost pole	N/A

Following an automatic shutdown, special instrumentation built into the power plant control system provides an indication of the source of the shutdown.

Noise Characteristics

The maximum free field noise level measured at any point 15 feet horizontally from the perimeter of the power plant, operating with or without blowers on, is estimated to be 60 dB(A).

Performance Characteristics

The on-site power plant is designed for a nominal net ac electrical output of 40 kW. The normal power range is zero to 40 kW with a transient overload capability to 56 kW at unity power factor for a minimum of 5 seconds, under balanced load conditions.

The electrical efficiency goal of the power plant at the 500-hour point of operation is shown as a function of output power in Figure 2-18. The electrical efficiency is based on the lower heating value of the input fuel and the net output power. Actual values will depend on the performance of the specific subsystems, the power consumed by ancillaries and, at part power, by the heat loss from components. The efficiency goal shown in Figure 2-18 was adjusted at the start of the program to reflect the effect of incorporation of a commercially-available but oversized coolant circulating pump. The original E&D power plant and actual field data for many of the present configuration units demonstrated 40% efficiency.

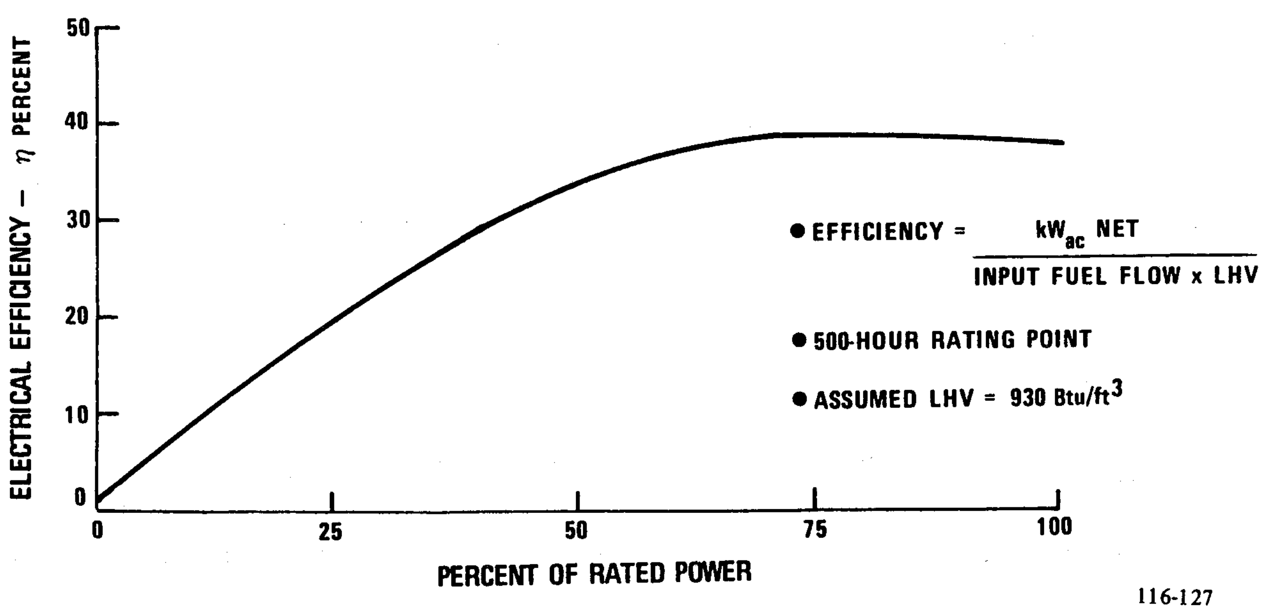

Figure 2-18. Power Plant Electrical Efficiency

TABLE 2-7. ELECTRICAL PERFORMANCE CHARACTERISTICS
Sea Level, 70°F Ambient Temperature

Rated Output Power - kW/kVA Net	40/47
Minimum Net Power -	Zero
Efficiency Goal	Shown in Figure 2-18
Regulated Transient Overload - kW/kVA Net	50/72 at 0.7 power factor under balanced net load conditions
Full Up- or Down-Transient Response	Two cycles or less
Duration of Transient Overload	Up to 5 seconds

The power plant electrical performance characteristics are shown in Table 2-7.

The on-site power plant permits heat recovery as a byproduct of electrical generation. Recovery of this heat results in high total fuel utilization. Total fuel utilization as a function of output power is shown in Figure 2-19.

Electrical Characteristics - Under normal, specified conditions, the power plant produces three-phase, ac power and has a steady-state, full-load rating of 40 kW and 47 kVA. Rated power is available at the power plant interface for imbalanced loads not to exceed 75 A between any two phases:

$$(I_{MAX} - I_{MIN}) < 75A$$

where: I_{MAX} is the maximum output current of any phase and I_{MIN} is the minimum output current of any phase. The power plant is capable of continuously producing any power between no-load and full-load. The power plant responds to full-load step changes (up or down) within two electrical cycles and sustains normal operation thereafter. The phase separation of the output voltages is within 120 ± 5 electrical degrees. Within specified steady-state load conditions, the total harmonic

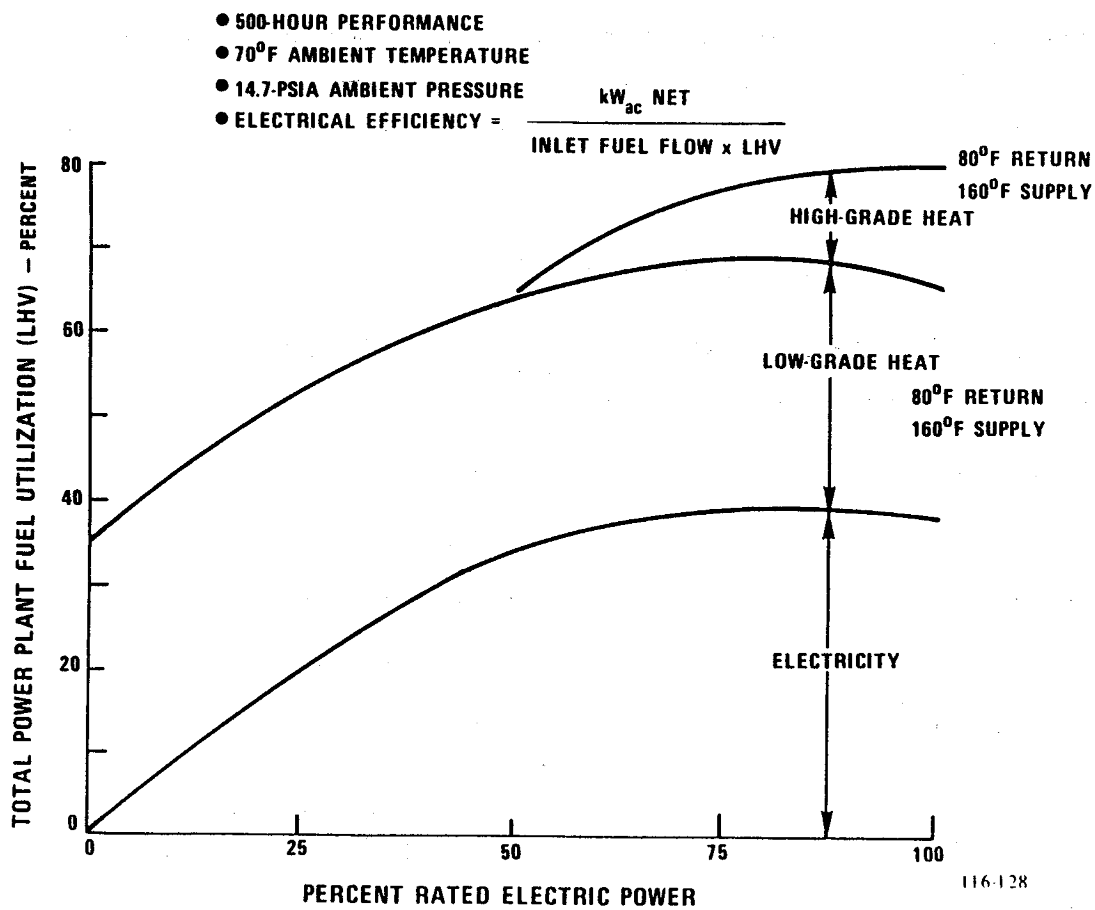

Figure 2-19. Total Power Plant Fuel Utilization

distortion of the output does not exceed 8 percent. The power plant sustains balanced overloads up to 56 kW at 80 kVA, and 10 percent unbalanced overloads up to 50 kW at 72 kVA for durations up to five seconds.

The inverter incorporates a rapid-action, current-limit feature to allow the output current to reach the zero-voltage fault-clearing value without exceeding the inverter power handling capability. Under fault conditions the inverter current shall not exceed 300 A rms for line-to-line short circuits and 450 A rms for line-to-neutral short circuits. Maximum duration of the current limit is 5 seconds. The power plant automatically interrupts output service to faulted loads lasting for more than 5 seconds. However, the power plant continues to operate in a standby mode to permit reconnection to the load after overload conditions have been corrected.

The foregoing overload characteristics apply for temperatures between -25°F and 110°F and for altitudes between sea level and 1000 feet. The duration of overload transients are reduced to 2 seconds for ambient temperatures between 110°F and 120°F.

The electrical characteristics are shown in Table 2-8.

TABLE 2-8. ELECTRICAL OUTPUT CHARACTERISTICS FOR ISOLATED OPERATIONS

Output Power Form	Three-phase, 4 wire
Frequency	60 hertz
Frequency Stability	± 0.0002 percent per year
Voltage	120/208 Volts ac
Voltage Regulation	±5 percent up to 72 kVA under balanced conditions
	±5 percent to 47 kVA with load unbalance (I_{MAX} - I_{MIN}) < 75 Amperes
Voltage Recovery	Within 2 cycles
Phase Separation	120° ±5° electrical
Current Limit	Up to 300 amps rms for line-to-line short circuits and 450 amps rms for line-to-neutral short circuits
Maximum Duration of Current Limit	5 seconds
Total Harmonic Distortion	≤8 percent
Electromagnetic Noise	Will not degrade performance of conventional electrical equipment located further than 10 feet from the power plant

Heat Recovery Characteristics - The power plant has the capability of transferring byproduct heat from the exhaust gases to a customer water loop by means of the low-grade heat exchanger.

Under design point conditions, the power plant is capable of heating 150 gal/hr of hot water at a supply temperature of 160°F, with a return temperature of 80°F. The quantity of heat delivered as a function of output power is in accordance with that shown by Figure 2-20.

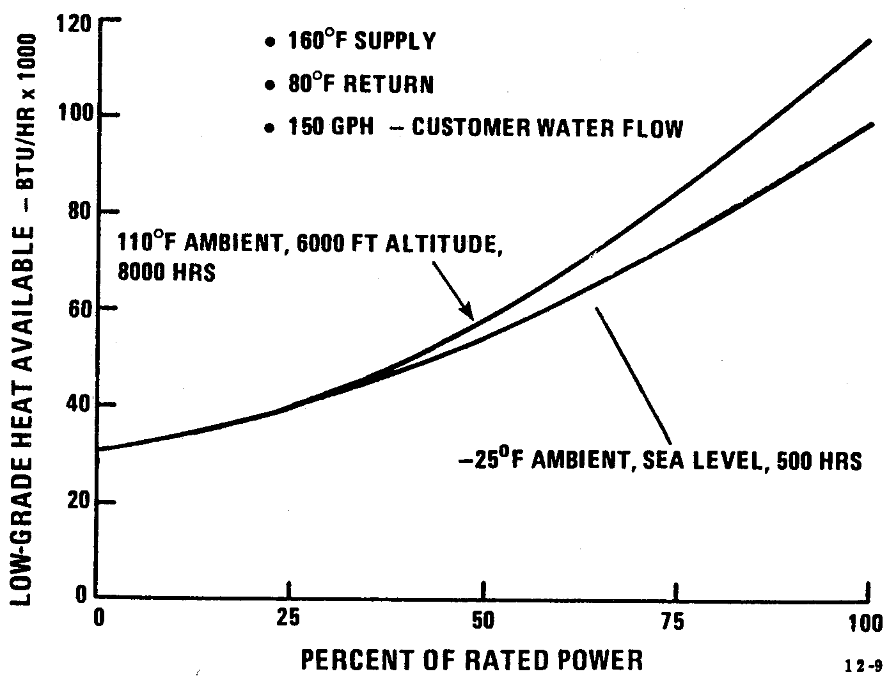

Figure 2-20. Low-Grade Heat Availability

The power plant permits the customer to control the hot water flow rate and temperatures. Usable low-grade heat energy at full electrical load is shown in Figure 2-21 as a function of supply temperature for a permissible range of flow rates and return temperatures. The estimated accuracy of these values is ±10%.

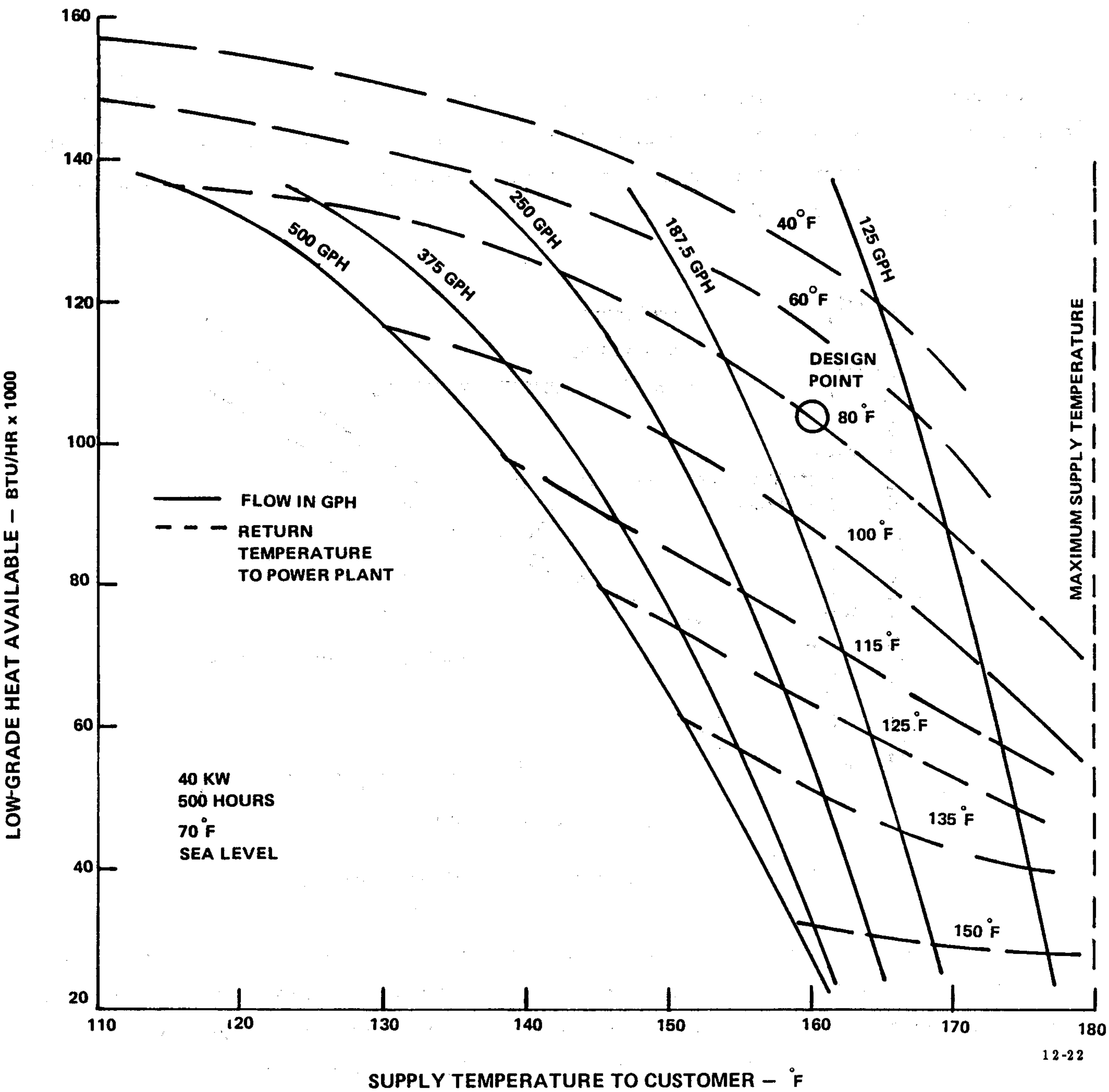

Figure 2-21. Low-Grade Heat Exchanger Performance

The power plant has the capability of supplying high-grade heat for hot water up to 275°F. High-grade energy is controlled by the power plant and is only delivered when excess is available from the cooling system. When excess heat is not available, the customer side of the high-grade heat exchanger is bypassed.

The design point for high-grade heat recovery is to heat 100 gal/hr of hot water at a supply temperature of 80°F. The thermal energy available as a function of rated output is shown in Figure 2-22. Some high-grade heat is available at low power plant electrical load if the energy added to the thermal management loop is greater than that required to maintain thermal control. This can occur during operation of the power plant independently of the thermal control logic when the heaters are activated by the controller stack protection logic to maintain a minimum electrical load on the cell stack. Low-power high-grade heat availability varies greatly at a given low-power level as a function of control deadbands and stack performance level.

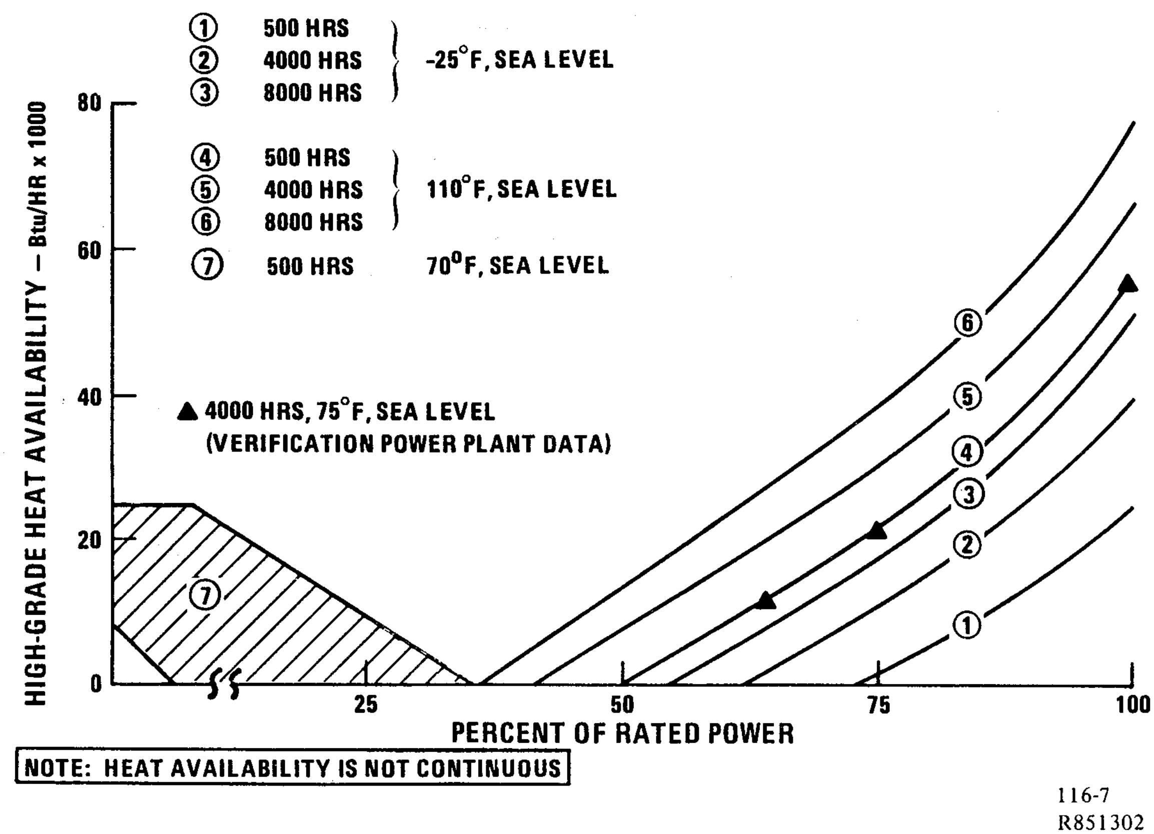

Figure 2-22. High-Grade Heat Availability

High-grade heat is available over a reasonable range of flow rates and temperatures that may be controlled by the customer. The quantity of high-grade heat available from the power plant under full electrical load is shown in Figure 2-23 for the permissible range of flow rates and input/output temperatures. Again, the estimated accuracy is ±10%.

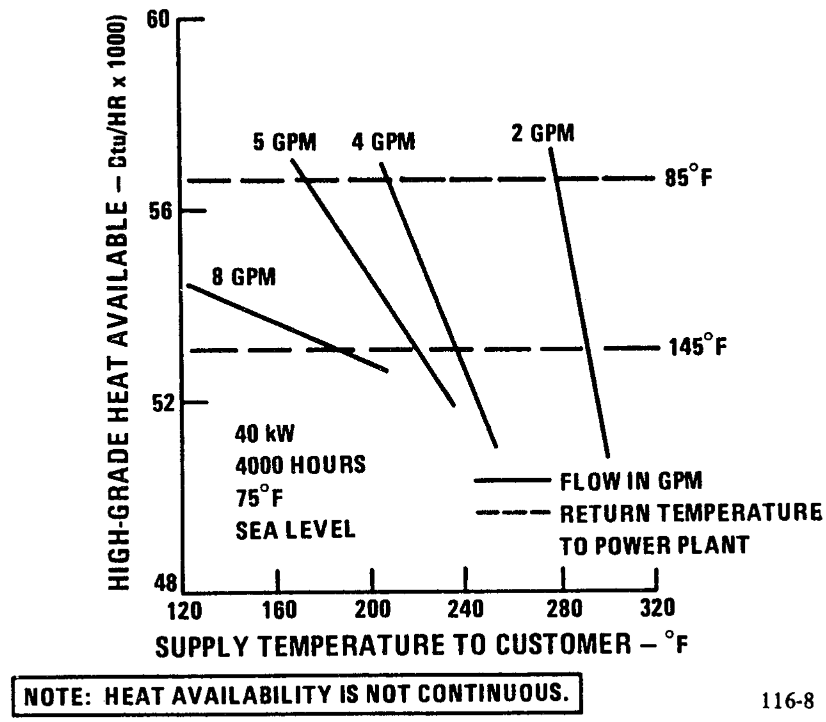

Figure 2-23. High-Grade Heat Exchanger Performance

Emission Characteristics - Using the fuels specified (Fuel Requirements), power plant exhaust emissions shall be below the maximum acceptable limits allowed by state and federal standards. Under any load up to full load, exhaust emissions of the power plant are estimated to be as shown in Table 2-9 when operated on pipeline gases within the content limits specified by Table 2-2.

TABLE 2-9. ESTIMATED POWER PLANT EXHAUST EMISSIONS

Emission	Emissions, Lb Per Million Btu Heat Input
NO_x	0.02
SO_2	0.00003
Particulates	0.000003
Smoke	None
Total Hydrocarbons	0.02

Water Recovery Characteristics - Water to satisfy the coolant loop and fuel processing steam requirements is provided by condensing the power section and reformer exhausts and collecting the water. The power plant exhaust condenser provides sufficient water recovery to permit operation under normal load requirements and ambient conditions. At high load and high ambient temperature, water condensed by the low-grade heat recovery system is required. These characteristics are described below:

Water recovery in the 40-kW power plant is a strong function of ambient temperature, as illustrated in Figures 2-24, 2-25, and 2-26. Without the low-grade heat recovery system, all water must be condensed in the exhaust condenser. At high load and high ambient temperature, a water recovery deficit will result. The figures (based on early test results) show the relationship of load, ambient temperature, and recovery water. For future designs, resizing the condenser would improve water recovery characteristics.

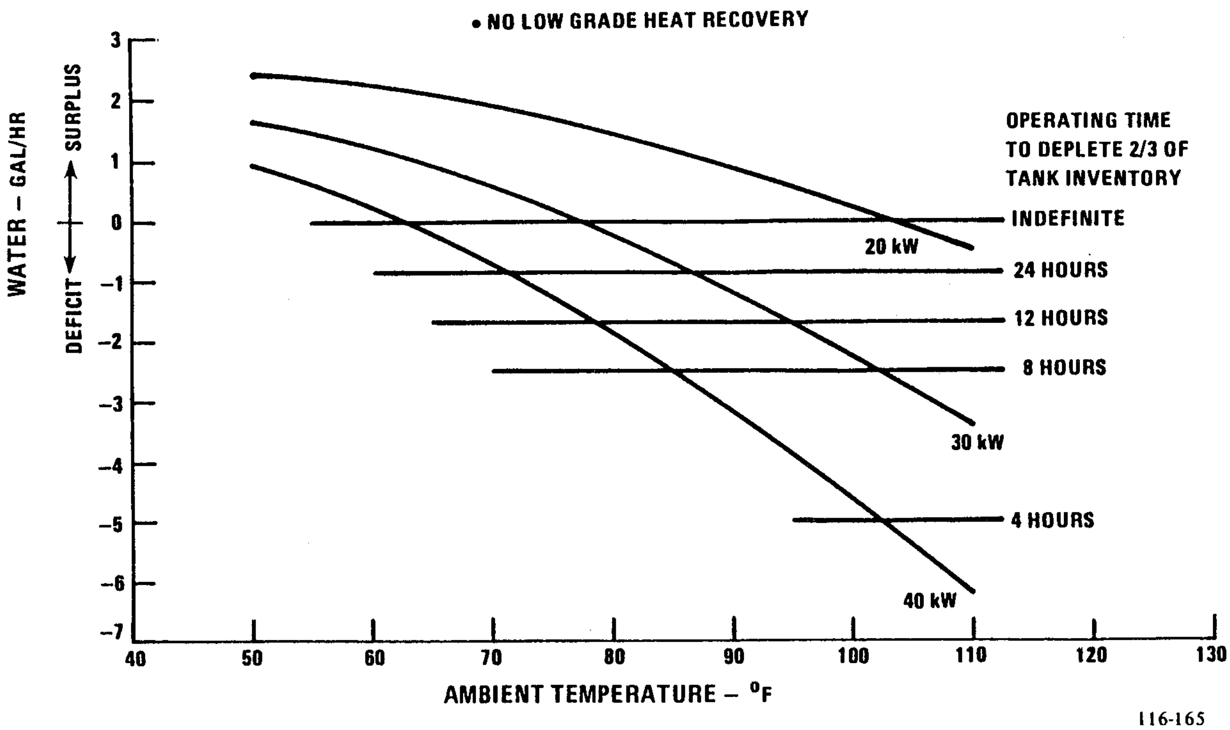

Figure 2-24. Water Recovery with No Low-Grade Heat Recovery

The water tank has a 25-gallon capacity of usable water. Therefore, the power plant can sustain a significant number of hours with a water recovery deficit. Any time the ambient temperature is less than 65°F, the water tank will fill again at any load up to 40 kW.

The curves show significant increase in water recovery if the low-grade heat recovery system is used. At times of high ambient temperatures, the use of low-grade heat recovery is recommended to satisfy the water requirements of the power plant. If this is not possible, the power plant load should be reduced accordingly or other means of heat rejection employed. For example, on a 90°F day with no heat recovery, the power plant will recover sufficient water at a load of approximately 25 kW or less.

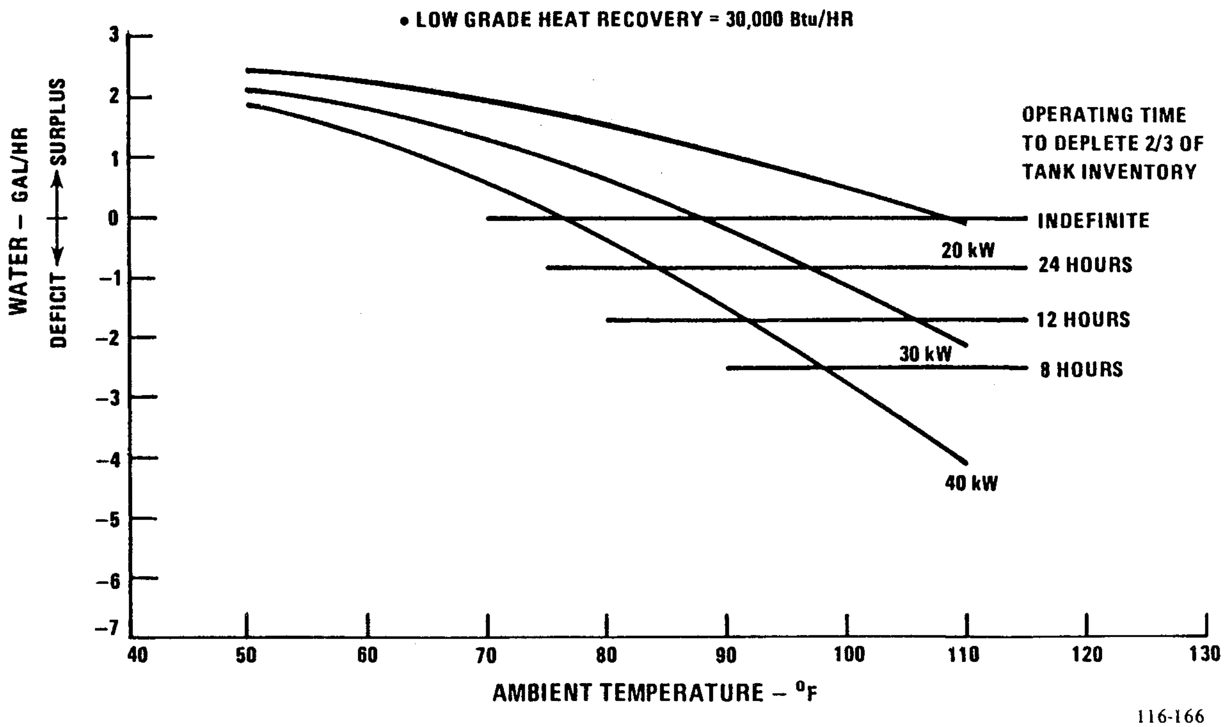

Figure 2-25. Water Recovery with Low-Grade Heat Recovery Equal to 30,000 Btu/hr

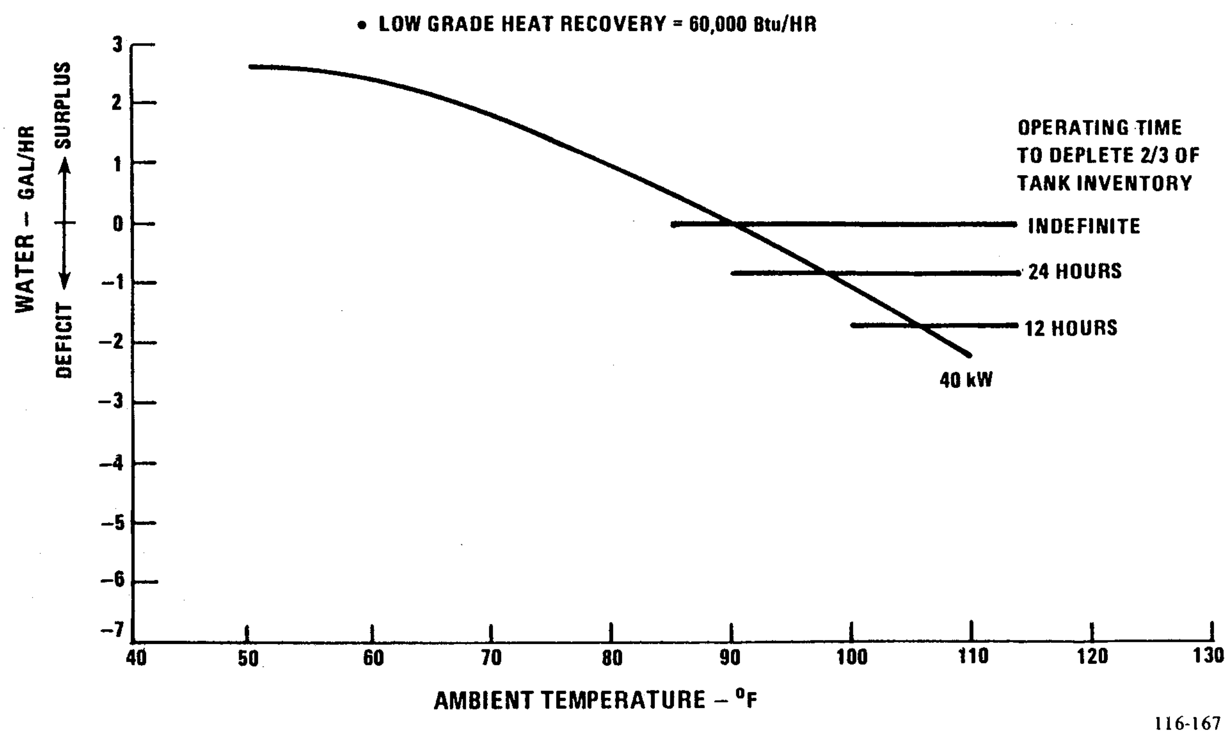

Figure 2-26. Water Recovery with Low-Grade Heat Recovery Equal to 60,000 Btu/hr

50-Hertz Frequency Configuration

In certain overseas areas the utility grid operates at 50 Hz frequency. The basic power plant was modified to provide 50 Hz power from the inverter, but required a utility-supplied 50 to 60 Hz frequency converter to allow normal operation of power plant internal electrical and mechanical controls without a complete redesign. The 50-Hz configuration was designated PC18B-5A and is also a grid-independent power plant.

Grid-Connected Power Plant

The 40-kW Power Plant (PC18B-2A) as described in the preceding sections was designed to operate independent of the utility grid, respond automatically to changes in load demand, and include protection for out-of-limits conditions in the load served, as well as for malfunction within the power plant.

An optional configuration that would permit the power plant to operate directly connected into the utility grid was requested by the program sponsors. This configuration was attractive to potential combination utility participants (gas and electric). In the interest of time and expense, it was decided to add this feature to the program by designing a separate grid connect unit (GCU) and not by redesigning the complete power plant. The resulting GCU also included proper interfacing with the utility line and protection functions and limits. Technical personnel representing utility companies participating in the program provided input and guidance to the design and specification of the grid connect unit. This effort was accomplished under a cost-shared contract with NASA, GRI, and the participating utilities.

The 40-kW grid-connect fuel cell power plant is housed in two enclosures. These are shown pictorially in Figures 2-27 and 2-28 and in one-line diagram form in Figure 2-29. The basic power plant, shown in Figure 2-27, is essentially the same as model PC18B-2A with some inverter modifications to accommodate the interface with the grid connect unit. The smaller unit, shown pictorially in Figure 2-28 and with dimensions in Figure 2-30 is the grid connect unit (GCU). It contains the switchgear, magnetics, and control/protection equipment that provide grid-connect operating capability. The GCU is designed to "plug in" to the basic power plant via connection of power cabling and logic control/protection cabling. The GCU provides the capability for both grid-connected operation and automatic transfer to grid-independent operation of selected isolated loads, if the utility line is unavailable or if isolated operation is desired. A more detailed description and explanation of the grid connect unit logic design and modifications to the basic PC18B-2A inverter logic is provided in Reference 8.

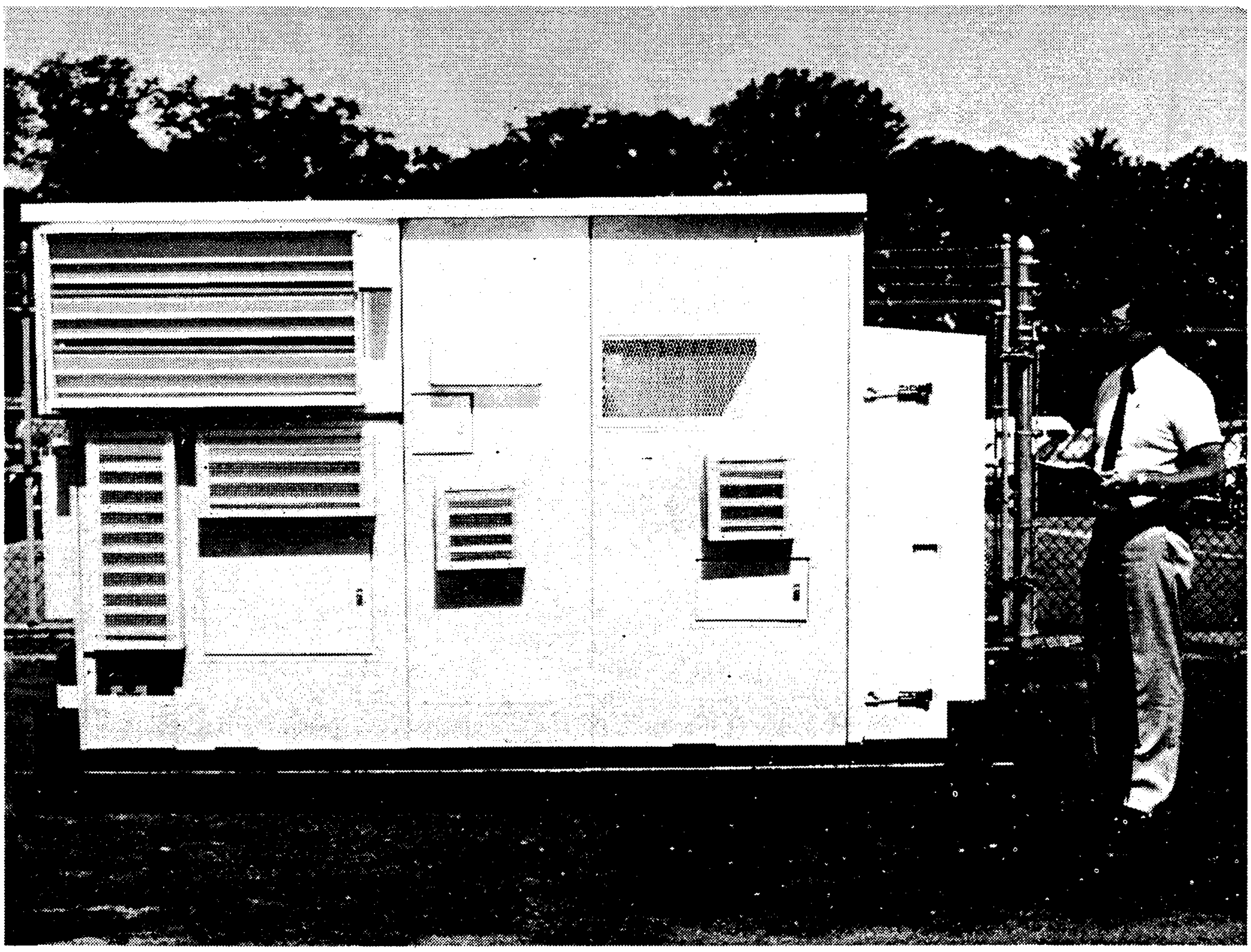

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Figure 2-27. Grid-Independent Power Plant

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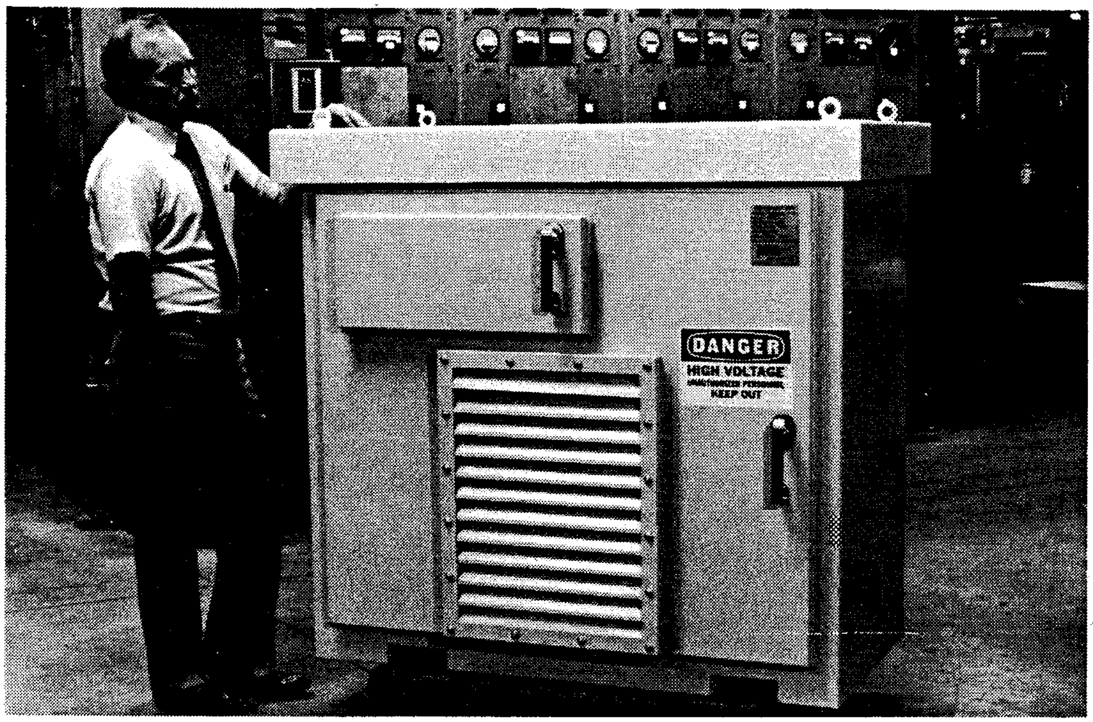

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Figure 2-28. Grid Connect Unit

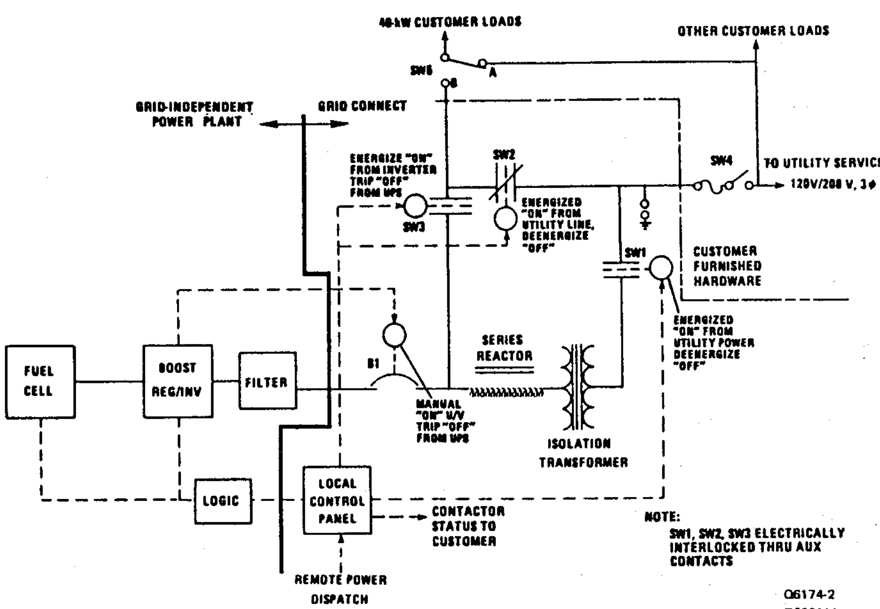

Figure 2-29. 40-kW Grid-Connect Power Plant One-Line Diagram

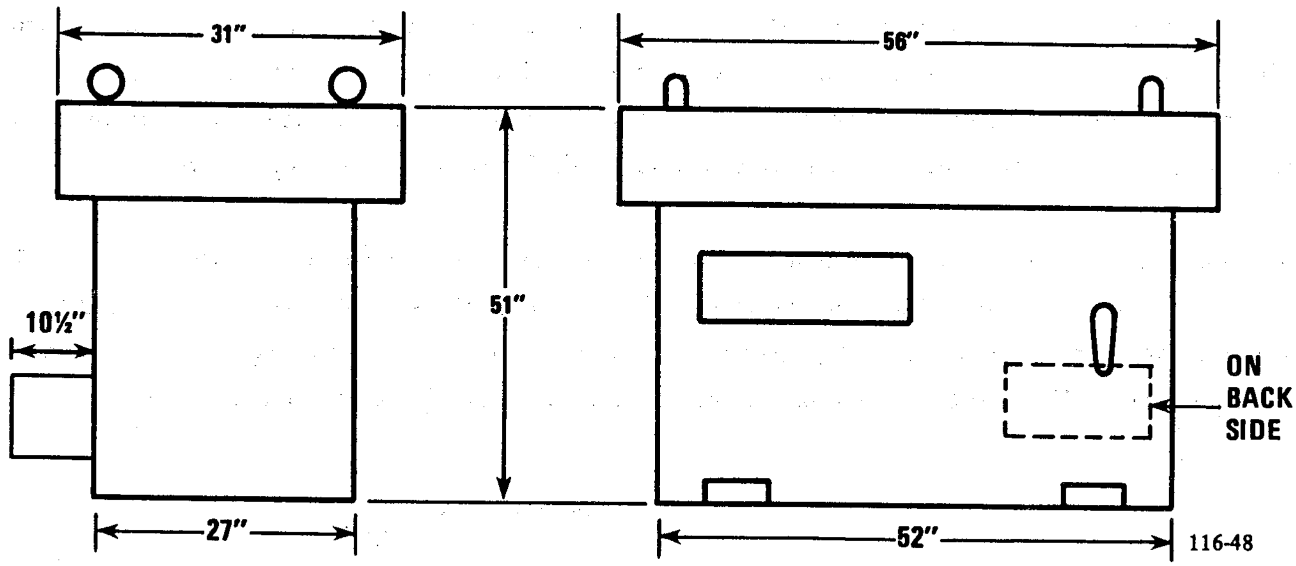

Figure 2-30. Grid Connect Unit Dimensions

As Figure 2-29 shows, the utility line interface with the GCU is made by a full two-winding isolation transformer and includes a customer-furnished, manual, fused, lockable disconnect (SW4) for fault protection. It also has the ability to manually disconnect, isolate, and lock out the power plant from the utility line. The isolation transformer provides ground isolation and prevents any dc currents from being injected into the utility line; both items are primary requirements of the utility companies. Being a fully isolated, two-winding transformer, any dc generated currents are not transformed to the utility line. The utility and power plant are isolated from one another, allowing proper implementation of ground references and elimination of undesirable stray ground current paths. Switches SW1, SW2, and SW3 are operated by the control logic within the GCU, which provides grid-connected operation or automatic transfer to isolated operation. Switch SW5 (customer-furnished) provides a manual safety transfer to allow continuation of service to the 40-kW customer "isolated" load when the power plant is disconnected from the grid (SW4 open). The equipment in the GCU is shown to the right of the heavy vertical line in Figure 2-29. However, switches SW4 and SW5 are furnished by the customer and are not part of the GCU.

A protection scheme is designed into the system to ensure proper protection of the utility line interface, the customer loads, the fuel cell power plant equipment, and personnel. Figure 2-31 presents the overall power plant protection concept in one-line diagram form and lists the appropriate IEEE protection designations.

The fuel cell power plant performs many of the protective functions in Figure 2-31 by electronics rather than standard utility protective relaying. In addition, fail-safe backup is provided by various levels of fusing, including the fused disconnect at the utility interface and power component fusing in the inverter.

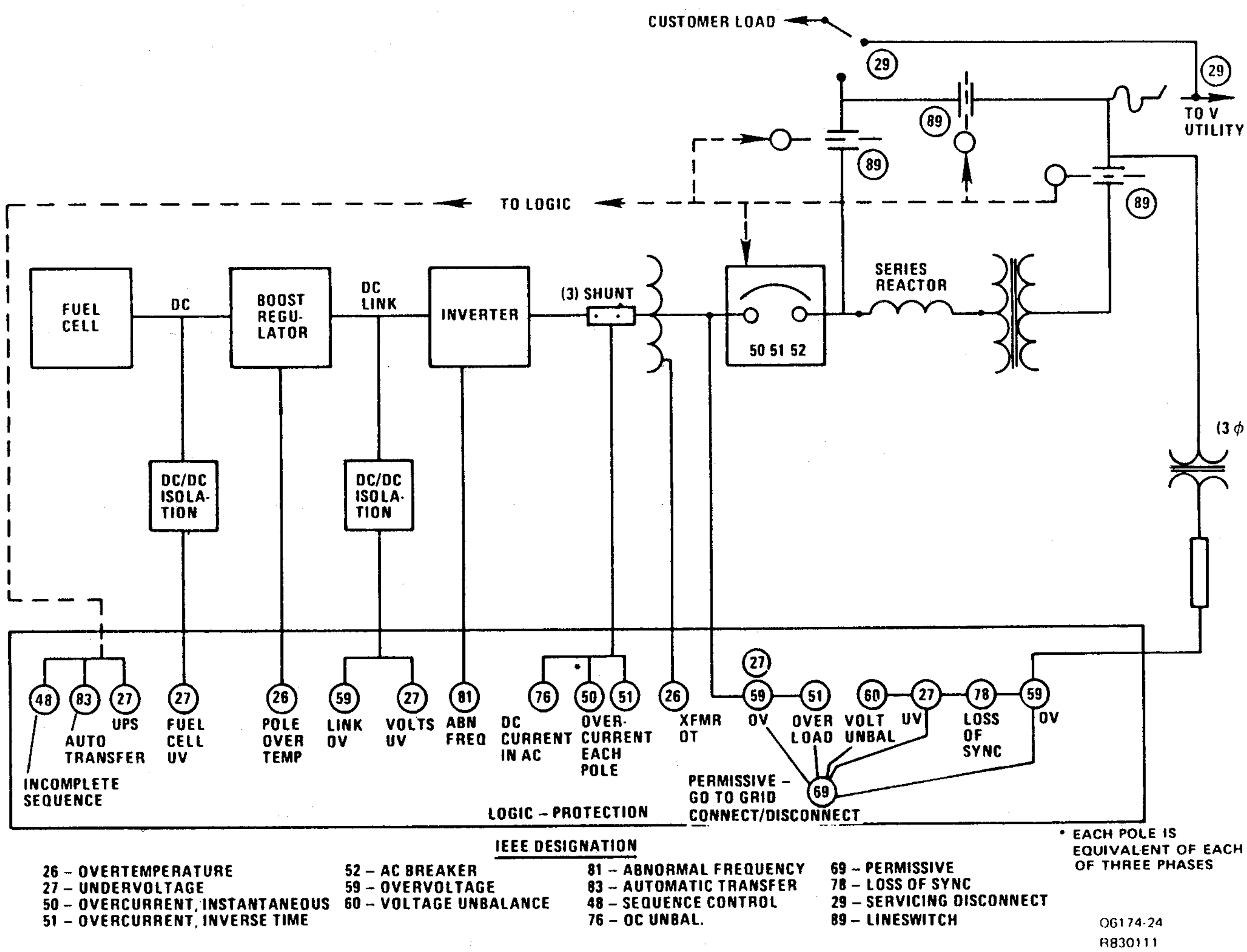

Figure 2-31. 40-kW Grid-Connect Power Plant Protection Function Diagram

The grid-connected, fuel cell power plant has inherent operating capabilities and characteristics that are different from the conventional rotating machinery type generator. The self-commutated inverter, employing solid-state (thyristor) power switches, has essentially zero inertia; consequently, it responds rapidly to operating commands or utility line fluctuations and disturbances. The flow of output current can be stopped in a few hundred microseconds, effectively eliminating any significant contribution to utility line faults. Thus, addition of a fuel cell generator does not impose additional burden on existing utility fault protection equipment. Changes in the utility line voltage can be tracked rapidly so that real power is controlled accurately to its desired level, and reactive power can be limited to provide 1.0 ± 0.05 power factor operation at full rated power (40 kW into grid). This design condition defines the maximum reactive power the system will consume or deliver as approximately 13 kVAR.

The rapid response and control/protection functions of the inverter, coupled with the GCU integrated controls and protection, result in a system that either operates on-line in an acceptable manner or automatically disconnects from the line without creating any detrimental transients or disturbances. If the utility line is lost, the system automatically can power selected customer loads independently. In the present design, transition from the grid-independent mode back to the grid-connect mode requires manual intervention. However, the unit will not reconnect to the grid if the utility is out of normal operating limits or if the power plant operation is out of limits.

III. DESIGN CHANGES DURING MANUFACTURING

Section II provided the background and described the specification and final design of the 40-kW Fuel Cell Power Plant configurations. Parts procurement and manufacturing processes were initiated using the initial PC18B-3 design. As the manufacturing program progressed, modifications were incorporated to overcome shortcomings found in the initial field testing of the first power plants deployed and those suggested by the manufacturing activity itself.

This section describes the significant changes made during the manufacturing phase that led to the final power plant configuration. The major design changes were made to correct deficiencies that could adversely affect accomplishments of Field Test Program objectives; they were not made as a result of a separate product improvement program or as an effort to exceed program goals.

As operation at early power plant sites was evaluated and as manufacturing problems were encountered at vendors and at in-house fabrication and assembly, design changes were incorporated into the bill-of-material. To the extent possible, design changes were incorporated during power plant fabrication, assembly, or final testing at UTC. In other cases, retrofit kits were packaged and documented, and field power plants were updated at a convenient time at the site. Formal records have been maintained to ensure that all power plants were modified to incorporate the most recently approved changes. In addition, identification plaques that document all configuration changes have been attached to each power plant.

During the NASA Design Change Review, discussed in Section II, changes were categorized to provide perspective to the data. Table 3-1 provides short definitions for each of the six categories used and the current statistics of the number of design changes in each category. Figure 3-1 shows the distribution of these changes by category at the end of the manufacturing phase.

TABLE 3-1. DESIGN CHANGE CATEGORIES

Category	Quantity	Description
I	304	Corrections to drawings, specifications, parts lists, or engineering releases o To correct errors in dimensions, locations, part numbers; change wording, etc.
II	60	Drawing Shortages o Add details on existing drawings or add new minor drawings
III	20	Vendor Part Number Update o Changes to vendor procured components may require new part numbers and, therefore, new drawings.
IV	251	Manufacturing Changes, Routine o Minor revisions to dimensions, tolerances, hole alignment locations, welds, washers, screws, markings, etc.
V	161	Routine Development Improvements o Upgraded instrumentation, component reorientation for accessibility, PC card revisions, improved sealing, etc.
VI	61	Major Changes o Changes which affect power plant or component function or durability.

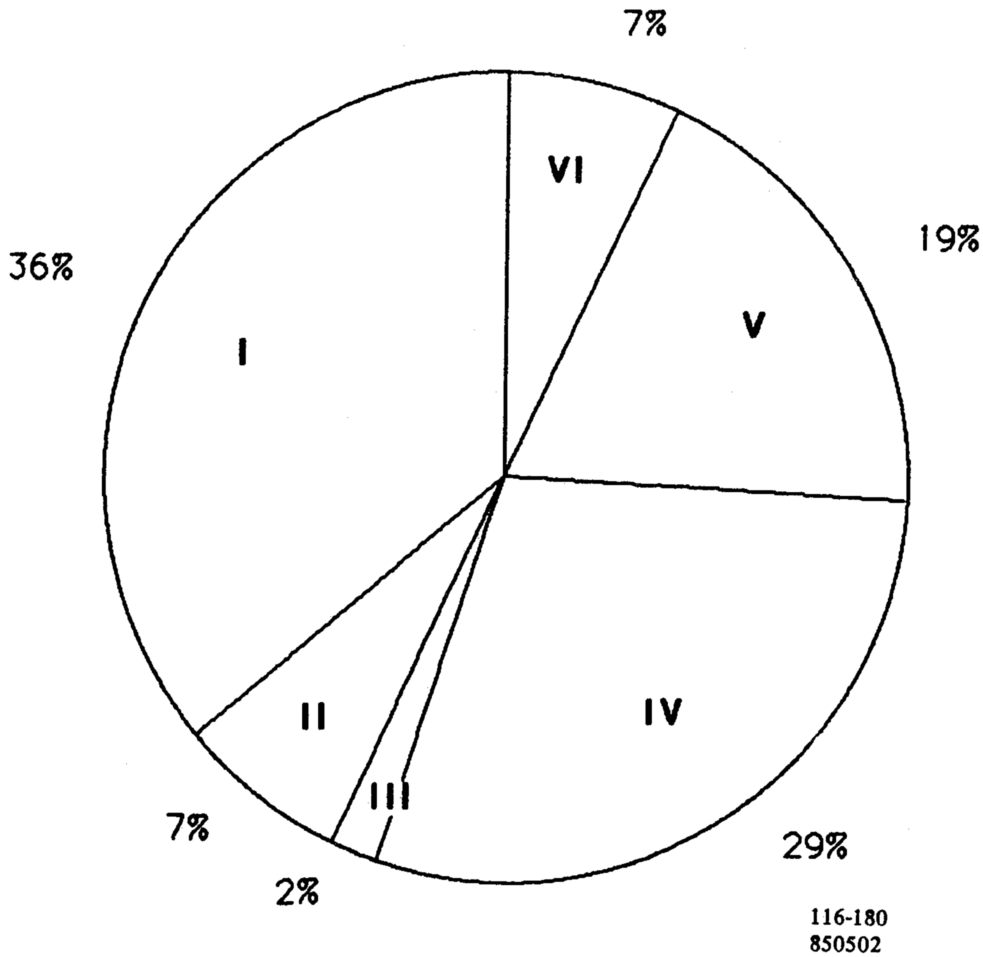

Figure 3-1. Design Change Category Distribution

As shown above, 93 percent of these changes are in the first five categories considered non-critical areas.

Table 3-2 lists the 61 major changes by subsystem and gives perspective as to why they were made.

TABLE 3-2. MAJOR DESIGN CHANGES

Release No.	Date	Description
Final Assembly:		
D83PB308	6/7/83	Upgrade wire insulation to withstand application temperatures
D82PB650	6/10/83	Change pipe thread sealant to reduce shutdowns due to water leakage.
D83PB697	12/8/83	Provide higher temperature seat material for 3-way actuator valves to withstand power plant temperature conditions.
Power Section:		
D83PB149	3/22/84	Install heavier wires to insure adequate electrical ground.
D83PB040	3/24/84	Change requirement of coating applied to the stack reactant plenums to improve adherence qualities.
Power Conditioning:		
D82PB443 D82PB443A D82PB443B	11/24/82 11/24/82 11/24/82	Provide new logic configuration. New card cage featuring printed circuit backboard to eliminate hand wiring and improve reliability.
D83PB127	6/10/83	Provide an additional shutdown function based on half stack voltage to protect against localized stack over-temperature.
D83PB448	8/9/83	Incorporate "loss of inverter" shutdown logic to provide additional power plant shutdown visibility.
D84PB072	3/8/84	Revise PC11 circuit card to provide positive disconnect during loss of utility line.
D84PB060	3/19/84	Revise PC1 circuit card to prevent false triggering of diagnostic bite balls.

TABLE 3-2. MAJOR DESIGN CHANGES (CONT'D)

Release No.	Date	Description
Controls and Water System:		
D475166J	3/29/82	Revise coil in component solenoid valves to improve reliability.
D495125	4/2/82	Revise steam relief valve to improve reliability.
D495822	5/10/82	Redesign low-grade heat exchanger to improve reliability, reduce cost, eliminate leakage problems, and simplify assembly.
D495166F	5/13/82	Installation of new coolant pump to provide a more reliable pump and eliminate seal failures encountered in present pumps.
D495146	6/8/82	Redesign the integrated fuel control to eliminate binding, erratic operations, and simplify assembly.
D495912	7/12/82	Redesign condensate preheater to simplify assembly and reduce cost.
D495906	7/19/82	Redesign air control valves to eliminate binding, erratic operation, and simplify assembly.
D495934	9/1/82	Redesign louver actuators to prevent side loads on the actuator that result in diaphragm leakage.
D495903	9/2/82	Redesign low-grade bypass valve to improve reliability and eliminate jamming.
D495925	9/14/82	Change coolant loop flow switch to improve reliability.
D495860A	9/16/82	Revise start fuel system components to improve trim accuracy.

TABLE 3-2. MAJOR DESIGN CHANGES (CONT'D)

Release No.	Date	Description
D495930	9/23/82	Change heater in the feedwater heat exchanger to improve durability and reliability.
D495949	9/28/82	Redesign the low-grade heat exchanger to improve heat transfer.
D495166N	10/1/82	Relocate the flow switch to minimize effect of dirt and deposits.
D495911	10/7/82	Add a low coolant level shutdown function to steam separator level control.
D495951	10/7/82	Provide an additional magnetic filter to increase capacity of filtration and reduce maintenance frequency.
D82PB266	12/15/82	Add venturi to provide a more reliable low coolant flow shutdown signal.
D82PB511	12/20/82	Provide a more reliable thermal switch with a faster response time.
D82PB544	1/10/82	Change material composition of condensate preheater to improve life.
D82PB581	1/10/82	Revise steam separator level control switch to eliminate erratic operation.
D82PB535	1/13/82	Modify steam separator to permit increase in coolant flow rate without causing water carryover.
D82PB128	2/18/83	Modify stack differential pressure switch to improve control life and reliability.
D83PB067	2/18/83	Increase heat input to water tank to improve deaeration characteristics.
D83PB054	3/8/83	Modify coolant pump to improve control life and reliability.

TABLE 3-2. MAJOR DESIGN CHANGES (CONT'D)

Release No.	Date	Description
D83PB164A	3/15/83	Relocate stack pressure differential switch to eliminate possibility of air pockets in lines.
D83PB129	3/28/83	Install stack pressure differential transmitters to permit monitoring of coolant flow rate on selected power plants.
D83PB187	3/24/83	Shutdown limit range changed on stack pressure differential switch to increase shutdown margin.
D83PB195	4/8/83	Water tank material changed to minimize the potential for corrosion.
D83PB237	4/13/83	Change deaerator materials to reduce potential water turbidity and deaerator corrosion.
D83PB258	4/18/83	Change stack pressure differential switch vendor to improve reliability.
D82PB653	4/18/83	Provide nitrogen to cathode air control valve to prevent leakage of air to cathode during power plant start.
D83PB046	5/3/83	Provide a valve having a higher temperature rating to be consistent with operating requirements.
D83PB231	5/6/83	Add shutdown feature to stack pressure differential transmitters to prevent stack damage in case of low coolant flow.
D83PB244	5/18/83	Vent gases from coolant pump inlet to prevent cavitation.
D83PB412	6/15/83	Change the size of coolant loop venturi for increased coolant pump flow.
D83PB359	6/17/83	Change feedwater regenerator material to improve quality of feedwater.

TABLE 3-2. MAJOR DESIGN CHANGES (CONT'D)

Release No.	Date	Description
D83PB411	6/17/83	Revise stack pressure differential switch to provide a more conservative shutdown function for low coolant flow.
D83PB463	7/20/83	Revise flow orifice to increase additional heat input to the water tank to improve degasification.
D83PB527	8/13/83	Addition of aerator tube to water tank to minimize coolant loop corrosion.
D84PB002	1/27/84	Provide additional cooling to polish demineralizer and reduce heat input to water tank to increase water recovery.

IV. MANUFACTURING PROCESS DESCRIPTION

INTRODUCTION

The objective of the 40-kW Power Plant Manufacturing Program was to produce forty-six 40-kW fuel cell power plants, 32 grid connect units, 7 master control units and the associated spare parts for field testing at various sites selected by participating host companies. Planning and preparation to meet this objective had to take into account the special problems associated with manufacturing items in small lot sizes for an experimental machine not yet reduced to commercial manufacturing practices. In addition, it was recognized that the design would undergo changes as a result of problems experienced during manufacturing, acceptance testing, and field testing of the units.

To accomplish the manufacture of the 46 PC18-B power plants, an administrative and supervisory organization was established to develop manufacturing plans, to conduct the fabrication of components, details, subassemblies and power plants, and to monitor the acceptance testing and quality of these power plants. Budgets were established for the significant items of manufacture and a financial system was implemented to control both labor and material resources. Make/Buy decisions were reviewed in light of previous experiences, and facility and manpower requirements were finalized. A Quality Assurance Plan was prepared and implemented, and facility rearrangements were defined and carried out.

At the onset of the program, a Manufacturing Plan was prepared that covered the procurement, fabrication, assembly, test, and delivery of the power plants and associated spares. Based on this plan, an overall manufacturing schedule was prepared which integrated the various activities to complete the 46 power plants within the contract resources. The overall manufacturing schedule is shown in Figure 4-1. This schedule is divided into seven subtasks, representing the power plant subsystems and assembly and test activities. Initial procurement began in April 1982. Power plant assembly activities were underway by mid-1983 with the first power plant delivery taking place in the fall of 1983. Forty-three power plants were completed and acceptance tested by the end of 1984, and the last three units were completed in January 1985. Figure 4-2 provides the monthly acceptance test experience and overall power plant completion rate.

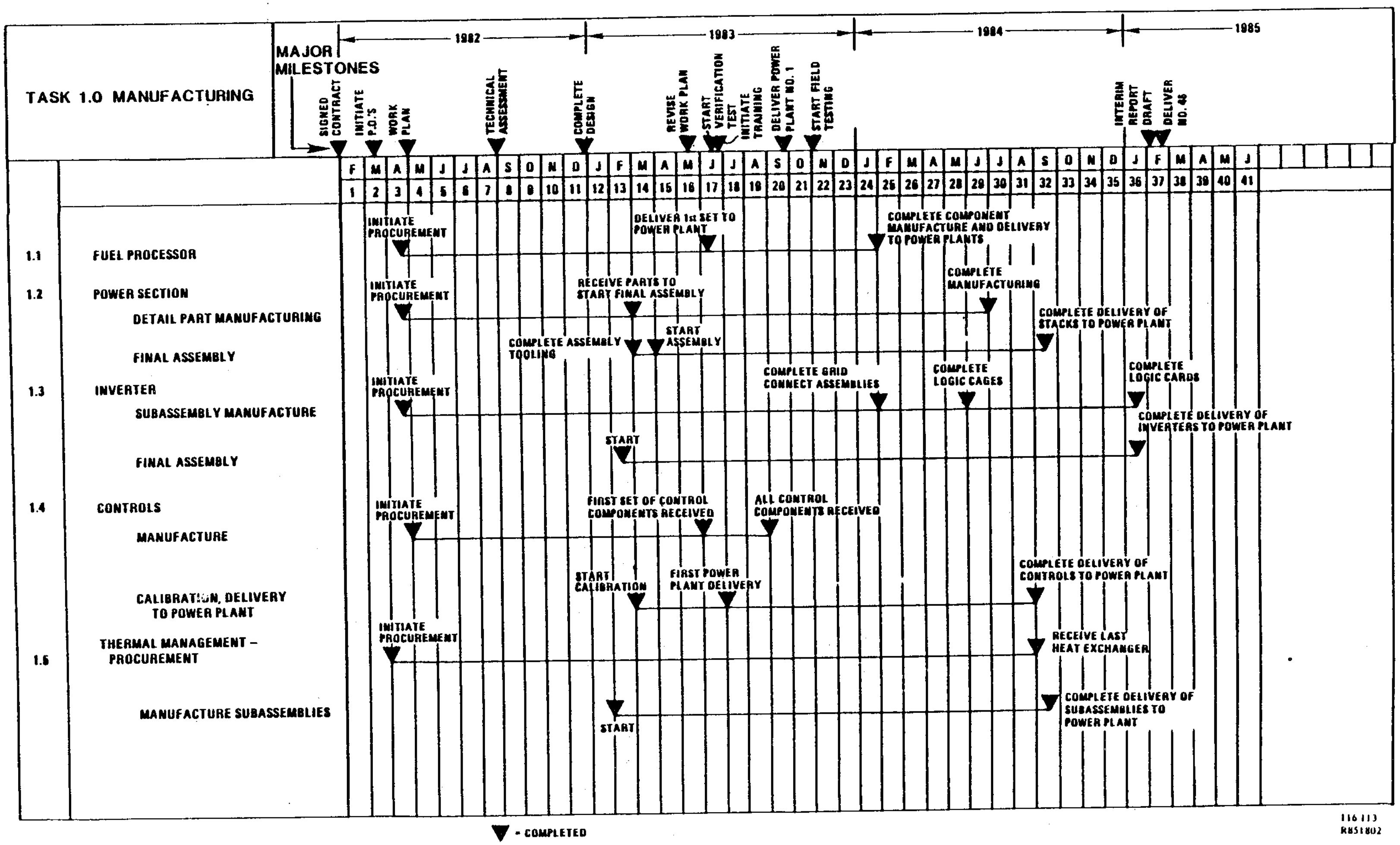

Figure 4-1. Milestone Schedule for Power Plant Manufacture

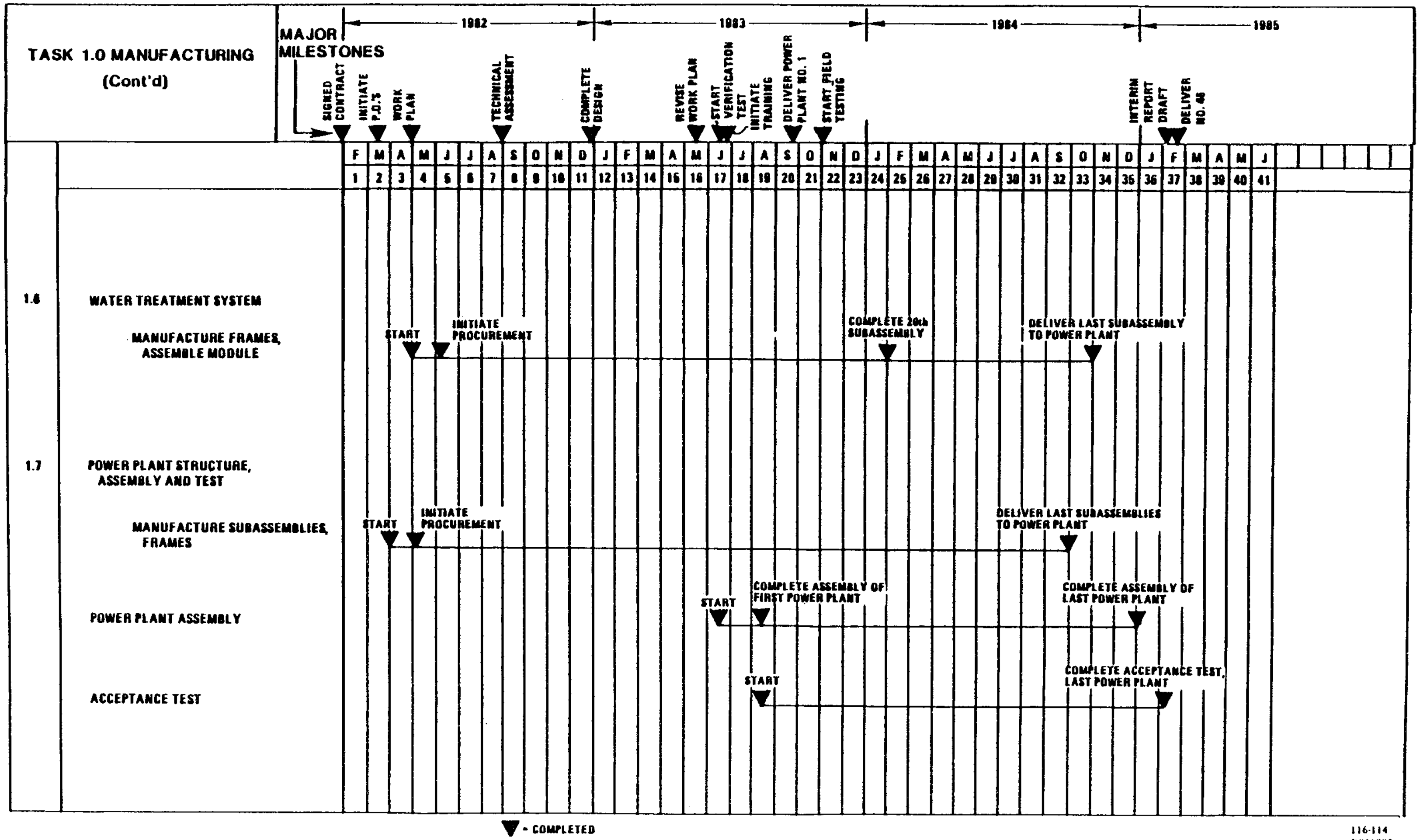

Figure 4-1. Milestone Schedule for Power Plant Manufacture (Cont'd)

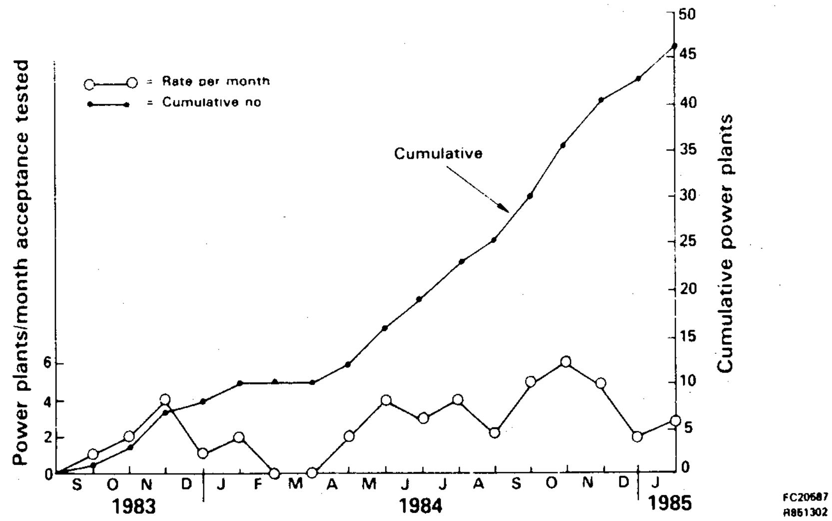

Figure 4-2. 40-kW Power Plant Acceptance Testing

This section discusses power plant manufacture and provides detail for the make/buy process, the Quality Assurance Plan and procedures, the manufacture and assembly of the major subsystems and the power plant, and the acceptance testing and shipping of the power plants.

MAKE/BUY PROCESS

For any manufacturing activity, a decision is made whether to produce a part or to purchase it. The make/buy selection process was instituted at the start of the program in accordance with the Manufacturing Plan. Experience gained during procurement and fabrication of parts and components for the earlier DOE program to manufacture three power plants formed the basis for this 46 power plant manufacturing effort. Supplier performance, cost comparisons, capital equipment in-place, and labor resource availability were then reviewed utilizing input from the internal assessment activity. Suppliers whose past performance or products were judged to be inadequate were eliminated from consideration. Quality Assurance, Engineering, and Purchasing Department surveys of new suppliers were conducted and qualified suppliers were added to our approved lists. In-house work capacity and Work Plan schedules were reviewed along with estimated costs to determine the relative effectiveness of a make versus a buy selection. Table 4-1 is a listing of the final make/buy selections used in the 40-kW Power Plant Manufacturing Program.

TABLE 4-1. MAKE/BUY LIST

MAKE COMPONENTS

- Electrodes
- Cell Stacks
- Power Plant Assy. & Test
- Sheet Metal Ducting
- Tubes under 1-inch Diameter
- Brackets
- Inverter Bus Bars
- Inverter Assy. & Test
- Cable Harnesses

BUY COMPONENTS

- Power Plant Structure
- Grid Connect Unit
- Spacer Plates
- End Plates
- Controls
- Heat Exchangers
- Cabinetry
- Water Treatment Components
- Reformer
- Electronic Assembly
- Master Control Unit
- Inverter Heat Sinks
- Inverter Rectifiers
- Inverter Commutation Capacitors
- Inverter Electronics
- Inverter Connectors
- Inverter Magnetics
- Tools
- Stacking Fixtures
- Stack Carts
- Heat Treat Tooling
- Tubes over 1-inch Diameter

MAKE AND BUY COMPONENTS

Substrates (buy heat treat)

Separator (buy molding and heat treat)

Hydrodesulfurizer/Shift Converter (buy vessel, fill and condition at UTC)

Inverter Fans (6) (buy, make frames and assemble at UTC)

Inverter Link Cap Assembly (buy, make frame and assemble at UTC)

Inverter Power Poles (buy clamps and all assembled parts, make miscellaneous brackets, and assemble at UTC)

Inverter Boost Regulator (assemble at UTC)

Cooler Assemblies (buy cooler tube arrays, separator plates, fiber, and resin powder; carbonize and graphitize, mill cooler holders and process separator plates at UTC)

Power Distribution Box Assembly

QUALITY ASSURANCE

A program of this magnitude needed a Quality Assurance program to assure that over 3500 separate part number items in the 40-kW bill-of-material met established requirements. The Quality Control practices in effect at UTC at the onset of the 40-kW Power Plant Manufacturing Program were oriented toward either one-of-a-kind products or very small lot size programs with extensive manned flight aerospace requirements. Neither system specifically met the needs of this power plant program, but did provide a sound basis for definition.

A Quality Assurance Manager and supporting staff were designated and given the responsibility of defining and implementing a quality assurance program consistent with specific program requirements. A plan (with supporting procedures) generally meeting the requirements of ANSI Std. Z1.8-1971 was prepared and incorporated into program activities. All elements of the quality standard were addressed including Procurement controls, Material Processing controls, Manufacturing controls and Non-Conforming Material controls. Specific methods and procedures for implementing these controls were in accordance with established UTC quality practices.

The quality requirements were divided into two broad areas: purchased parts and UTC manufactured parts. Quality Engineering, as part of its design review activity, examined part function, design complexity, application criticality, process sensitivity, supplier or shop experience, and part maturity to establish specific requirements. Based on these factors, appropriate levels of quality surveillance were specified and imposed on the purchased parts.

UTC-manufactured parts were likewise reviewed by Quality Engineering to define the specific in-process and final inspection and test requirements. In addition, parts and processes were identified which would require inspection by the Manufacturing Department with Quality Assurance audit or inspection by the Quality Control Department.

A sample of a 40-kW Purchased Parts Plan is shown in Table 4-2. Table 4-3 shows a typical plan for UTC-manufactured parts.

TABLE 4-2. 40-kW QUALITY PLAN FOR PURCHASED PARTS

		REQUIREMENTS										
		Design			Supplier				UTC			
Part Name	Part Number	SC/ ESA	ANSI Z 1.8	QA Approval	Source Inspection	QA Plan	Certi-fication	Mat'l Test Report	Receiving Inspection	Lab Release	First Piece	Additional Information
Grid Connect Unit	XFC4856-01			X	X				(X)			
PC Boards	All			X	X				(X)			
Master Control Unit				X	X				(X)			
PC Boards	All			X	X				(X)			
Tubes and Pipes												
Coolant System				X			X		(X)		X	
All Other Tubes and Pipes				X							X	
Fuel Processing												
HDS	FC1581-01		X	X	X		X		(X)			
- Catalyst	FCMS0226	X						X	X	X		
Shift Converter	FC1580-01		X	X	X		X		(X)			
- Catalyst	FCMS0003-01	X						X	X	X		
Pre-Ox, Assy of	FC1509-01		X		X		X		(X)			
Pre-Ox Assy	FC1508-01		X		X		X		(X)			
- Catalyst	FCMS0323-01	X						X	(X)	X		
Reformer Burner	FC3352		X	X	X		X		(X)			
Reformer Reactor	FC3351		X	X	X		X		(X)			
- Catalyst	FCMS316-01	X						X	X	X		
Reformer Assy	FC1507		X	X	X		X		(X)			

TABLE 4-3. 40-kW QUALITY PLAN FOR UTC-MANUFACTURED PARTS

PART NAME INVERTER

Process/Item	Part Number/Spec	Inspection Mfg.	Inspection QA	QA Audit	Additional Information
Inverter					
- Frame	FC3460-01		X		
- Panels	FC2532		X		
Components					
- Inductor Coil, Assy of	FC2572-01	X			Qualify Operator
- Inductor Coil, Assy of	FC2573-01	X			Qualify Operator
- Inductor Coil, Assy of	FC2718-01	X			Qualify Operator
- Inductor Coil, Assy of	FC2718-02	X			Qualify Operator
- Inverter Power Pole, Assy of	FC2690-01	X			Qualify Operator
- Inverter Boost Reg., Assy of	FC2691-01	X			Qualify Operator
EMI Box		X			Qualify Operator
Inverter Assembly	FC4303-01	X			Qualify Operator
- Sub Assy and Wiring Harnesses	OP 20	X			Qualify Operator
- Main Panel and Bus Bars	OP 30	X			Qualify Operator
- Cable and Electronic Assy	OP 30	X			Qualify Operator
- Assemblies Wiring Harness and Circuit Cards	OP 40	X			Qualify Operator
- Visually Check Assembly	OP 50	X			Qualify Operator
In process Inspect Invert Assy		X	X		
Final Inspect/ - Release to Test		X	X		
Acceptance Test				X	
Release to Ship		X	X		

A total of 305 inspection instruction sheets establishing part inspection requirements were prepared. Eighty-two inspection check points were established to control in-house manufacture of power sections, inverter and power plant assemblies. In addition approximately 400 source inspection visits to suppliers were conducted.

After the completion of the planning activities, procurement and assembly of the major power plant subsystems began, then the assembly of the complete 40-kW fuel cell power plant was completed. The major subsystem and power plant assembly activities are discussed next.

FUEL PROCESSING SUBSYSTEM

The make/buy list (Table 4-1) indicates that all fuel processing catalysts and containment vessels were purchased from outside vendors. Catalyst conditioning and final assembly for the hydrodesulfurizer/shift converter were done in-house.

The milestone schedule established for the procurement and manufacture of these components is presented in Figure 4-3, updated to reflect actual attained schedules. Successful experience in earlier programs permitted elimination of operational testing of these components prior to installation in the power plants. This decision turned out to be sound and resulted in significant cost savings. The non-operational testing consisted primarily of leak tests. Only one reformer subsequently demonstrated below specification conversion during power plant acceptance testing. The manufacturing and processing procedures for the major components through delivery to the power plant are illustrated by the block diagram in Figure 4-4.

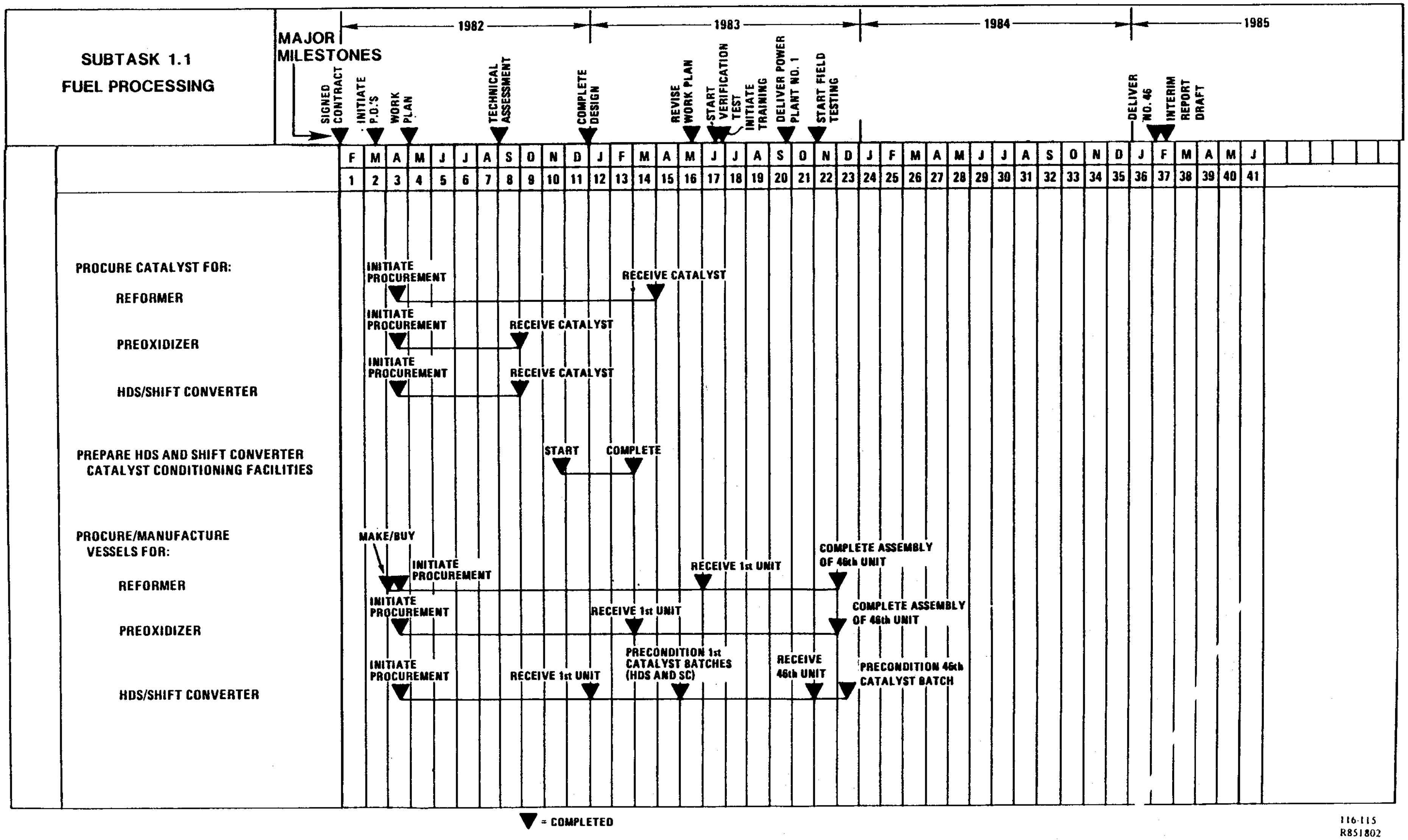

Figure 4-3. Milestone Schedule for
Fuel Processing Subsystem Manufacture

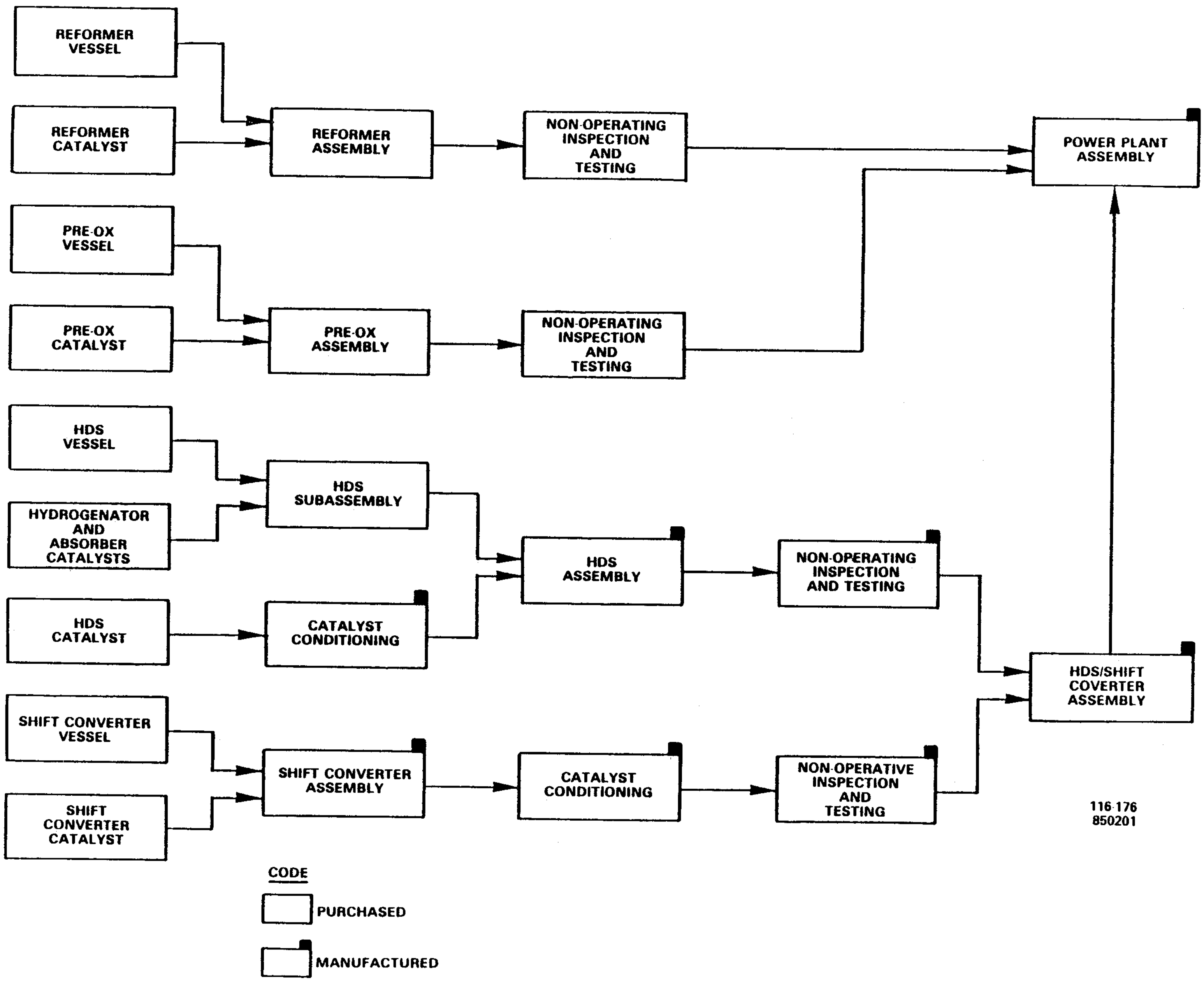

Figure 4-4. Fuel Processing Subsystem Manufacture

The reformer and pre-oxidizer were procured as complete assemblies ready for installation in the power plant.

The shift converter was procured as a completed mechanical assembly filled with catalyst. However, conditioning of catalyst (reduction) was required before this unit became a completed assembly ready for mating with the hydrodesulfurizer and installation in the power plant. After receipt, the shift converter was delivered to the shift converter catalyst conditioning work station shown in Figures 4-5 and 4-6 for conditioning. Catalyst conditioning was done at elevated pressure and temperature. Upon completion, the shift converter was purged with nitrogen prior to installation of caps over all ports. The complete shift converter unit was then delivered to an assembly area to await mating with a completed hydrodesulfurizer.

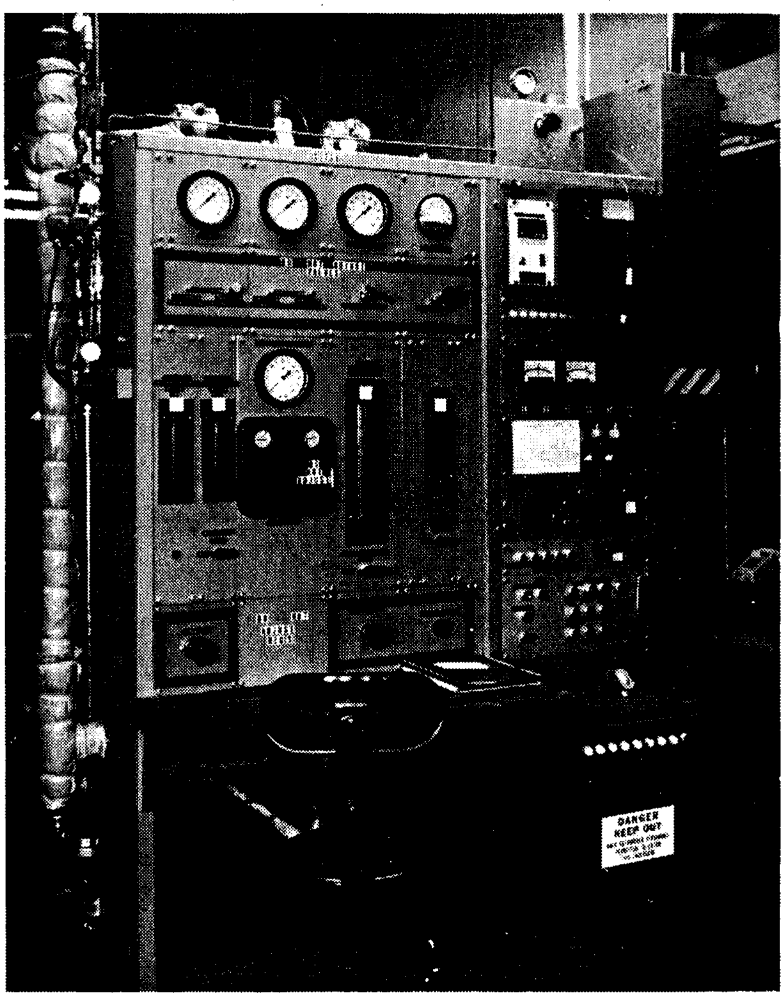

Figure 4-5.
Shift Converter Catalyst
Conditioning Work Station,
Front View

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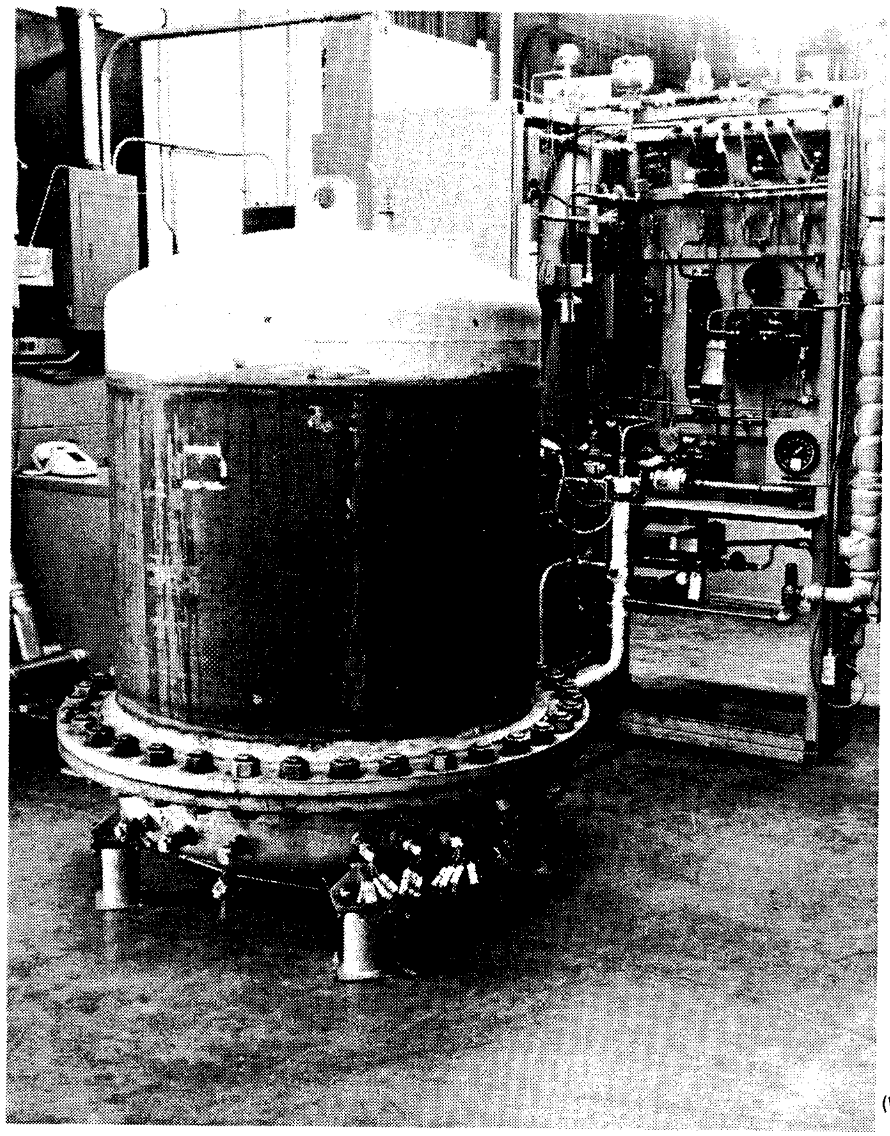

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Figure 4-6. Shift Converter Catalyst Conditioning Work Station, Back View

The hydrodesulfurizer was also procured as a complete mechanical assembly. After receipt, the hydrodesulfurizer was delivered to the hydrodesulfurizer catalyst loading and conditioning work station shown in Figure 4-7. Catalyst was loaded into a special conditioning vessel. The catalyst was then subjected to a pre-sulfiding procedure and upon completion it was maintained in a nitrogen environment. The hydrodesulfurizer, which was also in a nitrogen blanket, was then filled with the presulfided catalyst. The zinc oxide absorber and hydrogenation catalyst had previously been filled by the vessel manufacturer. The hydrodesulfurizer was then sealed and delivered to the shop where it was welded closed. The completed hydrodesulfurizer was then delivered to the assembly area for mating with the shift converter, after which it was ready for installation in a power plant.

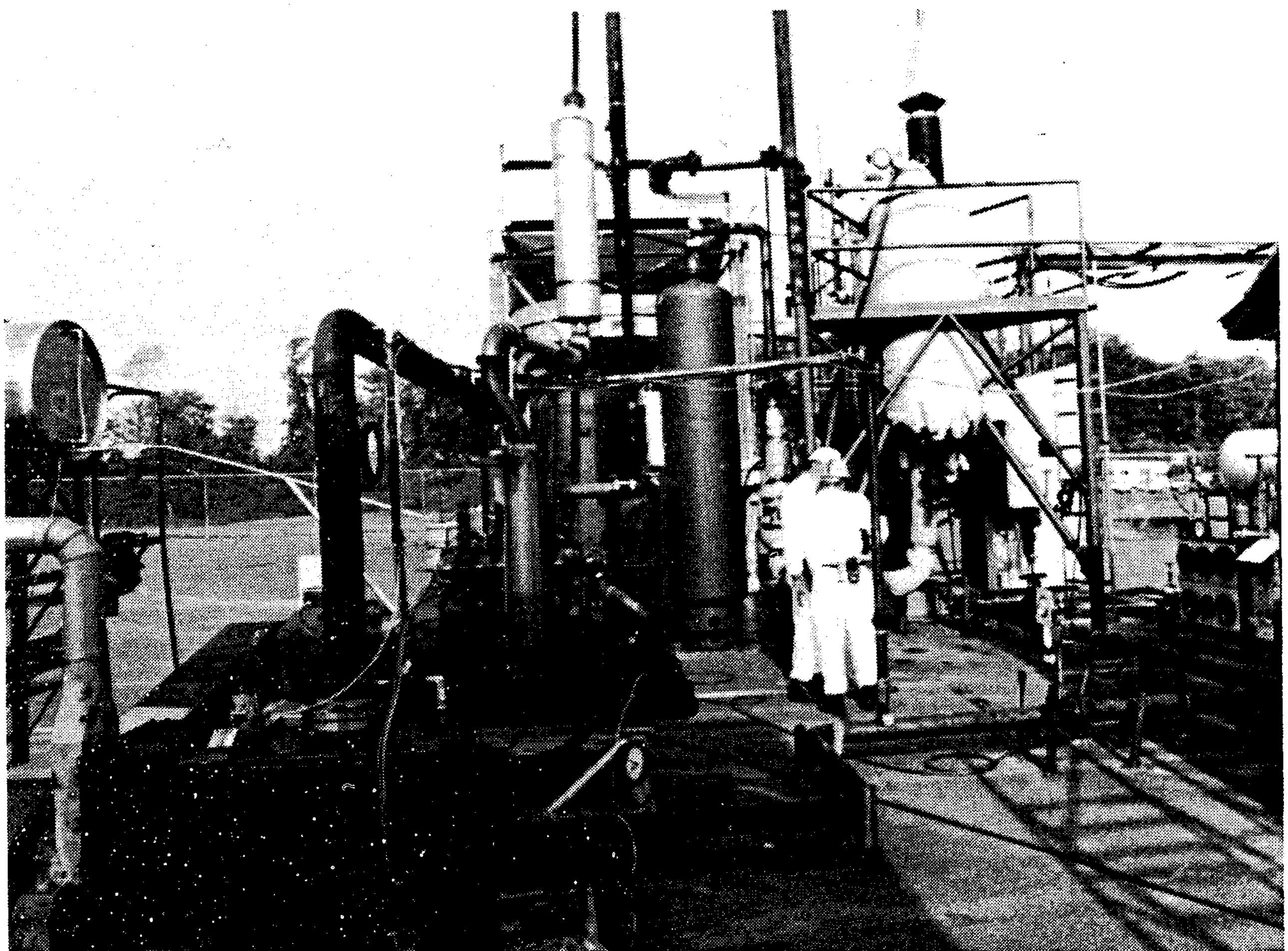

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Figure 4-7. Hydrodesulfurizer Catalyst Loading and Conditioning Work Station

THE POWER SECTION

The make/buy list indicates that a majority of the fuel cell power section components were produced by UTC at its South Windsor facility. This included the electrode substrates, electrodes, cell packages, cooler assemblies, and the power section assembly itself. Purchased parts included separator plates, raw materials, and heat treatment.

A milestone schedule was established for the production of the required 48 power sections (Figure 4-8). The procurement and manufacturing began during April 1982. The assembly of the first cell stack began in April 1983 and the final power section was completed in September 1984. Experience gained from other UTC programs resulted in the decision to eliminate the operational testing of each power section as an individual component. Only non-operational tests for electrical continuity, electrical insulation, and leak testing of reactant and fluid systems were performed prior to delivery of the power section to power plant assembly.

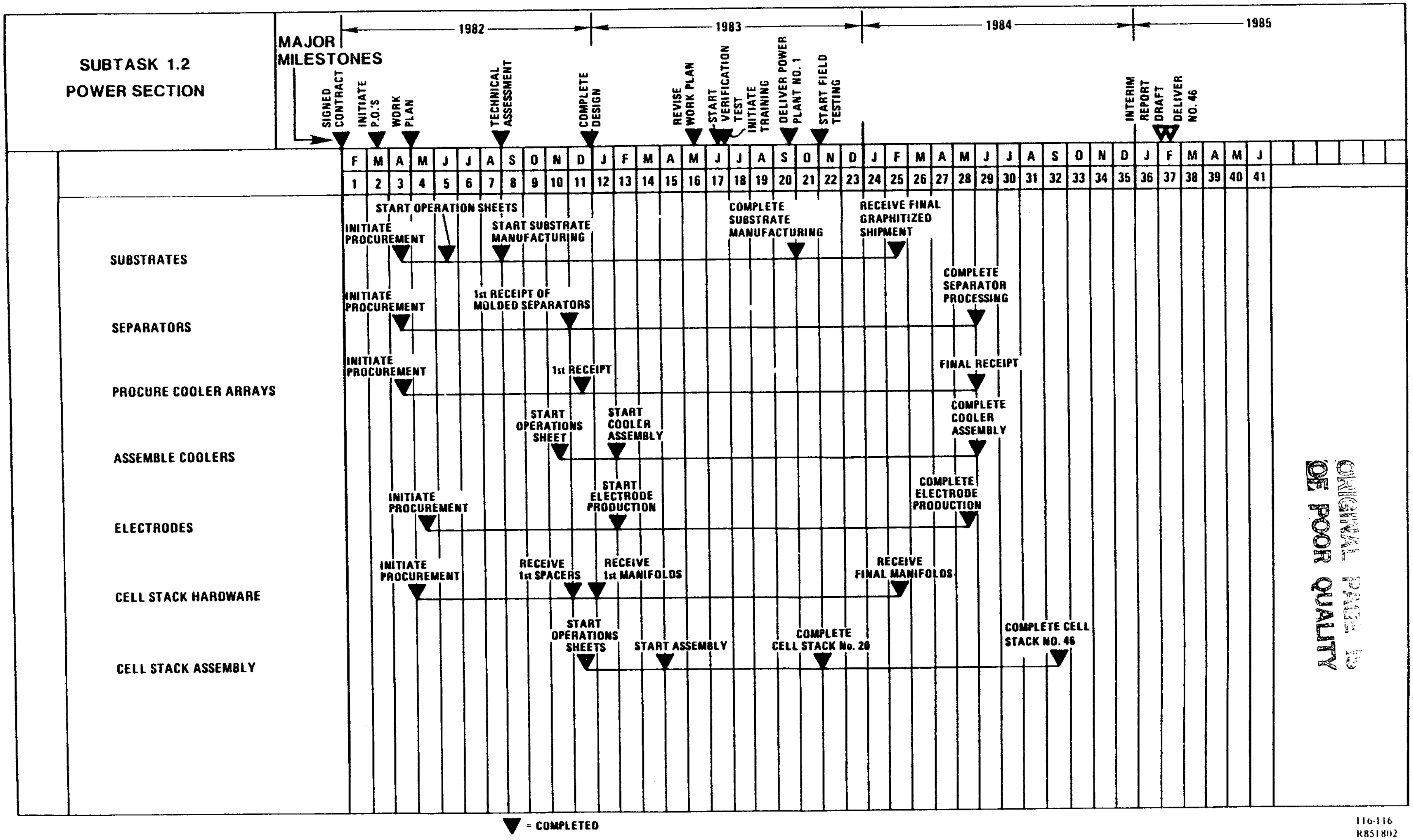

Figure 4-8. Milestone Schedule for Power Section Manufacture

The block diagram in Figure 4-9 describes the overall process for the manufacture and assembly of the power section. The power section is comprised of repeat parts including 270 single fuel cell assemblies which incorporate an anode, cathode, and electrolyte matrix; and 46 cooler assemblies. The non-repeat parts are the reactant and cooler manifolds, end plates, tie rods, spacer plates, electrical harnesses, and thermal insulation. Over 30,000 electrode substrates were produced for the manufacture of the power sections.

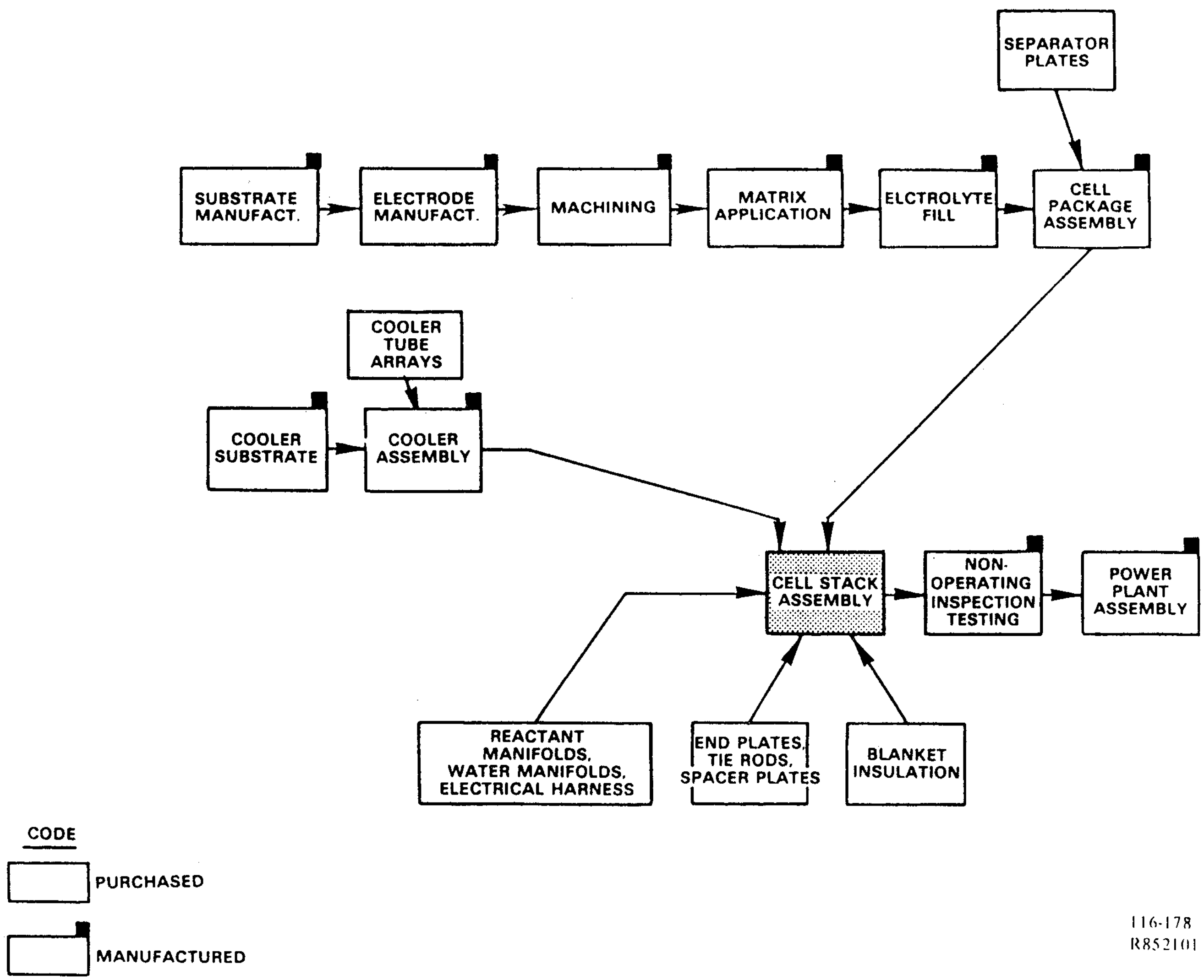

Figure 4-9. Power Section Manufacture

Substrates

The electrodes, mated in couples to form cells, are the building blocks of the cell stack or power section. The basic electrode structure is a molded substrate produced on a substrate machine (Figure 4-10). (This substrate machine was extensively upgraded as a result of a privately supported utility program.) In-process inspection controls were used to assure that the substrates met specification and delivery requirements. Completed substrates are shown awaiting heat treatment in Figure 4-11.

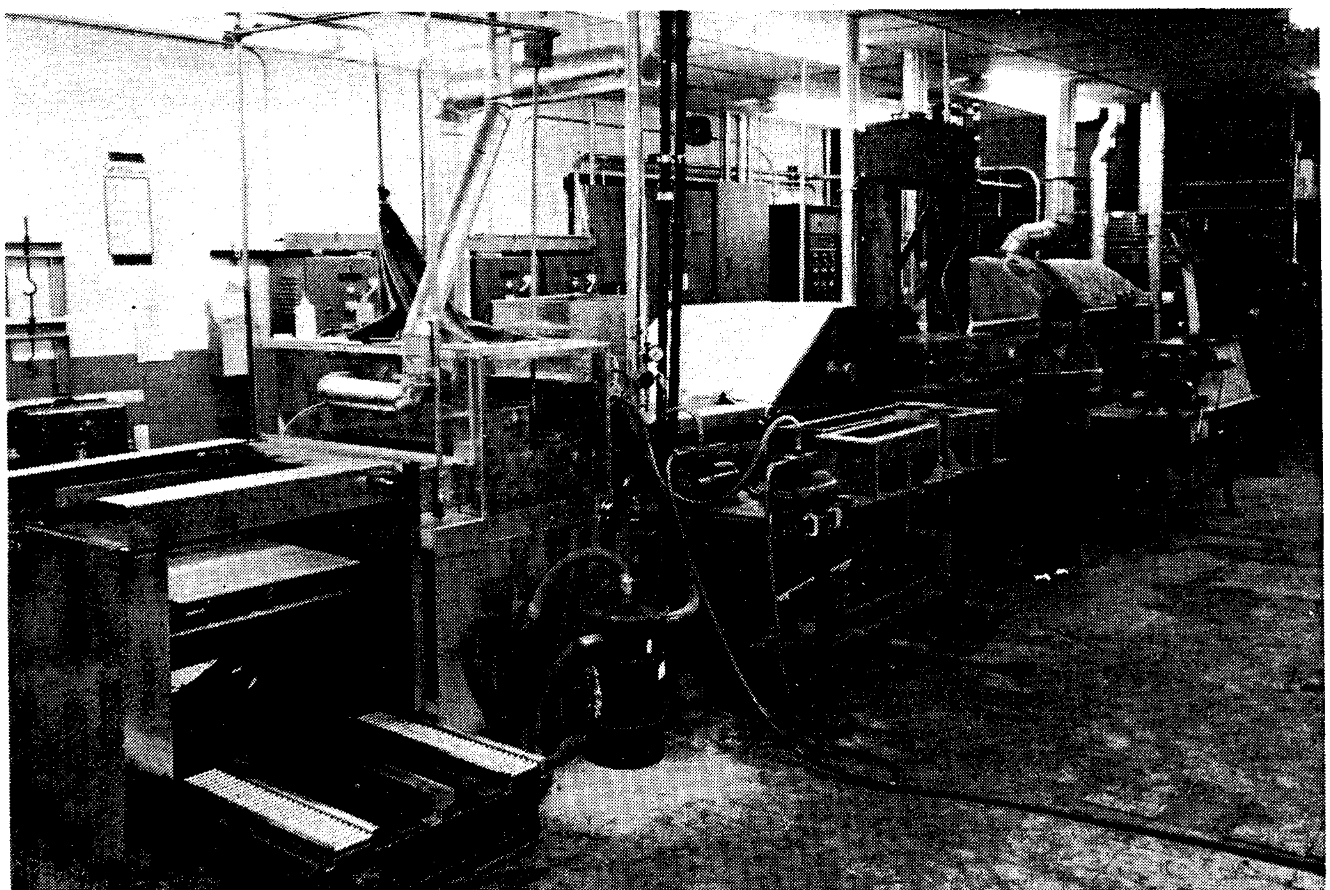

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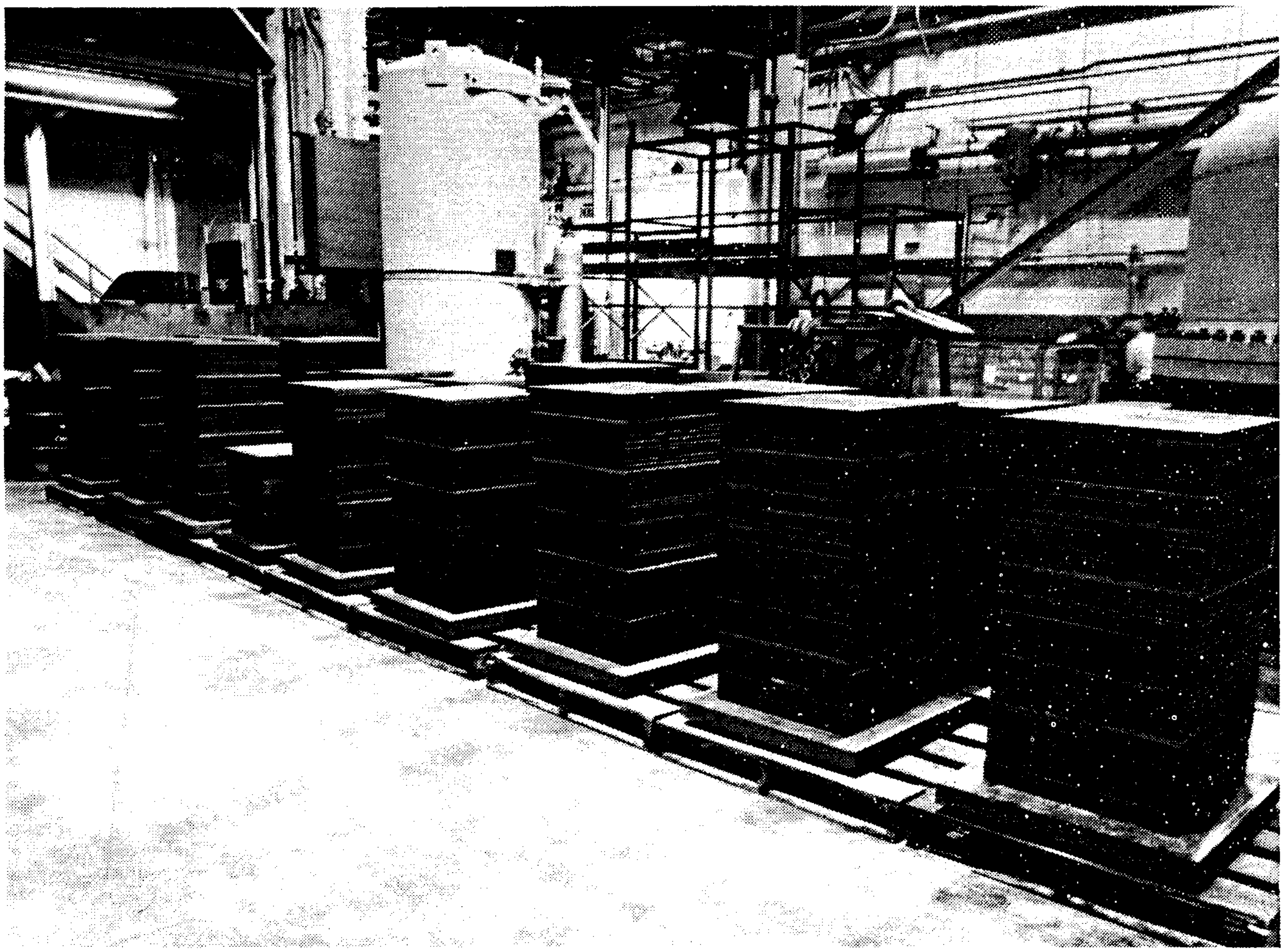
Figure 4-10. Substrate Fabrication Line



(WCN-9776)

Figure 4-11. Substrates Prepared for Heat Treatment

Electrodes

An existing semi-automatic fabrication line was used to apply the catalyst to the electrodes. Part of the electrode fabrication line is shown in Figure 4-12. The rear face of the electrodes were machined to form reactant grooves. The front faces of the electrodes then coated with the electrolyte matrix material. In-process inspection controls and visual inspections are used to assure that specifications were satisfied.

A number of automatic gaging devices and controls were installed on the electrode fabrication line, including gamma ray density monitors, an automatic check weigher providing computer controlled density with automatic reject of out-of-limits parts, and air-operated thickness gages.

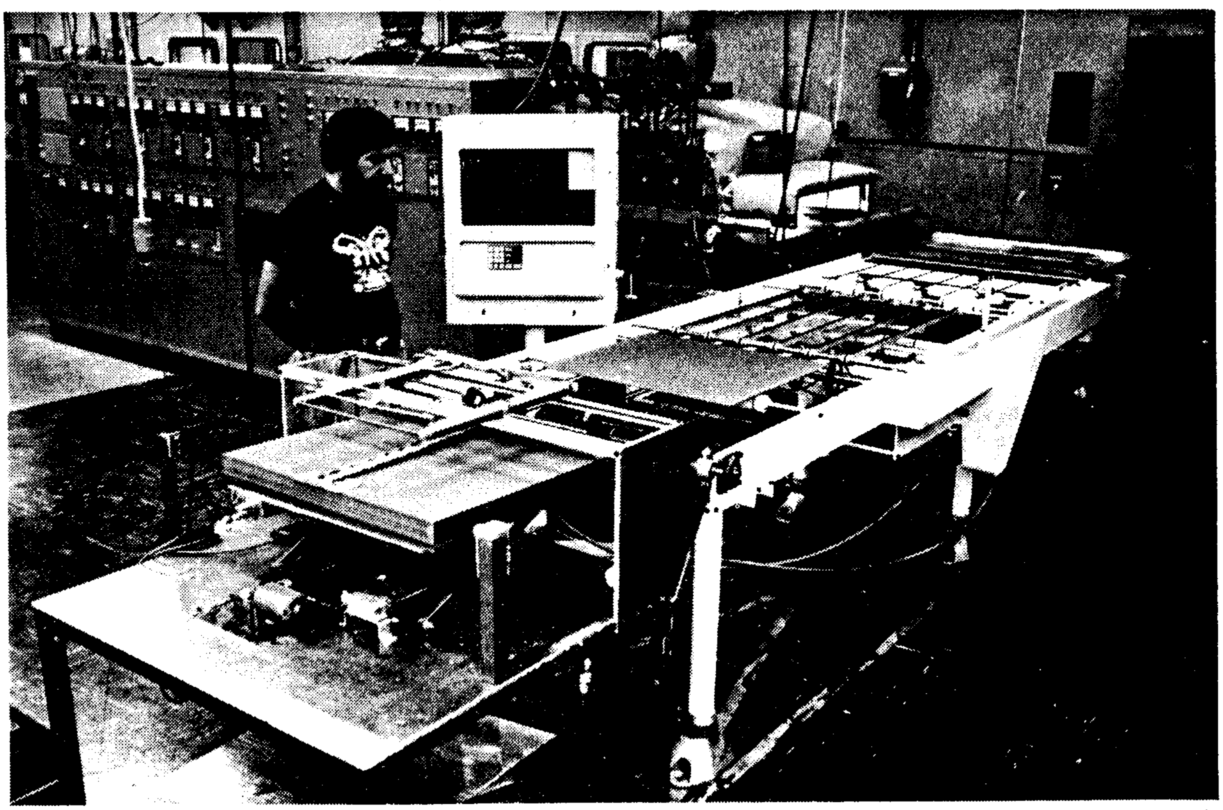


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Figure 4-12. Electrode Fabrication Line

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Separator Plates

The separator plates, which were purchased, are thin dense plates which are processed after receipt. They were subjected to heat treatment and grinding. Inspections were performed at various steps in the process to assure that requirements were satisfied.

Coolers

Cooler assemblies are composed of a tube array lying in grooves milled in the cooler holder and sealed by a separator plate. The cooler holder was fabricated in a fashion similar to the other cell substrates, but was thicker. The tube arrays were purchased. Inspections were performed on both the coolers and cooler holders to assure that requirements were satisfied. A typical cooler assembly is shown in Figure 4-13.

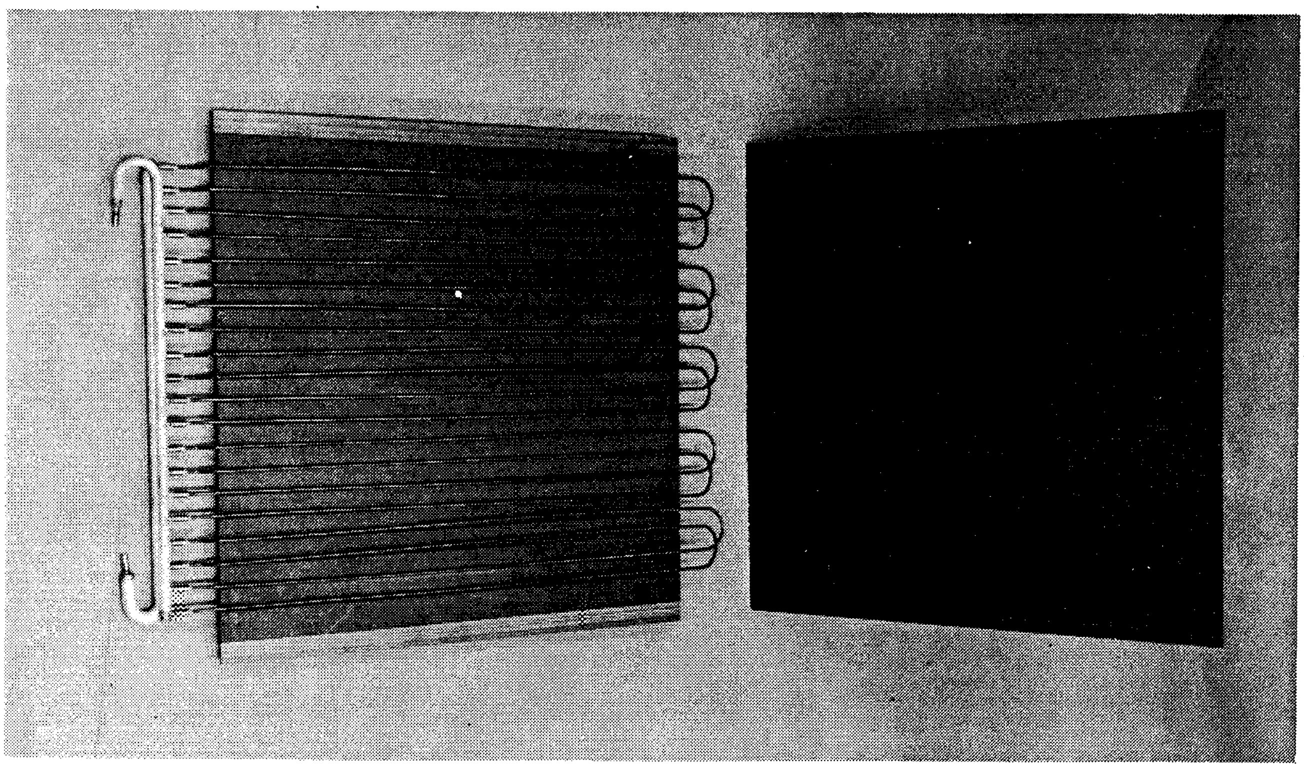

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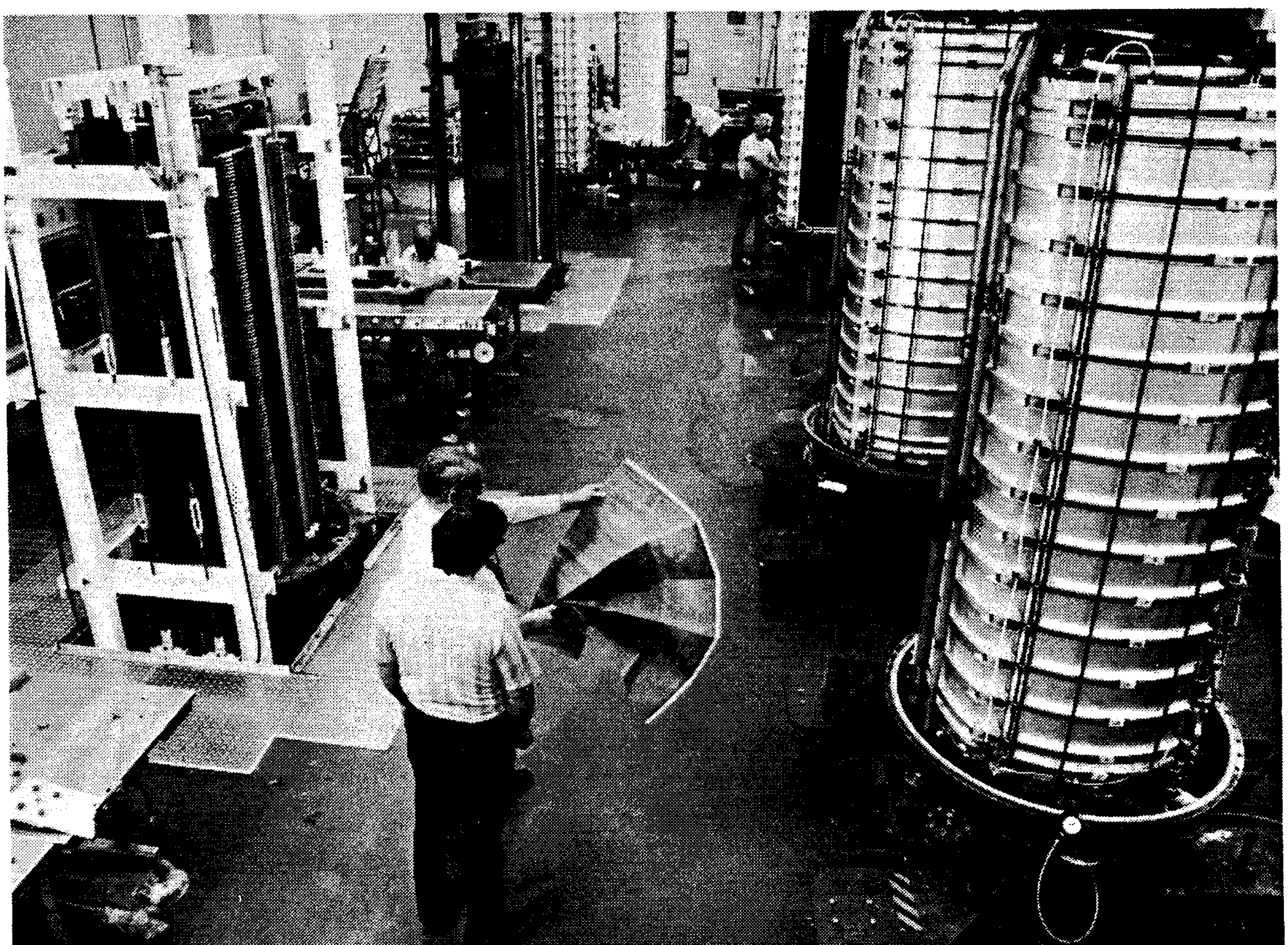
Figure 4-13. Cooler Assembly

Power Section Assembly

Power sections were assembled in a temperature and humidity-controlled work area (Figure 4-14) previously established to assemble power sections for an earlier program. The first operation in this work area was the filling of the electrode matrices with phosphoric acid and the mating of the two electrodes to form a cell. An automatic fill machine was completed part way through the manufacturing phase, Figure 4-15, and was then used to fill and mate the anode, cathode, and separator plate into the cell assembly.



(WCN-6618)

Figure 4-14. Power Section Assembly Room

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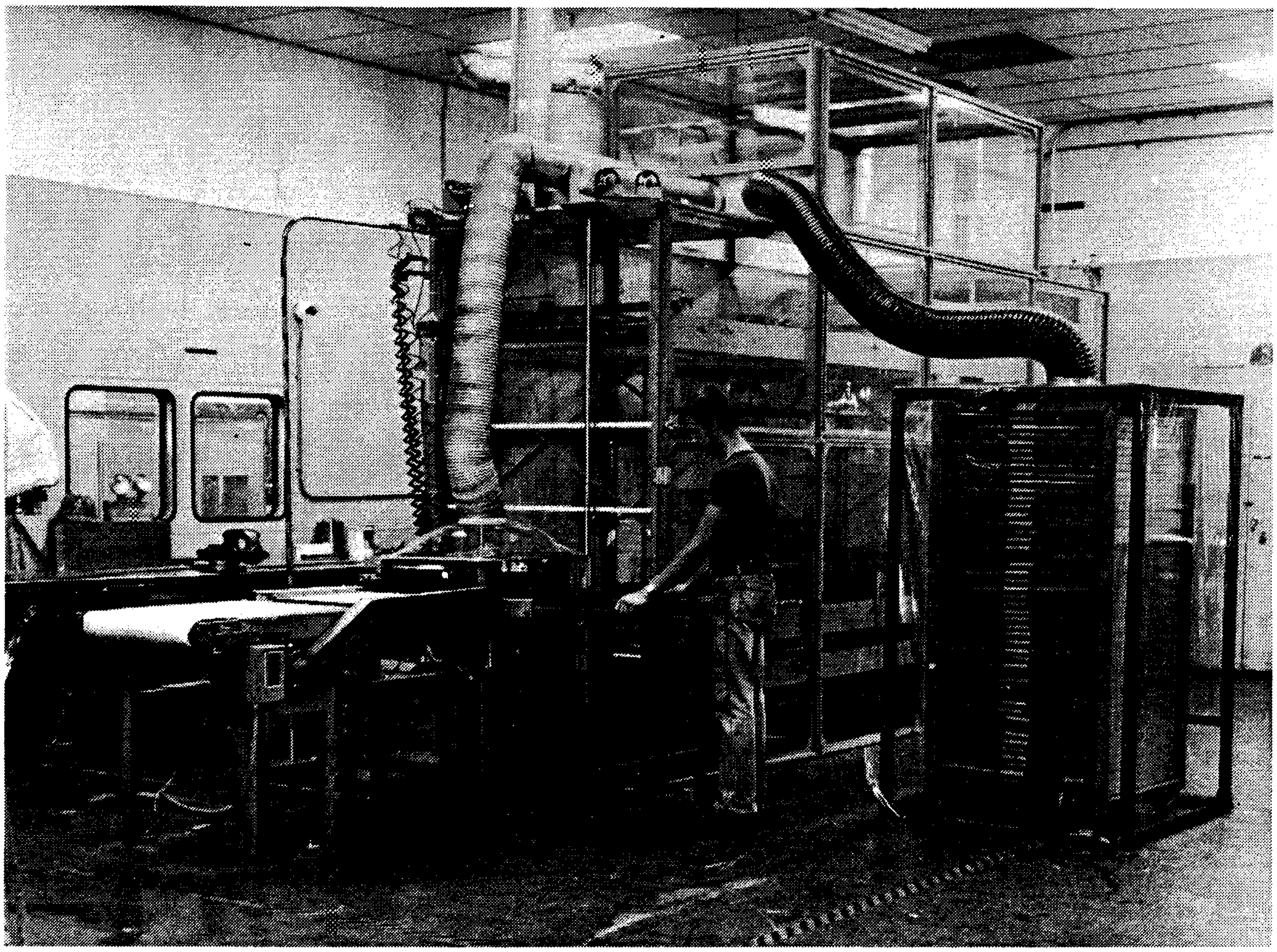

(WCN-10516)

Figure 4-15. Automatic Electrolyte Filling Facility

The cells, coolers, and separators were stacked in a fixture, shown in Figure 4-16, to facilitate reliable assembly of all parts. After the required number of cells were stacked, the stack was compressed and locked into position with tie-rods. The stack was next removed from the stacking fixture and other stack components (including reactant gas plenums, coolant manifolds, and instrumentation) were assembled on the stack (Figure 4-17). Quality checks including visual, pressure, and electrical were made and insulation installed. The power section was then ready for assembly into the power plant. Completed power sections awaiting power plant assembly are shown in Figure 4-18.

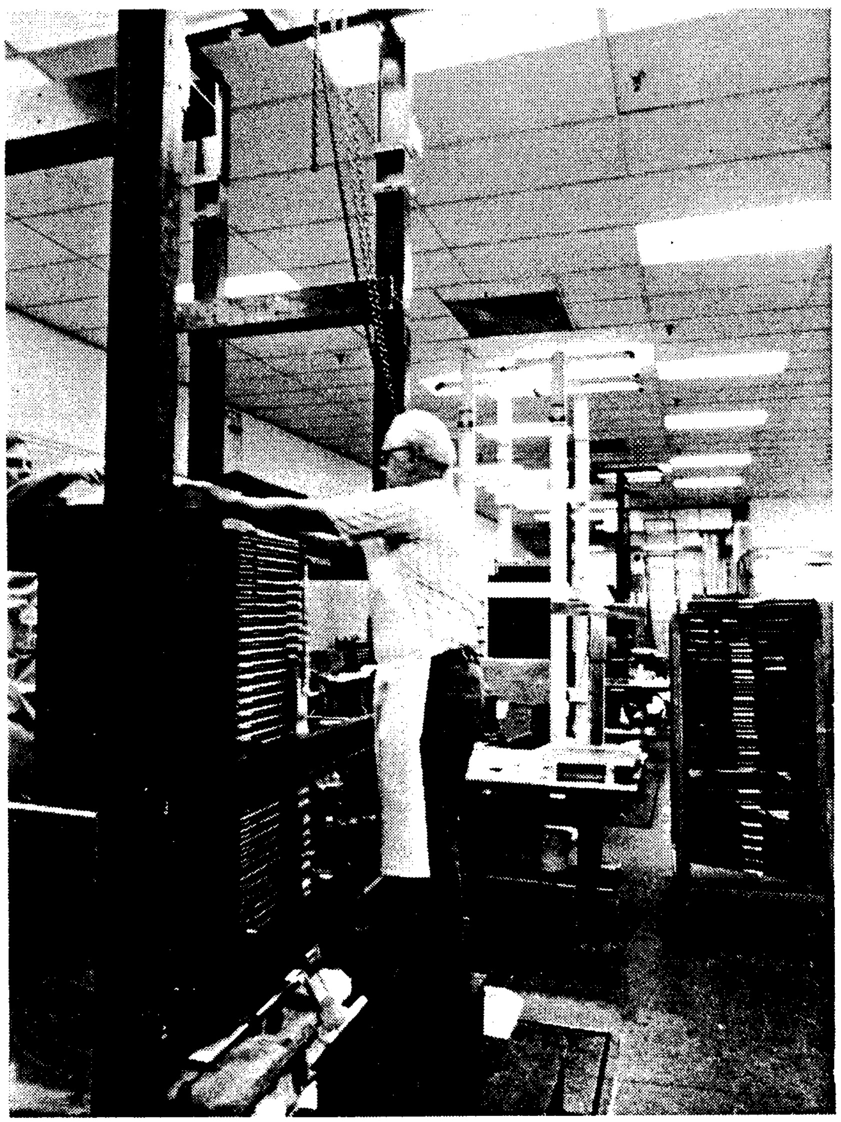

Figure 4-16.
Cell Stack
Assembly Fixture

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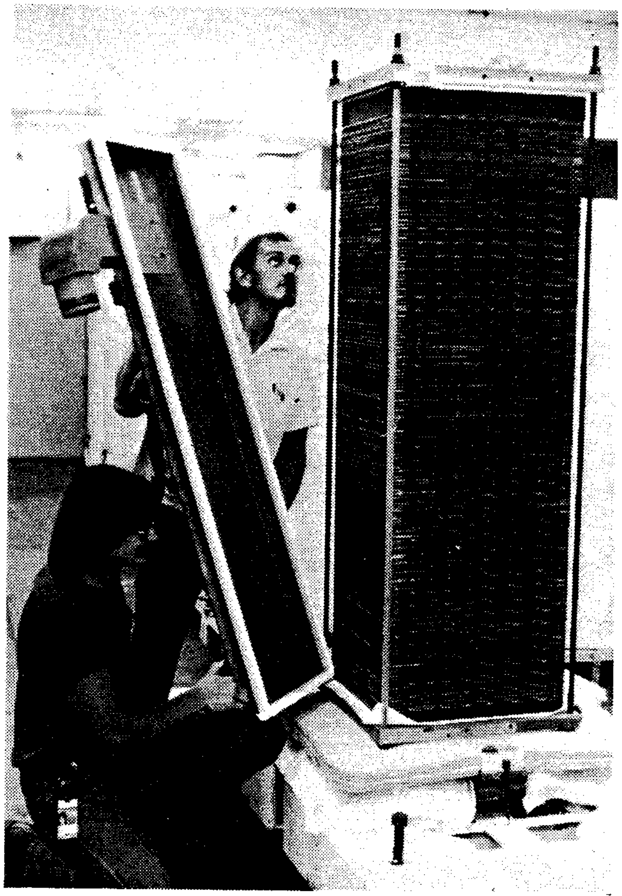

Figure 4-17.
Assembly of Reactant Manifold
on Cell Stack Assembly

(WCN-12090-27)

(WCN-12090-34)

Figure 4-18. Completed Power Sections Ready for Assembly into Power Plants

INVERTER

The major electrical subsystem in the power plant is the inverter, which converts the dc power output of the power section to the required three-phase, 208-volt power, and also contains the programmable logic that controls all of the power plant systems. The PC18B-3 configuration also includes a grid connect unit to provide control and interfacing with the utility grid.

The milestone schedule for the various electrical components, updated to reflect the actual accomplishments, is presented in Figure 4-19.

There are four model variations of inverters, those for isolated, grid-connected, multiple isolated unit (master control unit), and 50-Hz operation. These varying configurations are created generally by changing programmable jumpers on printed circuit cards and changing the magnetics in the case of the 50-Hz model.

All inverters were fabricated using a subassembly concept. This subassembly line approach reduced the manpower effort per unit from an estimated 200 manhours to roughly 140 manhours. Also, this approach allowed for easier troubleshooting by replacement of subassemblies.

Major subassemblies included the electromagnetic interference (EMI) box, the uninterruptible power supply (UPS), magnetics, power poles, and boost regulators. These major assemblies were built at UTC. The fan assembly, link cap assembly, and logic cabinet with printed wiring boards are examples of subassemblies purchased at vendors to UTC specifications. All wiring harnesses were completed on wire routing boards at UTC. Inverter frames and electrical bus bars were fabricated in-house. The aforementioned subassemblies, along with the magnetics, filter capacitors, and miscellaneous purchased parts, complete the inverter.

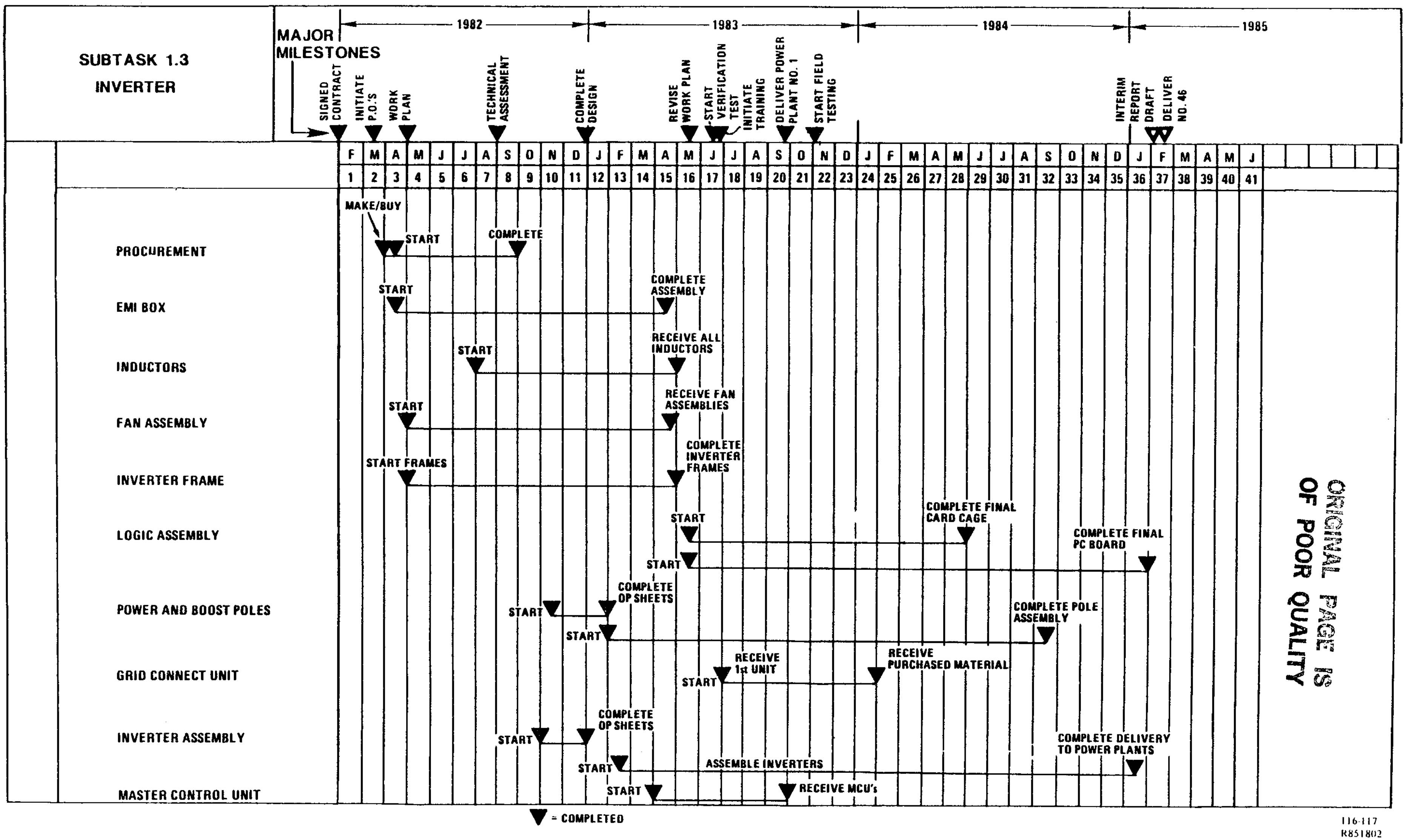

Figure 4-19. Milestone Schedule for Inverter Manufacture

The manufacturing and processing procedures developed for the inverter and grid connect unit are presented in a block diagram in Figure 4-20.

At the beginning of the program a new area was established within the Manufacturing Department for the fabrication of inverter assemblies. This facility (Figure 4-21) was established to assemble the magnetics, control logic, and power poles of the inverter, and also to provide for an acceptance test function. The acceptance test was computerized to allow for the efficient testing of the inverters.

Each printed circuit board used in the control logic system was processed through assembly, burn-in, pre-calibration, conformal coating, and post-calibration at the vendor's facility. During the 40-kW Power Plant Manufacturing Program, there have been nine circuit changes to these boards to improve their stability or increase the reliability of the inverter.

Inverter Tests

Following assembly of the inverter, two computerized test stations with data recording capability were employed to check all inverter functions. The first station verified wire harnesses and component installation for correct polarity and continuity, and was used to verify logic card cage voltages. It also confirmed operation of the uninterruptible power supply (UPS), read and compared 114 logic card cage voltage points against limits in the computer, and presented a pass/fail printout for each unit.

The second test station was used to perform all inverter dynamic testing. Various load points up to 140% of the inverter rating, along with bolted fault testing phase-to-phase, and phase-to-neutral, peak power, and protective functions, were checked. Data was recorded and computations made to verify proper inverter operation.

The protective functions tested in each inverter included dc undervoltage, ac undervoltage, and overload out to 81 kVA.

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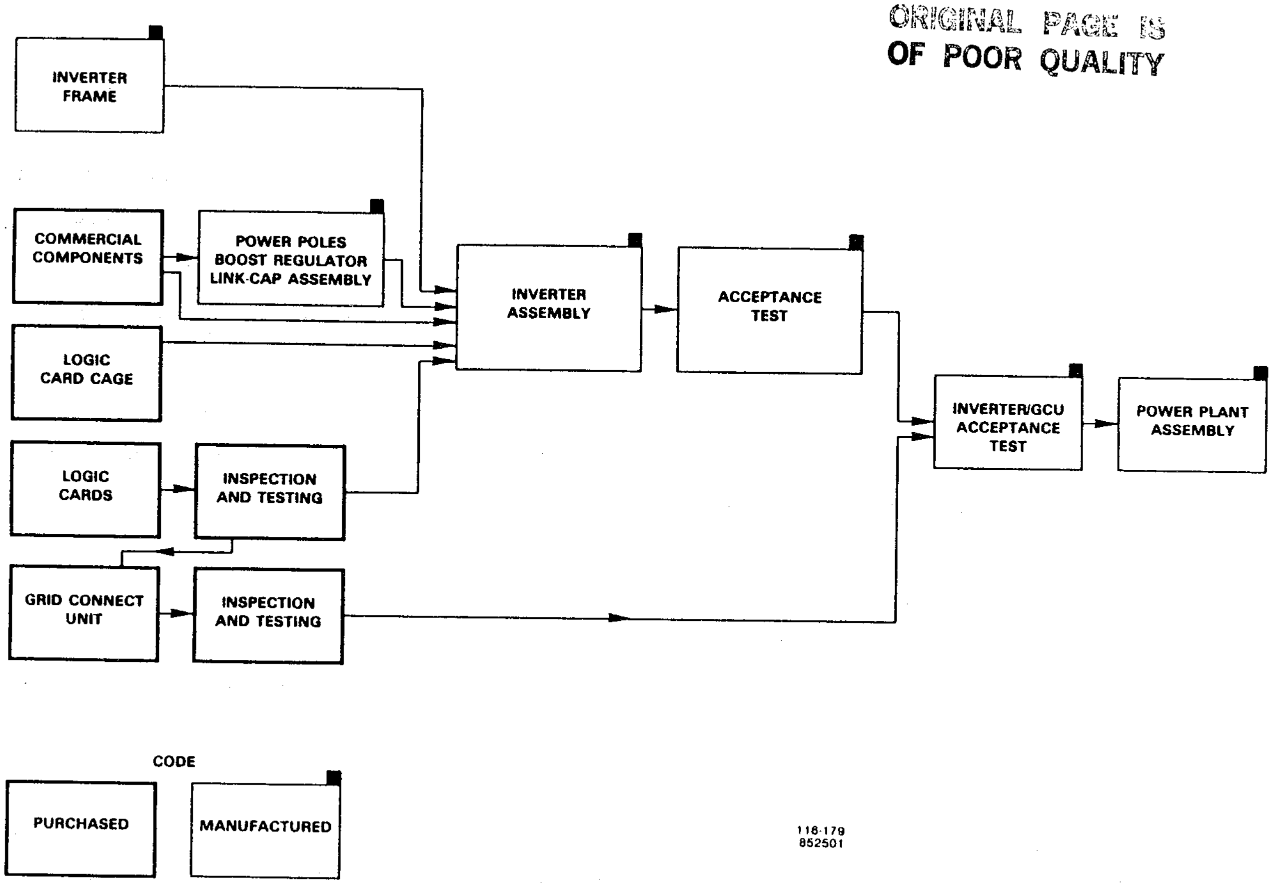

Figure 4-20. Inverter and Grid Connect Unit Manufacture

Figure 4-21.
Inverter Assembly Area

(WCN-9237)

Added Reliability Testing

Due to the number of inverter problems which surfaced during acceptance testing of power plants, and premature electrical failures associated with inverters in the initial field power plants, a more stringent inverter test program was developed in early 1984. Its purpose was to stress the inverter subsystems during the inverter qualification testing at UTC. This was designed to force early failures so that they could be understood and corrected. A test sequence was developed that used elevated temperatures, severe overloads, and isolated-to-grid switching, which exercised the inverter logic. Limited success was achieved by this testing in identifying and forcing premature failures.

A minimum 8-hour endurance period was added to each inverter test. During the early portion of the endurance run the inverter was heated to 115°F. An additional 30 transients to peak power were made during a 3-hour period with the inverter at the elevated temperature.

The grid connect unit was purchased as a complete tested assembly from two separate outside sources. For the PC18B-3A (grid-connect) configuration power plants, the qualification and final power plant acceptance tests were run using the grid connect unit scheduled to be shipped with that specific power plant. This was done to minimize the possibility of any mismatch or undesirable interactions between the units.

Figures 4-22 and 4-23 illustrate complete inverter assemblies, while Figure 4-24 is a close up of the logic card cage with the printed circuit cards installed.

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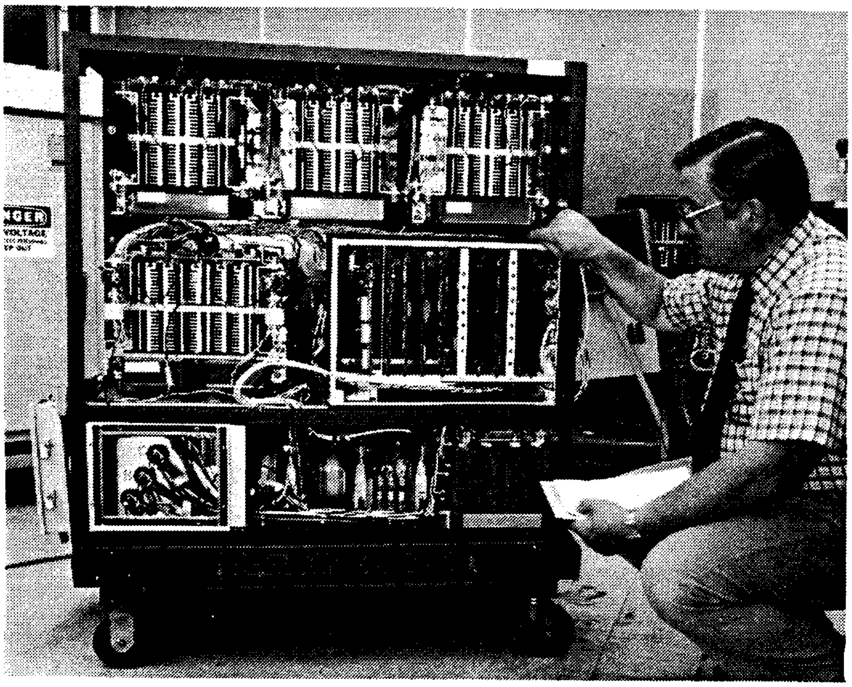

Figure 4-22.
Inverter

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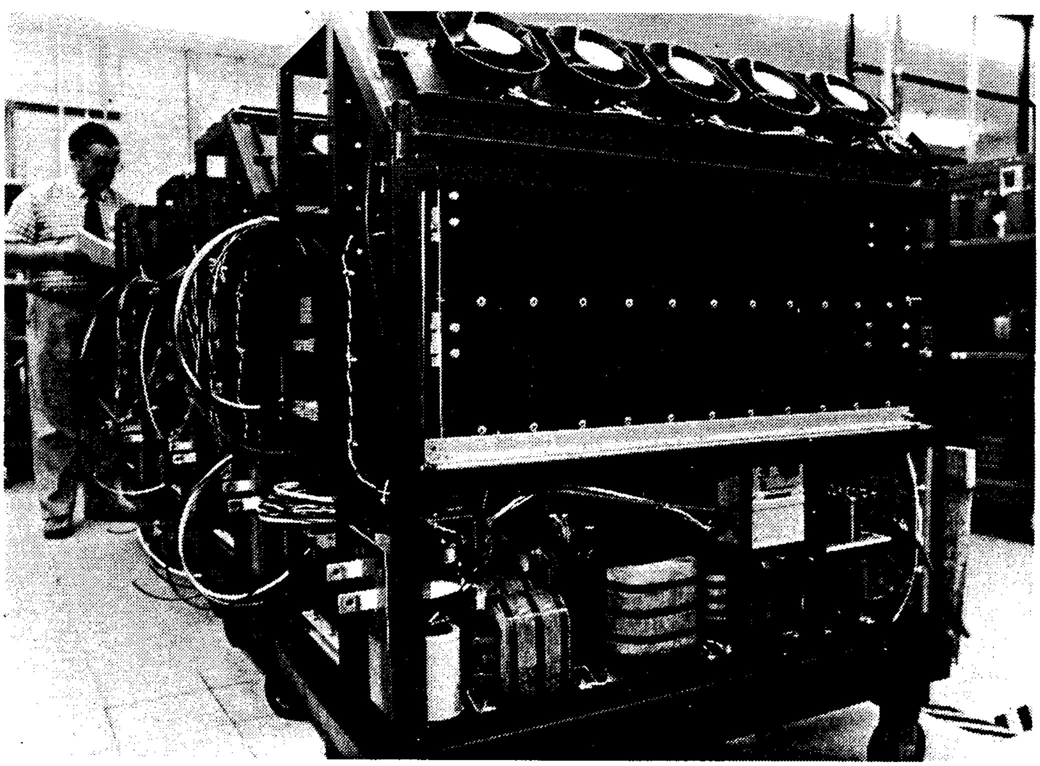

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Figure 4-23. Completed Inverters Ready for Assembly into Power Plants

C-2

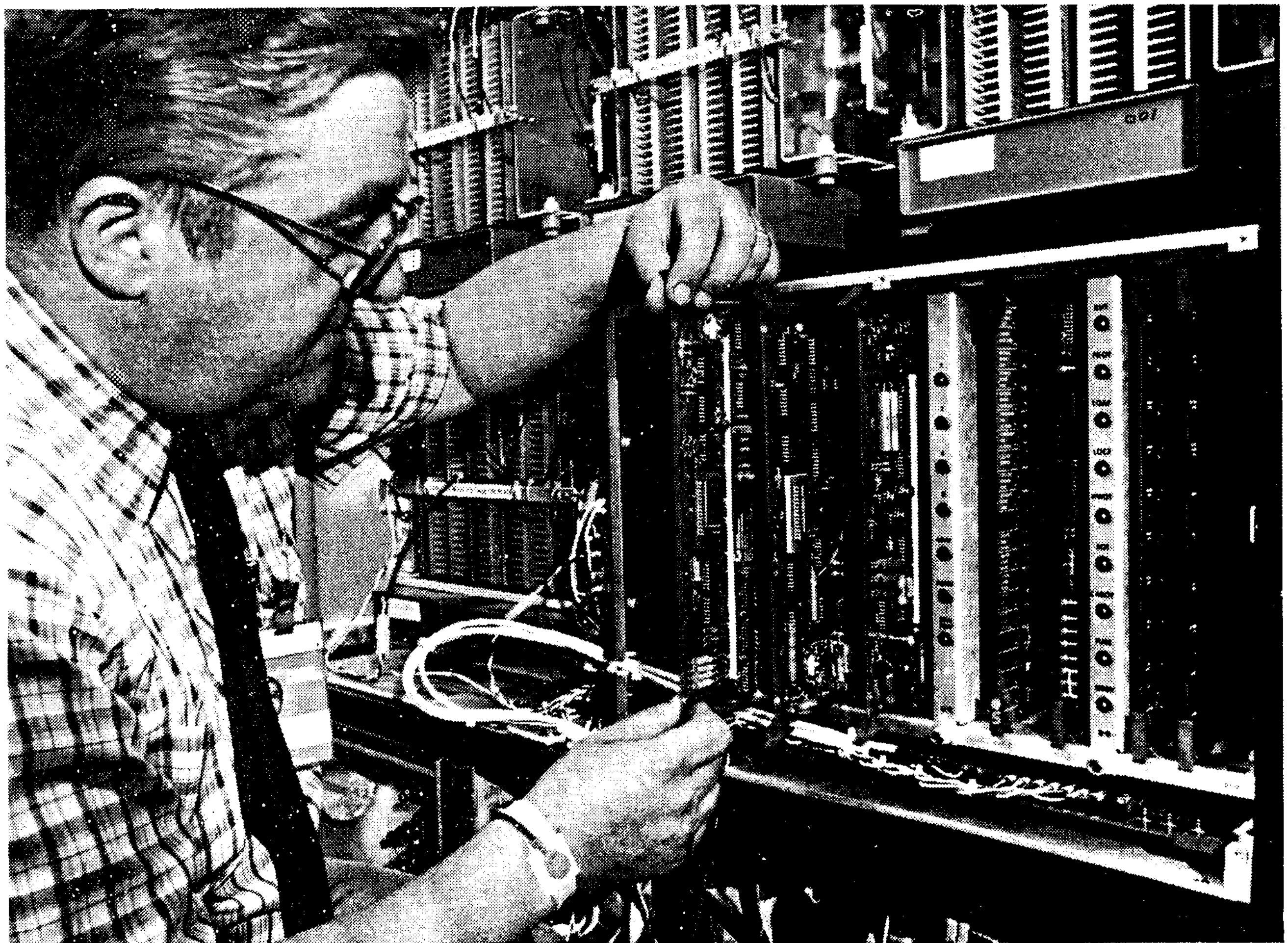

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Figure 4-24. Logic Card Cage with Logic Cards Installed

The grid connect unit is illustrated in Figure 4-25 with an interior view in Figure 4-26.

The master control unit (MCU) couples two or more grid-independent power plants to allow parallel operation. These units were also purchased as completed components.

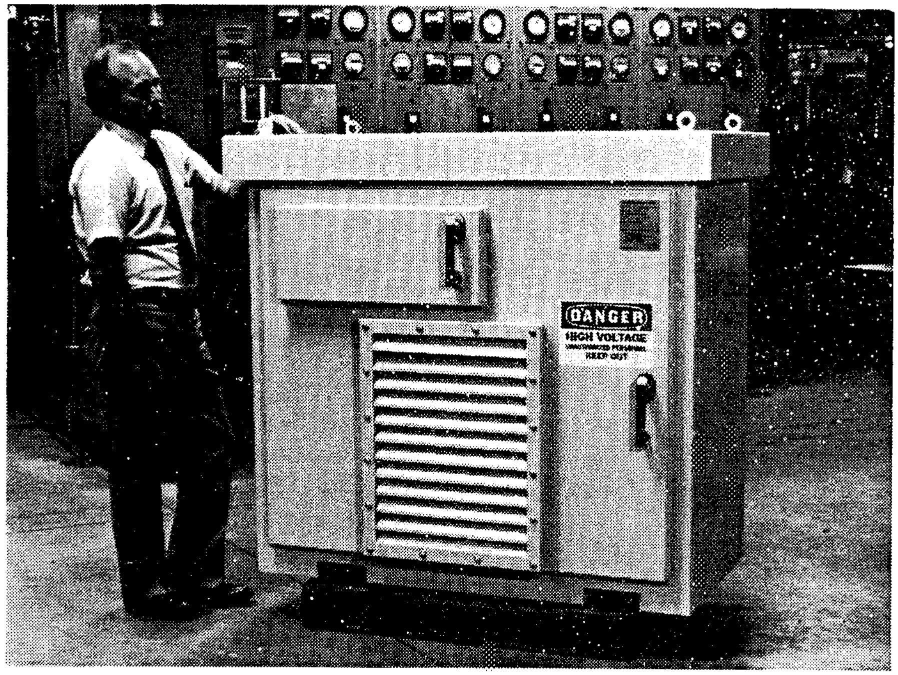

Figure 4-25.
Grid Connect Unit

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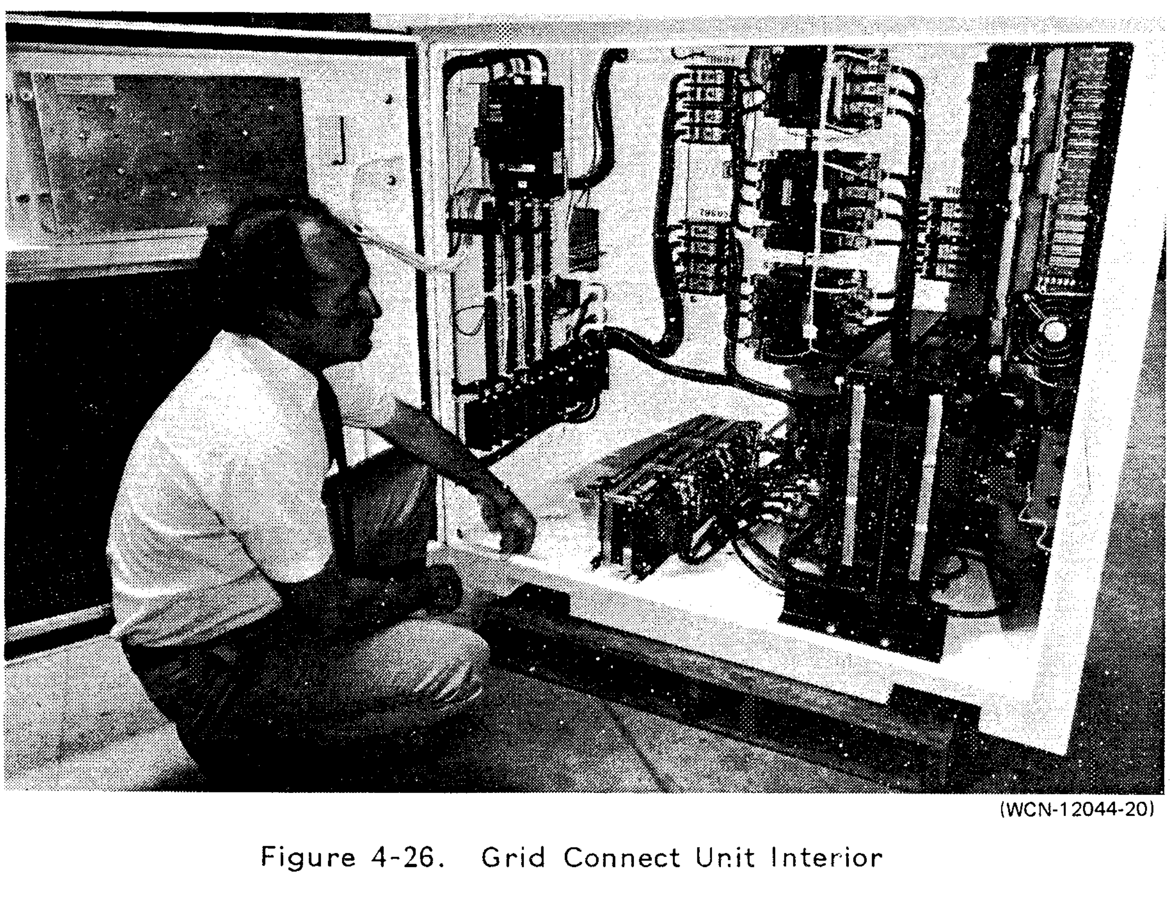

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Figure 4-26. Grid Connect Unit Interior

CONTROLS

With the exception of assembly of the power distribution box (the main electrical junction box) and manufacture of harnesses, all control components were purchased from outside sources. Some components such as the integrated fuel control, air valve assemblies, master control units, and certain electronic assemblies were manufactured to UTC-developed designs, but the majority were off-the-shelf commercial components.

The milestone schedule for procurement and assembly of controls is presented in Figure 4-27.

In most cases, UTC-specified components were calibrated and inspected at the source. Major subassemblies assembled in-house, in addition to the power distribution box, included the control valve trains and the feedwater module subassembly.

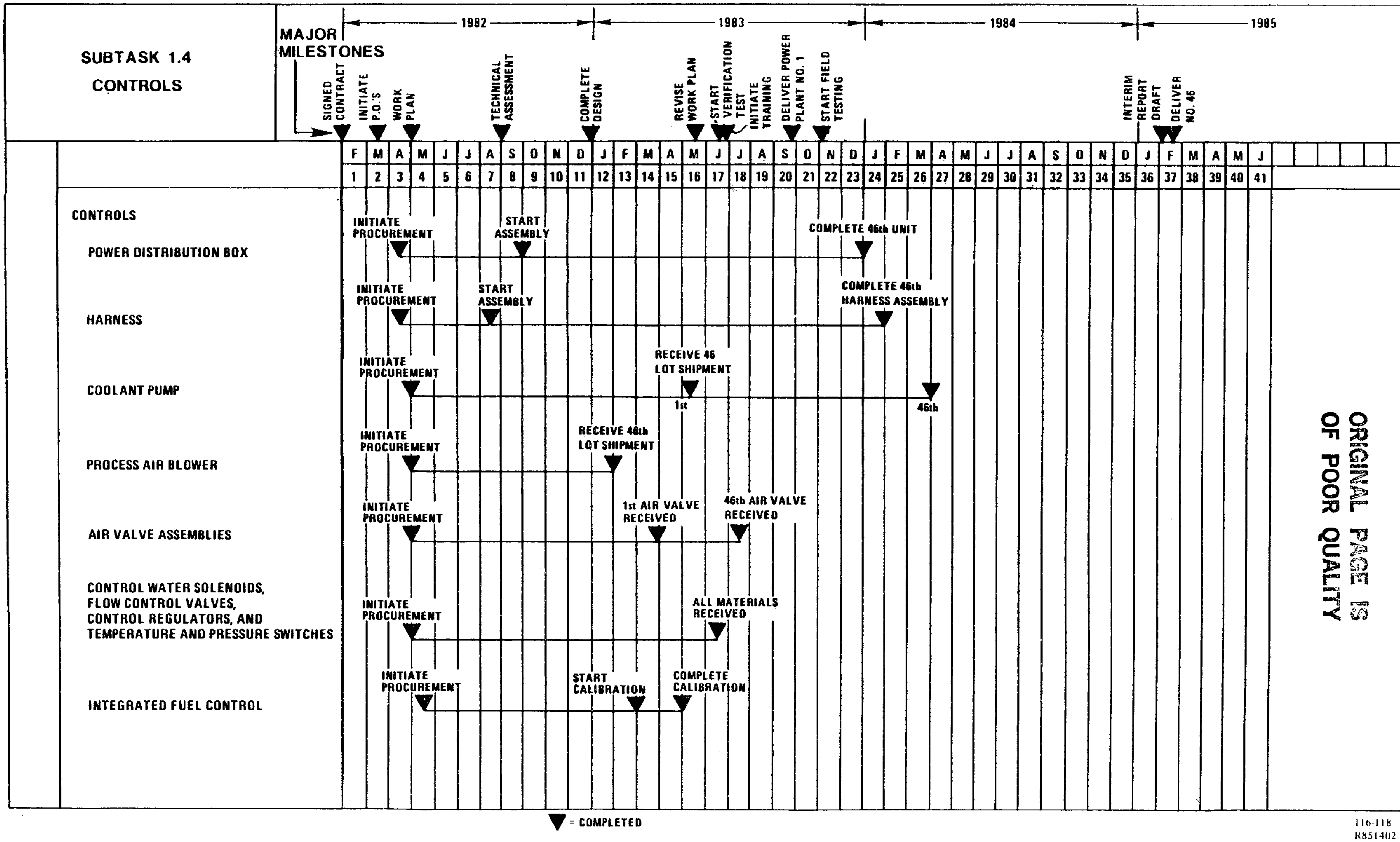

Figure 4-27. Milestone Schedule for Controls Manufacture

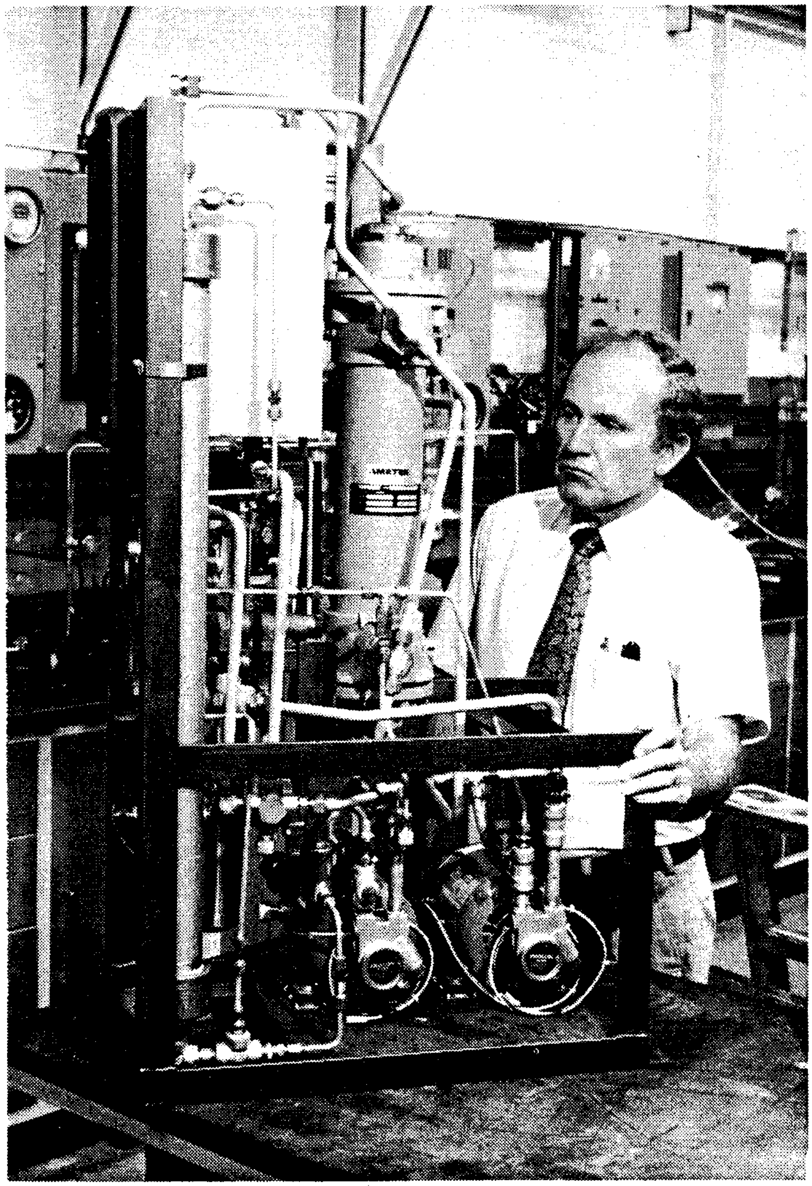

Figure 4-28.
Feedwater Module

(WCN-12044-24)

The feedwater module is shown in Figure 4-28, and the interior of the power distribution box is illustrated in Figure 4-29. The integrated fuel control and several valve train subassemblies installed in a power plant are illustrated in Figure 4-30.

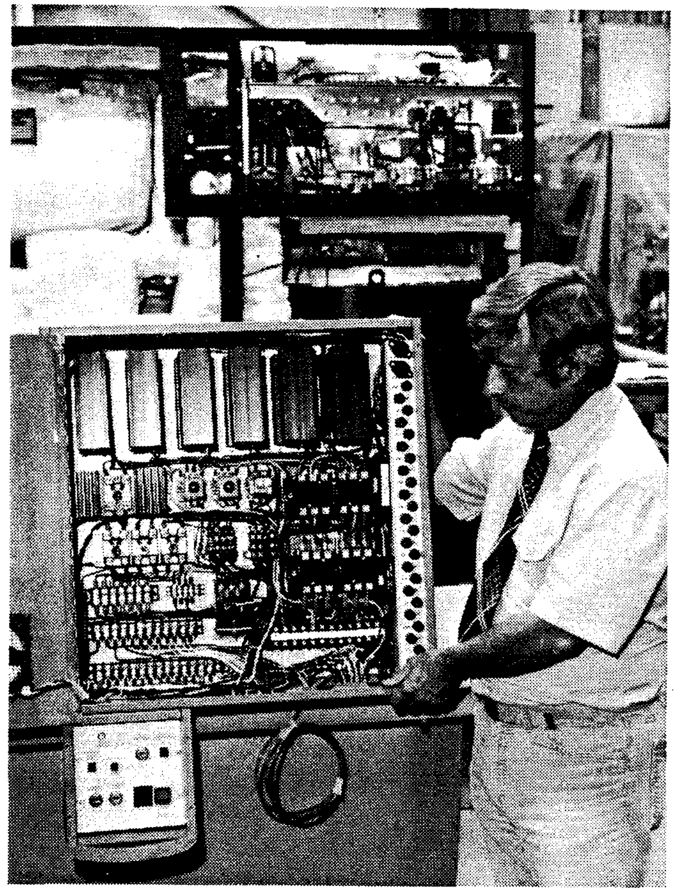

Figure 4-29.
Power Distribution Box Interior

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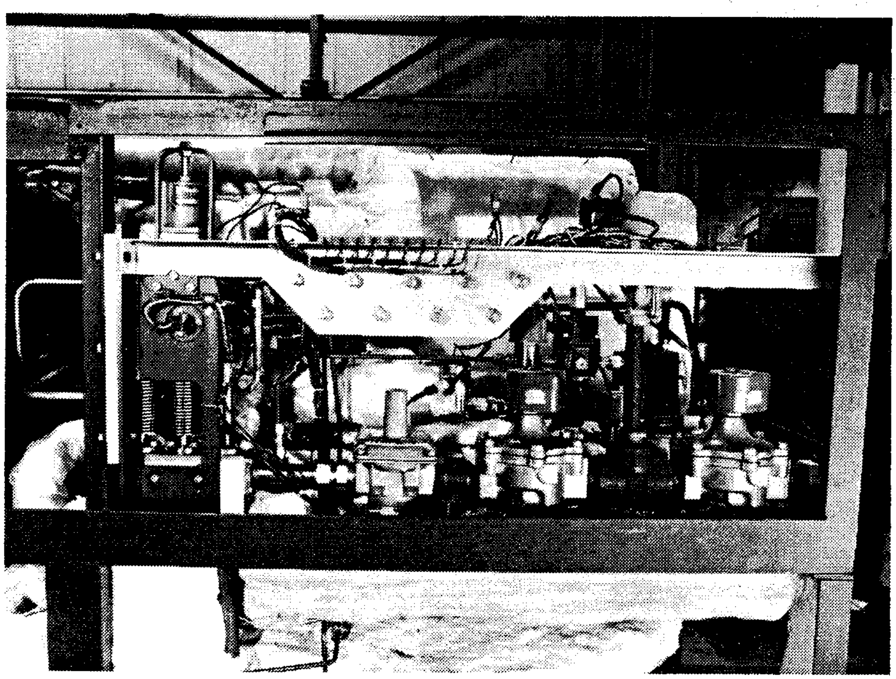

Figure 4-30.
Valve Train Assemblies
Installed in Power Plant

(WCN-12043-24)

THERMAL MANAGEMENT

Thermal management heat exchangers were purchased from three different vendors. The major "spider" assembly, which interconnects five reactant control heat exchangers, was assembled at UTC.

The source of interconnecting piping in the thermal management system and in the controls section was evenly divided between vendors and UTC fabrication. All tubes up to 1" in diameter were fabricated in-house, tubes exceeding 1" in diameter were fabricated by vendors who had the required equipment.

Two spider assemblies, each incorporating the five heat exchangers (HEX 202, 203, 204, 205, 206), are shown in Figure 4-31. The high-grade heat exchanger (HEX 307) is illustrated in Figure 4-32. The low-grade heat exchanger (HEX 513) is illustrated in Figure 4-33. Quality control inspection requirements, including leak- and pressure-testing, were met at the heat exchanger vendors, with additional inspection on the completed spider assembly done at UTC.

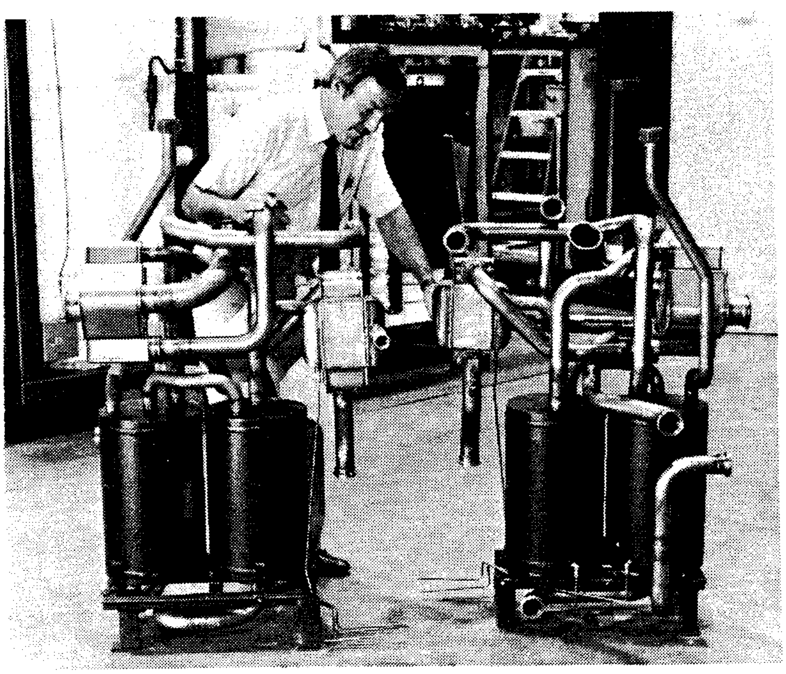

Figure 4-31.
"Spider" Assemblies,
Each Incorporating
Five Heat Exchangers

(WCN-12046-20)

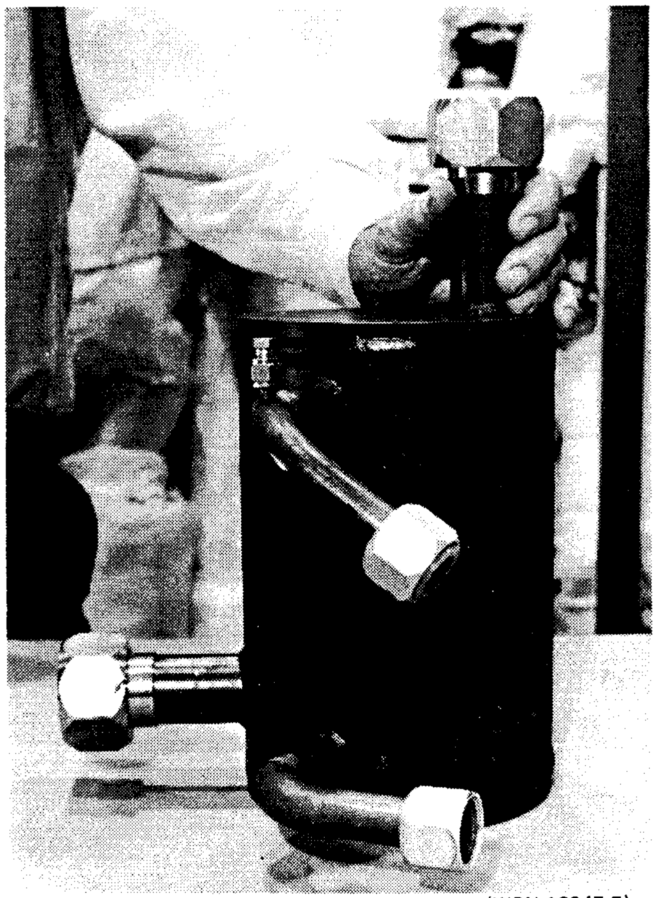

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Figure 4-32.
High-Grade Heat Exchanger HEX 307

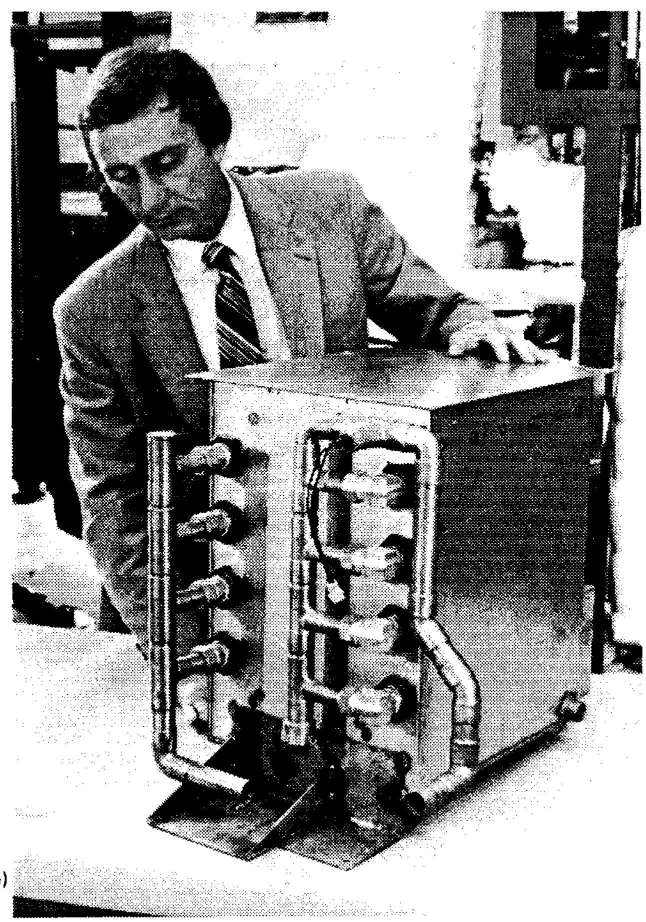

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Figure 4-33.
Low-Grade Heat Exchanger
HEX 513

The identification of heat exchangers by number and functional name follows:

HEX 201	Preoxidizer Heater
HEX 202	Preoxidizer Cooler
HEX 203	Shift Converter Precooler
HEX 204	Anode Precooler
HEX 205	Air Preheater
HEX 206	Hydrodesulfurizer Fuel Preheater
HEX 307	High-Grade Heat Exchanger
HEX 308	Thermal Control Heat Exchanger
HEX 312	Steam Superheater
HEX 409	Regenerator
HEX 410	Feedwater Cooler
HEX 411	Condensate Preheater
HEX 513	Low-Grade Heat Exchanger
HEX 514	Condenser

Procurement scheduling of these heat exchangers was treated as a group and is shown in Figure 4-34.

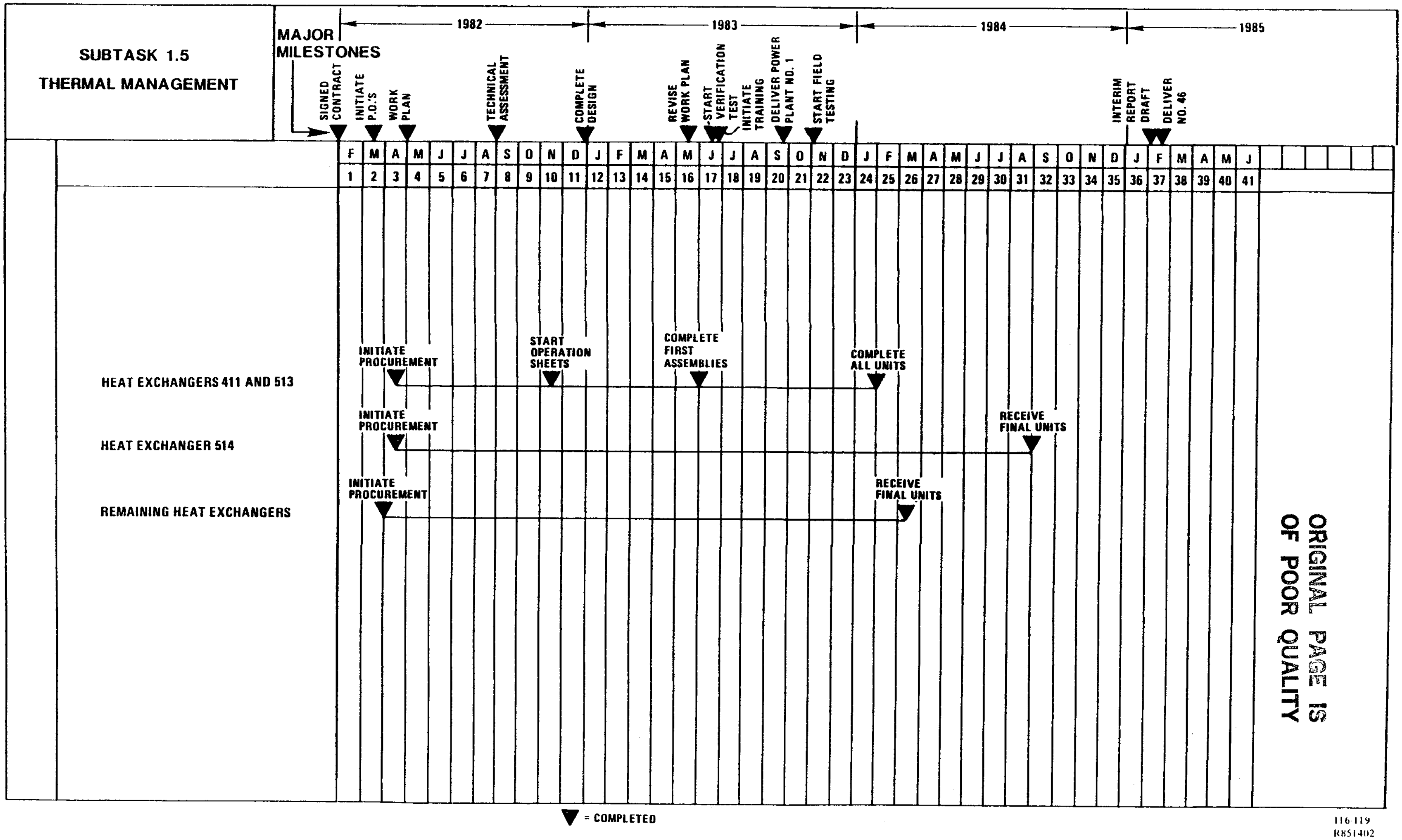

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Figure 4-34. Milestone Schedule for Thermal Management Subsystem Procurement

WATER TREATMENT

The major components of the power plant water treatment subsystem are the water storage tank with deaerator column, charcoal filter, mixed bed demineralizers, and coolant filter (combined mechanical and magnetic). These were all purchased components. The water tank deaerator was purchased to a UTC-originated specification, while the charcoal filter and demineralizer were commercially available.

The scheduling of the major components is treated as a group and is shown in Figure 4-35. The water storage tank is illustrated in Figure 4-36, the magnetic filter assembly in Figure 4-37, and demineralizers and charcoal filter in Figure 4-38.

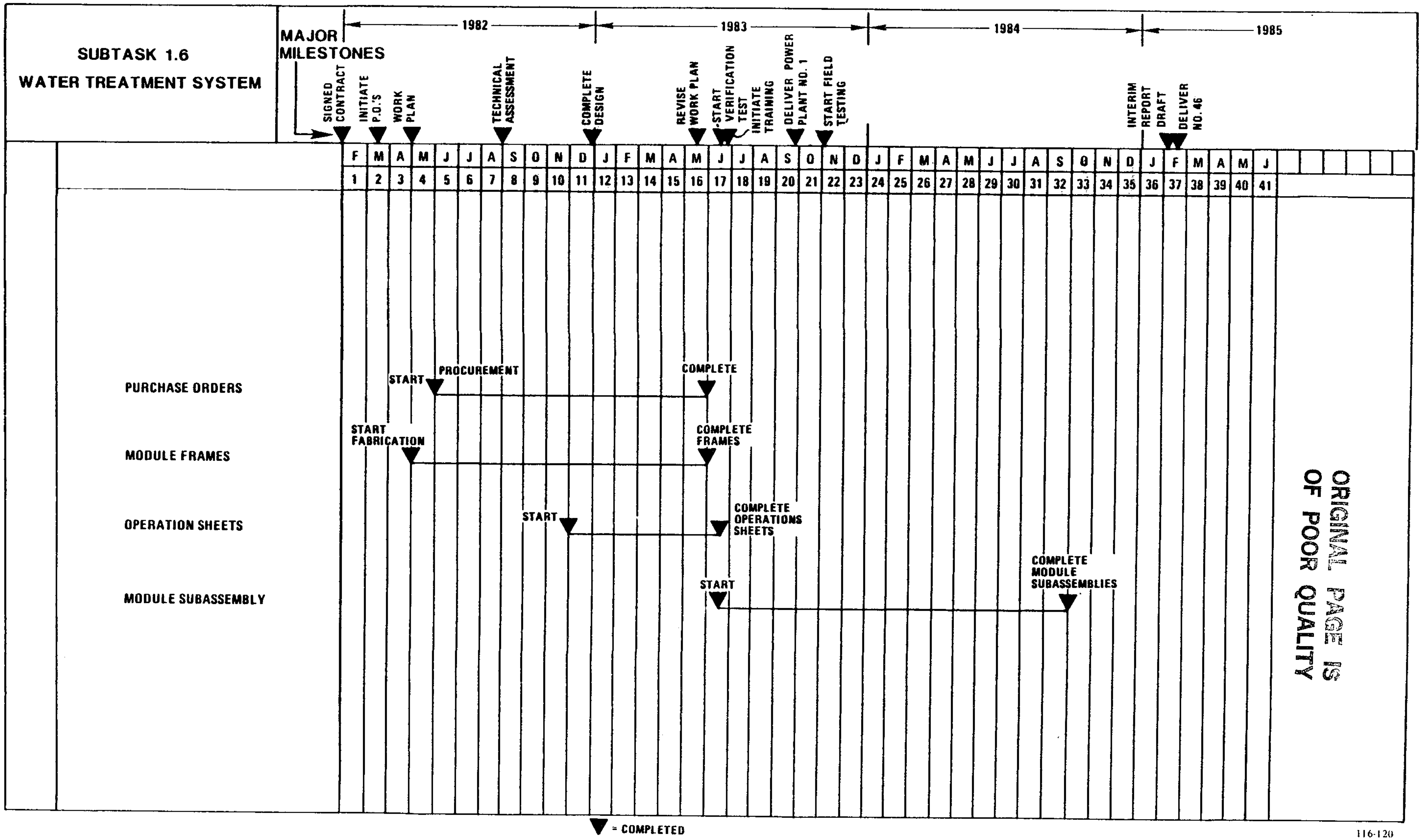

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Figure 4-35. Milestone Schedule for Water Treatment System Procurement

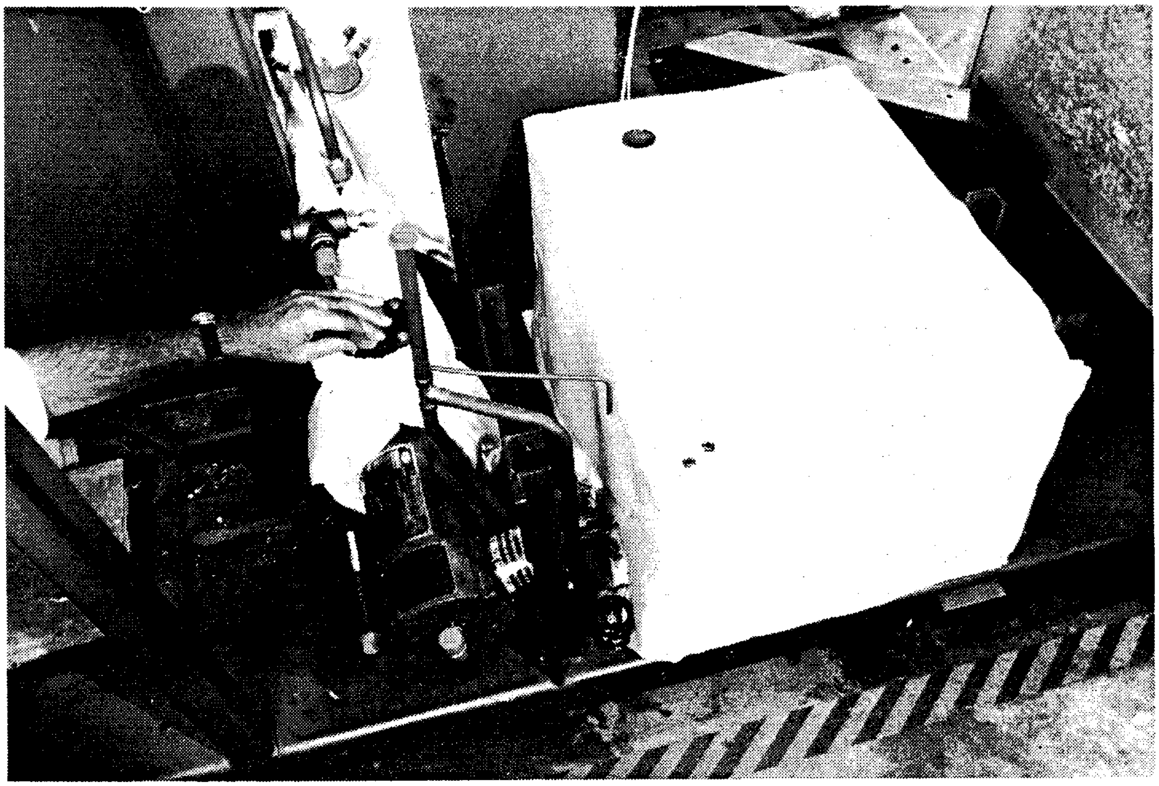

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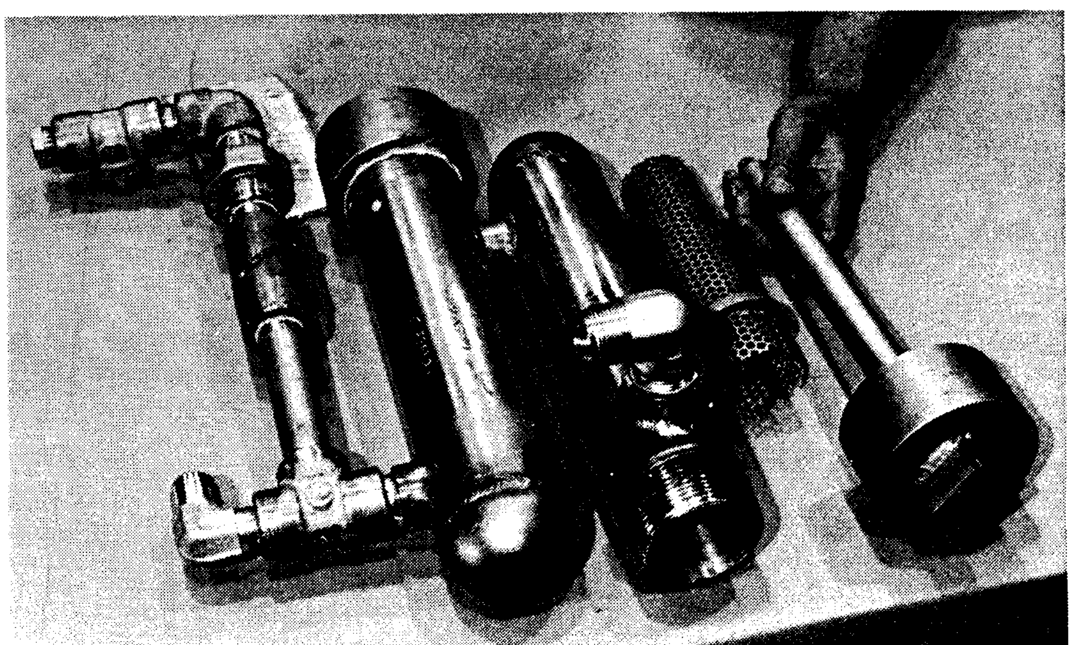
Figure 4-36. Water Storage Tank

Figure 4-37.
Magnetic Filter
Assembly



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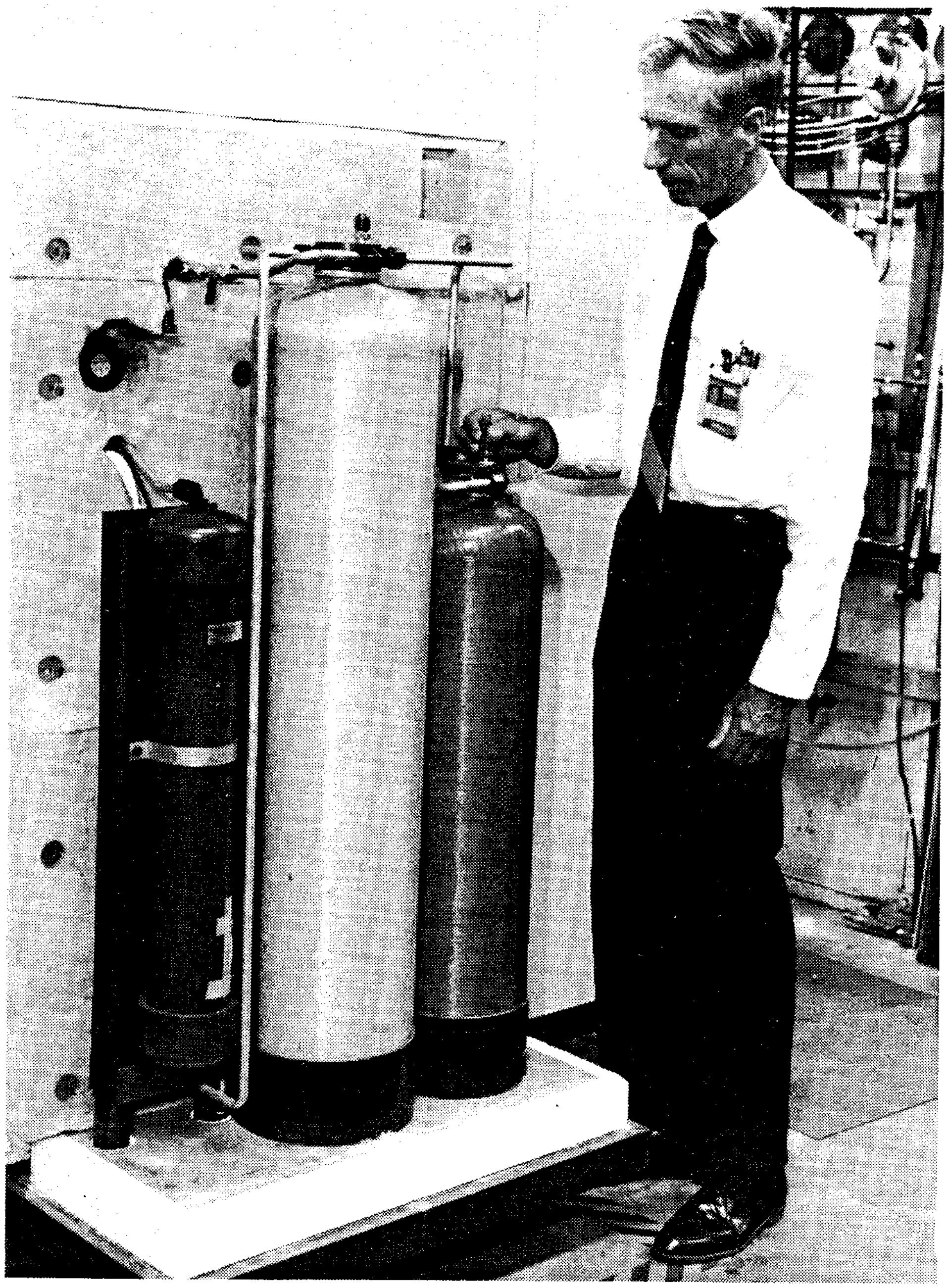

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Figure 4-38. Demineralizers and Charcoal Filter

Following receiving inspection these parts were stored until required for assembly into the power plant. After acceptance testing of the power plant, new dry demineralizers were installed to prevent freeze damage during storage and shipment.

POWER PLANT ASSEMBLY

The assembly of the 46 power plant delivery units was accomplished within a period of 18 months. Initial assembly time of approximately 1,500 hours per unit was reduced to 600 hours for the final units as assembly techniques were improved. This corresponds to a learning curve of approximately 85% for power plant assembly. A team approach was used for the construction of these units with two to three assemblers assigned to a particular power plant.

Assembly Details

The assembly process was directed by means of operation sheets with the primary assembler responsible for signing off each operation and suboperation as it was completed. The assembly was broken down into 16 major segments.

Power plant piping and plumbing subsections were preassembled off line, pressure tested, and delivered to power plant assembly as subassemblies. This technique allowed a simpler and smoother power plant assembly and moved the task of completing valve trains and pressure testing of plumbing outside of the power plant assembly area.

Throughout the power plant assembly process, extensive use was made of Quality Assurance personnel in order to guarantee that critical operations were performed properly. This included the witnessing of certain crucial operations. There was a continuous review of assembly work to insure that all operations were accomplished.

The hardware associated with final assembly consisted of the power plant structure and cabinet panels, which were purchased items, and electrical harnesses, which were manufactured in-house.

The milestone chart covering final assembly is presented in Figure 4-39.

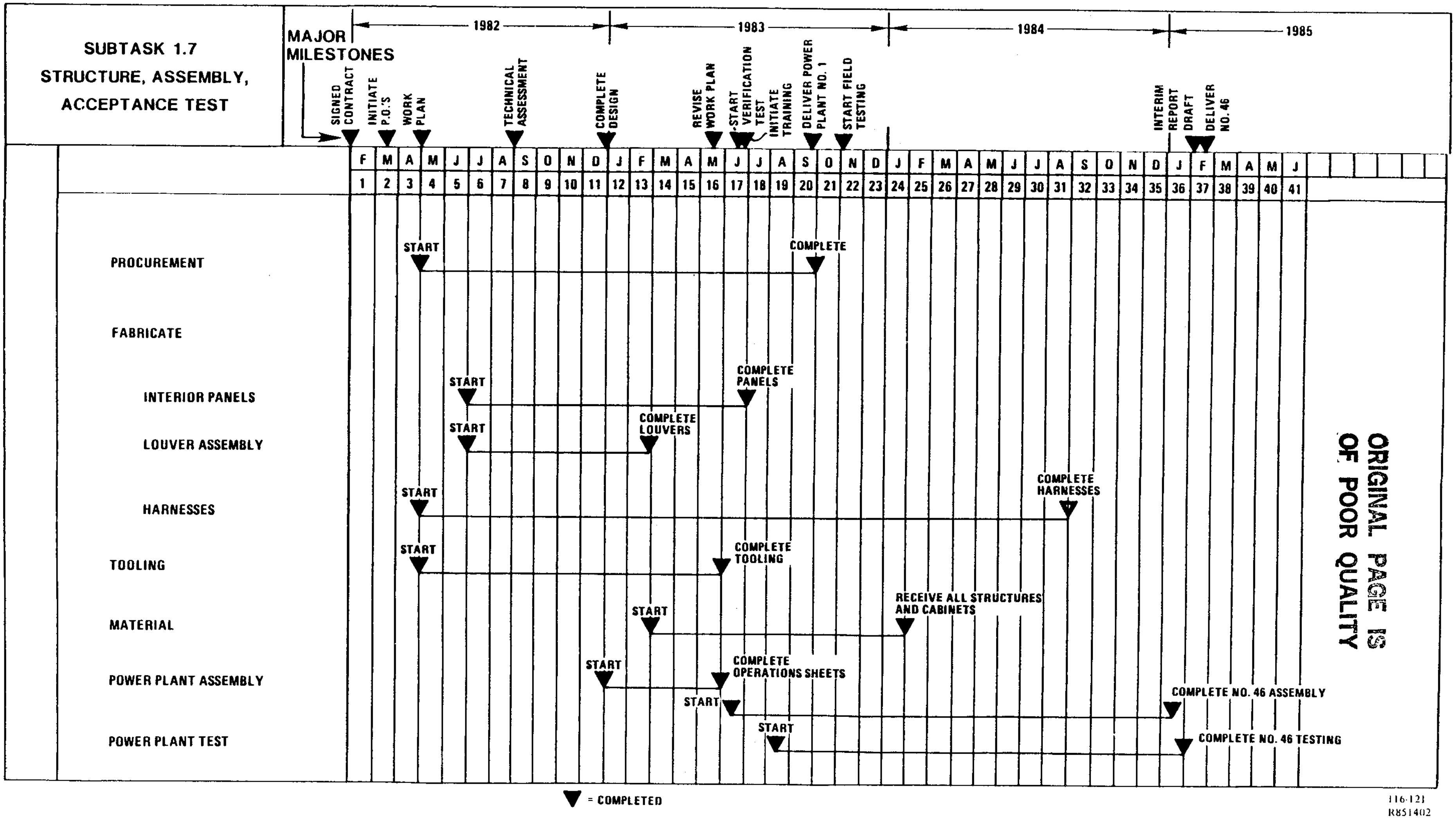

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Figure 4-39. Milestone Schedule for Structure, Assembly, and Acceptance Test

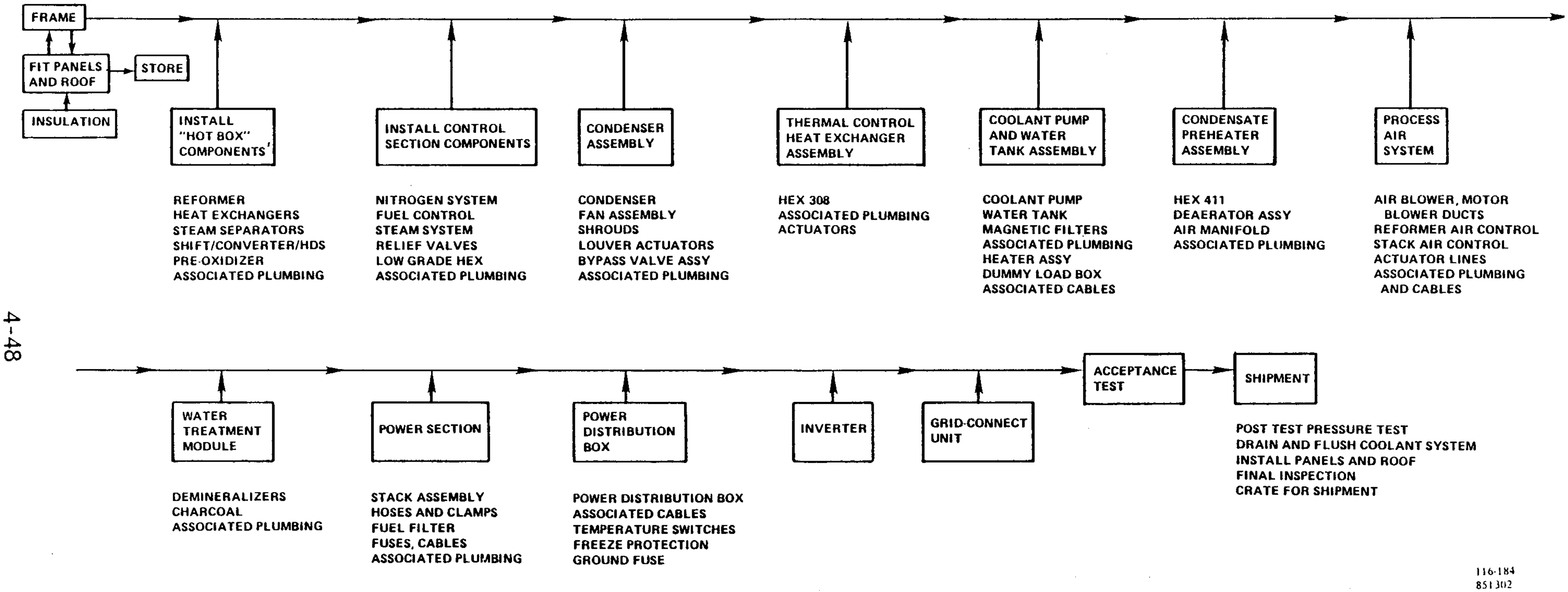

Figure 4-40. Power Plant Assembly

Assembly of the 40-kW power plants was performed in a specially designated section of the facility. Five assembly stations were constructed, each provided with a one-half ton crane and various services including pressurized air, nitrogen, electricity, and lighting. Assembly operations sheets and procedures were followed during power plant assembly.

A chart summarizing the normal sequence of manufacture of subassemblies feeding into the overall power plant assembly is shown in Figure 4-40.

Prior to start of assembly, the panels and roof were fit and drilled to match each frame and put aside for installation after the acceptance test to avoid excessive handling damage. The frame was then delivered to an assembly station where it remained until it was delivered to the acceptance test area. The initial assembly work began in the high temperature area, with installation of the major high-temperature fuel processing components, heat exchanger "spider" assembly, and the steam separator. Previously assembled control subassemblies and the low-grade heat exchanger were then fitted in the control section and additional plumbing, cables, and insulation installed as the work progressed.

The previously assembled condenser/fan assembly and associated components were then installed, followed by the thermal control heat exchanger. Next, the coolant pump, water tank, and condensate preheaters, including water filters, heater assembly, dummy load box, and required plumbing and cables were installed.

The process air system, including the blower and two air control valves, was installed next, followed by installation of the water treatment module on the frame extension. Although new resin beds were installed at this time, they were temporarily replaced with test stand beds during the acceptance test to assure that they would be shipped in a dry condition, not susceptible to freeze damage.

The power plant assembly was completed by the addition of the power section, power distribution box, and inverter, along with necessary plumbing and cables. Final electrical and pressure tests were performed prior to delivery to the acceptance test stand.

Following power plant acceptance testing, an additional pressure test was performed to verify coolant system integrity. The liquid systems were then drained and flushed with methanol to eliminate the possibility of freeze damage during shipment. The power section electrolyte concentration had previously been conditioned at the end of the acceptance test to prevent solidification.

The unused water treatment beds were then installed, final inspection by Quality Control was conducted, and final preparations for shipping were made, including blocking of plumbing for shipping support and removal of certain logic cards for separate, protected shipment. The final step before shipment was the installation of the power plant into a wooden shipping crate.

An overall view of the final assembly area, with 10 power plants in various stages of assembly, is shown in Figure 4-41. Views of the power plant prior to installation of the cabinet panels are shown in Figures 4-42 through 4-45.

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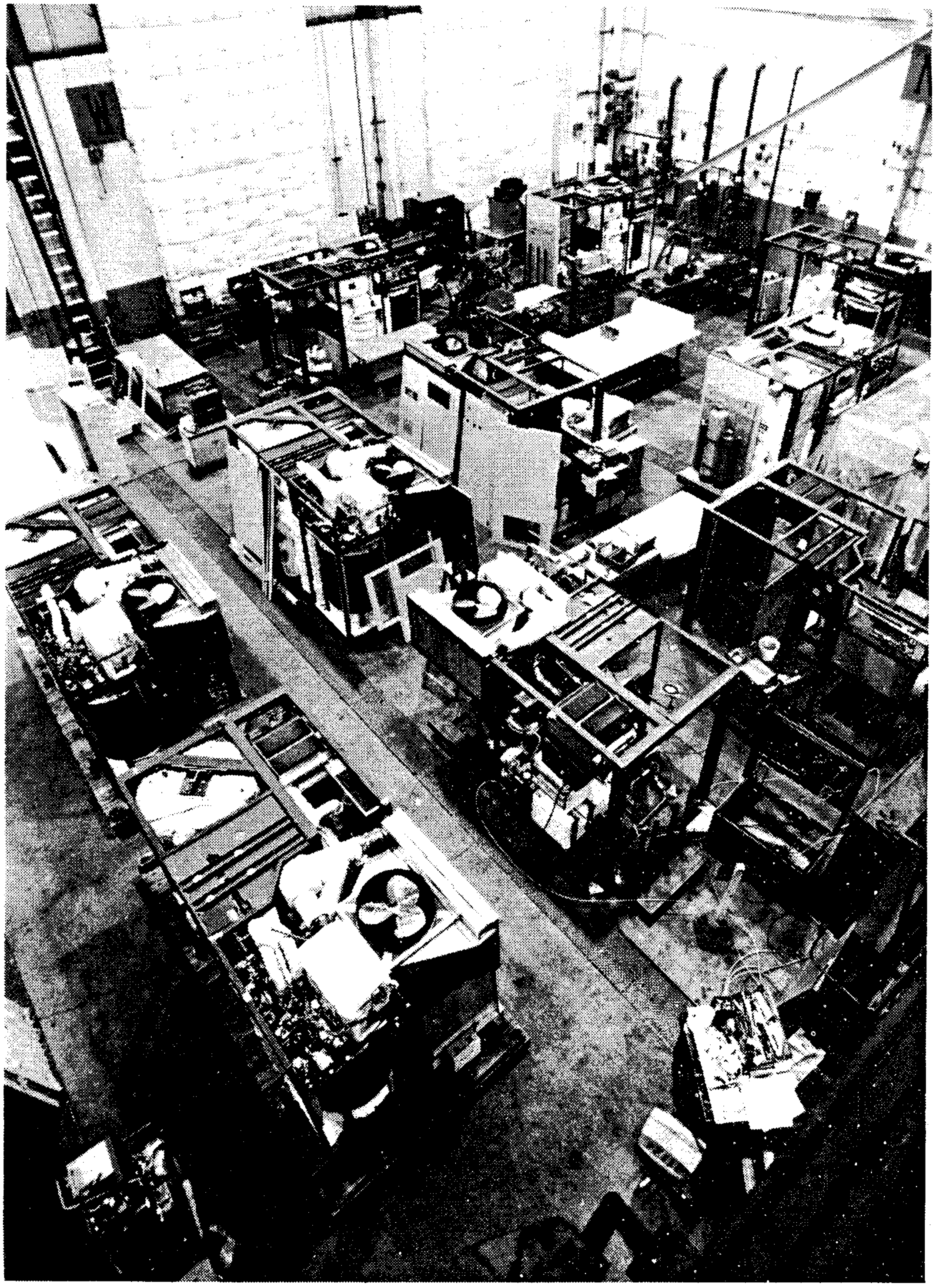

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Figure 4-41. Power Plant Assembly Area

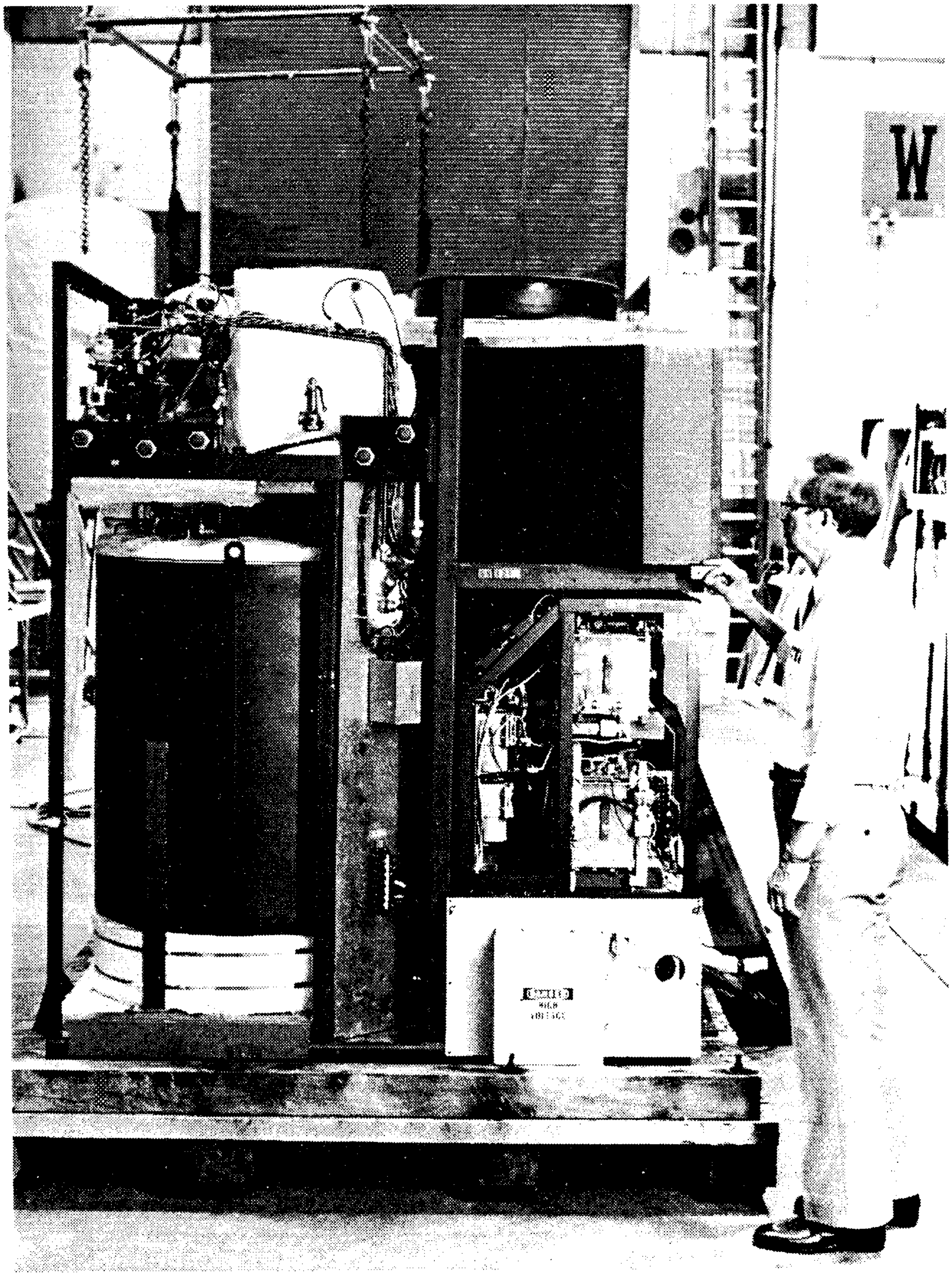

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Figure 4-42. Power Plant, Left Side

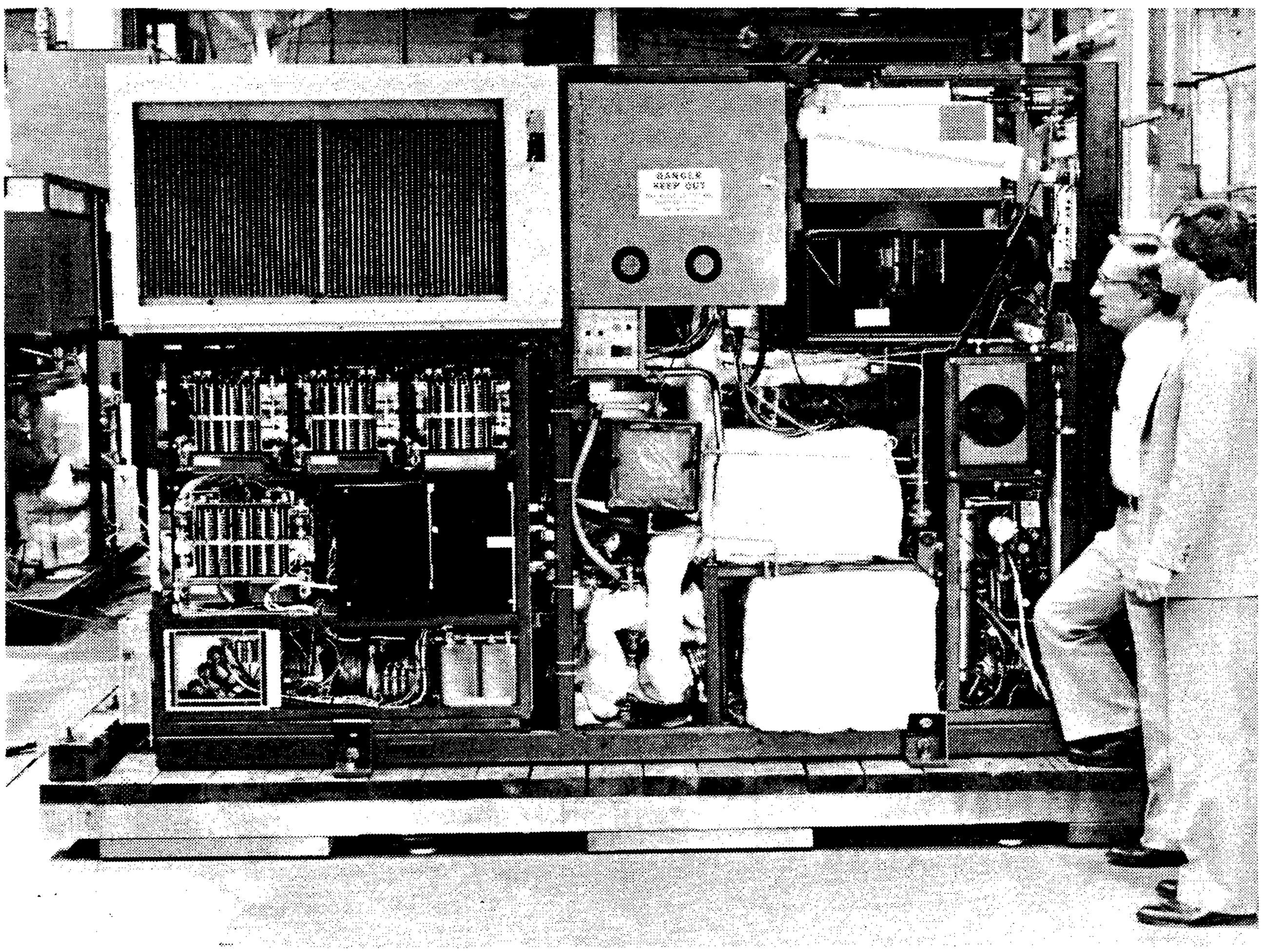

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Figure 4-43. Power Plant, Front

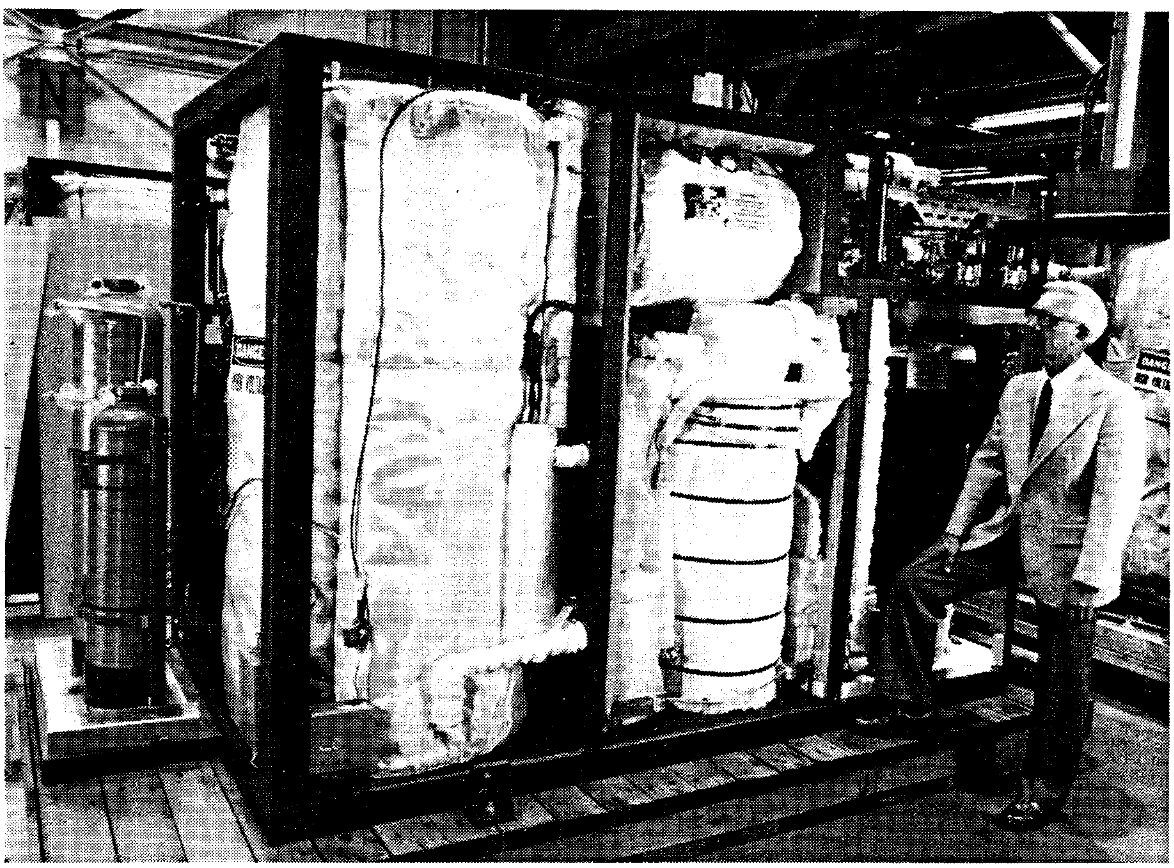

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Figure 4-44. Power Plant, Rear

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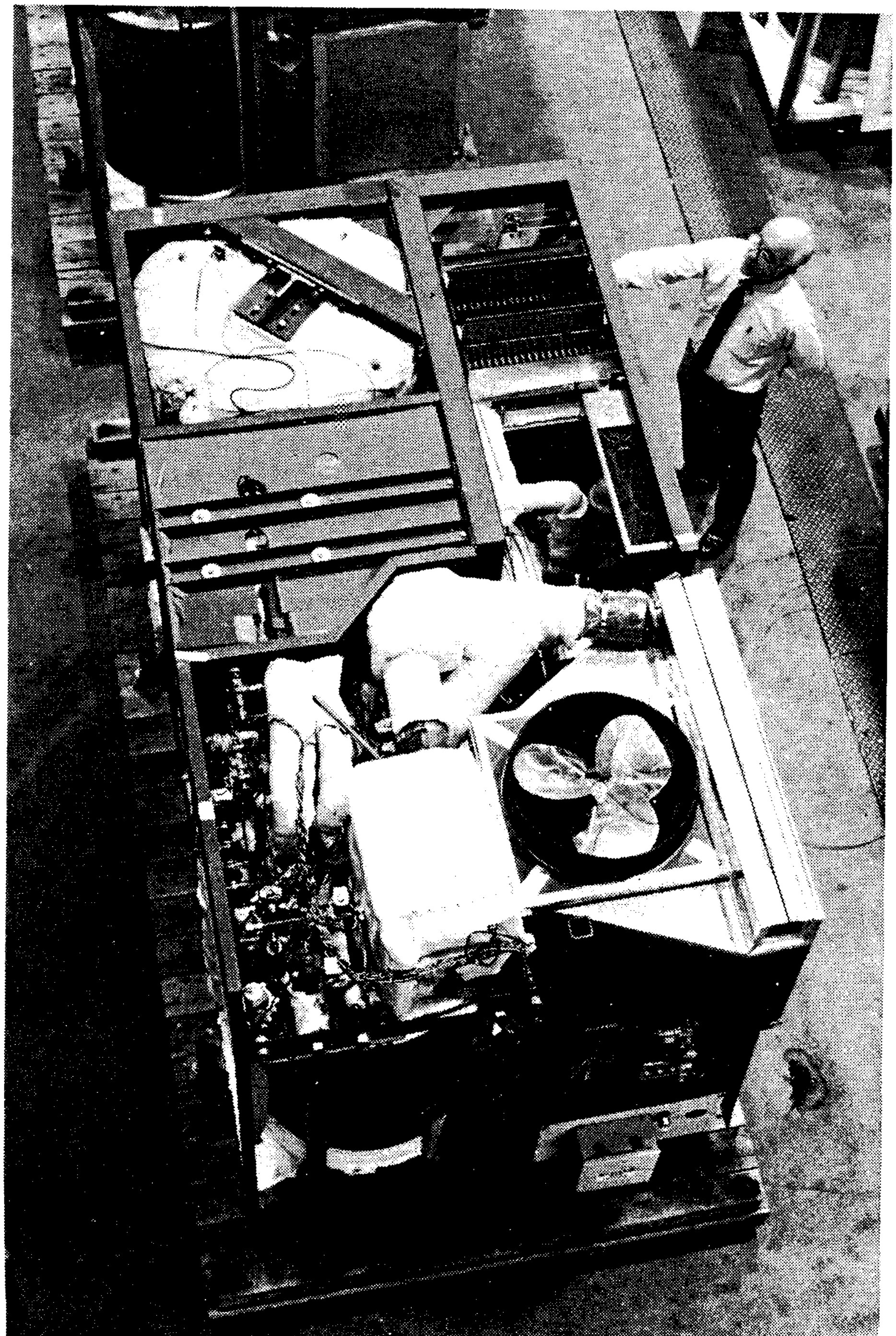

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Figure 4-45. Power Plant, Top

40-kW POWER PLANT ACCEPTANCE TEST

An existing test stand was modified for conducting acceptance tests. Each delivery power plant was tested in accordance with the Acceptance Test Procedure established under Section DR-6 of the NASA contract (Reference 10). The acceptance test verifies that each power plant starts, accepts electrical loads, performs under transient conditions, and shuts down properly, in accordance with specified performance limits. An overview of the major events in the acceptance test are listed below, and details of the test follow.

Overview of Major Events of the 40-kW Power Plant Acceptance Test

1) Power Plant Installation in Test Stand
2) Coolant System Fill
3) Diagnostic Tests
4) Reformer Burner Gas Flow Adjustment
5) Water Conditioning
6) Initial Power Plant Test
    A) Cell Stack Assembly Test
    B) Reformer Catalyst Break-In
    C) Power Plant Specification Test
7) Water Conditioning
8) Final Power Plant Test
9) Cell Stack Assembly Acid Conditioning
10) Coolant System Pressure Test
11) Methanol Flush
12) Power Plant Removal from Test Stand

Test Details

A series of diagnostic tests were used to verify the functionality of electrical and mechanical components prior to power plant start-up. The tests also permitted initial confirmation that power plant logic sequence was proper. The tests were accomplished by use of a special diagnostic test apparatus connected to control interface points which sequenced motors, valves, and pumps.

The acceptance test evolved during the manufacturing phase. Initially, the test consisted of one start and approximately six hours of total operation. Very early in the program the test was lengthened to include three starts and 75 hours of operation. The final test used for approximately one-half of the power plants is described here.

1. Power Plant Installation in Test Stand

With the power plant located in X-810 stand, the following electrical, instrumentation, and service systems were connected to the power plant interfaces:

Electrical

- AC Start-Up Power
- Inverter Output Power
- DC Power Supply
- Diagnostic Output
- Data Acquisition
- Grid Connect Unit Cable
- Power Plant Ground

Instrumentation

- Thermocouples required for Calibration and Documentation
- Pressure taps required for Calibration and Documentation

Service

- City Gas Supply
- Nitrogen Supply
- Deionized/Deoxygenated Water Supply
- Power Plant Water Drain

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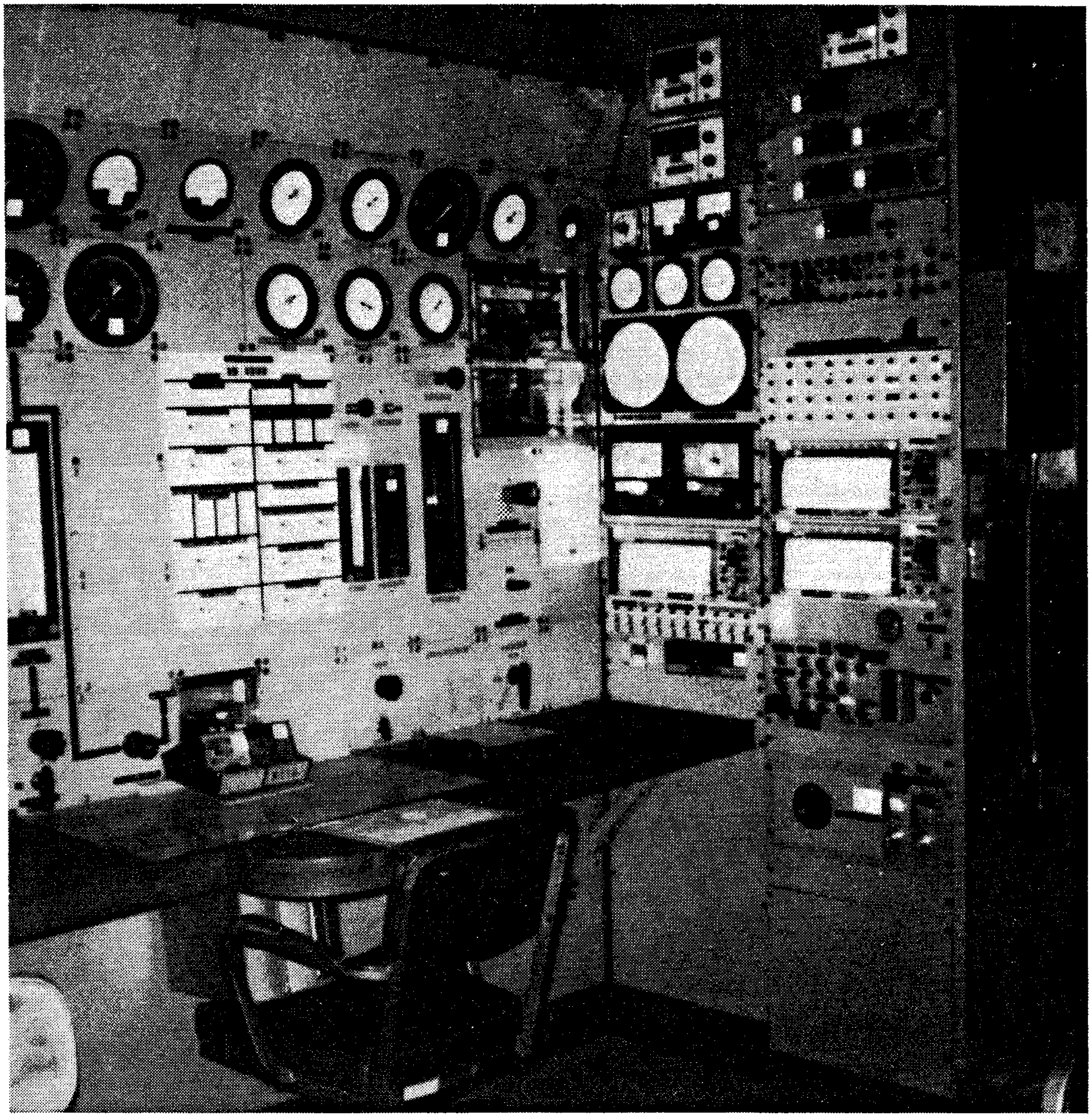
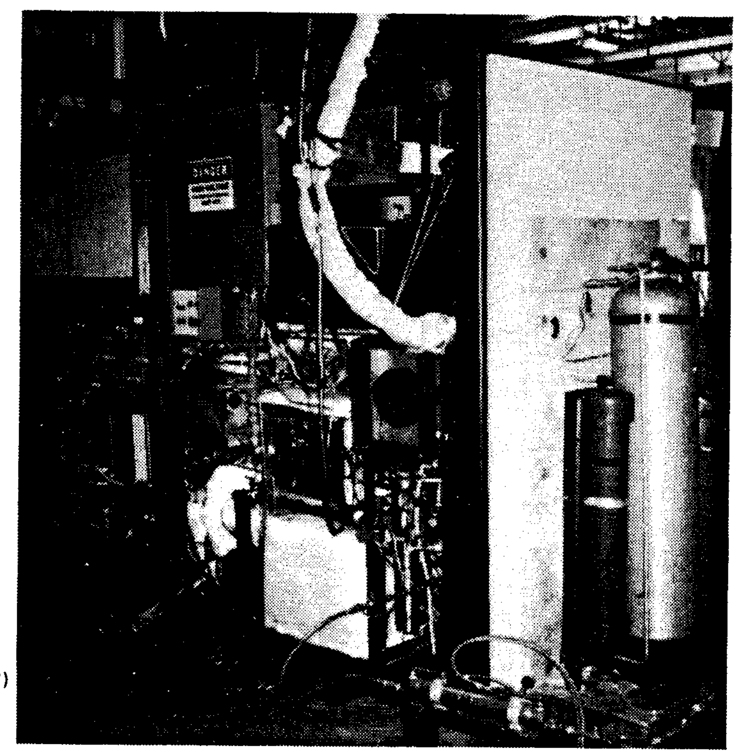
Photographs of the acceptance test stand, with a power plant installed are presented in Figures 4-46 and 4-47.



(WCN-13316)

Figure 4-46. Acceptance Test Stand Control Panel

(WCN-13318)



(WCN-13317)

Figure 4-47. Power Plant in Acceptance Test Stand

2. Coolant System Fill

The power plant coolant system was filled with deionized/deoxygenated water. During this process the following events occurred:

- o Air and inert gas vented from system.
- o System was checked for leaks.
- o The three level switches located in the hot well were checked for function during filling by observing the LED's on PC-5 cards in the microprocessor.

3. Diagnostic Tests

With the coolant system filled, a number of diagnostic tests were completed, including a simulated power plant start-up. Also included in these diagnostic tests were valve calibration of the three major control valves (reformer air valve, cathode air valve, and integrated fuel control valve), and a measurement of current flow for both the start-sustaining heaters and the shift converter heaters.

4. Reformer Burner Gas Flow Adjustment

Both the reformer torch and start fuel flow control valves required adjustment before starting the power plant heat-up. Once the correct natural gas flow was set, the reformer ignition sequence was tested using the diagnostic simulator.

5. Water Conditioning

Prior to a power plant heat-up, the water of the coolant system was conditioned to meet the following criteria:

1) Conductivity equal to or less than 0.5 micromho.

2) Turbidity equal to or less than 50 parts per billion of iron.

6. Initial Power Plant Heat-Up

A) Cell Stack Assembly Test

During the initial power plant heat-up, the normal heat-up sequence was interrupted in order to condition the electrolyte in the cell stack assembly. At the completion of this conditioning phase, a brief test was performed on the cell stack to verify stack performance and integrity.

B) Reformer Catalyst Break-In

Upon completion of the power plant start-up, the power plant was limited to 5 kW net power output for a minimum of one hour in order to allow for completion of the reformer catalyst break-in.

C) Power Plant Specification Tests

The power plant was operated for approximately 6 hours in order to run tests which demonstrate that the design criteria were met. These tests include:

1) Performance calibration from zero to 40-kW load.
2) Rapid down transient from 40-kW to zero-net load.
3) Overload inverter trip-out tests.
4) Limited endurance at 40-kW load.

If the power plant was to be used with a grid connect unit, additional testing was conducted. Included in these tests are:

1) Transfer of load from isolated load to the grid and back to isolated load at various power levels.

2) Line disconnect tests.

Final adjustments were also made at design conditions for the process steam pressure, the hydrogen desulfurizer pressure, and the coolant flow.

At the completion of this initial run, the power plant was then shut down and placed in the water conditioning mode.

7. Water Conditioning

As per Item (5), the water was conditioned prior to heating the power plant.

8. Final Power Plant Test

A second power plant test was made in order to verify the system integrity after a thermal cycle. During this second run additional transients were completed, followed by a 6-hour run at 40-kW load. Prior to the final shutdown, the power level was set at 35 kW and the half-stack voltage automatic shutdown limits were identified and set. A third cycle was introduced for selected power plants in an effort to improve the reliability of electronic components. This was discontinued when it was shown that few if any problems were resolved by this additional test.

9. Electrolyte Conditioning

Following the final power plant shutdown, the electrolyte concentration of the cell stack assembly was adjusted to prevent electrolyte solidification. This task was accomplished by purging moist hydrogen and air into the cell stack assembly while applying a dc load.

10. Coolant System Pressure Test

Prior to preparation for shipping, a final pressure test was made on the power plant coolant system. This test was similar to one performed in the field following delivery. The system was pressurized to 150 psig and decay tested for 15 minutes with a maximum allowable decay of 5 psi. During this time a visual check was made on all observable fittings for leakage. If leaks occurred, repairs were made and another test was run.

11. Methanol Flush

The entire coolant system including the actuation system was flushed with a methanol-water solution in order to prevent freezing and resultant damage during storage and shipping. When this flush was completed, the system was drained, purged with nitrogen, and sealed. The water clean-up demineralizer beds were removed during this operation and new, drained units are used for power plant delivery.

12. Power Plant Removal from Test Stand

Upon completion of the methanol flush operation, all lines were disconnected and caps placed on all fittings. The power plant was now ready to be moved to an area where it was prepared for shipping.

Power plant and grid connect units were tested to verify proper assembly and that the power plant was able to meet design requirements. The overall time required for power plant test was reduced through the program as a result of two major factors: (1) with experience there was less construction errors, and (2) time required for power plant water cleanup prior to start-up was significantly reduced by the use of the auxiliary cleanup system. Thus, power plant testing was accomplished on schedule despite the need to accommodate extended testing aimed at increasing the field reliability of 40-kW power plants.

Power plant testing proved to be one of the more difficult portions of the Manufacturing experience, however, and wound up being the critical path item. In retrospect, more than one power plant test station would have been appropriate and would have smoothed the manufacturing flow considerably through the assembly and test operations, but the long lead time and expense of constructing a second station made this option impractical.

Following testing, an acceptance data package was submitted for each power plant in accordance with the contractual requirement provided in Section DR-4 of the NASA contract. A typical test report is included in the appendix of this report.

SHIPPING PREPARATION

At the conclusion of the acceptance test, the power section electrolyte was conditioned as stated above. The phosphoric acid concentration was uniformly reduced to 80% to safeguard against electrolyte solidification that might occur from exposure to cold conditions during storage, shipment, or installation. The balance of the power plant was protected against potential freeze damage by circulating a mixture of methanol/water through all fluid piping and heat exchangers except the customer-side heat exchanger interfaces. These were purged dry with hot inert gas so that there was no chance of subsequently contaminating customer water.

All power plants were then prepared, cleaned, and inspected. This assured that wire bundles were tied and routed properly, panels fit precisely, all components were secured, and no visible anomalies existed. All dated changes and retrofits that applied to a particular power plant were verified for proper and complete incorporation. Quality Assurance personnel assisted during the power plant preparation activities.

The power plant was placed on a shipping skid and a wooden crate placed over it. Shock indicators were mounted and confirmed as set. Shipping was by air-ride tractor and trailer.

Figures 4-48 and 4-49 illustrate the cabinet panels being installed on the completed and tested power plant. Figure 4-50 is a power plant ready for final installation of the shipping crate.

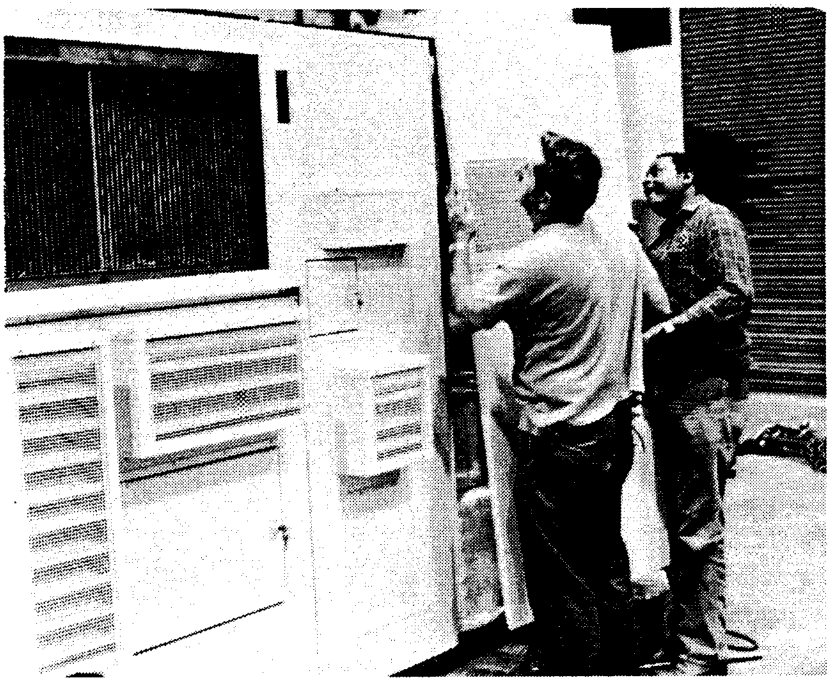


Figure 4-48.
Panels Being Installed on Front of Power Plant

(WCN-10731-20)

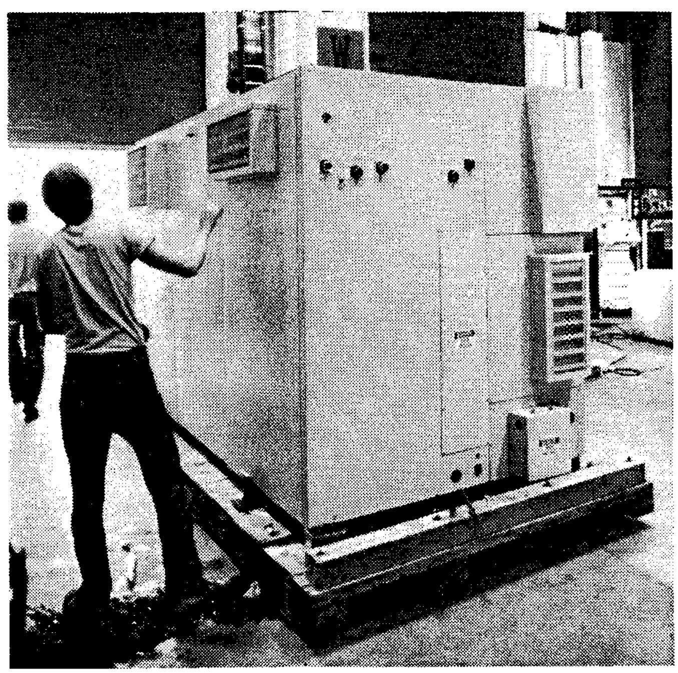


Figure 4-49.
Panels Installed on Left Side and Back of Power Plant

(WCN-10731-22)

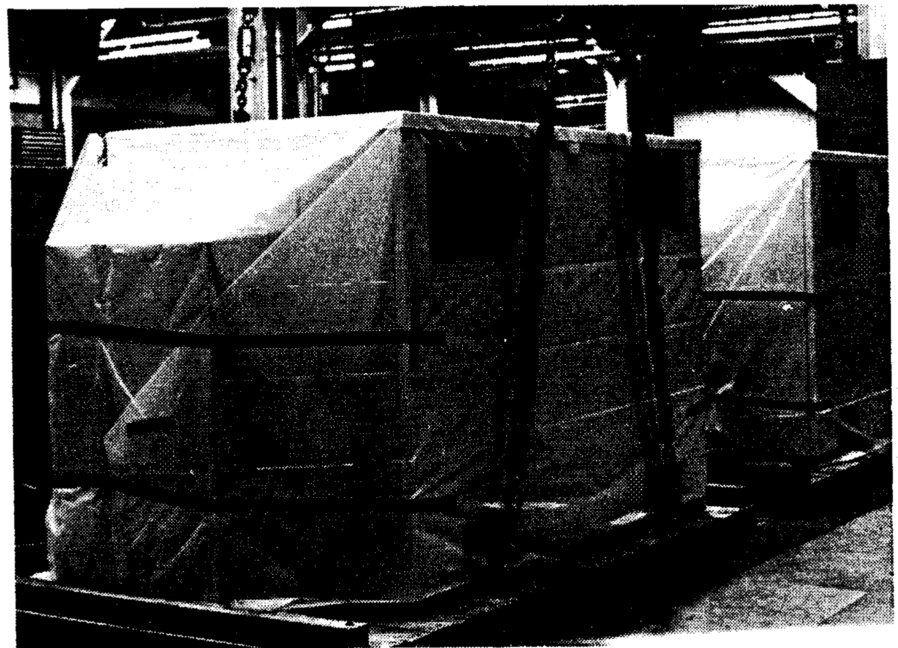


Figure 4-50.
Power Plant
Ready for Installation
in Shipping Crate

(WCN-10747-8)

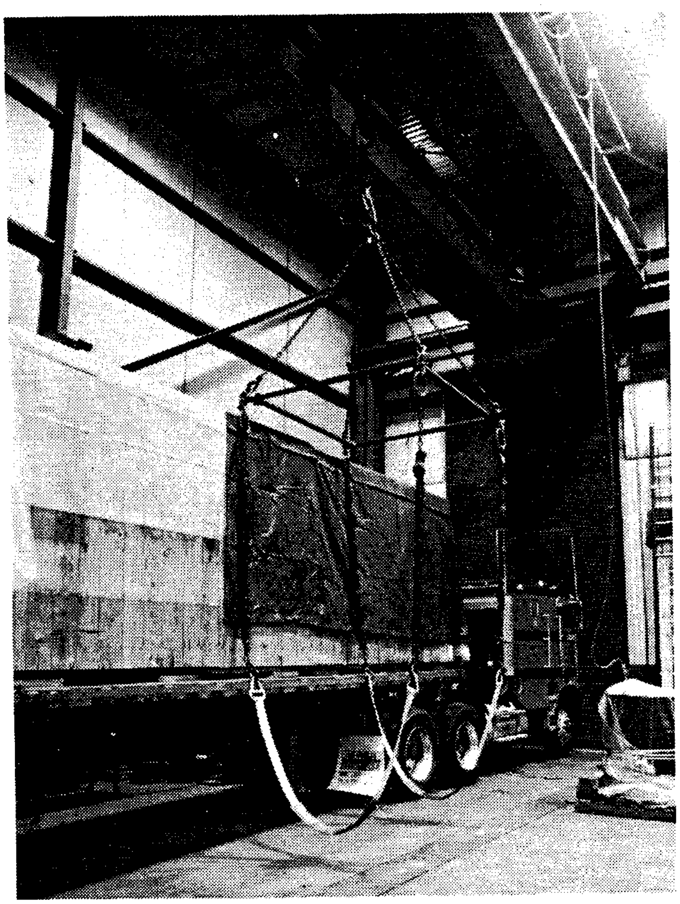


Figure 4-51.
Power Plants Loaded on
Air-Ride Trailer

(WCN-10733)

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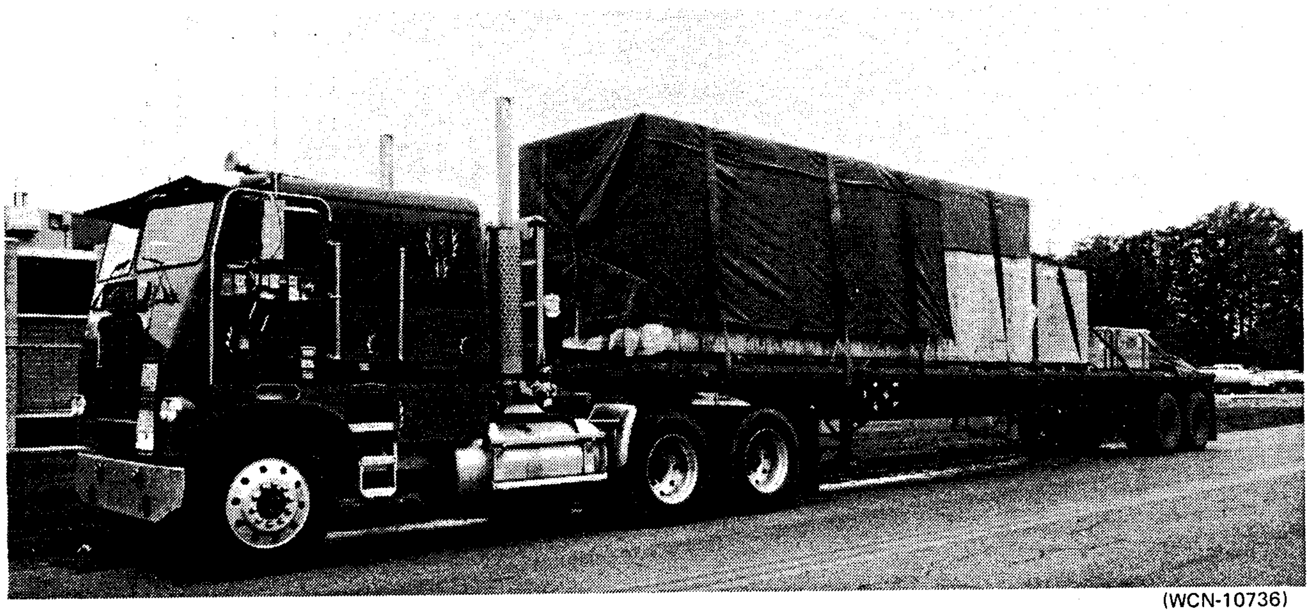
The loading of power plants on the air-ride trailer is shown in Figure 4-51, and two power plants on their way to a site are shown in Figure 4-52.



(WCN-10736)

Figure 4-52. Power Plants in Transit to Site

REFERENCES

1. NASA Contract DEN3-255, Manufacture and Field Test of Forty-Five 40-kW Fuel Cell Power Plants, January 28, 1982.

2. FCR-0528, Gas Industry Fuel Cell Program Report, December 9, 1977, to Team to Advance Research for Gas Energy Transformation, Inc. (TARGET).

3. DOE Contract DE-AC03-77ET11302 and GRI Contract 5010-344-0060, 40-kW Field Test Power Plant Modification and Development, April 1, 1977.

   (A) FCR-1019, Final Report Phase I, April 1, 1977 thru June 30, 1978.

   (B) FCR-2067, Annual Report Phase II, July 1, 1978 thru June 30, 1979.

   (C) FCR-2067, Annual Report (for GRI) and Final Report (for DOE) Phase II, July 1, 1979 thru July 31, 1980

   (D) FCR-4580, Final Report (for GRI) Phase II, August 1980 thru February 1982.

4. DOE Contract DE-AC01-80ET17109, Manufacture and Acceptance Test of Three 40-kW Power Plants, September 29, 1980.

   (A) FCR-5631, Final Report, September 29, 1980 to October 14, 1983.

5. S.N. Simons and R. A. Duscha, 40-kW Phosphoric Acid Fuel Cell Power Plant Readiness Analysis, NASA-Lewis Research Center, November 1982.

6. FCS-1460, On-Site 40-kW Fuel Cell Power Plant Model Specification, September 4, 1979.

   (A) FCS-1460, Revision A, February 6, 1981

   (B) FCS-1460, Revision B, May 28, 1982

   (C) FCS-1460, Revision C, July 15, 1983

7. FCR-5110, Summary of Product Assurance for the 40-kW Field Test Fuel Cell Power Plant, February 1983.

8. FCR-5892, Description of 40-kW Grid-Connected Power Plant Operating and Protection Functions, February 1984.

9. 40-kW On-Site Fuel Cell Power Plant Design Changes Review, Summary Report, NASA-Lewis Research Center, August 14, 1984.

10. FCR-5586, Acceptance Test Procedure for PC18B Power Plants, November 30, 1983.

APPENDIX A. 40-KW POWER PLANT ASSESSMENT

At the beginning of the manufacturing phase of the 40-kW fuel cell program under NASA contract DEN3-255, it was recognized that maximum use of the 40-kW power plant experience to that point would be required to meet manufacturing cost and schedule goals. Therefore, an internal assessment was made to determine UTC readiness to proceed with the procurement and fabrication activity and to define shortages, deficiencies, and corrective actions if required.

To accomplish this assessment, the power plant was divided into procurement/ fabrication packages based on the E&D and early field test power plant experience. The following "packages" were established and reviewed during February and March 1982.

1) Fuel Processor
2) Heat Exchangers
3) Mechanical Controls
4) Electronic Controls
5) Water Treatment System
6) UL Review
7) Power Plant Assembly
8) Power Section
9) Inverter
10) Grid Connect Unit
11) Master Control Unit

Participants in each review included representatives from the 40-kW Power Plant Project and Program Groups, and the Materials Control, Production, Purchasing, Design, Component Engineering, Quality Engineering and Program Administration

Groups. Prior to each of the above sessions, the appropriate organizations prepared material so that the specific package review would cover the following topics:

Technical Deficiencies
Manufacturing Deficiencies
Make/Buy Status
Vendor Adequacy
Detail Drawings
Assembly Drawings
Specifications
Quality Requirements
Process/Operation Sheets
Tooling and Facilities
Validity of Cost Estimates

Each session required a full day to complete. The following summarizes the conclusions and actions that resulted from this assessment review.

<u>Technical Deficiencies</u>

1. No serious technical deficiencies were noted that would prevent power plant functionality or cause it not to meet a specification requirement.

2. Several deficiencies were noted which affected power plant reliability. It was decided that correction of these could be accomplished by design change with no development required. These are discussed below.

3. Heat exchangers HEX 411, HEX 513, and HEX 514 were constructed of Cu/Ni cores that resulted in corrosion products unacceptable to the water treatment system. Material changes were authorized:

    - HEX 411 to be changed to a stainless steel core.
    - HEX 513 core to be coated with a phenolic coating.
    - HEX 514 would be replaced with a stainless steel unit.

4. Power plant thermal insulation had been of phenolic foam, which was found to produce dust and crumble easily. A new material/design was requested.

5. An electrical design activity was authorized to review codes and guidelines relative to fusing, switching, wiring, and connections in order to ensure proper electrical sizing.

Manufacturing and Vendor Deficiencies

1. Preconditioning hydrodesulfurizer (HDS) and shift converter (SC) catalyst in-house for the early field test power plants had been very troublesome and expensive. It was desired to have a vendor do the preconditioning and completely assemble the HDS and SC vessels. A vendor could not be found, however, and subsequently in-house capability had to be reestablished.

2. Assembly of HEX 411, the condensate preheater, had been difficult and required excessive labor. The unit was redesigned.

3. The vendor who provided logic card, logic cage, and power distribution box was considered inadequate based on workmanship and quality of performance. New suppliers were sought.

   The card cage was also considered very costly to manufacture because of its design, and extensive redesign was recommended.

4. The reactant plenum coating and the cooler array coating were considered inadequate because of poor workmanship and quality. Improved techniques or new vendors were to be found.

5. Inverter acceptance testing would be conducted by the Operations Group rather than by Engineering, as had been done in the early field test program. The logic cards and the card cage would be procured completely checked out and would not require further testing as components at UTC. (This subsequently proved inadequate for logic cards which were tested again at UTC.)

Drawings and Specifications

The preprototype power plant program was undertaken without complete bill-of-material definition in the form of released engineering drawings and specifications. Working with layouts and sketches proved to be difficult.

The procurement and fabrication of the DEN3-255 power plants would be accomplished using only released detail and assembly drawings and specifications. No procurement on fabrication packages would be authorized until all drawings and referenced specifications were complete.

A drawing release schedule was prepared based on drawing shortages and design changes submitted as a result of the preprototype power plant experience.

Quality Requirements

Quality requirements in the early field test power plant program were generally unspecified. As a result, Quality Engineering and Inspection attention was given after the fact to correct a problem rather than to prevent a problem from occurring.

Quality Assurance was to prepare an overall plan specifying requirements for major parts, components, and subassemblies. This was to cover procurement, fabrication, assembly, and testing of hardware and would define vendor, receiving, and in-house inspection requirements.

Validity of Cost Estimates

Proposal baseline material costs were based on vendor quotes escalated to then year dollars and were considered quite sound.

APPENDIX B

Typical Acceptance Test Report

40-kW POWER PLANT ACCEPTANCE TEST REPORT

S/N 8244

Acceptance Test Date 7/2/84

Summary and Objectives

Acceptance testing of the above 40-kW Fuel Cell Power Plant was completed on the date shown. The objective of the acceptance test is to verify the capability of the 40-kW fuel cell power plants manufactured under the DEN3-255 contract to meet the PC18B-3A test specification, FCTS-0586, and to be ready for testing under the Field Test Program. The acceptance test, consisting of the following items in accordance with the Acceptance Test Procedure FCR-5586 dated November 30, 1983, was successfully completed as specified unless otherwise noted under "Acceptance Test Waivers and Deviations."

- Mounting of Power Plant
- Set-up of Reformer Burner Gas Flows
- Water System Filling
- Functional Checks
- Coolant System Water Conditioning
- Power Plant Heatup
- Reformer Catalyst Break-in
- Operational Tests
- Shutdown and Electrolyte Conditioning
- Post-Test Inspection and Preparation for Shipping

Data Package

The following acceptance test data is attached and represents the results of the power plant testing.

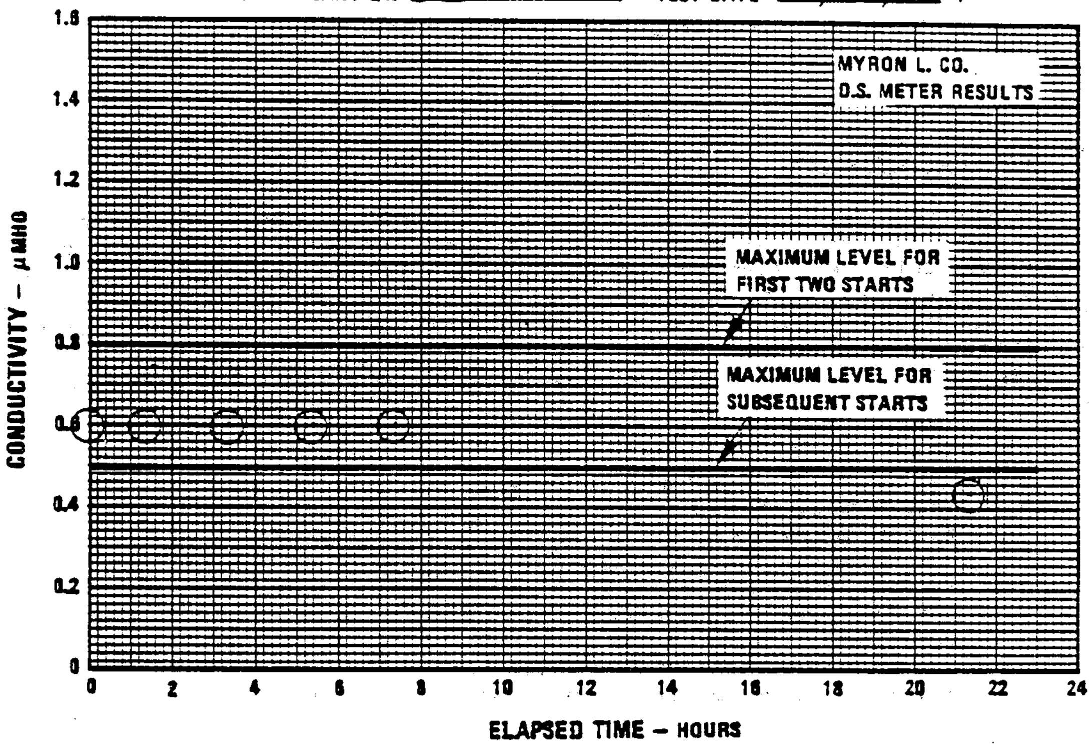
- Coolant System Water Conditioning
- Coolant System Heatup
- Shift Converter Heatup
- Reformer Heatup
- Power Plant Electrical Efficiency
- Power Section Performance
- Operational Test Data
- Overload Test
- Comments

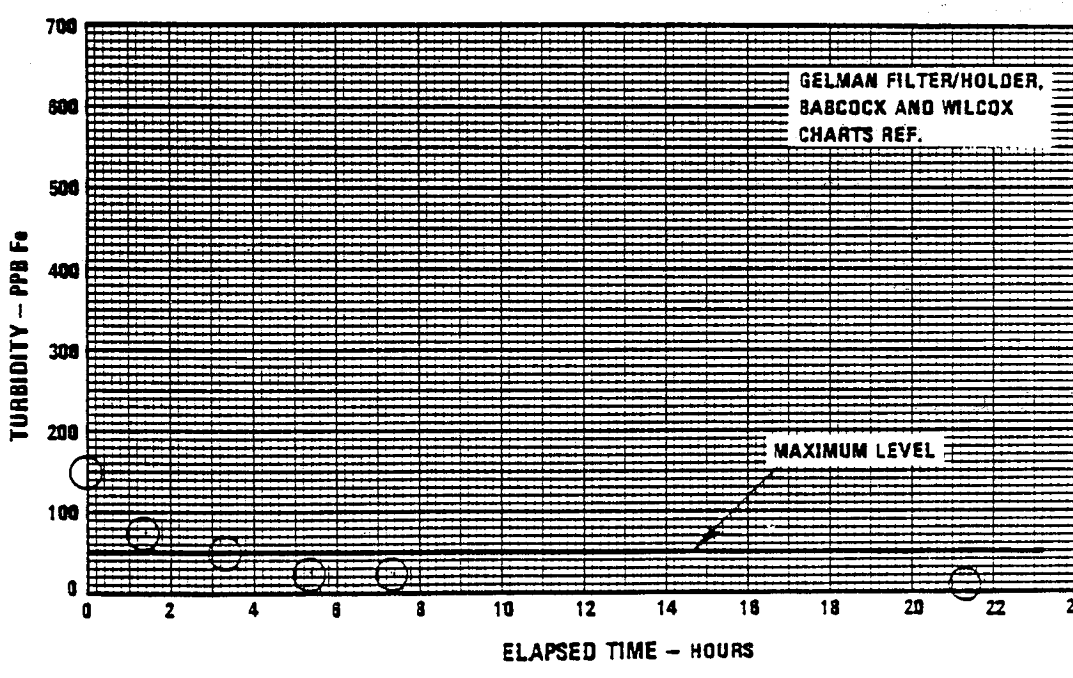
Acceptance Test Waivers and Deviations

None.

COOLANT SYSTEM WATER CONDITIONING

POWER PLANT S/N 8244 TEST DATE 7/2/84





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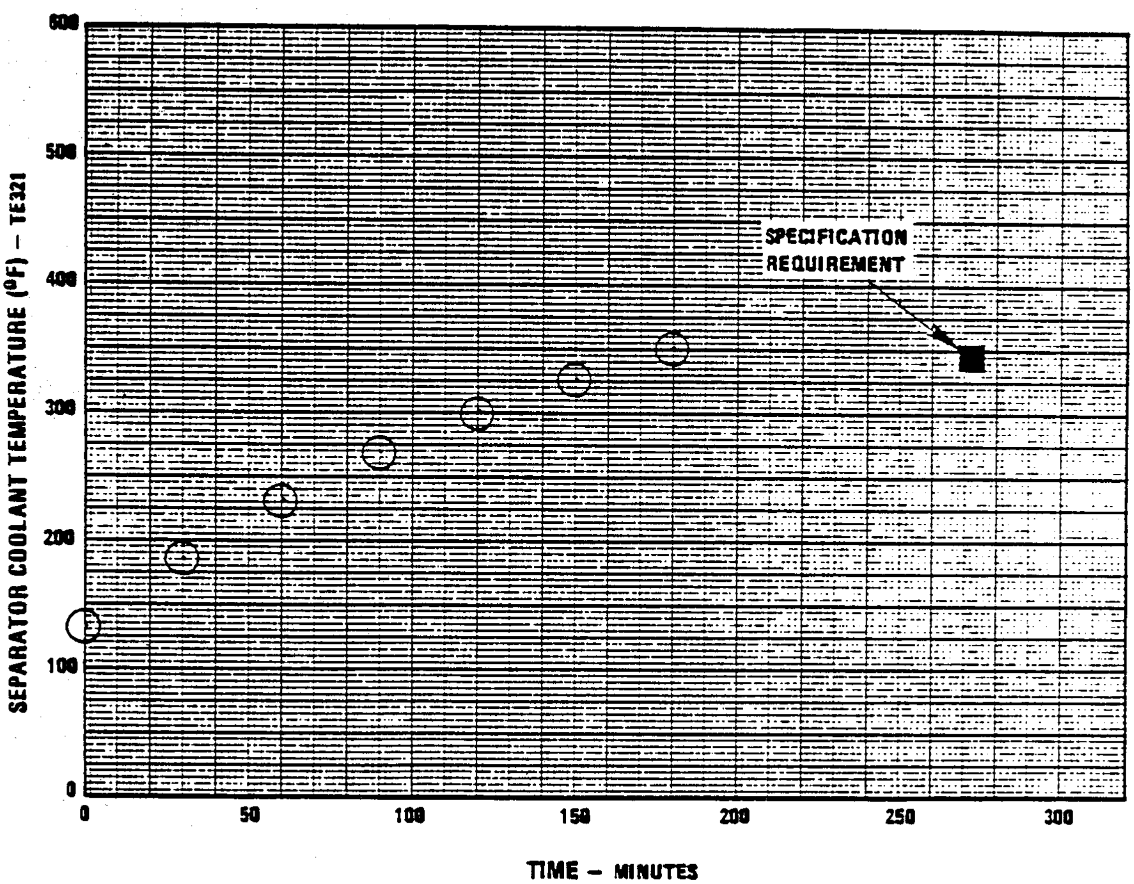
COOLANT SYSTEM HEATUP

POWER PLANT S/N 8244

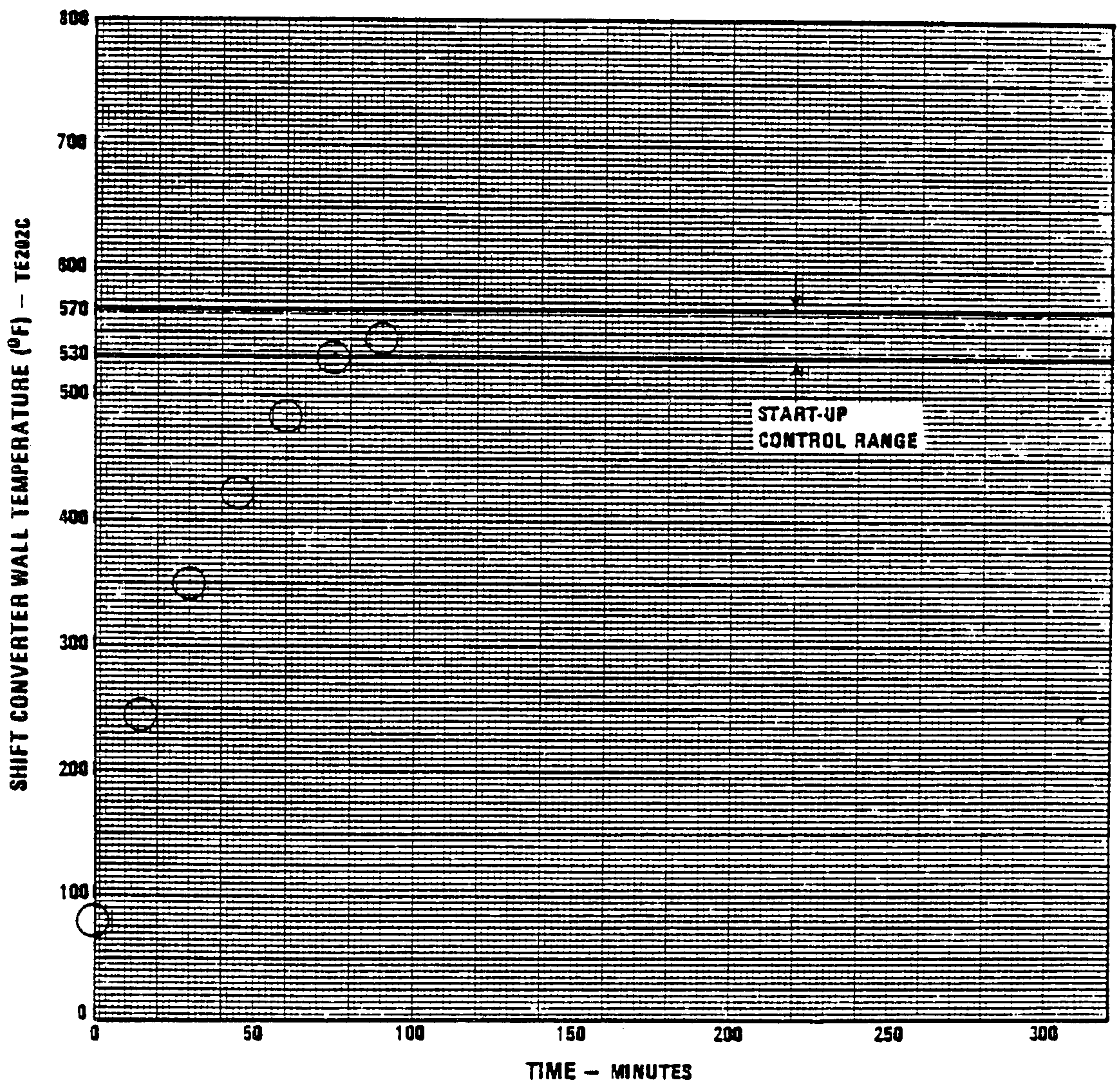
TEST DATE 7/2/84

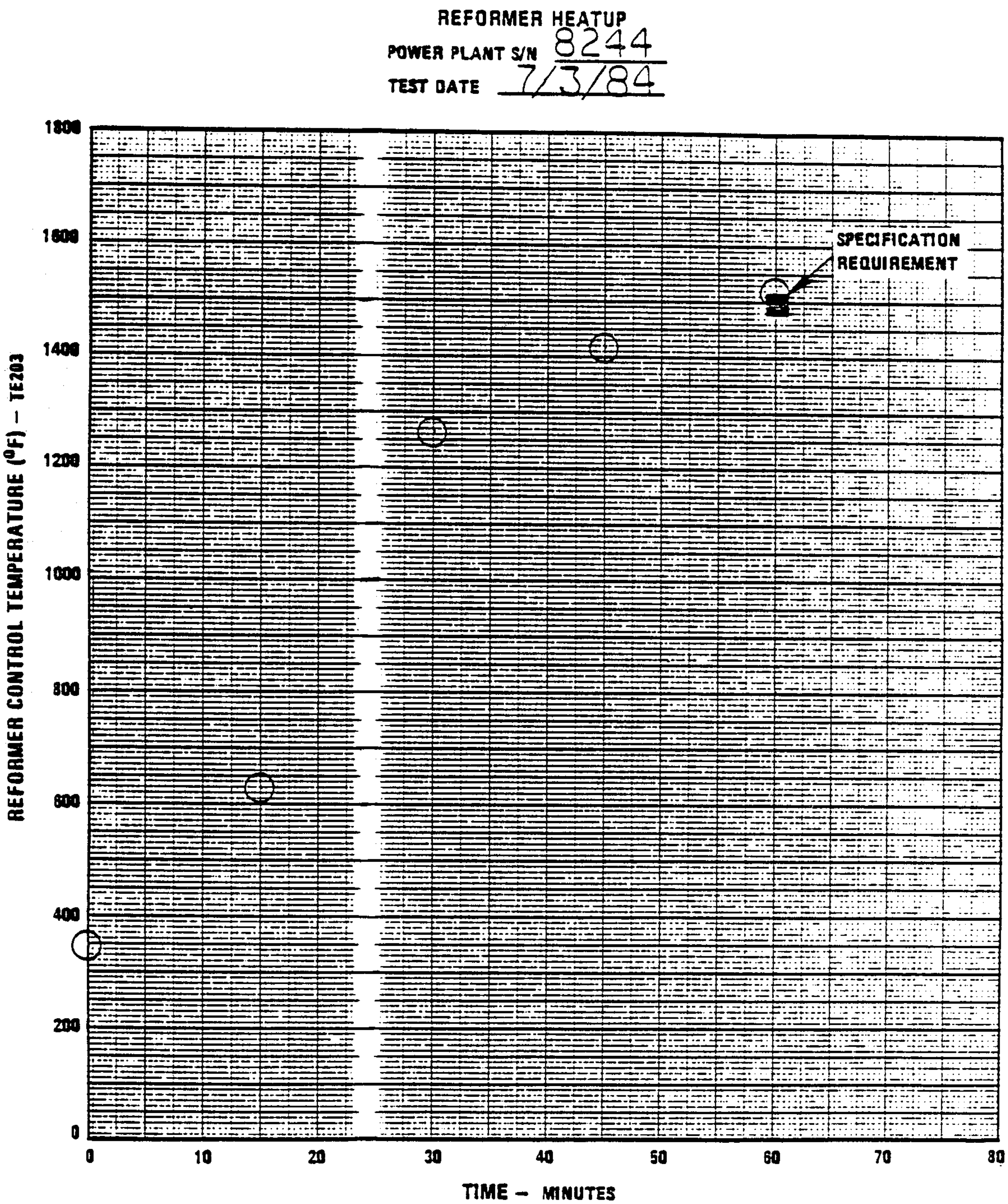


SHIFT CONVERTER HEATUP

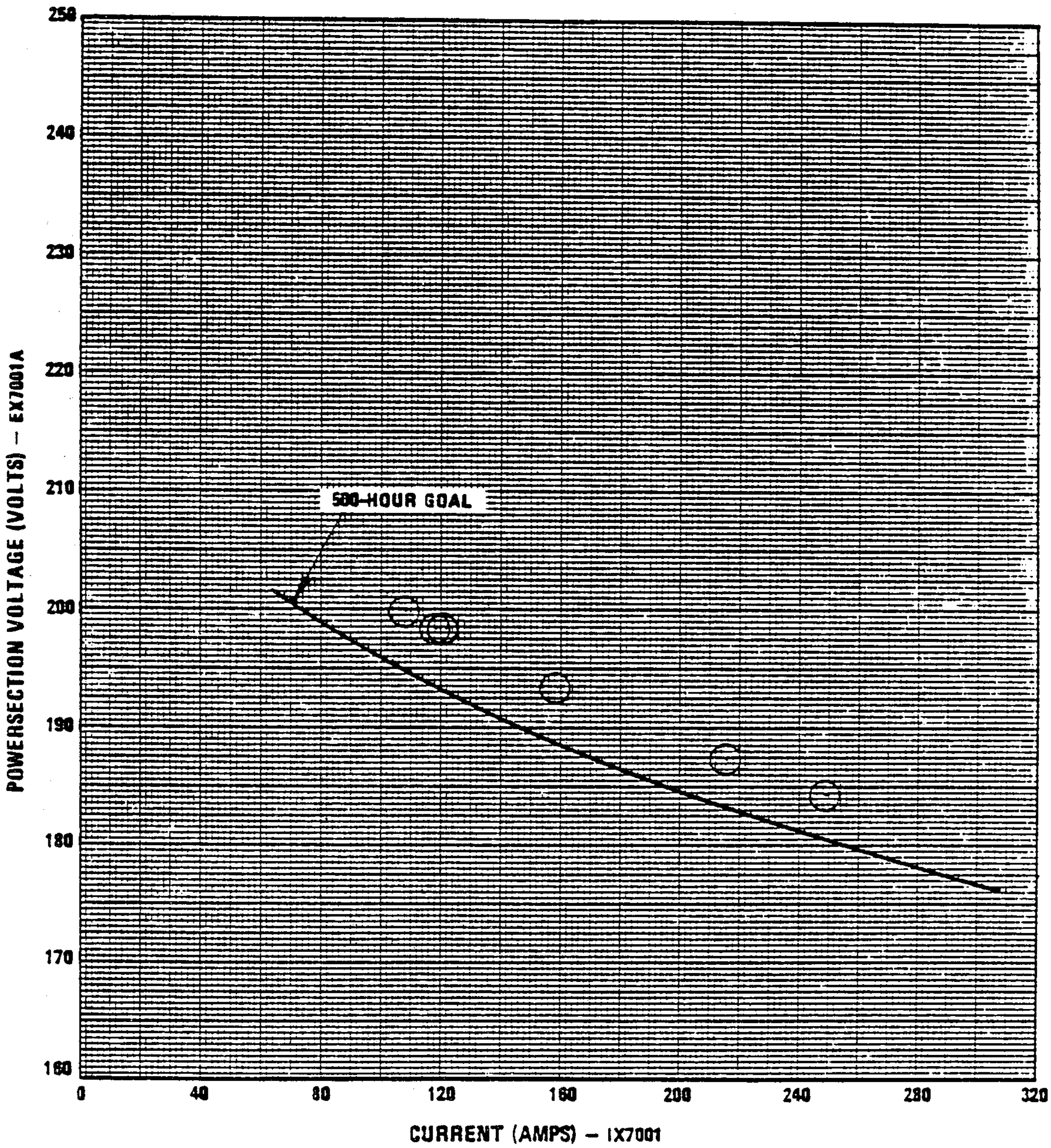
POWER PLANT S/N 8244

TEST DATE 7/2/84




REFORMER HEATUP
POWER PLANT S/N 8244
TEST DATE 7/3/84
REFORMER CONTROL TEMPERATURE (°F) – TE203
1800
1600
1400
1200
1000
800
600
400
200
0
SPECIFICATION REQUIREMENT
0
10
20
30
40
50
60
70
80
TIME – MINUTES

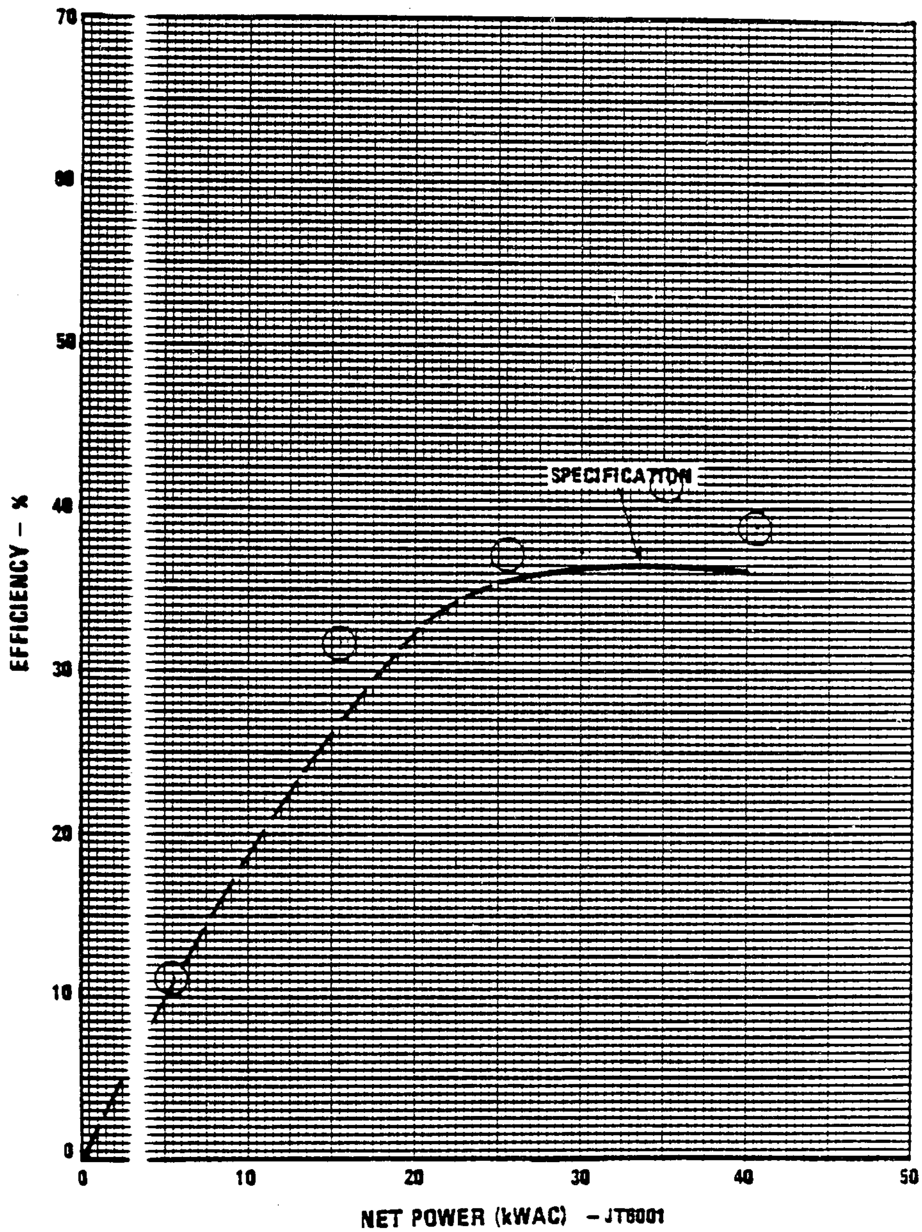
POWERSECTION PERFORMANCE
POWER PLANT S/N 8244
TEST DATE 7/2/84



POWER PLANT ELECTRICAL EFFICIENCY

POWER PLANT S/N 8244

TEST DATE 7/2/84



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OPERATIONAL TEST DATA

Power Systems Division FCR-6533

```
**** 40 KW POWERPLANT S/N 8244        ACCEPTANCE.  ****
**** DATE  7/ 2/84  TIME 1255 [redacted]****

NET PWR    EI  PWR    PWR FACT   % IUNB.    ELEC EFF
JT 6001    JX 6001A   JFX6001    IFX6001    XFX0002A
  -.01        .21       -.07        9.3       -.03
FUEL FT3   FUEL PPH   FUEL LHV   REF EFF      IDC
FX 2000A   FX2000B               XFX2002    IX 7001
  3.00        7.95      930.0      74.57      108.01
  VDC      5STK DEL   TE 321     TE 203     TE 202A
EX7001A    EDX7002    TX3200     TX 2316    TX 2241
199.84        .01      365.3      1353.      569.1
TE202B    TE 202C    TE 202D
TX 2270   TX 2272    TE 2271
439.5      388.0     420.6

*** INVERTER ***
ET6001A  ET6001B  ET6001C  IT6001A  IT6001B  IT6001C
   124.6    123.6    124.7      .6       .6       .5

*** POWERSECTION ***
TE2390   TE2391   TE3131   PT1120   PT2390   PT2391
   333.1    338.8    369.4      .82      .63      .39

*** 12 CELL GROUP VOLTAGE READINGS (ET7002 THRU ET7025) ***
      1     2     3     4     5     6     7     8     9    10
 0  2.20  8.81  8.82  8.83  8.80  8.84  8.83  8.80  8.85  8.84
10  8.89  8.89  8.84  8.83  8.84  8.81  8.81  8.84  8.78  8.86
20  8.83  8.80  8.74  2.12
    VBOT      VTOP      HSVCALC    EX7003    EX7001B    ET7001
    99.39     99.12       .27       8.87     198.51     199.57
*** 24 CELL GROUP VOLTAGES (ET7048 THRU ET7070) ***
      1      2      3      4      5      6      7      8      9     10
 0 11.00  17.72  17.73  17.73  17.74  17.75  17.71  17.73  17.77  17.81
10 17.87  17.82  17.77  17.77  17.74  17.73  17.77  17.72  17.74  17.78
20 17.71  17.63  10.97                EX7004 EX7001C EX7001D ET7001
                                      17.74  199.5    199.5   199.6


*** FPS FLOW CONTROL ***
ZT202    TE2000   PT2000   PT2271   PT2222   PT3240
   1.94     87.7     12.1     13.07     4.06    66.64

*** FPS REFORMER ***
PT2310   TE2311A  TE5000A  TE2316A
   15.04    633.8    725.0   1357.4

*** PROCESS AIR ***
ZT101    ZT102    PT1000
   5.30      2.6    14.64

*** THERMAL MANAGEMENT  ** PSS WATER RECOVERY  ** PWS WATER TREATMENT
    TE3200                     TE1131                  TE4131
     362.                       138.                    103.
X-810 READING STORED IN DATA BASE:
```

ZERO NET

```
**** 40 KW POWERPLANT S/N:8244        ACCEPTANCE    ****
**** DATE  7/ 2/84   TIME 1314  [redacted] ****

NET PWR    EI  PWR    PWR FACT   % IUNB.    ELEC EFF
JT 6001    JX 6001A   JFX6001    IFX6001    XFX0002A
  5.50       8.47       .65        6.5      11.23
FUEL FT3   FUEL PPH   FUEL LHV   REF EFF      IDC
FX 2000A   FX2000B               XFX2002    IX 7001
  2.99       7.93      930.0      83.59      120.86
  VDC      5STK DEL   TE 321     TE 203     TE 202A
EX7001A    EDX7002    TX3200     TX 2316    TX 2241
198.30       -.02      362.8      1347.      569.2
TE202B    TE 202C    TE 202D
TX 2270   TX 2272    TE 2271
457.5      380.9     417.5
```

5 KW

```
*** INVERTER ***
ET6001A  ET6001B  ET6001C  IT6001A  IT6001B  IT6001C
  123.9    123.4    123.8    21.4     22.8     24.3

*** POWERSECTION ***
TE2390   TE2391   TE3131   PT1120   PT2390   PT2391
  335.1    342.7    368.6     .94      .74      .48

*** 12 CELL GROUP VOLTAGE READINGS (ET7002 THRU ET7025) ***
     1      2      3      4      5      6      7      8      9      10
 0  2.18   8.75   8.76   8.77   8.74   8.78   8.76   8.74   8.79   8.77
10  8.83   8.83   8.79   8.78   8.79   8.75   8.76   8.78   8.73   8.80
20  8.77   8.74   8.69   2.11
    VBOT       VTOP       HSVCALC    EX7003    EX7001B    ET7001
    98.69      98.48        .21       8.80     197.17     198.09
*** 24 CELL GROUP VOLTAGES (ET7048 THRU ET7070) ***
     1      2      3      4      5      6      7      8      9      10
 0 10.93  17.59  17.60  17.60  17.61  17.62  17.58  17.60  17.64  17.69
10 17.74  17.70  17.65  17.65  17.62  17.61  17.65  17.60  17.61  17.66
20 17.59  17.51  10.88                 EX7004 EX7001C EX7001D ET7001
                                        17.61  198.1    198.1   198.1


*** FPS FLOW CONTROL ***
ZT202    TE2000   PT2000   PT2271   PT2222   PT3240
  2.28     89.2     12.0    13.08     4.01    63.13

*** FPS REFORMER ***
PT2310   TE2311A  TE5000A  TE2316A
  17.32    649.8    742.3   1349.8

*** PROCESS AIR ***
ZT101    ZT102    PT1000
  5.61     2.6     14.64

*** THERMAL MANAGEMENT  ** PSS WATER RECOVERY  ** PWS WATER TREATMENT
     TE3200                      TE1131                      TE4131
      360.                        138.                         97.
X-810 READING STORED IN DATA BASE:
```

15 KW

```
**** 40 KW POWERPLANT S/N:8244        ACCEPTANCE    ****
**** DATE  7/ 2/84  TIME 1330  [redacted]****

NET PWR    EI  PWR    PWR FACT   % IUNB.     ELEC EFF
JT 6001    JX 6001A   JFX6001    IFX6001     XFX0002A
 15.48      16.61       .93        2.3       31.78
FUEL FT3   FUEL PPH   FUEL LHV   REF EFF      , IDC
FX 2000A   FX2000B               XFX2002     IX 7001
  2.98       7.90       930.0      82.31      118.44
  VDC      5STK DEL   TE 321     TE 203      TE 202A
EX7001A    EDX7002    TX3200     TX 2316     TX 2241
198.29       -.08      365.4      1348.       569.2
TE202B    TE 202C    TE 202D
TX 2270   TX 2272    TE 2271
465.9      375.8     415.2

*** INVERTER ***
ET6001A   ET6001B   ET6001C   IT6001A   IT6001B   IT6001C
   124.1     122.6     124.0      42.7      45.8      45.8

*** POWERSECTION ***
TE2390    TE2391    TE3131    PT1120    PT2390    PT2391
   335.8     342.8     368.0      .88       .66       .42

*** 12 CELL GROUP VOLTAGE READINGS (ET7002 THRU ET7025) ***
      1      2      3      4      5      6      7      8      9     10
 0   2.14   8.77   8.77   8.78   8.76   8.79   8.78   8.75   8.80   8.79
10   8.84   8.84   8.80   8.80   8.81   8.77   8.77   8.80   8.74   8.83
20   8.79   8.76   8.70   2.12
     VBOT        VTOP        HSVCALC    EX7003     EX7001B    ET7001
     98.80       98.68        .12        8.82      197.48     198.36
*** 24 CELL GROUP VOLTAGES (ET7048 THRU ET7070) ***
      1      2      3      4      5      6      7      8      9     10
 0 10.95  17.62  17.63  17.63  17.64  17.65  17.61  17.63  17.67  17.72
10 17.78  17.74  17.69  17.69  17.67  17.65  17.69  17.65  17.66  17.70
20 17.64  17.55  10.91                EX7004 EX7001C EX7001D ET7001
                                       17.63  198.5   198.5  198.4


*** FPS FLOW CONTROL ***
ZT202     TE2000    PT2000    PT2271    PT2222    PT3240
    2.33      91.3      12.0     13.07      4.09     60.70

*** FPS REFORMER ***
PT2310    TE2311A   TE5000A   TE2316A
   15.62     656.0     744.8    1346.5

*** PROCESS AIR ***
ZT101     ZT102     PT1000
    5.44      2.6      14.64

*** THERMAL MANAGEMENT  ** PSS WATER RECOVERY  ** PWS WATER TREATMENT
      TE3200                          TE1131                    TE4131
        362.                           138.                       97.
X-810 READING STORED IN DATA BASE:
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Power Systems Division FCR-6533

**** 40 KW POWERPLANT S/N: 8244 ACCEPTANCE ****
**** DATE 7/ 2/84 TIME 1359 [redacted] ****

25 KW

NET PWR	EI PWR	PWR FACT	% IUNB.	ELEC EFF
JT 6001	JX 6001A	JFX6001	IFX6001	XFX0002A
25. 61	26. 17	98	2. 5	37. 20
FUEL FT3	FUEL PPH	FUEL LHV	REF EFF	IDC
FX 2000A	FX2000B		XFX2002	IX 7001
4. 21	11. 16	930. 0	77. 89	158. 41
VDC	5STK DEL	TE 321	TE 203	TE 202A
EX7001A	EDX7002	TX3200	TX 2316	TX 2241
193. 42	-. 12	357. 0	1367.	569. 3
TE202B	TE 202C	TE 202D		
TX 2270	TX 2272	TE 2271		
476. 2	368. 8	413. 8		

*** INVERTER ***

ET6001A	ET6001B	ET6001C	IT6001A	IT6001B	IT6001C
123. 1	122. 4	123. 1	68. 6	72. 8	71. 7

*** POWERSECTION ***

TE2390	TE2391	TE3131	PT1120	PT2390	PT2391
335. 1	343. 3	357. 6	1. 52	1. 25	. 87

*** 12 CELL GROUP VOLTAGE READINGS (ET7002 THRU ET7025) ***

	1	2	3	4	5	6	7	8	9	10
0	2. 08	8. 54	8. 54	8. 54	8. 52	8. 55	8. 54	8. 51	8. 56	8. 54
10	8. 60	8. 61	8. 57	8. 57	8. 57	8. 53	8. 55	8. 57	8. 50	8. 58
20	8. 55	8. 52	8. 47	2. 05						

VBOT	VTOP	HSVCALC	EX7003	EX7001B	ET7001
96. 13	96. 03	. 10	8. 59	192. 16	193. 29

*** 24 CELL GROUP VOLTAGES (ET7048 THRU ET7070) ***

	1	2	3	4	5	6	7	8	9	10
0	10. 66	17. 17	17. 17	17. 16	17. 17	17. 18	17. 13	17. 16	17. 19	17. 24
10	17. 30	17. 27	17. 23	17. 23	17. 20	17. 18	17. 22	17. 15	17. 18	17. 23
20	17. 16	17. 08	10. 62							

EX7004	EX7001C	EX7001D	ET7001
17. 18	193. 2	193. 2	193. 3

*** FPS FLOW CONTROL ***

ZT202	TE2000	PT2000	PT2271	PT2222	PT3240
3. 95	92. 0	11. 7	13. 17	4. 11	61. 01

*** FPS REFORMER ***

PT2310	TE2311A	TE5000A	TE2316A
25. 73	692. 0	783. 0	1370. 4

*** PROCESS AIR ***

ZT101	ZT102	PT1000
6. 59	3. 4	14. 64

*** THERMAL MANAGEMENT ** PSS WATER RECOVERY ** PWS WATER TREATMENT

TE3200	TE1131	TE4131
353.	143.	98.

X-810 READING STORED IN DATA BASE:

7-- 2--84 FAST SCAN STARTED AT 14:: 1:: 47

Power Systems Division FCR-6533

```
**** 40 KW POWERPLANT S/N:8244        ACCEPTANCE   ****
**** DATE  7/ 2/84  TIME 1430 [redacted] ****

NET PWR    EI  PWR    PWR FACT   % IUNB.    ELEC EFF
JT 6001    JX 6001A   JFX6001    IFX6001    XFX0002A
 35.35      35.72        .99       2.2      41.48
FUEL FT3   FUEL PPH   FUEL LHV   REF EFF      IDC
FX 2000A   FX2000B               XFX2002    IX 7001
  5.21      13.81       930.0      85.72     215.77
  VDC      5STK DEL   TE 321     TE 203     TE 202A
EX7001A    EDX7002    TX3200     TX 2316    TX 2241
187.31       -.21      352.6      1421.      569.4
TE202B   TE 202C    TE 202D
TX 2270  TX 2272    TE 2271
491.5     358.7     400.4

*** INVERTER ***
ET6001A  ET6001B  ET6001C  IT6001A  IT6001B  IT6001C
   122.9    122.2    122.9     94.4     99.2     97.5

*** POWERSECTION ***
TE2390   TE2391   TE3131   PT1120   PT2390   PT2391
   334.8    350.3    354.8    1.94     1.11 .     .61

*** 12 CELL GROUP VOLTAGE READINGS (ET7002 THRU ET7025) ***
      1     2     3     4     5     6     7     8     9    10
 0  2.02  8.28  8.26  8.27  8.25  8.28  8.26  8.23  8.29  8.26
10  8.32  8.34  8.31  8.31  8.32  8.27  8.28  8.30  8.22  8.32
20  8.29  8.25  8.21  1.99
    VBOT      VTOP      HSVCALC   EX7003    EX7001B   ET7001
    93.07     93.07       .00      8.33     186.14    187.41
*** 24 CELL GROUP VOLTAGES (ET7048 THRU ET7070) ***
      1     2     3     4     5     6     7     8     9    10
 0 10.33 16.63 16.63 16.62 16.63 16.63 16.58 16.61 16.65 16.68
10 16.76 16.75 16.73 16.73 16.68 16.66 16.70 16.63 16.65 16.72
20 16.66 16.57 10.29               EX7004 EX7001C EX7001D ET7001
                                   16.66  187.2    187.3   187.4


*** FPS FLOW CONTROL ***
ZT202    TE2000   PT2000   PT2271   PT2222   PT3240
   5.08     93.7     11.3    13.26     4.08    63.01

*** FPS REFORMER ***
PT2310   TE2311A  TE5000A  TE2316A
   35.58    739.8    851.9   1419.3

*** PROCESS AIR ***
ZT101    ZT102    PT1000
   8.09     3.7     14.64

*** THERMAL MANAGEMENT  ** PSS WATER RECOVERY  ** PWS WATER TREATMENT
     TE3200                  TE1131                 TE4131
      349.                   144.                    102.
X-810 READING STORED IN DATA BASE:
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35 KW

ORIGINAL PAGE IS
OF POOR QUALITY

**** 40 KW POWERPLANT S/N:8244 ACCEPTANCE ****
**** DATE 7/ 2/84 TIME 1453 [redacted] ****

40 KW

NET PWR	EI PWR	PWR FACT	% IUNB.	ELEC EFF
JT 6001	JX 6001A	JFX6001	IFX6001	XFX0002A
40. 55	40. 95	. 99	1. 5	38. 94
FUEL FT3	FUEL PPH	FUEL LHV	REF EFF	IDC
FX 2000A	FX2000B		XFX2002	IX 7001
6. 37	16. 88	930. 0	81. 00	249. 11
VDC	5STK DEL	TE 321	TE 203	TE 202A
EX7001A	EDX7002	TX3200	TX 2316	TX 2241
184. 43	-. 19	349. 2	1443.	569. 4
TE202B	TE 202C	TE 202D		
TX 2270	TX 2272	TE 2271		
493. 4	361. 5	380. 9		

*** INVERTER ***

ET6001A	ET6001B	ET6001C	IT6001A	IT6001B	IT6001C
122. 4	121. 8	122. 4	109. 4	113. 4	112. 3

*** POWERSECTION ***

TE2390	TE2391	TE3131	PT1120	PT2390	PT2391
292. 2	334. 3	334. 4	2. 64	1. 60	. 94

*** 12 CELL GROUP VOLTAGE READINGS (ET7002 THRU ET7025) ***

	1	2	3	4	5	6	7	8	9	10
0	1. 98	8. 17	8. 15	8. 15	8. 13	8. 16	8. 14	8. 11	8. 17	8. 14
10	8. 20	8. 21	8. 19	8. 19	8. 19	8. 14	8. 15	8. 17	8. 09	8. 20
20	8. 17	8. 13	8. 08	1. 94						

VBOT	VTOP	HSVCALC	EX7003	EX7001B	ET7001
91. 70	91. 66	. 04	8. 21	183. 35	184. 62

*** 24 CELL GROUP VOLTAGES (ET7048 THRU ET7070) ***

	1	2	3	4	5	6	7	8	9	10
0	10. 18	16. 41	16. 40	16. 40	16. 40	16. 39	16. 35	16. 38	16. 41	16. 44
10	16. 52	16. 51	16. 49	16. 49	16. 44	16. 41	16. 45	16. 37	16. 40	16. 48
20	16. 41	16. 32	10. 07							

EX7004	EX7001C	EX7001D	ET7001
16. 41	184. 5	184. 5	184. 6

*** FPS FLOW CONTROL ***

ZT202	TE2000	PT2000	PT2271	PT2222	PT3240
6. 84	93. 8	10. 9	13. 27	4. 05	62. 19

*** FPS REFORMER ***

PT2310	TE2311A	TE5000A	TE2316A
45. 93	760. 9	881. 3	1444. 8

*** PROCESS AIR ***

ZT101	ZT102	PT1000
9. 00	4. 4	14. 64

*** THERMAL MANAGEMENT	** PSS WATER RECOVERY	** PWS WATER TREATMENT
TE3200	TE1131	TE4131
346.	129.	92.

X-810 READING STORED IN DATA BASE:

Overload Test

An overload test was performed to a load of 56 kW/80 kVA for a period of 5.0 seconds and then reduced to zero kWac.

Comments

1. Items lined out on the Operational Test Data Sheet indicate invalid data readings.

2. Following the acceptance test, an extended test was performed on the power plant. This operation included full checkout of all operational functions and three start/stop cycles.

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15. Supplementary Notes

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16. Abstract

A joint Gas Research Institute and U.S. Department of Energy Program was initiated in 1982 to evaluate the use of fuel cell power systems for on-site energy service. Forty-six 40-kW fuel cell power plants were manufactured at the United Technologies Corporation facility in South Windsor, Connecticut, and are being delivered to host utilities and other program participants in the United States and Japan for field testing. The construction of the 46 fully-integrated power plants was completed in January 1985 within the constraints of the contract plan. The program has provided significant experience in the manufacture, acceptance testing, deployment, and support of on-site fuel cell systems. Initial field test results also show that these experimental power plants meet the performance and environmental requirements of a commercial specification. This Interim Report encompasses the design and manufacturing phases of the 40-kW Power Plant Manufacturing and Field Test program. The contract between UTC and NASA also provided UTC field engineering support to the host utilities, training programs and associated manuals for utility operating and maintenance personnel, spare parts support for a defined test period, and testing at UTC of a power plant made available from a preceding program phase. These activities are ongoing and will be reported subsequently.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
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