N O T I C E

Annual Technical Report

Fiscal Year 1980

May 15, 1981

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Fiscal Year 1980

ABSTRACT

This report summarizes the status of the JPL Solar Thermal Power Systems Project for FY 1980. Included is a discussion of the project's goals, program structure, and progress in parabolic dish technology. Analyses and test results of concentrators, receivers, and power converters are discussed. Progress toward the objectives of technology feasibility, technology readiness, system feasibility, and system readiness are covered.

PREFACE

This report was prepared by the Jet Propulsion Laboratory (JPL), California Institute of Technology, and the National Aeronautics and Space Administration (NASA) Lewis Research Center, for the U. S. Department of Energy under an agreement with NASA. The JPL Solar Thermal Power Systems Project is sponsored by the U.S. Department of Energy as part of their program to develop low cost solar thermal systems for the production of electricity, heat, or both.

GLOSSARY

AGT	Advanced Gas Turbine
ALO	DOE Albuquerque Operations Office
CEL	U.S. Navy Civil Engineering Laboratory
CY	Calendar Year
DOE	U.S. Department of Energy
DSSR	Dish Stirling Solar Receiver
EE	Engineering Experiment
EE-1	Electric Utility Applications Experiment Series
EE-2	Isolated Applications Experiment Series
EE-3	Industrial Applications Experiment Series
ETS	Edwards Test Station
FACC	Ford Aerospace and Communications Corporation
FY	Fiscal Year
GE	General Electric
HTES	High Temperature Energy Storage
IPH	Industrial Process Heat
JPL	Jet Propulsion Laboratory
LCC	Low-Cost Concentrator
LeRC	Lewis Research Center (NASA)
MCAS	Marine Corps Air Station
MMPE	Military Module Power Experiment
NASA	National Aeronautics and Space Administration
OG	OMNIUM-G
PCM	Phase Change Material

PCU	Power Conversion Unit
PDTS	Parabolic Dish Test Site
PFDR	Point Focusing Distributed Receiver
PMA	Permanent Magnet Alternator
PRDA	Program Research and Development Announcement
R&D	Research and Development
RFP	Request for Proposals
SAI	Science Applications, Inc.
SCE	Southern California Edison Company
SCSE	Small Community Solar Thermal Power Experiment
SERI	Solar Energy Research Institute
SLL	Sandia Laboratories, Livermore
SNET	Southern New England Telephone Company
"Solarized"	Modified for use in Solar Power Systems
TBC	Test Bed Concentrator
TES	Thermal Energy Storage
TPS	Thermal Power Systems

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PART ONE

EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

A. INTRODUCTION

The objective of the Solar Thermal Power Systems Project at the Jet Propulsion Laboratory (JPL) is to demonstrate technical, operational, and economic readiness of point-focusing distributed receiver (PFDR) technology for electric and thermal power applications. To reach this goal in a timely manner, the project has two parallel and complementary elements.

    (1)   The Technology Development element emphasizes feasibility testing followed by engineering, fabrication and testing of the complete modules (i.e., concentrator, receiver and engine).

    (2)   The Applications Development element is responsible for developing complete power plant systems and demonstrating the technology through a series of engineering experiments situated in a variety of potential user environments.

B. PERFORMANCE

In mid-FY 1980 two 11-m diameter Test Bed Concentrators (TBCs), as shown in Figure 1, were installed at JPL's Parabolic Dish Test Site (PDTS) and calibrated for use in testing receivers and power converters. The PDTS is illustrated in Figure 2. The TBC produces nominal thermal power at the focal plane of 80 kW for 1000 W/m^2 of insolation, a clean mirror, and no aperture constraint. The same nominal 80 kW was also measured through a 10-in. and an 8-in. aperture, implying a symmetric and highly peaked distribution of the optical energy. This performance is a result of the high accuracy of the reflective surface of the TBC, which has a slope error of less than 1 mrad. The intensity distribution of the solar flux at the focal point is shown in Figure 3.

The General Electric Low-Cost Concentrator (GE/LCC), shown in Figure 4, is under development for early applications and will be installed and tested in FY 1981 at JPL's PDTS. It is expected to have a performance corresponding to a slope error of about 2 mrad. (Refer to Table 2-1 for efficiency targets of both first and second-generation hardware, receivers, and power converters.)

1
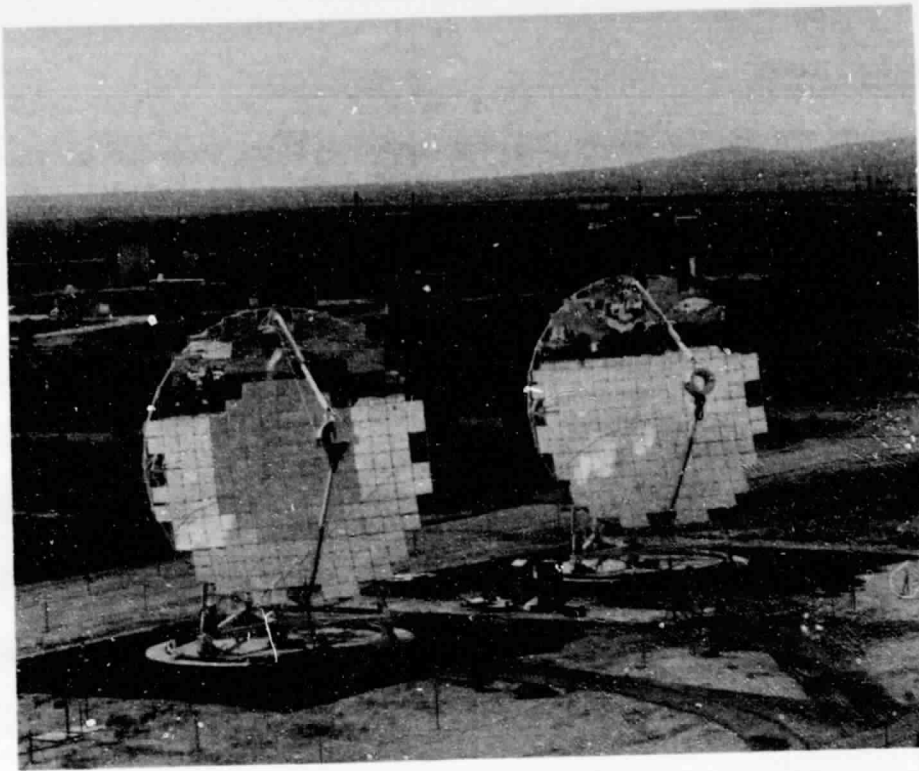
Figure 1. Two Test Bed Concentrators at JPL's Parabolic Dish Test Site
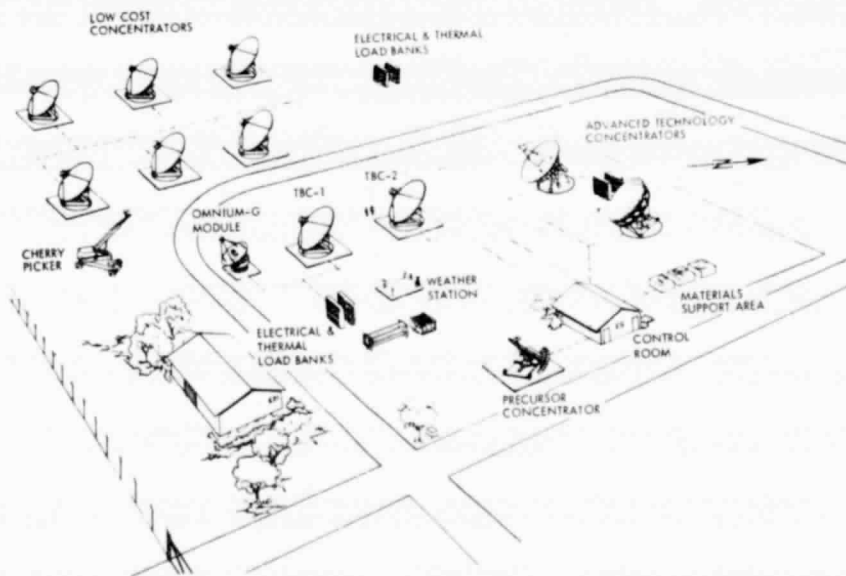
Figure 2. JPL's Parabolic Dish Test Site (PDTS) at
Edwards Test Station (ETS)

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TBC-1

224 MIRRORS
NORMALIZED TO
1 kW/m² INPUT

1498 W/cm²
1400
1200
1000
800
600
400
200

+Y

(-4.75, +4.75)   -X   -Y   (-4.75, -4.75)

(+4.75, -4.75)

2 JUNE 1980, RUN Z, 224 MIRRORS, 400 POINTS

RELATIVE IRRADIATION
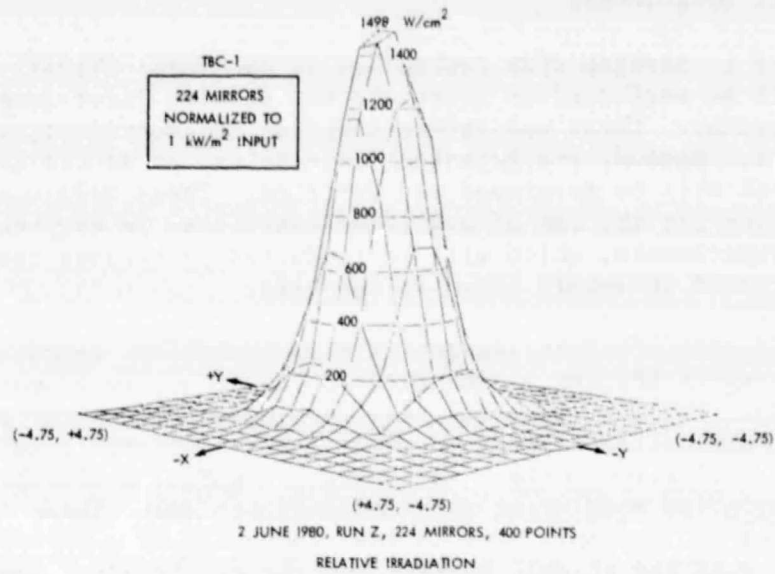
Figure 3.   The Test Bed Concentrator Flux Distribution
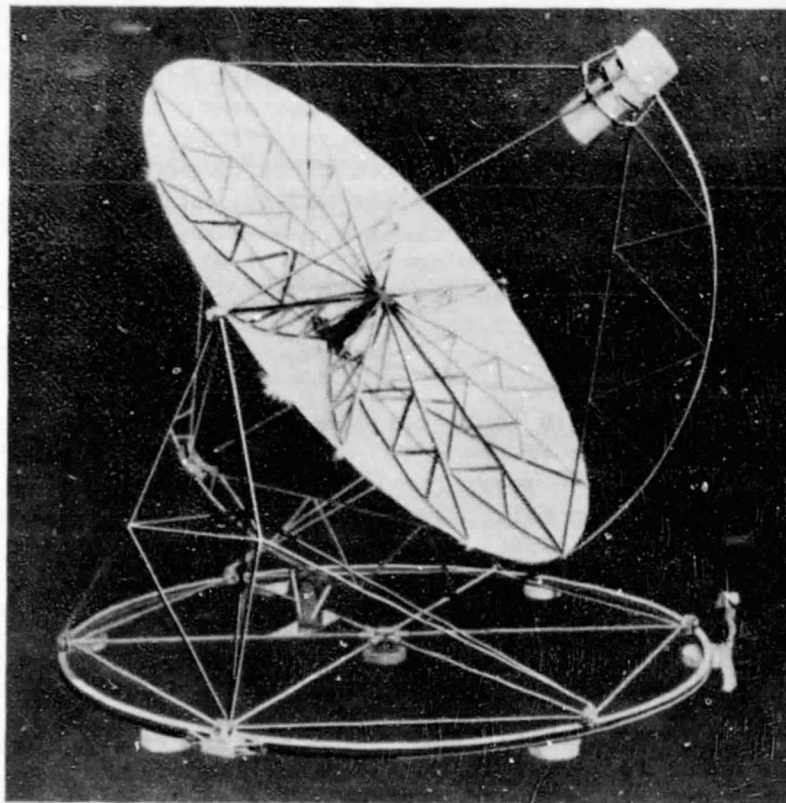
Figure 4.   General Electric Company's Low-Cost Concentrator (GE/LCC)

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C.   TECHNOLOGY DEVELOPMENT

The effort to develop dish technology is two-fold: First, tests and evaluations will be performed to integrate and develop first-generation dish collector subsystems. These subsystems comprise concentrators, receivers, and power converters. Second, the technical feasibility of second-generation collector subsystems will be developed and verified. These development efforts are in preparation for the use of qualified subsystems in engineering experiments. These experiments, which will be conducted in various user environments, are discussed in detail later in the text.

The development of first-generation dish technology emphasizes both the organic Rankine cycle (Figure 5) and the air Brayton cycle (Figure 6) for power conversion. In both cases the receiver/engine/alternator package is an integral unit. Concentrator stuctures will utilize plastic panels, or gores, to which a thin reflective surface is bonded. The panels will be manufactured either by an injection molding or sheet molding process. These techniques already exist and are commonly used in the production of a variety of commercial products. Both the organic Rankine and the air Brayton power converters being developed are turbine devices. The air Brayton converter will employ a turbine that is being developed for automotive use, which should facilitate the ultimate attainment of mass-producible, low-cost dish collectors.

The receiver for the organic Rankine power converter package shown in Figure 5 is being developed by the Ford Aerospace and Communications Corporation (FACC). The engine assembly is being developed by the Barber-Nichols Engineering Company under a sub-contract awarded to FACC in early FY 1980. The engine uses toluene as the working fluid. Waste heat from the turbine is largely recovered by means of an integral recuperator, or regenerator.

The Garrett air Brayton engine, which is being provided via a contract from the National Aeronautics and Space Administration Lewis Research Center is of the open-cycle type with a regenerator, as shown in Figure 6. The initial design has a maximum temperature rating of 815°C (1500°F) and can operate in a hybrid mode with solar or fossil fuel, or both. The contract was awarded in mid-FY 1980. The air-receiver is from Garrett and will be tested in mid-FY 1981.

The organic Rankine cycle converter (ORC) will be tested in mid-CY 1981 on the Test Bed Concentrators at the PDTS. The air Brayton will be tested by mid-CY 1982. A Stirling cycle power converter module, being developed by United Stirling of Sweden and Fairchild/Stratos Division, is scheduled for testing on the TBC in mid-CY 1981.

The United Stirling power converter and integral Fairchild/Stratos receiver are shown in Figure 7. The engine is a "solarized" version of the automotive P-40 engine. The receiver has a hybrid power input capability.

Buffer storage implies short-term energy storage of approximately one hour or less. In order to incorporate buffer heat storage directly in the receiver, General Electric Company was funded to conduct a preliminary design of a heat-pipe receiver that employs both sodium heat pipes and fluoride
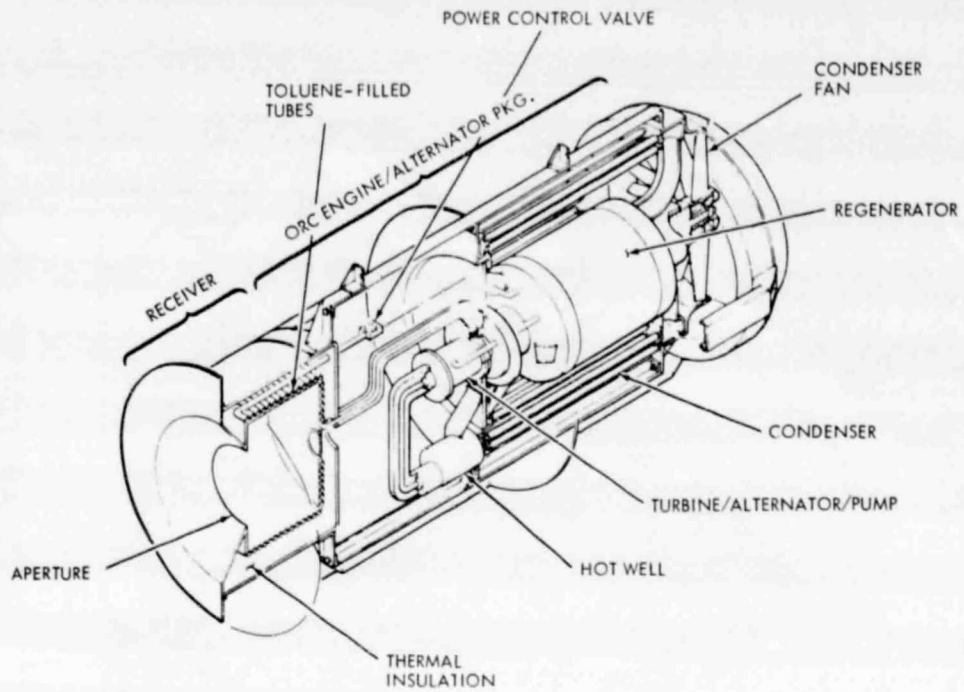
Figure 5. Organic Rankine Cycle (ORC) Power Conversion Assembly
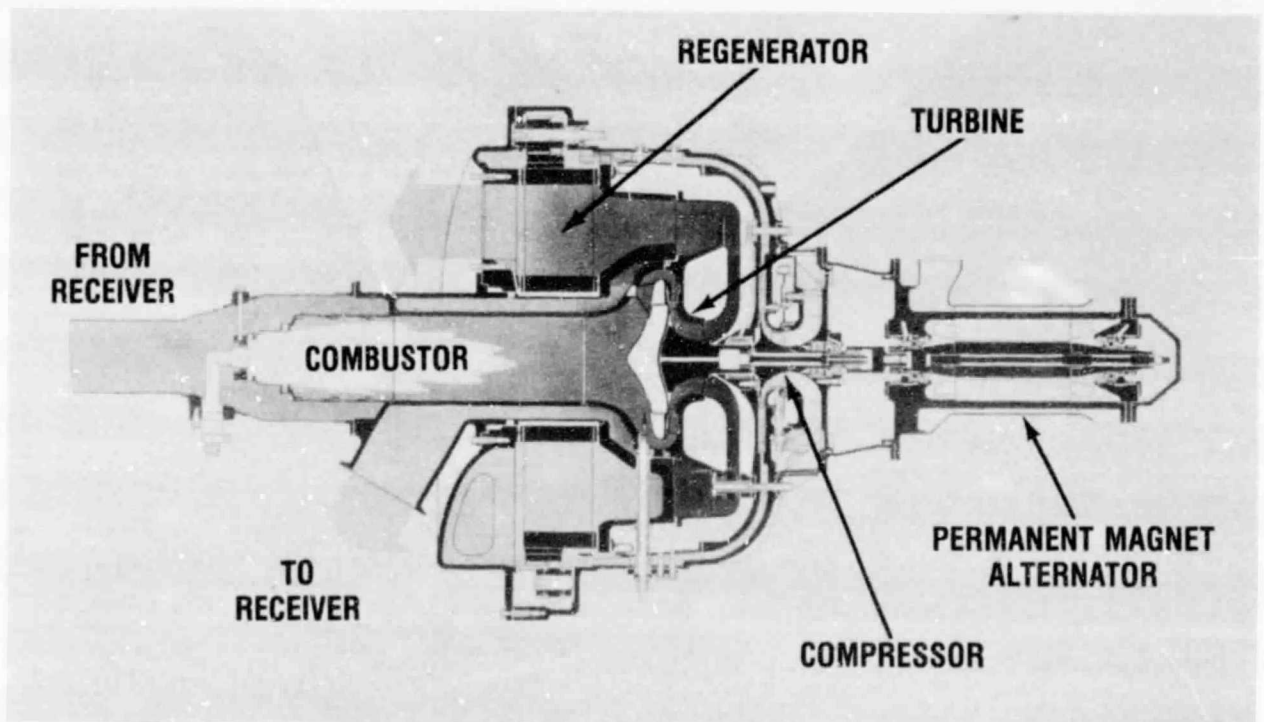
Figure 6. Air Brayton Cycle Power Converter
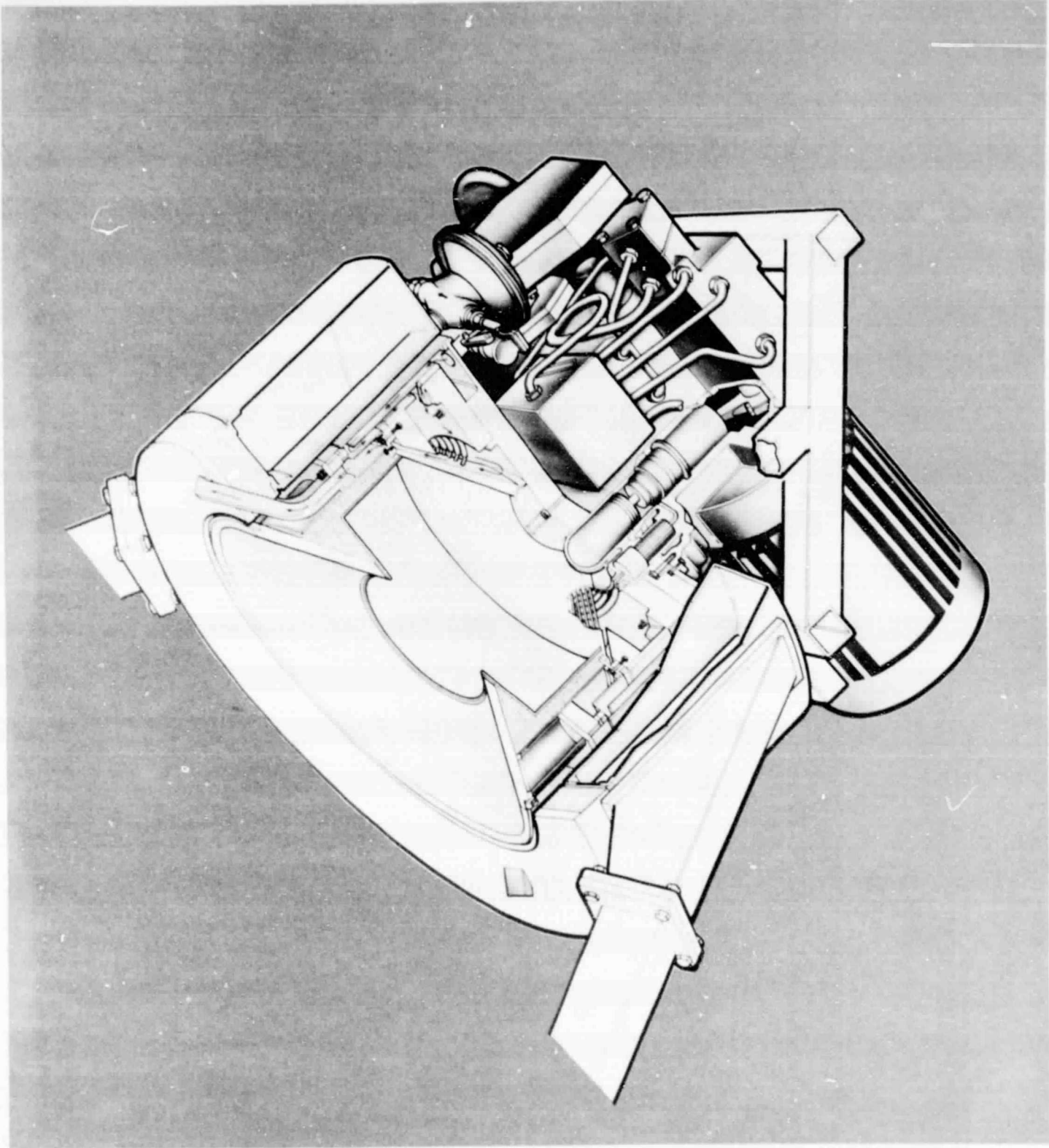
Figure 7. United Stirling Power Converter and Integral
Fairchild/Stratos Receiver

eutectic salt storage. It can operate in a hybrid mode, utilizing solar and/or fossil fuel energy. The receiver is designed to operate at 815°C (1500°F) and to provide about 0.8 hr of storage with a thermal input of 65 kWt to a P-40 Stirling engine having a 24 kWe generator output.

Extensive testing since early 1979 has been done on the 6-m diameter collector shown in Figure 8. It is produced commercially by the OMNIUM-G Company of Anaheim, California. Testing and evaluation continued during FY 1980, and focused on the power converter subsystem, which employs a reciprocating steam Rankine cycle. Testing of the Test Bed Concentrators began in April 1980 and by the end of FY 1980 they were ready to accept the first receiver to be delivered for dishes in the 80 kWt full-power range. This receiver uses steam as the working fluid and was produced by the Garrett AiResearch Co. It is designed for low, medium, and high-temperature process heat applications and is of the single pass design. It was delivered in May 1980 and instrumented for test by JPL. By controlling the water flow rate, the first full-power test was limited to outlet conditions of 700 psi and 316°C (600°F). The final full-power test will be at rated conditions of 2000 psi and 704°C (1300°F).

D.   APPLICATIONS DEVELOPMENT

Market applications experience with dish systems is vital to development of hardware best suited to future commercialization. Therefore, implementation of engineering experiments in various user environments is the major activity of the Applications Development work. It has the goal of demonstrating technical, operational, and economic readiness of dish systems in both electric and process heat applications. Three series of experiments have been defined which cover the major market sectors:

(1)   EE-1, known as the "Small Community Solar Thermal Power Experiment," is 1 MW in size and is directed toward the grid-connected market for small communities in the United States. Because this market is as important as it is difficult, work is underway through EE-1 to gain early experience in that highly competitive market. It is scheduled to be on-line in early CY 1984.

(2)   EE-2, is known formally as the "Isolated Application Experiment Series" and addresses island sites, rural electrification in foreign countries, and other stand-alone applications remote from the grid. A joint effort is now underway with the Navy Civil Engineering Laboratory on a cofunded basis. It is the first of the series, and the plant is scheduled to be operational in CY 1986.

(3)   EE-3, addressing the industrial market, will be implemented through a series of very small experiments (less than 20 kWe) for thermal, electric, and combined (cogeneration) applications.

For EE-1, the small community experiment, the site selection process was largely completed in FY 1980. The DOE site selection PRDA (Program Research and Development Announcement) resulted in an extremely encouraging response.
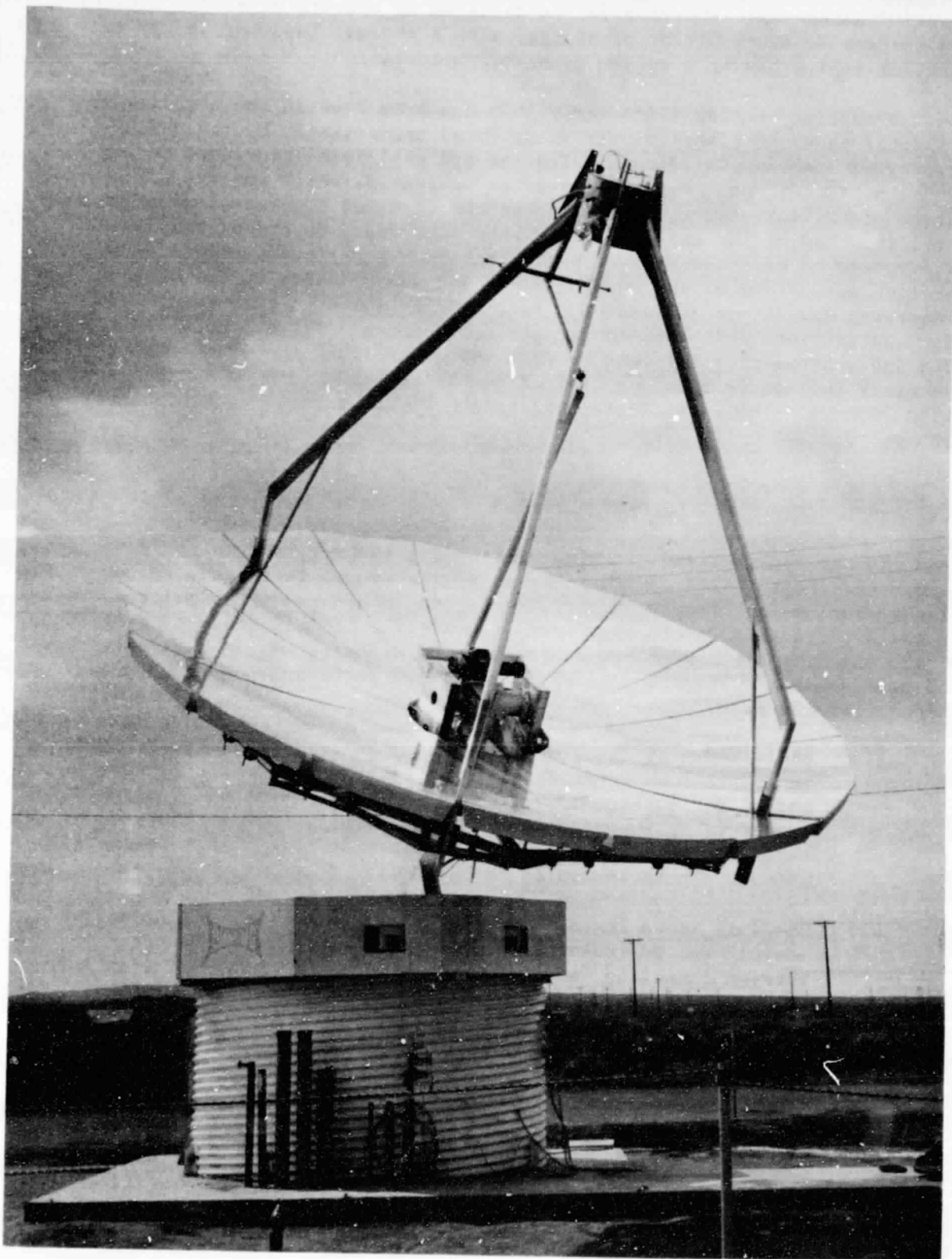
Figure 8.   OMNIUM-G Concentrator at JPL's Parabolic Dish Test Site

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Forty-five proposals were received from all regions of the country, as shown in Figure 9. Of these, six were selected for in-depth evaluation. The final site selection is expected to take place in early FY 1981. The selected community, its local utility, and the systems contractor will execute the experiment, with technical management by JPL. The dish module for the first community experiment will employ the GE/LCC and the organic Rankine receiver and integral power converter, discussed earlier. The power plant, to be nominally rated at 1 MWe, is shown in an artist's rendition in Figure 10.

The first engineering experiment of the EE-2 series, the isolated load experiment series, is known as the "Military Module Power Experiment." Six dish collectors will be installed at the Marine Corps Air Station in Yuma, Arizona. The six dishes will be either the General Electric Low-Cost Concentrator or the Acurex Corporation Low-Cost Concentrator, and they will be fitted with open-cycle, 815°C (1500°F) air Brayton power converters. A capability for hybrid operation using fossil fuel is provided to satisfy a need for storage. The military module will feature a high degree of self-containment, including a turbine starter, tracking sensors and two-axis drive, and a module control system. The module will be designed to be transportable, field erectable, and field serviceable.

The small EE-3 series experiments are known as the dish module experiments and will be conducted using available hardware to the maximum extent possible. Because they are small, they can be constructed in a short period of time.

In May 1980, 17 proposals for EE-3 series experiments were received, involving small businesses and universities. Twelve industrial market areas, including organic chemicals and petroleum extraction, in 11 different states were proposed for the siting of an EE-3 experiment featuring industrial process heat, cogeneration, or electricity. As a result of the solicitation, it was found that nine responders were involved in various stages of parabolic dish design and development. The announced award limit of $500,000 was approached by nearly all the bidders. Proposed program schedules varied from 24 to 36 months for experiment design, hardware fabrication, test- ing, and installation at a user site. A 12-month joint operations evaluation period would then take place. A contract award in early FY 1981 is expected.

The Southern New England Telephone Company (SNET), with partial funding by DOE, contracted with the OMNIUM-G Co. for installation of a single dish collector to provide both electricity and thermal powers for a small switching center. The installation was completed, with final checkout taking place in January 1980. Although the system was declared operational in March 1980, some tracking, control, and power converter problems appeared. System debugging efforts have continued.
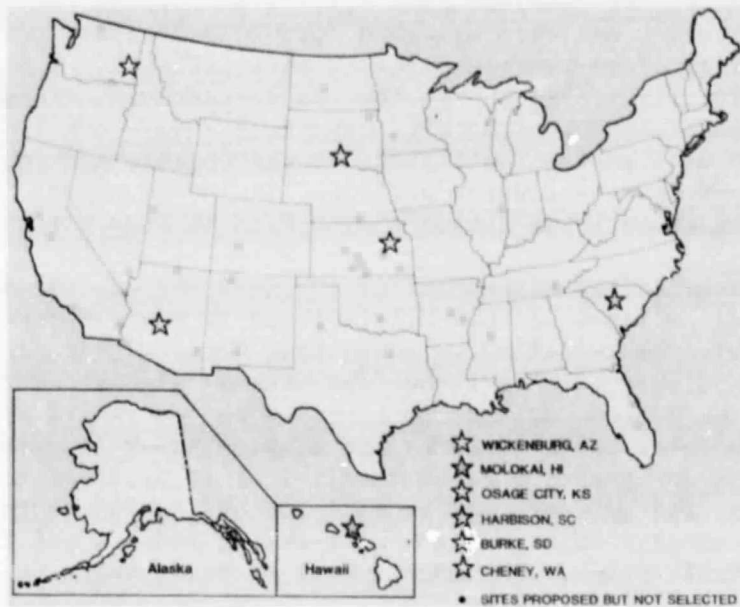
Figure 9. Map Showing Site Participation Responses to EE-1
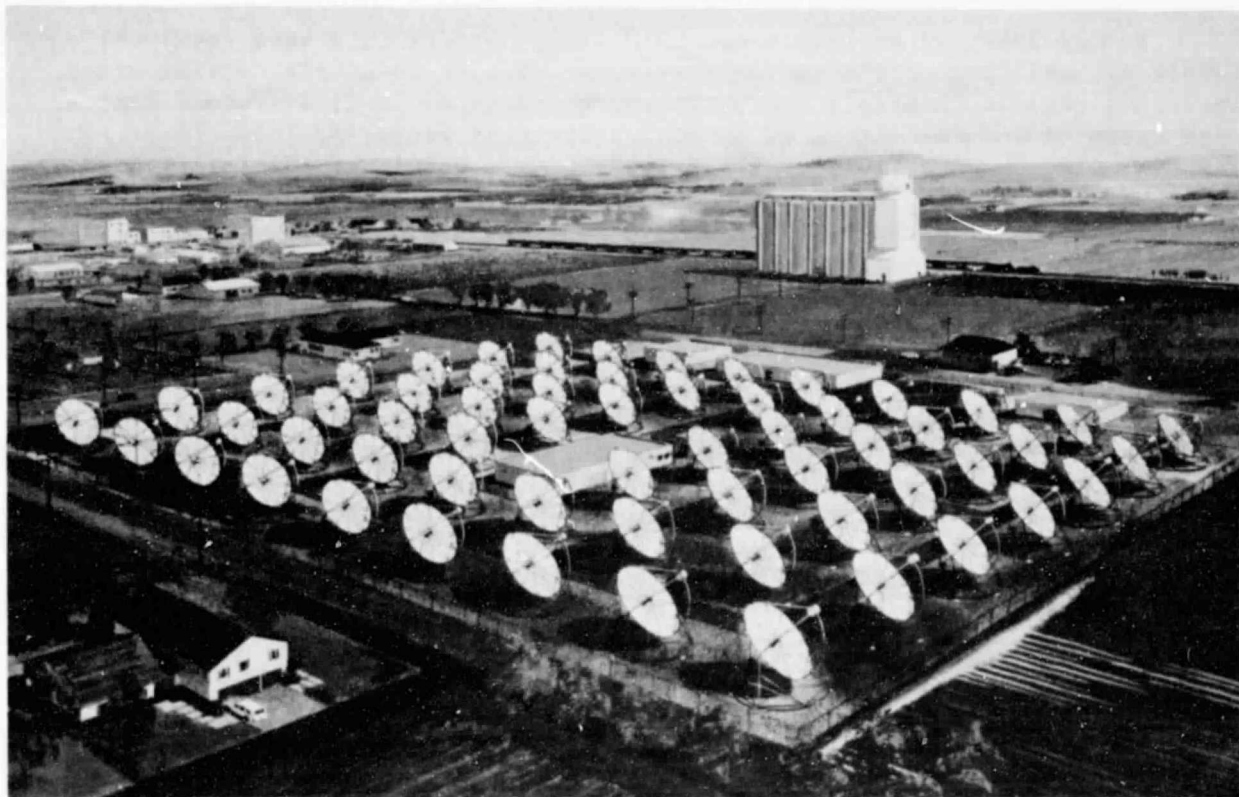
Figure 10. A Parabolic Dish Solar Power System Concept for EE-1

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PART TWO

DEVELOPMENT AND APPLICATIONS

SECTION I

INTRODUCTION

The NASA Jet Propulsion Laboratory with support from the NASA Lewis Research Center (NASA/LeRC) is responsible for the development of parabolic dish technology for the generation of electricity and/or, process heat. Parabolic dish systems are also known as point-focusing distributed-receiver (PFDR) systems and consist of a field of sun-tracking modules, each composed of a concentrator, a receiver, and either a power conversion unit for electrical generation or a thermal transport network for industrial heat processes. A typical dish is shown in Figure 1-1.

The work of the Thermal Power Systems Project (TPS) proceeds in two parallel and mutually supportive directions: 1) technology development, and 2) applications development. The goal of technology development is to attain technical feasibility of dish module elements, followed by technical readiness for commercial application. Applications development activity includes planning and implementing field tests in the user environments in order to verify system feasibility. These first-of-a-kind field tests are called "engineering experiments" and are described later in the text. Following their successful deployment, system readiness tests in various user environments are conducted to verify that parabolic dish systems have reached a stage of maturity at which the risks of mass production and marketing are acceptably low. System readiness tests will be conducted with a wide range of climatic and institutional environments. A simplified model of new technology and applications development is shown in Figure 1-2.

Major accomplishments in both technology development and applications development for FY 1980 are summarized in this report.
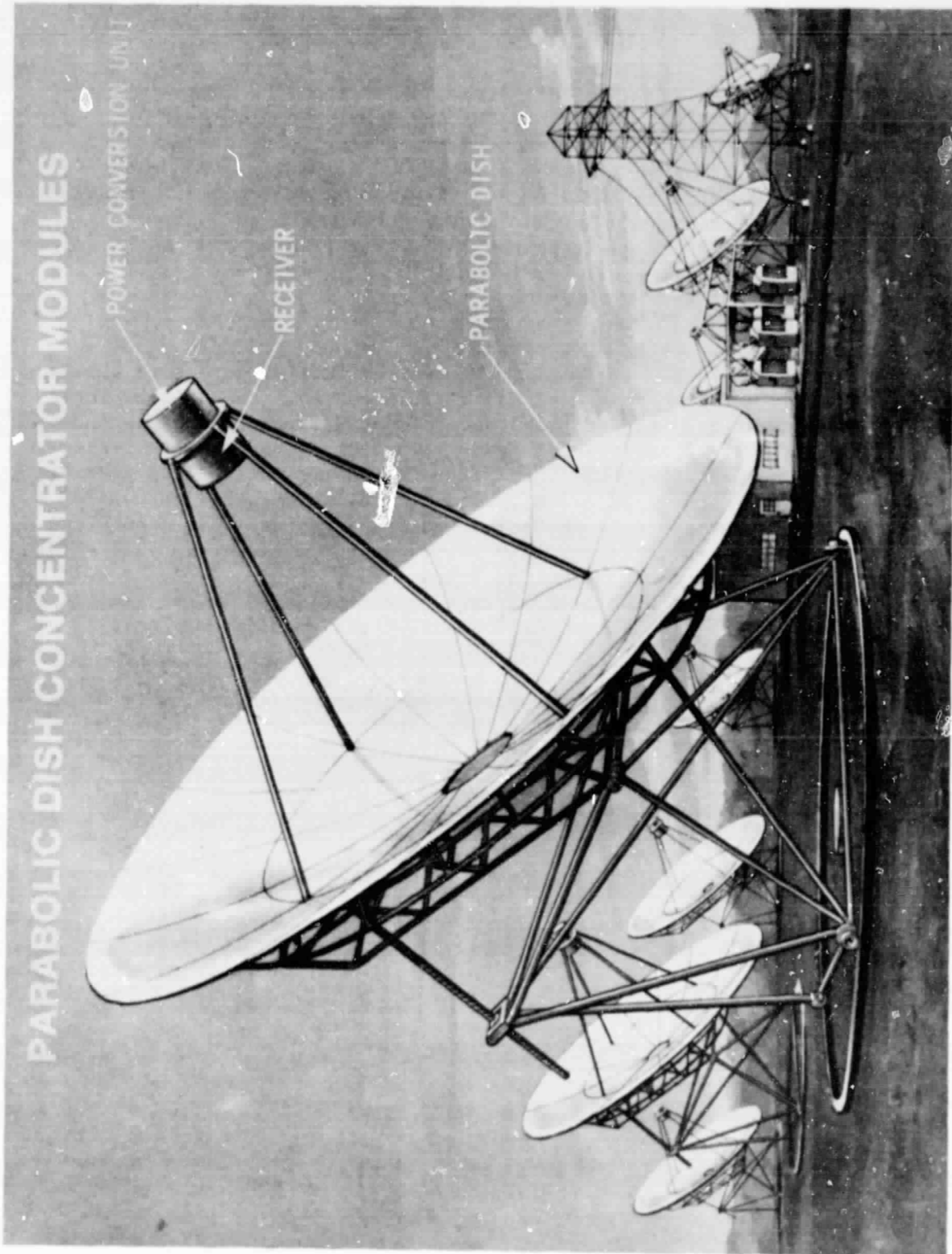
Figure 1-1. Typical Parabolic Dish Power Module
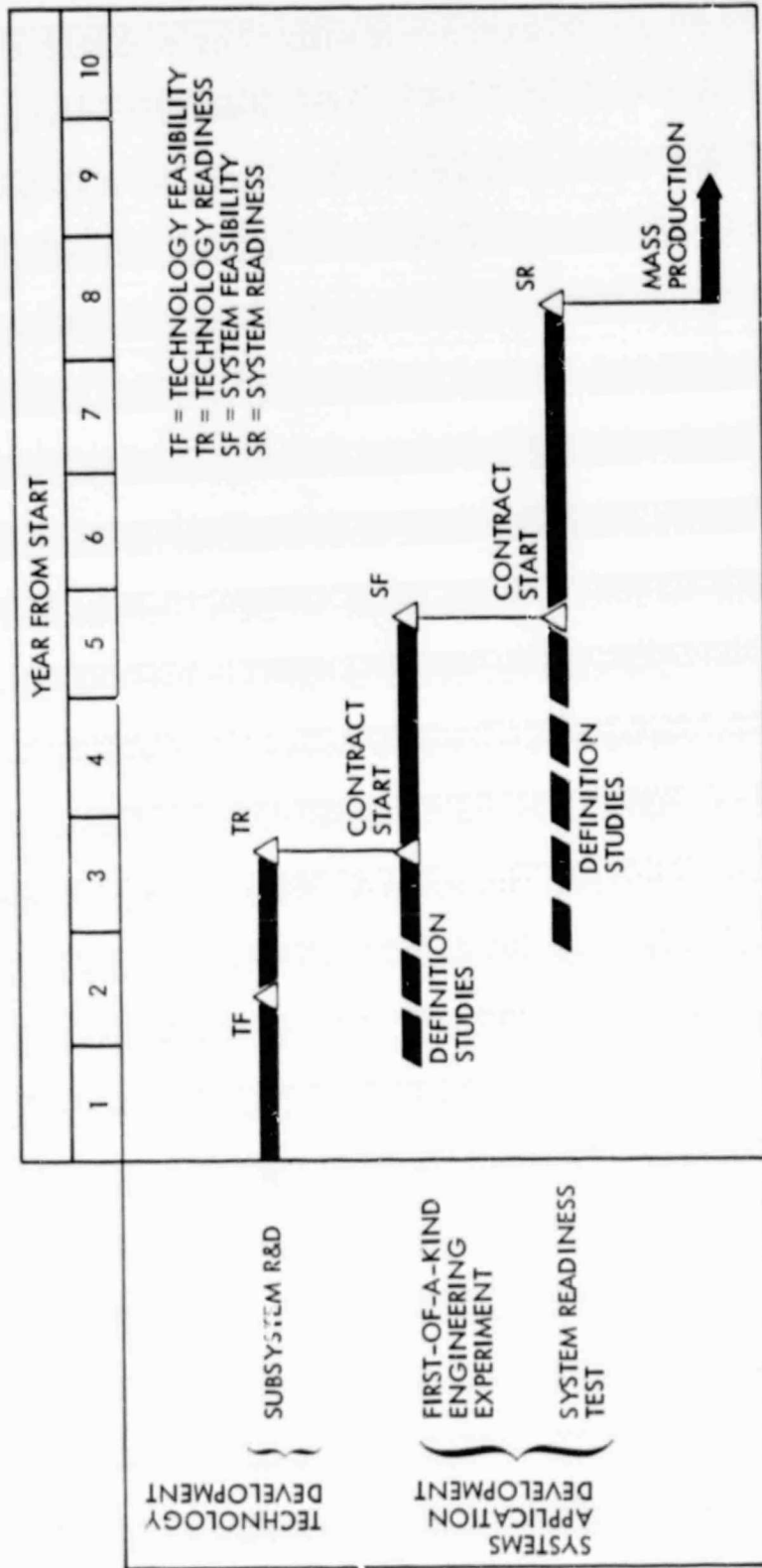
Figure 1-2. Flow Model for New Dish Technology

SECTION II

GOALS OF THE THERMAL POWER SYSTEMS PROJECT

The goal of the Thermal Power Systems Project is to establish the technical, operational, and economic readiness of parabolic dish systems for electric applications up to 10 MWe, and for thermal applications up to 30 MWt. An integral part of this activity is to foster industry participation in all phases of the technology development and field experiments.

Three prerequisites are required to demonstrate the technology readiness of parabolic dish systems:

(1)   System components must achieve performance levels that will ensure the economic feasibility of the overall system.

(2)   Components and modules must demonstrate durability and sufficient operational lifetime at design conditions to validate their cost-effectiveness.

(3)   Components and modules must be producible in quantity at low cost.

Target dates for system performance and price have been formulated for both electric generating power module (Table 2-1) and for power modules designed to produce process heat (Table 2-2).

The performance criteria used have been developed for each power module subsystem (Refer to Tables). Price and efficiency estimates for the development of each subsystem have been established for both near-term (First Generation) and far-term (Second Generation) project phases.

Performance testing of prototype hardware will take place at the JPL Parabolic Dish Test Site (PDTS) at the Edwards Test Station (ETS) near Lancaster, California. Although insufficient time will have elapsed by the dates indicated to permit the demonstration of actual hardware lifetime, performance goals are expected to be met on schedule, and the systems will have achieved technological readiness. Neither the achievement of mass-production or the demonstration of quantity production price can be forecasted, since they are largely dependent on industry. However, studies will have identified methods to produce dish hardware at the prices established as goals for the program.

Table 2-1. Preliminary Price and Performance Targets
for Electric Power Generation (1980 $)

Subsystem	Dominant Parameters	First Generation (1983)	Second Generation (1987)
Concentrators	Installed Price* ($/m^2)	120 – 170	80 – 120
	Surface Reflectance (%)	78 – 90	92
Receivers	Installed Price* ($/kWe)	45 – 70	25 – 45
	Efficiency (%)	82	87
Power Conversion	Installed Price* ($/kWe)	230 – 410	120 – 230
	Efficiency (%)	25 – 35	35 – 45

*Based on the following assumed ranges of production:
    First generation: ,000 –   25,000/yr
    Second generation: J,000 – 100,000/yr

Table 2-2. Preliminary Price and Performance Targets
for Process Heat Generation (1980 $)

Subsystem	Dominant Parameters	First Generation (1983)	Second Generation (1987)
Concentrators	Installed Price* ($/m^2)	120 – 170	70 – 120
	Reflector Efficiency (%)	78 – 90	92
Receivers	Installed Price* ($/kWt)	18	14
	Efficiency (%)	95	96
Thermal Transport	Installed Price* ($/kWt)	32	30
	Efficiency (%)	90	93

Note: These figures are for a module and do not include a ground heat
       transportation network

*Based on the following assumed ranges of production:
    First generation: 5,000–25,000/yr
    Second generation: 10,000–100,000/yr

SECTION III

TECHNOLOGY DEVELOPMENT

A. CONCENTRATORS

The concentrator technology development objectives are directed toward developing high-temperature, point-focusing, two-axis tracking concentrators. Emphasis is placed on the development of a technology having a potential for low cost when mass-produced. This is particularly important because the concentrator accounts for over half the cost of a solar thermal module. Implementing this task is accomplished primarily through contracts with industry and involves:

(1)   Developing concentrators which can be used as test beds in the testing and evaluation of components.

(2)   Developing first-generation, low-cost concentrators to operate efficiently in the 540° to 815°C (1000° to 1500°F) temperature range.

(3)   Developing second-generation low-cost concentrators having the maximum potential for mass production and for simple installation in the field.

Second generation concentrators will utilize the processes and techniques being developed by the advanced concentrator effort. During FY 1980, this effort emphasized the development of cost-effective, lightweight, reflective gores and supporting structures.

A contract for the detailed design, fabrication, and installation of three prototype Low-Cost Concentrators (LCCs) was awarded to General Electric Company (GE) during FY 1980. Design of the concentrator was completed and is shown in Figure 3-1. The first-generation GE/LCC has a 12-m diameter dish and uses metallized plastic film bonded to a glass reinforced plastic (GRP) sandwich substrate as the reflector surface. It is expected that the concentrator will provide 80 kWt, at 1000 W/m^2 insolation, to a receiver with a 33.7-cm (13.25-in.) diameter aperture and operating at a temperature of 815°C (1500°F). This concentrator is planned for use in the Small Community Solar Power Experiment and will be available as an option for the Military Module Power Experiment (EE-2) described later in this report.

Acurex Corporation was awarded a contract to design, fabricate, and install at the PDTS an alternate first-generation LCC. The concentrator will be available as an option for EE-2. An artist's rendition of the Acurex design concept is shown in Figure 3-2, and uses a compressed paraboloidal reflector. The reflector surface consists of a mosaic of second-surface glass mirrors bonded to glass-reinforced plastic substrates. This design has a projected performance of 78.6 kWt at 1000 W/m^2 insolation, using a receiver with a 31.1-cm (12.24-in) diameter aperture and operating at a temperature of 815°C (1500°F).

A key accomplishment in the area of advanced concentrators was the development of cost-effective, lightweight reflective gores using a sandwich
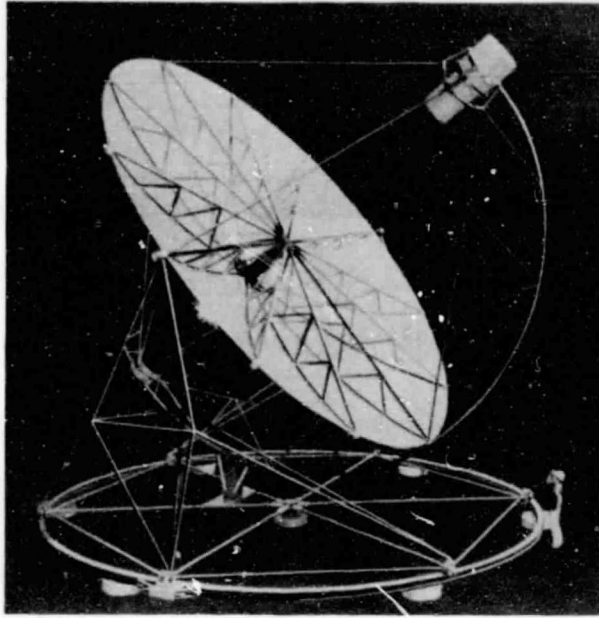
Figure 3-1. General Electric Low-Cost Concentrator (GE/LCC)
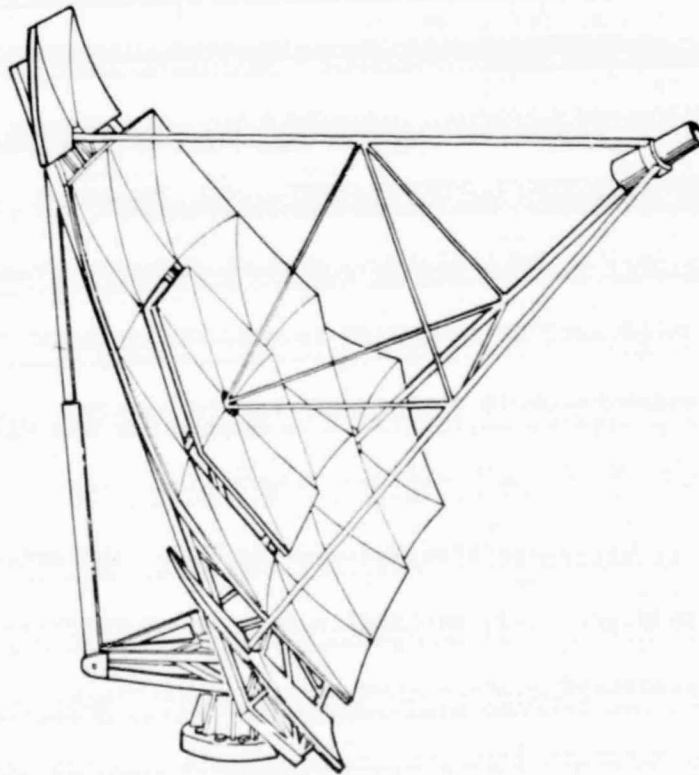
Figure 3-2. Acurex Low-Cost Concentrator Design

construction as shown in Figure 3-3. The back-silvered mirror is 1.5-mm (60-mil) thick and is cold-sagged and bonded to a paraboloidal surface of structural cellular glass to form a gore. These lightweight, structurally efficient gores will yield excellent optical quality at low cost when mass-produced. The inherent rigidity of the gores permits significant reduction in the weight of the reflector support structure.

Acurex concentrator design features were evaluated, and a concept was selected which minimizes the total installed cost of the concentrator. This design concept features an 11-m diameter, single-pedestal concentrator (Figure 3-4). The processes and techniques being developed in this effort are planned for use in second-generation concentrators.

It was determined that the costs of shipping, site preparation, foundation, installation, on-site assembly, and checkout were the major elements influencing concentrator costs. Consequently, the minimal installation costs associated with this design make it an attractive concept.

B. RECEIVERS

Cost-effective receivers and heat transport subsystems are required for parabolic dish systems. These subsystems must have long-term reliability at the temperature, pressure, and flow rate conditions at which the system operates. The designs must be completely compatible with the other module components: concentrators, engines, controls, and storage subsystems.

The receivers currently under development employ organic liquids, steam, air, or liquid metal as the working fluid. These receivers are designed to operate at power levels which match the capabilities of the various concentrators being developed in the parabolic dish program. In modules designed to produce electricity, the receivers are matched to specific power converters, such as Rankine, Brayton, or Stirling-cycle units. During FY 1980 an analytical receiver model and computer program were developed to facilitate system integration and to predict the impact of changes in subsystem characteristics.

A first-generation receiver using toluene as the primary working fluid was designed by Ford Aerospace and Communications Corporation (FACC) to be coupled with the organic Rankine engine for use in the Small Community Solar Thermal Power Experiment (EE-1). The receiver design was approved at the preliminary design review of the system in June 1980. The approved design is shown in Figure 3-5 and consists of a single stainless steel tube that conducts the toluene, and which is embedded in a copper plate to provide temperature leveling and buffer storage for improved engine operation.

Near the beginning of FY 1980, detailed resign reviews of first-generation air-Brayton and steam-Rankine receiver designs were conducted. The air-Brayton review was completed late in September 1979 and the steam-Rankine review early in October 1979. Both were presented by Garrett AiResearch Manufacturing Company of California. No major problems were discovered at these reviews, and the contractor was authorized to build two prototypes of each design.

FOCAL POINT

z

θ

GORE

PARABOLOIDAL
REFLECTIVE SURFACE

$r^2 = 4fz$

r

f

x

y

REFLECTIVE
GORE

MIRROR

A

A

CELLULAR GLASS
SUBSTRATE

GLASS

Section AA
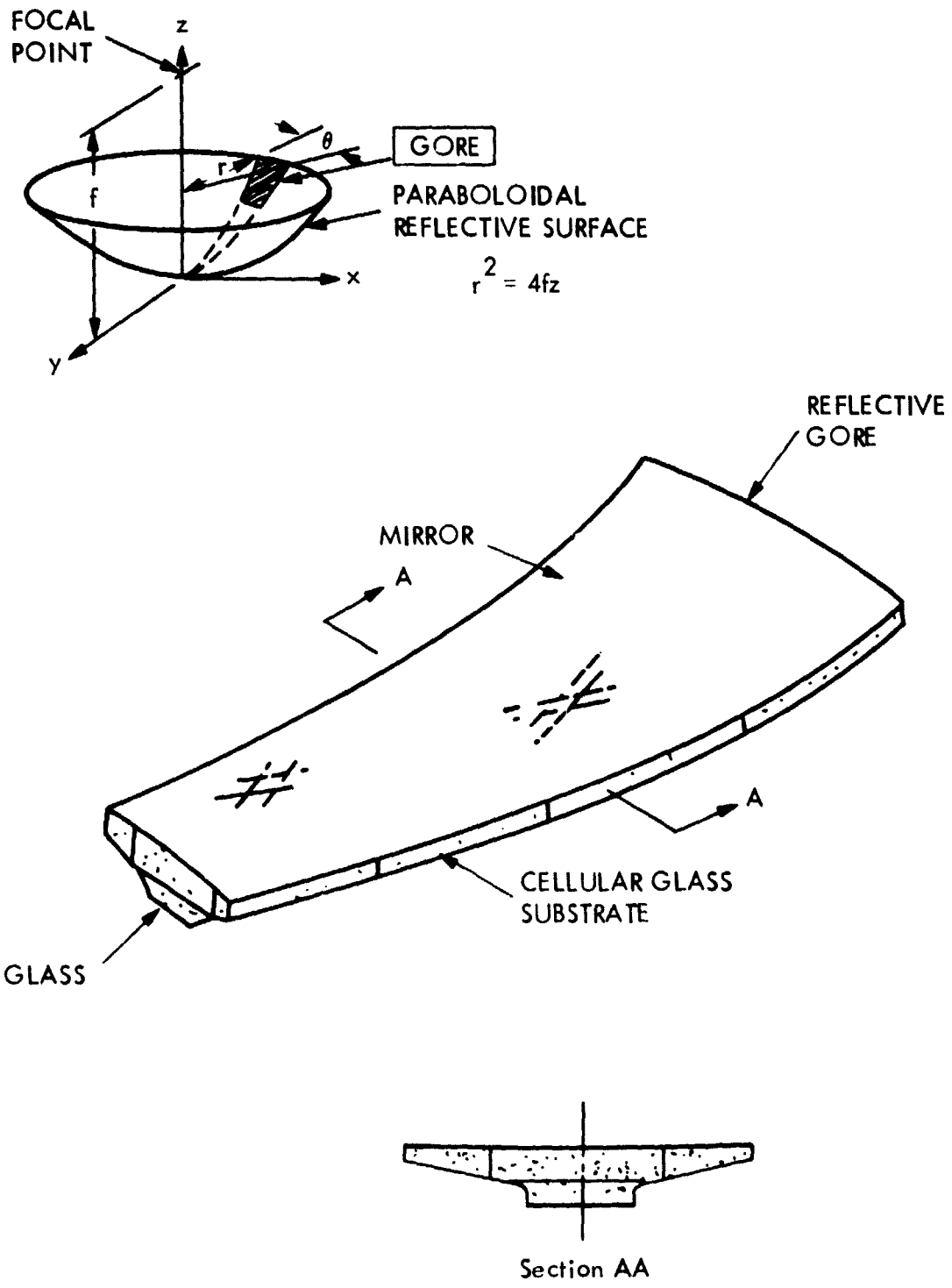
Figure 3-3.   Reflective Gore Design
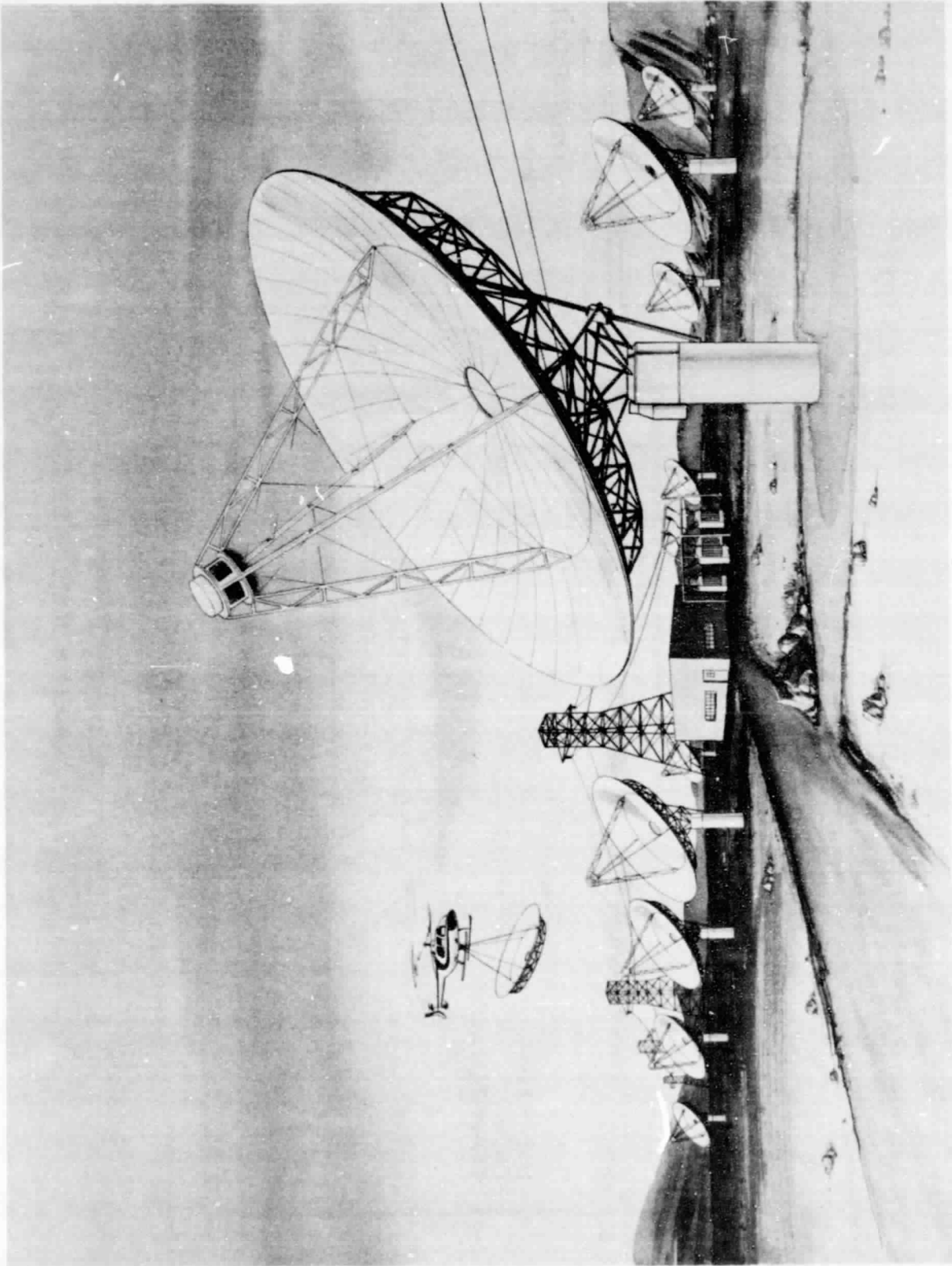
Figure 3-4. Acurex Advanced Concentrator Design Concept

3-5
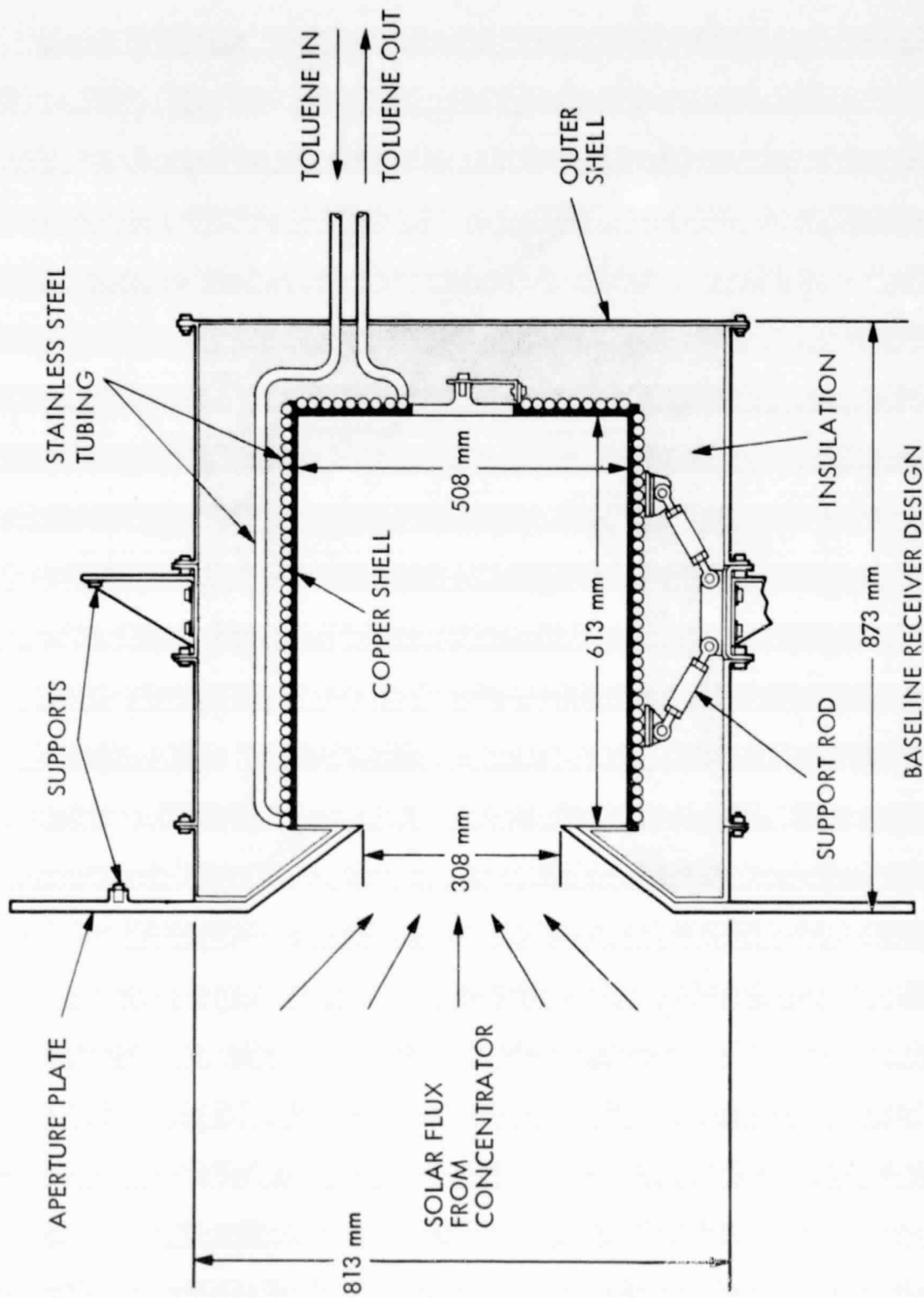
Figure 3-5. Organic Rankine Receiver Design

The first steam-Rankine receiver was delivered in late May 1980. Figure 3-6 shows the receiver from the aperture end as it was being instrumented for testing at the PDTS. This receiver was installed on Test Bed Concentrator-1 (TBC) in September 1980 and testing was initiated in late September. Early data reduction confirmed its performance. The first Brayton receiver was fabricated in early July 1980, and will be delivered to the PDTS for testing in early FY 1981. The remaining two prototype receivers will be delivered about a month later.

A second-generation dish-Stirling solar receiver is being developed by Fairchild Stratos Division of Fairchild Industries, Inc., for direct coupling to the Stirling engine as shown in Figure 3-7. The conical receiver body uses copper for high thermal conductivity to the Stirling heat exchanger tubes. A fossil-fuel combustor is located behind the copper body to augment solar heat input as needed. A detailed design review was held in October 1979, and long lead-time hardware was approved for fabrication. The remainder of the receiver was approved for fabrication after a supplementary design review in December 1979. The receiver was delivered in September 1980, and is scheduled for shipment to United Stirling of Sweden for integration assembly and test with the Stirling power conversion unit prior to delivery to the PDTS in mid-FY 1981.

Fairchild completed the preliminary design of a ceramic receiver body to replace the metal receiver body. The ceramic body is to be fabricated from silicon carbide with ceramic housing and heads for the Stirling engine. It will increase receiver life by eliminating creep problems associated with metallic receiver materials. It will also eliminate the high-cost strategic materials used in the metallic receiver. A contract was awarded to Advanco Corporation in late FY 1980 for subsystem integration and test support at the PDTS of the engine, alternator, receiver, and control system.

The preliminary design of a heat pipe solar receiver with buffer thermal energy storage was completed by General Electric Company and is shown in Figure 3-8. It will be used in an integrated, focus-mounted, hybrid, solar-Stirling power conversion subsystem. The receiver consists of primary and secondary heat pipes containing sodium. The secondary heat pipes are embedded in sodium fluoride-magnesium fluoride eutectic salt. A natural gas combustor with a set of tertiary heat pipes for transporting heat to the large secondary heat pipe allows fossil-fuel hybrid operation.

Initial testing of the primary heat pipes and the secondary heat pipe wicking was completed successfully. A modular test experiment was conducted, confirming the performance and defining the operating characteristics of the thermal transport and storage systems. The modular test confirmed adequate thermal transport from the primary heat pipes to the secondary heat pipe at near isothermal operation.

A preliminary design review of the heat pipe solar receiver was held in May 1980, and a detailed design review in September 1980. Fabrication was approved to support a June 1981 delivery to the PDTS. The receiver is designed to operate at 830°C (1520°F), and to provide approximately 0.8 hr of thermal storage with 65 kWt input to the P-40 Stirling engine. The design generator output is 24 kWe. The design receiver efficiency is in the 85% to 90% range.
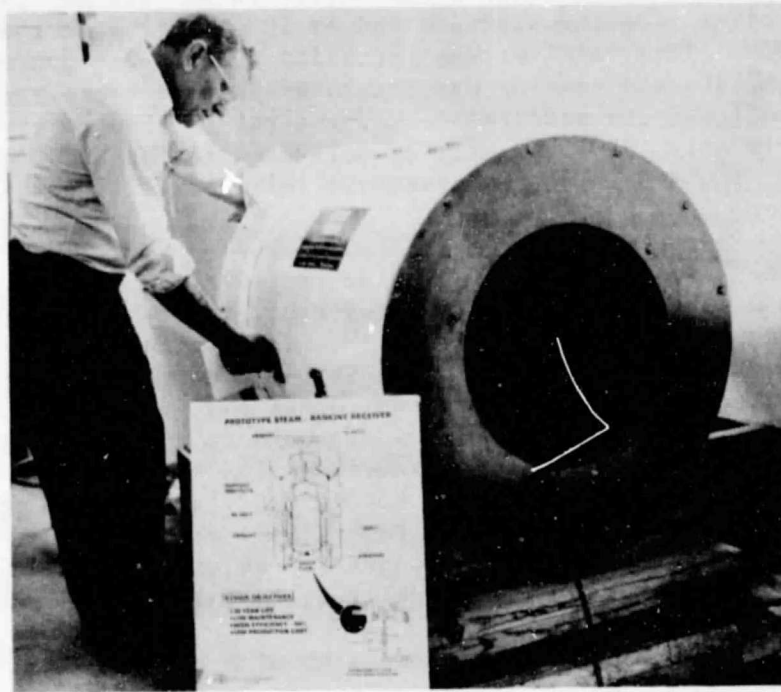
Figure 3-6.   Steam-Rankine Receiver
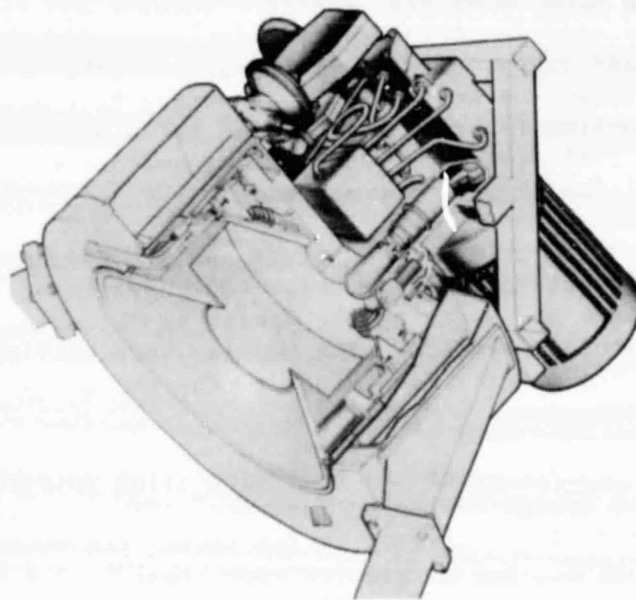
Figure 3-7.   Dish-Stirling Engine and Receiver

SECONDARY SODIUM
HEAT PIPE

NaF-MgF$_2$
LATENT HEAT
STORAGE

ELECTRICAL
GENERATOR

P40 STIRLING ENGINE

AIR IN*

RECUPERATOR*

EXHAUST*

PRIMARY SODIUM
HEAT PIPES

FLAME IMPINGEMENT
SHELL HEATER*

FUEL IN*

IGNITOR*

RECEIVER
APERTURE

*THESE FEATURES CONSTITUTE
THE COMBUSTOR WHICH PROVIDES
A HYBRID OPERATIONAL CAPABILITY

SOLAR FLUX
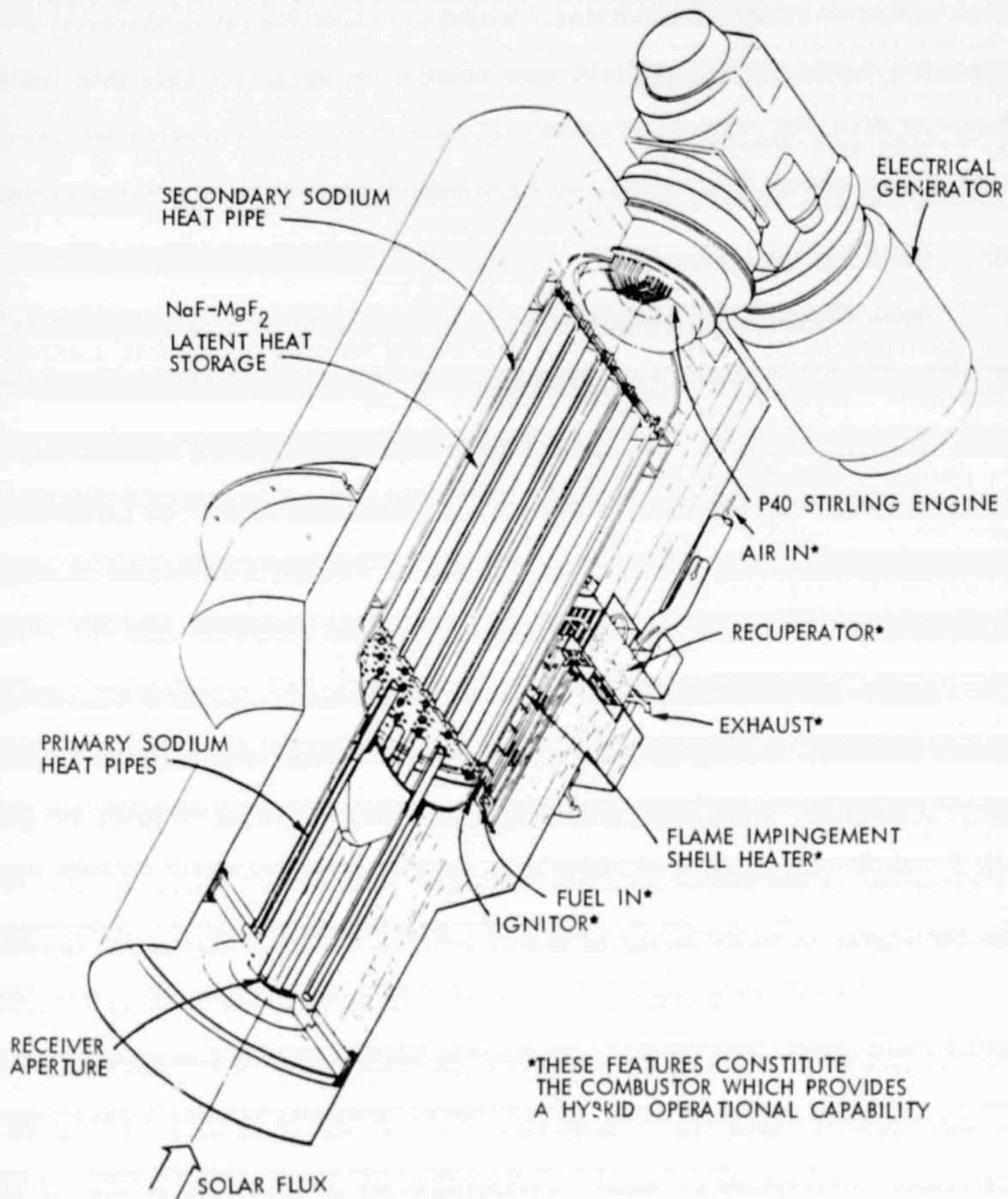
Figure 3-8. Heat Pipe Solar Receiver Concept with Thermal Energy Storage

3-9

C. HEAT TRANSPORT

In June 1980 a statement of work was prepared for a heat transport net-
work development RFP for dish arrays. The procurement package was completed
in July 1980. The release date was delayed to late FY 1981 because funding for
this effort in FY 1981 was deleted. However, in ongoing JPL assessment of
thermal transport, hot water and steam up to 510°C (950°F) were studied.
Transport losses for the networks were found to be generally less than 10% of
the total output from the dish arrays. Array sizes studied were in the range
below 30 MWt. JPL studies (Reference 1) have shown that automated factory and
semi- automated field assembly techniques can reduce costs as much as 50%
compared to conventional labor-intensive manufacturing and assembly methods.

D. POWER CONVERSION UNITS

Power conversion subsystems that will be coupled with solar receivers are
being developed under the cognizance of JPL and NASA/LeRC. Organic Rankine,
air-Brayton, and Stirling power conversion units are the primary cycles being
developed. The status of each is discussed below.

An organic Rankine cycle (ORC) power conversion unit was selected for use
in the Small Community Solar Thermal Power Experiment (EE-1) by the system con-
tractor, Ford Aerospace and Communications Corporation. Based on information
supplied by a panel of representatives from FACC, the Solar Energy Research
Institute (SERI), LeRC, and JPL, the ORC engine was selected because of its
potential for high efficiencies at moderate operating temperatures. Barber-
Nichols Engineering Company of Arvada, Colorado, was awarded a contract in
early FY 1980 to design and fabricate an ORC power conversion unit.

Figure 3-9 shows a cutaway of the FACC power conversion unit consisting
of an FACC toluene receiver previously described, and the Barber-Nichols ORC
engine assembly. A shaft-mounted permanent magnet alternator (PMA) is directly
coupled to the engine. Toluene was selected as the organic working fluid. The
entire assembly will be hermetically sealed. The PMA, being designed and fab-
ricated for Barber-Nichols by Simmons Precision of Norwich, New York, converts
the mechanical output to high-frequency, three-phase alternating current which
is converted to 600 Vdc by a ground-mounted inverter. A preliminary design
review was conducted in May 1980 and fabrication began in August. FACC expects
the ORC engine to be delivered in mid-FY 1981 for assembly with their receiver
and subsequent in-plant testing.

An open-cycle air-Brayton engine was selected for use in the Military
Module Power Experiment (EE-2). The Garrett Turbine Engine Company was awarded
a contract in early FY 1980 to design the Brayton engine. The unit will oper-
ate at a maximum temperature of 815°C (1500°F) using either solar, fossil-fuel
thermal input, or both, in a hybrid mode. An off-the-shelf Bendix Corporation
generator with a gearbox will be coupled to the engine to provide high-
efficiency, three-phase ac power. Preliminary and detailed design reviews were
held in May and August of 1980. A one year delay in the start of EE-2 led to
the decision to upgrade the engine prior to fabrication. The upgraded engine
will be based on Garrett's automotive advanced gas turbine (ACT) but will
incorporate the features of hybrid combustion chamber and nozzle and shaft-
coupled permanent magnet alternator. Garrett was directed to proceed with this
change in August 1980.
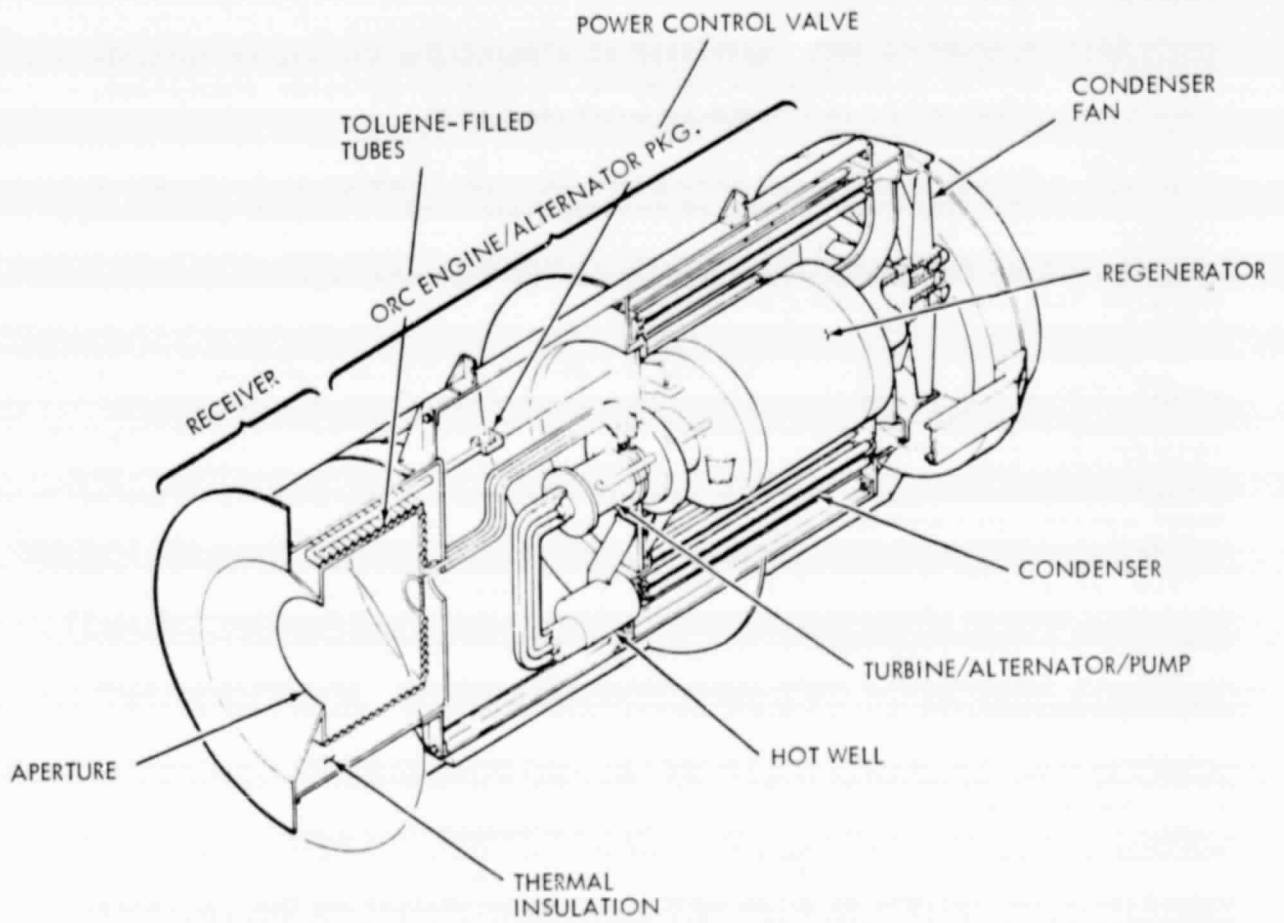
Figure 3-9. FACC Organic Rankine Cycle (ORC) Power Conversion Unit

Stirling engine technology is being considered for second-generation parabolic dish modules. Although Stirling engine development for solar use is not necessary, "solarization", performing modifications to adapt the automotive Stirling engine for solar applications, is required. The United Stirling P-40 engine was selected for solarization, and the following solarization-related actions were initiated:

(1) Relocation of the oil tank, flow passages, and pumps for inverted operation.

(2) Selection of long life seal and piston ring configurations and materials.

(3) A study of the feasibility of eliminating the engine controls and making provision for hermetic sealing to increase simplicity, lower cost, and decrease maintenance.

(4) Coordination of an evaluation of engine design with the automotive Stirling engine program to determine cost-reduction potentials.

An option for hybrid operation is included in the receiver portion of the P-40 Stirling power module design.

Other advanced engines that may be developed for production by approximately 1990 are also being studied. The automotive program under DOE is developing a 60-kWe low-cost engine. The application to Stirling engines of simplified, higher efficiency drive systems, such as V-4 and in-line-4 configurations, is being explored by several companies. The applicability of these systems to parabolic dish modules requires careful evaluation. Advanced engines utilizing sodium-vapor heat-transfer techniques are expected to demonstrate engine efficiences of 45% with 820°C (1500°F) thermal input. Additionally, studies (Reference 2) have indicated that "solarization" of small gas turbines employing ceramic components, which are being developed for automotive applications, constitute attractive options for parabolic dish power converters.

E.   MANUFACTURING STUDIES

High-performance, point-focusing modules that can be manufactured in high-production volumes at a low unit cost are essential to the successful marketing of parabolic dish systems. Consequently, a manufacturing development effort is being conducted to determine:

(1) Independent cost and selling price estimates for dish components and systems.

(2) Tooling, capital equipment, and facility costs required to produce dish modules.

(3) Possible use of automation techniques to produce dish modules at a lower cost.

(4) Changes in product design, material, or manufacturing methods, if any, that could result in a lower cost product.

These data will be obtained from the following independent sources:

(1) The contractors responsible for subsystem and system development.

(2) An independent contractor having mass-production expertise.

(3) JPL manufacturing engineering personnel.

During FY 1980 a report, "Cost and Price Estimate of Brayton and Stirling Engines in Selected production Volumes," (JPL Publication 80-42) was published. This study Produced cost and price estimates for 20 kWe (peak output) Brayton and 30 kWe (peak output) Stirling engines when produced in various quantities (Figure 3-10).

The Test Bed Concentrator was cost-analyzed for various annual production quantities by Pioneer Engineering and Manufacturing Company of Detroit. The results clearly indicate that this unit is not a low-cost, mass-producible design. Pioneer was also awarded a contract to estimate the costs of the Garrett AiResearch receiver designed for use with an air-Brayton engine, and a contract to cost-analyze the first-generation General Electric Low-Cost Concentrator.

In the last quarter of FY 1980, RFPs were released seeking industry assistance to cost-analyze both the first-generation Brayton engine and the P-40 Stirling engine (modified for solar collector application) in selected annual production volumes.

Model factory concepts are being studied for dish module subsystems: engines, receivers and concentrators. These models will be used in the development of more accurate estimates of costs and selling prices for dish modules.

F. SYSTEMS ENGINEERING STUDIES

During FY 1980 systems engineering work was conducted in the areas of:

(1) System/subsystem integration.

(2) Evaluation of groundrules for design of first generation organic Rankine and Brayton modules.

(3) Assessment of organic Rankine engine development plan.

(4) Review of the preliminary NASA Brayton receiver/power conversion unit (PCU) integration test plan.

(5) The Brayton PCU design phase contract work statement.
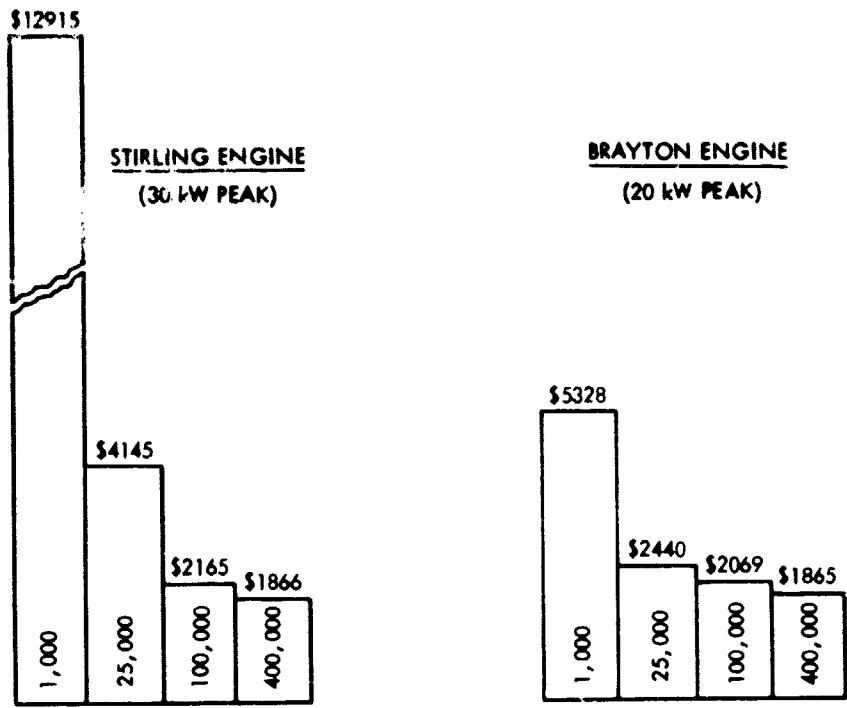
Figure 3-10. Engine Price versus Annual Volume for Stirling Engine (30 kWe Peak) and Brayton Engine (20 kWe Peak)

(6) The analysis of results of continuing field tests of the OMNIUM-G module.

(7) Cost and performance of dish collector configurations using various alternative subsystems.

Module performance estimates were made for a Brayton engine coupled with the Test Bed Concentrator and the GE/LCC. Module electric power outputs for these configurations are shown in Figure 3-11 for varying turbine inlet temperature and two values of insolation.

Results of a typical energy cost study for first-generation Brayton systems are shown in Figure 3-12; energy cost values have been normalized relative to the value at $815^\circ C$ ($1500^\circ F$) and a production rate of 100,000 units per year. Increasing system efficiency results from increasing temperature, which tends to decrease energy cost, but this is offset by increasing captial costs associated with increasing subsystem replacement rates.

Additional cost and performance studies were conducted. Energy cost targets were reevaluated based on latest capital cost and performance data for both electric and thermal power outputs. Refinements were made to foundation and balance-of-plant costs. Second-generation cost and performance targets were refined to account for anticipated improvement in subsystem performance.

A parametric study was performed to determine the best mix for fuel-burning and thermal storage in a solar hybrid plant. The main parameters varied were storage capacity, cost, efficiency, and fuel cost. Figure 3-13 shows the region where thermal storage may be justified for a 5-MWe plant. A curve for a conventional diesel plant is included. The horizontal dashed line indicates a solar plant with "ideal" storage, i.e., 100% efficient with zero cost.

The OMNIUM-G module at the Parabolic Dish Test Site received extensive development testing during FY 1980. Thermal power tests were concluded and the module was tested as a system for producing electric power. The latter tests were terminated following a series of failures in the steam engine.

Test results (Reference 3) of thermal power output by the OMNIUM-G module are shown in Figure 3-14. An early design receiver having a nominal 10.2-cm (4-in.) diameter was utilized as a calorimeter. Cold and hot receiver tests were run at approximately $93^\circ C$ ($200^\circ F$) and $204^\circ C$ ($400^\circ F$) respectively. Test data presented in Figure 3-14 were derived from the concentrator operating in the manual override mode due to inconsistancies in the automatic tracking mode.

A number of 24-hour tests were performed on the OMNIUM-G module to gather operation and maintenance data. Thermal performance was assessed by using the OMNIUM-G receiver, having a 20.3-cm (8-in.) diameter aperture as a cold water calorimeter. Most of these tests demonstrated a long-term thermal power performance in the 9-10 kWt range. This value is somewhat less than anticipated from previous investigations and further testing is planned to better understand the thermal power potential of the system.
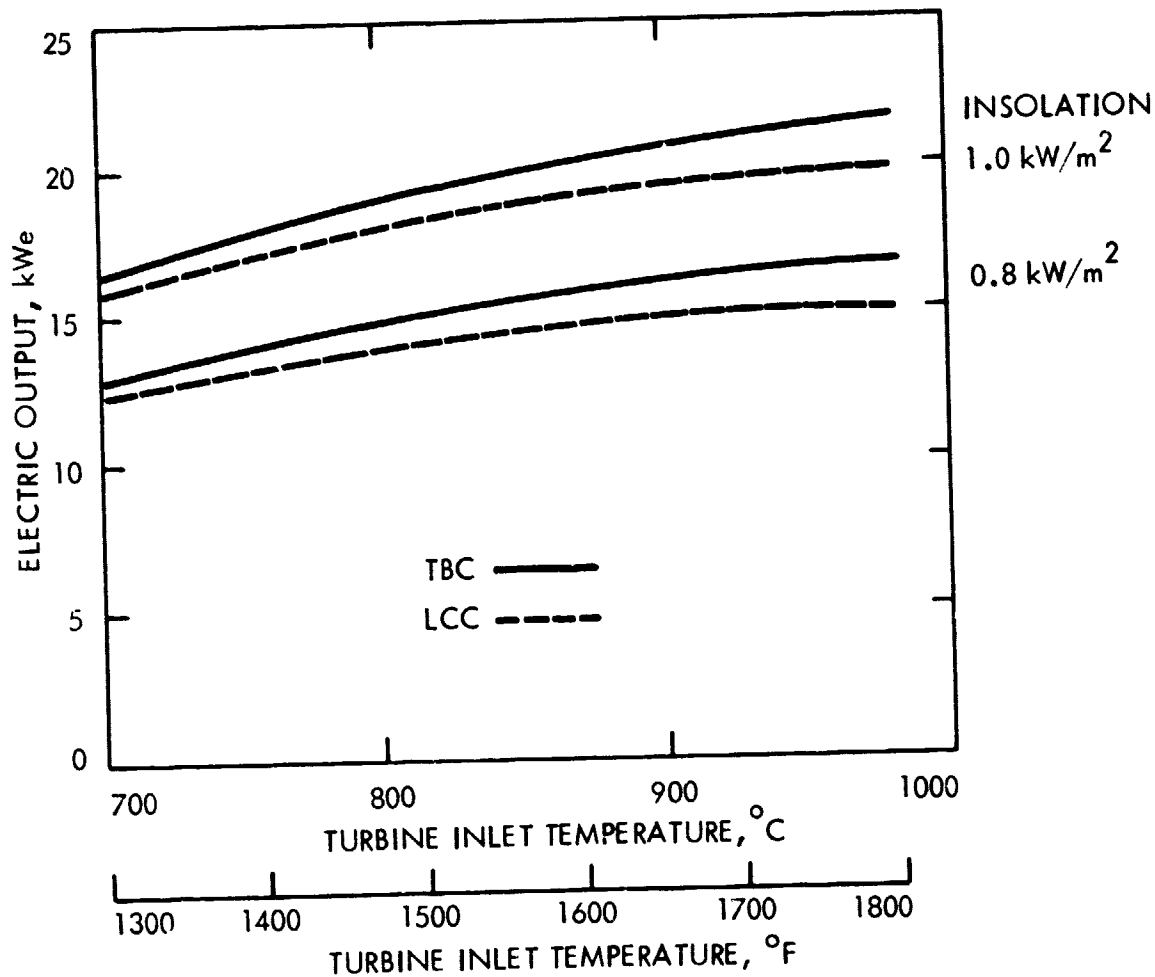
Figure 3-11. Performance Estimate for First-Generation Brayton Modules
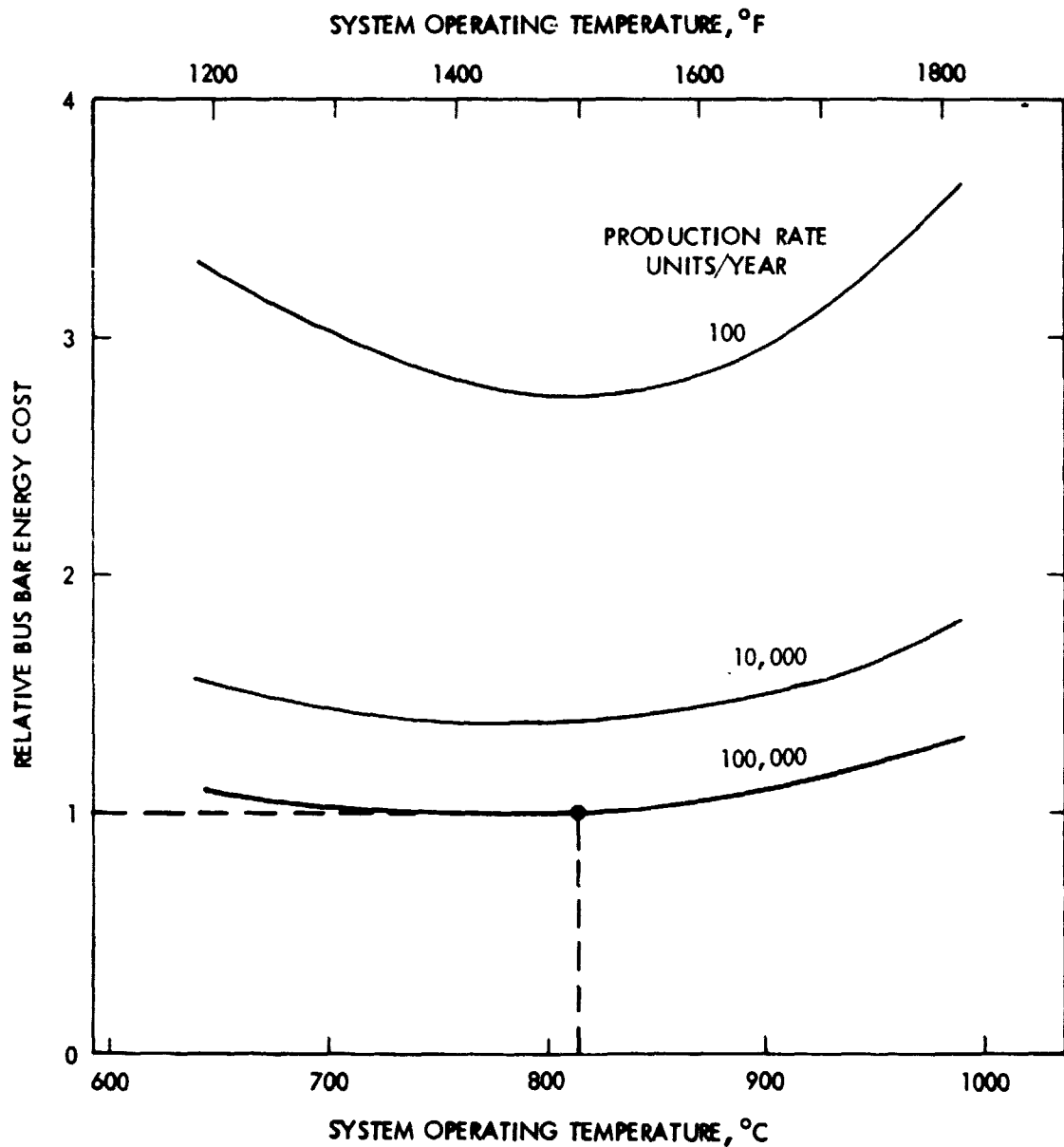
Figure 3-12. Relative Bus Bar Energy Cost $\overline{BBEC}$ Dependence on System Operating Temperature for First-Generation Brayton Systems.
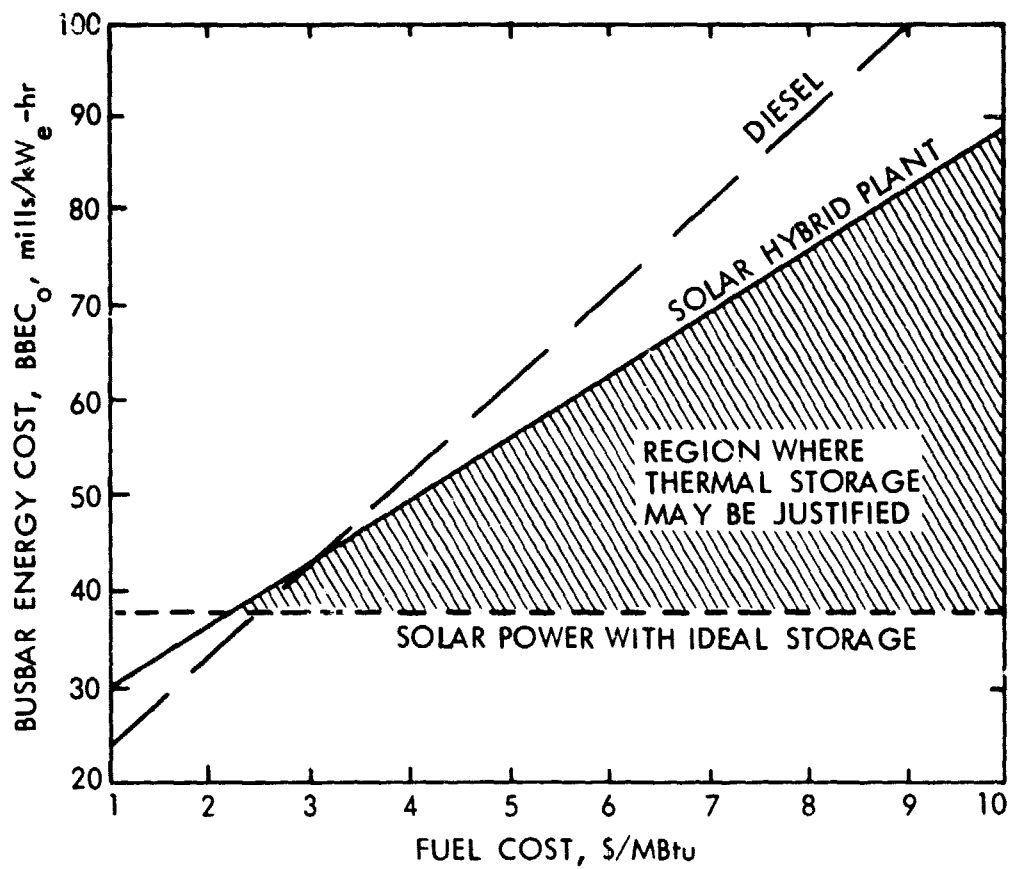
Figure 3-13. Sample Energy Cost Results for a 5-MWe Solar Hybrid
Plant with Thermal Storage
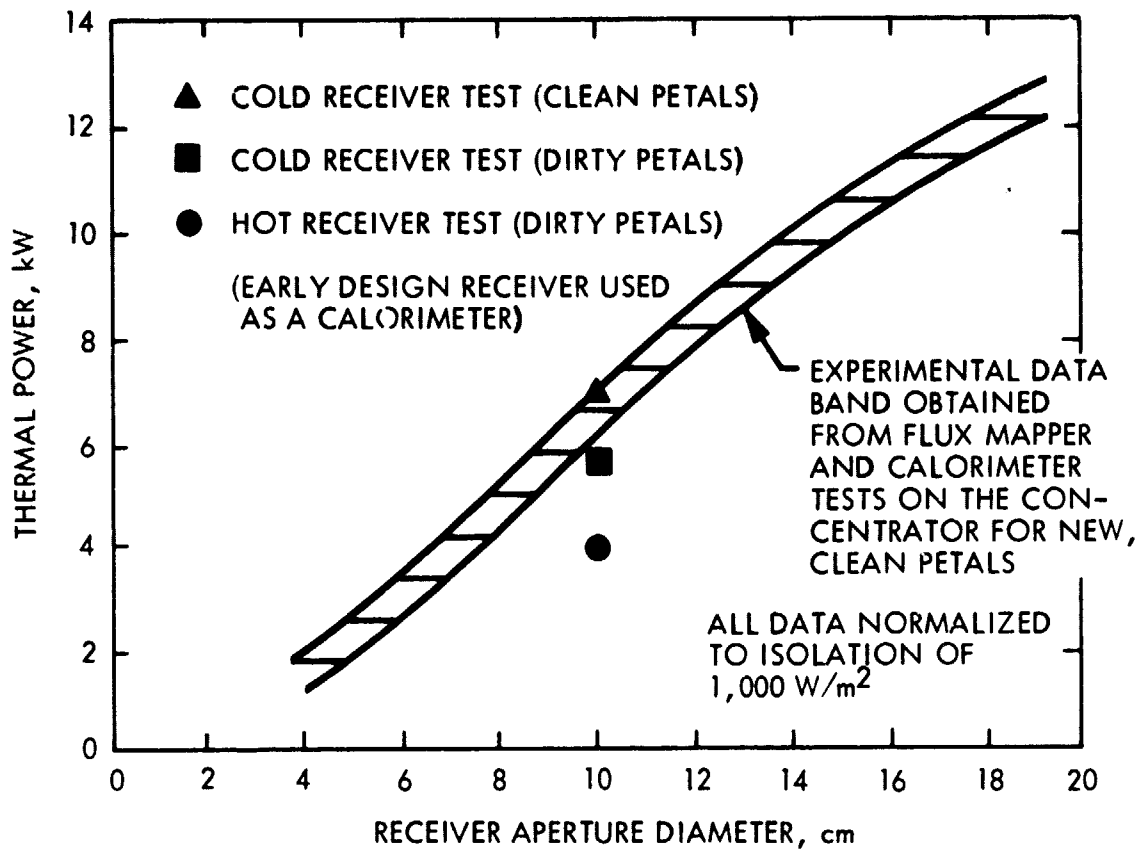
Figure 3-14. OMNIUM-G Module Thermal Power Test Results

A study was completed which ranked 1 to 10 MWe solar power systems such
as dishes, troughs, compound parabolic collectors, bowls, and central receiv-
ers. The study was a companion to studies conducted by SERI and Battelle
Pacific Northwest Laboratory. The results were similar although ranking posi-
tions differed for some systems. The JPL study concluded that point-focusing
systems in general, and dish systems in particular, have the lowest levelized
bus bar energy costs (Figure 3-15). Studies conducted in support of the
ranking study addressed balance-of-plant costs, plant equipment price, and
performance.

In 1980, the breakeven costs were estimated for a particular solar power
plant design in each of 13 U.S. regions. In addition, the effect of increasing
production levels of the levelized bus bar energy cost ($\overline{BBEC}$) of a reference
solar thermal electric power plant located in the 13 regions (Reference 4) were
evaluated. The solar thermal reference system consisted of a plant comprised
of modules with parabolic dish and Brayton engine characteristics at production
levels in the range between 1,000 and 25,000 units per year and a second gener-
ation case involving an improved dish but with a Stirling engine (same receiver
in both cases) at production levels in the range between 25,000 and 100,000
units per year.

The levelized bus bar energy costs for conventional power generation
(Figure 3-16 shows values for oil and coal in selected regions) were compared
to the solar thermal electric option to arrive at a breakeven cost. The
results (see Table 3-1) indicate that the reference system will reach
competitive levels (between the years 1990 and 2000) with small oil fired
plants (8 MW) and small coal fired plants (280 MW) in the North Central/North
Western regions, and with small oil (8 MW), small coal (280 MW), and large
coal fired (1000 MW) plants in the Southwestern regions. Figure 3-17
illustrates the breakeven costs for the highest (Mountain I) and lowest (East
South Central II) solar resource regions.

The financial parameters typical of municipal ownership were assumed. In
addition to the variation of the insolation resource by region, the operations
and maintenance costs for oil and coal plants (particularly the cost of fuel to
the utilities) were varied on a regional basis. The capital escalation rates
for the different plants also varied by type of plant and the plant capital
costs varied by region due to the differences in cost of various factors, e.g.
labor, capital, regulation, etc. Further work needs to be done to examine the
future markets of these technologies in relation to the solar thermal analysis
conducted here.

It was also observed that the solar thermal $\overline{BBEC}$ drops by a factor of two
in going from low insolation to high insolation regions (see Figure 3-17). The
evolution from first to second generation systems resulted in a reduction in
$\overline{BBEC}$ due to improvements in system efficiency. The magnitude of the cost re-
ductions was greater in low insolation regions than in high insolation regions.
This was due to the shape of the efficiency curve for the reference system and
indicates that a design tailored for the insolation resource of the region
could, in principle, operate with greater effective use of the resource than a
system designed for a sunbelt climate. Figure 3-18 illustrates this relation-
ship in terms of a low and high insolation location.

The requirement that the cost be less than the value is a necessary condition for parabolic dish systems to be a viable alternative to conventional systems. It is not a sufficient condition to guarantee market penetration. Future work and case studies will address the market penetration issue in greater detail.

Table 3-1. Regional Breakeven Costs (1980 $)

Regions	Breakeven with Small Oil Power Plants		Breakeven with Small Coal Power Plants		Breakeven with Large Coal Power Plants	
	Year	$\overline{BBEC}$	Year	$\overline{BBEC}$	Year	$\overline{BBEC}$
New England	1990	238	--	--	--	--
West South Central I	1990	236	1999	132	--	--
Middle Atlantic	1990	250	--	--	--	--
South Atlantic	1990	242	1996	160	--	--
East North Central	1989	285	--	--	--	--
West North Central	1990	186	--	--	--	--
East South Central I	1990	242	--	--	--	--
East South Central II	1991	188	--	--	--	--
West South Central II	1990	224	1993	140	1996	135
Mountain I	1986	250	1990	121	1991	95
Mountain II	1990	229	1995	128	--	--
Mountain III	1987	215	1990	105	1995	92
Pacific	1987	260	1992	132	1996	120

--Breakeven level will not be attained before the year 2000.

--$\overline{BBEC}$ = Levelized bus bar energy cost in mills/kWh.
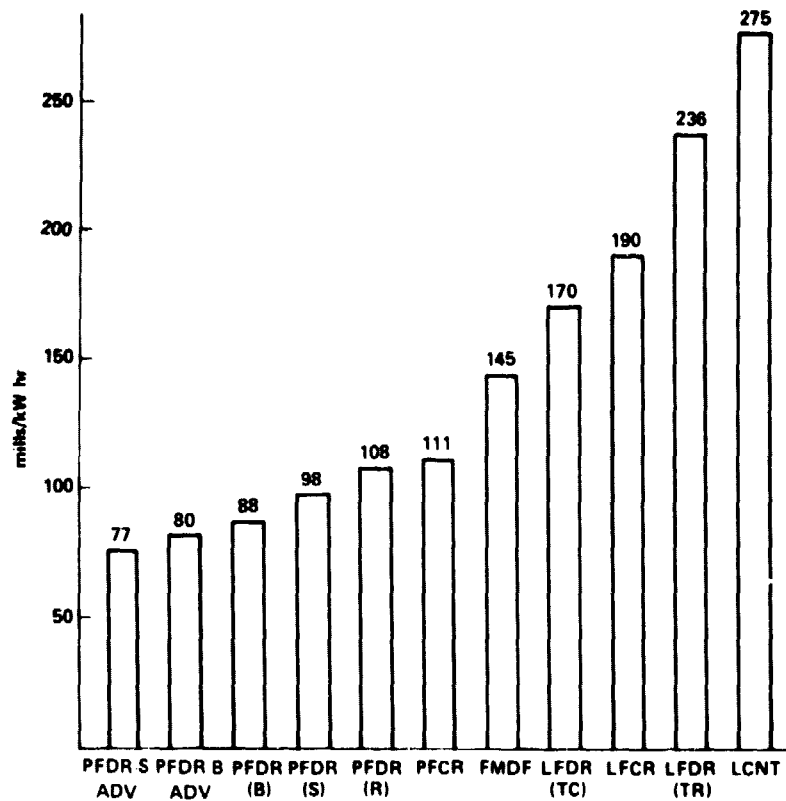
ADV - ADVANCED PARABOLIC DISH SOLAR THERMAL POWER SYSTEM
PFDR - POINT-FOCUSING DISTRIBUTED RECEIVER
S - STIRLING CYCLE POWER CONVERSION UNIT
B - BRAYTON CYCLE POWER CONVERSION UNIT
PFCR - POINT-FOCUSING CENTRAL RECEIVER
FMDF - FIXED-MIRROR DISTRIBUTED FOCUS
LFDR - LINE-FOCUS DISTRIBUTED RECEIVER
TC - TRACKING CONCENTRATOR
LFCR - LINE-FOCUS CENTRAL RECEIVER
TR - TRACKING RECEIVER
LCNT - LOW-CONCENTRATION, NON-TRACKING

Figure 3-15.   Results of Comparative Ranking Studies
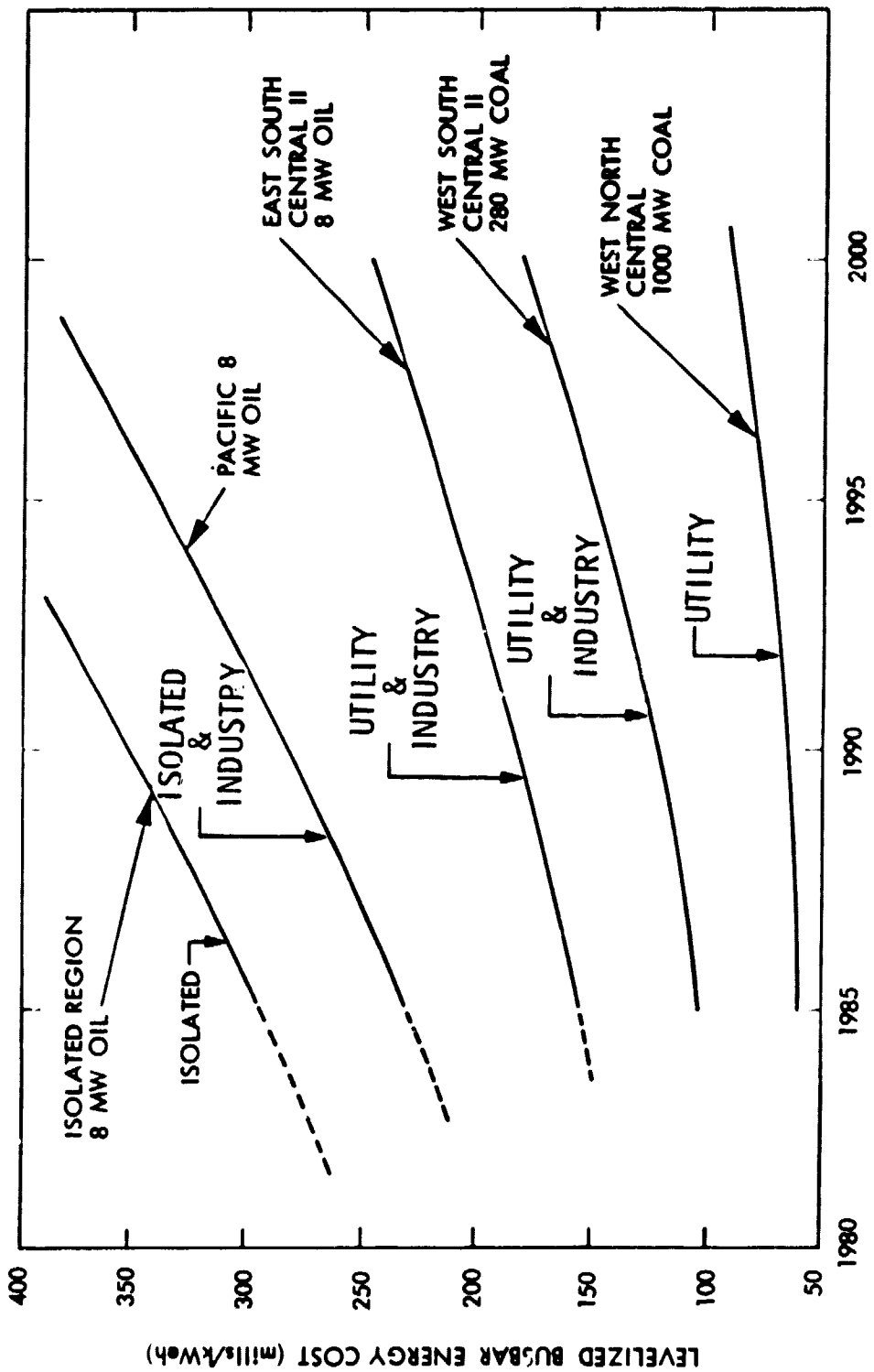
Figure 3-16. Levelized Bus Bar Energy Costs for New Conventional Power Plants by Sector and Region
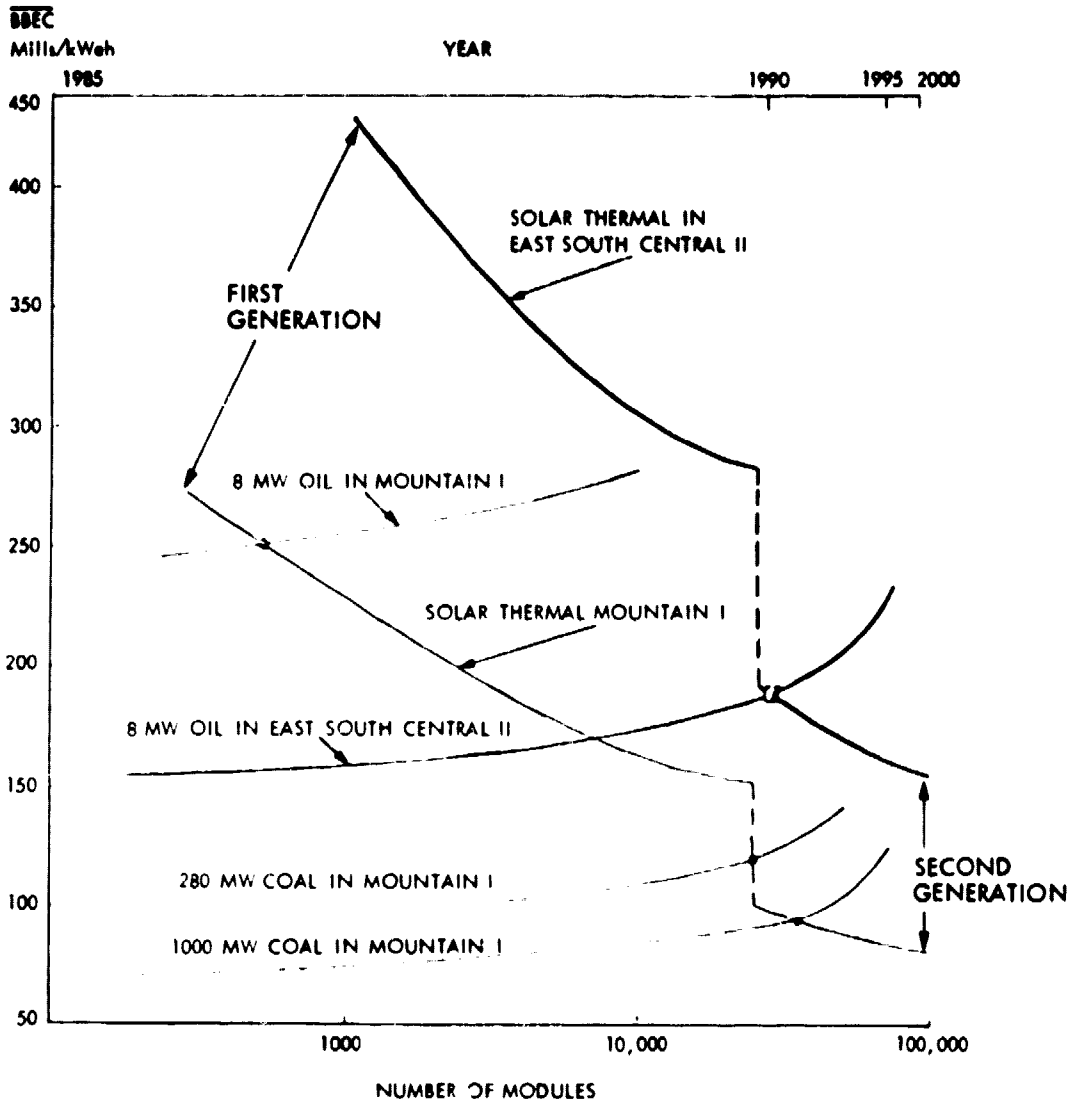
Figure 3-17.   Breakeven Cost: Solar Thermal Parabolic Dish
System and Conventional System (1980 $)
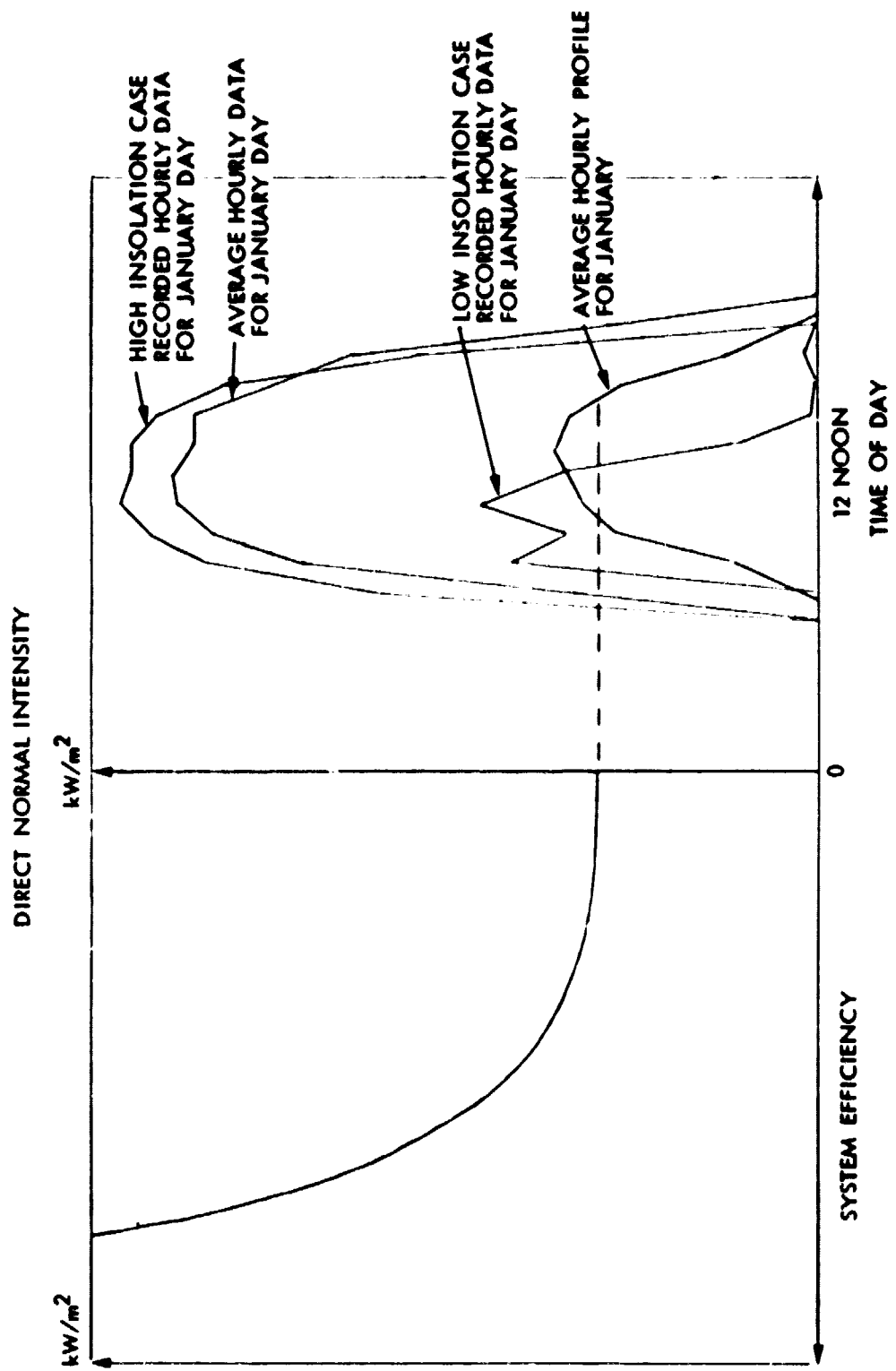
Figure 3-18. Effect of Average Insolation Data on System Power Output

G. PARABOLIC DISH TEST SITE (PDTS)

1. Description

The PDTS, located at the JPL Edwards Test Station, was established to perform testing of solar point-focusing concentrator systems and related hardware for the Department of Energy. The site, (Figure 3-19) was selected to utilize an existing JPL facility having high insolation levels, both peak and total. It is approximately 70 airline miles north of Los Angeles in the California high desert, and has an average rainfall of four inches per year. The site occupies approximately 10 acres of the 600-acre Edwards Test Station. Ample adjoining acreage has been set aside for future growth.

The primary purpose of the PDTS is to provide a site for the testing and evaluation of:

(1) Concentrators.

(2) High flux density receivers.

(3) Power conversion systems.

(4) Concentrator/receiver/power conversion assemblies.

(5) Thermal transport subsystems.

(6) Hybrid receiver or engine systems using point-focusing solar concentrators and fossil fuels.

The objectives of the PDTS are three fold. First, the PDTS will support solar thermal development activities. This will be done primarily through testing and evaluation of hardware developed by industry under DOE sponsorship. Second, acceptance testing of prototype solar thermal power systems will be accomplished at the PDTS prior to full-scale production. Third, test and evaluation of point-focusing systems developed independently by industry will be accomplished at the PDTS as time and funding permit. Feedback will be provided to industry on the results of the tests.

Currently three parabolic dishes are installed at the PDTS; a module manufactured by The OMNIUM-G Company and two Test Bed Concentrators which were provided for test purposes. The following items were also installed in 1980:

(1) An 18,921 (5000 gl) water tank and pump for closet-loop calorimeter testing of the TBCs.

(2) An engine/generator set to provide backup power for automatically slewing the TBCs off sun should a power outage occur.

(3) A computer-based data gathering and processing (DGAP) system.
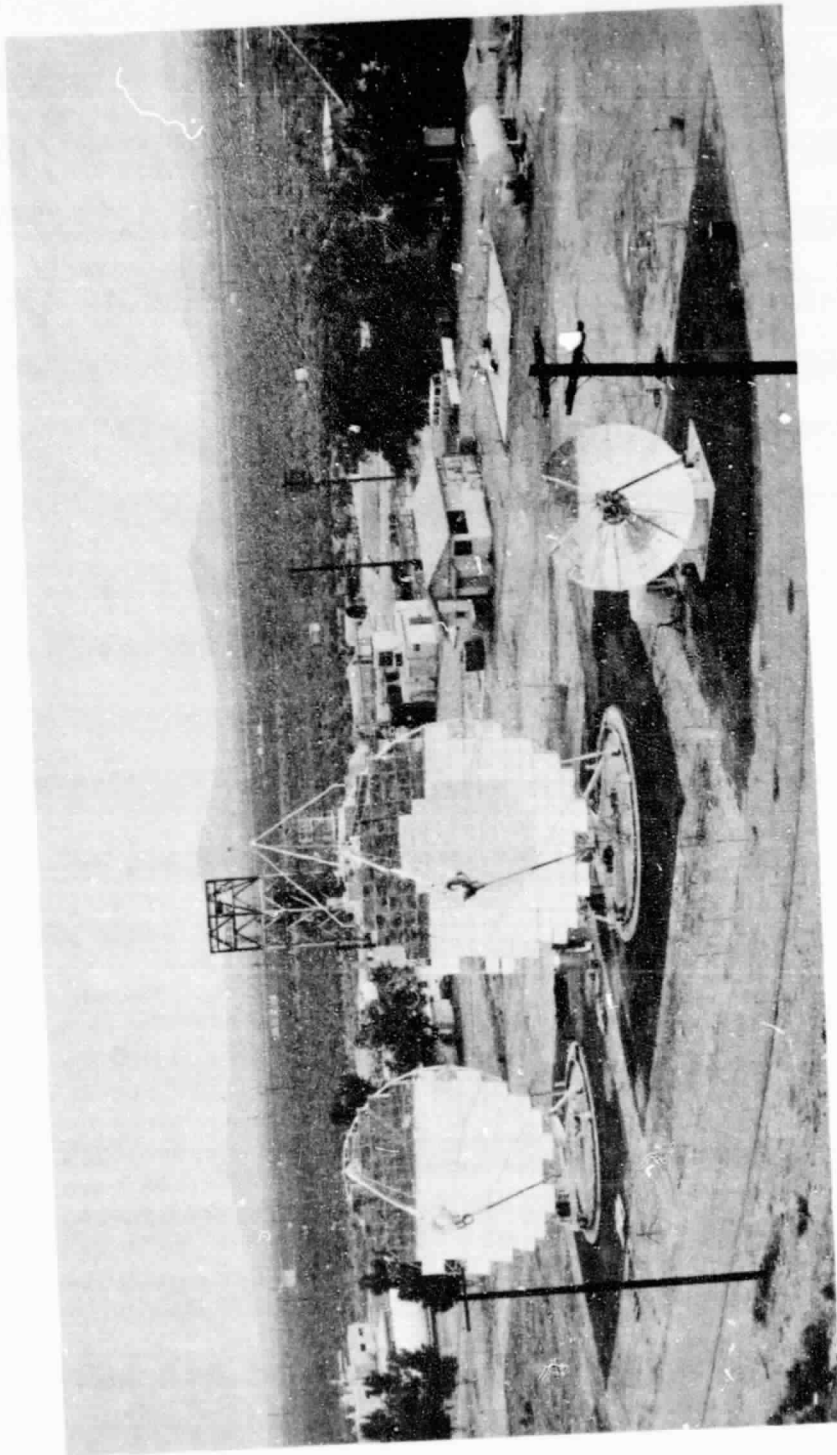
Figure 3-19. Parabolic Dish Test Site (PDTS)

Testing at the PDTS has been and will continue to be performed almost exclusively on industry supplied components, subsystems, and collector modules.

To obtain formatted data for efficient analysis during subsystem and system performance testing, the DGAP system was designed and implemented at the PDTS. DGAP equipment is required to periodically make meteorological measurements, display the data in real time, and to monitor and record on mass storage.

The computerized acquisition system at the PDTS includes a Digital Equipment Corporation PDP minicomputer with two RK05 disk drives, nine-track magnetic tape transport (on which all test data is stored), high-speed multiplexers, analogue to digital converters, three Acurex Autodata nine data loggers, CRT terminals and a printer-plotter.

Insolation and meteorological data being measured at the Edwards Test Station include the following:

(1) Direct component of radiation, using two pyrheliometers.

(2) Total sky radiation, using a pyranometer.

(3) Circumsolar telescope data.

(4) Temperature and dew point.

(5) Barometric pressure.

(6) Wind speed and direction.

The circumsolar telescope is on loan to JPL from the Lawrence Berkeley Laboratory. Typical results are shown in Figure 3-20 for a clear day and for a day when the insolation was highly diffuse.

During FY 1980, measurement and recording insolation and meteorological data at the PDTS continued. Software was developed for displaying a monthly summary of the data. Typical insolation measurements are shown in Figure 3-21 for a period of one month as derived from a normal incidence pyrheliometer.

The initial test series at the PDTS was devoted to an evaluation of the OMNIUM-G module manufactured in Anaheim, California. This module has a 6-m diameter, 4-m focal length, and an area of approximatey 30 m^2. It is provided with an elevation-over-azimuth, two-axis tracking system, and has been subject to intensive test and evaluation.

Testing of the OMNIUM-G unit at the system level using the 10.4-cm (4-in.) aperture receiver was completed. A long-term automated test of the OMNIUM-G unit was also conducted. This test provided data over extended periods of time on the thermal power output of the receiver, using a 20-cm (7.9-in.) aperture, in a fully automated operational mode.
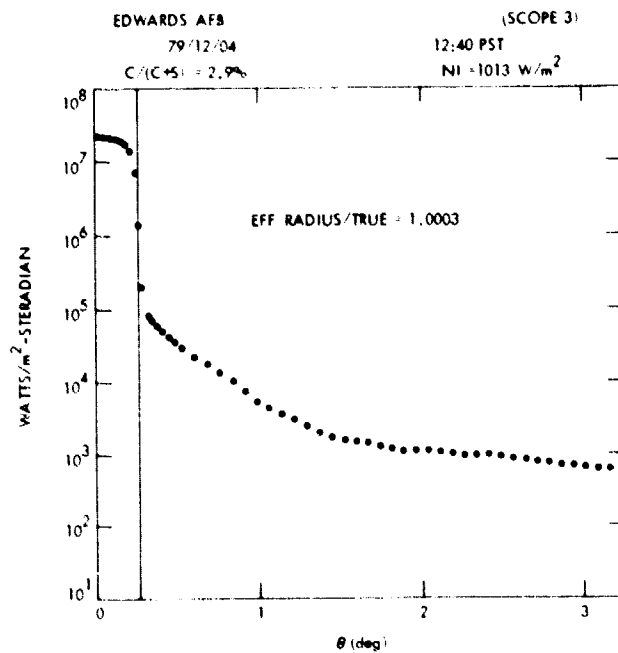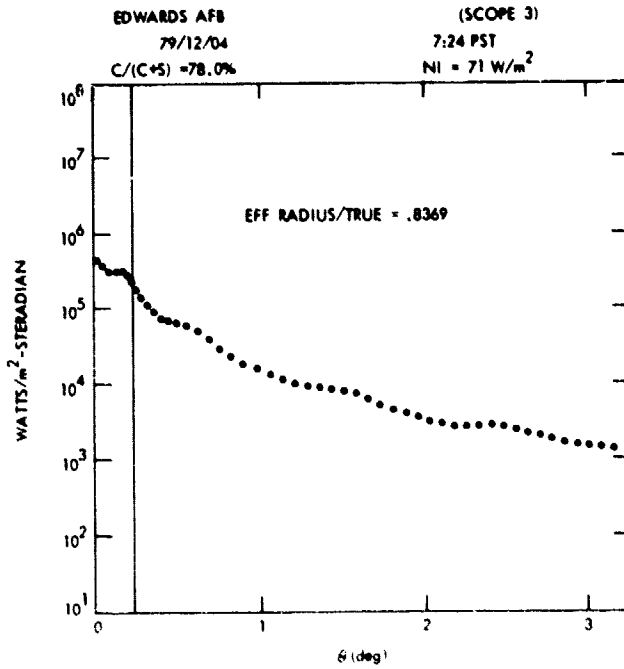
Figure 3-20.   Circumsolar Telescope Data
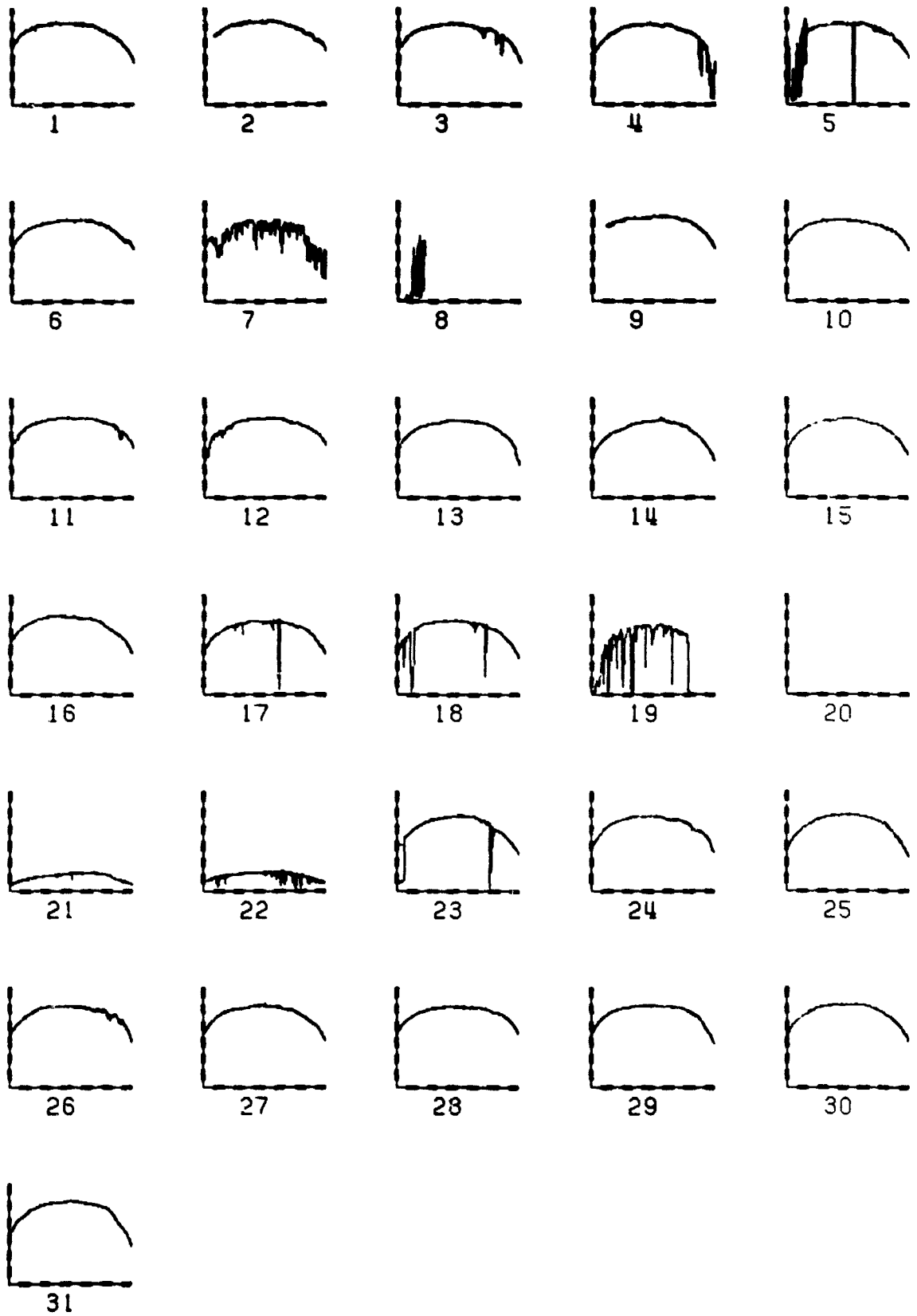
Figure 3-21. Insolation for September 1980

Two Test Bed Concentrators (TBCs) (Figure 3-22) were installed and calibrated for use in testing receivers and power converters.

The TBCs are part of an early test program to obtain concentrator performance data and to test several types of receiver and power conversion subsystems. Developed by E-Systems, Inc., of Dallas, Texas from an existing antenna design, the TBCs were modified to (1) accommodate JPL-developed mirror facets, (2) provide solar tracking, and (3) support a receiver/power conversion package of up to 500 kg (1100 lb) at the focal plane. Each TBC has a nominal diameter of 11.5 m, 6.6-m focal length, and 82 kWt output with clean mirrors at 1000 W/m^2 insolation. The controls for the TBCs were designed and built by Electrospace Systems, Inc., of Richardson, Texas.

FY 1980 test and evaluation activities included installation and test of the Test Bed Concentrators at the PDTS. The TBC mirrors were aligned and mechanical and electrical checkout of the TBCs was completed. A training class on TBC operation was conducted by Electrospace systems, Inc., for PDTS operators.

Calibration of the TBCs consisted of mapping the concentrated solar flux at the focal plane, and measuring the total collected solar energy using a cold water cavity calorimeter. Three different cold-water calorimeters were designed and fabricated: coiled-tubing, flat-plate, and cavity calorimeters. These calorimeters were used to measure the integrated thermal flux at the concentrator focal point and resulted in a value of 80 MWe with an insolation of 1000 W/m^2. The tests characterized the TBCs under various operating conditions of insolation and at wind speeds up to 48 km/hr (30 mph).

The flux mapper, designed and fabricated for use in characterizing concentrator flux patterns and intensities, is a three-axis scan system for measuring high radiant flux levels, such as those expected near the focal plane of a high-concentrator ratio solar concentrator. Shown mounted on TBC-1 in Figure 3-23, it was used to characterize the TBC mirror system by mapping various zones, e.g., center mirrors, peripheral mirrors, as well as the entire array. Figure 3-24 shows the energy distribution at the focal plane of the TBC with 36 mirrors uncovered. From these various mappings, system performance can be determined and analytical methods can be field-verified.

When calibration of the TBCs was completed, testing was then begun on a steam-Rankine receiver designed and fabricated by Garrett AiResearch of Hawthorne, California. Preparations were initiated for testing a high-temperature air Brayton receiver designed and fabricated by Sanders Associates, Inc., of Nashua, New Hampshire.

This ceramic receiver, produced by Sanders Associates, features a quartz aperture and operates at a temperature of 1370°C (2500°F). This test will be followed by a test of the 815°C (1500°F) air Brayton receiver manufactured by Garrett AiResearch, Torrance, California.

The detailed design of the equipment required to test the Brayton engine was initiated, along with preparations for testing the Stirling engine, receiver, and alternator on a TBC.
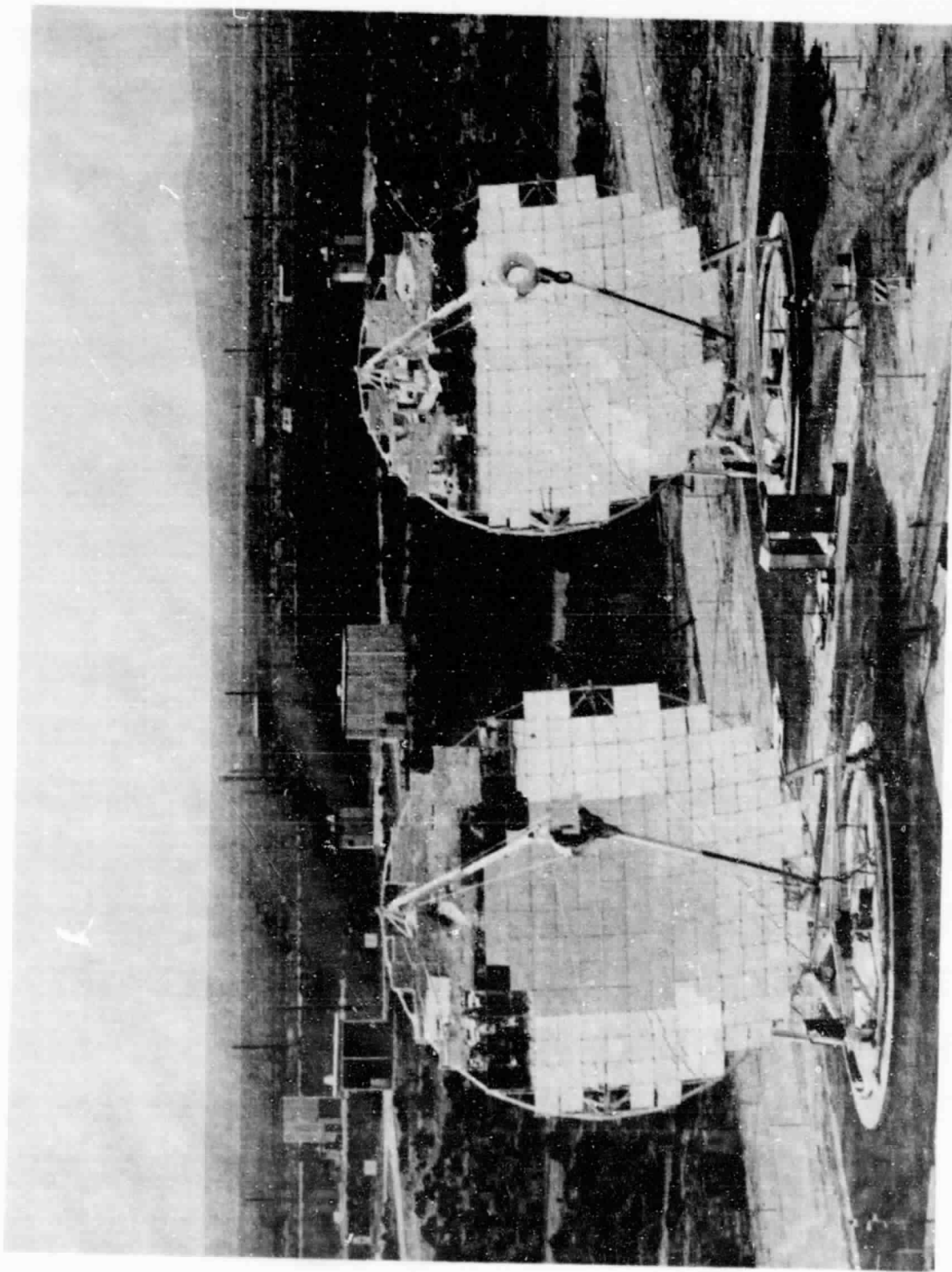
Figure 3-22. Test Bed Concentrators (TBCs) at Parabolic Dish Test Site

Figure 3-23. Flux Mapper

PLOT IS FULL SCALE
TOTAL ENERGY - 12.04 kW
91% OF THE ENERGY IS IN A
7.5-cm DIAMETER CIRCLE

400 W/cm^2
300 W/cm^2
200 W/cm^2
100 W/cm^2
25 W/cm^2
0 W/cm^2

1 cm

411
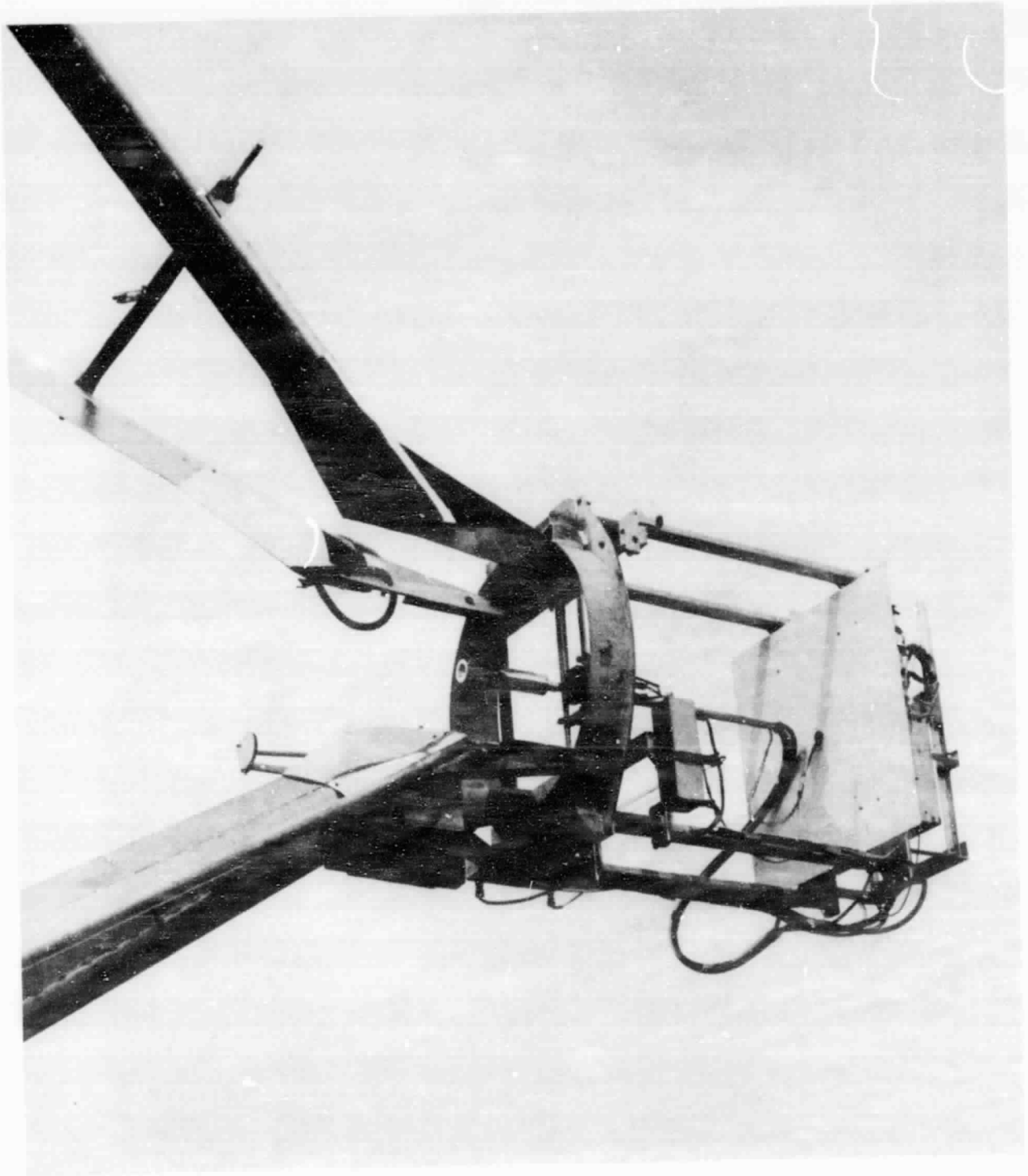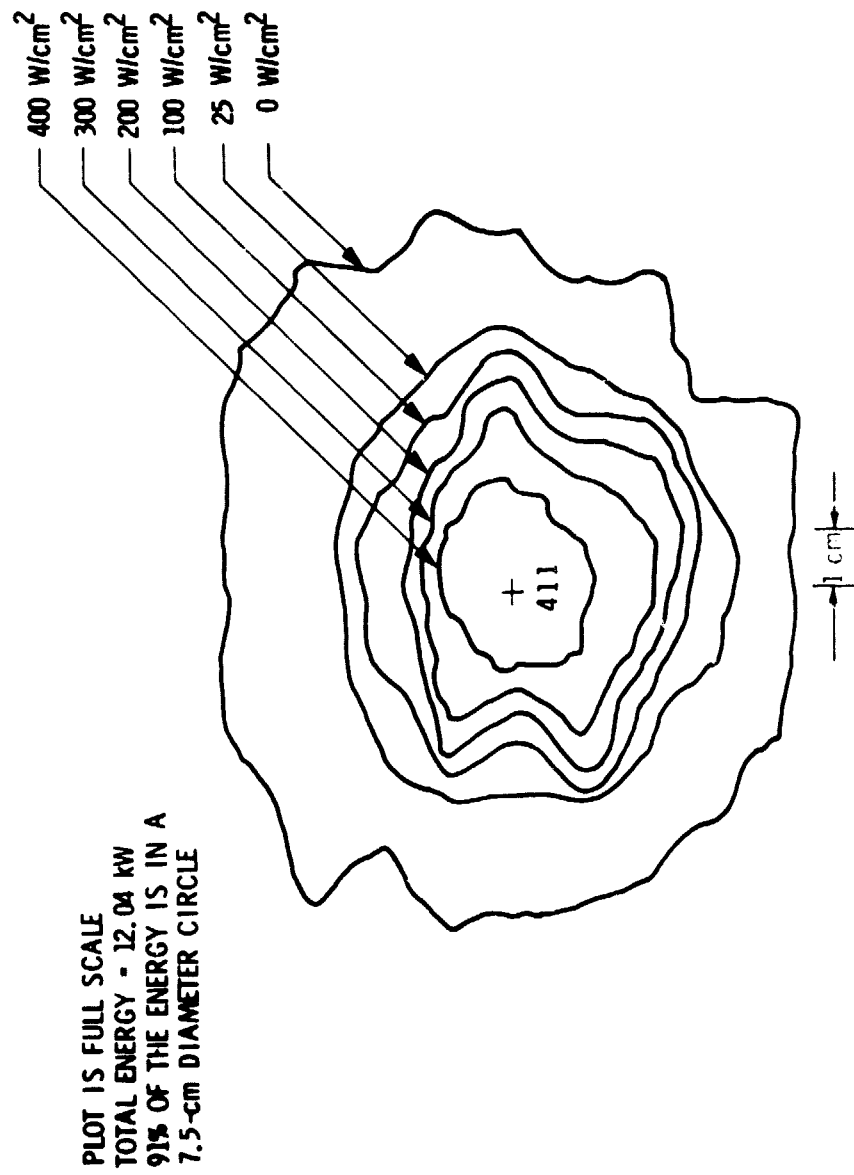
Figure 3-24.   Energy Distribution at TBC Focal Plane

Preparations are underway to test the following hardware in FY 1981.

(1)   A modified Ferrier steam engine built by the OMNIUM-G Co.

(2)   A 5 HP steam engine built by Jay Carter Enterprises, Inc., of Burkfurnett, Texas.

(3)   A 25 HP steam engine, also built by Jay Carter Enterprises, Inc.

(4)   An air-Brayton receiver designed and fabricated by Garrett AiResearch of Hawthorne, California, for operation at 815°C (1500°F).

(5)   A high temperature ceramic air receiver built by Sanders Associates.

(6)   An organic Rankine cycle (ORC) receiver and power converter by Ford Aerospace & Communications Corp. of Newport Beach, California, using a turbine by Barber-Nichols of Arvada, Colorado.

(7)   An alternator by Simmonds Precision of Norwich, New York, and a static inverter by Nova Electric Manufacturing Co. of Nutley, New Jersey.

(8)   A Stirling engine, designed by United Stirling of Sweden, which incorporates a receiver built by Fairchild Stratos Division, Manhattan Beach, California. The receiver and power converter module will be integrated by Advanco Corp. of El Segundo, California.

(9)   The Low-Cost Concentrator (LCC) developed by General Electric, Valley Forge, Pennsylvania.

(10) A Fresnel concentrating collector by Power Kinetics, Inc. (PKI) of Troy, New York. After initial characterization, a 14-month life test will follow.

Additional PDTS activities in FY 1980 included:

(1)   Generating of a list of operations and maintenance parameters to be monitored.

(2)   Distributing of PDTS Users' Manual for internal review.

(3)   Initiating of site modification designs to accommodate the GE/LCCs arriving in FY 1981.

(4)   Provision for the addition of three concentrators and ancillary equipment.

dish-mounted receivers equipped with Rankine, Brayton, and Stirling power convertors. The storage requirements definition study addresses the following tasks:

(1) Thermodynamic and economic analyses to determine the need for thermal buffer storage in terms of the required performance.

(2) Optimum size of buffer storage.

(3) Identification of candidate storage concepts which meet program-specified cost and weight goals.

(4) Recommendations for specific storage components and subsystem development needs.

To meet the above objectives, three separate contracts were awarded in FY 1980, one for each of three power conversion cycles. Buffer storage contracts were awarded to General Electric Company, Cincinnati, Ohio, for Stirling engines, and to Ford Aerospace and Communications Company, Newport Beach, California, for Rankine engines. Evaluation reviews were held in September 1980. Garrett AiResearch, Torrance, California was awarded a Brayton engine buffer storage contract in August 1980.

The second category in which a contract was awarded was latent heat storage media chemistry and corrosion studies. The objectives are to:

(1) Define the thermophysical properties of certain specified salt eutectics that are relevant to the latent heat storage requirements at approximately 440°, 550°, and 830°C (825°, 1025°, and 1525°F).

(2) Analyze the results of 2000 hours of tests conducted at JPL of heating and cooling cycles of specified eutectic-salt-containment-material combinations with and without corrosion inhibitors and impurities to determine the thermodynamic stability and corrosion characteristics of the selected salt eutectic.

The third category of contract award was latent heat storage solidification control. The objective of the contracted work is to experimentally determine the following:

(1) Effects of phase change material (PCM) containment wall geometry and configuration including concave and convex external and internal surfaces.

(2) Thermal conductivity enhancing additives.

(3) Types of surface finishing and coating of heat exchanger surfaces on PCM solidification.

(4) Identification of attractive solidification control options that will promote heat transfer in buffer storage systems for dish-mounted power converters.

Lastly, in July 1980 a contract was awarded to Hanford Engineering Development Laboratory of Richland, Washington to identify advanced concepts for high temperature buffer storage, and to perform some limited bench scale tests. A key task in the contract is the recommendation of preferred buffer thermal storage systems which are compatible with parabolic dish applications at an operating temperature of 1370°C (2500°F).

In-house studies during the FY 1980 included a latent heat buffer storage system definition study conducted to provide a data base upon which to develop a concept definition. Available thermophysical viscosity and thermal expansion data were not readily available, therefore literature searches are continuing. Candidate salt-containment combinations shown in Table 4-1 were tentatively selected for more detailed investigation into their applicability as candidate storage media for dish-mounted receivers.

Another in-house effort, concerning material evaluation, was an in-house molten salt laboratory test program initiated to assist and complement contracted effort by conducting tests of three candidate salts. Tests will include differential thermal analysis, differential scanning calorimetry, no. 316 and no. 321 stainless steel containment and cycling, alloy steel containment and cycling, no. 321 SS thermal loop test, and thermal conductivity of molten salts.

In support of latent heat buffer storage system studies, a computer program, High Temperature Energy Storage (HTES), was developed and assembled to simulate a parabolic dish receiver with latent heat buffer storage capability. The model predicts the performance of the dish-mounted receiver under varying solar flux, ambient temperatures, varying amounts of latent heat buffer storage, and different thermal control techniques. The program treats the receiver and storage subsystem on a nodal basis, and is capable of yielding local receiver, and receiver coolant temperature variations for transient conditions. A simple lumped parameter code was developed to assess first order transient characteristics of buffer storage systems. The benefits of buffer storage in attenuating variations in insolation due to closed passage were determined (Reference 5). Models for energy conversion systems including Rankine, Brayton, and Stirling cycles, will be incorporated in the computer program to simulate their responses as a function of buffer storage size. Various designs of receiver and storage subsystem combinations will be modeled by the program to aid in identifying and assessing attractive concepts.

The JPL thermal storage effort also included monitoring the following two related contracts:

(1)   Checker Stove Power Module Design, Fabrication, and Testing. This contract is with Sanders Associates, Inc. The objectives of this effort were to verify the performance of the selected components and to demonstrate that the checker stove concept represents a viable candidate for dispersed power systems applications. In FY 1980, prototype testing was conducted by Sanders, and preliminary results indicate the performance is better than expected.

(2)   Heat Pipe Receiver Module Design, Fabrication and Testing. The objective of this contract is to design, fabricate, and acceptance-

Table 4-1. Candidate Salt-Containment Combinations

Applications Temperatures	Salt Composition (By Weight)	Melting Point	Containment Material
427-454°C (800-850°F) (Rankine)	61 KCL-39 MgCl$_2$	436°C (816°F)	316 & 321 SS Cr-Mo alloy steel
538-566°C (1000-1050°F) (Steam Rankine)	25.9 Na$_2$CO$_3$-38.8 NaCl-35.3 NaF	557°C (1035°F)	316 & 321 SS, Cr-Mo alloy steel
802-728°C (1475-1525°F) (Brayton, Stirling)	66.9 NaF-33.1 MgF$_2$	813°C (1495°F)	3$_{i}$6 & 321 SS
788-829°C 1450-1525°F (Brayton, Stirling)	75 NaCl-25 Na	795°C (1463°F)	321 SS
802-829°C (1475-1525°F) (Brayton, Stirling)	100 NaCl	802°C (1475°F)	9 Cr/1 Mo alloy steel

test a heat pipe receiver with thermal energy storage (TES). It is to be used with a parabolic dish-Stirling solar power system in the 15-20 kWe range, and involves a solar heat receiver, latent heat thermal storage, and alkali metal heat pipe thermal transport. The latter supplies heat to a Stirling engine-generator to form an integrated power conversion system. General Electric Company is the contractor in this effort. In FY 1980, the heat pipe receiver design, modular experiment, and combustor design were completed, and alternative design concepts were proposed.

In direct support of the dish project, two major studies were conducted. One study pertained to assessing the feasibility of using reversible chemical reactions for energy transport and storage. From the large list of potential reactions, a screening process based on reaction chemistry identified ten promising candidates. As a result of further screening based on chemical engineering considerations, four candidates were selected. The four candidate reactions were examined in detail and their cost and performance were evaluated. This study showed that the thermal efficiencies of the four selected reversible chemical reactions, when used for storage, are relatively low (about 60%). When used for transport, however, higher values (about 90%) are possible. Thus, the most attractive use of the four candidate systems appears to be for energy transport. Even for transport, high estimated system costs

result when conventional high temperature metal heat exchangers and reactors are used. The development of low-cost, high-temperature ceramic materials for use in heat exchangers and reactors is needed to allow the advantages of reversible chemical processes to be exploited as an efficient means for thermal transport.

The second storage study addressed multi-dish cluster power systems at temperatures around 816°C (1500°F). This concept is based on the use of a cluster of parabolic dish collectors to supply heat to ground-based thermal storage power conversion systems. In this study three sensible heat and four latent heat concepts are linked with efficient Brayton and Stirling engines and were examined in detail as a means for six-hour storage. The results from this study show that there are some multi-dish cluster thermal storage candidates which are comparable to dish systems using advanced battery storage in terms of cost and performance characteristics.

B. ELECTROCHEMICAL STORAGE

An investigation and evaluation of existing and advanced electrochemical energy storage and inversion/conversion systems for use with solar thermal power systems was conducted. Specific objectives were to assess the status and performance of existing systems, establish current cost (for mid-1979 time frame) and to project cost, performance, and availability of advanced systems. The results may be used to evaluate the impact of electrochemical storage systems on both near-term and far-term solar thermal plants.

The investigation consisted of a three-step approach. First, a review was made of the existing literature on electrochemical storage and inversion/conversion systems. Second, discussions were held with the manufacturers and developers of these systems to obtain an update on the status of these systems. Third, the information collected was reduced, tabulated, and analyzed.

Three categories of electrochemical storage information were obtained. The first deals with the electrochemical or battery portion of the storage system. The second encompasses the balance of the system, which includes all components of the storage systems except the battery. The third category treats the solar thermal plant in its entirety, including electrochemical storage.

The existing lead-acid battery is the only electrochemical system presently considered technically ready for use in near-term demonstration programs. The specified type of lead-acid battery suitable for solar thermal applications is one that is designed for repetitive, deep discharges (of 5- to 8-hr duration on a daily basis) at moderate to high power densities. All of these characteristics are present in the "motive power" or "traction" type lead-acid battery. Depending on the given duty cycle, this type of lead-acid battery will cost from $170 to $220/kWeh, deliver 2000 cycles at 80% depth of discharge, and operate with an energy efficiency of 70% to 85%.

Several battery manufacturers are in the process of developing advanced lead-acid batteries for utility and electric vehicle applications. These advanced lead-acid batteries are expected to perform better with lower maintenance requirements, and cost less than existing lead-acid batteries.

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Table 4-2 presents a summary of the most important findings on sixteen advanced battery systems. Detailed information on these systems is contained in the report, <u>Electrochemical Energy Storage Systems for Solar Thermal Applications</u>, JPL Publication 79-95, which includes operating principles and temperatures, electrochemical reactions, and major technical problems.

A development plan for achieving the storage systems goals was initiated. This plan includes the results of a current study comparing thermal and electrochemical storage for dish systems.

Table 4-2. Cost and Performance of Advanced Electrochemical Storage Batteries

Battery Type	Initial Cost[1]	# Cycles At 80% DOD	Battery Efficiency%	Throughput Efficiency%[4]	Projected Availability	Probability of Availability[2]
Adv. Pb-Acid	$116-$130/kWeh	4000	80-85	73-78	1985	0.95
Na-S (FORD)	$43/kWeh	2500	76	70	1985	0.95
Na-S (FORD)	$43/kWeh	2500-5000	75	69	1985	0.80
Na-S (DOW)	$33/kWeh	3000	90	83	1990	0.20
Fe-Cr Redox (LeRC)	$132/kWe + $22/kWeh	10000	75	69	1990	0.80
Zn-Cl$_2$ (EDA)	$59/kWe + $27/kWeh	2500-3500	71-74	65-88	1985	0.95
(Argonne)	$54/kWeh	3000	85	78	1990	0.70
Zn-Br$_2$ (Gould)	$49-$59/kWeh	2500	70	65	1990	0.70
Zn-Br$_2$ (Exxon)	$32/kWeh	2500-5000	80	74	1990	0.70
Zn-Br$_2$ (GE)	$58/kWeh	2000	75	69	-	-
Fe-Air (Westg)	$32/kWeh	1000	50	46	1985	0.60
Ni-Fe (Westg)	$54/kWeh	2000	60	55	1985	0.70
Ni-Fe (EP)	$65/kWeh	2000	65-70	60-65	1990	0.70
Ni-H$_2$ (ERC)	$65/kWeh	10000	60-70	55-65	1990	0.20
Ni-Zn (Gould)	$108/kWeh	2000[3]	90	83	1985	0.60
H$_2$-Cl$_2$ (BNL)	$81/kWeh	-	65	60	-	-

[1]Updated to mid-1979 dollars: costs are based on 80% depth of discharge (DOD) and are for battery only (not Balance of Systems). Also batteries are overdesigned so that they will deliver full rated capacity at end of indicated number of cycles.

[2]Predicated upon EPRI data, vendor data, and best engineering judgment

[3]40% DOD

[4]Throughput efficiency (product of battery and inverter/converter efficiencies)

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SECTION V

DISH APPLICATIONS

The objective of the applications development work by the parabolic dish project is to prepare the way for commercial readiness of dish systems. The first step in establishing this objective will be through field tests in typical user environments. These tests are engineering experiments, and are designed to demonstrate the technical, operational and economic feasibility of parabolic dish systems. The series of experiments described below are being planned and implemented to demonstrate the feasibility of dish systems in three distinct markets: electric utilities, isolated areas, and industry.

A. SMALL COMMUNITY SOLAR THERMAL POWER EXPERIMENT SERIES (E_-1)

1. Introduction and Background

The first experiment in the Utility Series addressing the grid-connected utility market is the Small Community Solar Thermal Power Experiment (SCSE). For convenience, the experiment is also referred to as Engineering Experiment No. 1 or EE-1. The Experiment comprises three stages, Phase I, Phase II and Phase III. Phase II, currently in progress, covers the experimental design, and system verification tests of the design. The fabrication, installation, and testing of the completed experiments system will compose Phase III.

Competitive concept definition studies for a 1-MWe solar thermal electricity generating plant were completed in FY 1979 under a Phase I contract. Parabolic dishes with distributed power generation by FACC was determined to be best suited for the small community application in the 1- to 10-MWe size. Responding to a sole source RFP for Phase II of the experiment, FACC proposed to design a 1-MWe solar thermal power plant consisting of a field of parabolic dish concentrators.

2. System Description and Performance

As shown in Figure 5-1, the experimental power plant consists of a field of approximately 55 parabolic dish concentrators, each focusing sunlight to a receiver mounted as its focus. Directly coupled to each receiver is an organic Rankine engine (turbine) using toluene as a working fluid, and driving a high-speed permanent magnet alternator. Electric power produced by the individual power modules is collected and conditioned at a central inverter/ plant control station. Converting the alternating current to direct current at each dish facilitates the collection of energy output and its subsequent inversion of 60-Hz three-phase current for distribution to the small community from the highly automated control station.

The plant occupies a site of less than ten acres and is surrounded by a secure enclosure, with the shape and topography of the site determining the
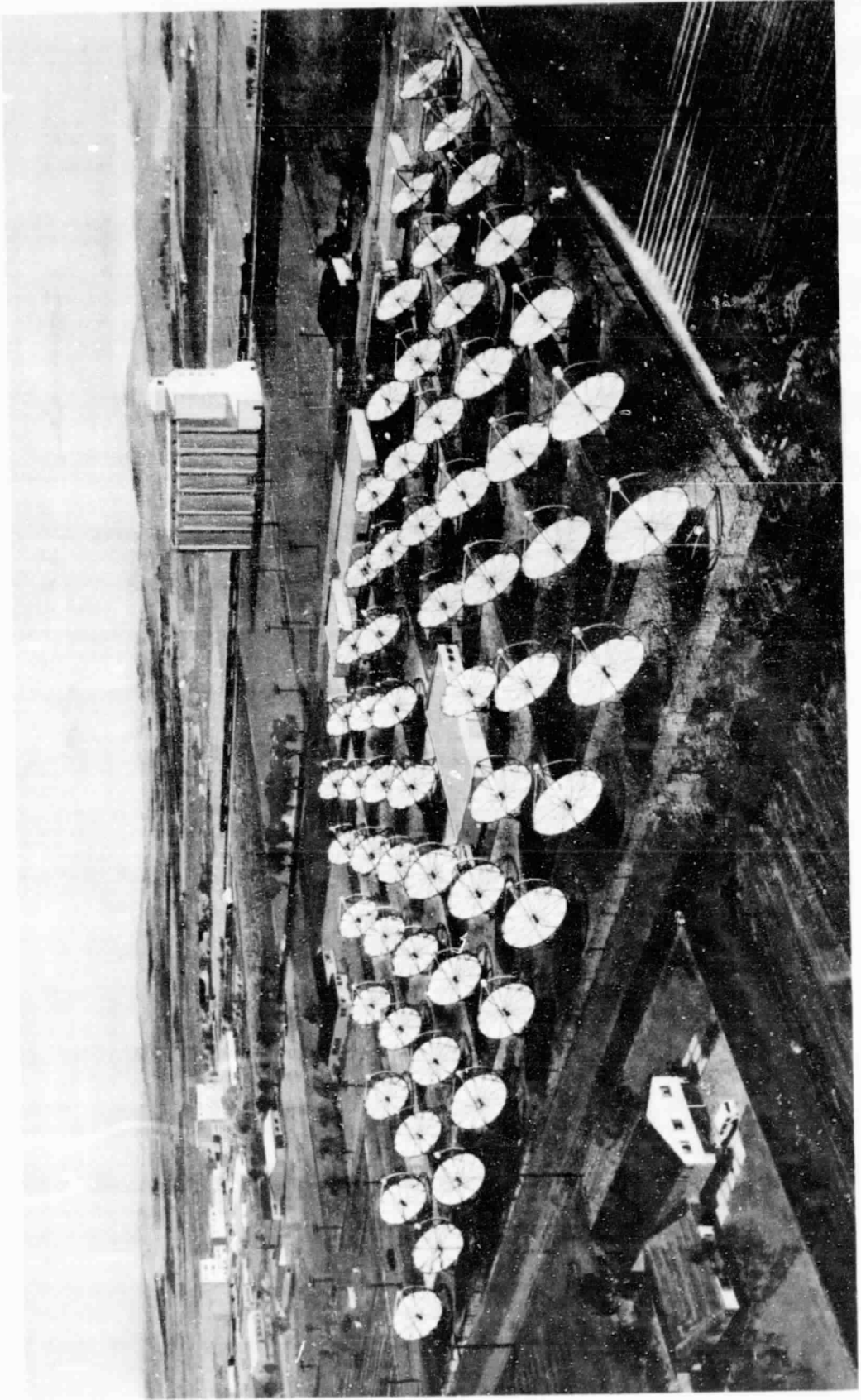
Figure 5-1. Small Community Solar Thermal Power Experiment (SCSE) 1-MWe Plant

detailed layout of the power modules and building. A visitor's center is provided to explain the purpose and function of the facility.

Concerning the status of EE-1 at the end of FY 1980, the Phase II effort had progressed to the point where the system definition and specification were complete, and procurement for hardware to fabricate the verification test power module had begun. A summary of the system specifications is given in Table 5-1. Phase II of the EE-1 contract is based on these specifications. Regarding the selection of the organic Rankine cycle (ORC) turbine as the choice for the power conversion unit, consideration was given first to the advantages and disadvantages of the ORC compared to steam. It was concluded that, although neither engine was an off-the-shelf item, both engines offered a reliable, low-risk, near-term option for an early experimental plant. Engines using other cycles or technology would require extensive development to achieve the same degree of readiness. Following this determination, JPL agreed with the choice of the organic Rankine cycle over the steam cycle by FACC. Concurrent with the selection of the organic cycle was the adoption of the plan to develop an FACC in-house receiver so that a more coordinated and economical integration of the engine-receiver assembly might be achieved than would be likely by using one procured from outside sources.

The SCSE plant consists of four major subsystems: Collector Subsystem, Power Conversion Subsystem, Energy Transport Subsystem, and Plant Control Subsystem. These subsystems are identified in the system schematic, Figure 5-2.

3. Collector Subsystem

The collector subsystem consists of the sun-tracking parabolic concentrator and the receiver subassembly. The function of the concentrator is to collect solar radiation and direct it to the walls of the receiver where the radiant energy is converted into sensible heat and transferred to the toluene working fluid within the receiver. The GE/LCC is to be used, and will be supplied directly for Phase II system verification tests to be conducted at the Parabolic Dish Test Site.

A model of a complete power module is shown in Figure 3-1. The dish is stowed in the inverted position so that wind loads are minimized and so that the reflecting surface can be protected from damage by hail, dust, and debris.

Guidance of the dish is accomplished by a computer, which points it to a predetermined position calculated from the solar ephemeris. When the dish is within about 1° of the sun's position, the sun sensor takes over and the dish tracks the sun, centering the solar image within the receiver aperture. A summary of the GE/LCC specifications are given in Table 5-2. Although GE/ LCC development was initiated prior to beginning Phase II of the Small Community Solar Thermal Power Experiment, the specifications of the concentrator are well matched to the experiment's requirements.

After a reappraisal of the GE/LCC's cost, weight, and performance, it was redesigned to meet required specifications at lower cost and weight than the initial design. In FY 1980 sample dish panels were successfully molded using the injection molding technique proposed for the prototype module. In this process, the glass fiber reinforced polyester resin is injected into a

Table 5-1. SCSE System Performance

Parameter	Value	Conditions/Comments
Net power delivered to grid	1 MWe (55 modules)	At rated conditions: - Insolation = 1000 W/m^2 - T = 28°C
Power plant efficiency (end-to-end)	0.160	At rated conditions and average LCC reflectivity
Component/subsystem efficiencies	- Collection Eff. = (0.670) - Concentrator (0.691) - Intercept (0.998) - Receiver (0.971) - PCS = 0.264 - Energy transport and conditioning = 0.935 - dc cables & SWXB (0.99) - Inverter (0.96) - ac cables & HV conn. (0.995) - LV/HV trans (0.99) - Plant parasitic losses = 0.970	- Concentrator Eff. in- cludes: Reflectivity = 0.78 (avg. value), Dust = 0.95, and Blockage = 0.932 - Concentration ratio = 1000 Barber-Nichols Calculation 8 kW + 250 W/module for A/C, station keeping, drives, etc.
Annual output*	2660 MWh/yr	For 1976 Barstow Data
Annual performance	- Annual capacity factor = 0.30 - Annualized plant efficiency = 0.152	For 1976 Barstow Data

*Start and stop of operation is 5° above the horizon.

Table 5-2. Low-Cost Concentrator Specifications

(Source: General Electric Company)

| Parameter	Specification
Physical Characteristics	- Diameter = 12m (39.37 ft) - Aperture Area = 113.1 m^2 (1217.4 ft^2) - Weight = 7830kg (17,262 lb) (less foundation, PCA and SCSE boxes mounted on support structure) - Weight capability at focal plane = 680kg (1500 lb), max - (Geometric concentration ratio (FACC Aperture) = 1000 - f/D = 0.5 (53.13° rim angle)
Optical Performance	- Shadowing (K_b) = 0.932 - Reflectivity (ρ) = 0.78, Minimum value for specular properties of new material (value also used by FACC for 10 yr. average) - Slope error = 0.12° RMS, Maximum, predicted value = 0.17° (9/28/80)
Tracking and Operation	- Computer course track within ± 1° (During clouds, etc.) - Fine track accuracy within ± -0.125° if sun is 7.5° above horizon - Automatic acquisition and stow: morning and evening - Track rate - adjustable, 0.2°/S nominal - Slew rate = 120°/min. (emergency detrack rate) - Stow 70-90° elevation and local sunrise in azimuth
Environmental	- Operate between 0° to 55°C (32° and 131°F) - Survive -29° to 60°C (-20° to 140°F) - Rain, hail, ice, seismic, sand and dust as specified in DM512142, Rev. D - 30 Year Life
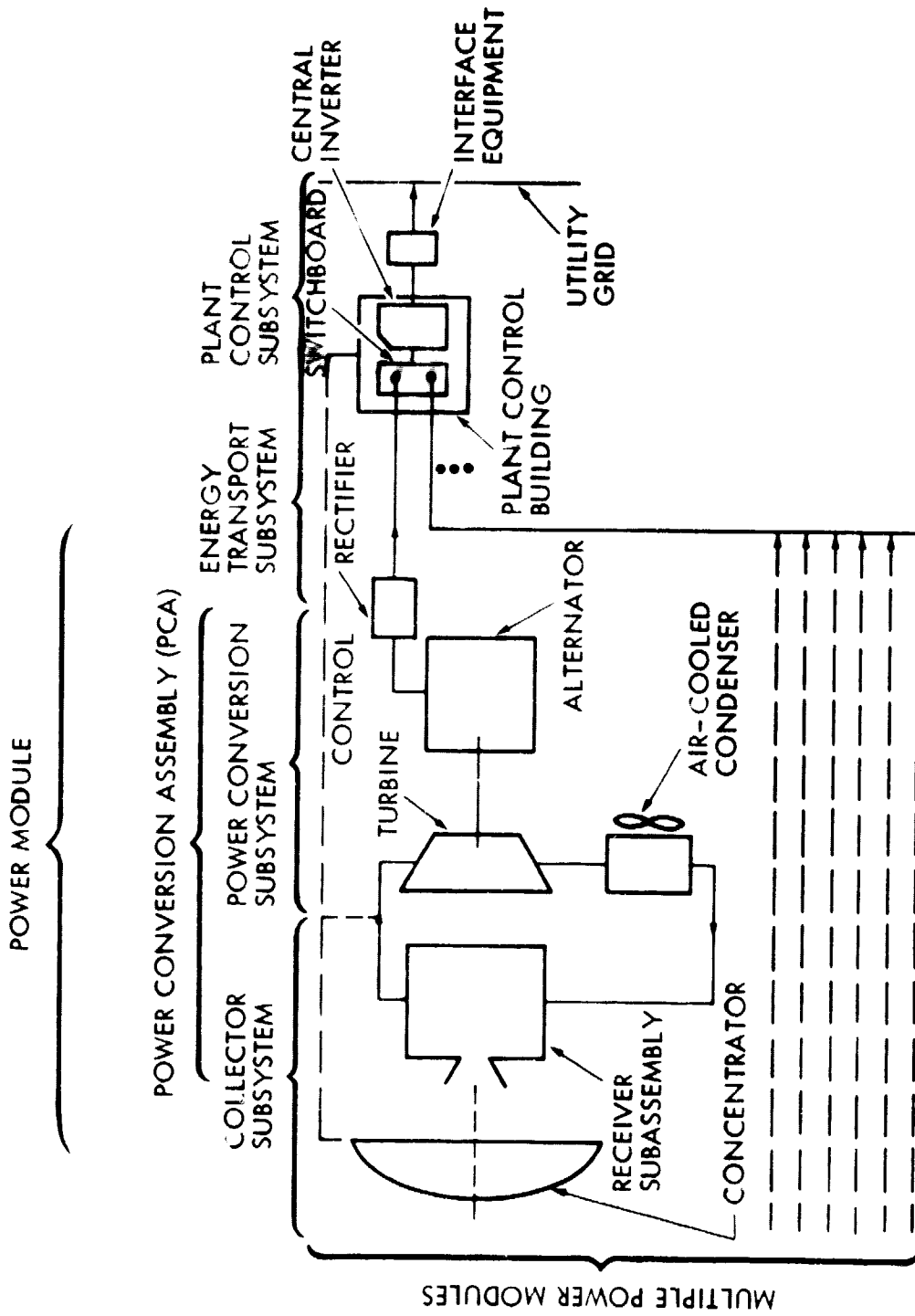
Figure 5-2. SCSE System Schematic and Definitions

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mold which contains the balsa wood core material that provides the stiffness required of the completed panel.

4. Power Conversion Assembly

The combined receiver, engine, and alternator package making up the power conversion assembly is supported by four tabular structural members which position it at the focus of the parabolic dish. The receiver, the component nearest the concentrator, has a circular aperture which admits the concentrated solar flux into the receiver cavity.

The receiver is shown in cross section in the drawing of the ORC power conversion assembly (see Figure 3-5). It consists of a single stainless steel tube wrapped around and partially imbedded in the copper receiver shell to which it is brazed. Toluene is circulated through this tube, which is heated by the solar flux. After leaving the receiver, the heated toluene (at supercritical pressure) is fed to a ring of turbine nozzles in the turbine/alternator/pump assembly. The toluene jet impinges on the blades of the impulse turbine wheel which shares a common shaft with the high speed permanent magnet alternator (Figure 5-3). The toluene then passes through a regenerator where it gives up some of its heat to that part of the working fluid going from the condenser back to the receiver. The diagram in Figure 5-4 shows the path of the toluene working fluid through the power conversion assembly as well as listing the temperature and pressures of the working fluid at selected locations (Table 5-3).

The final design of the Power Conversion Assembly was nearly completed in FY 1980, and fabrication of selected components was initiated by Barber-Nichols Engineering Company under a subcontract let by FACC. The main features of the design remained unchanged during the preliminary design period, but the following areas of concern or uncertainty were addressed:

(1) The cycle was modified to keep the toluene fluid in a super-critical state within the receiver to achieve more predictable heat transfer characteristics within the single pass, monotube boiler.

(2) The turbine wheel was changed to a pure impulse type to avoid possible flow problems, even though a small reduction in calculated efficiency did result.

(3) The condenser size was increased to fill the available envelope, and the longitudinal mounting rails were abandoned. The small increase in efficiency resulting from this change offset some of the loss in performance due to the turbine wheel design changes.

(4) Three-phase, two-speed condenser fan drives were adopted to increase partial load performance, and to increase the efficiency of the unit when operating under conditions of lower ambient temperature.

SUPERHEATED TOLUENE VAPOR

TURBINE WHEEL

GIMBALLED HYDRODYNAMIC THRUST BEARING

TURBINE NOZZLE MANIFOLD

ALTERNATOR ROTOR

ALTERNATOR WINDINGS

HYDRODYNAMIC RADIAL BEARINGS

HIGH PRESSURE LIQUID TOLUENE OUT

FEED PUMP

LIQUID TOLUENE IN
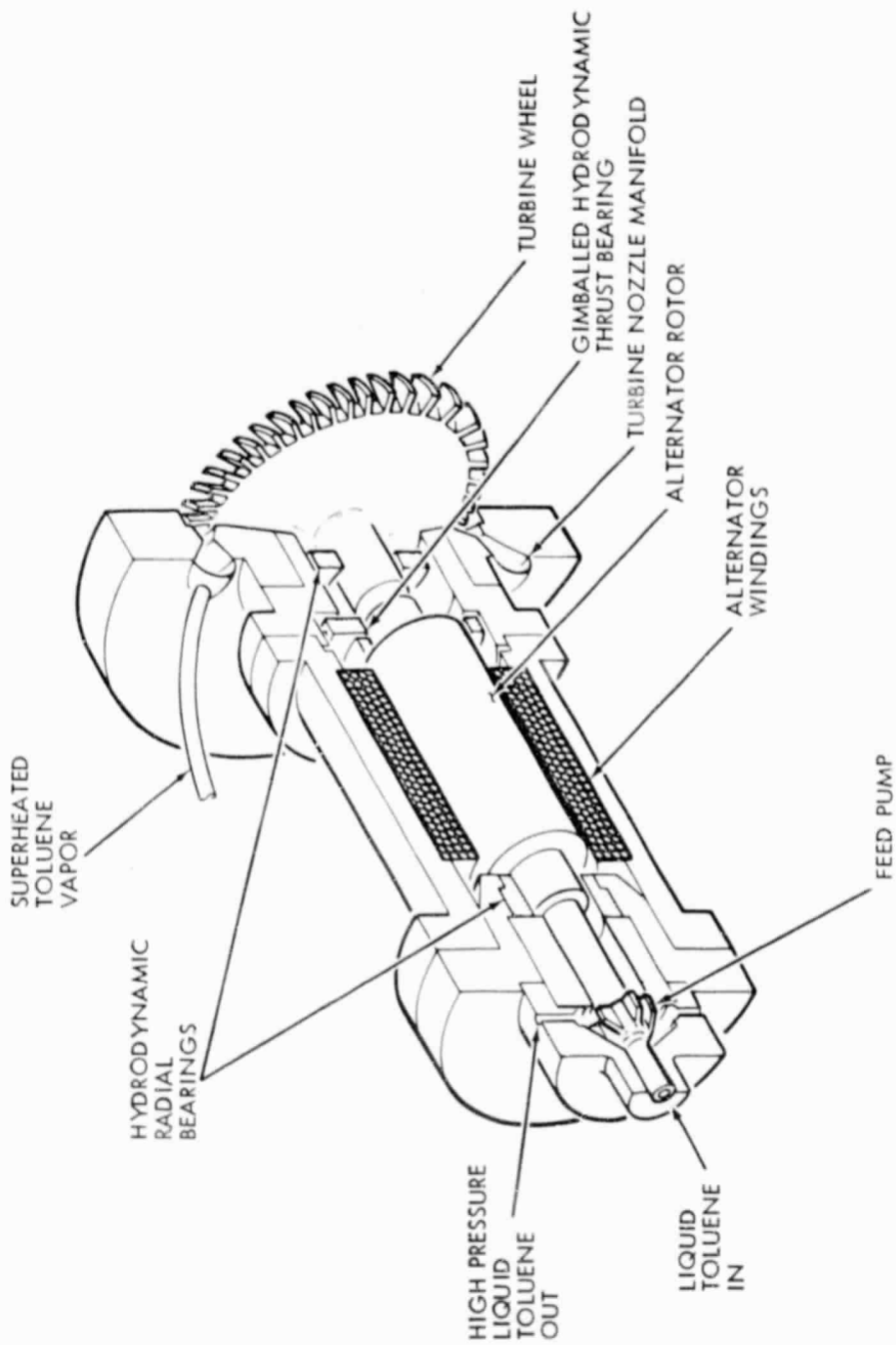
Figure 5-3. Turbine/Alternator/Pump Assembly
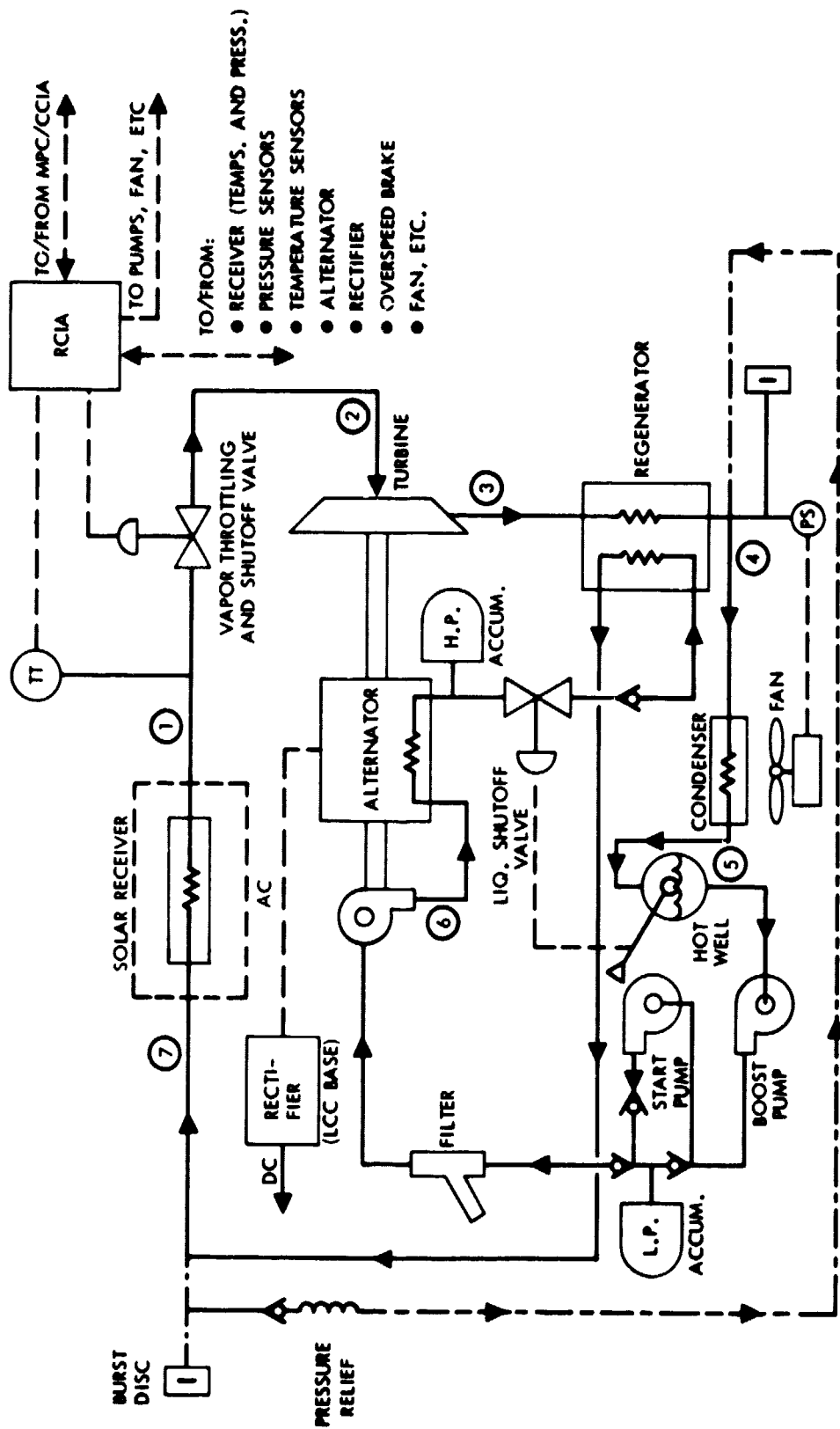
Figure 5-4.   Power Conversion Subsystem (PCS) Schematic

Table 5-3. Power Conversion Subsystem Pressure, Enthalpy and Temperature for Six Power Input Levels

Power In. kWt	Eff %	Flow Thru Receiver lb_m/hr**	Pressure, psia / Enthalpy, Btu/lb / Temperature,°F	1 Receiver Exit	2 Turbine Inlet	3 Turbine Exit	Regenerator 4 Exit (Vapor)	5 Condensor Exit	6 Pump Exit	7 Regenerator Exit (Liquid)
13.5***	11.5	183.1	P	644.6	101.0	0.93	0.92	0.91	646.7	646.2
			h	116.2	116.2	37.1	-116.8	-312.0	-290.5	-136.6
			T	750.0	708.7	545.9	162.2	96.0	145.8	445.2
28.7***	21.7	373.3	P	668.3	204.0	1.21	1.18	1.16	677.0	675.0
			h	114.9	114.9	30.1	-117.9	-308.3	-295.7	147.7
			T	750.0	713.3	531.2	158.8	105.3	131.6	425.3
44.5***	24.7	670.8	P	683.9	309.0	1.56	1.52	1.49	704.1	699.5
			h	114.1	114.1	27.6	-114.6	-304.4	294.3	-152.1
			T	750.0	719.3	625.9	169.4	115.3	134.5	417.4
59.7	25.6	745.2	P	698.9	400.0	1.37	1.28	1.22	733.6	725.8
			h	113.2	113.2	21.8	-116.1	-307.6	-298.2	-160.3
			T	750.0	724.7	613.7	164.7	107.2	124.7	403.1
76.2	26.4	946.0	P	710.8	503.0	1.60	1.49	1.42	766.2	753.7
			h	112.5	112.5	20.6	-113.6	-305.2	-295.0	-162.4
			T	750.0	731.7	511.1	174.7	113.4	129.9	399.1
92.4 (PEA)	26.9	1143.8	P	710.5	603.0	1.84	1.73	1.6	790.9	772.7
			h	112.5	112.5	20.6	-101.7	-302.7	-293.4	-103.1
			T	750.0	740.3	511.1	184.7	119.6	135.7	331.7

*All data shown for 30.6°C (82°F) ambient temperature
**Add 200 lb/hr through bearings for pump flow rate
***Half speed fan setting used

(5)   A double O-ring seal was incorporated to permit fabrication of the
        regenerator shell out of two different materials; stainless steel
        in the high temperature region and aluminum in the cooler regions.
        The leakage rates expected for this method of construction are con-
        sidered by FACC and Barber-Nichols to be so low as to be equivalent
        to true hermetic sealing.

(6)   Inducers were added to the boost and feed pumps to avoid
        cavitation.

(7)   Bearings which support the turbine/alternator shaft were changed
        from simple hydrodynamic to tilting-pad to avoid potential shaft
        instability.

5.   Energy Transport Subsystem

        The energy transport subsystem is used to carry electrical energy
from the alternators of each dish to a collection point for conditioning and
then to the local utility grid. Plant controls are discussed in the following
section. The energy transport subsystem consists of the following components:

        (1)   Electrical power cable network

        (2)   Switchboard

        (3)   Central inverter

        (4)   Interface equipment for connection to the grid

        The central inverter is the key element in the energy transport subsystem
in the 1-MWe plant. It receives the combined dc output of the many rectifiers
of the distribution system and inverts it to three-phase current at 480 V and
60 Hz for insertion into the utility distribution system (Figure 5-5). An
additional requirement for this system is that the inverter presents a nearly
constant voltage into which the individual modules feed their electrical
output.

        The total required inverter capacity for the Phase III experimental
plant is 1 MWe, but it remains to be determined whether a single inverter unit
will be used to condition the electric output of the plant or whether several
smaller modules will be used. The decision will be made on the basis of
economic and technical trade studies, by both JPL and the system contractor,
which will consider field layout and utility interface requirements.

        Because of the unique control requirements imposed on the design of the
inverter, it was decided to design and build a 1-kWe prototype before starting
fabrication of the 30-kWe unit. The unit selected for the single module veri-
fication test program at the JPL Parabolic Dish Test Site is being designed and
manufactured by Nova Electric Manufacturing Company Specifications for this
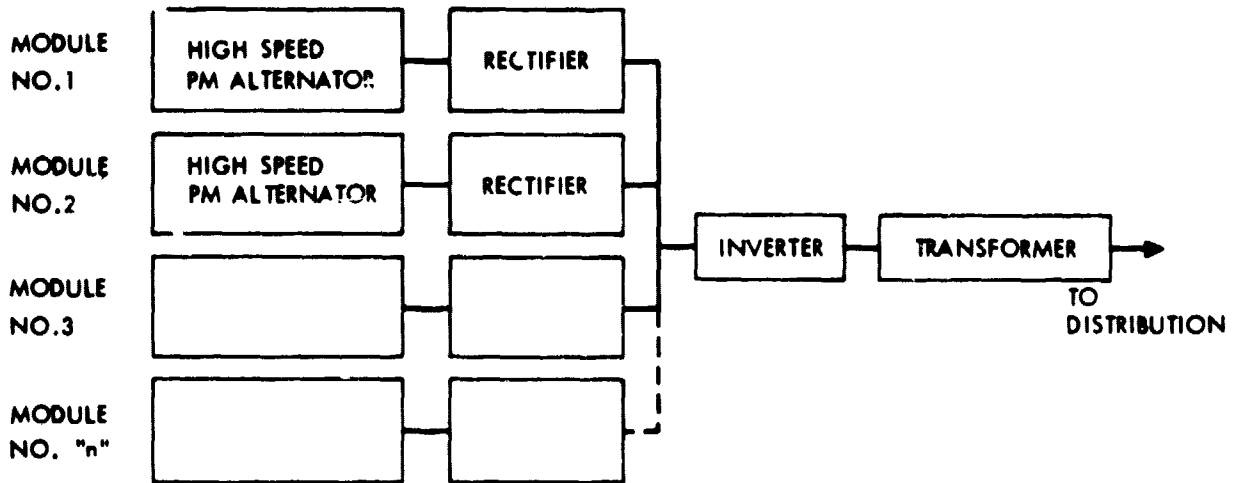
- HIGH SPEED, PERMANENT MAGNET ALTERNATOR ON DISH
- INDIVIDUAL AC → DC RECTIFIERS ON GROUND, NEAR DISH
- COLLECTION OF DC ELECTRICAL ENERGY AT 600 VOLTS
- INVERT 600 VOLTS DC TO 480 VOLTS 3 PHASE AC
- STEP UP VOLTAGE, DISTRIBUTE TO SMALL COMMUNITY
- FULLY PROTECTED, LOW DISTORTION POWER

Figure 5-5. Energy Transport Subsystem

inverter include:

    (1) Maximum output: 30 kVA at 480 V, into 60 Hz, utility interface transformer

    (2) Weight: Not to exceed 453.6 kg (1000 lb)

    (3) Estimated volume: 1.93 m^3 (70 ft^3 or less)

    (4) Input voltage: 600 + 30 Vdc

    (5) Input current: 0 - 54 A

    (6) Ripple: Less than 1%

    (7) Output power factor: 0.95 + 0.05

    (8) Line power factor: -0.07 to +0.7

    (9) Output distortion: Less than 5% harmonic output

    (10) Efficiency: Above 90% between 20-30 kVA output

    (11) Protection: Fully protected against overload or fault on input or output

The plant control subsystem consists of the hardware, software, and facilities necessary for the operation and monitoring of all plant subsystems. A schematic of the plant control system is given in Figure 5-6. The key component is a central microprocessor which performs the monitoring and stable control during start-up and shut-down, normal operation, intermittent operation and emergency operation. The building which houses the central control equipment also houses the switchboard and other electrical transport equipment.

During the FY 1980, the emphasis was on the design of the control subsystem as it applies to the single power module which will be subjected to the Phase II verification test program in July 1981. Drawings, which include the control subsystem specifications, were completed and hardware procurement initiated.

6.   Site Participation

Development and construction of the solar thermal power plant system is one of two coordinated SCSE endeavors. The other is the selection of a suitable site for the project.

The site participation Program Research and Development Announcement (PRDA) was initially drafted early in 1979. In March 1979, the DOE-Albuquerque Field Operations Office was designated as the cognizant procurement agency for the site participation procurement. More than 500 copies of the PRDA were distributed to potential site participants including small
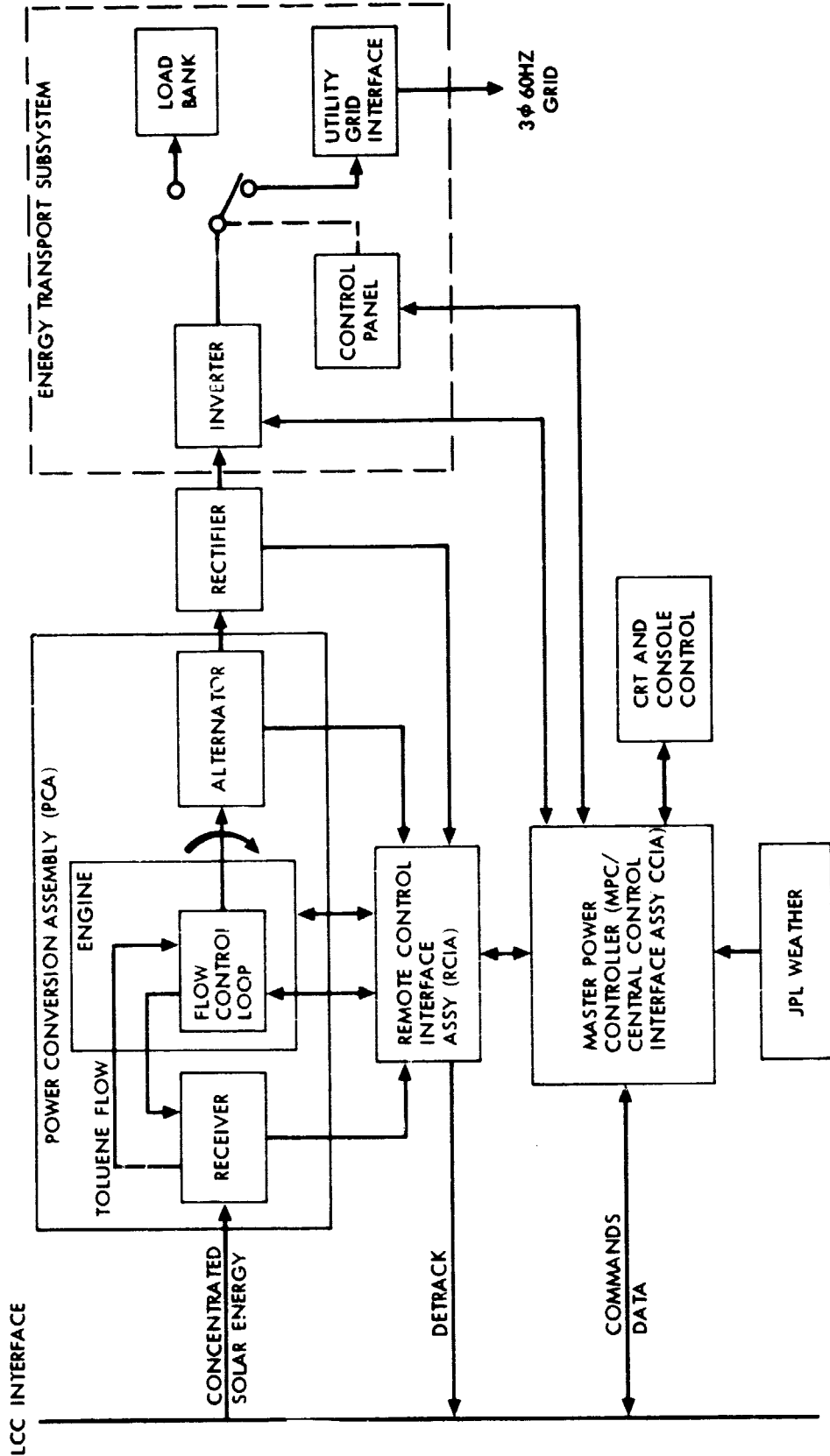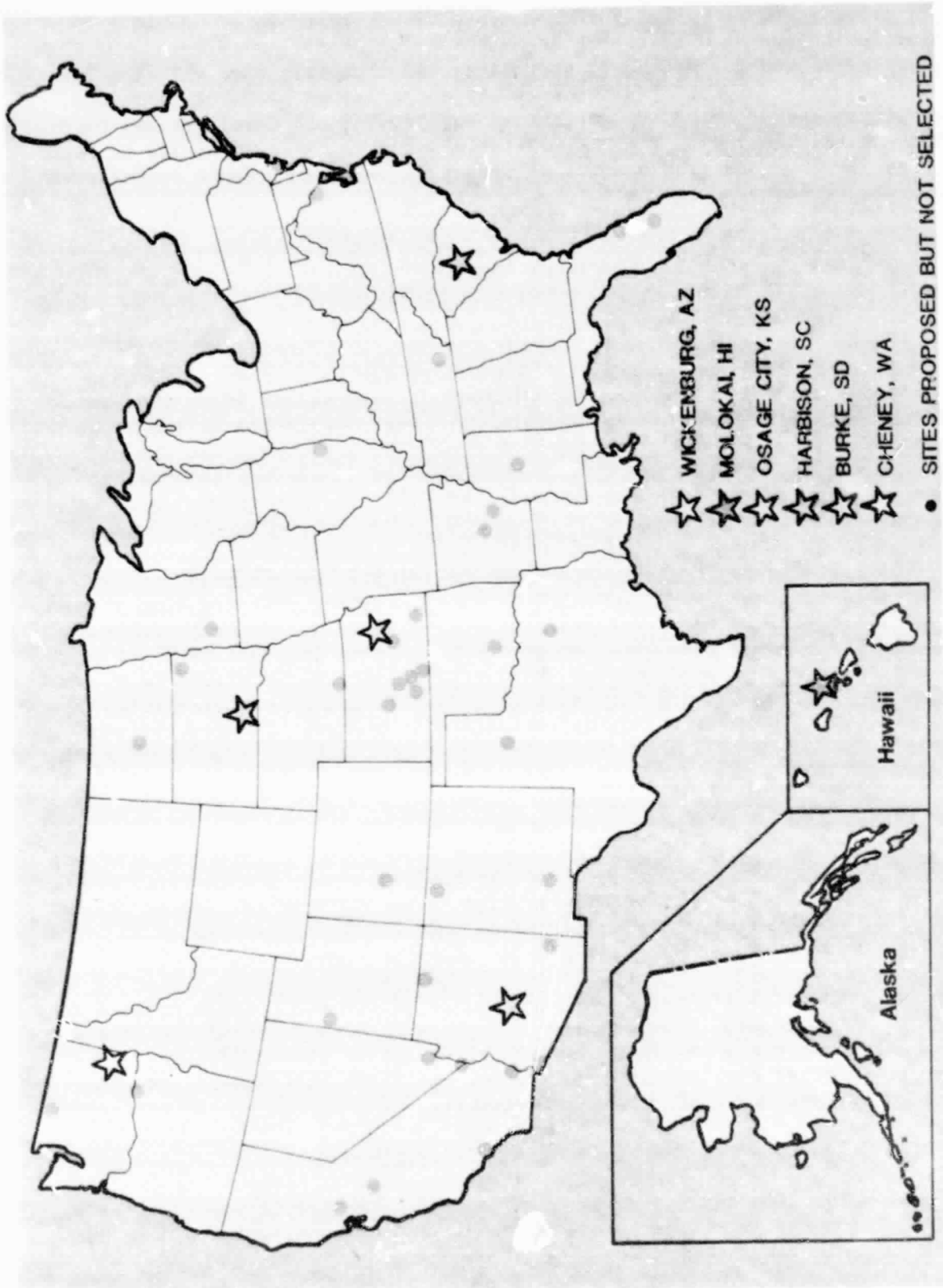
Figure 5-6. Plant Control System Schematic

Figure 5-7. SCSE Sites Selected by DOE

WICKENBURG, AZ
MOLOKAI, HI
OSAGE CITY, KS
HARBISON, SC
BURKE, SD
CHENEY, WA

● SITES PROPOSED BUT NOT SELECTED

Hawaii

Alaska

community agencies, municipal and investor-owned utilities, rural electric cooperatives, and various other supporting organizations. An indication of the interest in the experiment can be shown by the response of 45 U.S. communities to the site solicitation by DOE/ALO. Nearly every region of the U.S. was represented. Of the 45 proposals, six finalists were selected for participation in the SCSE: Wickenburg, Arizona; Island of Molokai, Hawaii; Osage City, Kansas; Burke, South Dakota; Harbison, South Carolina; and Cheney, Washington (Figure 5-7). The DOE will select one of these finalists to host the first experiment. The other five finalists will participate in detailed site characterization studies.

B. ISOLATED APPLICATION EXPERIMENT SERIES (EE-2)

1. Introduction and Background

The Isolated Application Experiment Series is the second major applications activity. This series of small (approximately 60 to 150 kWe) solar thermal point-focusing distributed receiver experiments will address separate isolated load applications with emphasis on electric and thermal power. The program is closely integrated with the Technology Development Element of the Project with the objective of utilizing the technologies being developed under that program.

The Isolated Application Experiment Series will be designed, installed, and operated to provide JPL, DOE, and industry a better understanding of solar thermal plant application, technical feasibility, and operational problems. As originally planned, the time period for deployment and test of first generation systems was from 1982 through 1986. FY 1981 budget cuts imposed by DOE late in FY 1980 have forced this series of experiments to be rescheduled, the first experiment being set back approximately 18 months. The revised schedule now calls for deployment and test of the experimental power plants during the period 1984-1988.

The objectives of the series are to:

(1) Test the feasibility of the technology at the system level and verify that the solar plant can produce electrical and/or thermal energy from solar radiation to meet energy requirements for isolated applications.

(2) Characterize the total performance of the plant (site preparation, components, subsystems, and modules as a function of load characteristics, insolation, weather, operation and maintenance activities, safety regulations, environmental regulations, and legal and socio-technical factors).

(3) Identify and understand plant failure modes.

(4) Identify and quantify the impact of solar hybrid plant operations on the daily operations activities of user personnel and on user manning requirements.

(5)   Identify and quantify the impact of solar hybrid plant installation and operations on the local environment and on the acceptance of solar power plants by local public officials, local power systems officials, and the local public.

(6)   Economically provide testing of technologies and markets, meeting principal program objectives without large expenditures.

(7)   Involve a large constituency of industrial suppliers and users.

(8)   Address the potential for near-to-mid-term markets for small power systems that is needed to provide the initial incentive to manufacture these systems.

(9)   Maintain program flexibility by employing a number of small and varied experiments.

Some experiments in this series are planned to operate in a hybrid mode; i.e., natural gas or other fossil fuels will be used in conjunction with solar energy to provide a high availability and capacity factor.

A JPL evaluation team completed technical and cost evaluation of the proposals in mid-FY 1980 and announcements of the award of two systems will be made in FY 1981. The procurement structure will allow two awards for system (module and plant) detail design and testing. Near the end of the design phase, an RFP will be issued requesting proposals for plant implementation, operation, and eventual decommissioning. Only one contractor will be selected for the implementation phase.   ·

The experiment will use first-generation dish hardware assembled into individual power modules, and a number of such modules will be interconnected to form a power plant. The baseline module for the system is the JPL first-generation dish Brayton system which consists of the General Electric Low-Cost Concentrator, the Garrett AiResearch gas receiver, and AiResearch Brayton cycle Mod 1 engine, alternator, and hybrid-fossil combustor. Each module will contain a concentrator, receiver, hybrid combustor, turbine, recuperator, compressor, alternator, module controls, starter, concentrator drives, tracking devices and sensors, some fuel storage, and necessary exhaust hardware.

A self-contained module will be employed with only the true plant functions centrally located. Plant functions will include combination and conditioning equipment; module and plant performance indicators; grid interconnection equipment (if employed in the experiment); computing and data recording facilities; instrumentation, plant safety, and control equipment. The module will normally operate unattended, however, each module will be equipped for safety or emergency shutdown, both manual and automatic. Although a fixed installation is expected, individual modules will be transportable, field erectable, and field serviceable.

Long-term thermal energy storage will be included in the plant. No thermal buffering will be provided except by the heat capacity of the installed components and working fluid. The hybrid combustor control system will provide the desired transient response characteristics.

Site selection has been a U.S. Navy responsibility. It was conducted in parallel with other experiment activities and has been independent of the technical tasks. Preliminary site screening and selection of the three most promising candidate sites were completed in FY 1979. The tentative site selected is the Marine Corps Air Station (MCAS), Yuma, Arizona. Site coordination and requirements definition were conducted with MCAS, Yuma, and CEL during FY 1980 and will continue in FY 1981.

2.   Planning for Future Experiments

Additional isolated application experiments are now being selected that will support the JPL market penetration strategy, with experiment deployment schedules based on technology readiness and the availability of funding. It is JPL's intention to establish and maintain a competitive environment for all experiments, and funding plans reflect that approach. Experiments will test hardware in applications such as foreign locations, islands, isolated mines, mills, U.S. Government sites, and isolated communities. The time period for deployment and testing of these systems is 1984 to 1988, and detailed planning for this series of experiments will continue during FY 1981.

In mid-FY 1980 two concept papers were presented to DOE which discussed the issues involved in conducting a foreign solar thermal power experiment. The first paper discussed the implications of the international market for the parabolic dish program. The second proposed a specific strategy for conducting a foreign experiment. The third experiment in the isolated applications series was proposed as a foreign experiment. Initiation awaits the necessary funding.

C.   INDUSTRIAL APPLICATION EXPERIMENT SERIES (EE-3)

1.   Experiment Definition

The Industrial Application Experiment Series seeks to develop potential industrial, commercial, and agricultural applications for parabolic dish systems including industrial process heat, enhanced oil recovery, alcohol generation, cogeneration, space conditioning, and industrial electricity. Through these experiments the technical feasibility of parabolic dish collector systems is proven in actual industrial, commercial, and agricultural environments.

Unlike EE-1 and EE-2, EE-3 experiments are identified and defined by proposers and selected by JPL. Industrial involvement and expertise are maximized throughout the planning and implementation of the experiment. Site application, user, and hardware are offered as a package by the proposer and selected by JPL through competitive procurements.

2.   Approach to Implementation

While JPL does not specify site, application, user, or hardware for EE-3, there are constraints. Acceptable hardware is that which will have been developed to the point where an integrated collector system is available

for purchase. The applications should represent near-term markets approaching economic viability and favoring parabolic dish technology over other renewable technologies. In addition to these constraints, one award is designated for small business in each procurement.

3. Experiment Objectives

The purpose of the EE-3 experiments is to prove the system feasibility of parabolic dish technology in industrial, commercial, and agricultural applications. The detailed objectives of the EE-3 experiments are focused upon the acquisition of technical performance data, and the assessment of the extent to which all user requirements are satisfied.

The technical performance evaluation objectives are to:

(1) Determine to what extent the parabolic dish system contributes to meeting the energy requirements of the application during designated test periods.

(2) Characterize the total performance of the plant as a function of load characteristics, user activities at the site, insolation, weather, operations and maintenance activities, safety regulations, environmental regulations, seismic factors, and legal and socio-technical factors.

(3) Identify and understand the failure modes of the selected parabolic dish system.

(4) Provide feedback to the component and system-level hardware and software design processes.

(5) Provide accurate input data to performance, cost, and energy/economic impact models.

The requirements definition objectives are to:

(1) Identify and quantify the impact of operating the selected parabolic dish system on the daily operations activities of user personnel and manning requirements.

(2) Identify the impact of the installation and operation of the selected parabolic dish sytem on the local environment.

(3) Identify the impact of the installation and operation of the selected parabolic dish system on potential acceptance of commercial units by the user and the local public, if appropriate.

(4) Integrate and analyze the above impacts and performance information to define economic and technical requirements.

In May of 1980, 17 proposals for EE-3 series experiments were received, involving small business and universities. Twelve industrial market areas, including organic chemicals and petroleum extraction, in eleven different states were proposed for the siting of an EE-3 experiment featuring industrial process heat, co-generation, or electricity. As a result of the solicitation, it was found that nine responders were involved in various stages of parabolic dish design and development. The announced award limit of $500,000 was approached by nearly all the bidders. Proposed program schedules varied from 24 to 36 months for experiment design, hardware fabrication, testing, and installation at a user site. A 12 month joint operations evaluation period would then take place. It is expected that a single contract will be awarded in FY 1981 to initiate the EE-3 series of industrial experiments.

D.   SOUTHERN NEW ENGLAND TELEPHONE COMPANY EXPERIMENT

In 1979, the Southern New England Telephone (SNET) Company was awarded a Federal energy grant of $44,000 for partial funding of the construction of a $100,000 computerized parabolic dish collector and associated building modifications at the SNET Bethany, Connecticut, switching center. The SNET building engineering group chose the OMNIUM-G collector to power most of the building's telephone switching equipment and to provide up to 90% of its cooling and 25% of its heating requirements. The dish as installed is shown in Figure 5-8. SNET contracted with OMNIUM-G of Anaheim, California, for delivery of their UGI Heliodyne Solar Power module, and with Stonier Service Company of Milford, Connecticut, for installation.

The OMNIUM-G module includes a receiver that collects the insolation reflected from the aluminum panels of a paraboloidal reflector. Water circulating through the receiver is heated to steam to power an engine providing electric power. The steam then condenses, providing hot water to power the building's heating and air conditioning units. Commercial power will be used when insolation levels are insufficient.

Work began on the project in 1979. By the end of FY 1979 the site had been selected and fenced, the concrete pad poured, and installation fittings roughed in. SNET personnel visited OMNIUM-G and the JPL Parabolic Dish Test Site to become familiar with the Heliodyne module and its testing and operational history.

Installation of the Heliodyne module by the OMNIUM-G crew was completed during the period December 11-17, 1979. This included petal-frame support installation and welding, installation and alignment of reflecting petals, and installation of the control system and receiver. The period January 17-23, 1980, was devoted to final system checkout and personnel training. Five of the original 18 reflective petals were replaced during this time to correct a manufacturing defect. During final checkout a blockage was discovered in the receiver which required its replacement, which was completed on March 3, 1980. Tracking and temperature sensing electronics which had not been operating correctly were also repaired and the OMNIUM-G Co. declared the module to be operational on March 6, 1980, and the warranty period began.
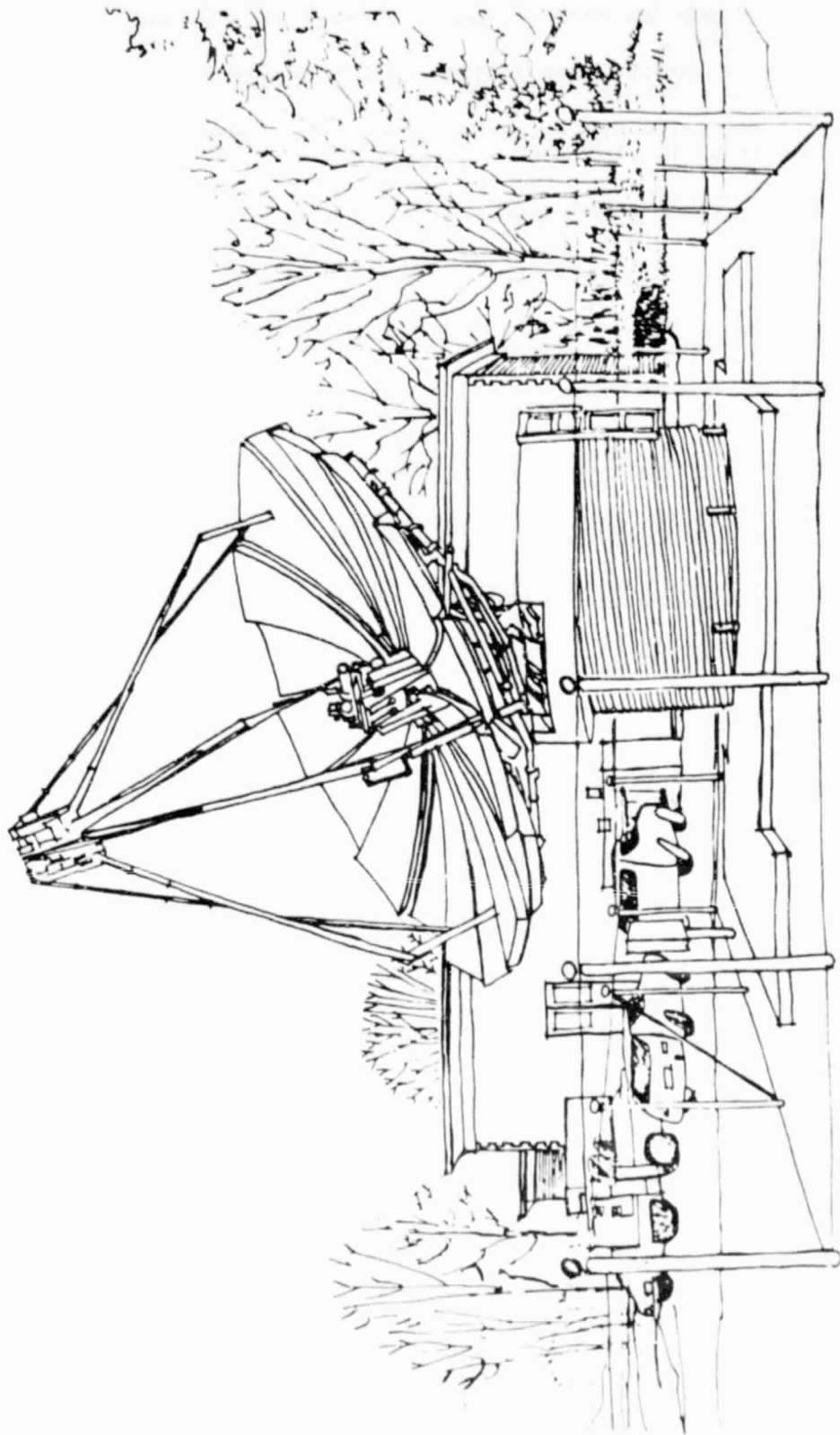
Figure 5-8. Southern New England Telephone (SNET) Company Parabolic Dish

Tracking and control problems continued with the unit, however, and SNET was not able to track the sun. Azimuth tracking and ephemeral clock printed circuit boards were replaced, and on March 19, 1980, SNET made its first attempt to operate the complete system. All components functioned as intended except the power converter. No power generation was detected on this run or the run of the following day. Clouds and haze precluded system operation until April 1, 1980, at which time multiple control and tracking problems appeared. These were resolved and repaired during the next two and-a-half months. Subsequently, a joint SNET - OMNIUM-G crew reinitiated testing operations which continued through the end of FY 1980.

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