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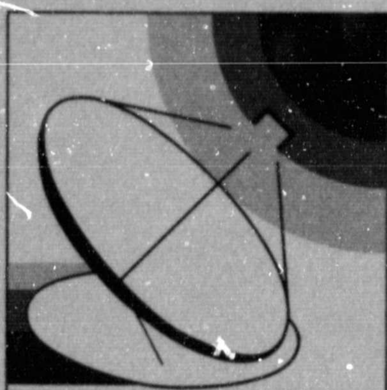
Solar Thermal Power Systems Project
Parabolic Dish Systems Development

DOE/JPL-1060-63
Distribution Category UC-62

Solar Parabolic Dish Annual Technology Evaluation Report

Fiscal Year 1982



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September 15, 1983

Prepared for
U.S. Department of Energy
Through an Agreement with
National Aeronautics and Space Administration
by

Jet Propulsion Laboratory
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Pasadena, California

JPL Publication 83-73

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The JPL Solar Thermal Power Systems Project is sponsored by the U.S. Department of Energy and is part of the Solar Thermal Program to develop low-cost solar thermal and electric power plants.

ABSTRACT

This report summarizes the activities of the JPL Solar Thermal Power Systems Parabolic Dish Project for FY 1982. Included are discussions on designs of module development including their concentrator, receiver, and power conversion subsystems. Analyses and test results, along with progress on field tests, Small Community Experiment System development, and tests at the Parabolic Dish Test Site are also included.

ACKNOWLEDGMENT

This report was published by the Jet Propulsion Laboratory through NASA Task Order RE-152, Amendment 327 and was sponsored by the U.S. Department of Energy (DOE) under Interagency Agreement DE-AT04-81AL16228 with the DOE Albuquerque Operations Office.

GLOSSARY

ACRONYMS

DOE	Department of Energy
JPL	Jet Propulsion Laboratory
NASA	National Aeronautics and Space Administration
PCA	Power Conversion Assembly
PDTS	Parabolic Dish Test Site
SCE	Southern California Edison Company
TBC	Test Bed Concentrator
USAB	United Stirling of Sweden
PON	Program Opportunity Notice
ORC	Organic Rankine Cycle
FACC	Ford Aerospace and Communications Corporation
B-N	Barber-Nichols
PMA	Permanent Magnet Alternator
PDC-1	Parabolic Dish Concentrator No. 1
S/A	Sanders Associates
GTEC	Garret Turbine Engine Company
SAGT	Solarized Advanced Gas Turbine
SABC	Subatmospheric Brayton Cycle
SCSE	Small Community Solar Experiment
LeRC	Lewis Research Center
ESOR	Experimental Solar-Only Receiver
TAP	Turbine-Alternator-Pump
PDC-2	Parabolic Dish Concentrator No. 2
AGT	Advanced Gas Turbine
GRI	Gas Research Institute
PKI	Power Kinetics Incorporated
ACC	Applied Concepts Corporation
SNLA	Sandia National Laboratories at Albuquerque

UNITS

C	centigrade
F	Fahrenheit
W/m^2	watts per square meter
%	percent
m	meter
ft	foot
M	million
kWt	kilowatt thermal
kWe	kilowatt electric
MPa	megapascals
psi	pounds per square inch
Hz	Hertz
mi/h	miles per hour
mm	millimeter
in.	inch

hp	horsepower
MW	megawatt
cm	centimeter
rev/min	revolutions per minute
h	hour
m^2	square meter
ft^2	square foot

CONTENTS

<u>Figures</u>

Tables

SECTION I

EXECUTIVE SUMMARY

Solar parabolic dish technology is being developed for the U.S. Department of Energy (DOE) by the Jet Propulsion Laboratory (JPL) under an Interagency Agreement with the National Aeronautics and Space Administration (NASA). The status of this work is described in this report in terms of concentrator and module development. The concentrators, or parabolic dishes, reflect the sun's rays into a very small aperture at the dish focal point. A power conversion assembly (PCA) consisting of an integral receiver, engine and alternator are mounted at the focal point converting the sun's heat entering the receiver into mechanical energy operating an alternator to produce electricity. A concentrator or dish with power conversion assembly and controls is called a module. Testing is accomplished at the Parabolic Dish Test Site (PDTS) to verify the performance of the module prior to deploying the dish systems in field experiments in user environments.

Parabolic dish systems uniquely combine the ability to develop high temperatures and a modular configuration. Dishes can be used to generate electricity or to produce thermal power; alternatively, dishes can be used for cogeneration purposes. Various fluids can be operated at temperatures between 315°C (600°F) and 1650°C (3000°F), providing maximum efficiencies for heat engines. Because dishes are modular, a single dish can be used autonomously in remote applications, or a field of dishes can be deployed with their outputs electrically connected. Power can be added incrementally, as required, and individual dishes serviced without disturbing other units in the field. Modularity also offers manufacturing, installation and control advantages because a large number of identical units are deployed.

A. MODULE DEVELOPMENT

Fiscal year 1982 was one of significant hardware accomplishments for the parabolic dish-electric project. Two modules based on different heat engine technologies modules provided the Southern California Edison Company (SCE) utility grid with electricity and the first pre-production parabolic dish concentrator was fabricated, assembled and is under test at the PDTS in California's Mojave Desert.

A number of Stirling-cycle PCA configurations operated at the focus of a parabolic test bed concentrator (TBC). One configuration, using a Fairchild-Stratos hybrid receiver and a United Stirling of Sweden (USAB) engine, successfully operated in both hybrid and non-hybrid modes, using solar and natural gas heat inputs until heater head brazing failures caused test termination. Funding limitations precluded redesign. Three different versions of USAB receivers, using only solar energy, successfully operated with a USAB engine on a TBC. Noteworthy accomplishments included a number of successive sunrise-to-sunset operation days that provided the SCE grid 20 kWe at a normalized solar insolation level of 1000 W/m^2. During one test 24 kWe were generated by the

PCA with an insolation level of 965 W/m^2, corresponding to a solar-to-electric conversion efficiency of approximately 29% (from sunlight incident on the concentrator to electricity at the generator, parasitic losses not included).

In response to a DOE Program Opportunity Notice (PON), a team of industrial and university contractors managed by Advanco Corporation entered into a Cooperative Agreement with the DOE Albuquerque Operations Office to design, build, and test a parabolic dish-Stirling module based on the above PCA. The concentrator will be designed and constructed under the plans and direction of Advanco.

An organic Rankine-cycle (ORC) PCA consisting of a Ford Aerospace and Communications Corporation (FACC) receiver and a Barber-Nichols (B-N, FACC subcontractor) ORC engine with an integral Simmonds Precision permanent magnet alternator (PMA) was operated on a TBC at the PDTS and produced over 15 kWe at an insolation level of 950 W/m^2. Electric power was supplied to the SCE grid. Throughout low, intermittent, and high insolation levels, the ORC PCA operated smoothly; and the control system performed flawlessly during engine start-up, operation, and shutdown. The PCA ran without incident during simulated and actual cloud passages. After 33 hours of operation, the PCA was removed and disassembled. Inspection revealed excessive bearing wear and electrical arcing between the winding and housing of the PMA. Work is progressing on a bearing redesign to correct the wear problem, and the PMA arcing problem is under investigation.

The ORC PCA unit tested is a prototype of a solar thermal electric generating system that is to be combined with a parabolic dish concentrator and deployed in the field at Osage City, Kansas, as the first Small Community Experiment.

A prototype parabolic dish concentrator called the PDC-1 was fabricated and erected at the PDTS during FY 1982. The 12-m (39-ft)-diameter dish was designed by General Electric Company and fabricated and erected by FACC and its subcontractors. The concentrator was designed for ORC temperatures of about 400°C (750°F). Initial tests indicate that the performance of the PDC-1 will meet design specifications.

The Brayton-cycle FY 1982 effort, although greatly reduced in scope because of budget constraints, also provided significant hardware and system progress. The systems contractor, Sanders Associates (S/A), fabricated a receiver for use with a Garrett Turbine Engine Company (GTEC) Brayton-cycle engine that will be tested on a TBC at the PDTS in 1984. The GTEC solar engine is a modified or solarized automotive advanced gas turbine (SAGT) engine. Development of the automotive and solar engines are under the direction of NASA's Lewis Research Center.

S/A also conducted trade studies that recommended a module for the 1980s using (1) a small Brayton cycle subatmospheric gas turbine engine (SABC), presently in development by the Garrett AiResearch Manufacturing Company for the Gas Research Institute; (2) a small S/A receiver; and (3) one of a number of independently developed small dishes (6 to 8 m in diameter). They further recommended a parallel program using an 11-m (36-ft)-diameter dish with a S/A receiver and a SAGT engine. All work on an 11-m (36-ft)-diameter parabolic dish being designed by Acurex was suspended for FY 1982 due to lack of funds.

The PDTS provided the test bed concentrator, instrumentation, and support facilities to test the PCAs and the facilities for evaluating the PDC-1. The TBCs were also used for high-temperature materials tests and a non-solar test series to detect high-energy gamma radiation emitted from various celestial objects.

B. SYSTEM EXPERIMENTS

The Small Community Solar Experiment (SCSE) was initiated in 1977 when Congress appropriated funds to build an experimental solar power plant as a first step in addressing the needs of the small community sector. FACC was selected to develop the ORC-based technology for this experiment. The progress made in this developmenmt is discussed in Section II.B of this document.

In FY 1982, Congress appropriated $4.0 M to construct the experiment. During the course of the year DOE directed the construction of a 100-kWe plant, a size considered sufficiently large to satisfy most of the technical requirements of the experiment while meeting the intent of the Congress to minimize the cost.

Concurrent with the development of the organic Rankine module, DOE was involved in the selection of a site for the experiment. During FY 1982, DOE selected Osage City, Kansas, for the SCSE plant; Molokai, Hawaii, was selected as the alternate site. This decision culminated the selection process in which 44 communities across the country competed.

Osage City is an ideal setting for the experiment because it is representative of a large number of small cities throughout the country. It has its own generation capability but also purchases power when it is economically advantageous to do so. Insolation at Osage City is about average for the nation. DOE has entered into negotiations with Osage City with the objective of signing a Cooperative Agreement in FY 1983 for site participation.

SECTION II

MODULE DEVELOPMENT

A. STIRLING-CYCLE TECHNOLOGY

The Stirling Parabolic Dish Program was initiated by the Jet Propulsion Laboratory (JPL) in FY 1978. United Stirling AB (USAB) of Sweden was selected as supplier for the basic engine, a derivative of their model 4-95, from an ongoing automotive development program with the National Aeronautics and Space Administration's (NASA's) Lewis Research Center (LeRC). The power conversion assembly (PCA), consisting of a Fairchild Stratos-fabricated hybrid receiver integrally mated to the USAB Stirling engine, was tested on an 11-m (36-ft)-diameter Test Bed Concentrator (TBC) at the Parabolic Dish Test Site (PDTS) in California's Mojave Desert (Figure 1).

The PCA was installed on the TBC at the PDTS by JPL with support from USAB and Advanco Corporation personnel who were responsible for the PCA integration and functional tests. The Stirling hybrid module successfully generated electricity, operating from both solar thermal power and natural gas. Tests, per specifications, included operating at heater head temperatures of up to 770°C (1420°F), mean engine pressures to 11 MPa (1625 psia), and solar thermal heat inputs to 20 kilowatts thermal (kWth) with only 25% of the TBC mirror facets uncovered.

After feeding up to 15 kilowatts electric (kWe) of power into the Southern California Edison Company's (SCE's) electric grid, the hybrid tests were terminated prior to performance testing because of brazing failures in the heater head/receiver when 50% of the TBC mirror facets were uncovered. Subsequent inspection revealed that the braze joint on the outermost heater head tube had opened up due to the hot combustor gas impingement on this tube. Limited funds precluded the necessary redesign and repair to conduct performance tests of the hybrid system.

Following the hybrid test, the PCA was reassembled using three different, but similar, USAB experimental solar-only receivers (ESORs). The ESOR-configured PCA module was evaluated for maximum performance, daily performance, and component performance. During a series of sunrise-to-sunset tests, the power output was in excess of 25 kWe with insolation normalized to 1000 W/m^2, corresponding to a solar-to-electric conversion efficiency of 29% (from sunlight incident to the concentrator to power out of the generator, parasitic losses not included). During a two-day consecutive sunrise-to-sunset operating period, over 500-kW hours of electricity were produced. Hydrogen was the working gas, operating at a mean temperature of 700°C (1290°F) and a mean pressure of 15 MPa (2200 psi).

Figure 2 shows the insolation level with the corresponding alternator power output and control temperature during the first of the sunrise-to-sunset test days. Fluctuations in the alternator power output early in the day were due to adjustments to optimize the control operating pressure.

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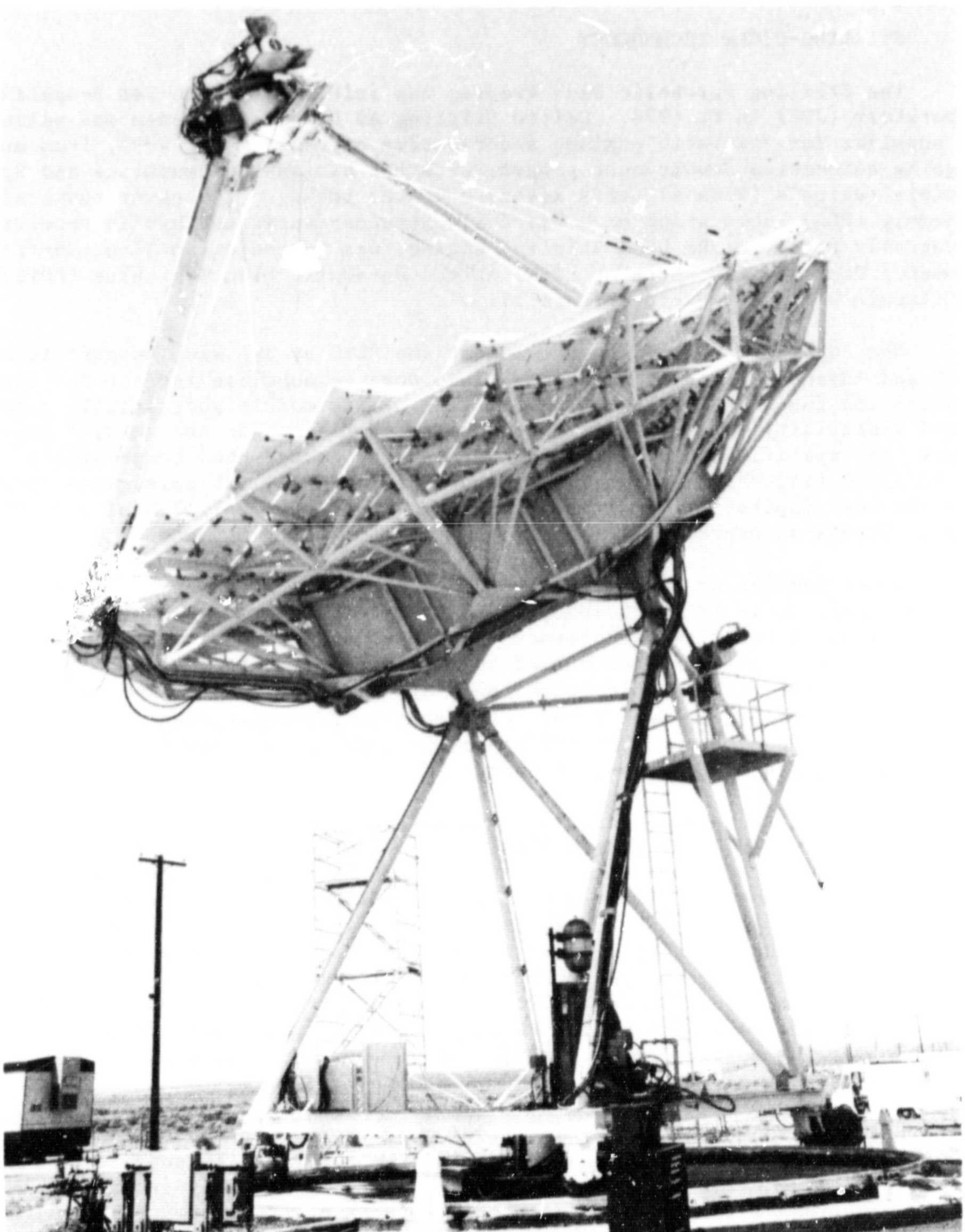

Figure 1. Stirling Engine Testing at the Parabolic Dish Test Site

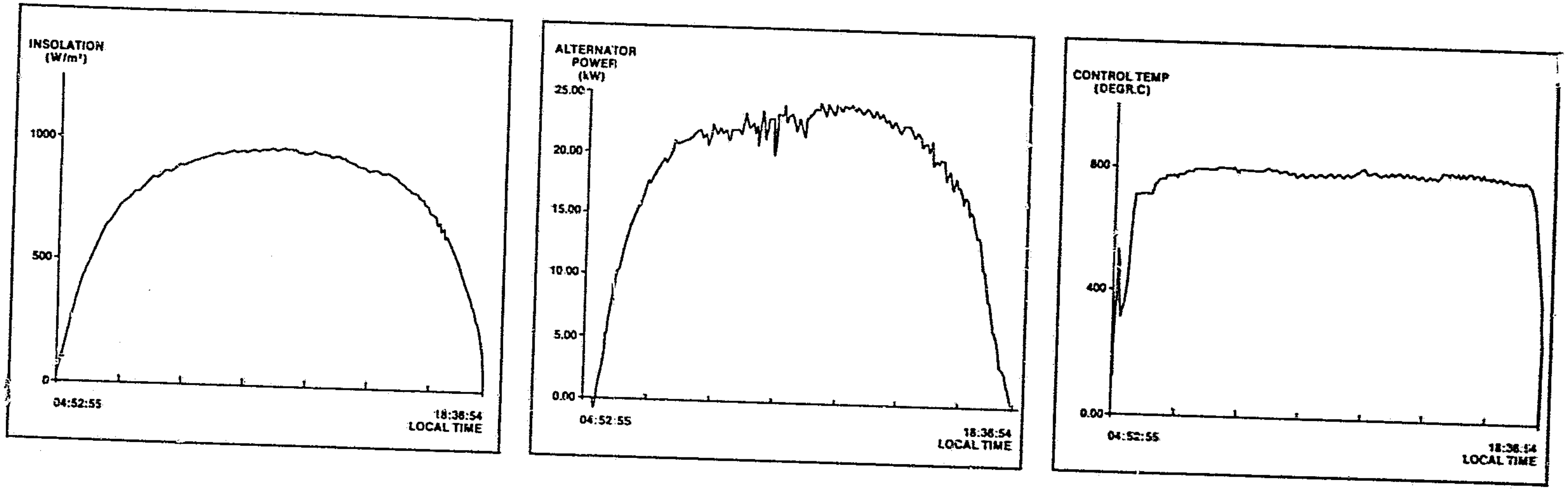

Figure 2. Stirling Module Test Data

In response to a Department of Energy (DOE) Program Opportunity Notice (PON), a team of industrial and university contractors managed by Advanco Corporation entered into a Cooperative Agreement with the U.S. Department of Energy (DOE) in FY 1982 to design, build, and test a parabolic dish-Stirling module. The major subsystems and contractors of the Stirling module, named Vanguard I, are:

Engine	United Stirling AB, Sweden
Concentrator	Advanco Corporation
Control System	Electrospace Incorporated
Generator	Onan Incorporated
General Contractor	Modern Alloys
System Integrator	Rockwell International
Site and User	Southern California Edison Company

Other team participants include Winsmith, Rotek, Sumitomo Cycle, Corning Glass Works and Georgia Institute of Technology.

The Vanguard team completed the conceptual design of several subsystems, as well as the market assessment and the sales implementation plan tasks in September. The module conceptual design is essentially complete. All major requirements have been identified, all major system features and characteristics have been defined, and in many cases, design details have been worked out. The subsystems, when fabricated, will be assembled at the test area near Palm Springs, California. Testing is scheduled for FY 1984.

The module is required to produce rated average power of 20 kWe at 480 Vac, 60 HZ at 850 W/m^2 direct normal insolation. It should produce net power for insolation levels as low as 250 W/m^2 and as high as 1100 W/m^2 with temperatures ranging from -25 to +50°C (-13 to 122°F) and wind gusts up to 13 m/s (30 mph) and survive at wind speeds of up to 40 m/s (90 mi/h).

Figure 3 shows an elevation view of the Vanguard dish-Stirling module with the features listed in Table 1.

The Vanguard team has projected a minimum market of 50,000 units/year for the parabolic dish-Stirling modules after the economic and technical risks are ameliorated and the module is competitive with alternative sources. The allowable sales price projected by Advanco in this market was predicted to be $1900/kWe. The major constraint to commercialization is simultaneously obtaining commercial sales that not only warrant higher production capacity but also provide an attractive rate of return on the investment. The approach for fulfilling all three criteria is using Federal and State tax credit incentives that are uniquely available to risk-prone venture capitalists who structure highly leveraged, limited partnerships that enter into purchase power agreements with an established utility.

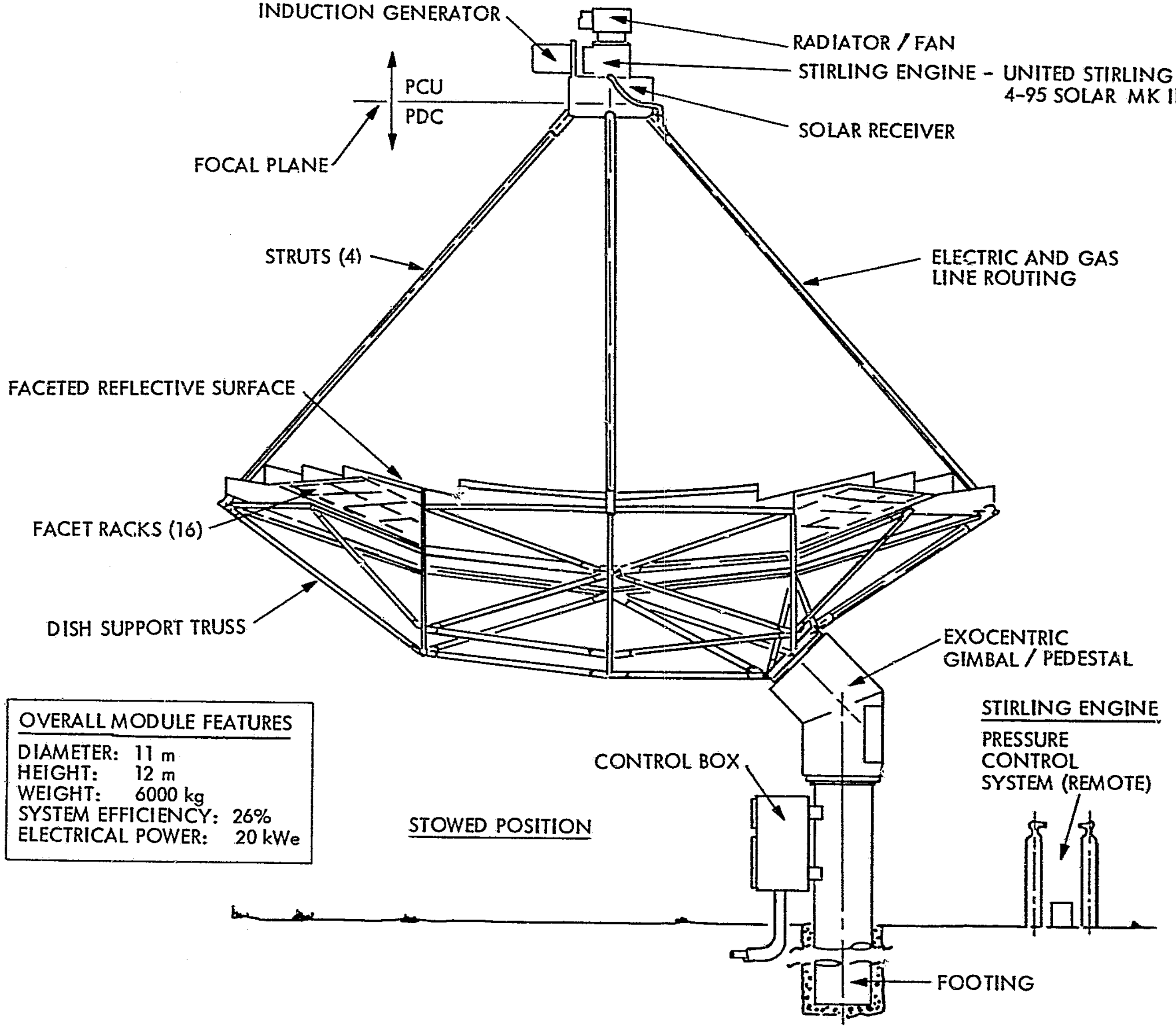

Figure 3. Detailed Drawing of the Vanguard Dish-Stirling Module

Table 1. Vanguard Dish Features of the Stirling Module

Feature	Details
Reflective surface	320 facets, 460 x 610 mm (18 x 24 in.) foamglass-backed thin glass, back-silvered mirrors with 89.2 m^2 (960 ft^2) total surface area
Dish structure	Carbon steel space frame
Dish articulation	Rockwell elevated-shoulder exocentric gimbal design
Dish control	Electrospace model 93C-15 antenna controller and motors
Dish pedestal	750-mm (30-in.) carbon steel pipe in poured concrete footing
Stirling engine	United Stirling 4-95 Solar Mark II, four-cylinder with integral, solar-only receiver
Generator	40-kW, 30-hp induction generator
Cooling	Dish-mounted radiator/fan combination
Working fluid	Gaseous hydrogen
Stirling engine control	Mean effective pressure variation controlled via remote supply and return system

The sales implementation plan involves four potential primary projects and three secondary projects that could develop into commercial realities. The four primary projects represent 99 MWe of peak capacity or 3960 Vanguard I modules.

B. ORGANIC RANKINE-CYCLE TECHNOLOGY

The organic Rankine-cycle (ORC) module consists of a parabolic dish, a cavity receiver, an ORC engine with an integral permanent magnet alternator (PMA), together with associated control and electric power conversion equipment.

The ORC power conversion assembly (PCA) development was initiated in December 1979 with a contract to the Ford Aerospace and Communications Corporation (FACC) for development of a receiver and electric power conversion equipment and system controls. FACC selected Barber Nichols (B-N) to develop the engine, which uses toluene as the working fluid. The FACC contract was expanded in 1982 to include the fabrication, assembly, and test of the parabolic dish concentrator, called PDC-1, designed by General Electric Company.

Progress during the year included performance testing of the ORC PCA on a TBC and production of over 15 kWe, supplying electricity to the SCE power grid. After 33 hours of operation, the PCA was removed and disassembled.

Inspection revealed excessive bearing wear and electrical arcing between the winding and housing of the PMA. Work is progressing on a bearing redesign to correct the excessive wear problem, and the PMA arcing problem is under investigation. To help solve these problems, Barber-Nichols assembled a dynomometer test apparatus that used a hydraulic motor, driving through step-up gearing, to operate the turbine-alternator-pump (TAP) assembly at rated speed and electrical power output while permitting measurements to be made of torque requirements and component performance. New thrust and radial bearing configurations were also tested and qualified. The Rayleigh stepped bearing was adopted as the optimum, while alternate lubricating methods for the radial bearings were also being studied.

Significant milestones, however, were passed in the development and testing of the PCA on the TBC. Figure 4 shows the PCA mounted and operating on the TBC at the PDTS. This test series, completed in March, included the electrical transport subsystem qualification of the inverter, switchboard and power grid interconnection. The PCA operated over a complete range of test conditions including:

(1) Variable insolation levels and cloud passages.

(2) Planned and random start-ups and shutdowns.

(3) Various inverter input voltage settings (equivalent to variable turbine speed).

(4) All control modes and parameters and other operating conditions.

A total of 33.6 hours of on-sun power generation was achieved and tests were satisfactory over the range of conditions. The tests verified the compatibility of all elements required to support a Small Community Solar Thermal Power Experiment. Key results are summarized in Table 2.

Figure 5, Effect of Cloud Passages on ORC Receiver Pressure and Fluid Outlet Temperature, is a pressure and temperature history of one run with the insolation interrupted by a series of clouds. The duration and intensity are indicated by the plot of solar insolation.

As part of the ORC module FACC contracted the parabolic dish concentrator No. 1 (PDC-1) steel fabrication to ALCO Machine Company, Birmingham,

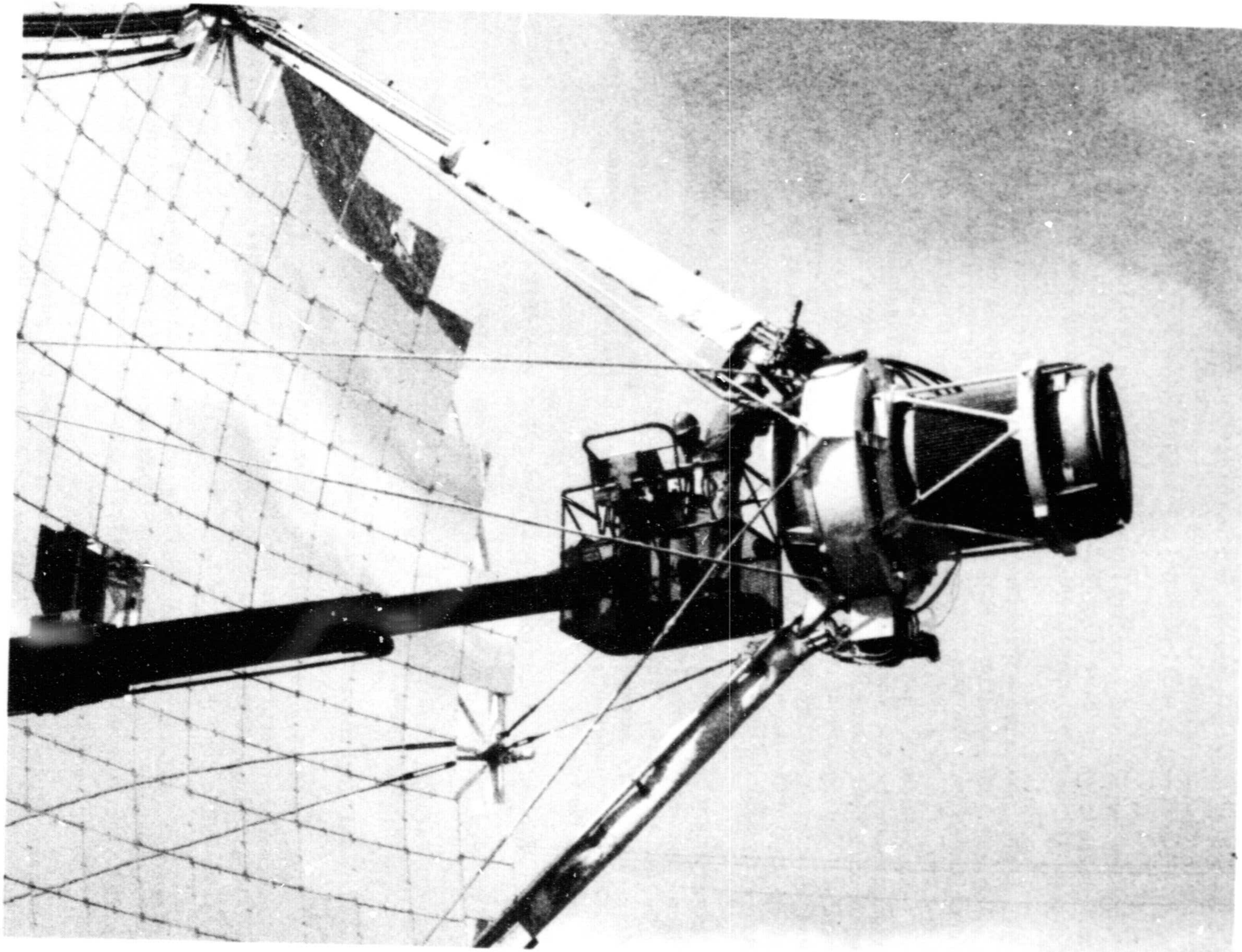

Figure 4. Organic Rankine-Cycle Engine Under Test at the Parabolic Dish Test Site

Table 2. Summary of ORC Test Accomplishments and Problems

(1)	33 hours of power generation under wide range of operating and solar conditions
(2)	First demonstration of a module control system
(3)	Verification of control stability, including operating under severe transient conditions
(4)	95% receiver efficiency at 400°C (750°F) and 980 W/m^2 insolation
(5)	23% organic Rankine engine/generator efficiency
(6)	19% efficiency from incident insolation to electricity out of alternator-rectifier (before parasitic losses)
(7)	Demonstrated inverter voltage (load) control concept for a single module and for two modules, one simulated
(8)	Excessive bearing wear
(9)	PMA arcing between winding and stator

Alabama, and the foundation and erection at the PDTS to Ashland Construction Company and Valley Iron, respectively, both of Lancaster, California. The reflector panels were fabricated by Design Evolution 4, Lebanon, Ohio, under contract to JPL.

The PDC-1, Figure 6, is designed to provide 80 kWt at 1000 W/m^2 of insolation and has the characteristics listed in Table 3.

The reflector panels have ultra-violet stabilized Llumar film laminated to plexiglass that is bonded to fiberglass sandwich substrates. The 36 panels are arranged in 12 gore segments, 3 panels per gore, and bolted to internal ribs. The base support is a tubular structure mounted on wheels; a track provides azimuth travel. Elevation rotation uses the base structure-supported bearings at the edge of the dish. Cable drive mechanisms are used for both azimuth and elevation drives.

PDC-1 performance tests are being conducted at the PDTS. Initial tests indicate that performance will meet design specifications during completion of tests in FY 1984. Upon completion, the ORC PCA is to be mounted on the PDC-1 for module testing.

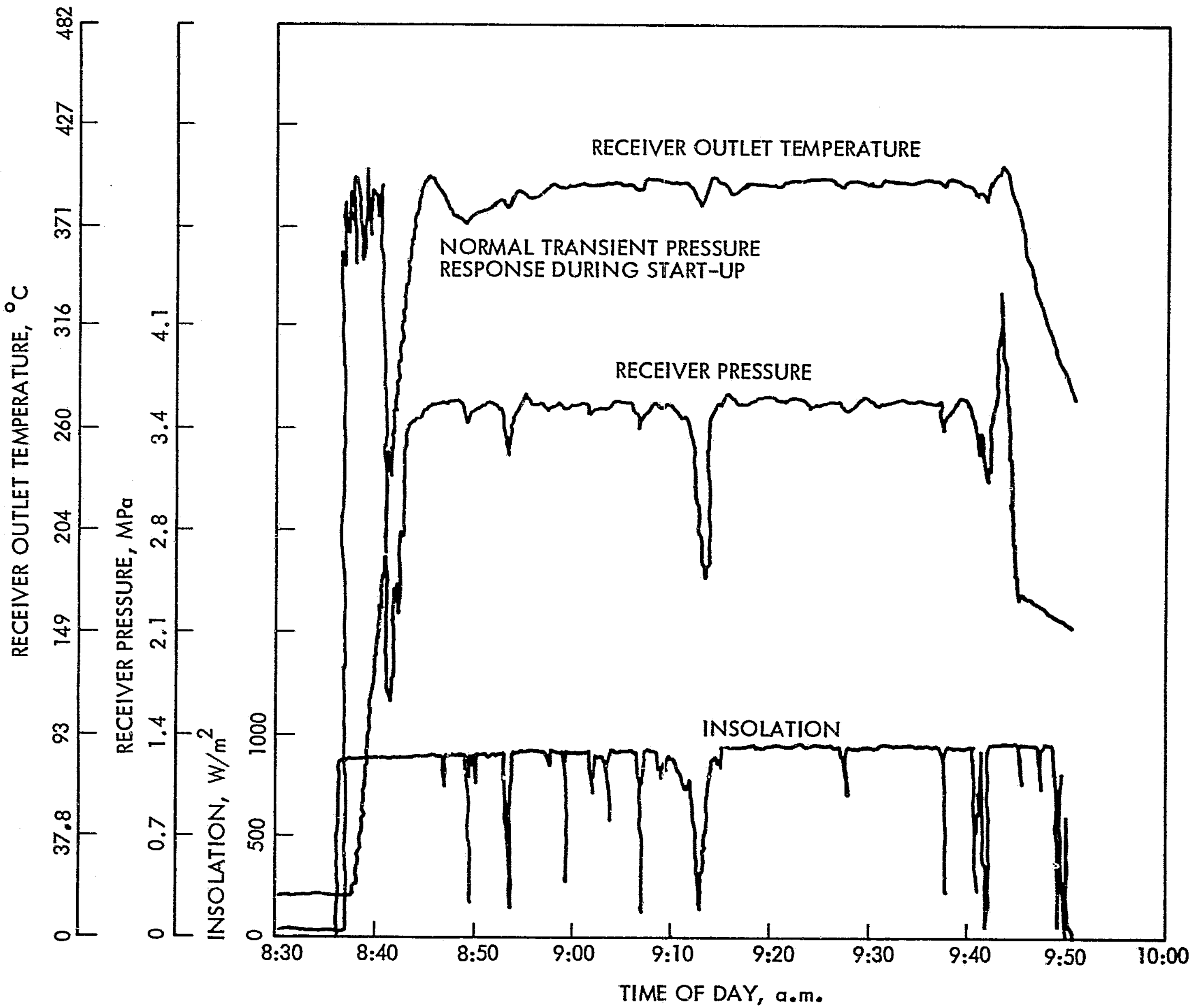

Figure 5. Effect of Cloud Passage on ORC Receiver Pressure and Fluid Outlet Temperature

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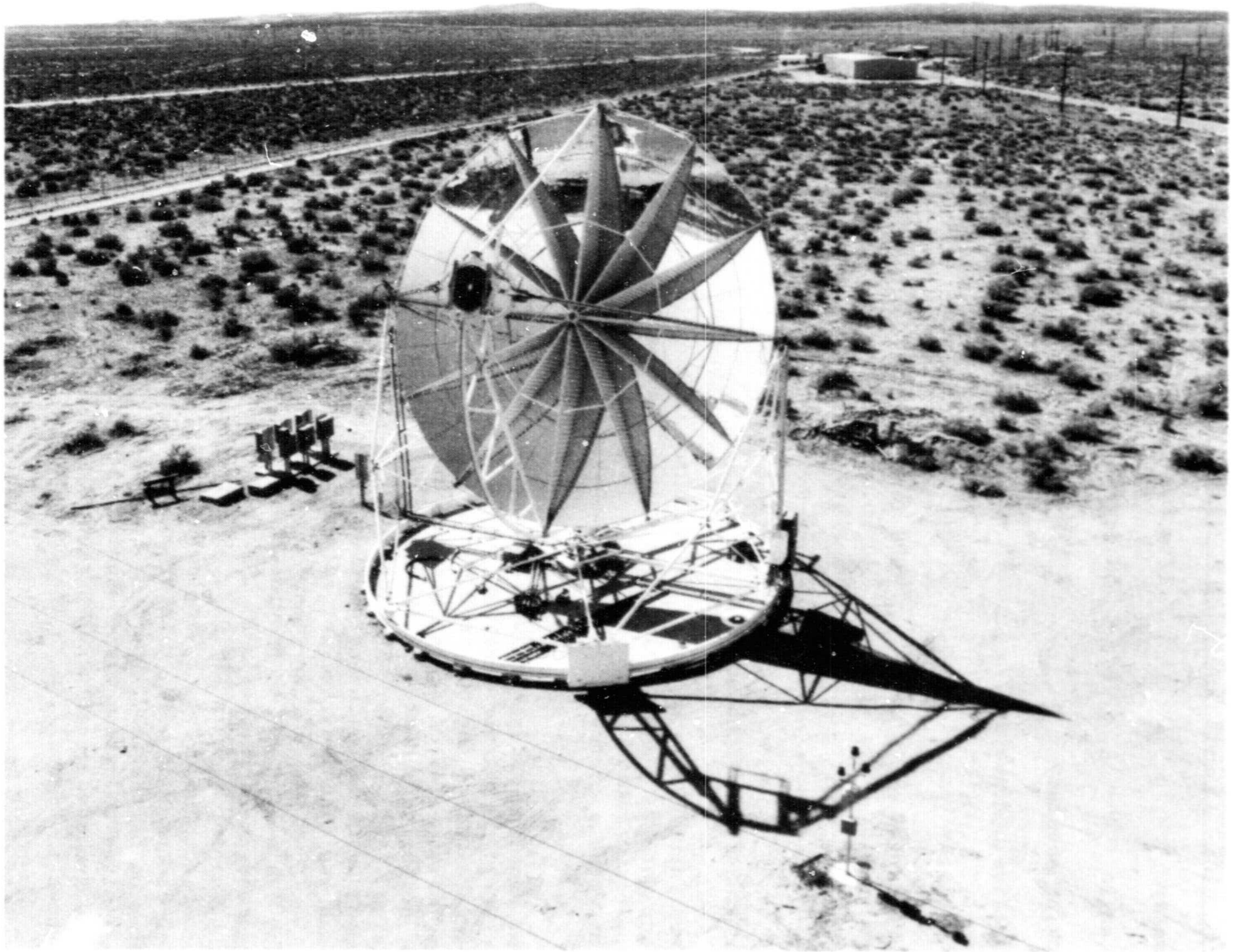

Figure 6. Parabolic Dish Concentrator No. 1 Installed at the PDTS

Table 3. Parabolic Dish Concentrator Characteristics

Characteristics	PDC-1	PDC-2
Diameter	12 m (40 ft)	11 m (36 ft)
Rim angle	53 degrees	45 degrees
Tracking accuracy	$\pm$ 1/8 degree	$\pm$ 1/8 degree
Reflective surface area	113 m^2 (1216 ft^2)	95 m^2 (1020 ft^2)
Reflectivity (specular)	0.78	0.95
Concentration ratio (geometric)	1000 for a 38-cm (15-in.)-diameter aperture	2000 for a 240-mm (9.4-in.)-diameter aperture

C. BRAYTON-CYCLE TECHNOLOGY

Late in FY 1981 a contract was executed with Sanders Associates (S/A) to design and integrate a parabolic dish module consisting of a concentrator, air receiver, recuperated Brayton-cycle gas turbine engine with hybrid combustor, generator, module controls, and other subsystems necessary to complete the module.

The baseline subsystems were defined as an Acurex parabolic dish concentrator (PDC-2), a S/A air receiver, and a pair of recuperated subatmospheric Brayton-cycle (SABC) engines from Garrett AiResearch Manufacturing Company, Torrance, California. A second module with another system contractor was planned, utilizing a Garrett Turbine Engine Company (GTEC) Solarized Advanced Gas Turbine (SAGT) engine. The advanced gas turbine (AGT) engine is under development by GTEC for the automotive industry by NASA's Lewis Research Center and would be modified for solar application.

The S/A effort was to provide the module and subsystem design and initiate long-lead procurements in FY 1982 leading to fabrication, assembly, and testing of a prototype in FY 1983. Funding limitations permitted only a single system contract and precluded implementation of the second module and also put the PDC-2 contract on hold. The S/A planning effort was changed to include consideration of the SABC, the SAGT, and other available Brayton engine designs but was limited to system trade studies and some preliminary design activity. Acurex had produced a set of unchecked drawings and specifications for the PDC-2, shown in Figure 7, with the characteristics listed in Table 3.

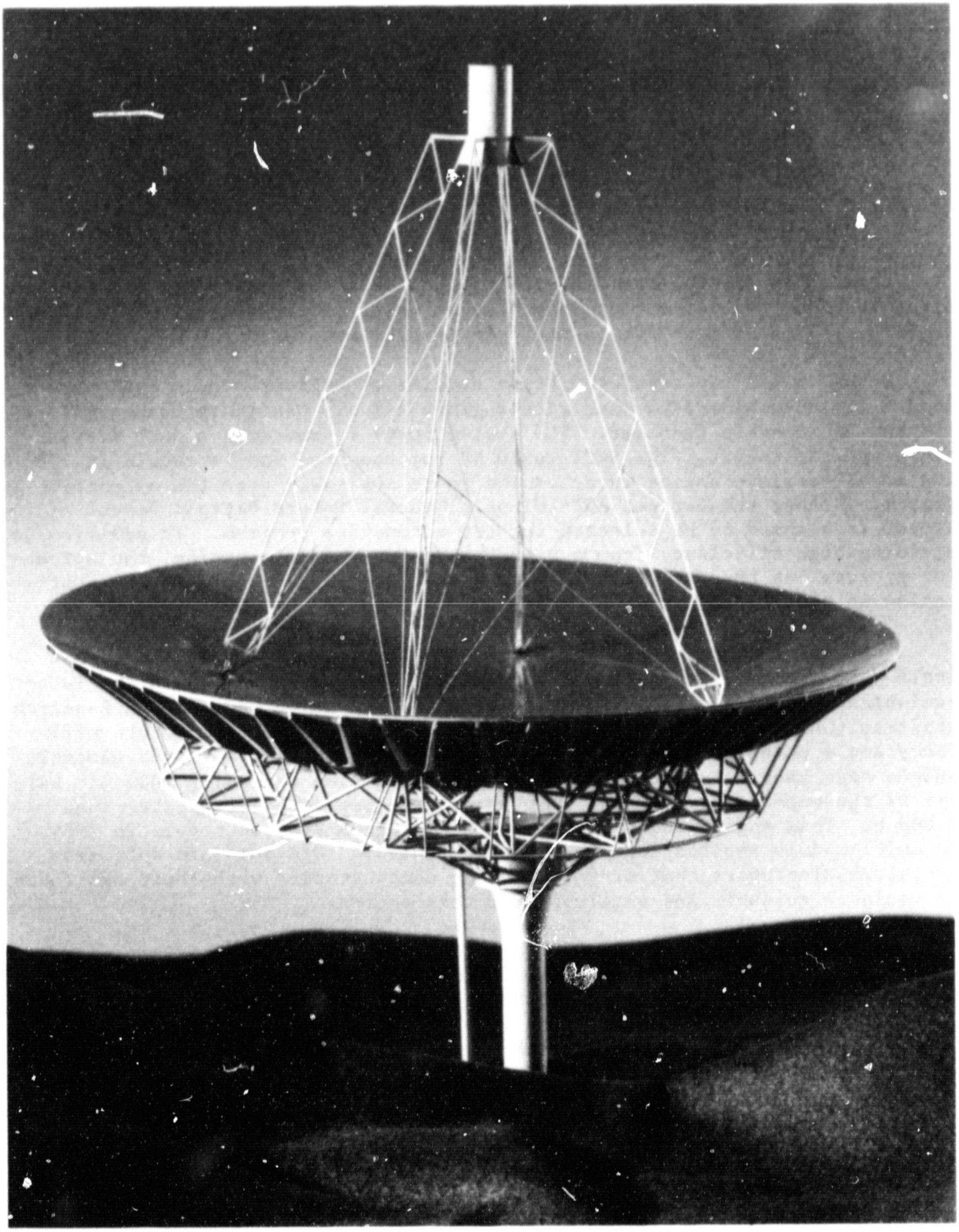

Figure 7. Parabolic Dish Concentrator No. 2

Bench testing of the metal AGT included runs to 100,000 rev/min under load. Development problems have included:

(1) Interference on re-start due to thermal expansion due to soak back.

(2) Intermittent dynamic stability problems in the 75,000 to 100,000 rev/min range.

(3) Excessive leakage in the rotating ceramic regenerator seals and in other joints.

Some of those problems are specific to the metal engine while others must be resolved for the later ceramic engine as well. Solar testing of the SAGT at the PDTS will await more AGT testing and problem resolution.

By March S/A had completed trade studies of various module configurations. Included were five candidate engines and six candidate concentrators. All used the Sanders receiver. The system study recommended a dual Brayton module program thrust. The SAGT would be incorporated into a module in 1985-86 when an all-ceramic engine is scheduled to be available from the automotive AGT program. Either the Garrett AGT-101 or a General Motors Detroit Diesel Allison AGT-100 is planned to be selected for the automotive program. In addition to providing high efficiency from a high-temperature ceramic engine, the automotive program has the potential for low costs associated with automobile production in the 1990s.

The near-term module in this dual thrust program would be based on a single SABC engine and a suitable concentrator. This engine is in the latter development stages for a gas-fired heat pump application under a Gas Research Institute (GRI) program and provides a near-term option with moderate efficiency and a potential near-term production base. Five Mark III development designs have been fabricated with operating test time exceeding 1000 h. Lifetime of the engine for the heat pump program is projected at greater than 50,000 h. This engine could be incorporated into a Brayton module in 1984, and multi-module applications could begin in 1985. S/A obtained data from several manufacturers that were developing concentrators with their own funds and would be suitable and available for this option.

Sanders was also given the task of conducting a solar Brayton-cycle receiver/engine feasibility test with GTEC support at the PDTS in FY 1984. Tests are to be performed on a test bed concentrator (TBC) using a PCA consisting of an SAGT-1A GTEC engine (a metallic development version of the AGT together with ducting, gearbox, electric generator, etc.) and a S/A receiver. The purpose of the feasibility tests are to:

(1) Integrate and test the PCA.

(2) Obtain operational characteristics for the PCA in solar and fuel modes.

(3) Characterize the receiver.

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Figure 8 is a photograph of a SAGT-1A engine coupled with a Sanders receiver undergoing fit and checkout tests at the GTEC facility in Phoenix, Arizona.

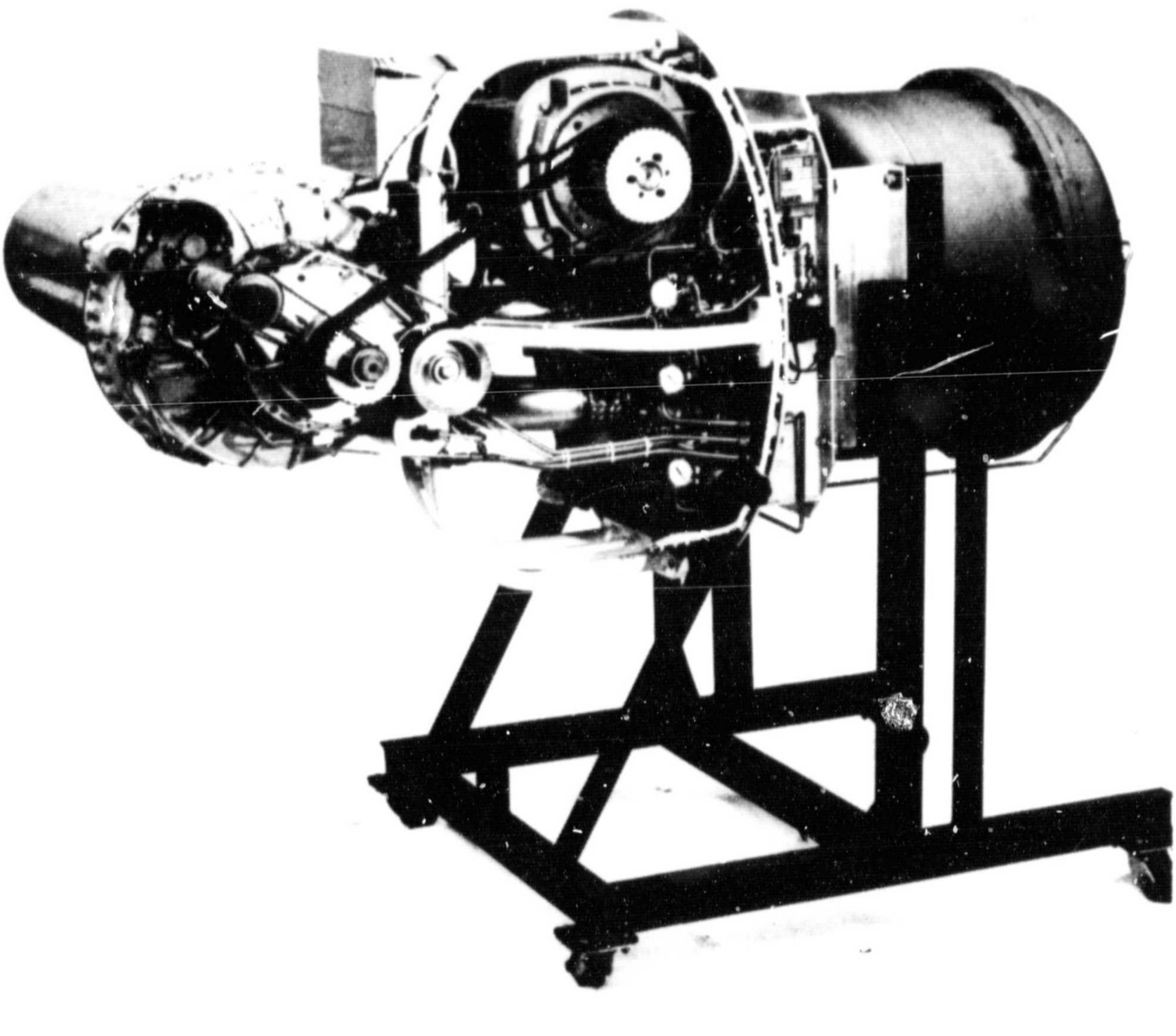

Figure 8. Brayton Module Power Conversion Assembly

SECTION III

SYSTEM EXPERIMENTS

A. SMALL COMMUNITY SOLAR THERMAL POWER EXPERIMENT

The Small Community Solar Experiment (SCSE) was initiated in 1977 when Congress appropriated funds to build an experimental solar power plant that would be a first step in addressing the needs of the small community sector. FACC was selected to develop the ORC-based technology for this experiment. The progress made in this development is discussed in Section II. B.

In FY 1982, Congress appropriated $4.0 M to construct the experiment. During the course of the year DOE directed the construction of a 100-kWe plant, a size considered sufficiently large to satisfy most of the technical requirements of the experiment while meeting the intent of the Congress to minimize the cost.

Concurrently with the development of the organic Rankine module, DOE was involved in the selection of a site for the experiment. During FY 1982 DOE selected Osage City, Kansas, for the SCSE plant with Molokai, Hawaii, selected as the alternate site. This decision culminated the selection process in which 44 communities across the country competed. Figure 9 illustrates the sites involved in this competition. Figure 10 provides information about the prime site, Osage City, Kansas.

Osage City is an ideal setting for the experiment because it is representative of a large number of small cities throughout the country. It has its own generation capability but also purchases power when it is economically advantageous to do so. Insolation at Osage City is about average for the nation.

DOE has entered into negotiations with Osage City with the objective of signing a Cooperative Agreement in FY 1983 for site participation. Preparation of the site will begin in April 1984, and installation of the first modules begins in August 1984. Plant system test and operation is scheduled to begin in February 1985.

B. CAPITOL CONCRETE EXPERIMENT

A parabolic dish collector manufactured by Power Kinetics, Incorporated (PKI), Troy, New York, and installed by Applied Concepts Corporation (ACC), Reston, Virginia, was constructed at Capitol Concrete Products, Topeka, Kansas. The engineering experiment was conducted to determine the technical feasibility of using the PKI Fresnel point-focusing collector to provide process steam in an industrial environment, in this case for the curing of concrete blocks.

The concentrator consists of 864 mirrors, each measuring 305 x 305 mm (1 x 1 ft), mounted on 108 identical curved modular support assemblies

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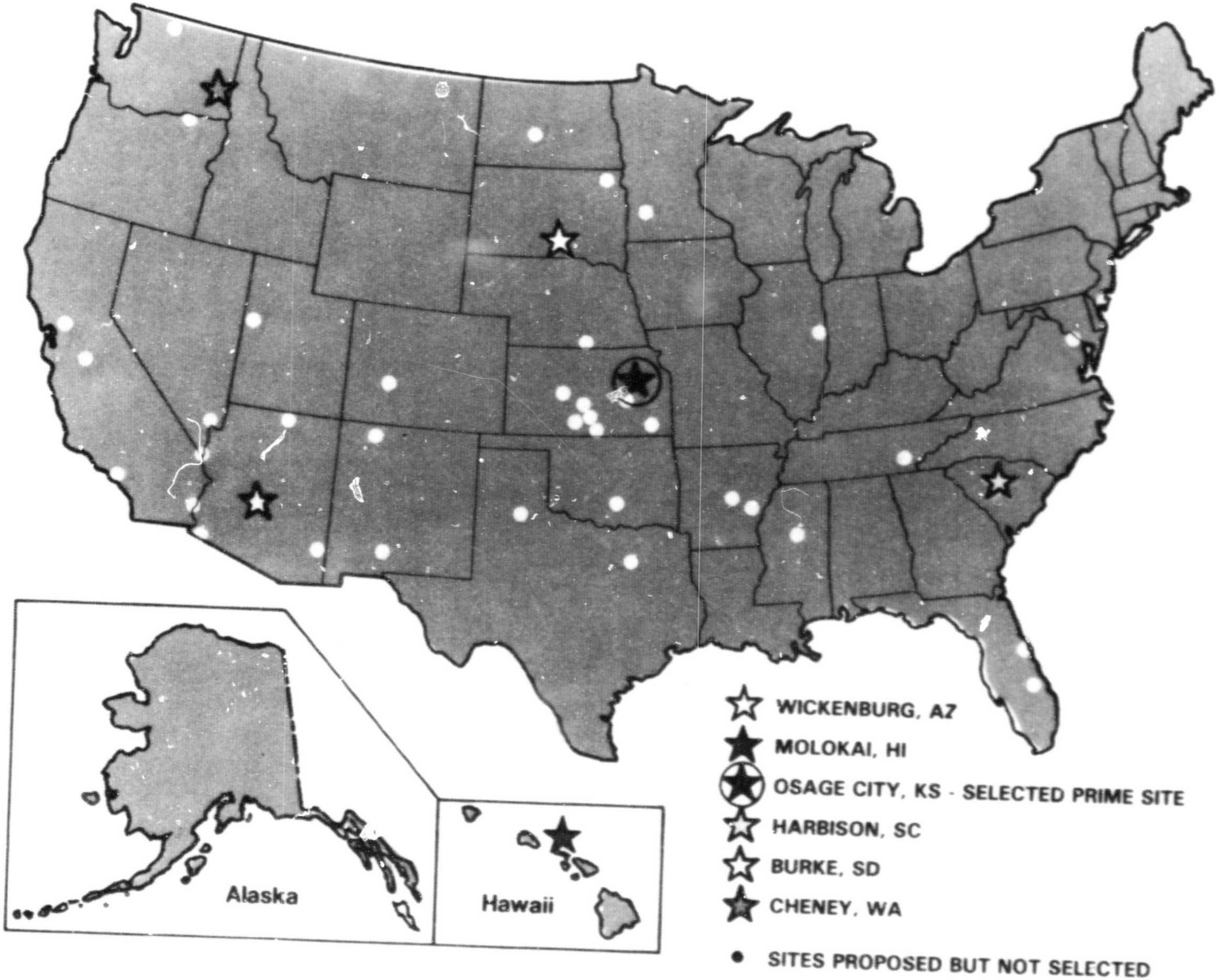


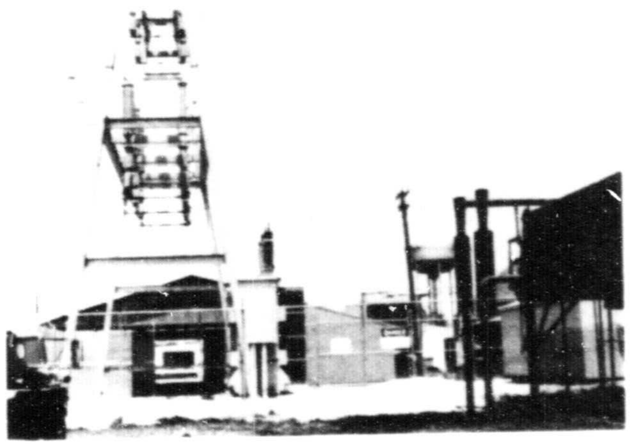
Figure 9. Proposal Participants and Site Selection Finalists for the Small Community Solar Experiment

SMALL COMMUNITY SOLAR THERMAL EXPERIMENT
OSAGE CITY, KANSAS

- MUNICIPAL UTILITY
- LOCATED IN CENTRAL U.S. – EASILY ACCESSIBLE
- 6-MWe PEAK DEMAND
- LOCAL GENERATION FROM DIESEL OR NATURAL GAS – 10-MWe PEAK CAPACITY
- FIVE UNITS: 1–2.8 MWe EACH
- PURCHASE POWER FROM KANSAS POWER AND LIGHT IN WINTER
- SERVES A POPULATION OF 2800
- NUMBER OF EMPLOYEES: 8 PLUS LINE CREW

SCSE SITE SELECTION

EXISTING PLANT



NEW SITE

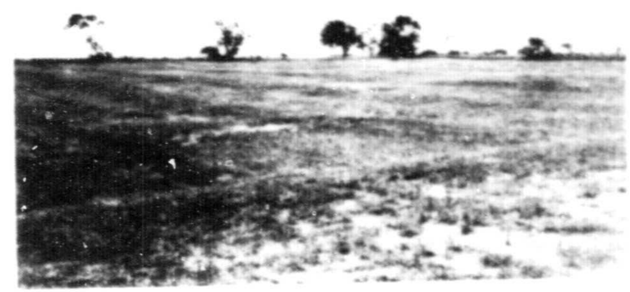


Figure 10. Small Community Solar Experiment, Osage City, Kansas

attached to a lightweight space-frame structure of steel tubing members and steel plate joints. The 80-m^2 (864-ft^2) array, approximately 9.1 m (30 ft) high and 10.4 m (34 ft) wide, mounts on a 7.3-m (24-ft)-diameter steel track. The track rests and rotates on eight casters mounted on a foundation provided by Capitol Concrete.

The dual axis tracking concentrator focuses the sunlight on the receiver throughout the day. Tracking is accomplished by rotating the collector track on its casters for azimuth and simultaneously rotating each mirror support assembly around its center of gravity for elevation.

The concentrator focuses sunlight on a cavity receiver consisting of a parallel tube boiler, a flux trap, and a fiberglass board-insulated galvanized steel housing. The 11-m (36-ft) boom supporting the receiver at the focal plane is hinged at the concentrator base for easy access and stabilized with guy wires. A piston pump supplies boiler water from a feed tank at a maximum pressure of 1.0 MPa (150 psi). Capitol Concrete supplies ambient temperature treated water or hot condensate to the feed tank. Steam at 0.67 MPa (100 psi) is provided to Capitol Concrete by a rotating union connector at the collector base.

A microcomputer control subsystem accepts feedback control signals through shadowband sensors mounted on the collector. Stored sunrise and sunset data permit start-up, shutdown, and tracking during cloud cover. Sensors also detect maximum allowable wind gust speeds, lack of sun for ten minutes, and collector malfunctions that direct the microcomputer to stow the collector mirrors in an inverted position. Automatic fluid loop drain-down is commanded for fluid temperatures below 4.5°C (40°F). The control system operates from a trickle-charged dc battery, assuring operation in the event of a power failure.

Figure 11 shows the PKI collector mounted on an elevated platform close to the plant steam supply line, minimizing thermal transport losses and shading from existing structures.

Preliminary collector test results of a similar unit installed at the Sandia National Laboratories at Albuquerque (SNLA) Mid-Temperature Systems Test Facility showed an approximate 80% efficiency at 980 W/m^2 insolation or about 60 kWth. These results compare with a specification of 75% efficiency at insolation levels above 870 W/m^2.

The successfully operating plant was turned over to the DOE Albuquerque Operations Office during FY 1982 for operational evaluation.

Figure 11. PKI Collector in Operation at the Capitol Concrete Block Plant in Topeka, Kansas

SECTION IV

TEST FACILITIES SUPPORTING THE PARABOLIC DISH PROGRAM

The two TBCs, each measuring 11 m (36 ft) in diameter and providing 78 kWth at the focal plane at 1000 W/m^2 insolation, continued to prove their worth and had excellent reliability throughout the year. The TBCs were used as test vehicles to characterize a solar/hybrid Stirling power conversion assembly, a solar-only Stirling power conversion assembly, and an organic Rankine power conversion assembly. Because of their excellent optical characteristics, the TBCs were also used at night to detect high-energy gamma radiation. A significant addition was made to the PDTS with the installation of a third dish, Parabolic Dish Concentrator No. 1 (PDC-1). Figure 12 shows the PDC-1 and the two TBCs at the PDTS.

Activities at the PDTS at Edwards Test Station were as follows:

(1) Initiated and completed a series of tests of the solar/hybrid Stirling power conversion assembly on TBC-2. Net power was delivered to the SCE grid.

(2) Initiated and completed a series of tests of the organic Rankine-cycle power conversion assembly on TBC-1. Fifteen kilowatts of electric power were generated for a solar-to-electric conversion efficiency of 19%, inverter and parasitic losses not included. The power was delivered to the SCE grid.

(3) Initiated and completed a series of tests of a Stirling power conversion assembly, using solar-only receivers on a TBC for United Stirling AB. Three different solar receiver designs were coupled to the Stirling engine during these tests, and 25 kW of electric power were generated for a solar-to-electric conversion efficiency of 29% prior to parasitic losses. This power was delivered to the SCE grid.

(4) Conducted calibration tests for both TBCs for concentrator characterization and for providing specific power levels for a particular experiment or test usage. Mirror realignment was performed to support the solar receiver Stirling PCA testing. A cavity calorimeter and a flux-mapper were used for the characterization.

(5) Installed a GORTRAC cable and hose carrier system on each TBC, removing virtually all stresses on the cables and hoses during azimuth motion of the TBCs. The carrier significantly increases the operational life of the cables and hoses.

(6) Installed a back-up slewing system on each TBC, using a 1.5-hp air motor for moving the concentrators off-sun in the event of a commercial power failure.

(7) Installed a TV camera on each TBC. The four center mirrors, which had little or no input to the concentrator because of shading from the PCA, were removed. The camera provides safe, direct observation of the concentrator focal plane while slewing on and off-sun and during all testing.

(8) Moved an Eppley pyrheliometer from a ground-mounted location onto each TBC for observing the same insolation as the concentrator. This provides a more accurate assessment of concentrator performance. The pyrheliometers were positioned on the low side of the dishes, permitting accurate boresighting while the concentrator is on-sun.

(9) Initiated and completed a series of tests to detect high-energy gamma radiation being emitted from various celestial objects. Dr. Richard Lamb, Professor of Physics at Iowa State University, was the Principal Experimenter. Both TBCs were used during these nighttime tests. The technique utilized a photomultiplier mounted at the focal plane of each TBC, which in turn were pointed accurately (and simultaneously) at the celestial object to be observed and then employing drift scans for the observation and recording of data.

(10) Initiated a series of materials tests on TBC-1 to find aperture material that will withstand sun walk-off as well as normal slewing on and off-sun.

(11) Installed a third dish, measuring 12 m (39 ft) in diameter. This dish has been designated as Parabolic Dish Concentrator No. 1 (PDC-1). Checkout of PDC-1 has been initiated.

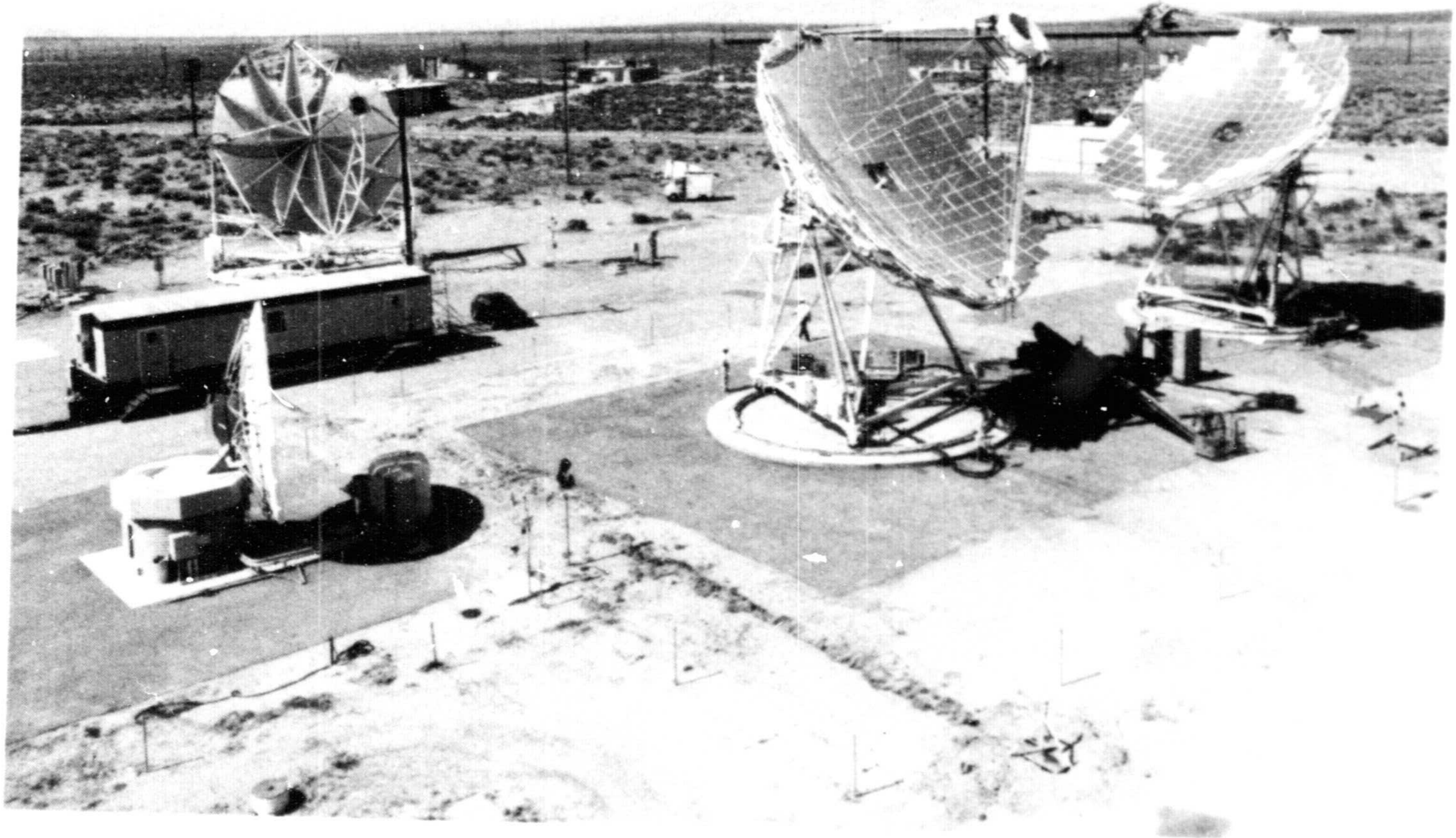


Figure 12. Parabolic Dish Test Site, Edwards, California

SECTION V

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