5104-61, Vol. I
Solar Thermal Power Systems
Point-Focusing
Distributed Receiver Technology Project
NASA CR 159715

DOE/JPL-1060-30, Vol. 1
Distribution Category UC-62

Annual Technical Report

Fiscal Year 1979

Volume I: Executive Summary

January 15, 1980

Prepared for
U.S. Department of Energy
Through an agreement with
National Aeronautics and Space Administration
by
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California
and
NASA Lewis Research Center
Cleveland, Ohio

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16. Abstract

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Present studies involve designs of modular units that collect and concentrate solar energy via highly reflective, parabolic-shaped dishes. The concentrated energy is then converted to heat in a working fluid, such as hot gas. In modules designed to produce heat for industrial applications, a flexible line conveys the heated fluid from the module to a heat transfer network. In modules designed to produce electricity, the fluid carries the heat directly to an engine in a power conversion unit located at the focus of the concentrator. The engine is mechanically linked to an electric generator. A Brayton-cycle engine is currently being developed as the most promising electrical energy converter to meet near-future needs.

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

ABSTRACT

This report details accomplishments of the Point-Focusing Distributed Receiver Technology Project during Fiscal Year 1979.

The objective of this Project is to produce thermal and electrical power from the sun's radiated energy by means of Point-Focusing Distributed Receiver (PFDR) technology. A specific goal of this effort is to develop industrial capability and system designs which will enable power produced by PFDR technology to be economically competitive with other energy sources.

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FOREWORD

The Distributed Receiver Systems Section is a part of the Thermal Power Systems Branch of the Department of Energy's (DOE) Division of Central Solar Technology. The Section's responsibilities include development of technology and applications for parabolic dish systems.

This Executive Summary presents the results of activities conducted by the Jet Propulsion Laboratory during Fiscal Year 1979 in support of this DOE Section. Specifically, it discusses the Point-Focusing Distributed Receiver (PFDR) Technology Project.

The PFDR Technology Project was initiated in August 1977 by an interagency agreement between the National Aeronautics and Space Administration (NASA) and DOE. The Jet Propulsion Laboratory (JPL) was named as the manager and the NASA Lewis Research Center (LeRC) was named to provide specific support to the project in the power conversion area. These two organizations, working with federal agencies, industry and universities, are leading in the development of point-focusing technology for use in applications projects.

This Summary covers the accomplishments during the second year of the Project and is intended as a means of briefly describing them to industry and universities. If additional information is needed or if the reader wishes to discuss any items, please contact Dr. John W. Lucas, Assistant Thermal Power Systems Project Manager for PFDR Technology, at Jet Propulsion Laboratory, FTS 792-9368, Commercial (213) 577-9368 or write him at Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, California 91103.

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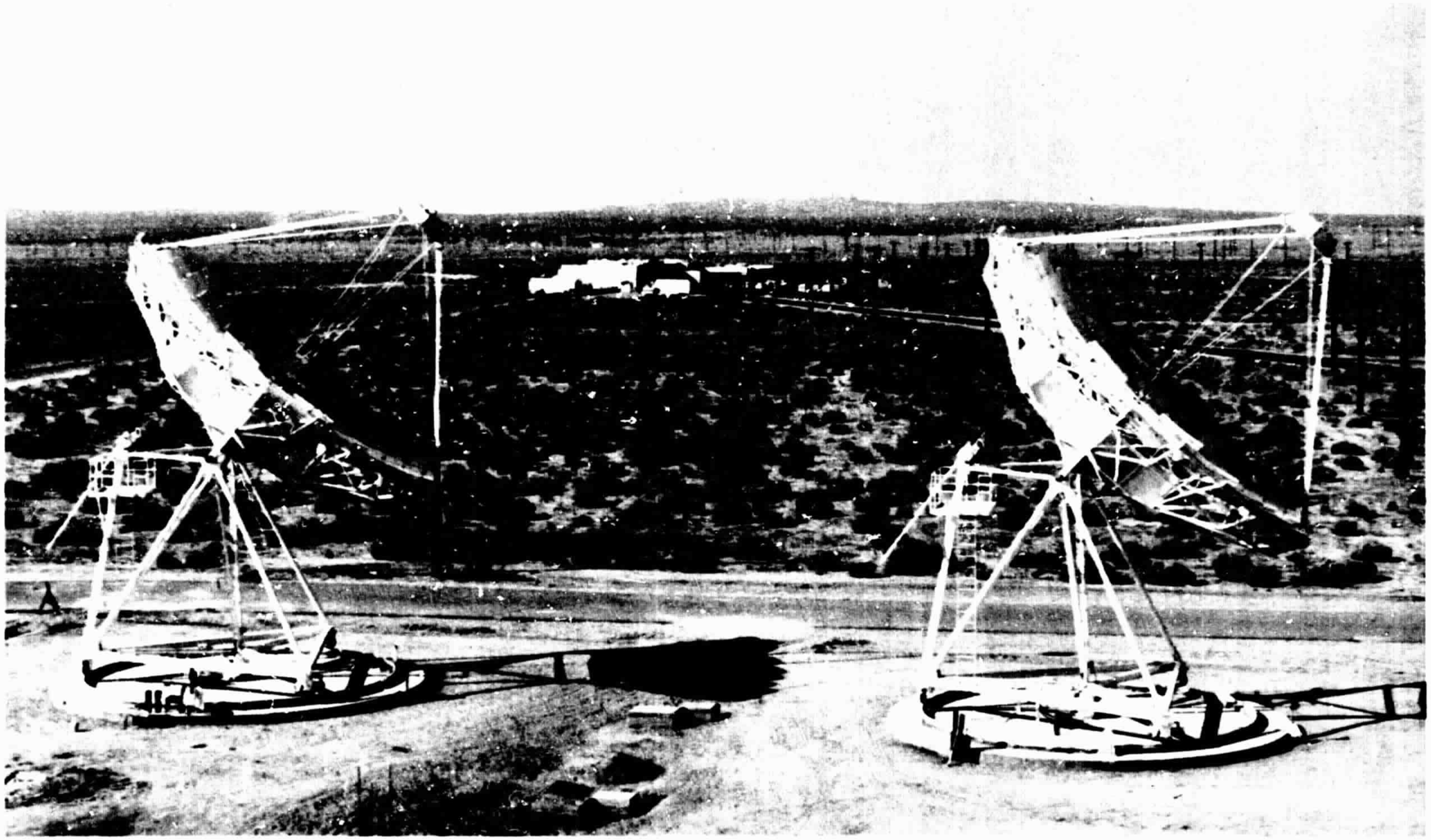

Test-Bed Concentrators at the Point-Focusing Solar Test Site

SECTION I

INTRODUCTION

The Point-Focusing Distributed Receiver (PFDR) Technology Project is concerned with small solar-thermal power systems for providing thermal and/or electrical power. The goal of this Project is to support the industrial development of point-focusing distributed receiver technology which will provide the most favorable life-cycle costs per unit of useful energy produced.

Point-Focusing Distributed Receiver systems are one form of dispersed power systems that can generate electricity and provide thermal power for rural communities and farms, municipal customers and industrial users by means of modular, sun-tracking collectors. The thrust of the present technology development is to bring prototype systems into operation by 1982 and to further improve systems, both in cost and efficiency, by 1985. As shown in Figure 1, the basic subsystems include the concentrator and receiver, combined called the collector, and the power conversion unit which consists of a suitable heat engine, alternator, and associated controls. Currently, the leading candidates for engines are the organic Rankine, the gas Brayton (open and closed cycle), and the Stirling. For thermal power production, the power conversion unit is replaced by the energy transport network.

The preliminary cost and performance targets for electric power are shown in Table I; targets for thermal power are being prepared. The cost targets will be achieved by industry employing new designs and mass-production techniques for the major subsystems. For concentrators and receivers it is expected that the reduction arising from mass production, relative to costs of prototypes fabricated in very limited quantities, will be a factor of five; for power conversion units the reduction factor is expected to be a factor of ten. In addition to the initial cost targets, appropriate attention will also be given to operation and maintenance (O&M) costs.

The major activity of the Project is to direct the development by industrial firms of the major subsystems listed in Table I. The first-generation subsystems are to be completed in FY 1982 (see Figure 2) to meet the associated performance targets. The costs shown in Table I should be interpreted as the costs that would result if the indicated mass-production levels were achieved. The second generation is to be completed in FY 1986 for the corresponding targets. The parallel effort to estimate mass-production costs and to assist in reducing them is shown at the bottom of Figure 2.

Funding information for FY 1979 is provided in the Solar Thermal Power Systems Program Summary to be published by the Department of Energy early in 1980.

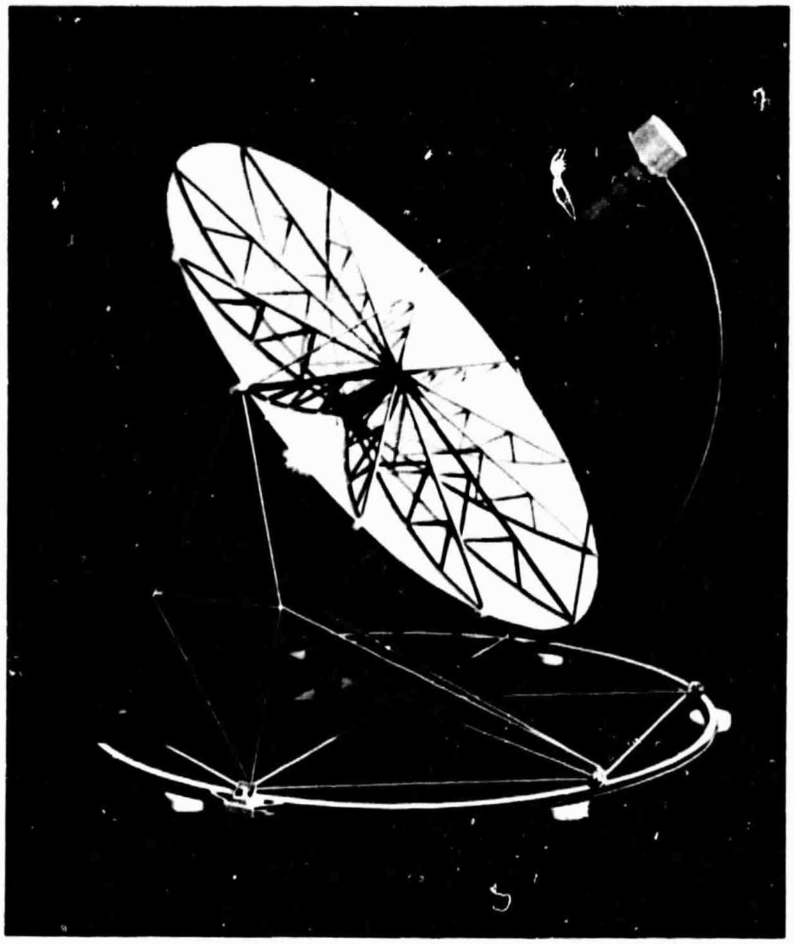

Figure 1. Typical PFDR Parabolic Dish Module

Table I. Preliminary Cost and Performance Targets for Electric Power

Subsystem	Target Item	1982 First Generation (1978 $)	1986 Second Generation (1978 $)
Concentrators	Capital Cost*	\$100-150/m^2	\$70-100/m^2
	Mirror Reflectance	78%	92%
Receivers	Capital Cost*	\$40-60/kWe	\$20-40/kWe
	Efficiency	82%	85%
Power Conversion	Capital Cost*	\$200-350/kWe	\$50-200/kWe
	Efficiency	25-35%	35-45%

*Range of first-generation costs if mass-produced at 5,000-25,000/yr.
Range of second-generation costs if mass-produced at 10,000-1,000,000/yr.

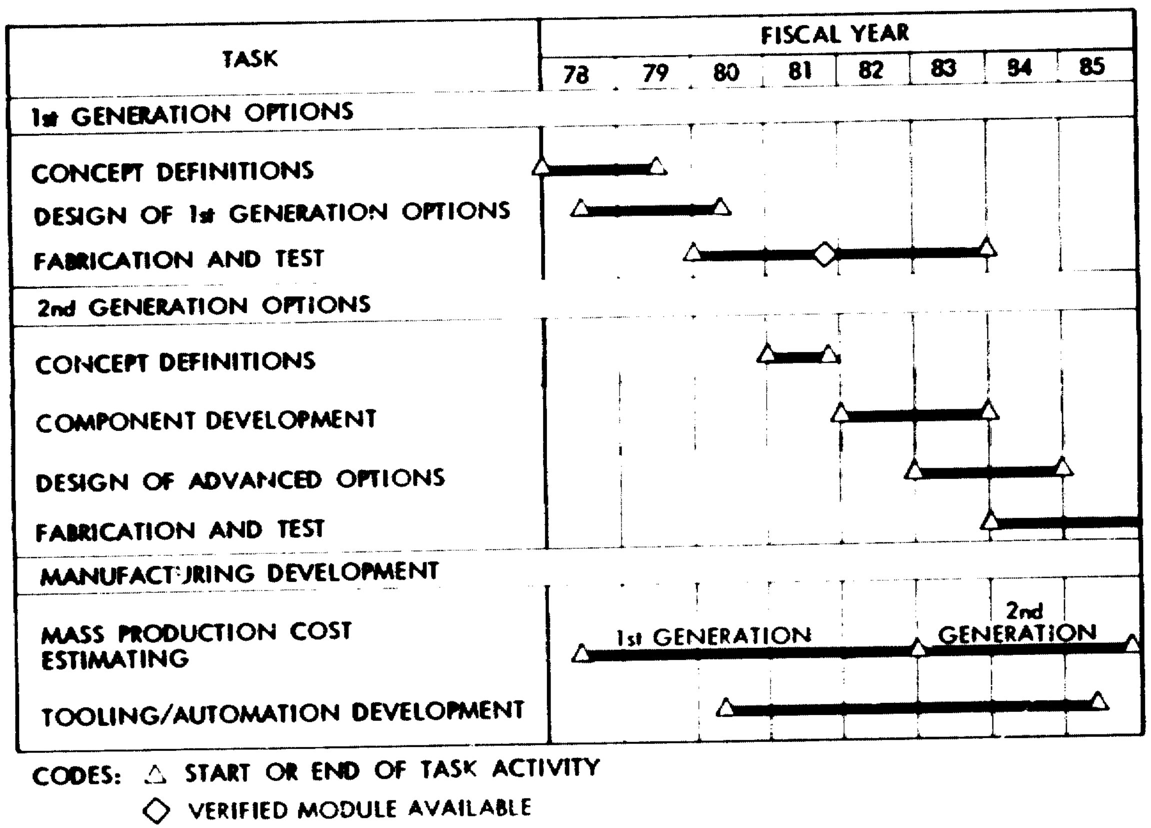

Figure 2. Overall Schedule of Subsystem Development

SECTION II

TECHNICAL APPROACH

The majority of the requirements of this Project are met by contracts to industry and universities. JPL maintains a staff to manage the Project and has developed a base of technical expertise to coordinate, monitor, direct and support, as required, the activities under contract. In those instances where independent analyses are deemed desirable by DOE, JPL provides the resources and management to conduct such studies.

The Project is divided into seven tasks. Table II summarizes the major objectives of each task. A summary of major project milestones through FY 1984 is given in Figure 3.

The technology effort centers on the development of key subsystems for point-focusing distributed receiver systems. Emphasis is on the major subsystems of low-cost concentrators, receivers and associated energy transport, and power conversion. Systems engineering coordinates the establishment of interfaces and functional requirements for each subsystem. It should be noted that the concentrator, receiver and power conversion units assembled together comprise an individual module for electric power generation.

The major test periods are shown in Figure 4. Testing is performed at the JPL Point-Focusing Solar Test Site (PFSTS)* located at Edwards Test Station, near Lancaster, California. Testing of Test-Bed Concentrator No. 1 will begin in early FY 1980. After test and evaluation the initial steam receiver will be installed on it and tested. The steam transport network will then be added to the assembly and tested. Following testing of Test-Bed Concentrator No. 2, the air receiver will be installed on it and tested. The air-Brayton power conversion unit will then be mounted on the receiver and the module tested.

After modules based on the Test Bed Concentrator have been developed and tested, modules based on the Low Cost Concentrator will be assembled and tested, as shown in the lower part of Figure 4.

Periodic assessments of the technology are planned to determine which configurations should be pursued in subsequent time periods. These assessments will be led by the Systems Engineering task area and will include inputs from both systems and each subsystem area. Anticipated assessment results include recommendations for the type of subsystem, and the temperature and power levels for each subsystem.

*In early FY 1980 the name was changed to Parabolic Dish Test Site.

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Table II. Project Objectives by Task

Task	Objectives
Project Management	Manage the project in order that project goals are met within the available budget, on schedule and in accordance with the annual operating plan.
Systems Engineering	Lead and provide support to design team.
	Define and analyze system configurations.
	Establish and monitor system and subsystem performance/cost targets.
Concentrator Development	Develop point-focusing concentrators to provide sufficient temperatures for steam Rankine, gas Brayton, and Stirling cycles.
	Optimize designs for low cost in large quantity production.
Receiver and Heat Transport Network Development	Develop cost-effective receivers to provide superheated steam and gas.
	Develop cost-effective heat transport networks.
Power Conversion	Provide efficient, cost-effective power conversion.
	Provide Brayton engines initially, and advanced Brayton and Stirling engines following early development by the Advanced Solar Thermal Technology Project.
Test and Evaluation	Provide a test site at minimum cost.
	Perform testing and evaluation of point-focusing distributed receiver subsystem modules.
Manufacturing Development	Estimate mass-production costs of subsystems.
	Develop tooling for mass production.
	Develop associated automation techniques.

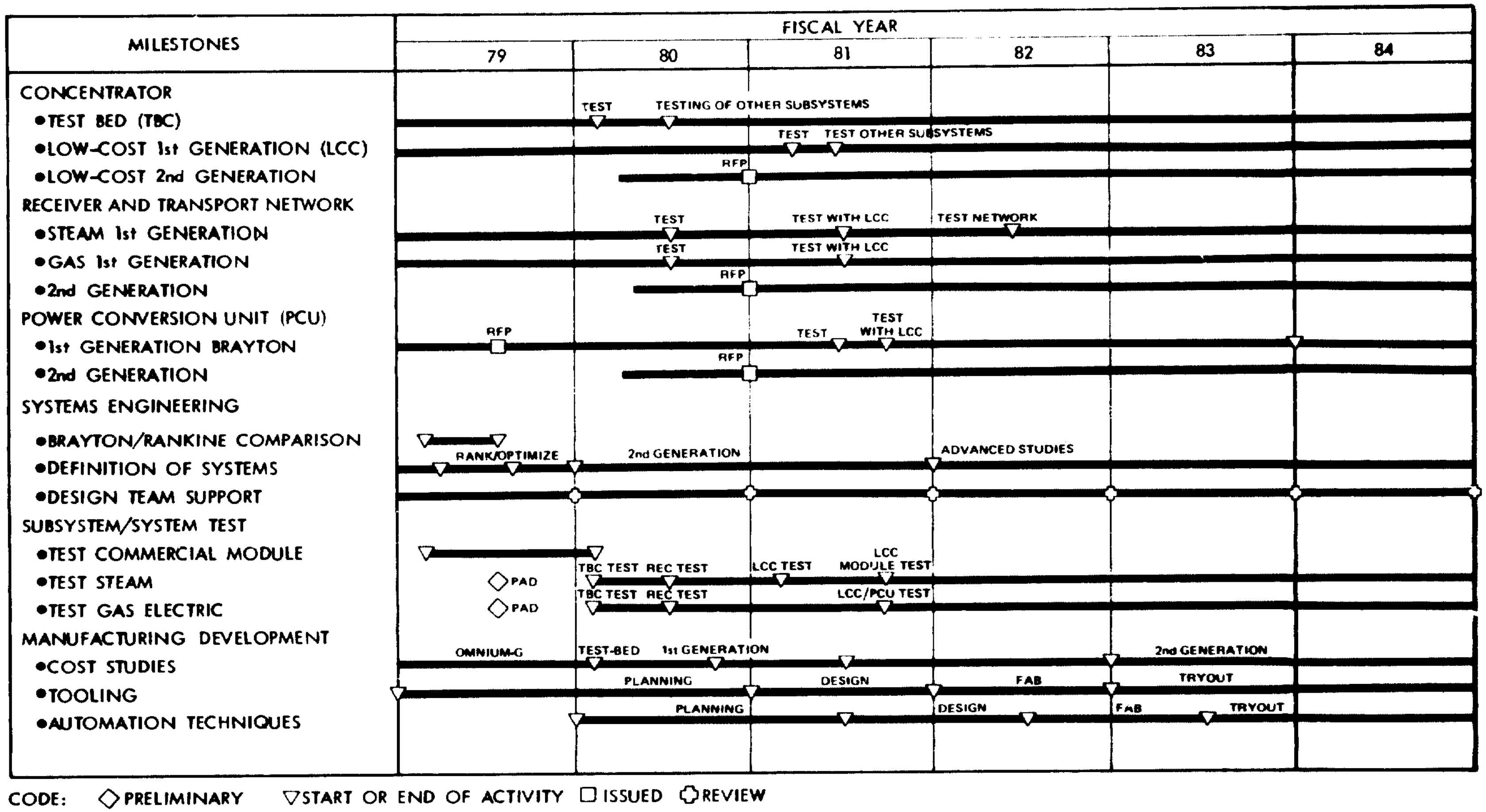

Figure 3. Six-Year Milestone Summary

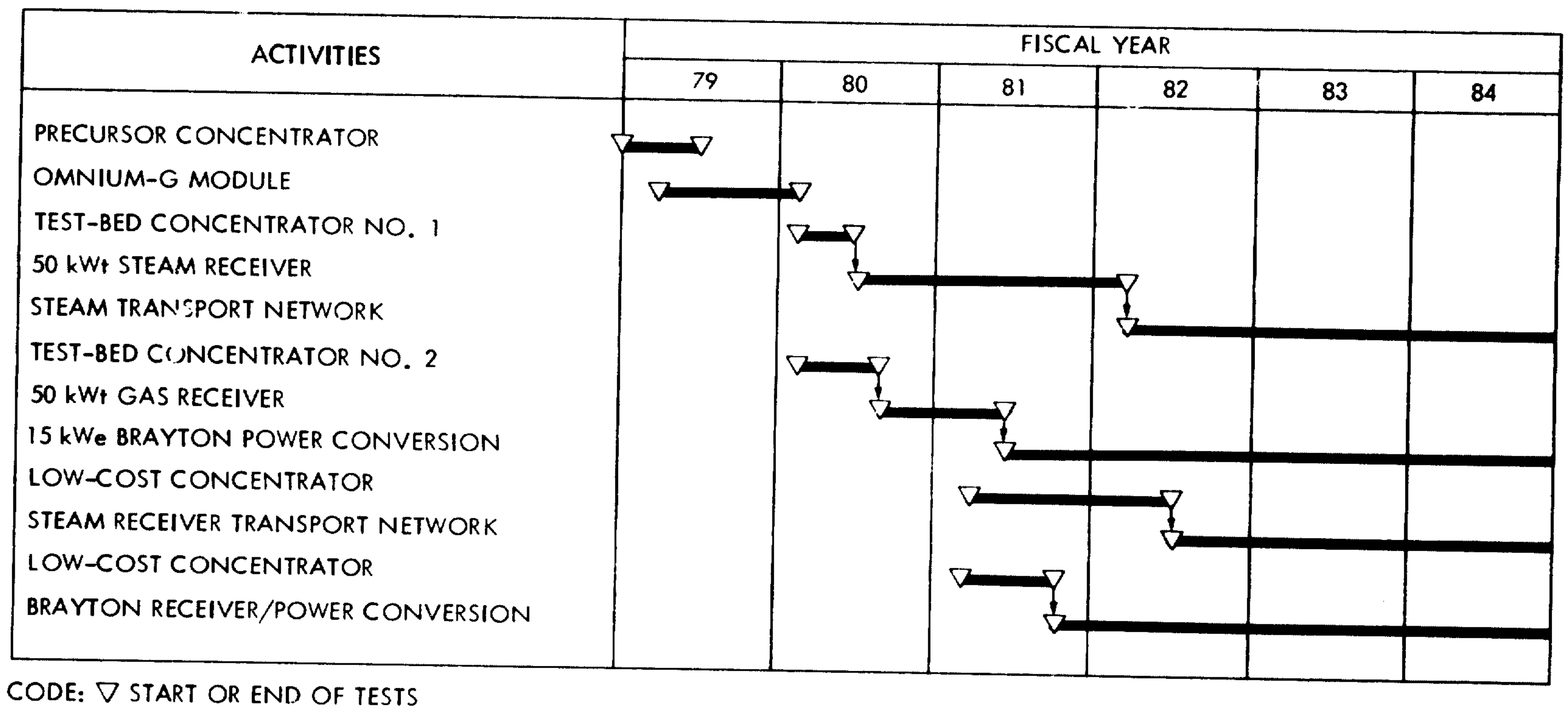

Figure 4. Six-Year First-Generation Subsystem Test Period Schedule

Initial work encompassed both steam-Rankine and air-Brayton subsystems. Due to future year funding constraints it was necessary during FY 1979 to select either steam Rankine or air Brayton for further effort. The latter was selected and the Brayton activity, then in the Advanced Solar Thermal Technology Project, was transferred to the PFDR Technology Project. As progress continues, work on advanced types may be added while effort on earlier ones may be completed or terminated.

SECTION III

TECHNOLOGY INFORMATION DISSEMINATION

This Project is ultimately concerned with the creation of a new product, a demand for the product, and an industrial capability for supplying the product. Studies on the advancement of technology have shown that the time from laboratory to marketplace is generally from 20 to 50 years, and sometimes even longer, unless there is some special stimulation to catalyze the process. There is a national need to establish options for new energy sources as rapidly as possible; therefore, a plan for accelerating the technology transfer process is a major component of this Project.

The effort to accelerate the transfer process includes both communication of Project results to the supplier, user, and regulatory communities of interest, as well as early involvement of representatives of these communities to ensure commercial practicability of the results. Communication and participation with the communities of interest is a major effort.

At present, the supplier community of solar energy industries is relatively small. Interest in solar energy, however, is growing rapidly and a large industrial community can be anticipated. The user community, in contrast, is already large and very complex. The largest segment of potential users is the public and private utilities. Other users could include industry, commerce, and agriculture. The regulatory community is also large, since it includes state and local governments, public utilities commissions, and environmental protection agencies.

The technology transfer plan has two major components: (1) efforts associated with this Project's activities and (2) active participation and interface with DOE and other appropriate governmental technology transfer activities.

This Project's technology transfer activities emphasize early and continuous involvement of industry, and dissemination of technical results. The industry involvement will be significant and widespread.

The Project's technology dissemination plan contains the following activities:

(1) Publication of results in scientific, technical, and trade journals.

(2) Presentations at scientific, technical, and trade conferences.

(3) Publication of an annual Technical Progress Report.

(4) Publication of leaflets and brochures.

TECHNICAL INFORMATION PAPERS

A Preliminary Assessment of Small Steam Rankine and Brayton Point-Focusing Solar Modules, E. J. Roschke, et al, DOE/JPL 1060-16, (JPL Publication 79-21), March 1979.

Comparative Study of Solar Optics for Paraboloidal Concentrators, L. Wen, L. Huang, P. Poon and W. Carley, 1979 ASME Winter Annual Meeting (79-WA/Sol-8) New York, New York, December 2-7, 1979.

Efficiency of Dispersed Solar Power Modules, H. Steele, AIChE 86th National Meeting, Houston, Texas, April 1-5, 1979.

Heat and Electricity from the Sun Using Parabolic Dish Collector Systems, V. C. Truscello and A. N. Williams, AIAA Utilization of Space Technology Conference, Los Angeles, California, November 15, 1979.

Parabolic Dish Technology for Industrial Process Heat Applications, J. W. Lucas, Solar Industrial Process Heat Conference, Oakland, California, October 31-November 2, 1979.

Point-Focusing Dishes, J. W. Lucas, DOE Advanced Solar Thermal Technology Semiannual Review, Long Beach, California, June 19-21, 1979.

Point-Focusing Distributed Receiver Technology Project, Annual Technical Report - Vols. I and II, J. Lucas, DOE/JPL 1060-7; Volume I: Executive Summary, September, 1978, and Volume II: Detailed Report, Fiscal Year 1978; (JPL Publication 79-1); February 15, 1979.

Solar Parabolic Dish Thermal Power Systems Technology and Applications, J. W. Lucas and A. T. Marriott, 14th IECEC, Boston, Massachusetts, August 5-10, 1979.

Solar Thermal Power Systems Point-Focusing Distributed Receiver (PFDR) Technology: A Project Description, J. W. Lucas, E. J. Roschke, AIAA Conference on Solar Energy (78-1771) Phoenix, Arizona, November 27-29, 1978.

SECTION IV

CONCENTRATOR DEVELOPMENT

The activities of the Concentrator Development Task are directed toward developing high-temperature, point-focusing concentrator technology with a major emphasis on low-cost in large quantity production. This approach is motivated by the fact that the concentrator comprises more than half of the cost of a solar thermal module. The implementation of this task is primarily through contracts with industry.

The Task consists of three thrusts:

(1) Hardware for an early test program.

(2) Development of a first-generation Low-Cost Concentrator (LCC) to operate efficiently in the 540°C (1000°F) to 815°C (1500°F) range.

(3) Development of second-generation concentrators.

During FY 1979 significant progress was made in the first two areas. The third, based upon current work by the Advanced Solar Thermal Technology Project, is to be initiated in FY 1980.

The first thrust encompassed three spheres of activity. A Precursor Concentrator, designed to simulate a section of a full-size reflector, was completed and used for a variety of tests requiring the solar source (Figure 5). A cold-water calorimeter (Figure 6) was designed, fabricated and used in the evaluation testing of the Omnium-G concentrator* (see Section VIII). The dominant activity in this early hardware area was the design, fabrication and installation of two Test-Bed Concentrators (TBCs) by E-System, Inc., together with the assembly of JPL-developed mirror facets used for the TBC reflector surfaces.

The TBCs were developed from an existing microwave antenna design which was modified to: (1) accomodate the JPL developed mirror facet, (2) provide solar tracking, and (3) support the receiver/power conversion unit at the focal point. The facets are 61 cm x 71 cm (24 in x 28 in), spherically-contoured, second-surface mirrors bonded to a Foamglas** substrate (Figure 7). Each TBC (Figure 8) is nominally 11 meters in diameter, has a focal length of 6.6 meters and is expected to produce 70 kWt with clean mirrors at 800 W/m^2 insolation. Techniques were developed to evaluate the optical characteristics of the mirrors and to align them after installation on the TBC. Design of a cold-water calorimeter to be used for evaluating the thermal performance of the TBC was initiated.

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*Heliodyne^tm Model MTC-25 manufactured by the Omnium-G Company
**Registered trademark of Pittsburgh Corning Corporation

The second Task thrust in FY 1979 was continued development of the first-generation Low-Cost Concentrator. Phase I studies for the definition of design parameters and preliminary design were completed. Thr final reports from these contractor studies are identified as follows:

(1) Acurex Corporation -- DOE/JPL Contract No. 955208

(2) Boeing Engineering and Construction Company -- DOE/JPL Contract No. 955209

(3) General Electric Company -- DOE/JPL Contract No. 955210

A Request for Proposal (RFP) was issued for Phase II/III, the detail design, fabrication and installation of three units. The contract was awarded to General Electric and work on this Phase began near the end of FY 1979. The LCC (Figure 9) is 12 meters in diameter and uses a film reflector on a fiberglass-epoxy substrate. An investigation of glass mirrors as an alternative reflector surface will also be undertaken during Phase II/III. The concentrator will produce a minimum of 66 kWt into the receiver aperture at an insolation of 800 W/m^2. Additionally, an RFP was released for study of the feasibility of modifying the central receiver heliostat design to a point-focusing concentrator.

Concentrator performance analyses were completed for the evaluation of the Omnium-G and LCC Concentrators, and for prediction of TBC performance.

Figure 5. Precursor Concentrator

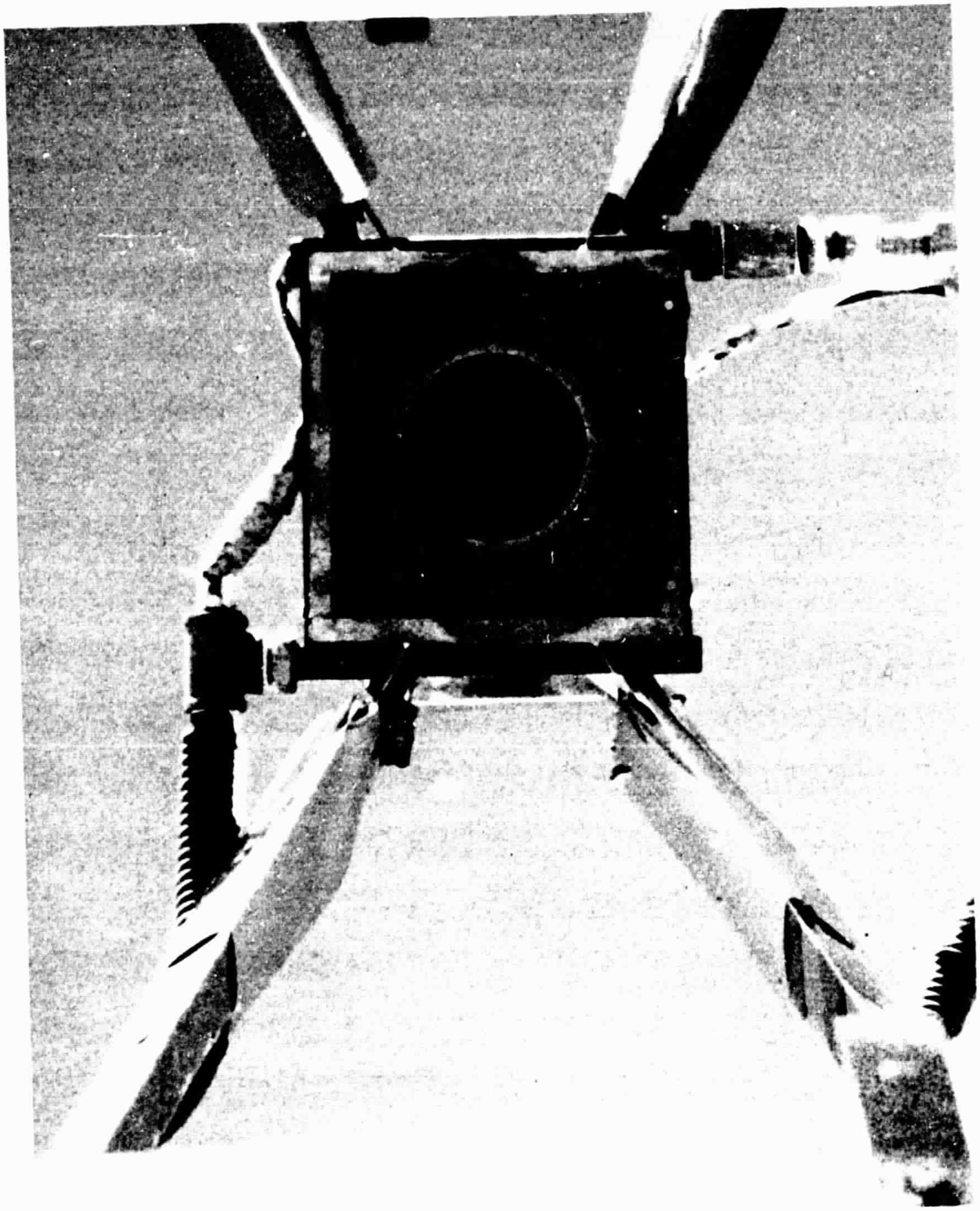

Figure 6. Cold-Water Calorimeter

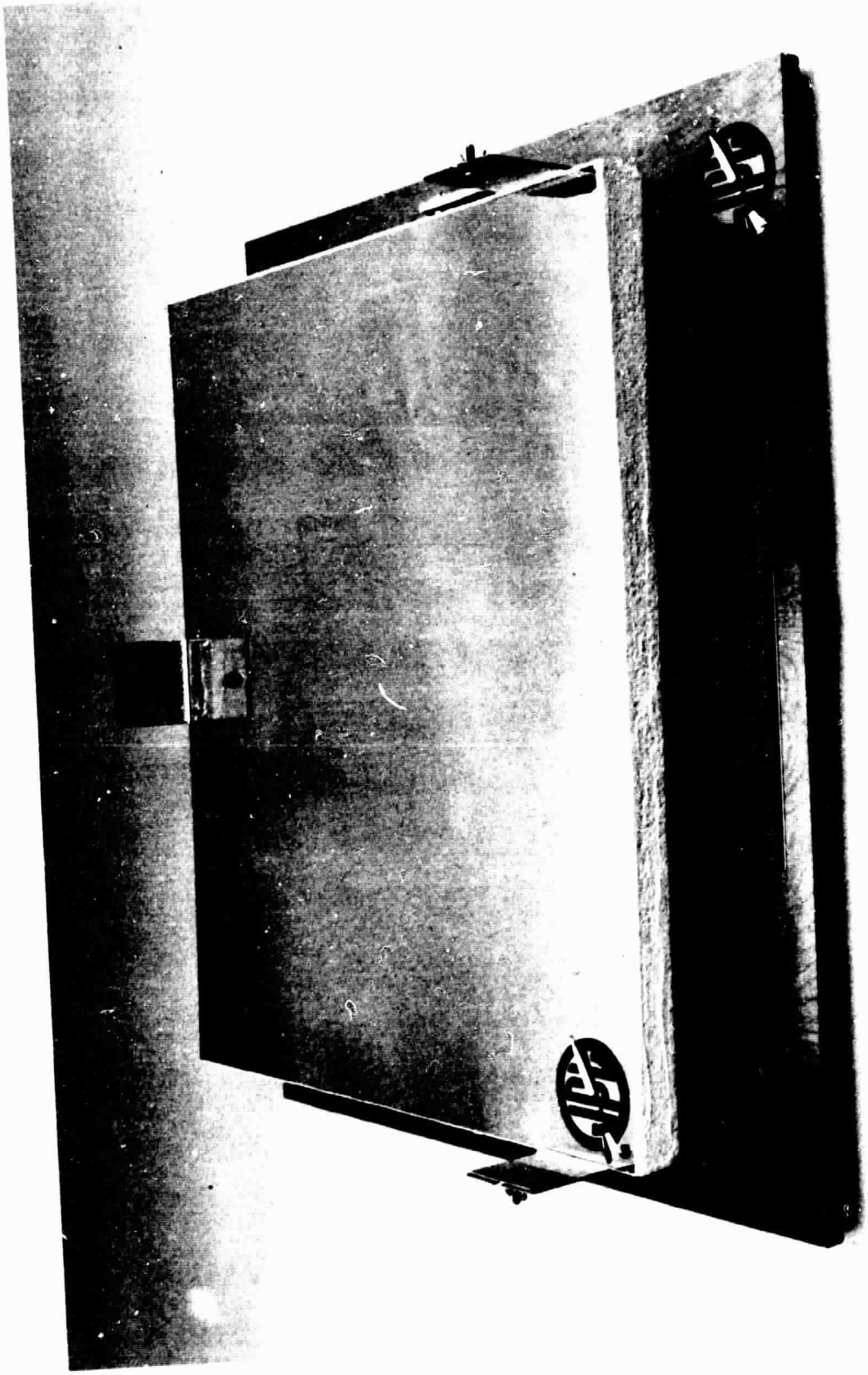

Figure 7. Spherical Mirror Facet for Test-Bed Concentrator

Figure 8. Test-Bed Concentrator

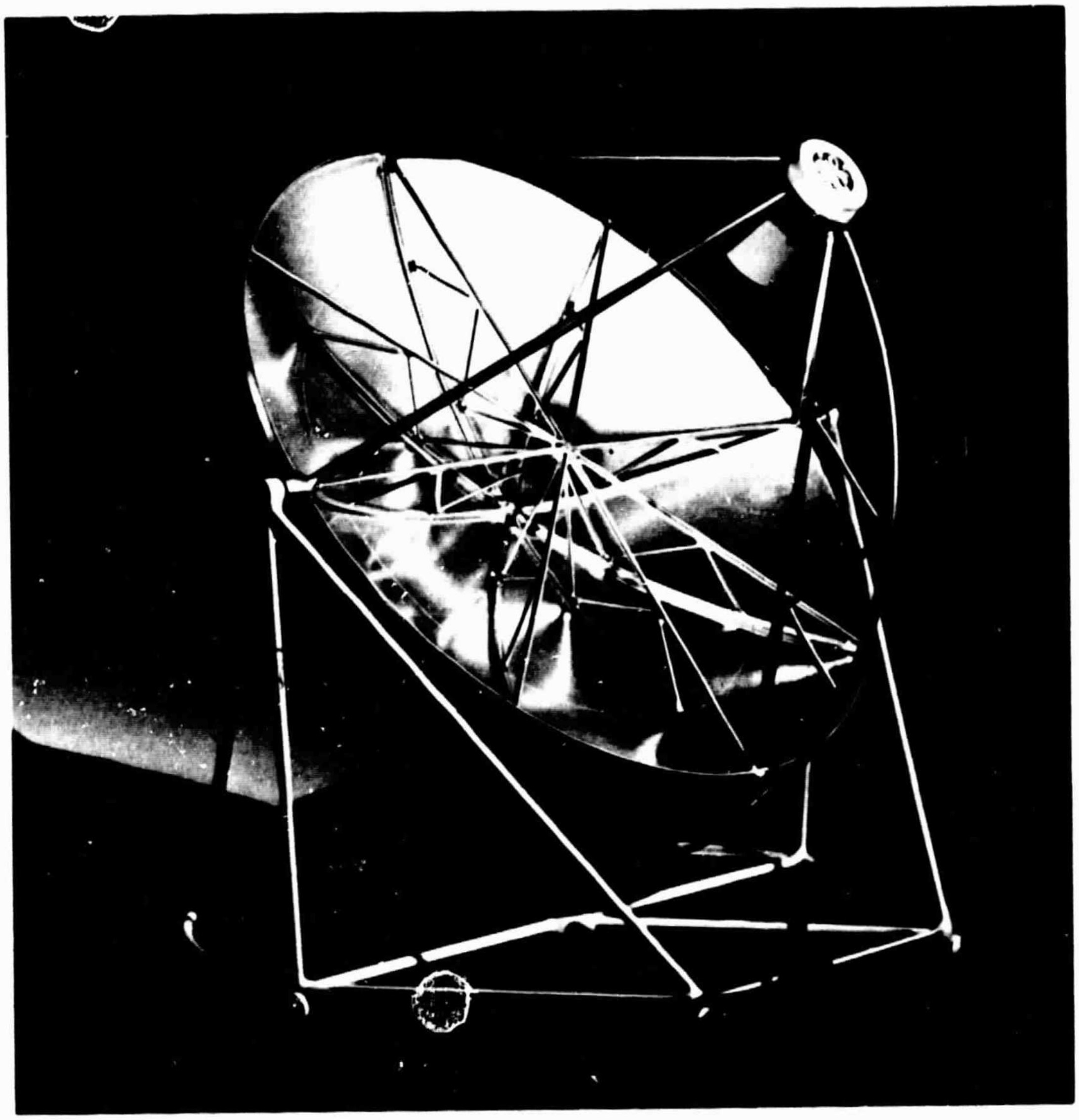

Figure 9. General Electric Low-Cost Concentrator

SECTION V

RECEIVER AND HEAT TRANSPORT NETWORK DEVELOPMENT

The fundamental objective of the Receiver Development Task is to provide efficient, cost-effective equipment utilizing the expertise of industry. During the past year, the scope of the task has been broadened to include the heat transport subsystems ancillary to the solar collectors.

Six, Phase I conceptual design receiver contracts were in progress at the start of the year. The final reports from the air Brayton solar receiver contracts are identified as follows:

(1) Boeing Corporation -- DOE/JPL Contract No. 955119

(2 Dynatherm Corporation -- DOE/JPL Contract No. 955135

(3) Garrett AiResearch Manufacturing Company of California -- DOE/JPL Contract No. 955136

(4) Sanders Associates -- DOE/JPL Contract No. 955120

For the steam solar receivers the final contractor reports are:

(1) Fairchild-Stratos Division -- DOE/JPL Contract No. 955158

(2) Garrett AiResearch Manufacturing Company of California -- DOE/JPL Contract No. 955157

Phase I produced conceptual receiver designs with 10-minute buffer storage, a parametric analysis, an initial production costing, and a proposal for a final design including the fabrication of prototype equipment.

Early in the year, the contractors were given a suitable design point to size and direct the final design. A Statement-of-Work (SOW) including evaluation criteria and Phase II requirements was prepared for release. The Request for Proposal (RFP) for Phase II, final design and prototype production, was released in December 1978.

The six proposals were received in January 1979. After a technical, cost/price, and management review, Garrett AiResearch was selected to continue with both the steam and air receivers. The Phase II contract for the air open-cycle Brayton receiver was awarded in May and for the steam Rankine in June.

Several important changes in the program influenced the design progress between the Phase I preliminary designs and the Phase II final design and production. Among the most important was the stipulation that all systems accommodate hybrid operation with fossil fuel. This allowed the 10-minute buffer storage requirement to be relaxed to the inherent storage of the receiver mass. In addition, the requirement to produce industrial process heat was emphasized to insure receiver compatibility with a variety of systems.

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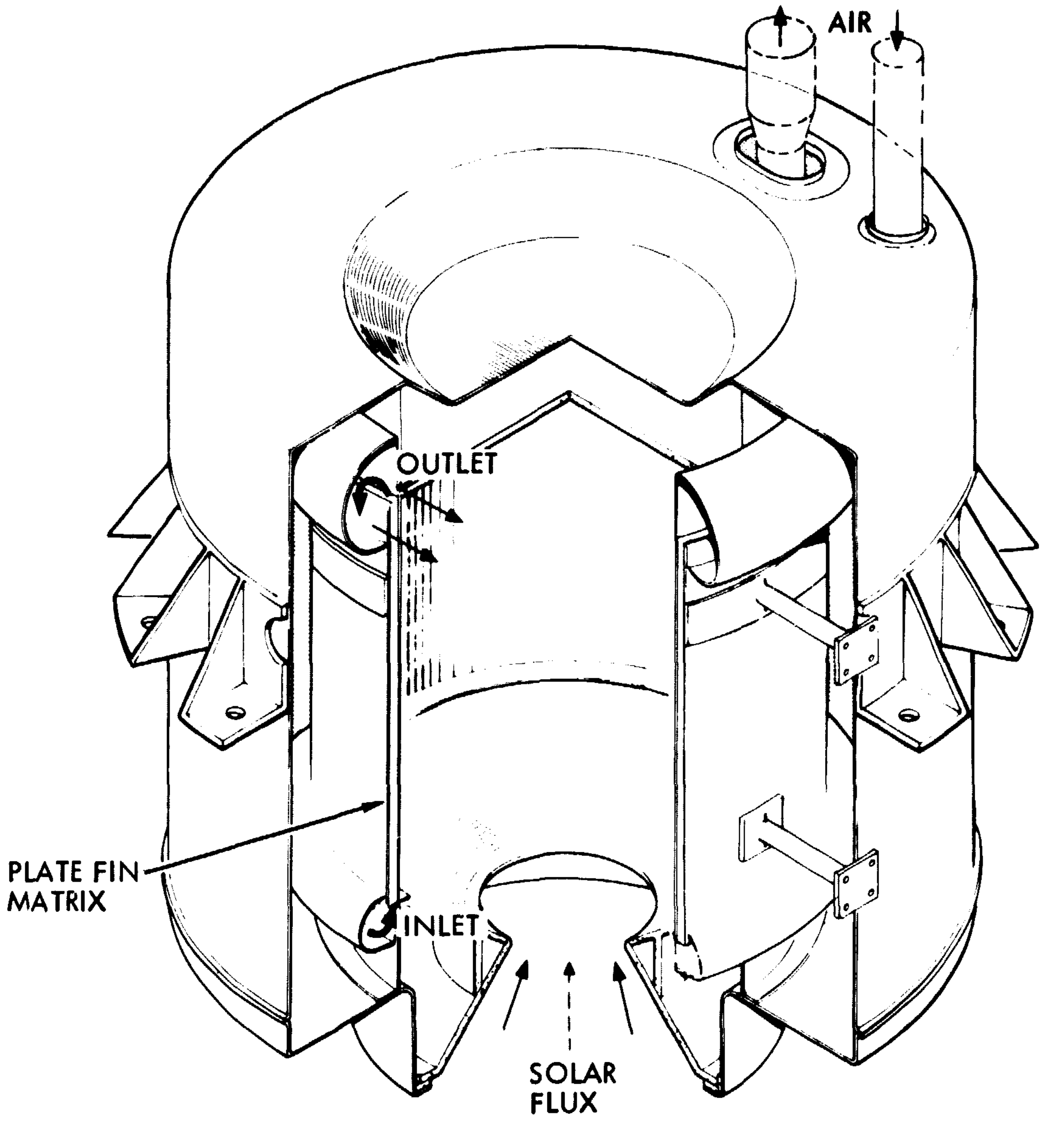


Figure 10. Air-Brayton Solar Receiver
(Garrett AiResearch Manufacturing Company)

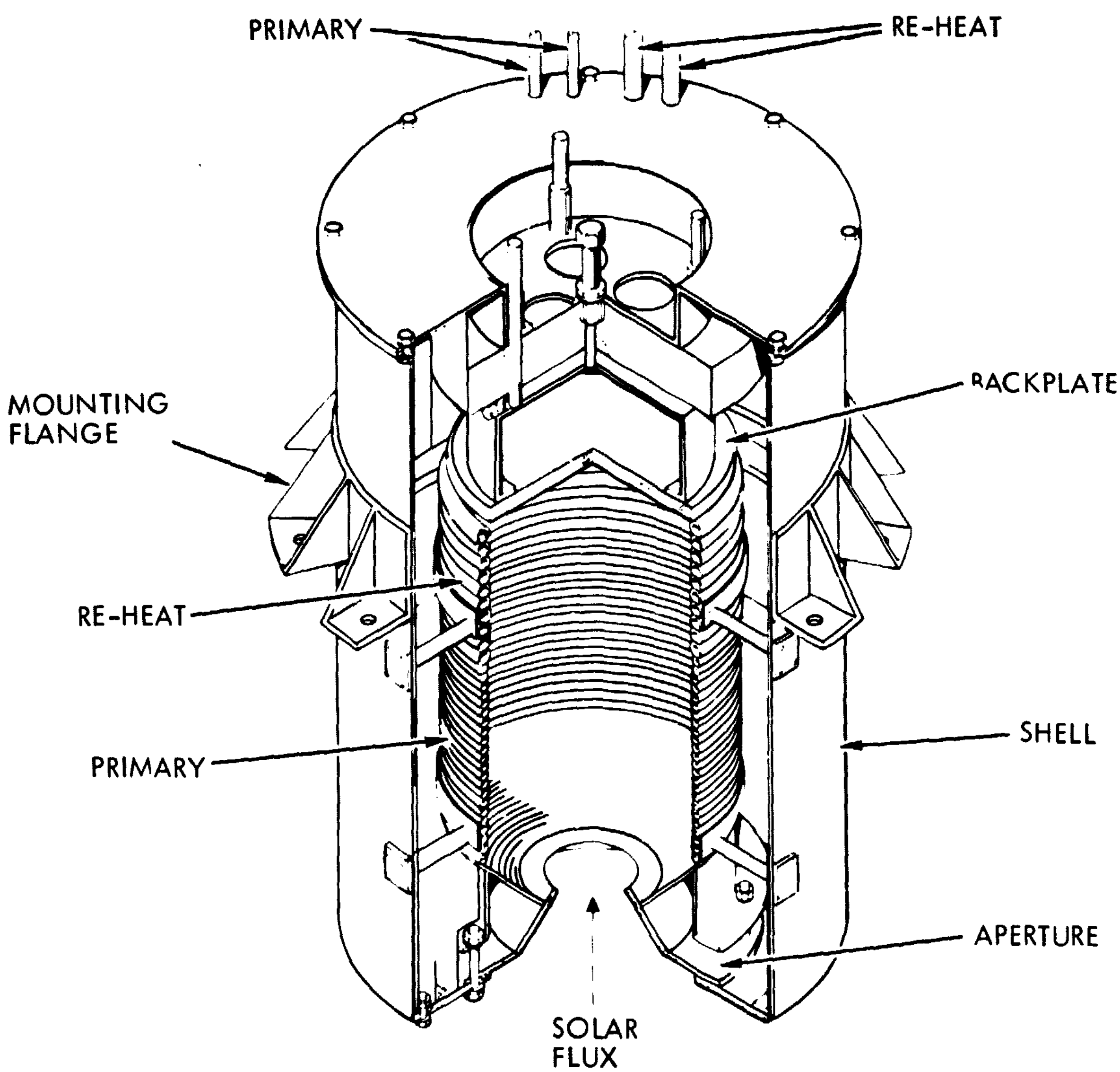


Figure 11. Steam Solar Receiver
(Garrett AiResearch Manufacturing Company)

A Phase II Preliminary Design Review for each receiver was conducted in August. The preferred designs, which meet all functional specifications, and the more important design features are shown in Figures 10 and 11. Final design of each receiver was started in August. Prior to the fabrication stage, Critical Design Reviews were scheduled in late September for the Brayton receiver and in October for the steam Rankine receiver.

Heat transport networks are an important element in producing cost-effective distributed receiver systems. An efficient heat transport system is essential not only for the production of electricity, but especially in utilizing module output for industrial process heat. A RFP was initiated in late June and a SOW was submitted for review. The SOW included:

(1) A systems analysis task to establish candidate transport systems.

(2) A component characterization to assess currently available hardware.

(3) A systems optimization review to insure optimum costs.

(4) A prototype production of key elements to be tested at the PFSTS.

(5) An O&M optimization requirement.

(6) Production cost estimates.

The RFP is planned for release early in FY 1980 for a contract start in early calendar year 1980. While Receiver and Transport Network Development is primarily implemented through contract with industry, a strong in-house support effort was pursued to insure timely, cost-effective management of the Task. This effort included: continued development of the flux mapper, support for Omnium-G testing program, an analytical receiver model program, and program support tasks.

The Mark I Flux Mapper was completed late in the first quarter of FY 1979. It was shipped to the PFSTS in January and mounted on the Precursor Concentrator. Test and calibration runs were completed between late January and early February. Delayed somewhat due to particularly windy weather, first flux maps of the Omnium-G system were made in April and May. The flux mapper functioned as predicted. As a further check of accuracy, a Kendall absolute cavity radiometer, suitable for operation at high intensities, was fabricated to mount on the flux mapper. Data reduction and comparison to earlier data is expected early in FY 1980.

The flux mapper was used to help characterize the performance of the Omnium-G system. Additional support to the test program for the Omnium-G system included: test planning, data analysis, receiver thermal analysis, calorimeter comparison and other tasks.

SECTION VI

POWER CONVERSION DEVELOPMENT

In support of the PFDR Project's goal of developing the necessary point-focusing dish technology for application in small solar-thermal power systems, NASA Lewis Research Center (LeRC) provides in-house and contracting efforts towards the development of efficient power conversion units. Key issues in the technology development area are efficiency, cost, and reliability. Engine reliability is critical to the overall system reliability because the heat engine is subject to high temperatures and pressures, and because it contains most of the moving parts of a system module. Reliability is critical to small dispersed power systems if they are to compete for the electric power generation market. A highly efficient power conversion unit reduces the area required for the solar concentrator, the major cost item, for a given power level. The engine is also a significant part of the total capital cost and must be considered in the trade-off between cost and efficiency.

During FY 1979, conceptual design study contracts were completed which identified small engines (Rankine and Brayton cycles) in the 10-20 kWe power level that could be adapted or modified for use by 1982. The final reports from the contracts are identified as follows:

(1) Rankine Turbine (baseline) - Sundstrand Energy Systems (DOE/NASA-0061-79/1)

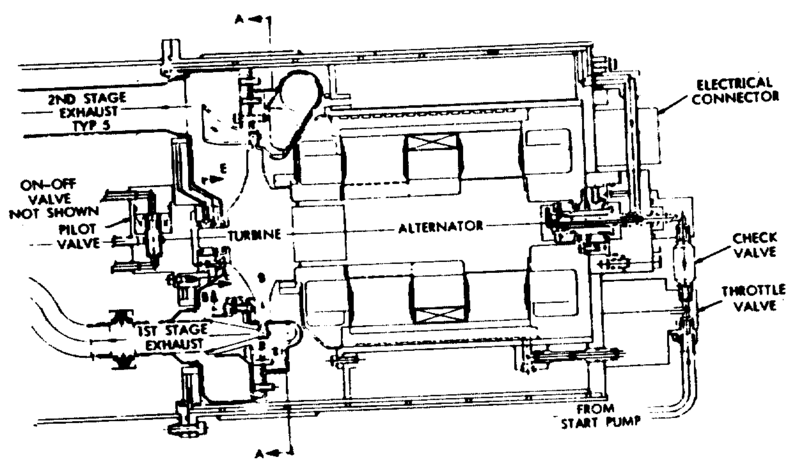
(2) Rankine Reciprocator (baseline) - Jay Carter Enterprises (DOE/NASA-0063-79/1)

(3) Rankine Reciprocator (Mod 1 or alternate) - Foster-Miller Associates, Inc. (DOE/NASA-0062-79/1)

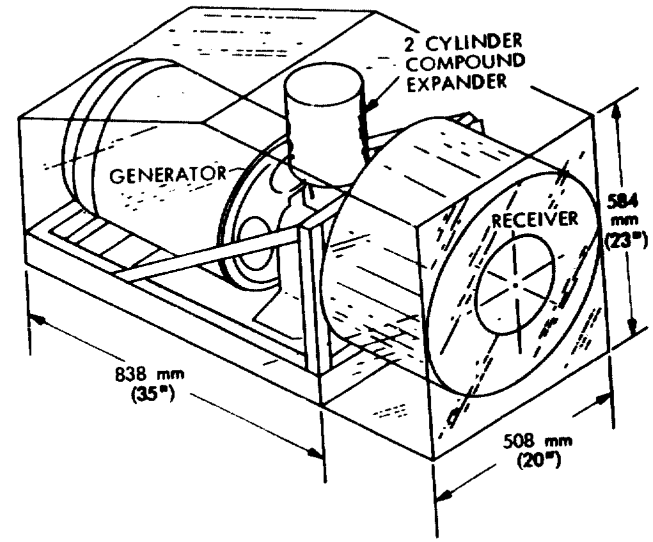
(4) Brayton (open and closed cycle; both baseline and alternate) - Garrett AiResearch Manufacturing Company of Arizona (DOE/NASA-0069-79/1)

Initiated under the Advanced Solar Thermal Technology Project the Brayton studies were transferred to the PFDR Technology Project in mid-FY 1979 prior to completion of the contract.

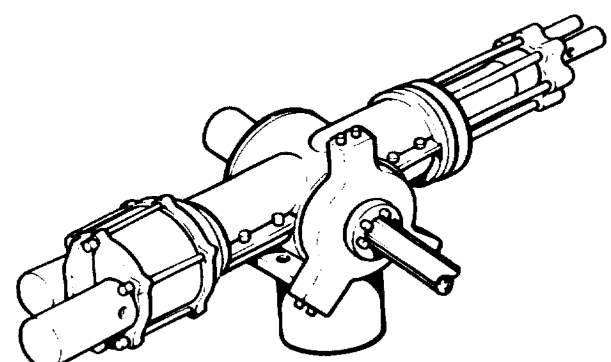
The engine studies were confined to engines presently available or those which could be modified, based on present technology, and made available by 1982. The inlet temperature on the steam cycles ranged between 450°C (845°F) and 815°C (1500°F) and on the Brayton between 650°C (1200°F) and 815°C (1500°F). The heat to the working fluid is supplied via the solar heat receiver. In some cases the steam system included a reheat cycle from the receiver. Following the parametric studies, specific design points were selected for each engine configuration and conceptual designs were evolved. Figure 12 contains illustrations of the three steam Rankine heat engine concepts



(a) Two-Stage Turbine
Sunstrand Energy Systems, Inc.



(b) Two-cycle Compound Reciprocator
Jay Carter Enterprises, Inc.



(c) Two-cycle Opposed, Compound Reciprocator
Foster Miller Associates, Inc.

Figure 12. Conceptual Steam-Rankine Engine Configurations

and Figure 13 of the Brayton heat engine concepts. The performance levels for each system were determined from these concepts and design points (see Table III).

The efficiencies cited in Table III correspond to engines at various stages of development and at rated conditions which differ for each engine. For example, the type of engine used to derive the steam engine efficiencies is further advanced than that used to derive the Brayton engine efficiencies. Therefore these efficiencies should not be compared directly. The last column of Table III partially illustrates the effect of engine designs at off-design conditions. It is based on a solar insolation curve over a year with reduced power input to the engine. An effect of off-design performance can be observed since each engine used the same annual insolation curve. Although all systems were relatively constant in performance, the steam Rankine systems had the best off-design performance. All of the designs showed substantial improvements over the off-the-shelf performances reported in "Handbook of Data on Engine Components for Solar Thermal Applications" (DOE/NASA 1060-78/1).

The steam Rankine systems would require some modest development, but no new technology, to achieve the goals of performance and life (100,000 hours) with scheduled maintenance. Jay Carter Enterprises' two-cylinder, compound-reheat-expander, reciprocating engine, designed to operate at 675°C (1250°F) would require some time to develop from a simple steam cycle (540°C, 1000°F) to a compound cycle. Potentially, the power conversion system could be designed to have major overhauls every ten years with some components lasting up to 30 years. The Sundstrand two-stage, re-entry turbine, designed to operate with 730°C (1350°F) inlet steam, would require development time to verify the design life of 100,000 hours for the bearing and seal designs and the overall operation at this temperature.

The Foster-Miller Associates design of the opposed, two-cylinder, compound-expander reciprocator, which was in the Mod-1 category, requires more development time to achieve their design performance goals at 700°C (1290°F). The flow in this concept is counterflow as opposed to uniflow in the Carter design. In the counterflow the heat transfer between inlet and exhaust must be essentially eliminated. This is critical to obtaining high performance. This design performance requires development and demonstration. In addition, because of the high temperature on the cylinders, consideration of graphite rings to eliminate the lubricating oil was included in the design. The desired life has yet to be demonstrated using this modified design. Another area requiring some development is the valving and hydraulic operation of the valves.

The Brayton cycles with reciprocators, both open and closed concepts designed by Garrett AiResearch, were based on existing engines in different phases of development or existing technology optimized to provide the improved performance required. For the open-cycle, near-term or baseline concept, the GTP 36-51 turbocompressor was chosen for a power level in the 70-80 kWt range. This turbocompressor was developed previously for a military generator

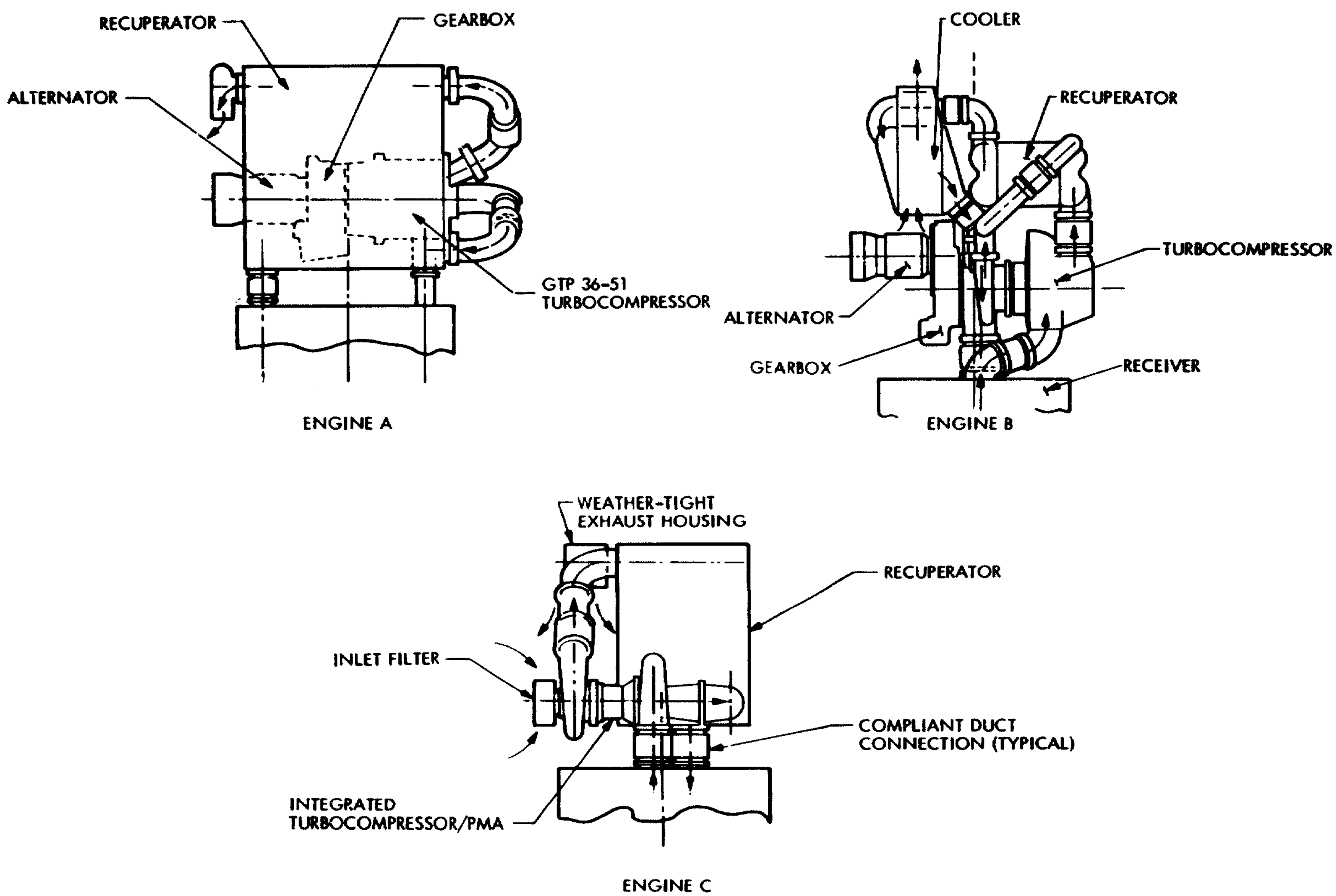


Figure 13. Conceptual Open- and Closed-Cyle Brayton Engine Configurations

set as an auxiliary power (30 kWe) unit. A test unit has been operated for several hundred hours. The design for the closed-cycle Brayton was based on a PFE (Pacific Fruit Express) engine developed to power a refrigeration unit for commercial transportation application in the 15-20 kWe power range. These two engines would require some modest development for application in the solar mode. The design selected for the Mod-1, open-cycle Brayton was an optimized turbocompressor based on the technology developed on the BRU (Brayton Rotating Unit) turbine and would include gas bearings and an integral, permanent magnet alternator (PMA) rather than the 400 Hz alternator proposed for early baseline designs. This concept would provide a slight increase in performance at the 815°C (1500°F) temperature level but would require a longer development program to reach the lifetime of 30 years (100,000 hours).

Although costs were obtained for each engine configuration, more information would be required to obtain data for a cost comparison. It may be concluded that for the designs presented, the cost for high-production manufacturing should be in the range of $150-250/kWe.

Procurement action was initiated during the year for detailed design and fabrication of the baseline, open-cycle Brayton power conversion unit.

Table III. Solar Engine Conditions and Performance Characteristics

POWER CONVERSION UNIT/COMPANY	WORKING FLUID	THERMAL POWER (kW)	INLET CONDITIONS TEMP. (°C)	INLET CONDITIONS PRESS. (MPa)	MASS FLOW (LB/HR)	EFFICIENCY ENGINE	EFFICIENCY ELECTRICAL GENERATION*	EFFICIENCY PCU	EFFICIENCY ANNUAL CONVERSION
STEAM RANKINE:									
2 STAGE TURBINE / SUNDSTRAND	STEAM (REHEAT)	80	732	4.137	179	.31	.87	.27	.26
COMPOUND RECIPROCATOR / J. CARTER	STEAM (REHEAT)	80	676	17.237	175	.33	.92	.31	.29
OPPOSED 2 CYC RECIPROCATOR / FOSTER-MILLER	STEAM (REHEAT)	80	700	12.066	136	.36	.92	.33	.32
BRAYTON:									
OPEN: GTP 36-51 / AIRESEARCH	AIR	72.7	815	.258	2226	.30	.80	.23	.22
CLOSED: PFE (MOD) / AIRESEARCH	AIR	72.7	815	.331	2443	.30	.80	.24	.22
OPEN: ADV (BRU) / AIRESEARCH	AIR	72.7	815	.269	2141	.32	.84	.28	.27

*FOR RANKINE TURBINE SYSTEMS THIS INCLUDES CONVERSION OF HIGH FREQUENCY AC TO 60 Hz, 3ϕ, FOR RANKINE RECIPROCATOR SYSTEMS, THE GENERATOR DELIVERS 60 Hz, 3ϕ. FOR BRAYTON SYSTEMS, GEARBOX AND CONVERSION OF HIGH FREQUENCY AC TO 60 Hz, 3ϕ IS INCLUDED AS NEEDED.

SECTION VII

MANUFACTURING DEVELOPMENT

The prime objective of this task area is to assist in the development of high-performance point-focusing subsystems that can be manufactured in high-production volumes at a low-unit cost. To accomplish this objective, efforts are directed toward:

(1) Developing independent costs for PFDR components and systems.

(2) Developing tooling and design costs for capital equipment and facilities needed to produce PFDR components.

(3) Studying possible uses of automation techniques to produce PFDR concentrators, receivers and power conversion units at a lower cost.

An existing state-of-the-art PFDR module, commercially available from the Omnium-G Company, was cost-analyzed for production quantities ranging from 100 to 100,000 units per year. The results of this study are shown in Table 4.

A preliminary study was completed that estimated the cost of tooling, capital equipment and facilities required to produce a typical PFDR system (concentrator, receiver, power control unit, and associated controls) in production quantities ranging from 5000 to 100,000 units per year. The preliminary results of this study are shown in Table 5.

A contract was awarded to Pioneer Engineering and Manufacturing Company to perform a cost-analysis of the Test-Bed Concentrator in selected annual production volumes.

Table IV. Cost of Omnium-G 7500 System in Selected Quantities

	COST $/MODULE			COST $/METER 2		
	QUANTITY MANUFACTURED/YEAR			QUANTITY MANUFACTURED/YEAR		
	100	25,000	100,000	100	25,000	100,000
CONCENTRATOR	8219	6162	4384	291	218	155
RECEIVER	493	371	259	17	13	9
POWER CART (INCLUDES STEAM ENGINE)	4307	3228	1959	153	115	70
TOTAL SYSTEM/MODULE	13,019	9761	6602	461	346	234

Table V. Cost of Tooling, Capital Equipment and Facilities Required to Produce PFDR Systems in Selected Quantities

	ANNUAL PRODUCTION QUANTITY				
	100,000	50,000	25,000	10,000	5,000
	COST ($K)				
CAPITAL EQUIPMENT & TOOLING	170,161	87,420	47,110	20,605	11,686
BUILDING & LAND	326,414	231,110	147,595	66,755	39,760
MISC. EQUIPMENT	1,500	810	580	315	160
ENGINE PLANT	200,000	150,000	110,000	75,000	--
TOTAL	698,075	469,340	305,195	162,775	51,606
CONTINGENCY FOR CHANGES - 10 YEARS	200,000	100,000	75,000	50,000	15,000
GRAND TOTAL	898,075	569,340	380,195	212,775	66,606

SECTION VIII

SYSTEMS ENGINEERING

The objectives set forth for this Task were met during FY 1979 by providing the Project with ongoing systems support throughout the year.

The Design Team (DT), organized late in FY 1978, established subsystem interfaces, issued and maintained a Design Point Document containing subsystem parameters, established system test requirements for the Test-Bed Concentrator, planned and monitored the testing of the Omnium-G module, supported RFP reviews and applications requirements, and recommended power conversion options.

Systems engineering studies included:

(1) A process heat survey which reinforced the option of employing PFDR technology for industrial process heat and chemical processes.

(2) A concentrator shading effects study which resulted in a methodology for determining an optimum collector field layout.

(3) A solar Brayton dynamic simulation model which was developed for simulating transient performance. The model can also be used for steady-state predictions. The modular computer program permits subsystems to reflect various designs and control strategies.

Testing of the commercial Omnium-G module was performed at PFSTS. Mechanical checkouts, optical alignments, and thermal tests were conducted. Full system tests could not be conducted during FY 1979 because the complete system had not been delivered; system tests should begin in early FY 1980.

Systems Engineering conducted cost and performance studies throughout the year. Energy cost targets were evaluated based on latest capital cost and performance target data. Systems evaluated included the 11-meter Test-Bed Concentrator design, the Low-Cost Concentrator design, and selected optimum concentrator sizes based on given input data.

SECTION IX

TEST AND EVALUATION

The activities of the Test and Evaluation Task during FY 1979 included several additions to the Point-Focusing Solar Test Site* (Figure 14). These additions included installation of the Omnium-G solar-powered electric module, two Test-Bed Concentrators (TBCs), housing for remote instrumentation and electric load bank, and all interfacing cabling and utilities. A formal design review for the PFSTS was held in June, 1979.

The planned tests utilizing the Precursor Concentrator were completed. These included optical quality tests of TBC mirrors, and calorimeter and flux-mapper qualification tests.

Tests of the Omnium-G module included mechanical, optical, tracking, thermal, and electrical performance.

Test preparations for the TBC neared completion at the end of the fiscal year. Instrumentation requirements were analyzed and equipment readied for interfacing with the TBC.

Computer support for the PFSTS included:

(1) Software development to collect and process experimental measurements during Precursor and Omnium-G Concentrator testing, and meteorological data recording.

(2) Organization of a software and hardware maintenance program to prevent schedule delays due to computer hardware failures or requests for software modifications.

(3) Procurement of peripheral equipment, e.g., additional memory, terminal, and printer.

(4) Organization of a data archive to store meteorological and concentrator test data and descriptions.

(5) Support of other PFDR Technology task groups' data analysis work with special data hardcopy print-outs.

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* In early FY 1980 the name was changed to Parabolic Dish Test Site.

The meteorological system was modified to monitor and record ambient air temperature, dew point, and atmospheric pressure, in addition to its existing capabilities for measuring direct and total insolation, wind speed and direction. These measurements are recorded on magnetic tape at one-minute intervals. One month of data is recorded on a reel, then sent to the Test Evaluation Center at JPL, Pasadena for data reduction and print-out.

As testing progressed from the Precursor to the TBC test phase, the safety precautions at the PFSTS became more numerous. Initially, fairly simple safety requirements sufficed, but as solar flux densities increased, stricter safety requirements were implemented.

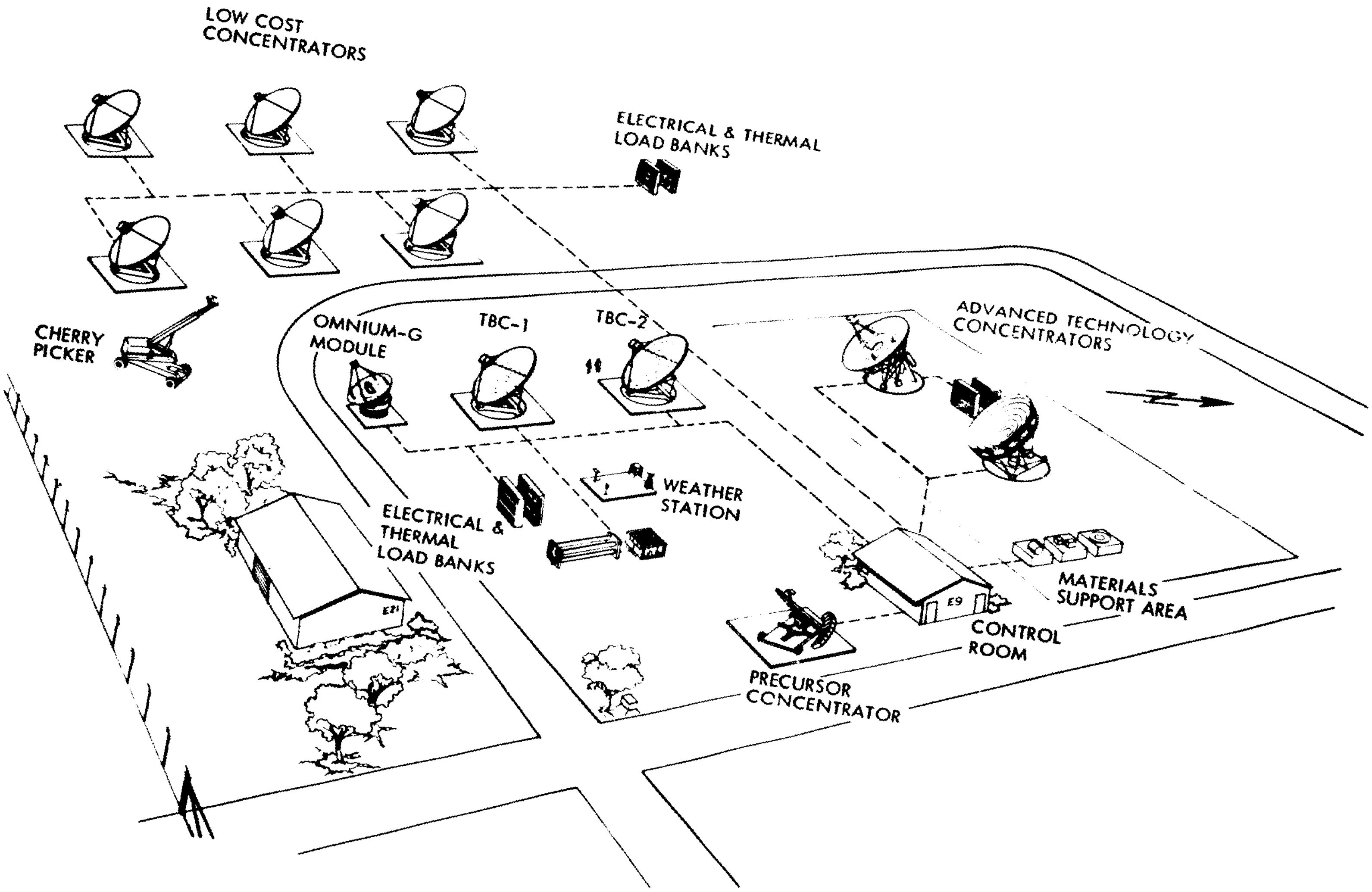

Figure 14. Point-Focusing Solar Test Site

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