

5105-83
Solar Thermal Power Systems Project
Parabolic Dish Systems Development

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Distribution Category UC-62

L. G. RADOSEVICH

Parabolic Dish Solar Thermal Power Annual Program Review Proceedings



May 1, 1981

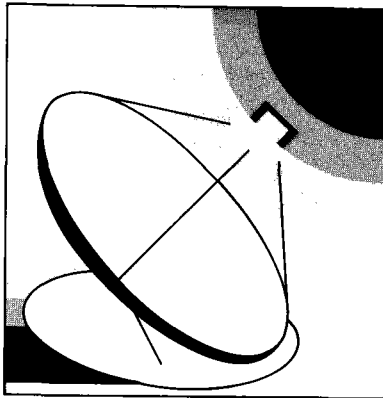
Prepared for
U.S. Department of Energy
Through an agreement with
National Aeronautics and Space Administration
by
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

(JPL PUBLICATION 81-44)

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ABSTRACT

These proceedings present the papers and panel discussions given at the Parabolic Dish Solar Thermal Power Annual Program Review held in Pasadena, California on January 13-15, 1981. It was sponsored by the U.S. Department of Energy, and conducted by Jet Propulsion Laboratory.

The objective of the review was to present the results of activities of the Parabolic Dish Technology and Applications Development portion of DOE's Solar Thermal Energy Systems Program. Thirty-four papers were presented on the subjects of development and testing of concentrators, receivers, and power conversion units; system design and development for engineering experiments; economic analysis and market assessment and advanced development activities. Two panel discussions were held regarding technology development issues and application/user needs.*

*Not all submitted papers and transcripts of the panel discussions were available at time of publication.

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INTRODUCTION

H. J. Holbeck, Conference Chairman

The three-day Parabolic Dish Solar Thermal Power Annual Program Review held this year at the Pasadena, California Conference Center was attended by 230 representatives from industry, utilities, national laboratories, universities, government and foreign research institutes. Thirty-four papers were presented in sessions on subsystem development, system and application development, market assessment and advanced development.

Introductory remarks were made by Dr. Marshall Alper, manager of the Solar Energy Program at JPL, James Rannels, manager of Solar Thermal Technology Development at the Department of Energy, and Dr. Vincent Truscello, manager of the Solar Thermal Power Systems Project at JPL. Dr. Alper also substituted as luncheon speaker for Russell Schweickart, chairman of the California Energy Commission. He discussed alternative energy perspectives.

The conference was highlighted by two panel discussions: a discussion by industry representatives on technology development issues and a discussion by potential user representatives on application/user needs. Summaries of these panel discussions are included in these proceedings.

The conference also included a tour of the Parabolic Dish Test Site (PDTS) at the Edwards Test Station. Attendees viewed two test bed concentrators (TBCs) with a demonstration of a steam receiver mounted at the focal point of TBC-1. An OMNIUM-G parabolic dish system was also displayed as were several receivers and engines scheduled for future tests.

The attendance and participation at the conference was very encouraging. A high interest in parabolic dish solar thermal technologies was indicated. Attendance remained high throughout all sessions with more than 100 attendees for the final event, the one-half day tour of the PDTS.

Session I

ENERGY CONVERSION

Session Chairman: E. E. Kempke, NASA/LeRC

THE SCSE ORGANIC RANKINE ENGINE

by

F. P. Boda

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ABSTRACT

This paper describes the Organic Rankine Cycle (ORC) engine currently under development for the Small Community Solar Thermal Power Experiment (SCSE) for JPL/DOE under Contract 955637. This engine is the heart of a Power Conversion Subsystem (PCS) located at the focal point of a sun-tracking parabolic dish concentrator. The ORC engine employs a single-stage axial-flow turbine driving a high speed alternator to produce up to 25 kW electrical output at the focus of each dish. The organic working fluid is toluene, circulating in a closed-loop system at temperature up to 400°C (750°F).

Design parameters, system description, predicted performance and program status are described. The first SCSE Organic Rankine Power Conversion Subsystem will be delivered to the JPL/Edwards test site in May 1981.

INTRODUCTION

Under Phase II of the SCSE Program, FACC will develop a solar thermal, point focusing, distributed receiver, distributed generation system employing a small Rankine-cycle power conversion subsystem (PCS) mounted at the focus of a parabolic dish concentrator. This paper describes only the Rankine-cycle PCS. The overall system and the solar receiver (boiler) are addressed in companion papers by R. Pons and H. Haskins, respectively.

The PCS converts the thermal energy of superheated vapor from the receiver into shaft horsepower which drives a direct-coupled alternator at the focal point. This high frequency ac power is converted to dc by a ground-mounted rectifier, combined with the outputs from other dishes, then inverted to 60 Hz ac electrical power supplied directly to the utility grid.

The Rankine cycle was selected for the SCSE program on the basis of highest performance for least program risk (compared with other heat engine cycles). The organic Rankine cycle (ORC) engine was chosen over a steam Rankine engine on the basis of programmatic and technical factors. FACC has selected Barber-Nichols Engineering Company (B-N) of Arvada, Colorado, to design and build the PCS. B-N is currently in the hardware fabrication phase and assembly of the first unit is scheduled for completion next month.

SYSTEM DESCRIPTION

The power conversion subsystem is comprised of a very compact turbine-alternator-pump assembly, an air-cooled condenser, a regenerator, boost pump, start pump, various valves, plumbing and instrumentation. The PCS also includes certain ground-mounted electrical support equipment, such as the rectifier, overspeed brake controller, relays, etc.

Figure 1 is a cutaway view of the PCS configuration, shown attached to the FACC cavity-type receiver assembly. The cylindrical condenser shape results in an efficient PCS packaging arrangement about 1.1 m (44") dia x 1.5 m (60") long. The power conversion assembly shown in Figure 1 is designed to attach to the mounting rings of the General Electric Low Cost Concentrator (LCC) and provide minimum shadowing of the mirror surface. PCS weight at the focal point is about 322 Kg (710 lbs.).

A cutaway view of the turbine-alternator pump (TAP) assembly is shown in Figure 2. The TAP is an extremely compact device -- about the size of a football. It has one rotating shaft with the turbine wheel mounted at one end, the alternator rotor in the middle and the feed pump impeller at the other end. The shaft spins on hydrodynamic fluid-film bearings fed by toluene lubricant passages through the shaft itself. Salient features of the TAP are listed below.

<u>TURBINE</u>	<u>ALTERNATOR</u>
Single stage, axial flow	Permanent magnet (PMA) type
Full admission, 10 nozzles	Rotor: 6 Samarium Cobalt magnets
Inconel 718, 110 blades	Stator: 9-tooth, copper wound
Tip diameter 125 mm (4.92")	72 mm (2.8") OD x 127 mm (5.0") long
Blade height 10.7 mm (0.42")	3 Ø, 3000 Hz AC at 60,000 rpm
Turbine efficiency 75%	95.0% peak efficiency

Turbine speed is nominally 60,000 rpm. It varies over a narrow range (55,000 to 60,000) as a function of input power. 60,000 rpm is not an excessive speed for turbomachinery (automotive turbochargers run twice as fast). It is this relatively high operating speed which makes the small TAP hardware size possible. As an example, the SCSE alternator is about one-twentieth the size and weight of more conventional generators associated with reciprocating-type heat engines. This turbine speed also allows the main feed pump to supply the full system flow at pressures up to 5.9 MPa (855 psi) with a centrifugal impeller only 33 mm (1.3") in diameter.

The condenser consists of 369 finned aluminum tubes in parallel, arranged in three concentric layers. Cooling air is drawn in axially by the two-speed fan and exhausted radially outward across the condenser tubes. This direction of air flow prevents stalling of the fan motor during high winds.

The regenerator is simply a heat exchanger designed to recover waste heat energy from the turbine exhaust vapor and use it to pre-heat the liquid before it enters the receiver (boiler), thereby enhancing overall system efficiency. The regenerator core is constructed of stainless steel tubing with aluminum fins. The liquid follows one continuous path (in the counterflow direction) through the finned tubing which makes 112 passes through the hot vapor flow.

The PCS is designed to operate at all solar-related elevation angles from 5° to 90° above the horizon. For this reason, the hotwell (liquid collection reservoir) is located at the low point of the PCS. The total working fluid inventory is about 15 litres (4 gal). The low pressure side of the system operates at sub-atmospheric pressure to optimize turbine performance, so a small electrically-driven centrifugal boost pump is used to provide a moderate positive pressure to feed liquid to the main pump and the bearings. The boost pump obtains liquid from the hotwell.

The temperature of the vapor at the exit of the solar receiver is maintained near a constant 399°C (750°F) by means of a vapor throttling control valve between the receiver outlet and the turbine inlet. The constant temperature can be maintained by controlling the mass flow rate of the working fluid to compensate for variations in solar flux level. The vapor control valve is a pintle-type valve operated by a hydraulic actuator which is powered by high pressure working fluid. Valve command signals are keyed to temperature sensors at the receiver outlet.

Figure 3 is a simplified schematic diagram of the PCS showing the major components and the plumbing loop. The Remote Control Interface Assembly (RCIA) box shown in the figure is a FACC-designed controller/computer located near the base of each dish. Each RCIA communicates with a Master Power Controller (MPC) which performs central control and monitoring functions for a large array of SCSE power modules.

TOLUENE

The organic working fluid is reagent grade toluene ($C_6H_5CH_3$), a clear liquid similar to common paint thinner. The thermodynamic properties of toluene are ideally suited for use in small ORC turbines for solar applications. It yields high performance at relatively lower temperatures and pressures, compared to steam, and its freezing point is minus 95°C (minus 139°). Toluene is a fully characterized substance and its toxicity, flammability and other environmentally sensitive parameters are quite well known and safe handling procedures are well established.

For any given working fluid, efficiency increases with temperature; however, all organic fluids have an upper temperature limit beyond which they tend to decompose, evolve noncondensable gases, etc. Some existing toluene systems have operated at 427°C (800°F) and beyond, but 399°C (750°F) is planned as the upper limit for SCSE to promote long fluid life (years). The maximum temperature may be adjusted up or down as more experience is gained with the system. Adding 28°C (50°F) is worth about 1% gain in overall sub-system efficiency.

A few ORC systems in the field have experienced problems related to leakage, i.e., fluid degradation caused by air, moisture or oil contaminating the working fluid. For this reason, the SCSE system was designed as a hermetically sealed, closed-loop system to avoid the possible pitfalls associated with high speed shaft seals. Gearboxes, pipe threads, rust, etc. The PCS has no external moving seals. The toluene acts to lubricate all bearings,

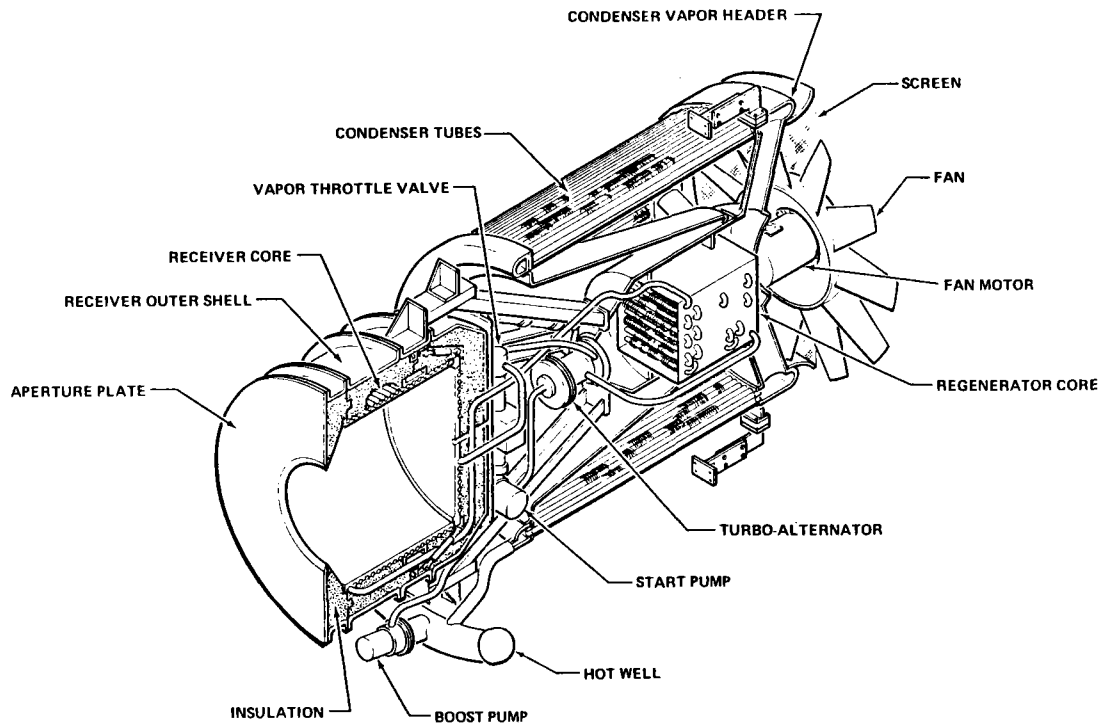


FIGURE 1. POWER CONVERSION ASSEMBLY

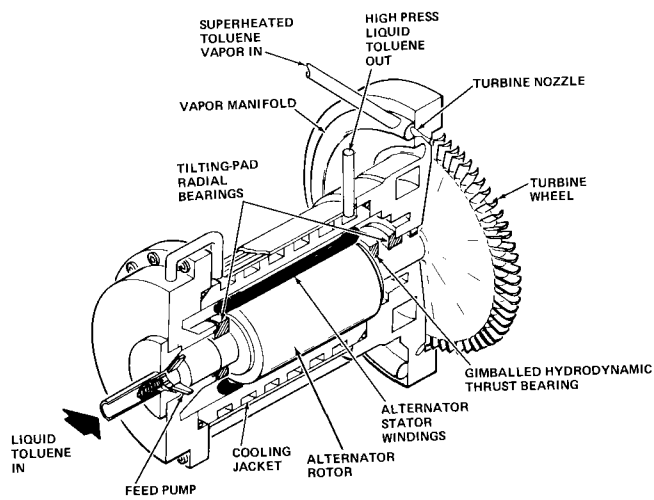


FIGURE 2. TURBINE-ALTERNATOR-PUMP (TAP)

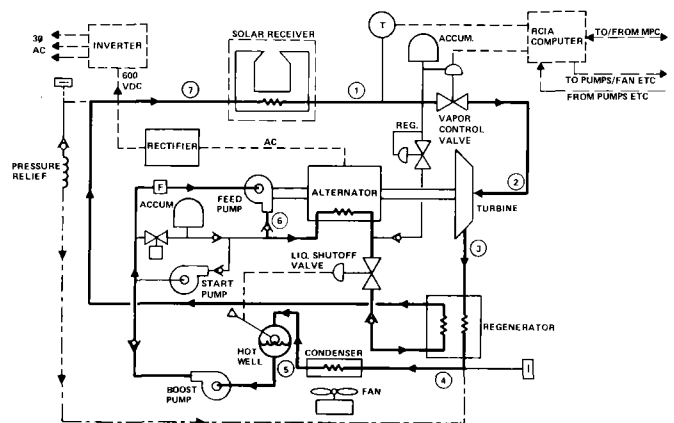


FIGURE 3. POWER CONVERSION SUBSYSTEM (PCA) SCHEMATIC

cool the alternator and pumps, and to operate the hydraulic actuator of the control valve (in addition to its primary function of powering the turbine).

PERFORMANCE

Electrical power output of the PCS is about 20 kW_e at rated conditions of 75.6 kW_t thermal input and 28°C (82°F) ambient air^e temperature. PCS output is about 25 kW_e at peak power conditions of 92.4 kW_t input.

Figure 4 shows PCS efficiency as a function of thermal input for various ambient temperatures. PCS efficiency is defined as the net dc electrical power out (accounting for parasitics) divided by thermal energy input from the receiver. Predicted efficiency at rated power is about 26 percent. Note the relatively flat shape of the curves, denoting high efficiencies across a very broad range of solar operating conditions. This excellent "part-load" characteristic helps maximize power output on an annualized basis and not just at a rated power point.

PROGRAM STATUS

Some PCS components are currently undergoing development testing at Barber-Nichols. B-N expects to complete assembly of the first deliverable unit in February, test it as a subsystem in March, test it combined with the FACC receiver and controller in April and ship it to the JPL test site in May of 1981.

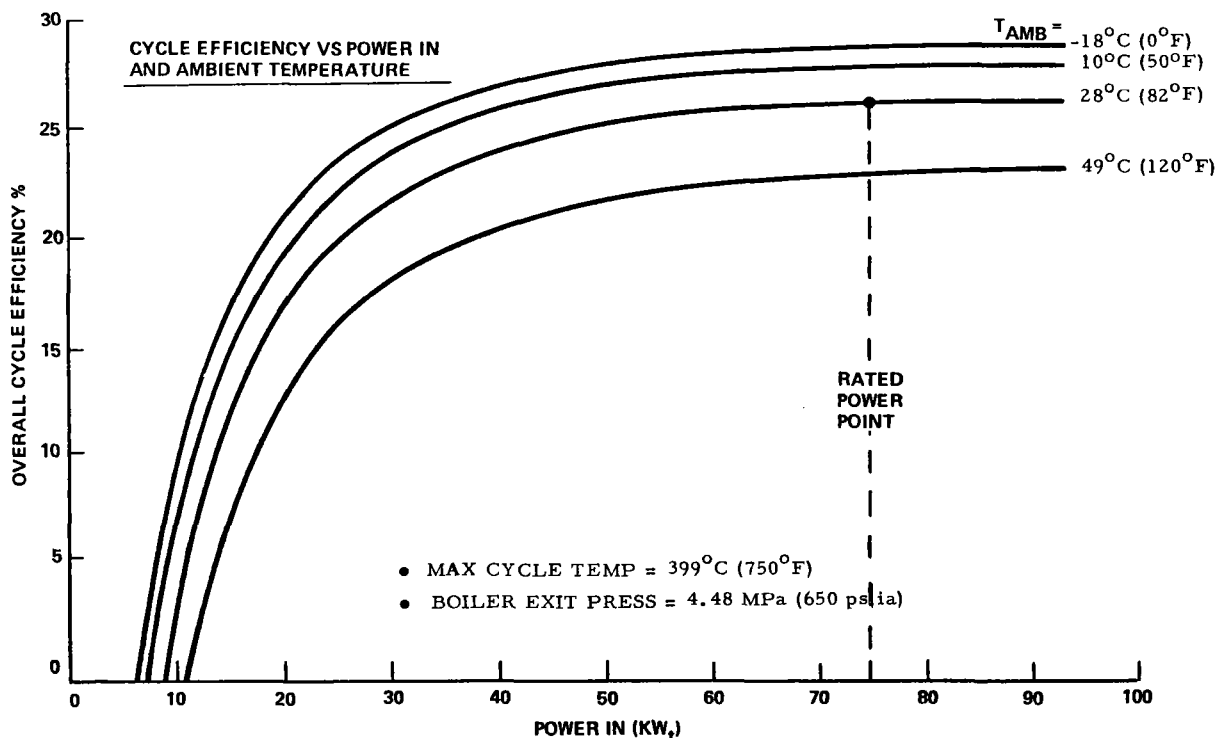


FIGURE 4. PCA PERFORMANCE

JAY CARTER ENTERPRISES, INC. STEAM ENGINE

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ABSTRACT

The Small Community Solar Thermal Power Experiment (SCSE) has selected an organic rankine cycle (ORC) engine driving a high speed permanent magnet alternator (PMA) as the baseline power conversion subsystem (PCS) design. The high frequency alternating current from the PMA is rectified and inverted to grid quality electricity. The back-up conceptual PCS design is a Jay Carter steam engine driving an induction alternator delivering power directly to the grid. This paper traces the development of Carter's automotive reciprocating simple rankine cycle steam engine and how an engine of similar design might be incorporated into the SCSE. A description of the third generation automotive engine is included along with some preliminary test data. Tests were conducted with the third generation engine driving an induction alternator delivering power directly to the grid. The purpose of these tests is to further verify the effects of expander inlet temperature, input thermal power level, expansion ratio, and other parameters affecting engine performance to aid in the development of an SCSE PCS.

INTRODUCTION

Early in Phase II of SCSE a fact-finding panel, consisting of personnel from the Jet Propulsion Laboratory, Lewis Research Center, Ford Aerospace and Communications Corp., and the Solar Energy Research Institute, was formed to assess the state-of-the-art in small organic and steam rankine cycle engines. The panel concluded that neither organic nor steam engines of the desired size range were off-the-shelf items and both were at a comparable state of development. After the ORC was selected as the baseline design, a parallel program was initiated to test the Carter third generation automotive engine driving an induction alternator. Testing is currently underway at the Jay Carter Enterprises, Inc. west coast office Santa Barbara, California. Preliminary results are available which will be presented along with a general description of how a Carter engine might be utilized in a solar application.

History of Engine Development

The main office of Jay Carter Enterprises, Inc. (JCE) is located in Burkburnett, Texas and was established in 1968. The first three years at JCE were spent developing inlet steam valves and piston cylinder expanders. A first generation engine was completed in 1971, tested for nine months, and in March, 1972 installed in a 1964 VW Squareback sedan. The maximum expander inlet conditions were 538°C (1,000°F) and 13.79 M Pa (2000 psia). The expander consisted of four radial piston cylinders with 574 cm³ (35 in³) displacement and an 11.3:1 expansion ratio (1).

The VW Squareback sedan with the first generation JCE engine demonstrated exceptional overall vehicle performance. Peak engine power was 52 KW (70 HP) mechanical at 5,000 RPM. Road tests were conducted for 9,700 Km (6,000 miles) at speeds as high as 130 Km/hr (80 miles/hour) and at the end of 3,200 Km (2,000 miles) the engine showed no signs of wear. This automobile had a cold start-up to vehicle moving time capability of less than 15 seconds. This was the first automobile to meet the original 1976 emissions standards without add-on devices and demonstrated the best officially documented fuel mileage for a rankine-powered motor vehicle up to that time (June, 1974)(2, 3).

The second generation engine was developed to operate in a 74 VW Dasher or an AMF designed paratransit vehicle (PTV). Paratransit was defined as all types of transit between privately owned and operated cars on one side and scheduled rail and bus service on the other. The second generation engine expander consisted of two cylinders vertically mounted which delivered 75 KW (100 HP) at 5,500 RPM. The 6.35 cm (2.5 in.) diameter and 7.62 cm (3.0 in.) stroke piston cylinders produced a total engine displacement of 483 cm³ (30 in³) and an expansion ratio of 10:1. Expander inlet temperature was held constant at 566°C (1,050°F) while pressure varied up to 17.24 MPa (2,500 psia) approximately proportional to input power level (4).

A third generation engine was built in 1977 which was virtually identical to the second generation engine. One modification incorporated into the third generation engine was screw on heads.

Description of Third Generation Test Engine

The expander on the third generation engine shown schematically in Figure 1 for a solar application consists of two vertically mounted piston-cylinders operating in parallel. Each piston-cylinder has a spring return inlet valve opened by a spike attached to the piston. These valves are commonly referred to as "bash valves". This valve design is a fixed cutoff type meaning a constant volume of steam is admitted into the cylinder at the top of each stroke. Power output from the engine is controlled by varying the boiler pressure which also changes the mass flowrate into the expander. This type of control system requires minimal throttle valve control; however, a positive displacement feed pump with solenoid valving is required to deliver controlled mass flow at variable pressures. Toward the end of each stroke oil is injected directly onto the piston rings to minimize wear and leakage around the rings. The oil is a non-emulsifying oil which is allowed to freely mix with the steam at the expander exhaust. The expander is a uniflow design, meaning that at the end of each stroke the piston uncovers exhaust ports which allows the oil/steam mixture to pass through the feedwater heater and on to the air-cooled condenser. After the steam is condensed the oil and water are separated using the centrifuge which returns the oil to the expander and the water to an open to atmosphere water tank. The piston type feed pump delivers the water from the water tank through the feedwater heater and back to the boiler.

Test Results

The third generation engine was tested at expander inlet temperatures between 399°C (750°F) and 566°C (1,050°F) and at power levels from 25 to 80 KWth input. Efficiencies as high as 20% were measured, based on net electrical power delivered to the grid divided by the thermal input to the working fluid. All electric power parasitics were subtracted from the alternator output to obtain the net electric output. Preliminary data showing efficiency versus thermal input are plotted in Figure 2 at 538°C (1,000°F) expander inlet temperatures for a 10:1 expansion ratio. These efficiencies could be improved by adding insulation and repairing leaks in the condenser which created an excessive expander back pressure. Testing at a 14 to 1 expansion ratio was initiated; however, the data is not currently available. Engine simulations predict improved efficiencies at this higher expansion ratio.

Engine Solar Applications

JCE completed a preliminary design study evaluating a JCE engine mounted at the focus of a parabolic dish solar collector (5). The study determined that for a 15 KW_e engine/induction alternator unit, a single cylinder expander was optimal for a simple cycle and two cylinders were optimal for a reheat cycle. Maximum design inlet steam temperatures and pressures were 677°C (1,250°F) and 17.2 MPa (2,500 psia). An engine design speed of 3,600 RPM and maximum thermal input of 80 KWth was selected. Under these conditions a simple cycle and a compound reheat cycle had predicted total power conversion efficiencies (thermal-to-electric) of 26 and 30 percent, respectively. This engine would be easily adaptable to a total energy application which would use the high temperature steam to generate electricity and the 100°C (212°F) exhaust heat for domestic, commercial or industrial heating applications. This would increase the total system efficiency to approximately 90%.

Several engine mounting configurations are possible with a JCE engine on a parabolic dish collector. The JCE approach described in the study would mount everything except the condenser and the oil/water separation storage tank at the focal point of the dish. This configuration would have a dish mounted weight of 297 KG (654 lb.) and a total weight of 601 KG (1,323 lb.). The condenser would be fitted with a chimney to minimize parasitic fan power. Other mounting configurations might include using the condenser as a counter weight for the concentrator or simply mounting everything at the focus. Freeze protection could be accomplished with flexible freeze tanks, resistance heaters or a buried water storage tank.

Conclusion

The JCE third generation automotive engine has demonstrated total power conversion efficiencies (thermal to electric) of approximately 20%. The engine test data corresponds closely with the predicted data at several operating conditions which add credibility to the model. Verification of the engine and model through testing indicates predicted 26% simple cycle and 30% reheat cycle thermal to electric efficiencies are achievable at 677°C (1,250°F) for 15 KW_e power levels. The value of this engine in a solar application could be further enhanced by using the 100°C (215°F) exhaust heat, thus increasing the total system efficiency to approximately 90%.

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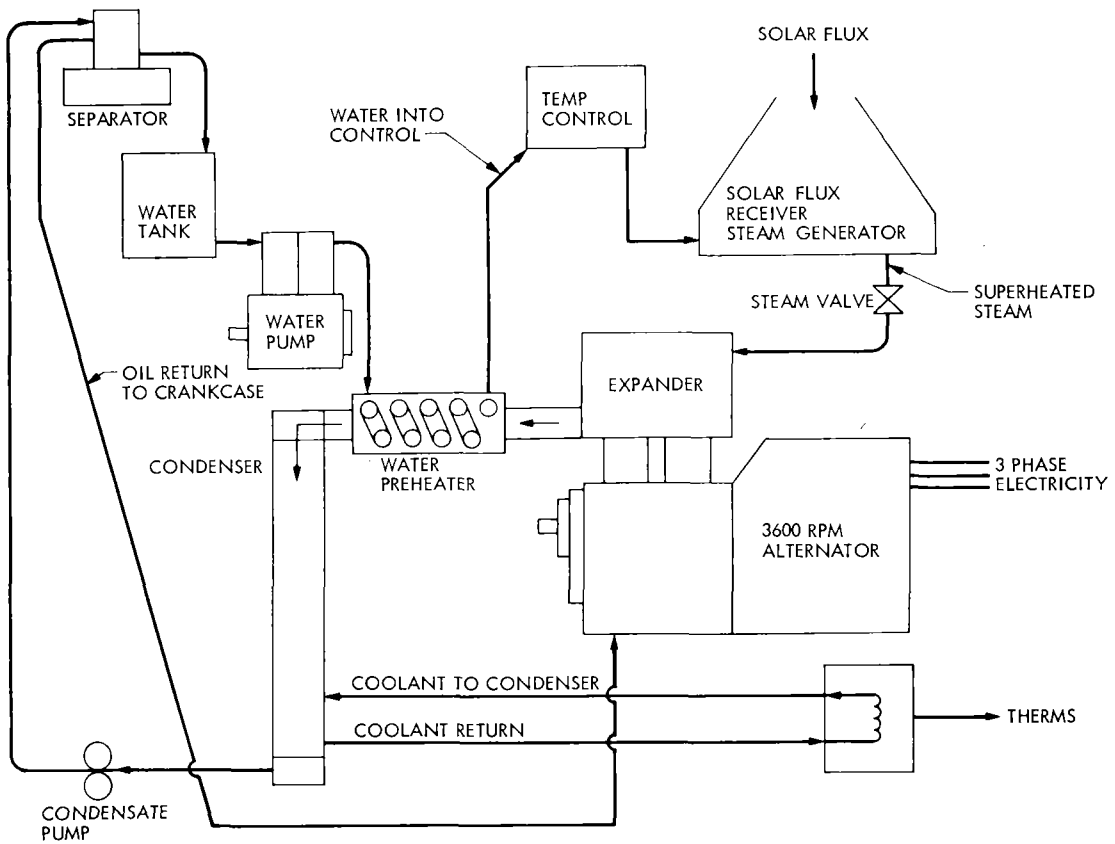


Figure 1. Power Module Schematic

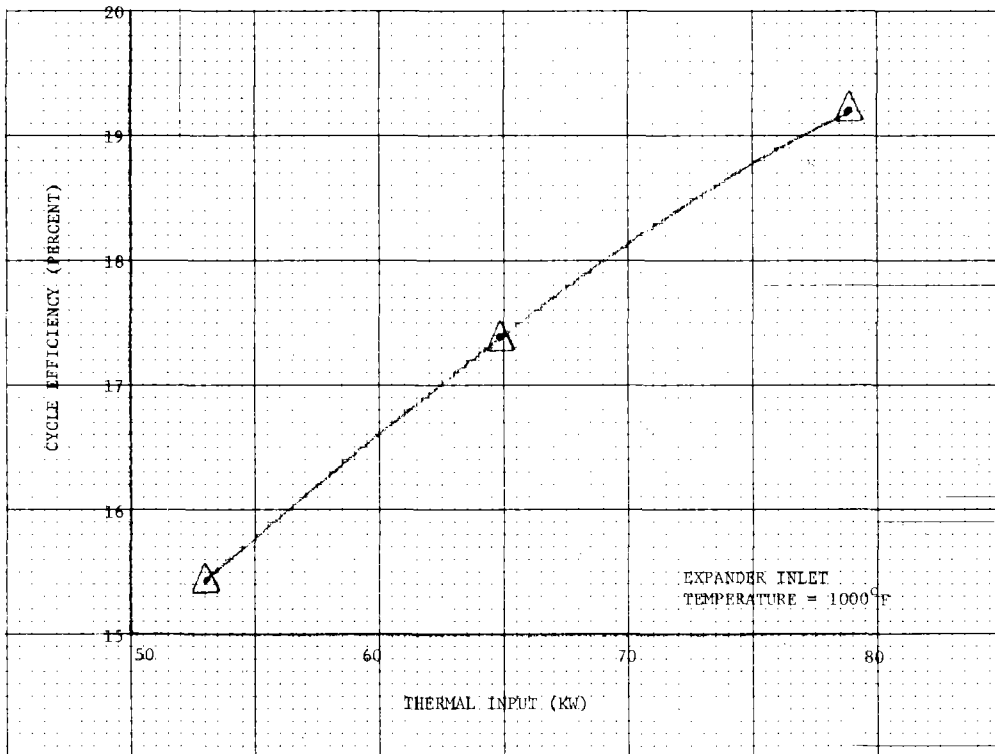


Figure 2. Preliminary Engine Data

STEAM ENGINE RESEARCH FOR SOLAR PARABOLIC DISH

Roger L. Demler
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ABSTRACT

A steam engine design and experimental program is exploring the efficiency potential of a small 25 kW compound reheat cycle piston engine. An engine efficiency of 35 percent is estimated for a 700°C steam temperature from the solar receiver.

BACKGROUND

The parabolic dish solar concentrator provides an opportunity to generate high grade energy in a modular system. Most of the capital cost is projected to be in the dish and its installation. Assurance of a high production demand of a standard dish could lead to dramatic cost reductions. High production volume in turn depends upon maximum application flexibility by providing energy output options, e.g. heat, electricity, chemicals and combinations thereof. Subsets of these options include energy storage and combustion assist.

Individual dish mounted engine generator sets represent a major market opportunity.

The Market

Projecting new product market potential is a risky business. Presuming success in meeting system cost and performance goals, dish-engine production has been studied in the 10,000 to 100,000 range of annual unit volume.

Selection of the best engine type from among the Brayton, Stirling and Rankine engines will have to wait for development results.

The Steam Rankine Engine

The positive displacement steam engine is an excellent fit in the component chain. High efficiency at moderate temperatures (55 to 59 percent of Carnot) yields high dish and receiver efficiencies as well. Engine efficiency is insensitive to load and ambient variations. A high efficiency 60 Hz alternator can be directly driven. Waste heat is accessible and at a useful temperature. Combustion assist and thermal storage coupling are straightforward.

All of the hardware is conventional in materials of construction and virtually already mass produced. The needed research is limited to the durability development of the hot cylinder, valves and long term water quality needs.

DESIGN STUDY

Two independent steam engine design studies were conducted for the DOE parabolic solar dish program managed by JPL. NASA LeRC as solar engine consultants contracted with Jay Carter Enterprises (1) and ourselves, Foster-Miller Associates (FMA) (2) for parametric and preliminary designs. The results were very similar in concept and performance potential.

The system arrangement places the high temperature and pressure engine components in the shadow of the receiver. The 60 Hz generator is directly driven. An atmospheric pressure condenser is mounted on the ground and cooled with a natural draft stack. FMA selected a drain down sump buried below the frost line. The water boost/emergency receiver coolant pump and electronics are also at ground level.

Compound expansion reheat cycles were chosen to maximize efficiency (Figure 1). One high pressure cylinder and one low pressure cylinder were predicted to be as efficient as any other combination of cylinder numbers.

Performance Analysis

FMA, combined with acquisition of the engine research group of Scientific Energy Systems, Inc., has developed a steam expander performance model. This work (3) is based on 5,000 hours of steam expander testing at an inlet temperature of 540°C. The important conclusions from this work were used to analyze the potential of cycle variations matched to specific expander designs (Figure 2, Table 1).

Trends of interest are the influences of temperature and pressure ratios. Increasing inlet temperatures result in increasing efficiency nearly proportional to the respective Carnot efficiencies. Increasing pressure ratios increase efficiency but with little benefit at the higher pressures. The limiting factors are the onset of cyclic heat transfer in the cylinders when the higher expansion ratios drive the exhaust temperature below the inlet steam saturation temperature and increasing friction losses in the larger low pressure cylinders required to handle the increasing exhaust volume.

Preliminary Design Study

The selected cycle and design approach were matched to a reheat steam receiver study conducted by AiResearch. The peak steam pressure and temperature were selected based on the demonstrated properties of stainless steels. ASME code properties for 316SS were judged to be adequate but Incoloy 800H, an iron based higher alloy, is suggested as a more cost effective material for the high pressure tubing.

The engine specifications (Table 2, Figure 3) calls for a low piston speed, 30 Hz expander of moderate displacement. Engine efficiency over the load range exceeds 34 percent.

Four features of the system design are unproven. The first issue is the validity of the performance model. The supporting data is derived from a lower temperature but higher stage pressure ratio engine. The extrapolation

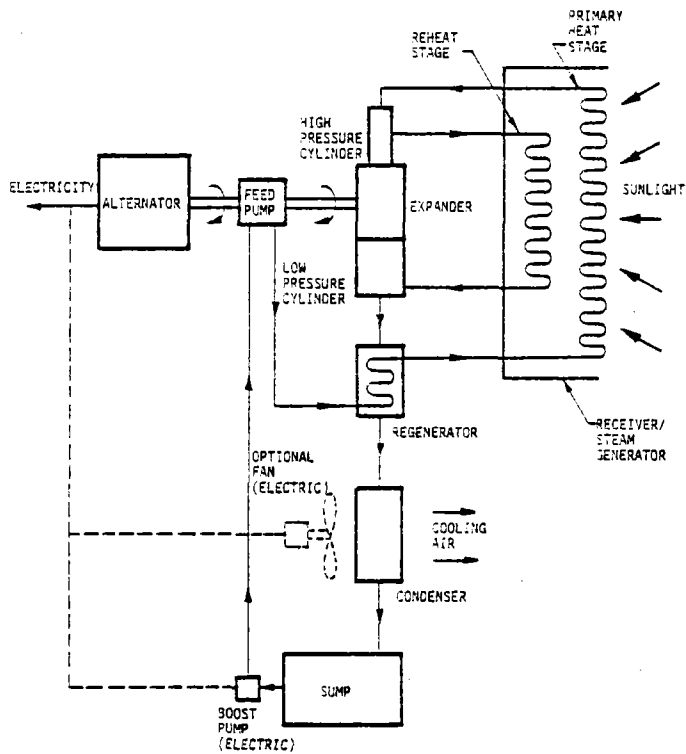


FIGURE 1. ENGINE SCHEMATIC

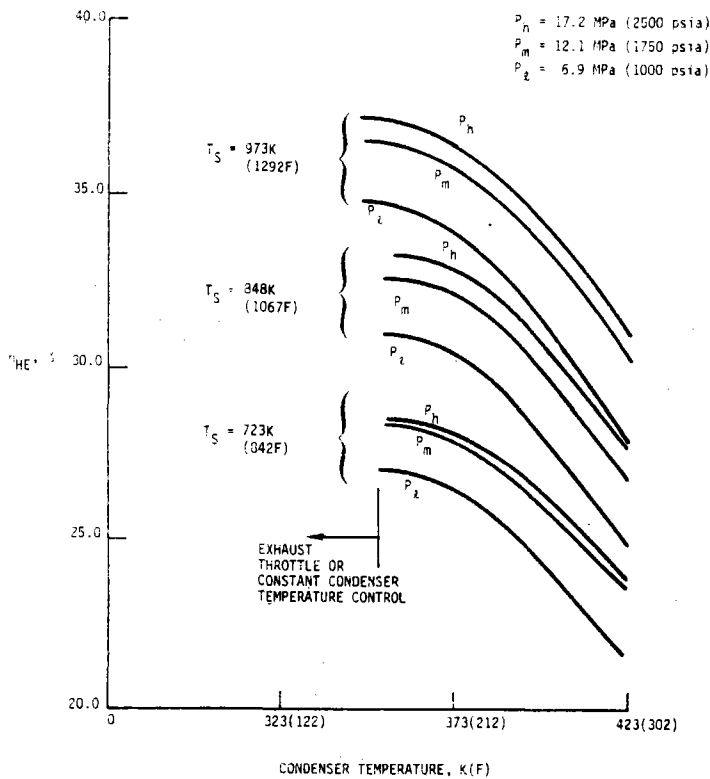


FIGURE 2. PARAMETRIC ENGINE EFFICIENCY

TABLE 1. PARAMETRIC DESIGN DETAILS

Inlet Steam			Mass Flow Rate g/s (lb/hr)	Displacement cm ³ (in. ³)		Condenser Temperature K (°F)		Feedwater Temperature K (°F)	Auxiliary Power Required (kW)	Efficiencies (%)			Ratio to Ideal Cycle
Temperature K (°F)	Pressure MPa (psia)	1st Stage 2nd Stage		1st Stage	2nd Stage	K	°F			Prime Mover	Heat Engine	Overall Power Conversion	
723 (1942)	6.9 (1000)	1.4 (200)	21.4 (170)	81.5 (4.97)	1336 (81.5)	311 (101)	367 (201)	0.28	59.1	24.7	21.0	0.614	
			20.3 (161)	77.2 (4.71)	1240 (75.7)	322 (120)	362 (193)	0.27	65.8	25.9	22.1	0.671	
			19.8 (157)	75.4 (4.60)	1121 (68.4)	339 (150)	368 (203)	0.27	73.5	26.8	22.7	0.775	
			20.9 (165)	79.4 (4.85)	719 (43.9)	372 (210)	403 (265)	0.30	84.7	26.7	22.7	0.850	
			29.3 (232)	112.2 (6.85)	472 (28.8)	422 (300)	494 (430)	0.40	92.7	21.6	18.3	0.857	
			19.7 (156)	52.8 (3.22)	1228 (75.0)	311 (101)	368 (203)	0.46	60.2	26.2	22.3	0.631	
	12.1 (1750)	18.7 (148)	50.2 (3.06)	1145 (69.9)	322 (120)	364 (195)	0.44	66.6	27.4	23.3	0.687		
		18.3 (145)	49.1 (3.00)	1036 (63.2)	339 (150)	370 (206)	0.43	73.8	28.2	24.0	0.775		
		19.1 (152)	51.6 (3.15)	864 (40.5)	372 (210)	405 (270)	0.46	83.7	28.1	23.9	0.846		
		25.7 (203)	68.8 (4.20)	411 (25.2)	422 (300)	494 (430)	0.63	91.1	23.8	20.3	0.875		
		19.9 (157)	40.3 (2.46)	1239 (75.6)	311 (101)	370 (206)	0.67	59.9	26.0	22.1	0.625		
		18.9 (149)	38.3 (2.36)	1154 (70.4)	322 (120)	365 (198)	0.63	66.2	27.2	23.2	0.673		
17.2 (2500)	18.4 (146)	37.4 (2.28)	1042 (63.2)	339 (150)	371 (209)	0.62	73.3	28.1	23.9	0.770			
	19.4 (154)	39.3 (2.40)	668 (40.8)	372 (210)	407 (272)	0.67	83.0	27.9	23.7	0.835			
	26.0 (206)	52.0 (3.22)	419 (25.5)	422 (300)	496 (433)	0.92	89.8	23.6	20.0	0.849			
	17.6 (139)	81.5 (4.97)	1297 (79.1)	311 (101)	361 (263)	0.24	61.0	28.1	24.1	0.660			
	16.0 (127)	74.0 (4.52)	1069 (65.2)	339 (150)	394 (250)	0.22	68.7	29.9	25.4	0.722			
	16.9 (134)	78.1 (4.77)	687 (41.9)	372 (210)	433 (319)	0.24	76.2	30.8	26.2	0.794			
848 (1967)	6.9 (1000)	1.4 (200)	24.0 (190)	111.5 (6.80)	456 (27.9)	422 (300)	539 (511)	0.33	86.8	30.5	26.0	0.860	
			15.5 (123)	52.5 (3.20)	1141 (69.8)	311 (101)	381 (244)	0.36	93.1	21.2	21.2	0.459	
			15.1 (120)	51.1 (3.12)	1091 (66.6)	322 (120)	390 (243)	0.35	64.8	30.8	26.2	0.693	
			14.0 (117)	50.0 (3.05)	989 (60.4)	339 (150)	395 (252)	0.35	69.7	31.6	26.9	0.731	
			15.5 (124)	53.5 (3.26)	635 (38.8)	372 (210)	434 (322)	0.39	76.4	32.4	27.6	0.798	
			21.7 (172)	73.6 (4.49)	412 (25.1)	422 (300)	542 (516)	0.53	85.9	32.3	27.5	0.861	
	17.2 (2500)	15.2 (120)	40.6 (2.48)	1117 (68.1)	311 (101)	392 (247)	0.51	91.2	26.8	22.8	0.851		
		14.8 (117)	39.6 (2.42)	1067 (65.1)	322 (120)	392 (245)	0.49	64.7	31.2	26.5	0.690		
		14.4 (114)	38.7 (2.36)	965 (58.9)	339 (150)	396 (253)	0.49	69.4	32.0	27.2	0.731		
		15.2 (120)	40.7 (2.48)	618 (37.7)	372 (210)	416 (325)	0.52	76.0	32.9	28.0	0.797		
		20.6 (163)	55.1 (3.36)	391 (23.8)	422 (300)	540 (513)	0.73	85.2	32.8	27.8	0.859		
		89.7	27.8	23.6	0.853								
973 (1292)	6.9 (1000)	1.4 (200)	13.7 (108)	73.9 (4.51)	1161 (70.8)	311 (101)	411 (280)	0.18	67.4	33.3	28.3	0.732	
			13.4 (106)	72.8 (4.44)	1117 (68.2)	322 (120)	413 (281)	0.18	72.0	34.0	28.9	0.782	
			13.3 (105)	71.9 (4.39)	1020 (62.2)	339 (150)	419 (294)	0.18	78.7	34.8	29.5	0.837	
			14.5 (115)	78.5 (4.79)	678 (41.4)	372 (210)	470 (387)	0.20	87.0	33.8	28.7	0.860	
			20.5 (162)	111.0 (6.77)	448 (27.3)	422 (300)	587 (596)	0.28	93.1	27.8	23.6	0.858	
			12.9 (102)	51.5 (3.14)	1212 (74.0)	311 (101)	422 (299)	0.30	66.7	34.6	29.4	0.732	
	12.1 (1750)	12.4 (98)	49.9 (3.05)	1031 (62.9)	322 (120)	416 (288)	0.29	72.5	35.8	30.4	0.790		
		12.2 (97)	49.1 (3.00)	940 (57.4)	339 (150)	422 (299)	0.29	78.8	36.5	31.1	0.818		
		13.3 (105)	53.3 (3.25)	623 (37.9)	372 (210)	473 (391)	0.32	86.3	35.7	30.3	0.858		
		18.1 (143)	72.8 (4.44)	396 (24.2)	422 (300)	589 (601)	0.44	93.4	30.2	25.7	0.853		
		12.5 (99)	40.2 (2.45)	1057 (64.5)	311 (101)	423 (302)	0.42	66.8	35.1	30.0	0.732		
		12.1 (95)	39.2 (2.39)	1003 (61.2)	322 (120)	419 (293)	0.40	72.4	36.4	30.9	0.790		
17.2 (2500)	11.9 (94)	38.6 (2.36)	915 (55.8)	339 (150)	424 (304)	0.40	78.5	37.1	31.6	0.815			
	12.9 (102)	41.7 (2.54)	602 (36.7)	372 (210)	475 (396)	0.44	85.7	36.3	30.9	0.854			
	17.4 (139)	56.5 (3.45)	380 (23.2)	422 (300)	592 (605)	0.61	90.2	31.0	26.4	0.847			

TABLE 2. PRELIMINARY DESIGN SPECIFICATION

Two cylinder, opposed, single throw crank
 Single acting with crossheads
 Compound expansion with reheat
 Inlet temperatures 973K (1292F)
 Atmospheric pressure condensing
 Poppet valves, feedwater pressure actuated
 Counterflow: 3% clearance volume
 Carbon piston rings (no oil in steam)
 Speed: 60π rad/s (1800 rpm) nominal - actual ≈ 1840 rpm
 Stroke: 68 mm (2.67 in.)
 Piston speed: 4.1 m/s (800 ft/min)

	Stage I	Stage II
Inlet pressure, MPa (lb/in. ²)	12 (1750)	1.1 (153)
Bore, mm (in.)	43 (1.71)	149 (5.86)
Displacement, cm ³ (in. ³)	100 (6.12)	1179 (72.0)
Maximum piston thrust, kN (lb)	17.0 (3816)	17.4 (3916)

Performance	Design Point	Maximum	Minimum
Electric output, kW	21	26	13
Cut-off (%)	18.0	23.0	11.2
Flow rate, g/s (lb/hr)	16.8 (136)	21.0 (166)	11.1 (87.9)
Stage I MEP, MPa (lb/in. ²)	4.2 (602)	5.1 (737)	2.7 (389)
Stage II MEP, kPa (lb/in. ²)	363 (52.6)	444 (64.4)	234 (33.9)
1kW (IHP)	25.3 (33.9)	31.0 (41.5)	16.3 (21.9)
Expander efficiency (%)	87.9	87.4	82.8
Engine efficiency (%)	35.9	35.9	34.1
Alternator efficiency	92.1	91.6	90.8
Net electrical efficiency (%)	33.0	33.0	31.4

is done from basic principals starting from individually measured losses such as friction, pressure and heat transfer. A sensitivity analysis of each loss mechanism indicates that the net efficiency is rather forgiving. The reheat steam cycle is uniquely forgiving of internal losses by virtue of its highly regenerative nature (reheat recovery and feedwater heater) and low pumping power (1½ percent).

The high steam temperature is unusual in a steam power system. Fossil fueled plants are primarily limited by sulfur corrosion on the air side. Internally, steam turbines are considered to be life limited by particulate erosion of the transonic blades and low cycle fatigue of the massive rotors. The small piston engine is relatively free of these problems. A more severe problem *may* be the long term water quality that can be economically provided in the field.

Two design choices recommended for development are dry lubricated piston rings and water pressure actuated hydraulic valves. Oil lubricated rings have been proven in steam with a 370°C face temperature in a 540°C expander. A similar environment could be obtained for this design using the hidden and cooled techniques used in Stirling engines with plastic rings. Avoidance of oil carryover and cylinder cooling losses suggests that dry lubrication is a valuable goal.

Similarly the valve actuation system could be accomplished with a cam and tappet system and/or a piston opened bash valve on the intake. It was felt that performance, complexity, life, and sealing would all benefit from feed-water pressure actuated pistons on the valve stems.

EXPANDER RESEARCH

FMA is starting to test the critical expander features of the preliminary design. Funding is provided by DOE through a small business program for Innovative Research on Solar Thermal Power Systems (4).

A prototype compound expander following the general principals and sizing results of the study has been built to test cylinder performance, dry (graphite) piston rings and water actuated valves.

The first build graphite piston rings are rectangular unbalanced snap types. Pressure balancing can be incorporated in later builds when basic pressure velocity wear data is obtained. Other alternative piston sealing methods such as hard on hard pairs and controlled leakage options can also be researched.

The valve actuation method is currently subject to Government patent disclosure. In principal feedwater pressure operates on alternate sides of a piston on the valve stem. A mechanically driven spool valve switches the water and is close coupled to the valve piston to minimize line dynamics. Squeeze film dampening is used on both ends of the valve stroke to control impact velocities.

The expander design is intended to grow into a field demonstration engine if the research results are encouraging. For example, the crankcase includes complete balancing shafts and accessory drive shafts.

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3. Demler, R., The Application of the Positive Displacement Reciprocating Steam Expander to the Passenger Car, Society of Automotive Engineers, Automotive Engineering Congress and Exposition, Detroit, MI, SAE 76034, February, 1976.
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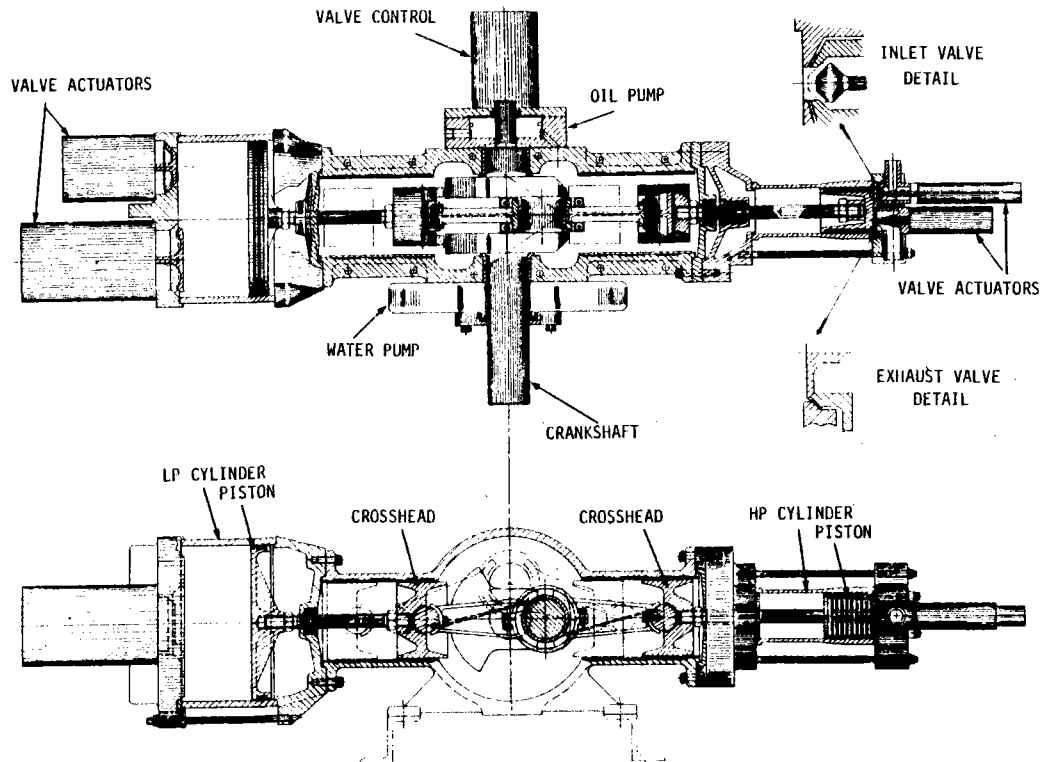


FIGURE 3. PRELIMINARY EXPANDER DESIGN

SOLAR BRAYTON ENGINE/ALTERNATOR SET

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Garrett Turbine Engine Company
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ABSTRACT

Garrett's work on the Mod 0 solar Brayton engine/alternator set is being redirected to utilize solarized components of the automotive advanced gas turbine (AGT) being developed by Ford and Garrett under contract to NASA. The new configuration is referred to as the Mod I. Commercialization of solar Brayton engines thus should be enhanced not only by relating the design to an engine expected to reach the high quantity, low cost production rates associated with the automotive market, but also by the potential the AGT components provide for growth of efficiency and power rating. This growth would be achieved through use of ceramics in later versions making operation possible at temperatures up to 2500°F. The longer program duration and higher cost of the Mod I is considered compatible with the extended schedule of the application and the system test program for which the Brayton engine/alternator set is first intended. Subject to funding availability, the initial solarized AGT should be under test by Nov 1981, and a complete Mod I engine/alternator set deliverable approximately one year later.

The Mod I will operate at 1500°F turbine inlet temperature (TIT) and produce 23 kw shaft output power at about 32 percent shaft efficiency. Growth versions incorporating ceramic parts will be capable of operation at 2100 to 2500°F TIT and should develop 51 to 71 kw shaft power at efficiencies from 40 to 48 percent.

INTRODUCTION

This paper will report the status of the design, procurement and test effort by Garrett under NASA/DOE Contract DEN3-181. The purpose of this effort is to provide Brayton engine/alternator set hardware for demonstration of parabolic dish solar electric power modules.

When commercialized, the solar power modules will be the building blocks of dispersed solar power plants ranging in size from a few kilowatts to systems up to 10 megawatts. The concept of a dispersed power plant consists of combining the electrical output from the required number of identical solar power modules. The modules would be controlled from a conveniently located substation where any final power conditioning also would be performed. Each module would comprise a concentrator, a receiver, and an engine/alternator (E/A) set sometimes referred to as a power conversion subsystem (PCS). The E/A set hardware being procured under Contract DEN3-181 is expected to be

evaluated at JPL's Parabolic Dish Test Site at Edwards Air Force Base, California. The E/A set will be part of an experimental solar power module that also includes a test bed concentrator and a Garrett solar receiver.

During the period from February to July of 1980 the analysis and design of the Mod 0 engine/alternator set was essentially completed. The resulting configuration which is shown in Figure 1 reflected the initial guidelines, a low risk approach with minimum program cost and schedule. The Mod 0 design was based on use of the turbocompressor from the GTP36-51, a high performance state-of-the-art gas turbine recently designed for production rates up to 1000 per year as an Army generator set, two GT601 truck gas turbine production configuration recuperator cores, and an off-the-shelf Bendix 400 Hz alternator. At the 1500°F TIT limitation, set by the intended use with a metallic solar receiver, the estimated Mod 0 shaft efficiency was 30 percent.

Redirection of the contract effort to a Mod I design was initiated in July 1980 to replace the Mod 0 components with more advanced components designed with lower cost higher production rates in mind. The Mod I design selected by JPL includes solarized versions of the turbocompressor and regenerator from the automotive advanced gas turbine (AGT) under development by Ford and Garrett on NASA Contract DEN3-167 and a new permanent magnet alternator (PMA). This selection was made on the basis that these components would reduce the overall cost and schedule for achieving a commercialized Brayton engine for the solar power market in the 1990's.

This Mod I engine/alternator set (see Figure 1) will operate at 1500°F and produce 23 kw of shaftpower at about 32 percent shaft efficiency in the initial metallic version. When ceramic AGT housings become available from the automotive program, the solarized version with a ceramic receiver should be capable of operation to 2100 to 2500°F where the shaft output power and efficiency should be 51 to 71 kw and 40 to 48 percent respectively.

MOD I COMPONENTS

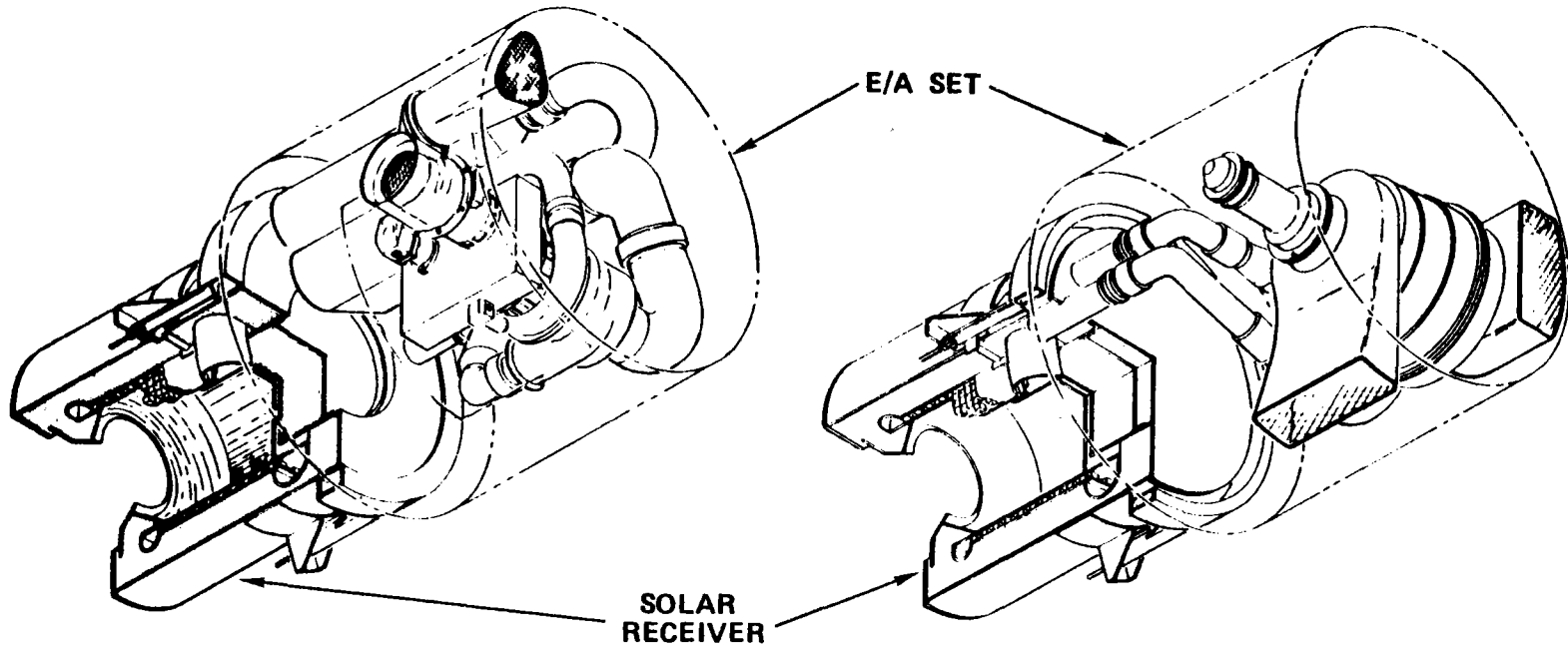
Figure 2 illustrates the key design changes made to improve the commercialization potential of the Brayton engine generator set. The solarized GTP36-51 turbocompressor and GT601 truck recuperator cores were replaced by the solarized AGT turbocompressor and regenerator. A comparison of some of the design features is made in Table 1.



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MOD 0

MOD I



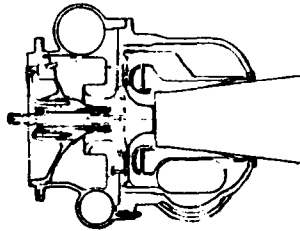
**E/A SET BASED ON
30 KW ARMY GENERATOR SET
GTP36-51**

**E/A SET BASED ON
AUTOMOTIVE ADVANCED GAS TURBINE
AGT101**

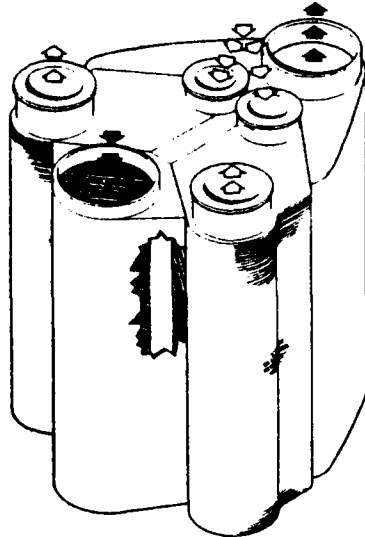
Figure 1. Brayton Engine/Alternator Set and Receiver.



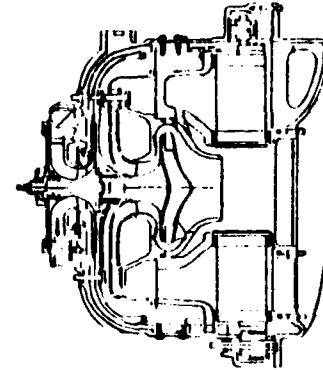
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MOD 0
**(SOLARIZED
GTP36-51)**



- **TURBO COMPRESSOR**
EXISTING GTP36-51 GENERATOR SET
ALL METALLIC DESIGN
- **RECUPERATOR**
EXISTING GT601 TRUCK CORF



MOD 1
**(SOLARIZED
AGT)**

- **TURBO COMPRESSOR**
DESIGNED FOR AUTOMOTIVE
APPLICATIONS
ADVANCED PERFORMANCE
CERAMIC HOUSINGS
IN FUTURE UNITS
- **REGENERATOR**
CERAMIC AUTOMOTIVE DESIGN

Figure 2. Engine and Recuperator/Generator.



TABLE 1. SOURCE ENGINE COMPARISON

	GTP36-51 ARMY GENERATOR SET AND GT601 TRUCK RECUPERATOR	AGT101 AUTOMOTIVE ENGINE
<ul style="list-style-type: none">● MAX OPERATING TEMPERATURE – TURBINE WITH METALLIC TURBOCOMPRESSOR °F WITH CERAMIC TURBOCOMPRESSOR HOUSINGS °F WITH CERAMIC ROTOR AND HOUSINGS °F	1675	1600 2100 2500
<ul style="list-style-type: none">● MAX OPERATING TEMPERATURE – RECUPERATOR WITH METALLIC RECUPERATOR °F WITH CERAMIC REGENERATOR °F	1300	1800-2000
<ul style="list-style-type: none">● BEARINGS	2 BALL BEARINGS	1 BALL BEARING AND 1 FOIL BEARING
<ul style="list-style-type: none">● MAX DESIGN SPEED, RPM	80,000	100,000
<ul style="list-style-type: none">● COMPRESSOR DIAMETER, IN MATERIAL	4.86 15-5 PH	4.3 2219-T6
<ul style="list-style-type: none">● TURBINE DIAMETER, IN MATERIAL	5.156 IN738	5.2 ASTROLOY
<ul style="list-style-type: none">● DATE OF FIRST OPERATION	4/75	7/81

(PMA)

Figure 3 illustrates other changes that were incorporated to upgrade the Mod I concept to more closely represent a commercialized configuration. The slab gearbox and off-the-shelf 400 Hz Bendix alternator were replaced with a direct driven permanent magnet alternator to be developed specifically for this solar application. The PMA will be designed to also perform as a synchronous starter motor when supplied with suitable power from a dual converter. The dual converter is so named because it also serves as the output power conditioning element, controlling and converting the alternator high frequency output to 60 Hz ac during periods of power generation. This alternator start capability will eliminate the need for a separate starter such as the hydraulic starter, included for reasons of expediency, in the Mod 0.

MOD I PERFORMANCE

The range of possible maximum power design points for the Mod I engine is plotted on Figure 4 with two illustrative choices "A" and "B" identified. When ceramic housings and a 17-meter dish become available, the maximum rated shaft power can be 51 kw with the engine operating at 2100°F and 90,600 rpm, (Point "B"). At this design point, the use of a gearbox will probably be required since the power delivered at engine shaft speed is too great for present day direct drive permanent magnet alternator technology. Initially, for use with the existing 1500°F metallic solar receiver and the 11- to 12-meter dishes, the engine design point (Point "A") will be 23 kw and 80,200 rpm. For reference, the Mod 0 design point (Point C) also is shown on the figure.

The 80°F sea level design speed for Point "B" was chosen to allow adequate margin for operation at other ambient conditions. For instance, if the same engine/alternator set were installed at 5000 feet and operated on a clear hot day, the engine speed must increase to absorb the concentrator heat output from 90,600 rpm to approximately 100,000 rpm, which is the AGT turbocompressor design limit.

Part-load characteristics of the Mod I engine corresponding to the two previously identified design Points "A" and "B" are shown on Figure 5. Currently, the part load control strategy is to hold the variable inlet guide vane (IGV) angle constant at about 20 degrees from full open for a 1500°F rating and reduce engine speed to match reduced thermal outputs from the solar concentrator and receiver. Note that this control strategy results in much higher part load efficiency than does holding the speed constant. From Figure 5, it is apparent that the efficiency is essentially constant over the 100 to 50 percent part-load power range.

Figure 3 illustrates other changes that were incorporated to upgrade the Mod I concept to more closely represent a commercialized configuration. The slab gearbox and off-the-shelf 400 Hz Bendix alternator were replaced with a direct driven permanent magnet alternator to be developed specifically for this solar application. The PMA will be designed to also perform as a synchronous starter motor when supplied with suitable power from a dual converter. The dual converter is so named because it also serves as the output power conditioning element, controlling and converting the alternator high frequency output to 60 Hz ac during periods of power generation. This alternator start capability will eliminate the need for a separate starter such as the hydraulic starter, included for reasons of expediency, in the Mod 0.

MOD I PERFORMANCE

The range of possible maximum power design points for the Mod I engine is plotted on Figure 4 with two most probable choices "A" and "B" identified. When ceramic housings and a 17-meter dish become available, the maximum rated shaft power will be 51 kw with the engine operating at 2100°F and 90,600 rpm, (Point "B"). At this design point, the use of a gearbox will probably be required since the power delivered at engine shaft speed is too great for present day direct drive permanent magnet alternator technology. Initially, for use with the existing 1500°F metallic solar receiver and the 11- to 12-meter dishes, the engine design point (Point "A") will be 23 kw and 80,200 rpm. For reference, the Mod 0 design point (Point C) also is shown on the figure.

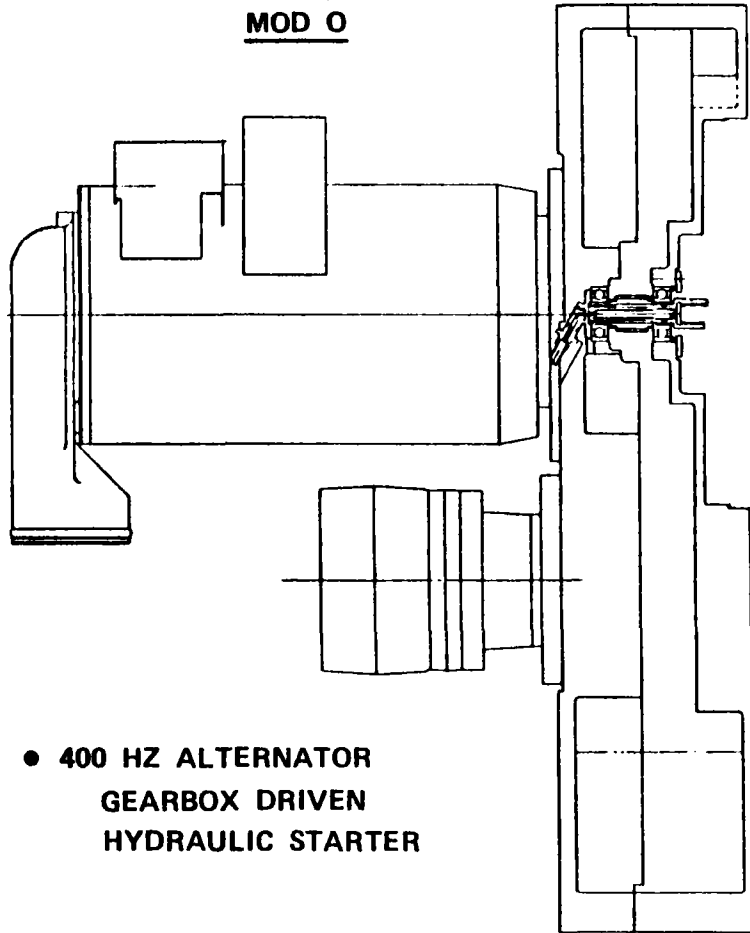
Point "B", the 80°F sea level design point for 2100°F, was chosen to allow adequate margin for operation at other ambient conditions. For instance, if the same engine/alternator set were installed at 5000 feet and operated on a clear hot day, the engine speed must increase to absorb the concentrator heat output from 90,600 rpm to approximately 100,000 rpm, which is the AGT turbocompressor design limit.

Part-load characteristics of the Mod I engine corresponding to the two previously selected design Points "A" and "B" are shown on Figure 5. Currently, the part load control strategy for the Mod I is to hold the variable inlet guide vane (IGV) angle constant at about 20 degrees from full open and reduce engine speed to match reduced thermal outputs from the solar concentrator and receiver. Note that this control strategy results in much higher part load efficiency than does holding the speed constant. From Figure 5, it is apparent that the efficiency is constant over the 100 to 50 percent power range.



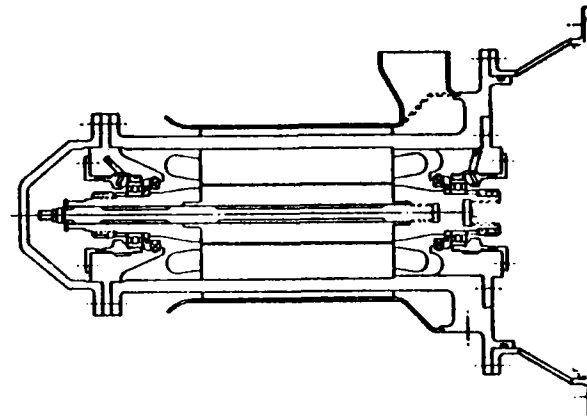
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MOD 0



- 400 HZ ALTERNATOR
GEARBOX DRIVEN
HYDRAULIC STARTER

MOD 1



- PERMANENT MAGNET ALTERNATOR
(WITH STARTER CAPABILITY)
DIRECT DRIVE

30

Figure 3. Alternator (Plus Gearbox) and Starter.

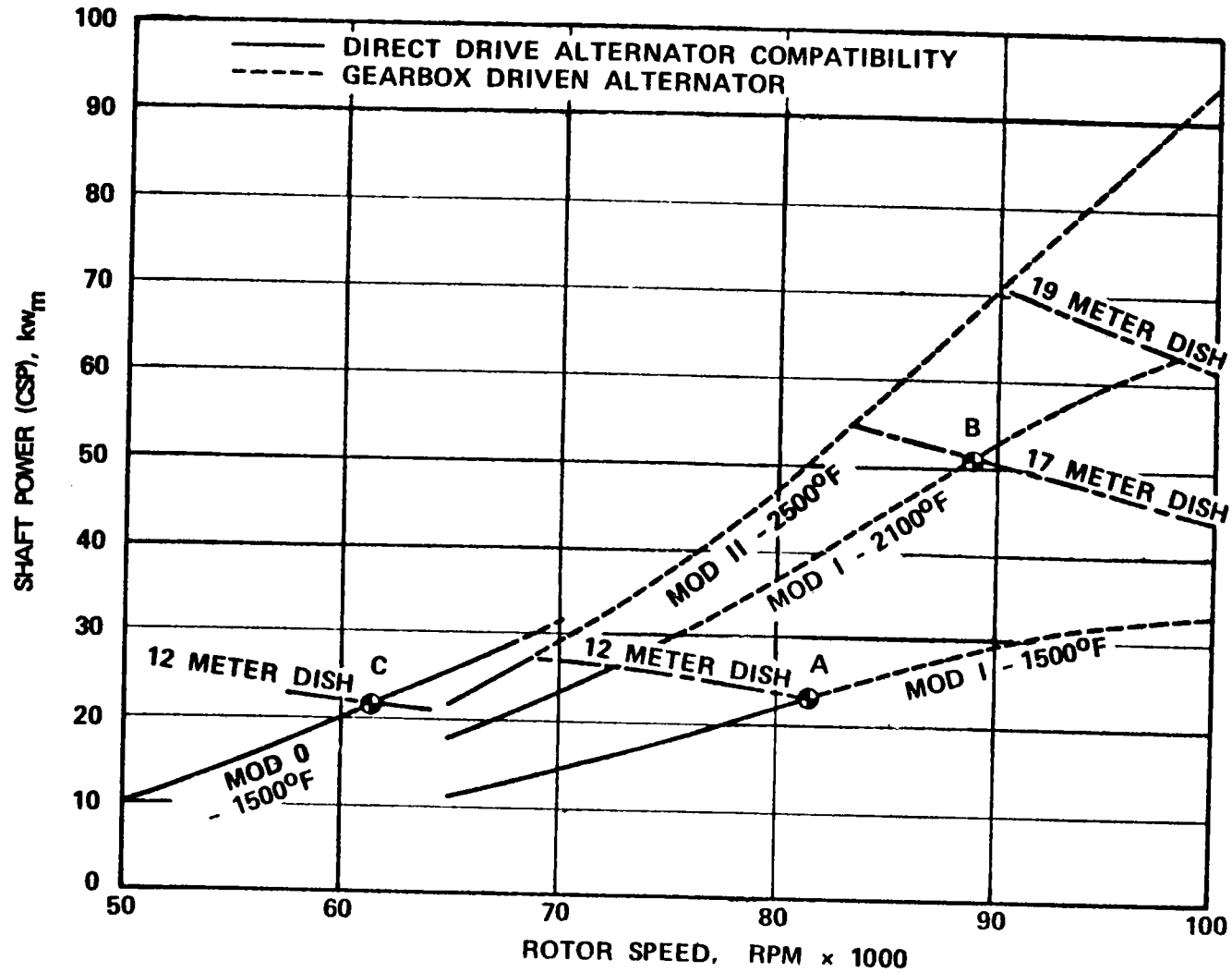


Figure 4. Design Point Performance



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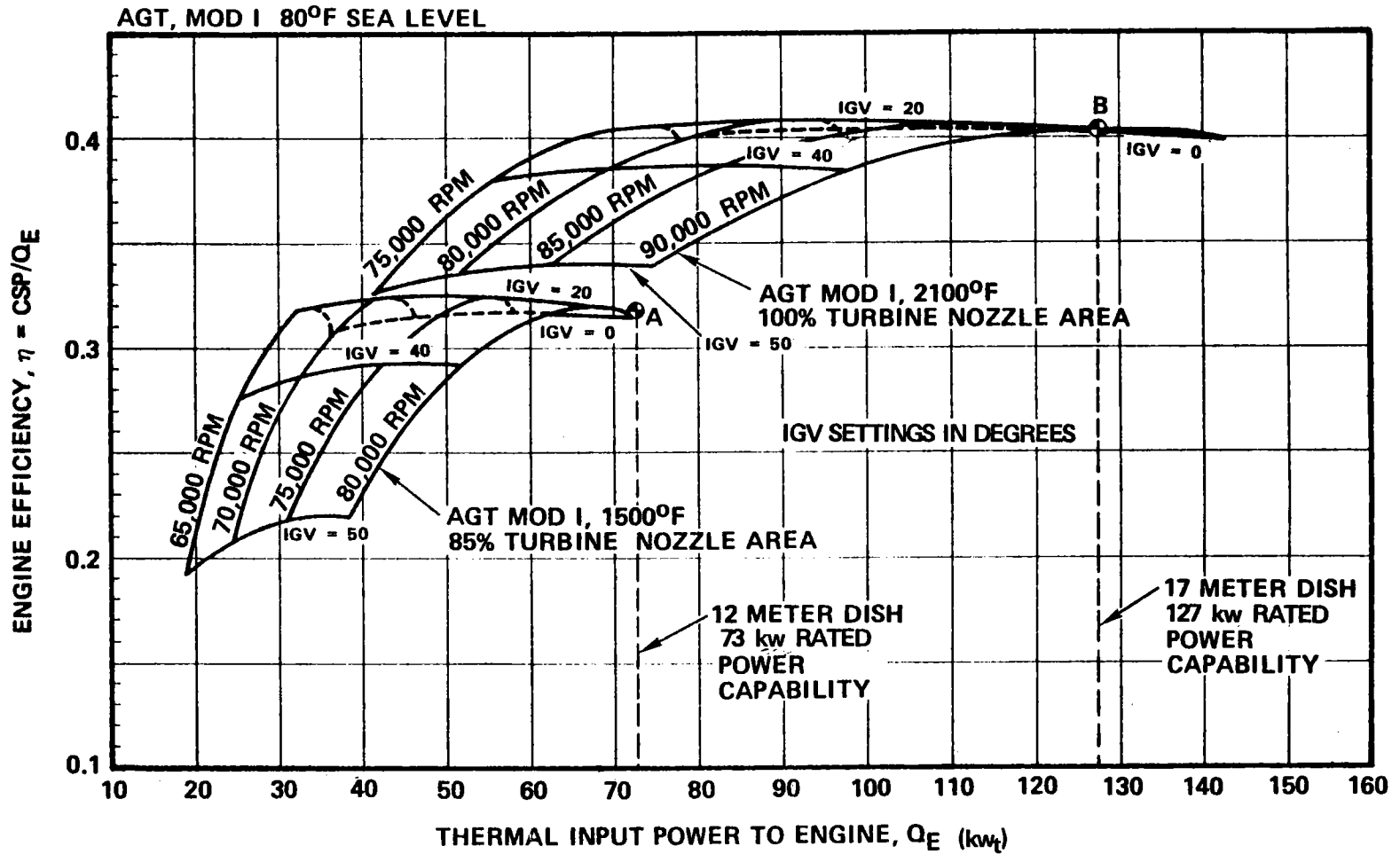


Figure 5. Part-Load Performance.

PROGRAM APPROACH AND SCHEDULE

As shown on Table 2, the Mod I program has been structured to accommodate vagaries of funds availability. Subject to go ahead in January, 1981 funds remaining on the contract will be used to design the solarized metallic AGT. As additional funds become available the solarized AGT will be fabricated and operated in the Garrett test laboratory, thus completing the first column of Table 2. Further funding will allow the balance of the Mod I engine/alternator set to be designed, fabricated and tested preparatory to shipment for evaluation at JPL's Parabolic Dish Test Site at Edwards Air Force Base. This activity is defined in the second column of Table 2. Depending on the requirements of future programs such as the EE-2a and the MX-RES, the design will be modified as indicated in the third column of Table 2 with required quantities fabricated and delivered.

SUMMARY

In mid-year of CY 1980, requirements for the Brayton engine/alternator set hardware appeared to be slipping, and additional development funds appeared to be forthcoming. Therefore, redirection of the Mod 0 program was initiated by JPL. The object of the redirection was to utilize the added time and funds to upgrade the Mod 0 design to a Mod I configuration, allowing incorporation of design features that would enhance the ultimate commercialization of Brayton engine/alternator sets. The more important of these Mod I design features are summarized as follows:

- A low cost, high production rate automotive design
- A potential for growth to 40-48 percent shaft efficiency
- A potential for growth to 51-71 kw shaft power

The Mod I program has been restructured to provide for achievement of meaningful milestones consistent with the expected incremental nature of future funding. Two major milestones are now defined as follows:

First test, solarized AGT - November 1981

Delivery, first Mod I E/A Set - March 1983

These milestones should be periodically reviewed to evaluate whether they are adequate and timely for requirements such as the EE-2a and MX-RES.

PROGRAM APPROACH AND SCHEDULE

As shown on Table 2, the Mod I program has been structured to accommodate vagaries of funds availability. Subject to go ahead in January, 1981 funds remaining on the contract will be used to design the metallic AGT solarization. As additional funds become available the solarized AGT will be fabricated and operated in the Garrett test laboratory, thus completing the first column of Table 2. Further funding will allow the balance of the Mod I engine/alternator set to be designed, fabricated and tested preparatory to shipment in March 1983 for evaluation at JPL's Parabolic Dish Test Site at Edwards Air Force Base. This activity is defined in the second column of Table 2. Depending on the requirements of future programs such as the EE-2a and the MX-RES, the design will be modified as indicated in the third column of Table 2 with required quantities fabricated and delivered. As a first step toward design and building the third column units, additional analysis will be required to confirm the design or define the additional design modifications required in areas such as:

- o Durability for solar duty cycle
 - Regenerator core and seals
 - Ceramic housings
 - Bearing life
- o Maintenance cost and selling price
- o Power rating and concentrator size for the 2100°F engine/alternator set
- o Type of alternator and power conditioning equipment for higher power rating

SUMMARY

Toward the end of FY 1980, predicated schedule requirements for the Brayton engine/alternator set slipped, and additional development funds appeared to be forthcoming. Therefore, redirection of the Mod 0 program was initiated by JPL. The object of the redirection was to utilize the time and expenditures necessary in upgrading the Mod 0 design to a Mod I configuration, and incorporating design features that will enhance the ultimate commercialization of Brayton engine/alternator sets. The more important of these Mod I design features are summarized as follows:

- o A low cost, high production rate automotive design
- o A potential for growth to 40-48 percent shaft efficiency
- o A potential for growth to 51-71 kw shaft power

TABLE 2

PROGRAM APPROACH - MOD I

APPLICATION	FIRST TEST HARDWARE (DEN3-181)		SUBSEQUENT HARDWARE
	NEAR TERM SAGT ENGINE LABORATORY DEMONSTRATION	² COMPLETE MOD I E/A SET FOR PDTS	COMPLETE E/A SETS FOR EE-2A OR MX-RES
RATING, °F TIT/KW _s	1500/23	1500/23	1500/23 OR 2100/27 OR 2100/54
COMPONENTS			
TURBOCOMPRESSOR	METALLIC AGT	METALLIC AGT	METALLIC OR CERAMIC AGT
REGENERATOR/ RECUPERATOR	AGT CERAMIC REGENERATOR	AGT CERAMIC REGENERATOR	AGT CERAMIC REGENERATOR
REMOTE COMBUSTOR	UNMODIFIED	MODIFIED	MODIFIED
POWER EXTRACTION	LABORATORY GEARBOX AND BRAKE	PMA	TBD
POWER CONDITIONING	NONE	DUAL CONVERTER, AC OUTPUT AND STARTING	TBD
CONTROLS	LAB CONTROLS	DEVELOPED CONTROLS	DEVELOPED CONTROLS
FUEL AND LUBE SYSTEMS	LABORATORY SYSTEMS	DEVELOPED SYSTEMS	DEVELOPED SYSTEMS
INSULATION, FILTER, STRUCTURE AND ENCLOSURE	NONE	DEVELOPED EQUIPMENT	DEVELOPED EQUIPMENT
SCHEDULE			
FIRST ENGINE TEST	NOV. 1981 ⁽¹⁾	NOV. 1981 ⁽¹⁾	TBD
FIRST ENGINE/ ALTERNATOR	N.A.	DEC. 1982 ⁽¹⁾	TBD



FIRST PHASE TESTING OF SOLAR THERMAL ENGINE AT UNITED STIRLING

WORTH PERCIVAL
Technical Director
United Stirling Incorporated

HANS-GÖRAN NELVING
Project Engineer, Concept Analysis
United Stirling, Sweden

INTRODUCTION

During 1980 United Stirling of Malmö, Sweden, (USS) has been under contract from the Jet Propulsion Laboratory, for the modification of one of their series of laboratory test engines, known as the model 4-95 (formerly P40), for operation as a solar power plant in a parabolic dish concentrator. The engine with its receiver (solar heat exchanger), alternator and control system is to be installed on the Test Bed Concentrator, located at the JPL Parabolic Dish Test Site at Edwards, California, in June 1981.

The objective of the program is to demonstrate that the Stirling engine is a practical, efficient and reliable energy converter when integrated with a parabolic dish concentrator, and that it has the potential of being cost competitive with fossil fueled electric generating systems of today.

Also during 1979-1980, United Stirling has been supporting the Fairchild Stratos Division of Fairchild Industries in a team effort to design a "direct coupled" hybrid receiver for the 4-95 engine to be installed in the above mentioned test. It will permit the engine to operate at constant load on either a "solar only" mode, or with a fossil fuel burner in a "combustion mode" during cloud cover or at night. The receiver is being fabricated by Fairchild Stratos and is to be integrated with the engine by United Stirling and the Advanco Corporation. The Stirling receiver activity (DSSR) is described in another paper at this Review.

Recent studies have shown that a Dish/Stirling system employing mass produced components has the potential to produce electricity for 50-70 mils/kWh and at a capital cost of under \$1000/kW (1,2,3). Contributing to this is the relatively high thermal efficiency of the Stirling and its projected low selling price (4). The importance of thermal efficiency is related to the concentrator/engine production cost ratio. This ratio is not yet certain, but is believed to be between 2.5 and 4. Since concentrator mirror area is inversely proportional to thermal efficiency, power plant thermal efficiency has a leverage effect on overall system cost.



UNITED STIRLING IN-HOUSE PROGRAM

The Stirling engine being modified for the program has its roots in the USS development program going back to 1972 when the decision was made to concentrate all efforts on double-acting four cylinder designs, rather than the classical displacer type engines. Double-acting engines have proven to be lighter, more compact and less costly compared to multi-cylinder displacer engines.

In 1975 a new double-acting 40 kW engine was designed and first tested in 1976. It was originally termed the P40 but more recently designated the 4-95, having a displacement of 95 cc/cylinder. The design objective was to achieve a reliable experimental engine for the development of specific components such as the heater head (the high temperature heat exchanger receiving heat from an external source), piston rod seals, piston rings and control systems. In combination with a requirement of high cycle efficiency and high power density, this called for a concept with parallel cylinders, a heater head with rotational symmetry, and a twin crank shaft drive unit. The 4-95 cross-section is shown in figure 1. The involute heater head is seen in figure 2, and the engine on a dynamometer is shown in figure 3.

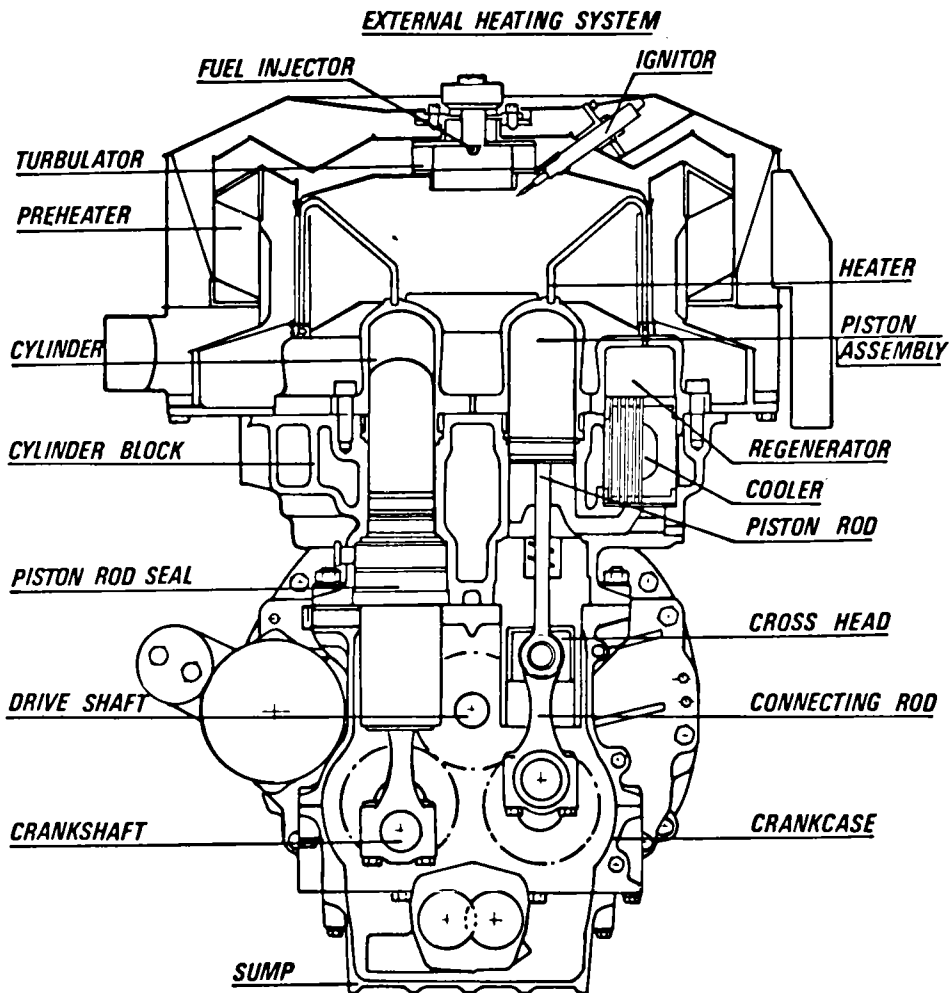


Fig1. Cross-section 4-95 engine.

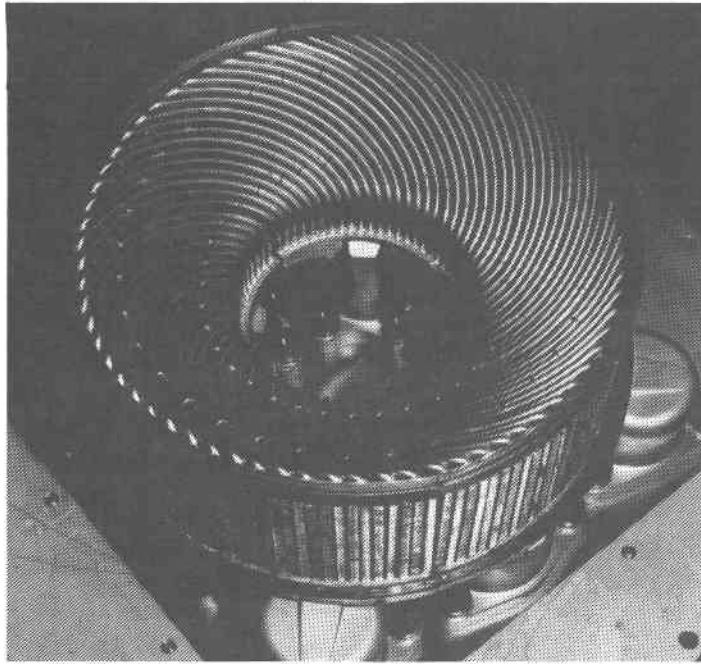


Fig2. 4-95 involute heater head.

The engine is structurally built up from three main assemblies, the drive unit, block and heater head. It is possible to split the engine between block and drive unit without disassembling the heater head. This option minimized the effort and time needed for assembling and disassembling in conjunction with modifications and servicing.

Twentyone 4-95 engines have been built for in-house use as well as for special testing by government agencies and private organizations in the United States, Britain and West Germany. The 4-95 is playing a key role as a baseline engine in the DOE/NASA Automotive Stirling Engine (ASE) program. Three passenger cars, so far, have been operating with the 4-95 engine.

Several conceptual and design features give the 4-95 engine a potential for long life between overhauls. Such unique features include:

- absence of sharp pressure impulses within cylinders
- inherent low linear and torsional vibration
- absence of valve gear
- lubrication system operates in non-contaminating atmosphere
- piston rings and seals operate in cool region
- cross head design eliminates side forces on piston assembly

As of December 1980, total test time for all 4-95 engines on dynamometers and in demonstration programs exceeds 13,000 hours. One engine operating on a special high temperature (820 °C) endurance cycle has been running over 5800 hours. The critical piston rod seal, known as the new PL design, has achieved approximately 120,000 hours of successful running on all seal units, with one seal exceeding 7000 hours without failure. Additionally, about 150,000 hours of separate component and accessory testing contribute to overall reliability of the 4-95.

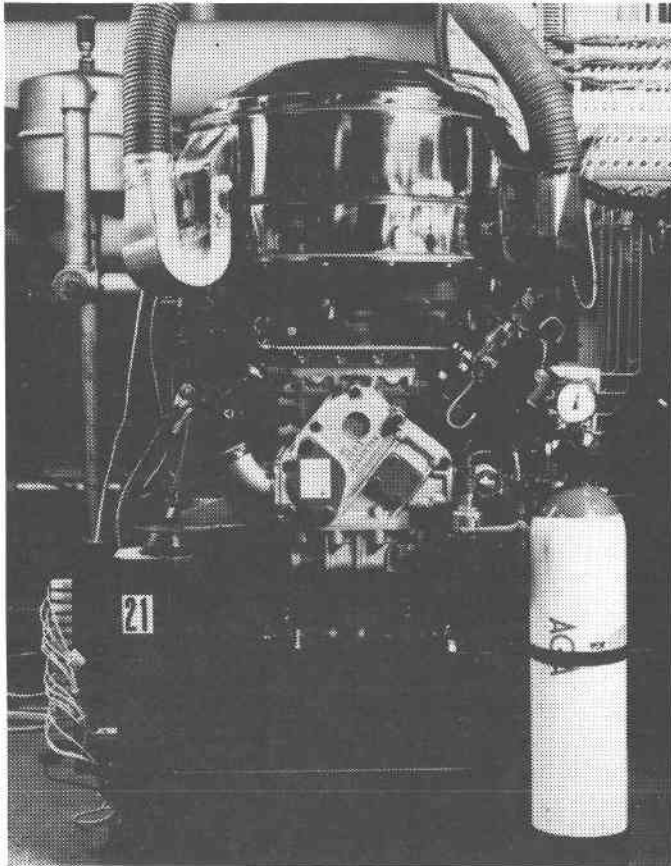


Fig3. 4-95 no 21,
JPL engine in test rig.

PROGRAM SCHEDULES AND ACCOMPLISHMENTS

Under the JPL Program, procurement of components for the baseline 4-95 Stirling solar engine (number 21 in series) began September 1, 1980, with engine assembly later that month. Acceptance testing was to be done using a conventional fossil fuel combustion system and with the engine up-right rather than inverted. The program schedule is shown in figure 4.

The engine began its initial dynamometer "run-in" for checking out engine functions on November 13. The test included constant speed operation on helium at 1800 rpm and half load for about 11 hours. Following this, acceptance tests requiring about 12 hours were run between idle and full load (3 MPa to 15 MPa mean pressure) and between 600 and 4000 rpm, at 720 °C nominal tube temperature and 50 °C coolant temperature. Data logging include usual temperatures and pressures and all parameters required to determine power and thermal efficiency over the load and speed range. Final tests included control system measurements, requiring 8 hours.

During the acceptance and control tests, check out of data indicated higher than normal friction especially at the lower speeds. At the end of 31 hours the engine was disassembled for inspection. One cross head and its cylinder liner were found scuffed as the result of improper clearance and, possibly, lube oil contamination with machining residues from fabrication. After cleaning and replacing the parts, a second run-in test was made for 11 hours, followed by 6 hours of acceptance testing between 1000 and 4000 rpm, under all load conditions. Data indicated no further problems, and the tests were completed after a total of 48 hours running time on December 8th, ahead of schedule.



SCHEDULE

- PROGRAM START
- COMPONENT MANUFACTURING
- ENGINE ASSEMBLY
- STANDARD ENGINE ACCEPTANCE TEST
- ENGINE MODIFICATION AND TEST IN INVERTED POSITION
- RECEIVER INTEGRATION AND TEST OF RECEIVER/ENGINE/ALTERNATOR SYSTEM WITH COMPLETE CONTROL SYSTEM
- DELIVERY TO US
- INTEGRATION TO TEST BED CONCENTRATOR (EDWARDS AIR FORCE BASE)
- START OF SOLAR TEST

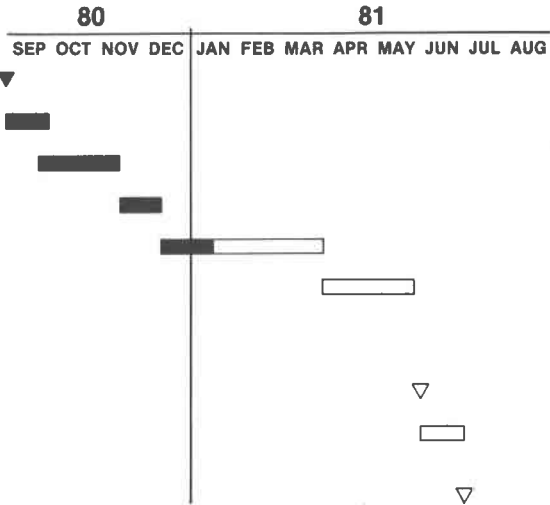


Fig4. Program schedule.

Results of testing engine 4-95-021 with a standard involute heater, figure 2, are presented in the curves, figure 5, 6. To summarize, it can be noted that the engine power at 1800 rpm ranges from 20 kW at 11 MPa to 27 kW at 15 MPa. Auxiliaries include the lube oil pump and the helium pump, which are the only ones to be engine driven at the Edwards Test Site. The water pump will be at ground level and is the responsibility of JPL.

TEST DATA — JPL ENGINE SOLAR ENGINE PERFORMANCE

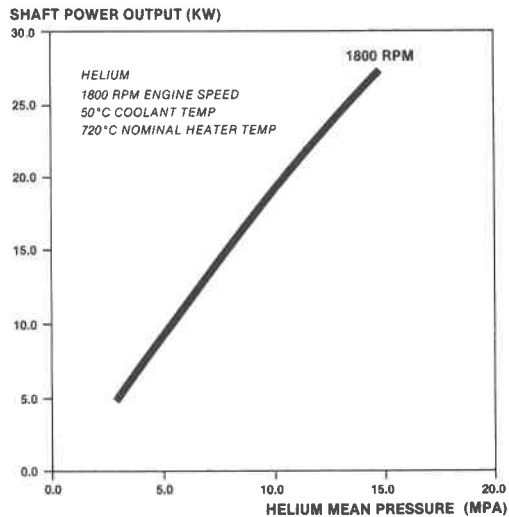


Fig5. Acceptance test data- power.

TEST DATA — JPL ENGINE SOLAR ENGINE PERFORMANCE

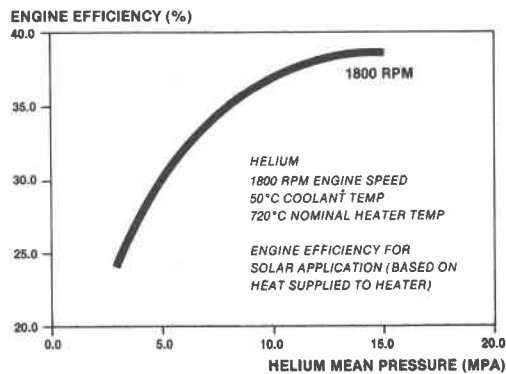


Fig6. Acceptance test data- efficiency.



Engine thermal efficiency for solar applications is based on net heat into the heater, rather than on gross heat (from fuel) as in automotive applications. The net heat value is the result of 2 measurements -- the overall brake thermal efficiency and the so-called "furnace" or external heat system efficiency, η_b . The latter is equal to:

$$\eta_b = \frac{\dot{Q}_H - (\dot{Q}_{eg} + \dot{Q}_{rad})}{\dot{Q}_H}$$

$$\eta_{ST} = \frac{\eta_e}{\eta_b}$$

- η_b = external heat system efficiency
- \dot{Q}_H = heat input from fuel and air
- \dot{Q}_{eg} = heat losses in exhaust gases
- \dot{Q}_{rad} = heat losses through radiation
- η_e = overall brake thermal engine efficiency
- η_{ST} = solar thermal efficiency

The difficulty lies in the accurate determination of the bracketed term, which is the result of measurements (temperatures in the exhaust gas and insulated spaces of combustor) and calculations. However, the end result is believed to be conservative. The curves in figure 6 show the solar thermal efficiency ranging from 37% at 11 MPa to 39% at 15 MPa, on helium. On hydrogen the efficiency at 15 MPa is estimated to be 41%.

The estimated performance with the Fairchild hybrid receiver installed, in place of the present involute heater, is shown in figure 7. The efficiencies are lower by about 2 percentage points because the heater tubes in the hybrid receiver are approximately 50% longer than for the standard heater, which causes higher internal flow losses.

Coolant Temp. 50°C Mean pressure 15 MPa	Nominal outer tube wall temp.			
	710°C		810°C	
	He	H ₂	He	H ₂
Max. power, kW	24	26	27	28
Max. efficiency, %	36	38	40	41

Fig7. Predicted engine performance in a solar application.

The next major task in the program includes a functional test of about 100 hours using the same engine and heating system combined with the 25 kW induction alternator (to be used in the final system), operating at 3 or more angles from 90° to completely inverted. Components are on hand and modifications to the lubricating system have been made for gravity drainage in all positions. A preliminary test of a mock-up of the crankcase, with external plumbing and oil sump, was made recently at Ricardo in England, who have been fabricating the 4-95 engine crankcases and drive units. Gravity drainage was found to be satisfactory at all angles (figure 8).

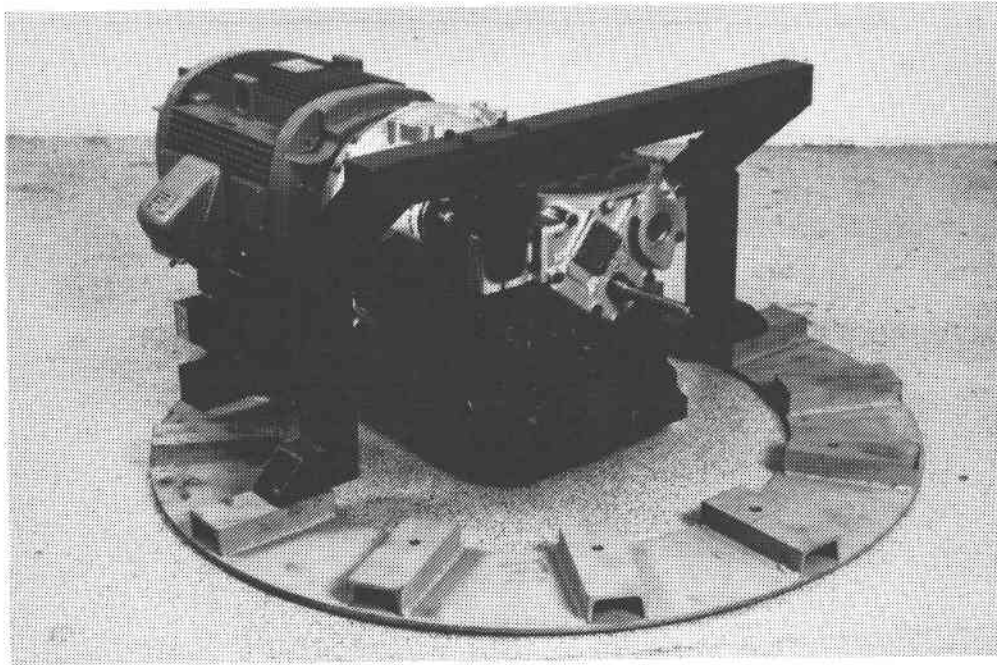


Fig8. Engine/alternator in mounting structure and TBC mounting ring (mock-up).

The new PL-seal unit has been tested in the inverted position in a separate test rig for 1500 hours. No oil was found to pass into the engine working spaces.

Numerous meetings between JPL, Fairchild and USS have been taking place during 1980 for coordination of the instrumentation and controls to interface with the new receiver and with the JPL test equipment at the Edwards Test Site.

The Fairchild receiver is scheduled for delivery to USS by March 1, 1981. Functional and performance testing of the receiver, integrated with the modified 4-95-21 engine, is scheduled for April and May, 1981. It will operate in the combustion mode only and at one inverted angle. The complete power package, including the modified engine equipped with the DSSR, alternator, controls and mounting structure, will be delivered to the TBC site at Edwards in late May, 1981.



FUTURE PLANS AND ADVANCED ENGINES

United Stirling has a continuing program for improvement of components and accessories for all engine designs. In particular, for solar designs, the extreme requirements for long unattended operation and time between overhaul, justifies further work to prolong the life of specific components, such as the piston rings. Progress is being made in this area. Present life of rings ranges from about 2500 to 4000 hours.

In addition, the introduction of the ceramic receiver/heater head has the potential of substantially reducing the life cycle cost of the engine, as well as the need for strategic materials.

At a working temperature of 1100 °C, ceramic components, such as a silicon carbide heater, will produce a 50% power increase and a thermal efficiency of about 49%.

In some solar applications a sodium cooled solar receiver will be advantageous, especially when thermal energy storage is included. The Stirling engine with a sodium heater head operates more efficiently since the heater tubes can be shorter and temperatures more uniform. Thermal efficiency increases about 3 percentage points in a sodium heated engine at the same nominal tube temperature.

Based on a relatively low-risk development program, United Stirling believes that for solar applications engine time between major overhauls of 30,000 hours is achievable.

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2. J W Stearns, et al, "Solar Stirling System Development," A.I.A.A. Terrestrial Energy Systems Conference, Paper No 79-1009, June 1979.
3. V C Truscello, A N Williams, "The JPL Parabolic Dish Project," 15th Intersociety Energy Conversion Engineering Conference, Paper No 809346, August 1980.
4. H R Fortgang, H F Mayers, "Cost and Price Estimate of Brayton and Stirling Engines in Selected Production Volumes," JPL Publication 80-42, Report No DOE/JPL-1060-35, May 1980.

Session II

RECEIVERS

Session Chairman: W. Owen, JPL

NON-HEAT PIPE RECEIVER/P-40 STIRLING ENGINE

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ABSTRACT

This project will demonstrate the technology for a full-up hybrid dish-Stirling Solar Thermal Power system by mid 1981 at JPL's Desert Solar Test Facility near Lancaster, California. Overall solar-to-electric efficiency for the dish-Stirling system demonstration is approximately 30%. Hybrid operation is provided by fossil fuel combustion augmentation, which enables the Stirling engine to operate continuously at constant speed and power, regardless of insolation level, thus providing the capability to operate on cloudy days and at night.

The Non-Heat-Pipe Receiver/P-40 Stirling Engine system will be installed and operated on the JPL Test Bed Concentrator. A 25-kW direct-driven induction-type alternator will be mounted directly to the P-40 engine to produce to a 60-Hz, 460-480-volt output.

NON-HEAT PIPE RECEIVER DESIGN

The Non-Heat-Pipe Receiver design is a cavity-type receiver, as illustrated in Figure 1. The primary receiver surface is a conical plate with integral passages for the helium working fluid. The passages are formed by Inconel 617 tubes imbedded in a copper matrix, which in turn is encapsulated in an Inconel 617 sheet. The cone is heated by solar insolation on the surface exposed to the receiver cavity and by combustion gas on the back surface and the regenerator tubes. The receiver is attached directly to the Stirling engine cylinders and regenerator housings.

The combustion system design is based on heavy duty industrial burner technology, scaled to the size and configuration required to assure reliable cold start, stable combustion over the full operating range and uniform heating of the heater tubes extending from the underside of the cone to the engine regenerator manifolds. The combustion air, provided by an electric-motor-driven constant speed blower, is directed through a preheater into the combustion chamber, which contains eight integrally cast venturies, oriented to produce a swirling flow field inside the combustion chamber, providing sufficient residence time to complete combustion and uniform combustion gas temperature upstream of the heater tubes. Fuel is introduced through a jet

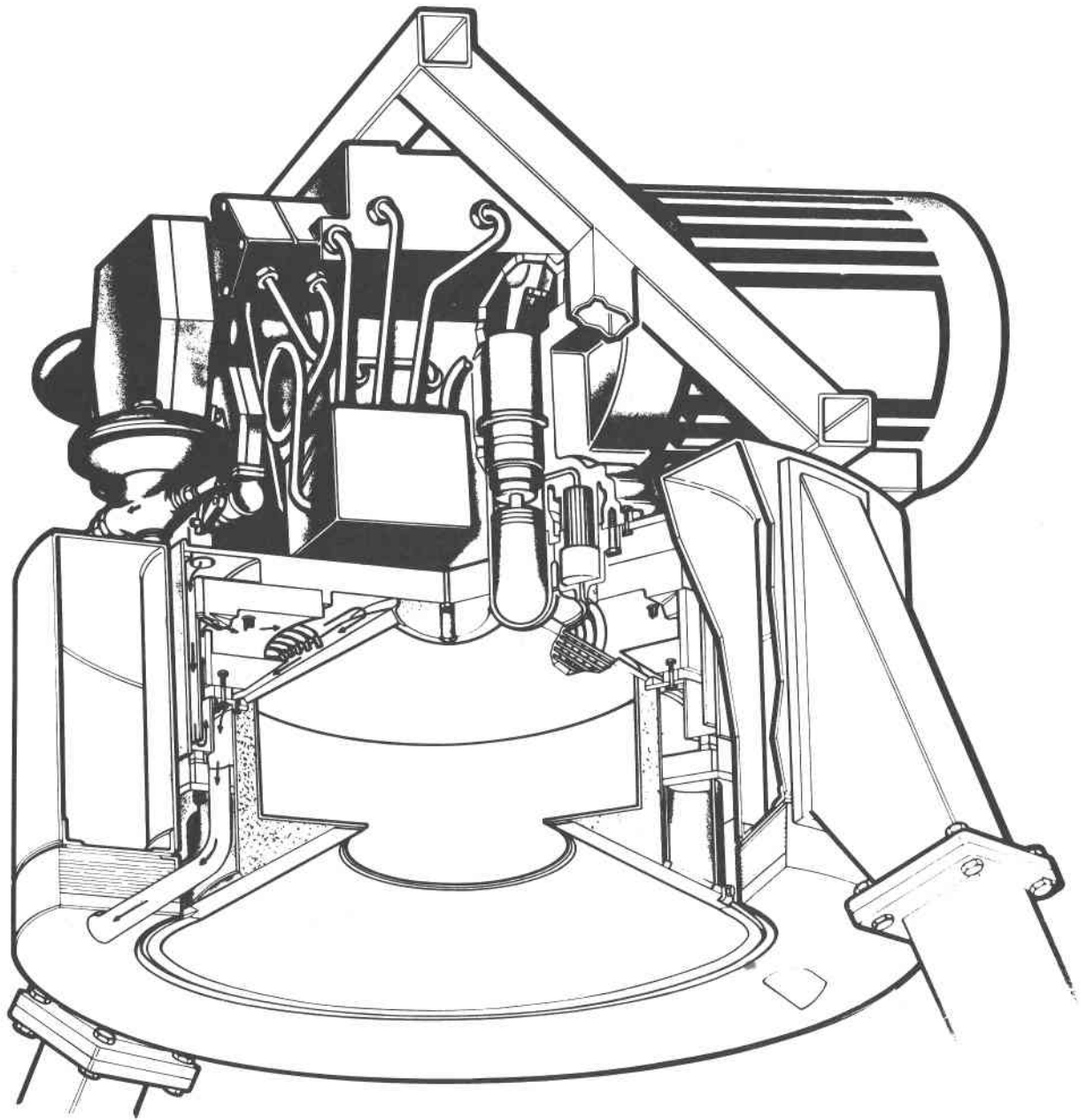


Figure 1. DSSR and P-40 Engine/Alternator

located inside each venturi. Direct electric spark ignition and flame sensing is provided. The flame sensing subsystem causes the main fuel valve to close automatically in the event of flame-out. Automatic restart is provided.

Performance Goals

The following performance goals have been identified by JPL for the Non-Heat-Pipe Receiver design:

Concentrator diameter (active)	10 m
Geometric concentration ratio	2000
Peak insolation (1 kW.m ²)	76.5 kW
Concentrator efficiency (clean)	0.83
Total error (slope plus pointing)	3 mr
Fossil fuel combustor peak input to helium	70.0 kW _t
Combustor turndown ratio	10:1
Working fluid temperature (helium)	650°C to 815°C (1200° to 1500°F)
Peak engine pressure (helium)	17 Mpa to 20 Mpa (2500 to 3000 psi)

The expected thermal efficiency of the receiver is 90 percent and 85 percent at 650°C (1200°F) and 815°C (1500°F) helium temperature respectively.

Program Status

The receiver has been completed and delivered to JPL for further test and evaluation prior to shipment to United Stirling for engine integration tests. Combustion and heat transfer tests have been conducted at Fairchild Stratos Division in Manhattan Beach, California and were carried out jointly by JPL, Fairchild and the Institute of Gas Technology. Test objectives included evaluation and demonstration of cold start, combustion stability and energy release at various power levels, combustion air preheat, pressure drop, fuel/air ratios and heat transfer. Reliable cold start performance, full design output power and turndown capability have been demonstrated. The general arrangement of the combustion test is illustrated in Figure 2.

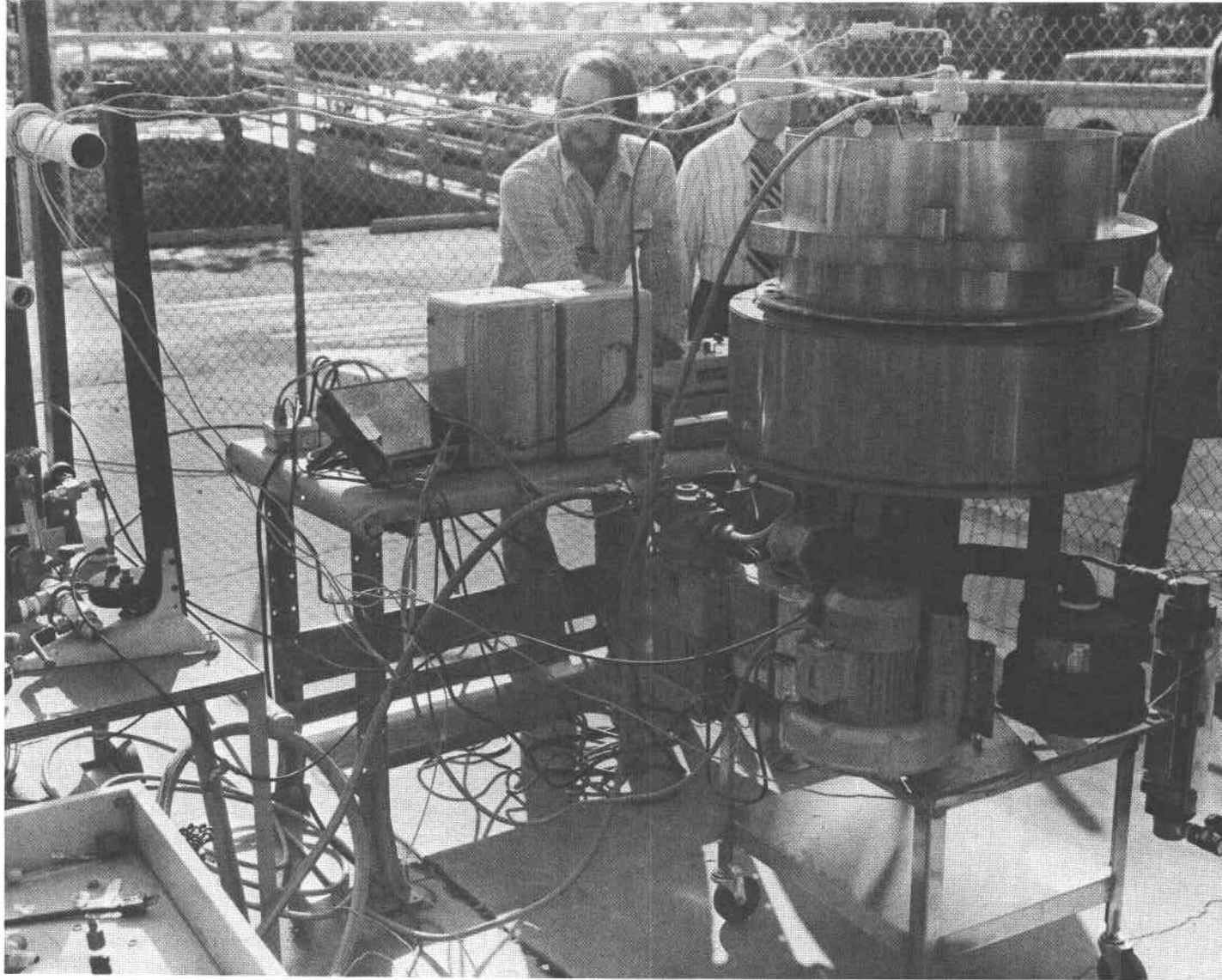


Figure 2. DSSR Test Setup

HEAT PIPE SOLAR RECEIVER WITH THERMAL ENERGY STORAGE

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ABSTRACT

A heat pipe solar receiver (HPSR) Stirling engine generator system featuring latent heat thermal energy storage, excellent thermal stability and self regulating, effective thermal transport at low system ΔT is described. The system has been supported by component technology testing of heat pipes and of thermal storage and energy transport models which define the expected performance of the system. Preliminary and detailed design efforts have been completed and manufacturing of HPSR components has begun. The modification of a Stirling engine for operation on condensing sodium vapor is required during 1981 in order that the system can be committed to a solar test at an early date. Additional developments will include the later design, construction and test of a flame impingement combustor which can be directly added to the existing system without major modifications. A progressive development of this first prototype toward low cost, mass production hardware is expected for wide solar applications.

SYSTEM DESCRIPTION

The heat pipe solar receiver with TES (HPSR) is a high efficiency solar receiver and thermal storage system for use as part of a self-contained 15-25 kW_e Stirling engine power conversion system located at the focal point of a parabolic dish concentrator and operating at an engine temperature of $\sim 1520^{\circ}\text{F}$. Its unique feature is the efficient collection, transport, storage and retrieval of solar energy through the use of high temperature sodium heat pipes and NaF-MgF₂ latent heat storage.

The concept of heat flow in the system and a conceptual design of an advanced development system are shown in Figures 1 and 2. The fourteen primary heat pipes in the receiver deliver heat through a bulkhead into a large secondary heat pipe containing (1) 73 capsules, each 2 inches in diameter and 33 inches in length and containing the eutectic fluoride TES salt, (2) a shell-side heat exchanger surface to accept heat from an efficient flame impingement combustor and (3) the heat exchanger tubes of a Stirling engine. The primary heat pipes transfer heat in one direction only to prevent heat loss from the TES. Heat transfer in the secondary heat pipe is effected in a near-isothermal manner by sodium vapor thermal transport without pumps, valves, controls or flow sensors; the hotter surfaces, such as the primary heat pipe, condensers or the combustor heat exchanger reject heat and the colder surfaces, where heat is being extracted, accept heat at near-isothermal temperatures. Differences in equilibrium vapor pressure within the system provide the driving force. Thus the system is self regulating in that the heat flow into and out of the system, the storage of energy in the latent heat salt and the provision of heat to

the engine are based upon minor temperature differentials occasioned by the operation of the system itself. Simple temperature instrumentation within the isothermal secondary heat pipe can indicate the subcooling or superheating of the TES; the temperature source for operation of the engine remains relatively stable varying only with the ΔT required to extract heat from the large surface area of TES material at low heat flux levels.

The small aperture of the receiver reduces convection and reradiation losses which results in high receiver efficiency.

The proposed flame impingement combustor on the TES shell features a high gas-side heat transfer coefficient approaching 120 Btu/hr-ft²-°F; sodium-side heat transfer coefficients are, of course, orders-of-magnitude higher. The technology of flame impingement combustors has been well advanced by Rasor Associates* through the development of large thermionic converters and through demonstrated improvements in combustors for Stirling engines using silicon carbide ceramic materials and advanced impingement combustor design techniques.

Other features of the advanced HPSR concept include the following. First, the all-stainless-steel construction made possible (1) by the use of dished heads on the secondary heat pipes to minimize the stresses from very low differential pressure within and outside this heat pipe and (2) by the use of sectioned-stiffened stainless steel forward and aft salt capsule support plates to carry axial loads from the salt capsules. Second, the development of reduced wicking requirements for supplying sodium with the TES. Third, improvement in Stirling engine efficiency from 39.6% to about 43% by engine heater head redesign to take advantage of improved sodium heat transfer coefficients at the heater tubes. This latter improvement in turn, decreases solar collection costs, improves TES storage time for equivalent weight and cost and results in less COE sensitivity to increase in fuel cost for the combustor assisted system. The general effects of these expected changes in efficiency and of the value of TES in increasing the ratio of solar-to-fossil fuel utilization are shown in Figure 3; results are based upon system performance and economic analysis over a one year period of simulated solar operation of hybrid Stirling solar systems.

SUPPORTING TECHNOLOGY

The technology of the HPSR is based upon well-founded heat pipe and latent heat storage data and experience and upon related heat pipe and latent heat storage developments for space applications. In addition, and specific to the present program, the primary heat pipe have been experimentally tested** in all operating attitudes as indicated in Figures 4 and 5.

*E.J. Britt, Rasor Associates, Inc., Sunnyvale, CA. 94086, Private Communication, October, 1980.

**Divakaruni, S.M., "Heat Pipe Design Confirmation Testing", DOE/JPL, 1060-27, GEAEP-55, September 25, 1979. See also Zimmerman, W.F., Divakaruni, S.M. and Won, Y.S., "Sodium Heat Pipe Use in Solar Stirling Power Conversion Systems", ASME 80-C2/S06-13 presented at ASME Century 2 Conference, San Fransisco, August 10-21-1980.

A modular TES experiment featuring a single primary heat pipe and a secondary heat pipe containing three standard design salt containers and a heat extraction coil to simulate the Stirling engine has been designed, built and tested at initial design heat flux conditions on the TES salt containers. This modular test apparatus was operated successfully at all operating angles in various modes of charging, discharging, direct heat through-put and mixed modes of operation. The test indicated the excellent thermal inertia of the system (less than 2°F/min. outside the latent heat range), low ΔT across heat pipes and isothermal operation of the secondary heat pipe. The components of the system and a typical TES charging curve are shown in Figures 6 and 7.

The above experimental effort has contributed significantly to the demonstration of the validity and expected performance demonstration of the thermal transport and storage concept.

SYSTEM DESIGN

During the past months a preliminary design has been submitted, modifications in that preliminary design have been made to accommodate, at a later date, the addition of the flame impingement combustor to the TES shell and a final detailed design has been prepared. This final design of a system using a United Stirling P40 engine and a 25 kW_e induction generator is shown in Figure 8. Sodium wicking is included inside the TES shell to permit internal heat transfer from the flame impingement combustor, which can be added at a later date. Other TES wicking includes arterial wicks which provide liquid sodium from a pool in the lower forward part of this large heat pipe; these wicks feed wire wicks on the surfaces of the primary heat pipe condensers and on the lower half of the TES salt containers. The upper half of the salt containers are supplied with sodium by gravity return from the engine through a diffusion bonded arterial wick at the rear salt container support plate and, thence, along wire wicks on the salt containers. Figure 9 shows these details.

The key characteristics of the prototype design, on which manufacturing work has just begun, is shown in Table 1. With about 0.8 hours of latent and sensible heat storage the entire system should weight about 2900 pounds. Higher engine and system efficiencies than those shown should be achieved with the modification of the P40 engine heater head for operation on condensing sodium vapor.

FUTURE EFFORTS

During the coming months the first prototype will be fabricated filled with sodium, thermally conditioned to assure that all the arterial wicks are filled and the capillary wicks are saturated with liquid sodium, the system will be shipped to Edwards Air Force Base in late summer 1981 for installation and solar test on the Test Bed Concentrator. A key element in the assembly and operation of this system is the availability of sodium heater head version of the P40 Stirling engine which is to be supplied by JPL for assembly with the HPSR prior to sodium filling. Work has not started yet on the modification

of the engine but is expected to begin soon. Thermal performance testing of the HPSR prior to solar operation would be desirable to check out the thermal transport and integrated operation of the receiver, TES and engine-generator. The development of the flame impingement combustor can be carried out separately and that combustor can later be mated with this prototype HPSR without modification to the interior of the secondary TES heat pipe. The test of the combustor on the HPSR could then be performed in either a factory test or a test on the solar concentrator. Finally, future design modifications and improvements will be required to minimize presently redundant wicking requirements and to introduce, in subsequent test hardware, lower cost components such as dished heads and alternative design support plates, etc.

The advantages of the excellent thermal transport, stable operating temperature and stored energy inherent in the HPSR are worthy of continued evaluation, exploitation and improvement, not only as these concepts apply to the Solar Stirling systems, but for the benefit of other high temperature solar energy systems, as well.

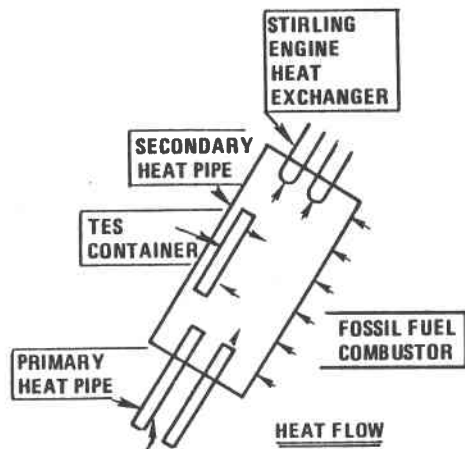


Figure 1. Schematic Diagram of Heat Flow in the HPSR

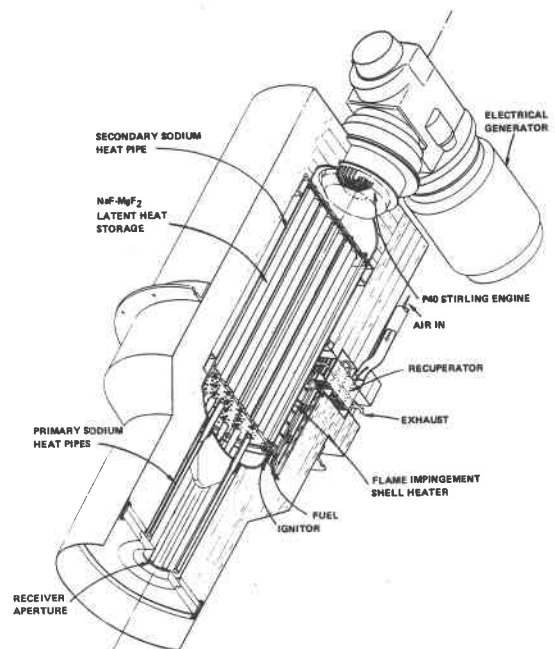


Figure 2. Advanced Development HPSR with Flame Impingement Fossil Fuel Combustor

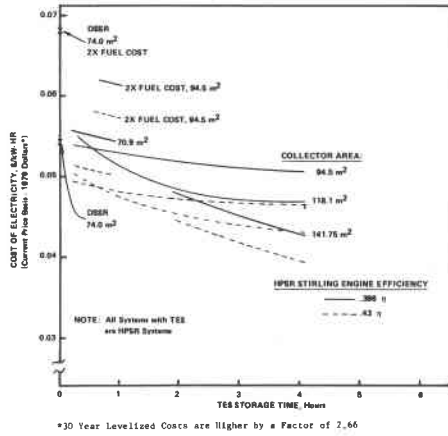


Figure 3. Cost of Electricity vs. TES Storage Time for Systems with Combustors

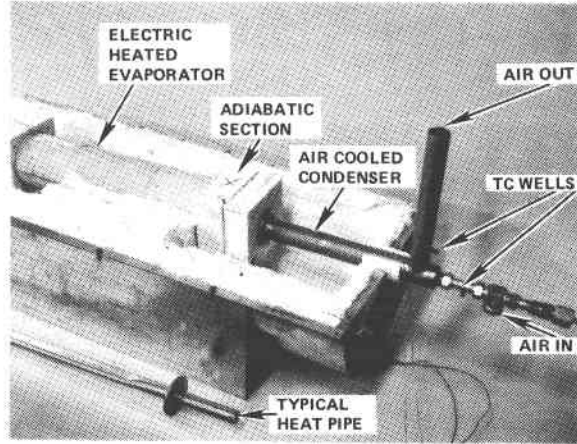


Figure 4. Heat Pipe Test Facility

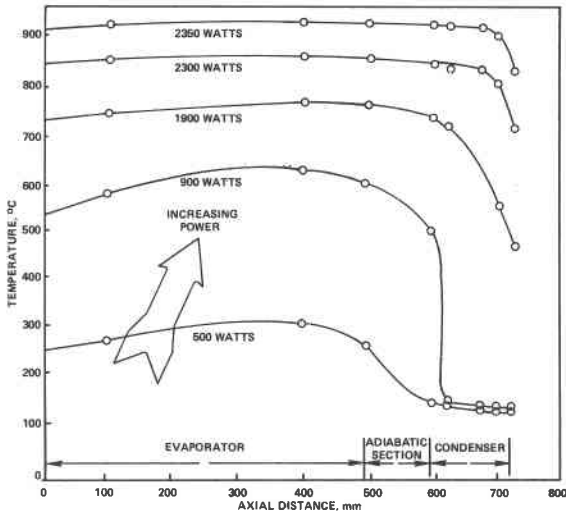


Figure 5. Operating Characteristics of Heat Pipe No. 1 at 10° Inclination

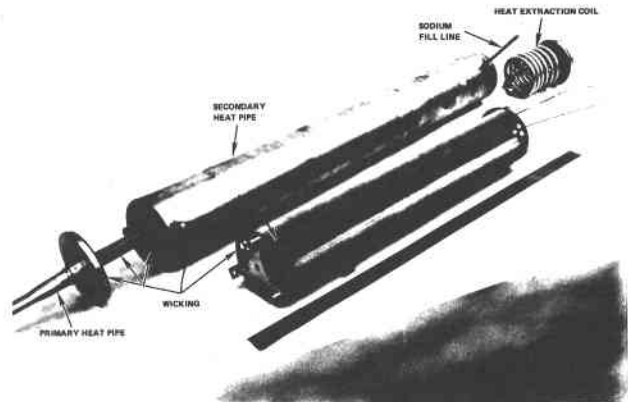


Figure 6. TES Modular Experiment Components

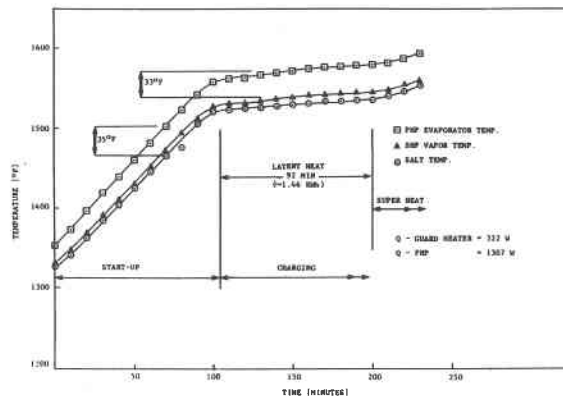


Figure 7. Typical TES Charging Curve for the Modular Experiment

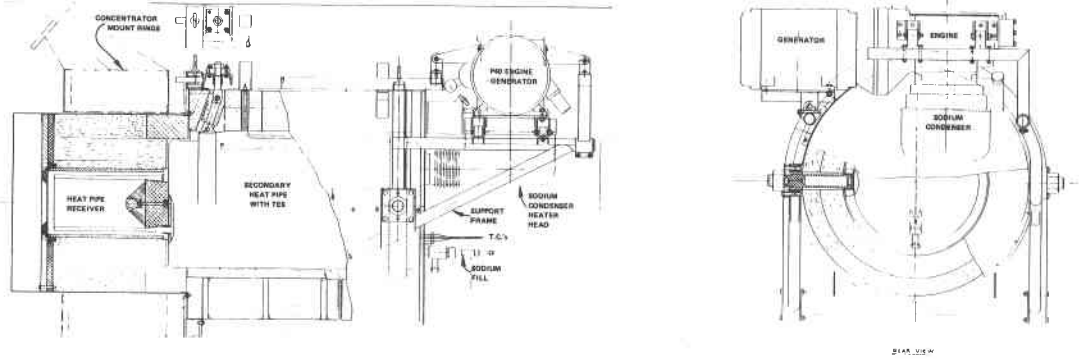


Figure 8. 25 kW_e Prototype HPSR/ TES/ Engine Generator System

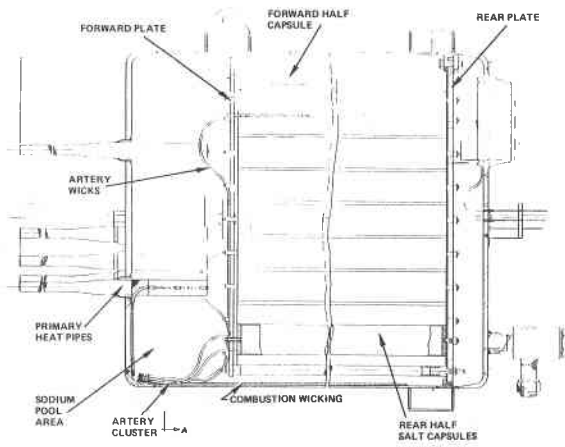


Figure 9. Secondary Heat Pipe Wicking

TABLE I
KEY CHARACTERISTICS OF HPSR SYSTEM

<u>Test Bed Concentrator</u>	
Concentrator Diameter	11 m
Concentration Ratio	2000
Overall Concentrator Efficiency	0.9259
Shaded Concentrator Focal Plane Power	77.0
<u>Solar Receiver</u>	
Aperture Diameter	6.5 in.
Intercept Factor	0.98
Receiver Efficiency	0.908
Power Output	68.5 kW _t
<u>TES Heat Pipe</u>	
TES Material	67NaF-33MgF ₂
Storage Time (latent + sensible at 66.2 kW _t)	~0.8 hr
TES Efficiency	0.966
TES Operating Temperature Range	1480-1535°F
Power Output	66.2 kW _t
<u>P40 Stirling Engine - Generator</u>	
Nominal HX Temperature	1520°F
Engine Performance (150 Atm He, 1800 RPM, 1520°F)	
Efficiency	0.396*
Power	26.2 kW
Generator Efficiency	0.93
Generator Output	24.4 kW _e
Overall System Efficiency (Solar/Electric)	0.323

* Conservative estimate; 0.43 with engine heat exchanger design for sodium condenser. Overall system efficiency 0.35 with sodium HX.

THE DEVELOPMENT OF AN 85-kW (THERMAL)
AIR BRAYTON SOLAR RECEIVER

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ABSTRACT

The AiResearch Manufacturing Company is under contact to the Jet Propulsion Laboratory (JPL) to manufacture prototype Brayton receivers for the Parabolic Dish Solar Thermal Power Systems Project. This paper summarizes the work accomplished in the program and describes the JPL testing of the receiver at the Parabolic Dish Test Site, Edwards AFB, California.

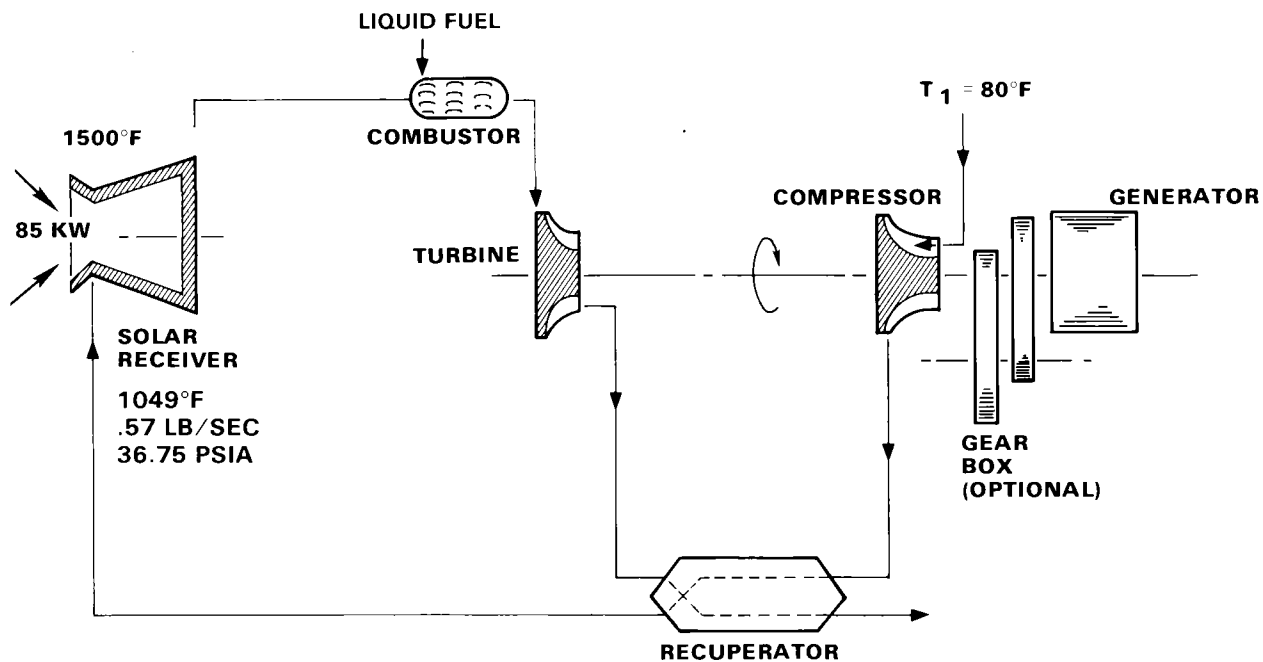
INTRODUCTION

In June 1979, The AiResearch Manufacturing Company received a contract from the Jet Propulsion Laboratory (JPL) for the design and fabrication of two prototype air Brayton solar receivers (ABSR's) as part of the Parabolic Dish Solar Thermal Power Systems Project directed by JPL and sponsored by the Department of Energy. These prototypes are designed to receive 85-kW thermal insolation at the focal plane of a parabolic dish concentrator and transfer that energy into the fluid stream of an open, regenerated, Brayton-cycle system. Initial receiver evaluation testing is now being conducted by JPL, utilizing the test bed concentrator developed for this type of activity at the Parabolic Dish Test Site. Following that evaluation, the prototypes will be available for incorporation into a demonstration of the Brayton cycle.

This paper describes the results of the program from its inception through December 1980. The first section will briefly describe the design requirements, concept, and significant analysis upon which the receiver is based. Section two will describe the fabrication processes that have been utilized in the construction of the prototype receivers now at the test station. Section three, the concluding section, describes the test and evaluation phase underway at the Parabolic Dish Test Site.

DESIGN REQUIREMENTS, CONCEPT, AND ANALYSIS

The design requirements for the ABSR were prepared by JPL, based upon its application as the heat source in a gas turbine engine system. The system schematic is shown in Figure 1. The solar input is 85 kW. The energy is concentrated at the receiver aperture by an 11-m parabolic dish that has a focal length of 6.6 m and an assumed slope error of between 1 and 2 milliradians. This energy is used to heat the air of the recuperated open-cycle gas turbine engine from 565° to 816°C (1049° to 1500°F). The operating air pressure is 225.5 kPa (36.75 psia) and the pressure drop of the receiver is 2.5 percent



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FIGURE 1. BRAYTON SYSTEM SCHEMATIC

$\Delta P/P$. Transient and off-design conditions are consistent with gas turbine operation. The unit will be mounted at the focal point of the concentrator and will be exposed to the ambient at the test site. As a consequence, the specified environmental conditions are for a high-desert environment, including ambient temperatures between -18° and 51.7°C (0° and 125°F), and wind gusts to 58 km/h (36 mph) with sand and dust.

The ABSR concept developed for this application uses direct air heating. Solar flux passes through an aperture located on the concentrator focal plane and falls upon the interior surfaces of a closed cylinder whose axis is located on the concentrator center line. The cylinder contains axial flow passages that bring the air discharging from the recuperator into contact with solar-heated surfaces. Heat transfer in the flow passages is enhanced by the use of an extended-fin surface. Neither the closed nor aperture ends of the receiver have airflow. These surfaces reradiate the impinging energy to the cooled heat-transfer cylinder.

Design optimization was based on thermal analysis performed by a finite element computer code developed by AiResearch. This optimization led to the ABSR design shown in Figure 2. The single sandwich cylindrical panel with an offset fin matrix of 4.72 fins/cm (12 fins/in.) has a 1.27-cm (1/2-in.) high-flow passage. The heat exchanger is supported by a series of slotted tubes and is insulated from the outer case. The heat exchanger is a brazed and welded structure

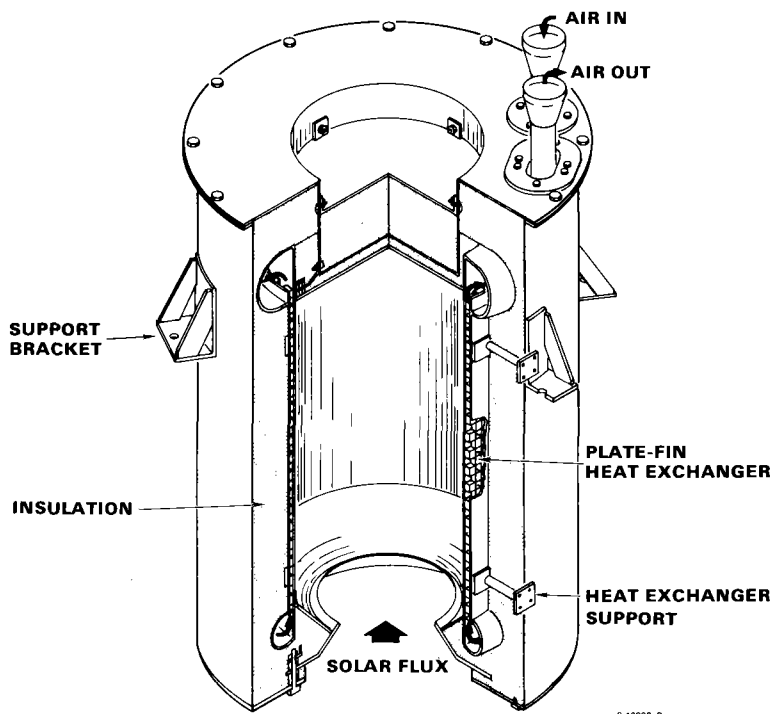


FIGURE 2. PROTOTYPE AIR BRAYTON RECEIVER

fabricated from Inconel 625. The stainless steel mount system allows for both axial and radial expansion of the heat exchanger with respect to the external mild steel case. The uncooled aperture and closed end are fabricated from silicon carbide. Both the circular closed end plate and the aperture assembly are mounted to minimize heat loss to the relatively cold receiver case. The physical characteristics of the design are shown in Table 1. The method followed in optical and thermal design has previously been reported and will not be repeated here.* The results of the thermal design indicate that the ABSR will perform with an overall efficiency of more than 90 percent.

A detailed structural analysis was undertaken to verify the adequacy of this design. The combined thermal and pressure-induced stresses were calculated for critical design elements. In the initial phases of this analysis, it became apparent that a continuous inner and outer shell would not be successful. This conclusion was based on the thermal gradient that is calculated to exist between the inner and outer shell (see in Figure 3). The peak heat input to this cylinder occurs approximately 1/3 of the distance toward the closed end. At that point, a 110°C (230°F) thermal gradient exists between the two surfaces. The thermally created stress, which develops as the result of the differential expansion of the two continuous cylinders, significantly exceeds the material strength limits.

*M. Greeven, M. Coombs, and J. Eastwood, The Design of a Solar Receiver for a 25-kW(e) Gas Turbine Engine, paper presented at the Gas Turbine Division Conference of the American Society of Mechanical Engineers, March 1980.

TABLE 1

PHYSICAL CHARACTERISTICS OF THE ABSR

Materials		
Heat exchanger		Inconel 625
Insulation		Cerablanket
Case		Mild steel
Aperture		Silicon carbide
Receiver		
Weight, kg (lb)	203	(447)
Length, cm (in.)	116.1	(45.7)
Diameter, cm (in.)	76.2	(30.0)
Heat exchanger		
Length, cm (in.)	80.3	(31.6)
Diameter, cm (in.)	50.8	(20.0)
Skin thickness, cm (in.)	0.02	(0.008)
Fin thickness, cm (in.)	0.01	(0.004)
Aperture		
Diameter, cm (in.)	25.4	(10)
Conical height, cm (in.)	8.6	(3.4)

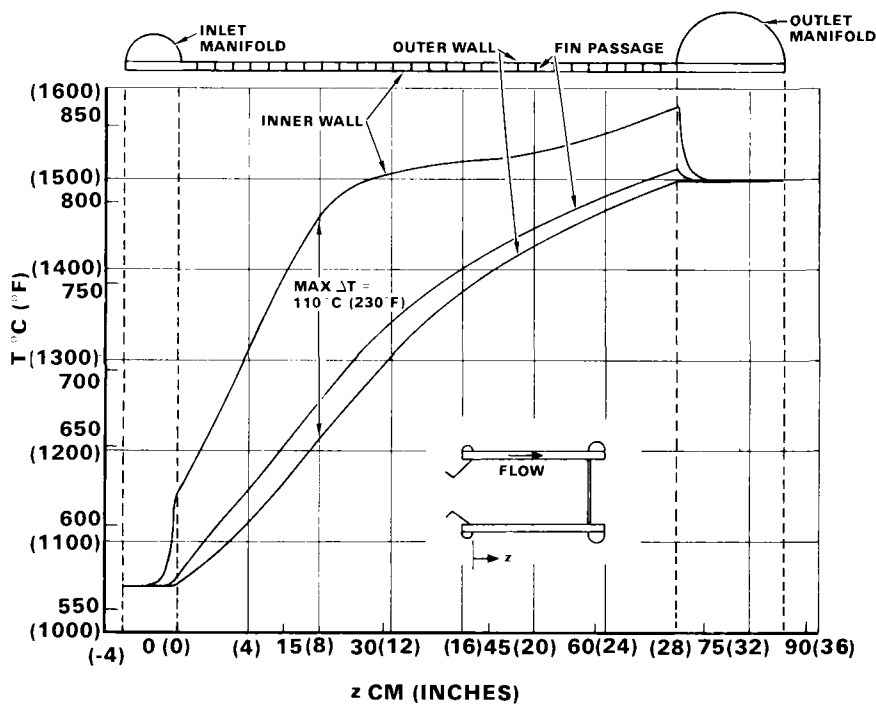


FIGURE 3. RECEIVER THERMAL GRADIENTS

The thermal gradient could be decreased by increasing the performance and conductive cross section of the fin; however, the air pressure drop limitation of 2.5 percent $\Delta P/P$ total is not consistent with this approach.

As a consequence, it was decided to segment the inner surface, and based on the results obtained by analysis, 36 segments were selected. The stress values of various critical design elements are shown in Table 2. These stresses were obtained by developing a structural model of a segment and applying the previously calculated temperatures as well as operating pressures. The analysis revealed that the unit was cycle-life limited as compared to operating-time limited. The inner surface of the unit at the point of maximum thermal gradient could be expected to withstand 6,000 full start/stop excursions prior to initial fracture. This is an acceptable value for a prototype configuration. The structural adequacy of the remaining design components, including the receiver mounting, heat exchanger supports, and manifolds, was verified. None of these elements are stressed to a limiting degree. This completed the analysis, and the design was released for fabrication.

TABLE 2
ABSR OPERATING STRESSES

<u>Location</u>	<u>Temperature, °C (°F)</u>	<u>Stress, MPa (kpsi)</u>
Inner skin	795 (1463)	187.1 (27.12)
Outer skin	666 (1230)	195.3 (28.31)
Fin	730 (1346)	85.1 (12.33)

RECEIVER FABRICATION

The critical fabrication processes for the ABSR are these: forming the offset heat transfer fin, joining of the heat exchanger into a continuous structure, and manufacture of the silicon carbide components.

Fin fabrication requires complex form tooling. The large available inventory of these tools permits selection from a number of different fin geometries. During fin fabrication, the formed fin was reduced from the 12.7-mm (0.5-in.) height selected in design to 6.35 mm (0.25 in.) and then contoured to the cylindrical surface. The lower fin height was selected for the fabrication because it allowed the best match with the desired fin contour, given existing fin tooling. The flow passage height was maintained at 12.7 mm (0.5 in.) by

using two fin segments stacked one on top of the other. The principal detail parts of the heat exchanger assembly are shown in Figure 4.

The heat exchanger was initially brazed in three equal 120-deg full-length segments, utilizing an atmosphere furnace. The segments were assembled, tack welded, and then rebrazed for a continuous structure. The two-stage braze procedure also allowed for the braze attachment of the mounting rings and the manifold structure (see Figure 5 for a photograph of the completed heat exchanger assembly prior to manifold attachment). Following final braze, the inlet and outlet manifolds and ducting were welded to the heat exchanger to form the complete heat exchanger assembly.

Each assembly was subjected to both a pressure test and a verification of the predicted pressure drop prior to final assembly into the housing. The pressure test, which was conducted at 446 kPa (64.7 psia) and at room temperature, was based upon an ASME pressure vessel code type requirement; however, code certification was not obtained, because the number of units and their usage did not warrant this activity.

The aperture and reflecting plate were manufactured by the Norton Company, a leading manufacturer of silicon carbide components. The 3-ft and 2-ft diameter of these parts represented a significant fabrication task, but Norton met the challenge. These parts were slip-cast to their finished dimensions.

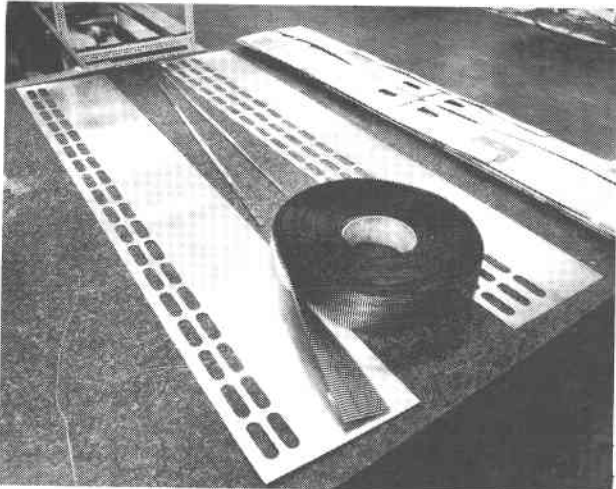
The first completed ABSR (shown in Figure 6) was delivered to JPL in September 1980; the second, in November. Unit testing is discussed in the following section.

RECEIVER TEST AND EVALUATION

The ABSR was designed to meet several requirements. Primarily conceived as part of a distributed electrical power generation module, it will also be used to heat gases for a variety of other purposes, such as heating process gas streams, preheating combustion gases, and providing heat flows for industrial processes that for economic or safety reasons do not use liquids. Thus the testing program was designed to include a wide range of conditions to demonstrate the versatility of the ABSR in many applications.

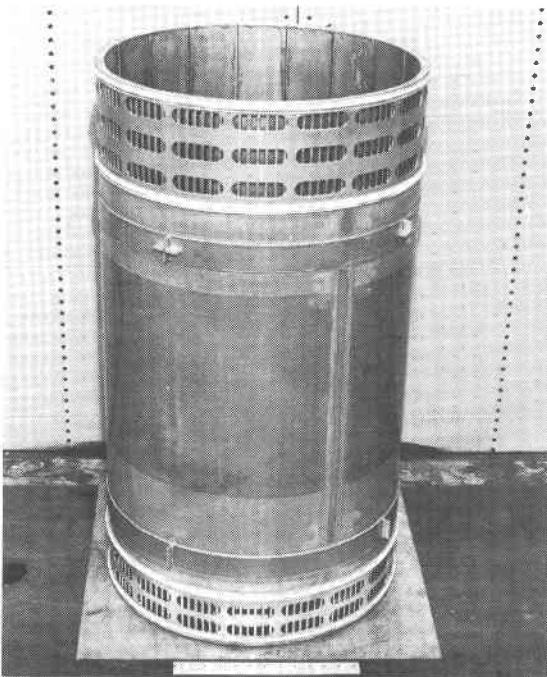
Initial tests on each ABSR were performed at AiResearch; these consisted of leakage, proof pressure, and flow continuity tests to ensure basic mechanical integrity. All tests were conducted at essentially ambient temperatures. Performance testing will be conducted at JPL's Parabolic Dish Test Site (see Figure 7). There, two 11-m-dia test bed concentrators have been installed. On a clear day each can concentrate about 82 kW(th) into a 20.3-cm (8-in.) dia focal spot. In addition, an expert test staff and all necessary support equipment, including instrumentation, a computerized data acquisition system, and shops, are available.

Airflow is provided by a 750-cfm diesel-powered air compressor. The air passes through an aftercooler, oil separator, dryer, and filter to ensure flow with only about 0.05-ppm contaminants. Flow rates between 0 and 0.43 kg/sec (0.93 lb/sec) can be produced, which brackets the 0.23 to 0.27 kg/sec (0.5 to 0.6



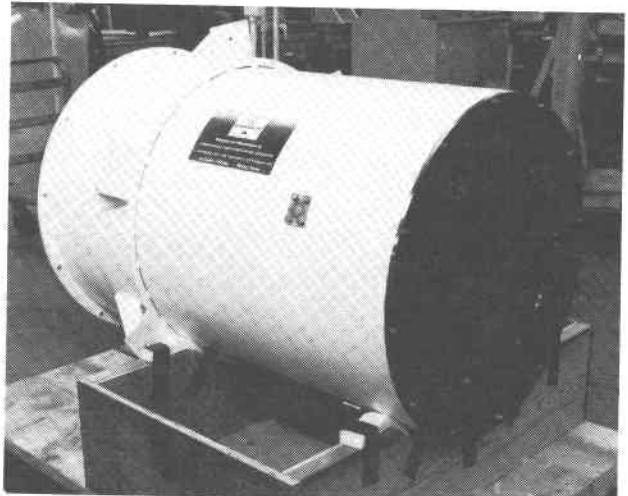
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FIGURE 4. HEAT EXCHANGER DETAIL PARTS



83318-2

FIGURE 5. COMPLETED BRAZE ASSEMBLY



83682-4

FIGURE 6. COMPLETED BRAYTON RECEIVER

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FIGURE 7. PARABOLIC DISH TEST SITE

lb/sec) design flow of the ABSR. Inlet pressures to the receiver will be in the 138 to 276 kPa (20 to 40 psia) range. Flow is controlled by a series of automatic valves; pressure in the ABSR is maintained by a ceramic orifice plate in the outlet piping.

The outlet temperature of the receiver is automatically maintained by the control system. Temperatures will range from about 260°C (500°F) up to the design maximum of 816°C (1500°F). Inlet temperatures range from ambient to about 700°C (1300°F), the maximum-design inlet temperature. In the 200° to 700°C (400° to 1300°F) range, heat is supplied by a propane-fired preheater.

The test matrix proper is a combination of three dynamic variables: mass flow, temperature, and pressure, plus a range of power inputs at 25, 50 and 75 percent as well as full power. Less than full power runs are made by masking off individual mirror facets in patterns devised to maintain the proper overall flux distribution. Testing will begin with the lowest temperatures and power levels and will be increased in steps until full power at maximum temperature is attained. Extensive thermal instrumentation, about 50 channels, as well as a full array of pressures and flows, is automatically monitored by a computerized control and data acquisition system during each test run. Both real time and posttest computational ability is available.

This series of tests is designed primarily to assess the efficiency and dynamic response of the ABSR. Life and fatigue tests will be conducted later as resources permit.

Testing is scheduled to begin in mid-January 1981, with initial data to be available within a month. Variable winter weather is a problem on the high desert, but a maximum effort is being made to hold to this schedule.

THE DEVELOPMENT OF AN 85-kW (THERMAL)
STEAM RANKINE SOLAR RECEIVER

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ABSTRACT

The AiResearch Manufacturing Company of California is under contract to the Jet Propulsion Laboratory (JPL) to manufacture a prototype Steam Rankine Solar Receiver (SRSR) for the Parabolic Dish Solar Thermal Power Systems Project. This paper summarizes the work accomplished in this program and describes the JPL testing of the receiver at the Parabolic Dish Test Site, Edwards AFB. The receiver is a once-through monotube boiler designed for steam/electric and process steam applications at pressures up to 17.24 MPa (2500 psia) and temperatures up to 704°C (1300°F). The unit is 76.2 cm (30.0 in.) in diameter and 95.8 cm (37.7 in.) in length; it weighs 220 kg (485 lb). Its heat transfer surface, which is 45.7 cm (18 in.) in diameter by 57 cm (22.4 in.) long, is an Inconel 625, cylindrical, tube-coil assembly composed of primary and reheat sections. A test unit has been successfully operated at up to 6.9 MPa (1000 psia) and 704°C (1300°F) with solar input from a 11-m-dia parabolic dish concentrator.

INTRODUCTION

The participation of AiResearch in the Solar Thermal Power Systems Project at JPL began with a Phase I conceptual design study of a Steam Rankine Solar Receiver (SRSR) in July 1978. The final report on this study was completed in January 1979. On the basis of the Phase I study, final design conditions were formulated by JPL, and in June 1979 a Phase II contract was awarded to AiResearch for the final design and fabrication of an 85-kW (thermal) SRSR. A final design review was held in October 1979, and the first test unit was shipped to JPL in June 1980. A final report on the design and fabrication of the receiver described herein is in preparation. Testing by JPL at the Parabolic Dish Test Site commenced in September 1980.

The purpose of this paper is to (1) summarize the final design goals and conditions, (2) describe the construction details of the receiver, (3) present the estimated performance for a steam/electric application, (4) discuss methods of adapting the SRSR to industrial process steam applications, and (5) present preliminary test results.

DESIGN REQUIREMENTS AND CONDITIONS

The final design requirements are that the SRSR be sized for a steam/electric application with provisions for dual-mode operation (with or without reheat)

and that the SRSR be adaptable to industrial process steam applications. The design life is to be 10,000 hours, with 1500 cycles of operation. Weight and size are to be minimal.

The design conditions for both applications are summarized in Table 1. The diurnal solar input is from an 11-m-dia parabolic dish concentrator on an average sunny spring day. The peak input is 85 kW, and the receiver must accept irregularities in solar flux input caused by mirror slope errors, reduced power (10 percent) from one-half of the mirror, and an asymmetric flux profile resulting from a ± 2.54 -cm (1.0-in.) offset of the receiver axis from the optical axis.

TABLE 1

SRSR DESIGN CONDITIONS

Solar energy source: 11-meter concentrator
 Peak power input: 85kW

	<u>Process Steam</u> (up to)	<u>Steam/ Electric</u>
Primary section		
Inlet feedwater temperature, °C (°F)	149 (300)	93 to 149 (200 to 300)
Outlet steam		
Temperature, °C (°F)	704 (1300)	704 (1300)
Pressure, MPa (psia)	17.24 (2500)	17.24 (2500)
Reheat section		
Outlet steam temperature, °C (°F)	704 (1300)	704 (1300)
Inlet steam		
Temperature, °C (°F)	704 (1300)	343 (650)
Pressure, MPa (psia)	17.24 (2500)	1.21 (175)
Flow rate:	Determine from energy balance; same in both sections	
Pressure drop:	$\Delta P/P = 10$ percent	

DESCRIPTION OF THE SRSR

A cutaway drawing of the SRSR is shown in Figure 1. The SRSR is a once-through monotube boiler that uses concentrated solar energy as a heat source to produce high-pressure, high-temperature steam at the conditions listed in Table 1. The major components are the outer shell assembly, 15.2 cm (6 in.) of Cerablanket insulation, an Inconel 625 tube-coil heat exchanger assembly, a rear plate that can be moved axially 7.6 cm (3 in.), and an aperture assembly that can be adjusted from 20.3 to 25.4 cm (8 to 10 in.). The rear plate and aperture assembly were made of NC405 silicon carbide, but, as a result of test experience, change to a rear plate of chromium nickel steel (RA 330) and an aperture assembly of graphite is recommended.

The tube-coil heat exchanger assembly is shown in Figure 2. The active heat transfer portion consists of 34 turns of 11.11-mm OD by 1.728-mm wall (7/16 by 0.070 in.) primary section tubing and 10 turns of 19.05-mm OD by 3.05-mm wall

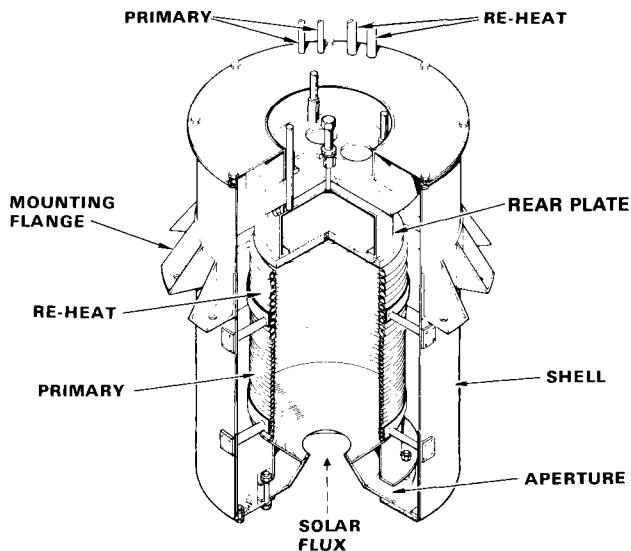


FIGURE 1. STEAM RANKINE SOLAR RECEIVER (CUTAWAY)

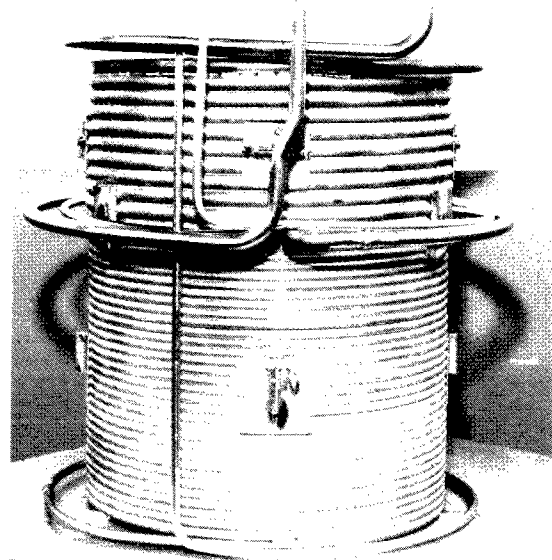


FIGURE 2. TUBE-COIL HEAT EXCHANGER ASSEMBLY

(3/4 by 0.120 in.) reheat section tubing. An additional turn of tubing at the ends of each section allows for thermal contraction and expansion of the assembly, and straight runs of tubing are used to route the water or steam to and from the coil. The inner surface of the coil is oxide-coated to produce a surface emissivity of about 0.8. Each section is a rigid, brazed unit, and the two sections are held together by three hinge-type joints. Eight radial post-type supports welded to the coil are used to attach the assembly to the outer case. These supports allow for radial and axial thermal expansion or contraction while preventing rigid body movement of the coil. The entire assembly is mounted to the concentrator boom structures so that the center of the receiver aperture is located at the focal point. The two coil sections can be connected in series for operation in primary mode only or in parallel for operation in the primary plus reheat mode. In the latter case, the primary and reheat outlets are adjacent to each other.

ESTIMATED PERFORMANCE

Method of Analysis

A finite element method of analysis was used to estimate the receiver performance. Incident solar flux on the inner surfaces of the receiver was computed by assuming parallel rays from the sun (point source) as being reflected from a perfect parabolic concentrator. The resulting flux profile was smoothed out and represented in a histogram input to a computer program for computation of the radiation interchange, fluid heat transfer, and pressure drop. This flux profile was the baseline for a sensitivity analysis of various possible incident flux profiles caused by concentrator irregularities.

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Radiation interchange computations were based on the assumption of flat surfaces, an equal solar absorptance and infrared emittance of 0.80, and diffuse radiation (both reflected solar and emitted infrared). Also, the heated surface of the tubes was assumed to be one-third (120 deg) of the total tube outside area. Aperture convection losses were assumed to be 2.5 percent of the solar input.

Heat transfer to the fluid inside the tube in the subcooled liquid and the superheated vapor regions was computed from Colburn modulus versus Reynolds number data for flow in round tubes (1). A tube-length-to-diameter ratio of $L/D = 25$ was used to account for the effects of tube coil curvature. In the boiling region up to a steam quality of 70 percent, the John Chen correlation was used (2). Vapor heat transfer coefficients were used thereafter.

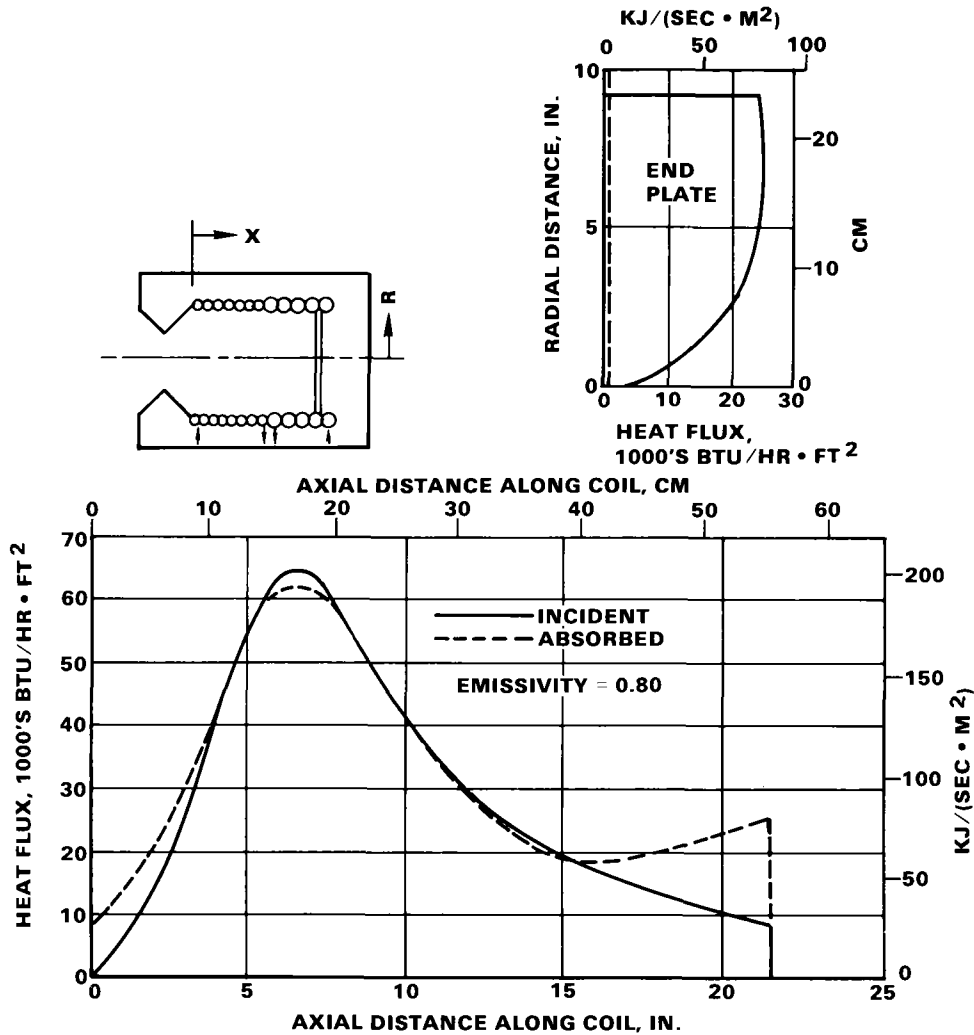
Pressure drop in the liquid and vapor regions was computed from Fanning friction factor versus Reynolds number data for round tubes having an $L/D = 25$ (see Reference 1). Pressure drop in the boiling region resulting from momentum change and friction losses was computed with the Lockhart and Martinelli correlation for two-phase flow pressure drop (3). Stable and homogeneous flow was assumed. A stable match point for pump and flow system can be achieved by installing a suitably sized orifice in the plumbing line between the pump and receiver (see Reference 4 for a general discussion of methods for obtaining forced-flow boiling stability).

The thermodynamic process path in the receiver coil for the steam/electric plus reheat mode of operation consists of 28 percent liquid heating, 20 percent boiling, 32 percent superheating, and 20 percent reheating.

Heat Flux Distribution and Temperature Profiles

The solid-line curve in Figure 3 is a graph of the baseline incident heat flux distribution inside the receiver cavity. The absorbed flux for the primary plus reheat steam/electric design condition is represented by the dashed line. This occurs after radiation interchange and heat transfer to the fluid has taken place. The difference between the incident and absorbed flux is caused by radiation from the uncooled end plate and front cone, where very little heat flux is absorbed, and by the heat losses (radiation out of the aperture and convection from the receiver casing, especially the front end).

Figure 4 is a graph of the resulting tube-wall and fluid temperatures in the axial direction along the coil. Note that the primary and reheat fluid inlets are on opposite ends of the coil assembly and that the two outlets are adjacent to each other. This flow arrangement was selected to avoid a large temperature discontinuity at the junction of the two coils. Also, the lengths of the two coils were proportioned to obtain equal temperatures at the primary and reheat steam outlets. The temperature profiles in Figure 4 are valid only for the incident heat flux distribution displayed in Figure 3. If some other incident flux distribution occurs, then the positionable end plate must be moved either forward or backward to equalize the steam outlet temperatures and to prevent overheating of one of the coils at its outlet. For example, if the concentrator has a larger slope error than the baseline case or if there is haze in the atmosphere, the heat flux will be shifted towards the rear of the cavity. This will cause underheating of the primary steam and overheating of the reheat steam (and tubing near the outlet). Equalization of the steam outlet temperatures can be accomplished by moving the end plate forward.



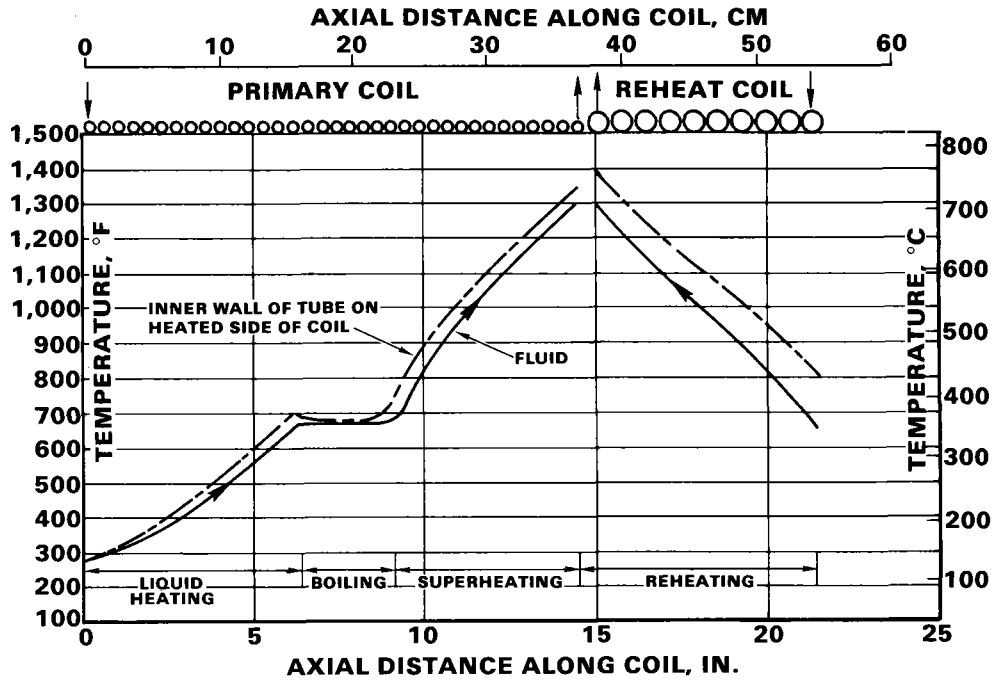
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FIGURE 3. BASELINE HEAT FLUX DISTRIBUTION

In the primary mode only operation, during which the two coils are connected in series, the three zones (liquid heating, boiling, and superheating) will be extended over a greater axial distance, and the steam outlet will occur at the rear of the coil assembly. In this mode, the position of the end plate remains fixed at the rear for all incident heat flux distribution.

Summary of Estimated Performance

The estimated overall energy balance and pressure drop performance of the SRSR for the steam/electric application is presented in Table 2. Ninety-four percent of the 85-kW solar thermal input is absorbed by the working fluid (water) to produce primary steam at 17.24 MPa (2500 psia) and 704°C (1300°F) or both primary steam at the same conditions and reheat steam at 1.21 MPa (175 psia) and 704°C (1300°F).



A-10523

FIGURE 4. TUBE WALL AND FLUID TEMPERATURE PROFILES FOR BASELINE HEAT FLUX DISTRIBUTION

TABLE 2

SRSR ESTIMATED PERFORMANCE
STEAM/ELECTRIC APPLICATION

<u>Parameter</u>	<u>Value</u>
Solar input, kW(th)	85
Aperture (9-in. dia) radiation loss, kW(th)	1.3
Insulation loss, kW(th)	1.2
Assumed aperture convection loss, kW(th)	2.5
Thermal power to fluid, kW(th)	80
Receiver efficiency, percent	94
Flow rate, gm/sec (lb/hr)	19.81 (157.2)
Pressure drop, percent	
Primary	2
Reheat	10
Primary mode only	
Flow rate, gm/sec (lb/hr)	24.66 (195.7)
Pressure drop, percent	3

ADAPTATION TO PROCESS STEAM APPLICATIONS

Although the unit was designed as a steam Rankine solar receiver for a high-pressure, high-temperature steam/electric application, the receiver can be operated as a once-through boiler at higher flow rates to produce process steam at lower temperatures and lower pressures (down to about 3.45 MPa or 500 psia). Also, the receiver can be operated as a recirculation boiler or a high-pressure water receiver. Both of these adaptations require the use of external equipment to produce steam. The first procedure requires a liquid/vapor drum (or equivalent) type of separator and the second requires a steam generator. The pressurized water receiver concept requires the use of distilled, polished water in a closed-fluid circulating loop between the receiver and the steam generator.

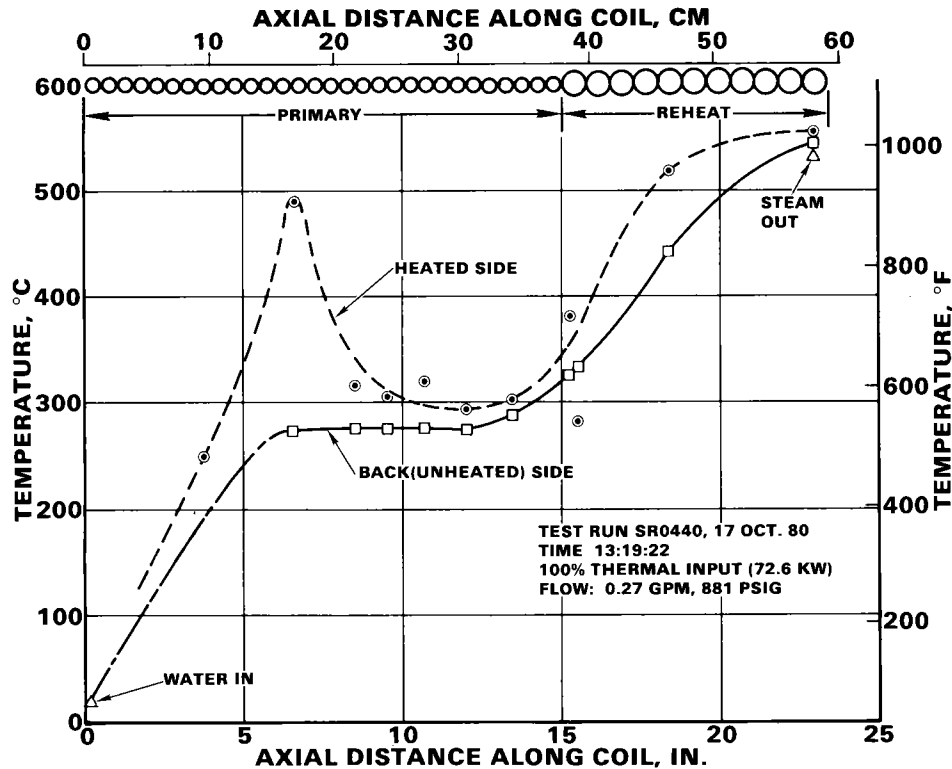
TEST RESULTS AT PARABOLIC DISH TEST SITE

Preliminary testing was started at the Parabolic Dish Test Site in September 1980. The JPL concentrator contains 224 rectangular, separately focused mirrors approximately 57 by 61 cm (22.5 by 24 in.). The total solar power input capability was 80 kW for an insolation of 1000 W/m² (317 Btu/hr·ft²).

Initial testing was done with water heating at 25- and 50-percent mirrors at low pressures (about 1.1 MPa or 160 psia) and low temperatures (about 150°C or 300°F). The second series of tests was conducted at medium pressures and temperatures (about 4.8 MPa or 700 psia and 288°C or 550°F) using 50-, 75-, and 100-percent mirrors. Exploratory high-temperature high-pressure tests have been started. In all runs, the primary and reheat sections of the coil were connected in series. Also, for procurement reasons, the material was changed to type 321 stainless steel, and the primary section tubing size was increased to 12.7-mm OD by 2.41-mm wall (1/2 by 0.095 in.), and the number of turns was reduced to 30.

The tests of the receiver indicated good thermal and flow performance, with efficiencies in the range of 80 to 88 percent. No major instabilities were detected, but some modifications to the receiver were required. The ceramic end plate and aperture cone were severely damaged (shattered) by the solar heating during early tests. An end plate of RA 330 nickel chromium steel and a water-cooled aluminum aperture assembly were needed to continue the testing.

A typical test result obtained by JPL during the exploratory high-temperature testing on 17 October 1980 is shown in Figure 5. This is a graph of the back-side and heated-side tube-wall temperature versus axial distance along the coil. Also, the water inlet and steam outlet temperatures are identified. The back-side or unheated tube-wall temperature profile is as predicted, but the heated-side temperature profile shows a very high peak at the beginning of the boiling region. This may be due to a thermocouple error or to excessive local incident solar heat flux. Prior to further testing, JPL plans to install new thermocouples on the heated side of the tube coil (welded to the coil to ensure a good thermal bond) and to defocus the mirrors, which may reduce the peak incident heat flux.



A-10524

FIGURE 5. TYPICAL TEST RESULT, TUBE-WALL TEMPERATURE PROFILE

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ORGANIC RANKINE CYCLE RECEIVER DEVELOPMENT

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ABSTRACT

A solar receiver is being developed for use with an organic Rankine cycle (ORC) engine as part of the Small Community Solar Experiment (SCSE). The selected receiver concept is a direct-heated, once-through, monotube boiler operated at supercritical pressure. The cavity is formed by a cylindrical copper shell and backwall, with stainless steel tubing brazed to the outside surface. This core is surrounded by lightweight refractory insulation, load-bearing struts, and an outer case. The aperture plate is made of copper to provide long life by conduction and reradiation of heat away from the aperture lip. The receiver thermal efficiency is estimated to be 97 percent at rated conditions (energy transferred to toluene divided by energy incident on aperture opening). Development of the core manufacturing and corrosion protection methods is complete with development testing of the core to be completed in January 1981. A prototype receiver will be supplied in March 1981 for integration and test at the engine supplier's facility.

INTRODUCTION

The SCSE Phase II program in progress at Ford Aerospace & Communications Corporation (FACC) includes development of a prototype power conversion assembly (PCA). The PCA will be mounted at the focal point of a 12 meter parabolic dish and will output approximately 20 kW of 3 kHz ac power to a ground-mounted rectifier. The PCA includes a cavity receiver coupled to an ORC engine. The engine working fluid is toluene with a nominal bulk temperature limit of 399°C (750°F) at the receiver exit. The receiver design requirements include input thermal power up to 95 kW_t, toluene flow from 54 to 545 kg/h, operating pressure up to 5862 kPa (850 psia), and a nominal 30 year component life. The two principal constraints on the design are a weight limit of 272 kg (600 lbm) and a maximum toluene pressure loss of 448 kPa (65 psi). The performance goals of the receiver design are to maximize the thermal efficiency, and to maximize the heat capacity of the core. The latter goal is desired for stabilizing the PCA operation during intermittent cloud cover.

CONCEPT SELECTION

The original baseline receiver concept for the SCSE program was a pool-boiling configuration using a secondary fluid and separate toluene heat exchanger (1). A detailed evaluation of candidate secondary fluids led to the conclusion that

this concept was not practical for the ORC temperature of $\sim 400^{\circ}\text{C}$. Alternate concepts were then considered including use of a pumped secondary liquid, use of a non-boiling sodium pool, and finally, a direct-heated copper shell with tubing brazed to the outside. After development of a feasible manufacturing process, the copper shell/brazed tubing concept was selected as the baseline receiver. This concept offers the maximum in serviceability in its fabrication, operation, and maintenance.

Several toluene boiler design options were also considered as part of the receiver concept evaluation. A once-through configuration was chosen over a recirculating boiler/superheater combination in order to minimize hardware complexity. A monotube, rather than multiple parallel tubes, was selected to help avoid flow instabilities. An important receiver/engine control decision was to throttle the toluene flow at the receiver exit (vapor phase) rather than at the inlet (liquid phase). The receiver then operates at an approximately constant toluene pressure over the full range of flows. This minimizes the risk of boiling instabilities and burnout occurring in the receiver tubing. A final boiler design trade-off was to select the toluene pressure level at the receiver. A minimum value of 4482 kPa (650 psia) is used (which is about 10 percent above the critical pressure of toluene) to further reduce the possibility of tube burnout.

In performing the receiver concept tradeoffs, it was found that the weight and complexity of an aperture door assembly could not be justified in comparison with the slight reduction in energy losses during transient cloud passages. In addition, the receiver performance was maximized by flowing the toluene from the front (aperture end) of the cavity to the rear, and by using a toluene-cooled backwall instead of an insulated backwall. The receiver transient performance was found to be best for a uniformly distributed heat capacity (uniform thickness) in the cavity wall.

DESIGN DESCRIPTION

The principal receiver components are the core assembly, core support structure, thermal insulation, outer case, and the aperture plate (see Figure 1).

The core consists of a barrel section and a flat plate backwall. These copper pieces have grooves machined in their outside surfaces to match a helical coil and a spiral coil of 347 stainless tubing. The tubing is mechanically held within the grooves and brazed to assure good thermal contact with the copper. The overall coppershell thickness is 1.71 cm (0.75 in.) with a nominal groove depth of 1.27 cm (0.5 in.). The cavity diameter and length are 0.61 m (24.0 in.) by 0.56 m (22.0 in.), respectively. The tubing outside diameter and wall thickness are 1.59 cm (0.625 in.) by 0.889 mm (0.035 in.), respectively, and the total tube length is 63.1 m (207 ft.). The core accounts for 147 kg (325 lbm.) of the total receiver weight of 271 kg (597 lbm.).

The copper shell and tube/shell braze joint are protected from corrosion in air by an application of electroless nickel plating. The cavity interior is then given a coat of flat black high temperature paint to increase its surface solar absorptivity to about 0.95.

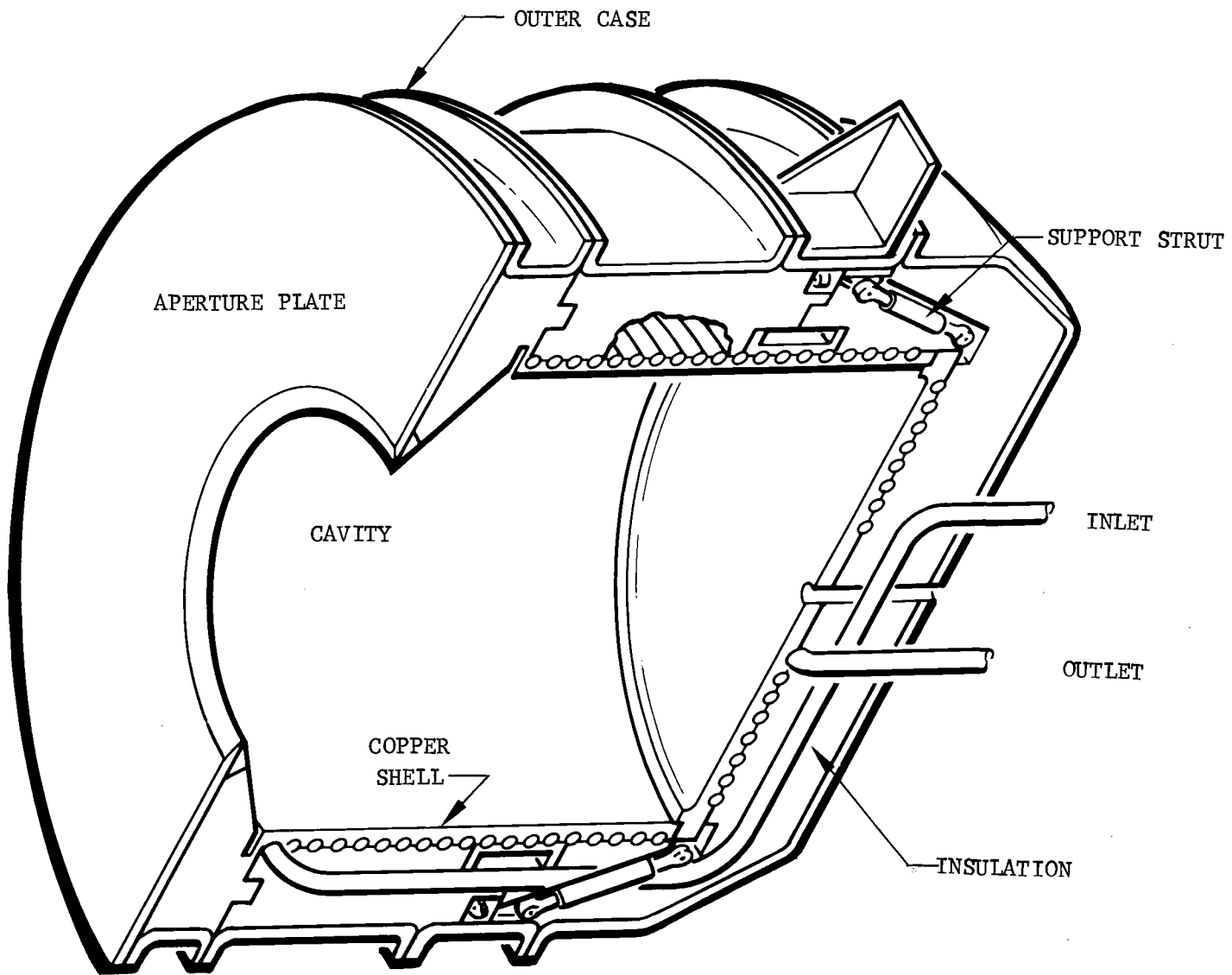


FIGURE 1. CUT-AWAY VIEW OF RECEIVER ASSEMBLY

The core temperature will be monitored at six locations using type K thermocouples. Four locations are on the cylindrical shell and two are on the central region of the backwall. The two thermocouples on the backwall provide an estimate of the cavity flux which may be used in the PCA control system if necessary.

The core support structure features a circumferential band around the core at its center-of-mass. Four struts tie this "belly band" to the main support ring of the receiver which is in turn attached to the four mount rails of the PCA structure. These central struts provide complete lateral support for the core. Support against axial and pitch/yaw loads is provided by four additional struts running from the cylinder/backwall junction of the core out to the main support ring. The struts are length-adjustable and are pinned at each end to accommodate thermal expansion of the core relative to the support ring.

The insulation around the core is formed from a low density refractory wool. Insulation pieces are molded to the desired shape and set using a rigidizer compound. After forming, the pieces are given a water-resistant treatment. Although the insulation properties are unaffected by cyclic moisture absorption and dryout, the coating minimizes the risk of insulation damage from rapid heating while moisture is present.

The outer case forms a protective enclosure for the insulation against the external environment. It also serves to tie the aperture plate to the main support ring. The case segments are formed from aluminum sheet except for the forward segment and the support ring, which are stainless steel.

The aperture plate is made of 3.2 mm (0.125 in.) copper sheet, with a thicker copper ring welded to the sheet metal to form the aperture lip. The nominal aperture diameter is 37.95 cm (14.94 in.), providing a collector concentration ratio of 1000. The assembly is nickel plated to prevent oxidation and is painted with high temperature black paint on the exterior. In normal operation, the concentrated solar beam is subject to dynamic and static pointing errors which result in transient lip heating. Circumferential conduction in the lip ring helps average out this heating. Radial conduction from the lip into the face plate is a major factor in maintaining a low ($< 400^{\circ}\text{C}$) lip temperature. The heat conducted into the face plate is rejected to the environment by reradiation and free convection. This simple, passive approach provides for very long life for this important component. Normal sun acquisition and detrack maneuvers, performed at nominal rates of 2 degrees in each of two axes, result in a transient heat pulse for the face plate as the solar beam sweeps off the receiver axis. The heat capacity of the copper is sufficient to limit the transient temperature rise in the face plate to about 55°C (100°F).

PERFORMANCE

The receiver thermal efficiency is estimated to be better than 97 percent at rated conditions. These conditions include a direct, normal solar insolation on the concentrator of 1000 W/m^2 , ambient temperature of 28°C (82°F), and the nominal concentrator parameters of 0.78 reflectivity, 0.95 dust factor,

and 0.932 blockage factor. With the exception of a small reflection loss, the receiver thermal losses are independent of insolation and are typically 2 to 2.5 kW_t. This insensitivity of loss to solar input is due to the nearly constant receiver cavity temperature over the range of input thermal power. The average cavity surface temperature is 360°C (680°F).

The core heat capacity is approximately 13 Wh/°C (25 Btu/°F), which provides some transient operating capability for the engine during cloud passages. If the sun is suddenly obscured by a cloud, the engine can be run at rated power for about one minute or for about 2 1/2 minutes at 40 percent of rated power. During these periods, the toluene vapor temperature at the turbine inlet would be reduced about 55°C (100°F).

MANUFACTURING DEVELOPMENT

The feasibility of the copper shell/brazed tubing concept for the receiver core was initially established using small, flat braze samples. These samples verified the material selections for the brazing process and identified the level of manufacturing tolerances desired to obtain a low porosity joint. Cylindrical samples have now verified the method of assembling the tubing onto the shells, and the technique for retaining the tubing in intimate contact with the shell during the braze cycle. A complete development receiver core will be used to demonstrate the performance of the receiver concept. A complete prototype receiver will then be fabricated for use in the SCSE prototype power module.

The initial core development testing will be conducted at FACC using a toluene test loop to simulate the ORC engine, and using a ~100 kW radiant cavity heater to simulate the input solar beam. The tests will include static thermal performance measurements at several input power levels. Following these, the dynamic (open-loop) response of the receiver to step changes in input power and toluene flow will be measured. These data will permit optimization of the PCA control system to maintain stable operation of the engine at a nominally constant turbine inlet temperature. Thus, engine efficiency will be maximized over a wide range of input power.

The complete prototype receiver will be sent to the engine vendor's facility following initial proof testing and performance checks. There it will be integrated with the ORC engine for qualification testing of the complete PCA and control system.

The present SCSE program schedule calls for completion of the core development tests in January 1981 and shipment of the prototype receiver to the engine supplier in March 1981.

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Panel Discussion I

TECHNOLOGY DEVELOPMENT ISSUES

Moderator: J. Lucas, JPL

GARRETT TURBINE ENGINE COMPANY

Paul Craig

The Garrett Corporation would like to express its appreciation for the arrangement of the panel, and in particular, for the extraordinary efforts of making the panel meaningful, not only for us who are presenting in the panel, but also for those who are going to add some new items of interest on the subject of solar technology.

I would like to discuss three general areas with you and then summarize those areas at the end of the meeting. We are going to talk about the required technology areas: Where they come from, where they are today, and where they are going.

Another area to be discussed will concern the approach to the required technology development: subsystem development, system development, and the relation between these two.

The final items, to which all of us in the industry are very sensitive and sympathetic, are the funding agencies and the funding gaps and the impact of these funding interruptions on our particular programs.

In regard to solar energy technology, in the early days of Tempe, Arizona, around the turn of the century, a group of farmers developed a solar dish to collect solar energy in order to supply energy for a steam engine to pump water for irrigation systems. It consisted of many flat-mirrors glued on a dish. It worked very well until the first hail storm hit in that particular area. I present this story because the criterion that I think we all face, in emerging technologies, is that if we are ready to meet the need in the marketplace, we should have the technology at hand to answer all the requirements and not be surprised, if you will, by the first hail storm.

One approach that is extremely critical in acquiring the technology for solar dish technology is not necessarily the straightforward approach of funding that is required for technology. Present DOE programs give an appropriate solution to acquiring the necessary technology. These leveraging programs use and take advantage of existing parallel programs and only fund those aspects of technology that would be directly used in solar dish technology. Briefly, an example will provide the technology we need. This example is the DOE-funded gas turbine technology program. From the Garrett Corporation's view, it appears that we can evolve a small gas turbine that is extremely appropriate for solar dish technology with a relatively small percentage of the funding necessary.

The second major area I would like to address is the development of components or subsystems in the solar energy program. There is a variety of ways to develop an overall system, and in context, a system would be defined as a commercially viable electrical power system used in solar energy or solar dish as a source of energy. The major component subsystems would be the receiver, the dishes, the engine, and the power producing part of that engine. This morning you have heard about a variety of development programs relating to the subsystem. However, as we listened and observed, an area that needs

greater attention is the development of those systems and subsystems as it relates to the overall system requirement. There is a greater need for the integration optimization of the variety of subsystems, whether they be receivers, engines, or dishes. We believe that by a greater degree of subsystems optimization and integration, with regard to solar systems, we can minimize the future redefinition of the subsystems and optimize and improve the performance of the subsystems which will, in turn, enhance the potential success of the overall system.

It is interesting to reflect on a variety of technologies that have emerged and have come into play over the past few years. Some technologies are not readily obvious but they are necessary for a successful endeavor in solar dish commercializations. One which comes to my mind is the emergence of the microprocessor technology. Five years ago, the utilization of microprocessor technology for gas turbines was in the far research and development stages. Today we are using it in production application. Without microprocessor technology, the sophistication of the control systems, not only for the dish but also for the system, probably would be at a distance behind us for cost and technological reasons. The use of small, high-speed alternators for the conversion of solar energy to electrical power has emerged over the past decade. Without that, the utilization of Brayton cycle engines most likely would not be as viable as we perceive it to be today.

One item of particular interest to Garrett is the evolution of materials, particularly the progress that has been made in the area of ceramics. A paper was presented this morning discussing the impact of ceramics and what we perceive ceramics will do for us in terms of increasing efficiency in the Brayton cycle engine. We think that ceramics will be utilized at a greater degree in the 1980 decade. Without the use of ceramics, there is a great deal of suspicion within the gas turbine industry that high volume production of gas turbines (high volume production being 10,000 to 500,000 units per year) will not come about in the near future. Competition is almost impossible because of the high cost of metallic components. Furthermore, the advantages in terms of efficiency with utilizing high-temperature ceramics would not be available to us.

An item that we are always faced with in the high technology development area is the allocation of research funds. Those of you representing high technology companies recognize the resource limitations that we continually face.

Technology development depends on an engineering team that is carefully selected and brought together. Our management is opposed to committing themselves to the pursuit of high technology markets with intermittent funding or delays. We have no commercial base to perceive the potential market. Quite often, other programs with more of a definition of end results are pursued. Funding gaps result in losing our team, and finally the resources being applied to other areas. I recognize and sympathize with the funding agencies, but from the standpoint of the industry, it is most important to minimize these problems.

In summary, we believe that technology is available which will provide a viable commercial venture for solar technology. The latest technology that is available is what should be used. We believe that tests of the subsystem and system are extremely critical to the development demonstration of these systems. We believe that this is the first time solar power has in its grasp the technology to answer the challenge of the marketplace today.

UNITED STIRLING, INC.

Worth Percival

Today we want to address these key technology development factors which we feel are essential to commercialization of any solar thermal powerplant, and specifically the Stirling engine. These factors are thermal efficiency, cost and reliability.

As discussed in this morning's presentation, thermal efficiency has a leverage effect on solar thermal costs. While efforts to raise thermal efficiency by United Stirling will continue indefinitely, present results in a range of 36 to 40 percent appear sufficiently attractive to make the dish Stirling system cost effective today. We believe that further increases in thermal efficiency will come from gradual improvements of each engine component, auxiliary and accessory, as well as a better understanding of cycle optimization, rather than from any sudden design breakthrough. Of course, higher heater temperatures in excess of 800°C will give rather dramatic improvements, but this must wait on ceramic developments. United Stirling has closely monitored the development of ceramic materials and fabrication over the last decade. This has primarily been done by maintaining contacts with leading manufacturers in this field. Small-scale component testing on our own has helped us establish an understanding of potentials as well as problems.

As a result of our state of the art assessment, we have recently increased our ceramic development capability. Conceptual designs have been prepared that show a potential for increasing engine efficiency by as much as 10 percentage units with a moderate heater temperature increase to about 1100°C.

Ideally, the heater tubes should be made of a high conductivity material such as silicon carbide while the cylinders and regenerator housing should be made of a lower conductivity material such as silicon nitride to reduce heat losses. Ceramic strengths of 50,000 psi appear adequate for Stirling applications since the pressure-induced stresses are generally under 10,000 psi.

During the last 18 months, United Stirling has made a thorough cost study for production of 4-95 automotive Stirling engines. In 1980, JPL made a similar cost analysis of the same engine for solar use. Further studies will be made by an outside contractor funded by JPL in the near future.

JPL's conclusion, so far, is that a solar Stirling O.E.M. selling price, including materials, labor, overhead, amortization of tooling, financing, taxes, and profit will be, for 25,000 engines a year, \$138.00 per kilowatt of peak power; for 100,000 units per year, \$72.00 per kilowatt of peak power. We believe these figures are realistic and cost competitive.

As a part of their cost studies, United Stirling has made numerous contacts with manufacturers and machine tool suppliers concerning fabrication of parts in mass production. Manufacturing techniques for certain key components, such as the heater and regenerator, are being reviewed periodically to correspond with the latest design changes and the introduction of new technology including computer integrated manufacturing. In the past 11 years, United

Stirling has built 49 engines, 44 of which were four-cylinder designs and 5 were single cylinder engines. Twenty-one of the 4-95 series have been constructed in the past 3 years.

The question of reliability is of no less importance than cost and efficiency. Electric utility people define reliability as the probability that a power plant will function for a period of time under specified conditions. The essence of reliability is, of course, mean-time-between-failures. For a complete power plant with hundreds of components, each component has its own level of reliability, and each contributes to the reliability of the whole system. For most engines, there is little redundancy, so that the system reliability will be less than any of the components. A Stirling engine, operating on a so-called solar only mode, requires fewer components than a more conventional automotive or stationary engine. Therefore, we believe that a solar Stirling engine should be a more reliable engine.

Perhaps the most critical components in today's Stirling engine are the piston rings. These usually are made of Rulon, a proprietary tetrafluoroethylene plastic with fillers. For best results, they must operate in an oil-free environment. Their wear rate depends on the so-called "PV factor," which is the product of the nominal pressure loading on the rings and the sliding velocity. They are also very temperature sensitive. We believe that when piston rings are manufactured to specifications, installed correctly, and the engine is operated properly, the current ring life ranges from about 2,500 to 4,000 hours. However, mean-time-between-failures, for all reasons, during test cell running over the past 2 years, is close to 500 hours. Reasons for failure include improper design, material and fabrication, also improper assembly, oil contamination, overheating and other accidental causes. The contractors working in the Automotive Stirling Engine Program, under the direction of NASA, have dedicated programs for improving piston ring material, design and fabrication. United Stirling also has made engine design changes to improve cooling in the piston ring region and are taking other steps to reduce ring temperature. Piston ring replacement is considered a minor overhaul requiring about 3 hours work by two experienced technicians. We believe that as Stirling Engines are phased into production during the latter half of the 1980's, time between major overhauls will approach 30,000 hours.

An indicator of reliability improvements in recent years is the total engine running time in the test cells. In 1978 total time in all engines at United Stirling was about 1,500 hours. In 1979 it was 4,000 hours; in 1980 it was 17,000 hours. We are projecting in excess of 25,000 in 1981.

United Stirling believes in the future of dish-solar thermal power and that it will become a practical and cost-effective method of generating electricity. United Stirling has obligated itself, by corporate policy, to concentrate on the three technology factors discussed here, both in cooperation with government programs as well as in its own in-house engine developments. The goal is, of course, commercialization. For greater enhancement of future dish solar thermal power programs, it is suggested that more interaction with end users of solar power systems be implemented as soon as possible. In addition, more engineering experiments are needed to advance the state-of-the-art in all areas, particularly development of lower cost concentrators; also, to better understand the interface requirements between the concentrator-receiver-engine-generator and load; and finally to gain much needed experience in control system optimization.

GENERAL ELECTRIC

Walter Pijawka

We, at General Electric, welcome the opportunity to participate in the Point Focus Program managed by JPL and are pleased to be able to express some of our views at this panel discussion.

I brought a few vu-graphs to assist me in making the presentation and to focus our attention during the next few minutes (see Figure 1).

We believe that the Point Focus Dish engineering concept for renewable energy collection and, in particular, the generation of electricity--a premium form of energy--is a viable one. We are pursuing the concept, in conjunction with the JPL-defined component and system development programs.

Figure 2 shows several things. First, it shows the generation-by-generation development of point focus dishes, proceeding from the initial 7-meter dish at Shenandoah through the second generation Low Cost Concentrator of 12 meters, following on to an Advanced Concentrator yet to be defined. Under each of these particular concentrators, I have illustrated the finite cycle of development that has occurred, or is planned to occur. Specifically, the Shenandoah design cycle has been completed, as has been its fabrication and test cycle. It is presently under implementation in the construction of the total energy system at Shenandoah, Georgia.

Feeding from the experience gained from the Shenandoah collector development, after the first fabrication and test experience, the second generation Low Cost Concentrator was conceived and proceeded into design. Fabrication has been initiated and testing is planned for later this year and, in fact, several system applications using various engines--Rankine, Brayton, and Stirling--have been identified and planned.

Following the experience gained after the testing of the Low Cost Concentrator, a third generation advanced concentrator is planned to enter into a complete cycle from design, then fabrication and test, and then into application.

This arrangement of generation-by-generation development of the critical component designs, so that lessons learned from one generation can be incorporated into the design of the following generation, is a very sound one and indicates that the planned program by JPL and DOE is a sound, orderly, and well-managed development activity.

Supporting the generation-by-generation product evolution, at the bottom of the chart, I have shown the supporting technology required to hasten the component developments, these being high temperature material, research and development, reflective surface developments, construction and use of the test bed concentrators for general knowledge gained, as well as development of advanced receiver and high temperature engines.

There are two keys to the successful completion of a conceptual development, which this chart hopefully illustrates. First, an orderly generation-by-generation development cycle to produce an ultimate product and, secondly, the continuity in the program to carry through in a continuous fashion the design teams and contractors involved in the programs.

I will attempt now to run quickly through the critical technology needs as we are facing them in the development of point focus concentrators (see Figure 3). One of the key technology needs is the development of cost-effective, long-life reflectors.

Quite a bit of technical work still must be done in order to achieve performance and cost goals to evolve a commercially viable product. Both the silvered-glass mirrors and metallized films which are being pursued today have their shortcomings. The concept outlined under "Approach" on the chart should be supported by separate technical efforts to provide a basis to produce effective commercial products.

Figure 4 illustrates one concept of the integrated reflective surface and structure that General Electric has been working on. We recognize that it is just a first step along the path that I have previously indicated.

In an attempt to evolve low cost concentrators, we have identified the need to employ new and low cost structural materials to be cost-effective. Structural plastics have the potential of satisfying these needs. In the construction of the Low Cost Concentrator, we are employing structural plastics to demonstrate the application and cost reduction potential, and Chart 5 does indicate additional needs.

In Figure 6 we are illustrating some of the work in molded plastics that we, at General Electric, have developed for the application to solar use, as well as other large structural members, such as appliances and automobile parts. The evolution of single component molding compounds allows the use of relatively low cost molds with high production rates within those molds.

Figure 7 is a picture of an engineering prototype mold of approximately the same curvature and size as one of the elements to be molded for the Low Cost Concentrator 12-meter dish. It is a proof-of-concept mold and has worked out quite well.

Figure 8 shows a finished molded part which has been produced in the mold shown previously. Its surface contour and structural properties are as designed.

To show further application of molded structural plastics, we have designed and fabricated a low cost molded trough whose parts are shown here. The type of structural detail and reinforcement which can be achieved are excellent and the strength and surface tolerances required can be achieved using molded structural plastics (see Figure 9).

General Electric has also been involved in engine receiver development activities for DOE and JPL (Figure 10). Specifically, we have evolved a multi-vane rotary expander Rankine cycling engine and have developed Stirling engine designs and hardware.

We have developed a family of receivers, from the initial cavity receiver used for the original Shenandoah 7-meter dish, applicable to Rankine cycling engines, to a high temperature receiver applicable to Brayton cycling engines, and culminating in the heat pipe receiver that is being developed presently for Stirling engines. This receiver does have energy storage capacity within it.

Figure 11 gives a view looking through an appropriate filter into the receiver aperture of the GE-developed 7-meter dish system on test at Sandia Laboratories, Albuquerque facility. Output fluid from the receiver tubes is at 750°F. You can see the concentrated solar energy distribution on the coils within the receiver produced by the 7-meter concentrator.

Because point focus dishes, of necessity, are 2-axis tracking, the need for controls and sensors is inherent. Also, the various modes of operation, including start-up and shutdown logic, routine and emergency focus and defocus, and other operations, are required. Figure 12 shows the general development needs within this area.

As I mentioned previously, one of the key elements to recognize in the development of a commercial product is the necessity for a number of required design cycles (see Figure 13). Each cycle proceeding from initial design through fabrication and field service must be completed before the next cycle can legitimately be started. Our experience in industry has been that at least three of these cycles, and sometimes more, are required before a commercial product evolves. The JPL program, as designed, does have built within it these design cycles. It is necessary that the program be retained with these features, and the continuity to maintain the flow of knowledge and development in industry be maintained.

Figure 14 shows one example of many I could have chosen to illustrate the product evolution design cycle phenomenon. The development of air-conditioning equipment for private homes, for example, went through this process with the result that over one half the homes built today in the United States are equipped with central air-conditioning, not to mention all of the commercial and institutional buildings which have air-conditioning incorporated within them. The road to this commercial product was one that went through three, and possibly four, design cycles as the product moved from the early prototype stage through that of an emerging product to the cost-effective reliable commercial product that industry supplies today.

Figure 15 shows what one quad of energy supplied to the United States would mean in terms of various types of energy generation. It compares the required 1 million parabolic dishes to the 17 equivalent nuclear plants and the vast amount of fossil energy required to replace this renewable energy source.

In summary, we at General Electric believe solar thermal parabolic dish energy applications:

- (1) Are a viable distributed renewable power generating option.
- (2) Produce quality energy in the form of electricity and high temperature heat.

- (3) Are modular and can be distributed to new or existing plants in increments.
- (4) Are factory mass producible with associated economies of production.
- (5) Have progressed under DOE and industry development.
- (6) Can be developed to produce renewable energy in support of the nation's energy goals.

Thank you.



**GENERAL
ELECTRIC**

**SOLAR THERMAL
PARABOLIC DISH
ENERGY APPLICATIONS**

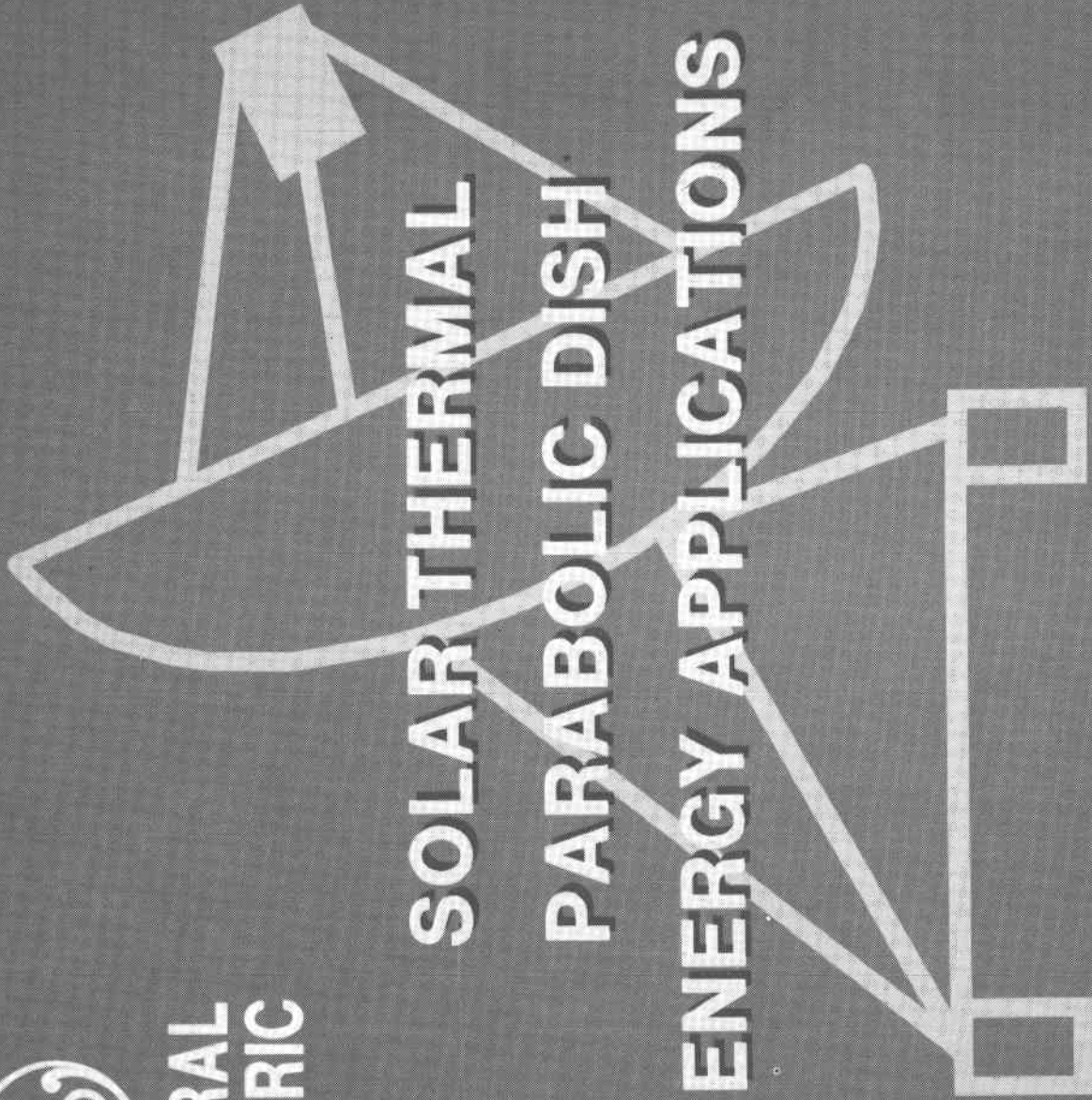


Figure 1.



GENERAL ELECTRIC

DISH TECHNOLOGY DEVELOPMENT AND DEMONSTRATION

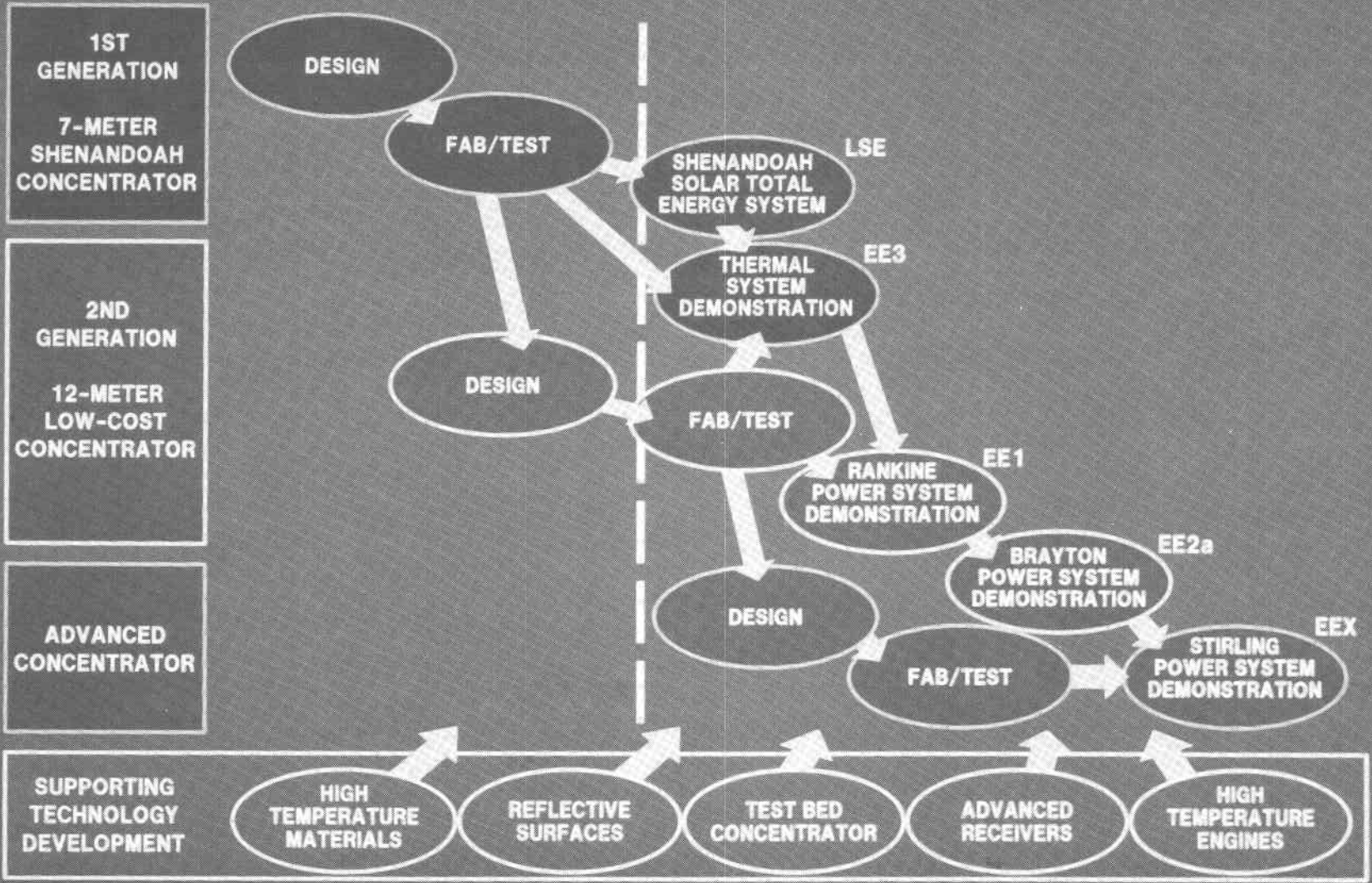


Figure 2.

TECHNOLOGY NEEDS

POINT FOCUS
SOLAR THERMAL PROGRAM

REFLECTIVE SURFACES

- COST EFFECTIVE, LONG LIFE REFLECTOR REQUIRED
- APPROACH
 - DEVELOP LOW COST SILVER INTEGRATED REFLECTORS
 - IMPROVE DURABILITY OF METALIZED FILMS
 - UTILIZE GLASS COATED ALUMINUM AND SILVER REFLECTORS

Figure 3.



Figure 4.

TECHNOLOGY NEEDS

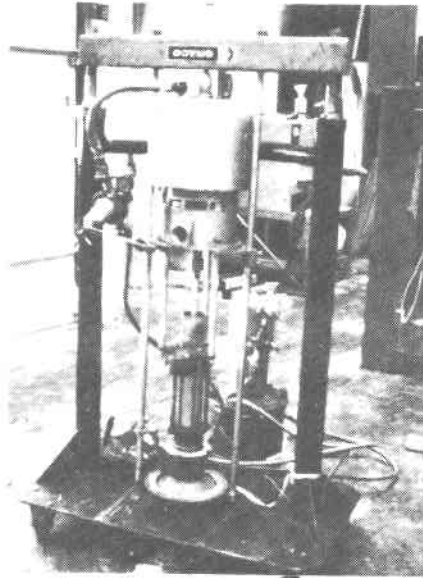
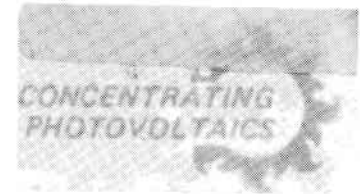
POINT FOCUS
SOLAR THERMAL PROGRAM

STRUCTURAL PLASTICS

- EVOLUTION OF MATERIAL, PROCESS AND COMPONENT DESIGN
- GENERATION OF PROPERTY AND PERFORMANCE DATA
- REFLECTOR - SUBSTRATE INTEGRATION
- GENERATE COST DATA BASE FOR PRODUCTION

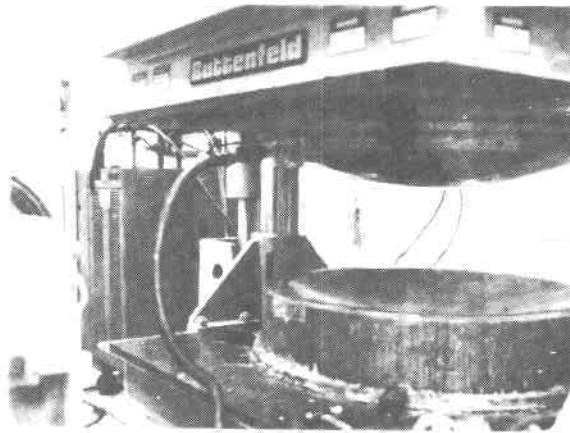
Figure 5.

CANDIDATE LARGE STRUCTURAL PART PROCESS EQUIPMENT

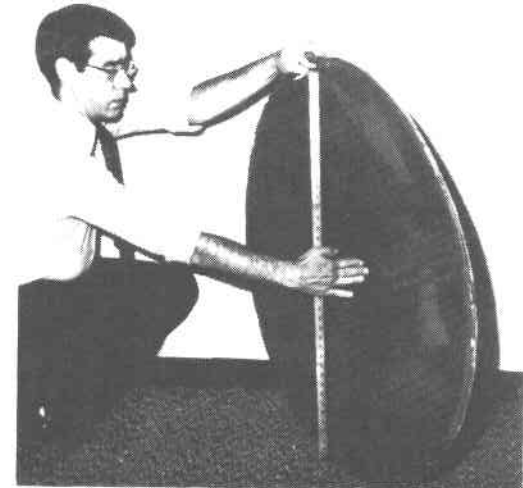


SINGLE COMPONENT EQUIPMENT

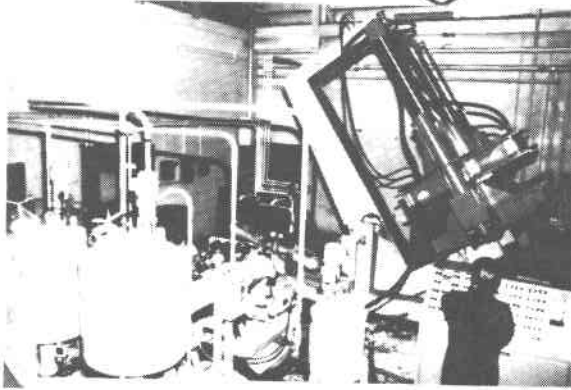
HEATED MOLD AND PRESS



MOLDED 1 METER DISH



OR



**CONVENTIONAL TWO COMPONENT RIM
EQUIPMENT**

Figure 6.



Figure 7.

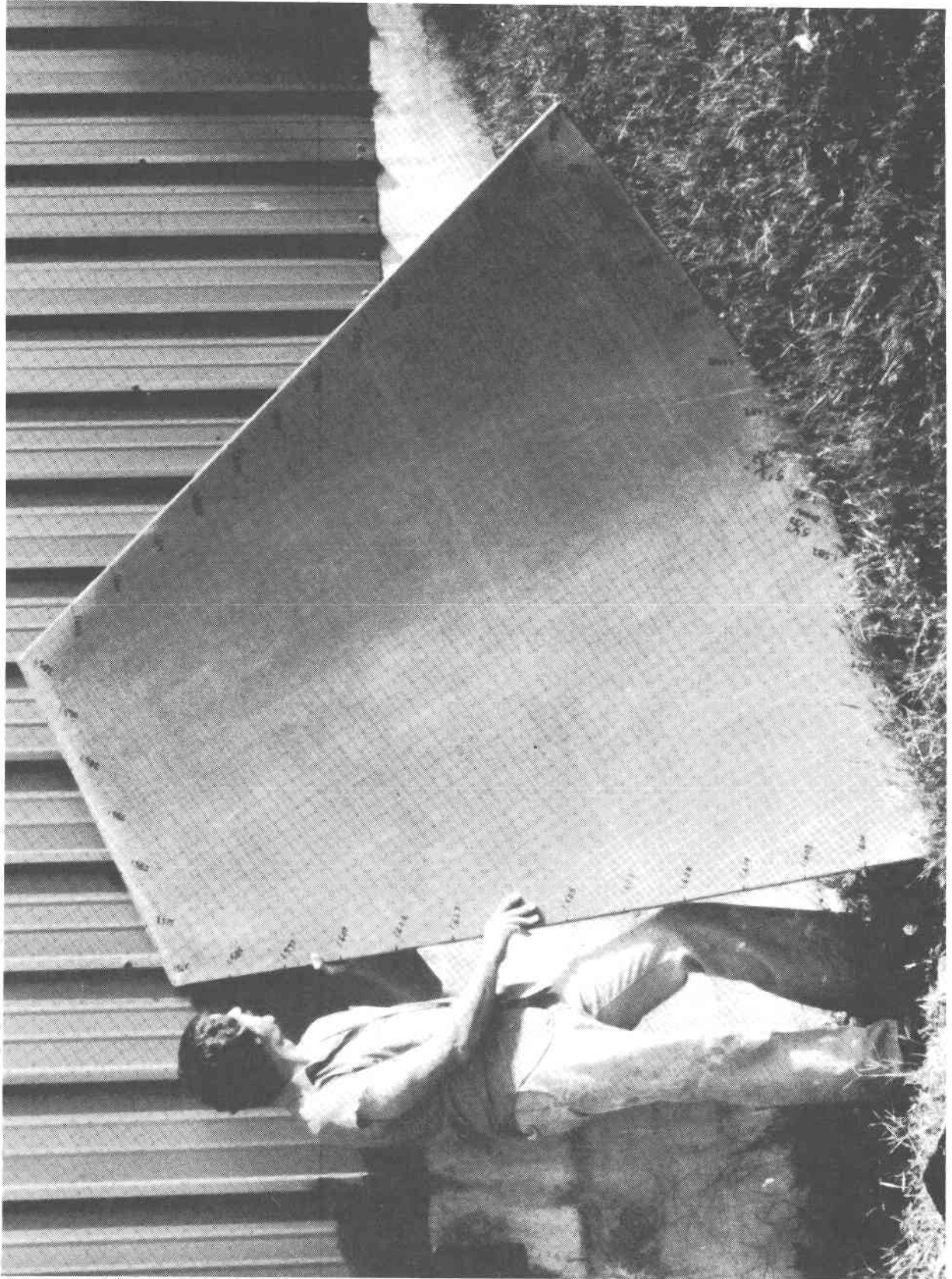


Figure 8.

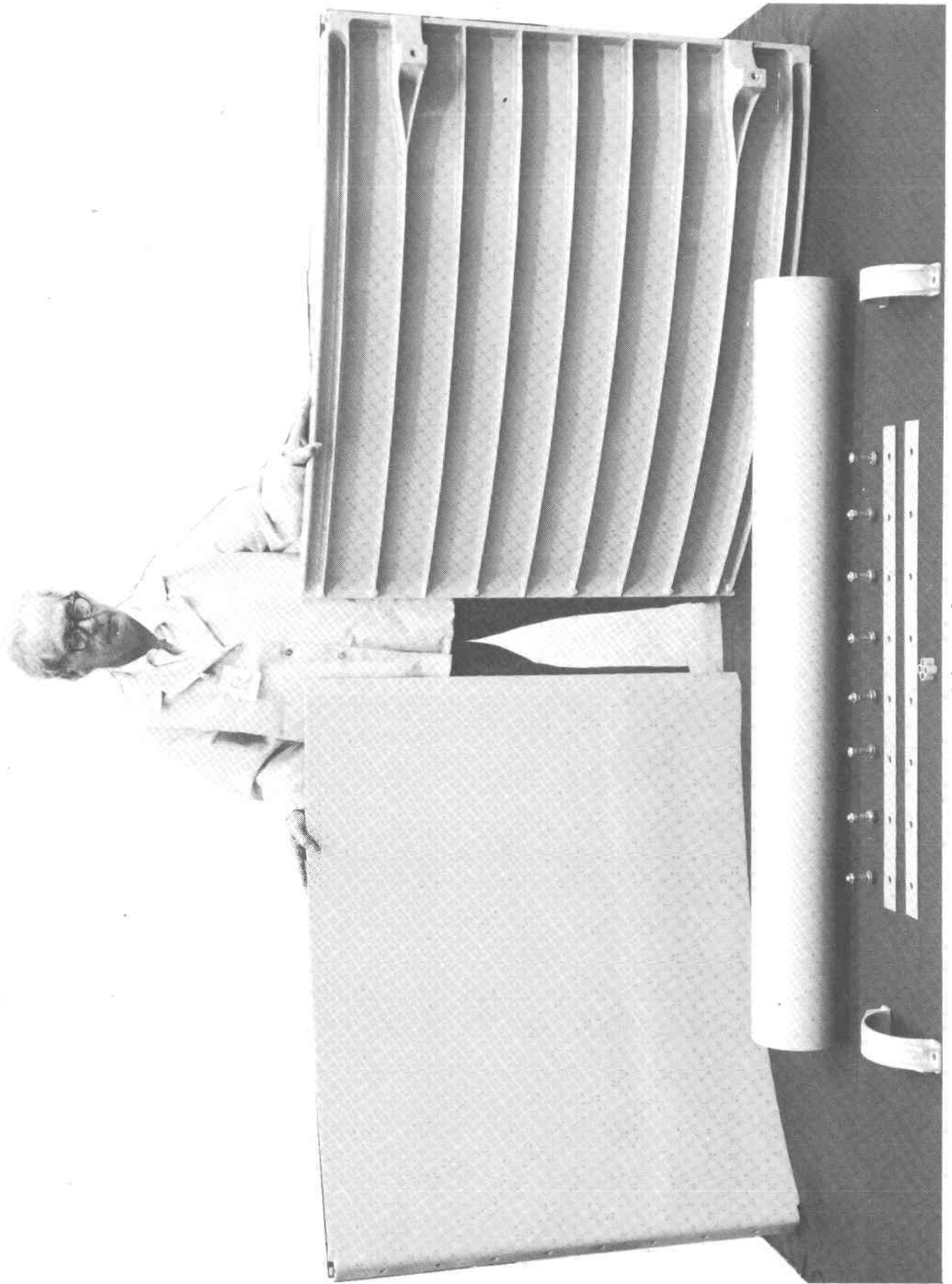


Figure 9.

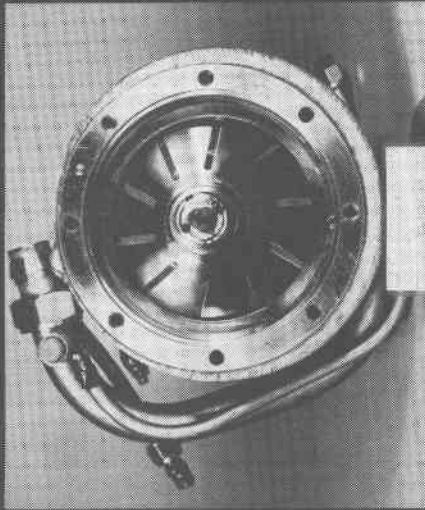


**GENERAL
ELECTRIC**

Engine/Receiver Program Activity

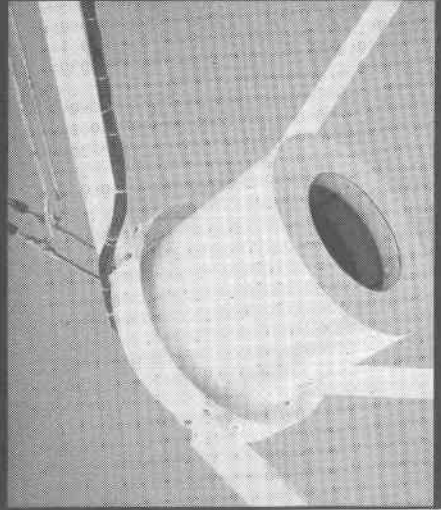


RANKINE



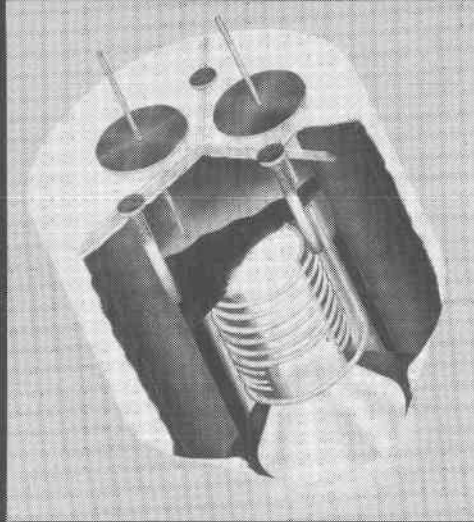
MULTI-VANE ROTARY EXPANDER

RANKINE RECEIVER



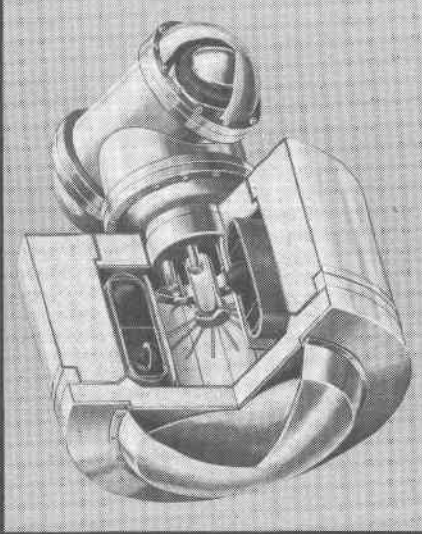
2ND GENERATION LSE RECEIVER

BRAYTON



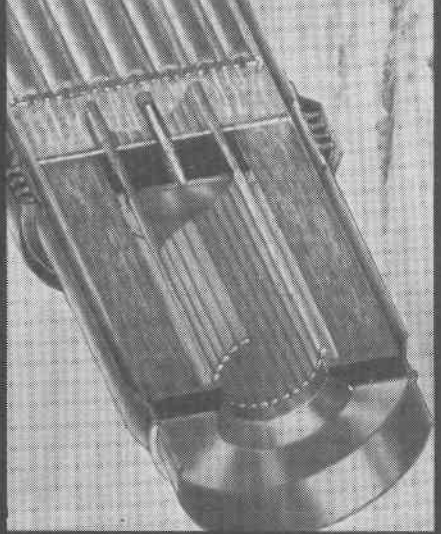
HIGH TEMPERATURE RECEIVER

STIRLING



STIRLING ENGINE DEVELOPMENT

STIRLING ENGINE RECEIVER



HEAT PIPE RECEIVER

Figure 10.

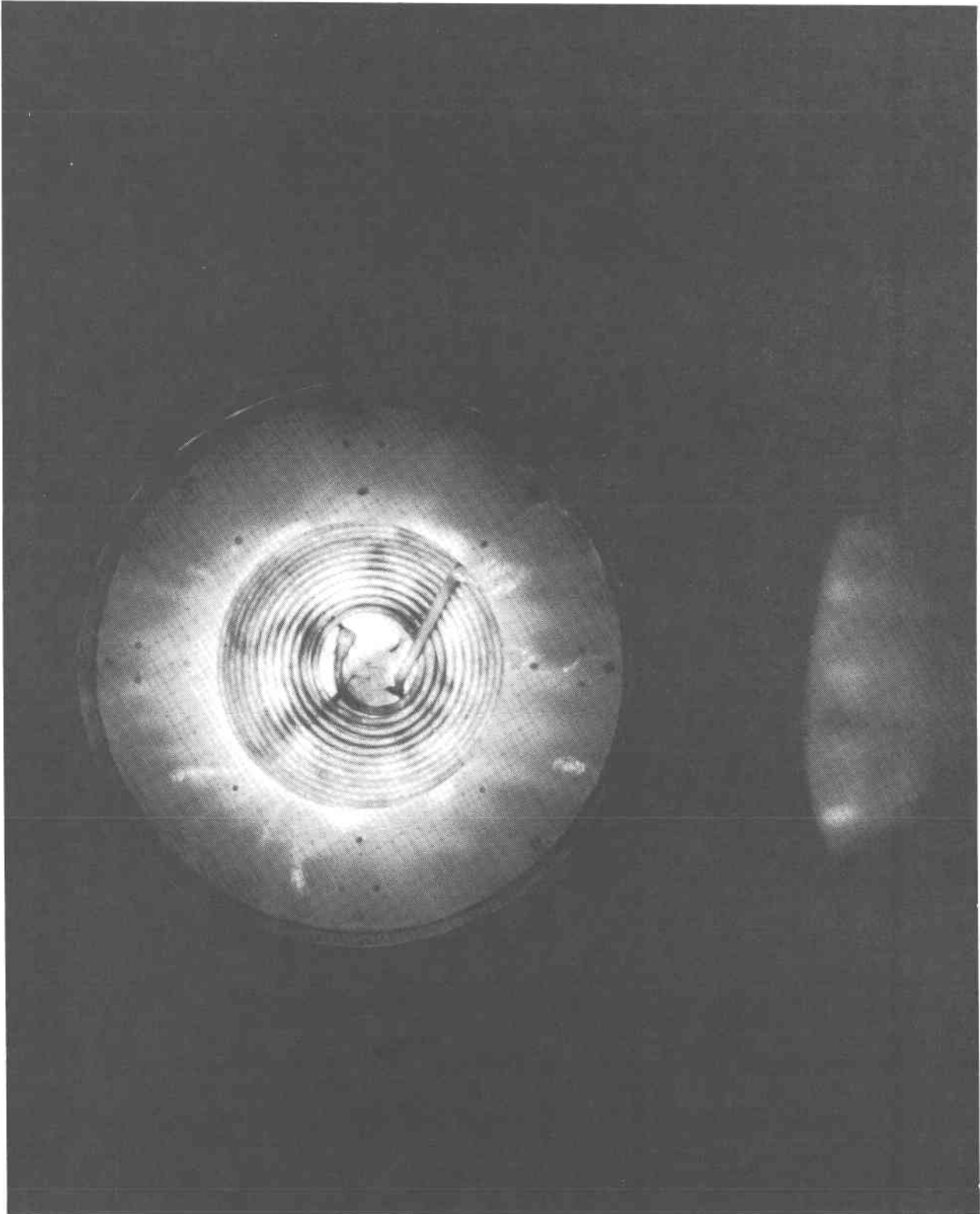


Figure 11.

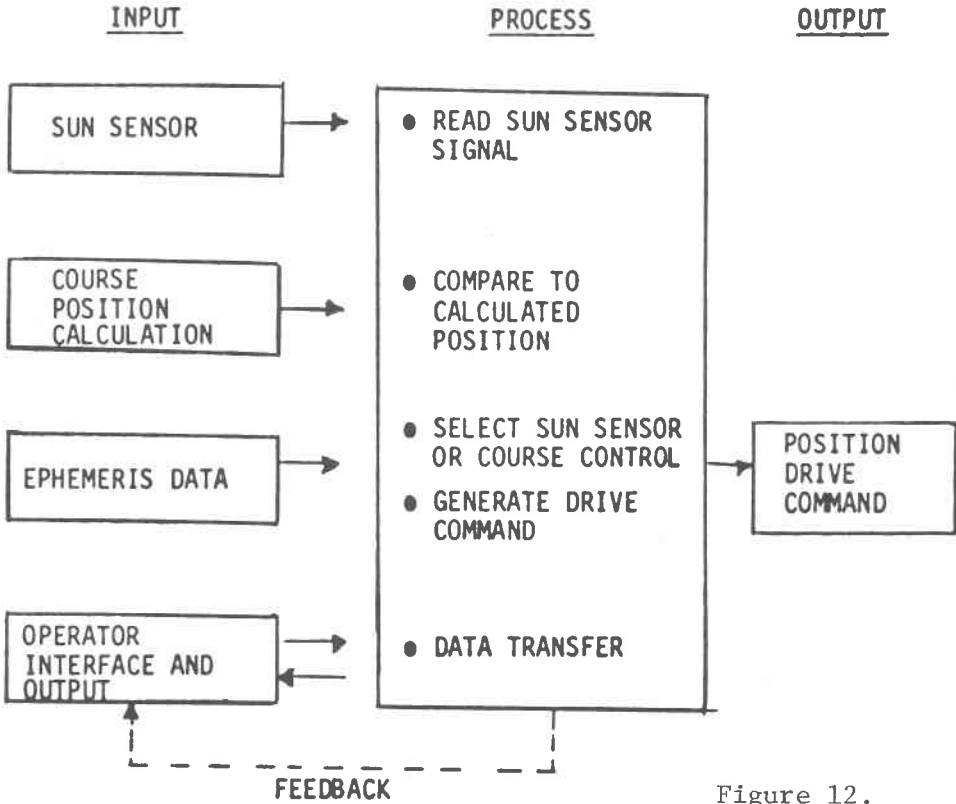
TECHNOLOGY NEEDS

POINT FOCUS
SOLAR THERMAL PROGRAM

CONTROLS AND SENSORS

GENERAL CONTROL PROCESS

ADDITIONAL DEVELOPMENT



- HARDWARE/SOFTWARE TRADEOFFS
- HARDWARE DEVELOPMENT
- REQUIREMENTS DEFINITIONS
 - DETAILED
 - TAILORED TO SPECIAL APPLICATIONS
 - UNNECESSARY REQUIREMENTS ELIMINATED
- SUN SENSOR SENSITIVITY TO GLINT AND CLOUD COVER

Figure 12.

PRODUCT EVOLUTION

POINT FOCUS
SOLAR THERMAL PROGRAM

REQUIRED DESIGN CYCLES

DEVELOPMENT
PROTOTYPE

DESIGN
FABRICATE
TEST
FIELD SERVICE

- BENCH STATION FABRICATION
- EXISTING TECHNOLOGY
- PRODUCT UNKNOWN IN MARKET

EMERGING
PRODUCT

DESIGN
FABRICATE
TEST
FIELD SERVICE

- LIMITED SOFT TOOLING
- TECHNICAL INNOVATIONS
- DEMONSTRATIONS SPARK MARKET INTEREST

COMMERCIAL
PRODUCT

DESIGN
FABRICATE
TEST
FIELD SERVICE

- HARD TOOLING
- MATERIALS SUBSTITUTION AND MANUFACTURING TRADEOFFS
- PRODUCT PROMISE CREATES MARKET DEMAND

DECISION

COMMERCIAL VENTURE

Figure 13.

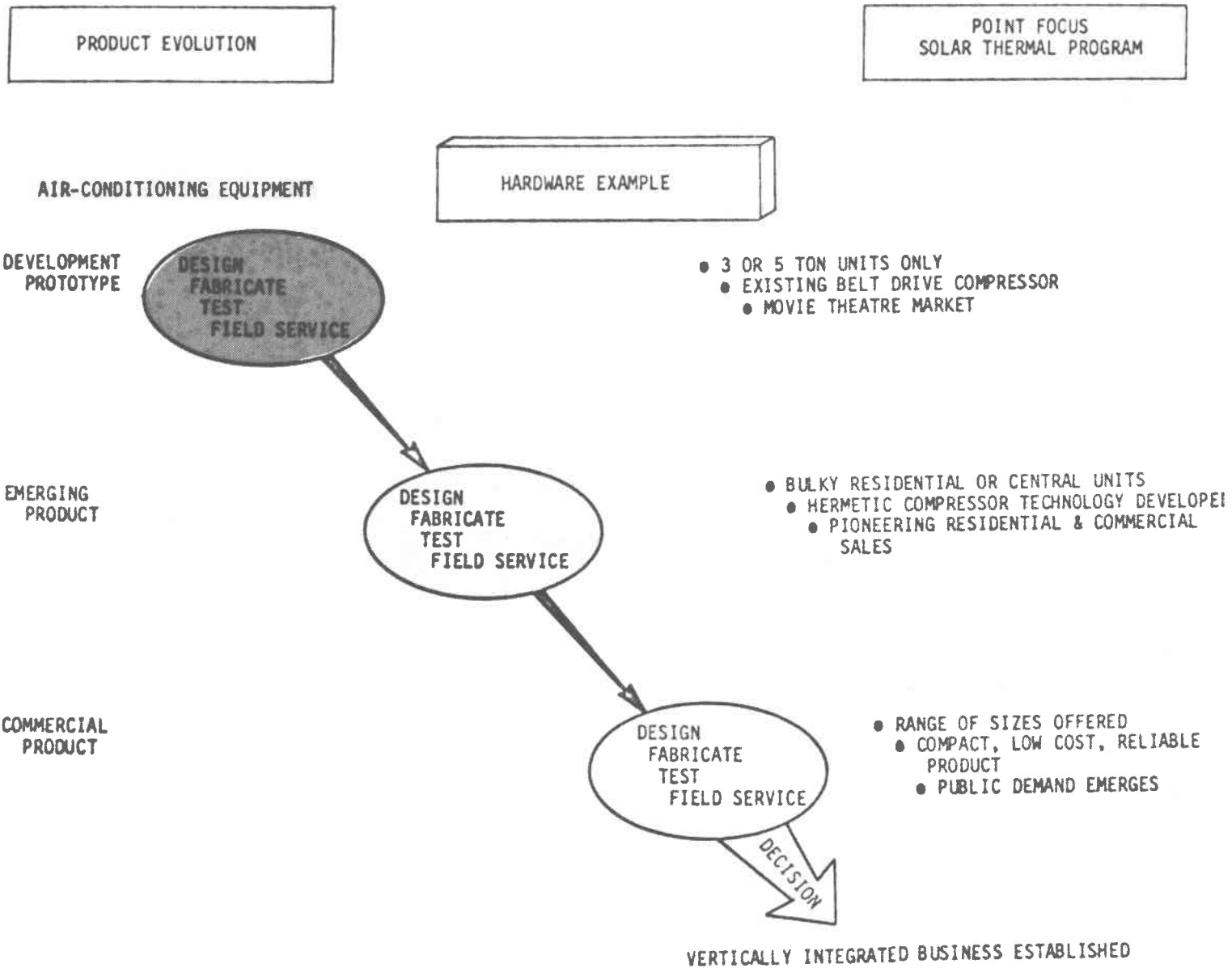


Figure 14.



**GENERAL
ELECTRIC**

POTENTIAL DISH CONTRIBUTION

BY THE YEAR 2000, PARABOLIC DISH SYSTEMS HAVE THE POTENTIAL TO SUPPLY 1 QUAD/YEAR TOWARD MEETING THE U.S. ENERGY REQUIREMENT AND CAN PLAY AN INTEGRAL ROLE IN ACHIEVING THE NATIONAL ENERGY GOAL OF 3 QUADS/YEAR OF SOLAR THERMAL GENERATED POWER

1 QUAD/YEAR = 1 MILLION PARABOLIC DISHES

= 17 NUCLEAR PLANTS

= 50 MILLION TONS COAL/YR.

= 200 MILLION BARRELS OF OIL/YR.

**= SAN FRANCISCO METROPOLITAN
AREA POWER REQUIREMENT**

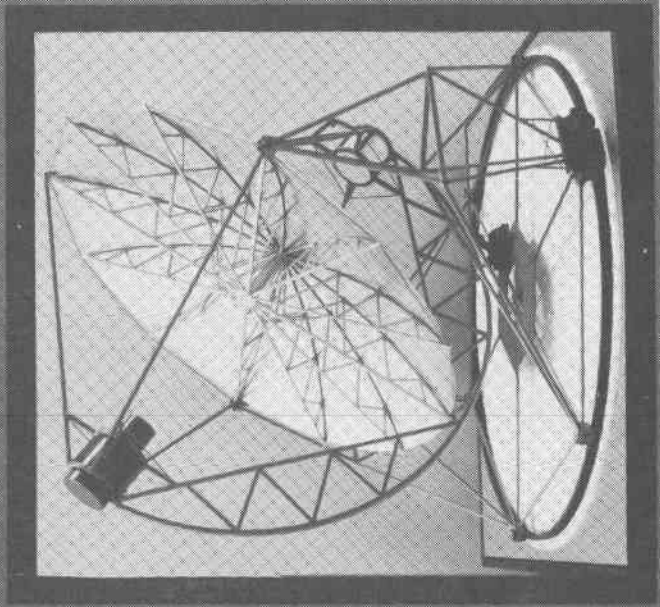


Figure 15.



**GENERAL
ELECTRIC**

SUMMARY

SOLAR PARABOLIC DISH SYSTEMS:

- **ARE A VIABLE DISTRIBUTED RENEWABLE POWER GENERATING OPTION**
- **PRODUCE QUALITY ENERGY IN THE FORM OF ELECTRICITY AND HIGH TEMPERATURE HEAT**
- **ARE MODULAR AND CAN BE DISTRIBUTED TO NEW OR EXISTING PLANTS IN INCREMENTS**
- **ARE FACTORY MASS PRODUCIBLE WITH ASSOCIATED ECONOMIES OF PRODUCTION**
- **HAVE PROGRESSED UNDER DOE AND INDUSTRY DEVELOPMENT**
- **CAN BE DEVELOPED TO PRODUCE RENEWABLE ENERGY IN SUPPORT OF THE NATION ENERGY GOALS**

Figure 16.

FORD AEROSPACE AND COMMUNICATIONS CORPORATION

Calhoun Sumrall

Ladies and gentlemen, I am delighted to be here to provide an industrial viewpoint commentary on the status of the current parabolic dish technology and the associated DOE funded programs which assist in the development of commercialization.

I am substituting for Bob Pons who is well known to many of you. I am happy to report that Bob is making a strong recovery from open heart surgery, and he will be back leading our Solar Energy Systems engineering effort in a few weeks. He sends his regards.

First, are PFDR systems competitive? Chart 1 shows a study that compares BBEC (kWeh) for Point Focus-Distributed Receiver-Distributed Generation Systems as a function of production volume and time. This analysis draws upon much background data from JPL as well as FACC analysis. The solid lines 1-4 represent cost projections for new conventional oil fired power plants in small capacities (8 MW) at specific locations ranging from Catalina Island across the nation. The shaded area projects the cost of new coal-fired 1,000 MW capacities in the south Atlantic states to the west and north central states. Such calculations are highly sensitive to assumptions relative to fuel inflation rates over the 30 year period as well as assumed module production rates. Nonetheless, the salient point is that PFDR systems can be competitive in a large number of small communities, provided that adequate production volume can be developed.

Second, is the technology available? We think so, and intend to prove it by the operation of Engineering Experiment No. 1 this year at the JPL Parabolic Dish Test Site. You have heard, or will hear, a great deal about the Organic Rankine Engine, Phase II Experiment at this annual meeting. Further, you will hear a great deal about glass and plastic concentrators, and Stirling and Brayton engines.

Chart 2 presents the total system efficiency for each engine candidate coupled with either plastic or glass concentrators. Note the predicted engine thermodynamic performance increase is partially offset by the increased loss of the receiver at the higher temperature. The higher reflectivity of the glass concentrator provides a consistent 3-4 percent point improvement.

Third, system costs are highly sensitive to subsystem specifications. A few caveats are noted:

- (1) Concentrator costs are a strong function of surface reflectivity, slope error, and concentration ratio.
- (2) High temperature engine performance requires high concentration ratios, low slope errors, and high reflectance.
- (3) Sun acquisition, track, and emergency detrack requirements strongly influence aperture face plate design and power conversion structural integrity, and survivability.

- (4) Low life cycle costs require a fault tolerant design which utilizes simple maintenance procedures, and which does not propagate failure to adjacent modules.
- (5) Low operating costs require a totally unmanned, computer controlled automatic mode of operation.

Fourth, are we heading toward the commercialization objective? Chart 4 projects a typical power module cost as a function of production quantity after initial R&D quantities have been tested. A commitment to production rates in excess of 1,000 power modules per year must be reached to achieve economic viability, and support the necessary investment in facilities and tooling. Note that the concentrator represents the largest component of cost.

Fifth, do the R&D programs phase into production? Chart 5 is an approximate schedule of current DOE development programs. Through 1984 only 65 power modules are programmed. Then a 2-year pause occurs before a production decision for first generation equipment is made. Low production rates will result in high unit costs.

We feel that it is essential that the period of 1984-86 be augmented with a number of additional 1 MW or larger systems. Secondly, we need an acceleration in production rate of prototypes to justify adequate production type tooling.

Sixth, what are the major problems inhibiting commercialization? Chart 6 lists five. Insufficient funds are currently programmed to support a full scale development transitioning into production. A multiplicity of programs is required.

PFDR technology suffers from an identity crisis. What are the appropriate markets? Does it complement the Power Tower? Is it applicable to repowering? If federal R&D funds are further reduced, will we have only the Power Tower as the sole solar thermal candidate?

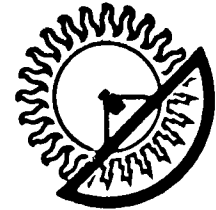
It is my personal opinion that we - both government and corporate researchers - have failed to clearly delineate the roles for parabolic dish technology, particularly in regards to the decision makers in the Congress of the United States. In the months ahead, in view of the personnel changes in the Congress and the rather unsettled situation in the DOE, we ought to make a major effort to identify the roles and comparative benefits of this technology and present it to our government leaders. Given the desirability of this technology, I believe there is a major difficulty in bringing it to rapid and successful development and production. Although virtually all economic analyses show that the concentrator is approximately one-half the cost of the system, concentrator development is not proceeding at a pace sufficient to give the system developer choices and flexibility. Furthermore, there is not strong evidence that advanced concentrators are being developed which result in installed costs of less than \$100/m². We need to develop a parabolic dish industry as quickly as we can.

We feel that Parabolic Dish Technology offers significant advantages for thermal-electric application and it can be competitive in many situations. Industry faces the need to aggressively market these system advantages to obtain development funds and to proceed on a schedule which would permit timely evaluations and comparisons with alternate systems. We, at Ford, are dedicated to making this happen.



**Ford Aerospace &
Communications Corporation
Aeronutronic Division**

SYSTEM EFFICIENCY TRAINS



110

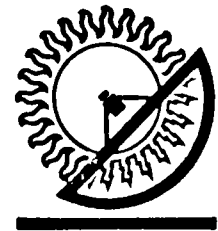
<u>ENGINE TYPE</u>	<u>TURBINE INLET TEMP.</u>	<u>REFLECTOR</u>	<u>EFFICIENCIES</u>		
			<u>COLLECTION</u>	<u>PCS</u>	<u>SYSTEM</u>
ORC	750 ^o F	PLASTIC	0.67	0.28	0.17
		GLASS	0.79	0.28	0.20
STIRLING	1500 ^o F	PLASTIC	0.61	0.37	0.21
		GLASS	0.73	0.37	0.25
	2200 ^o F	PLASTIC	0.51	0.50	0.23
		GLASS	0.63	0.50	0.28
BRAYTON	1500 ^o F	PLASTIC	0.61	0.30	0.17
		GLASS	0.73	0.30	0.20
	2200 ^o F	PLASTIC	0.51	0.40	0.19
		GLASS	0.63	0.40	0.23



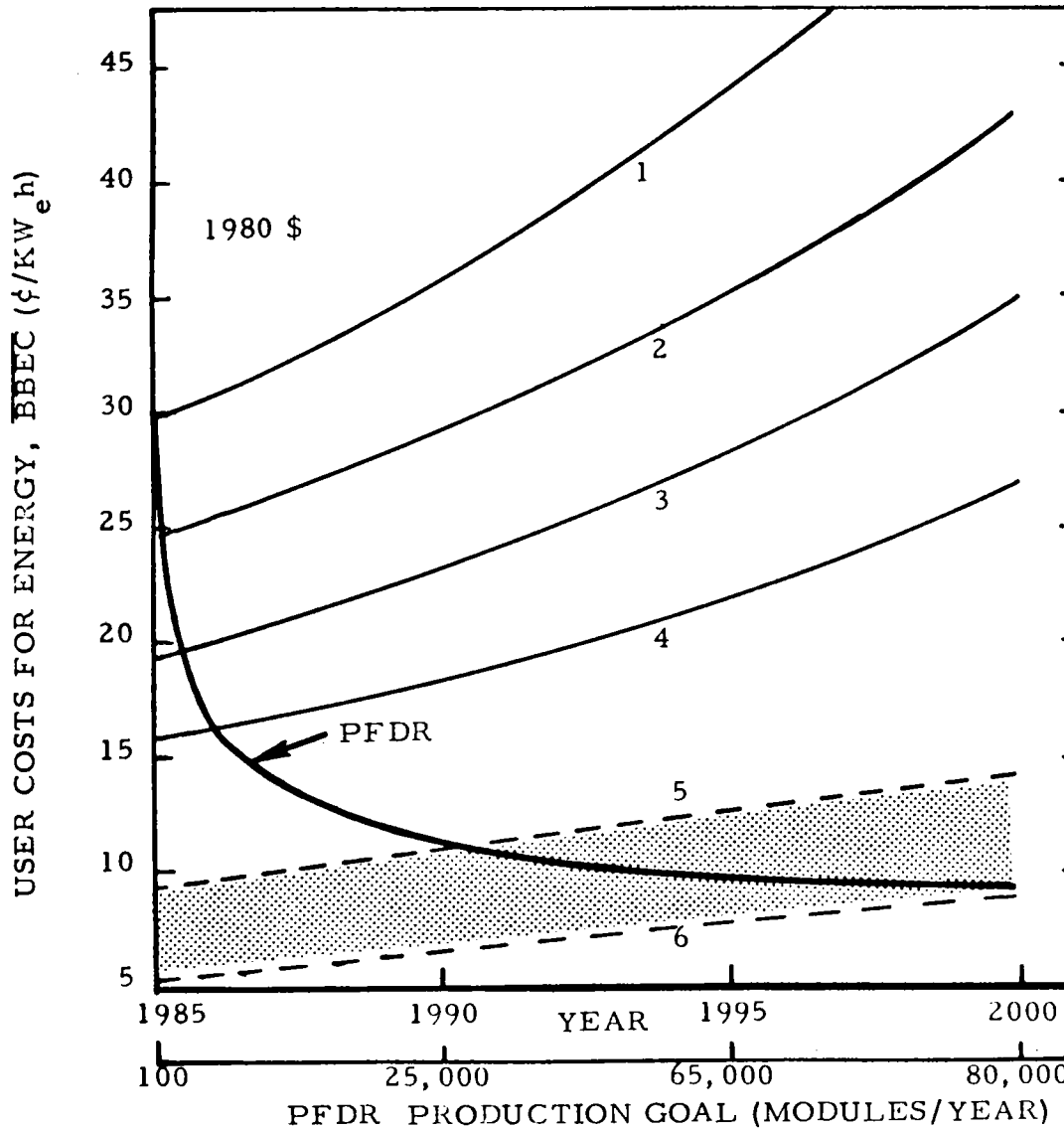
**Ford Aerospace &
Communications Corporation
Aeronutronic Division**

**POINT FOCUS DISTRIBUTED RECEIVER
DISTRIBUTED GENERATION SYSTEMS
ARE COST COMPETITIVE**

- NEAR TERM - SMALL COMMUNITIES
- FAR TERM - UTILITIES



III



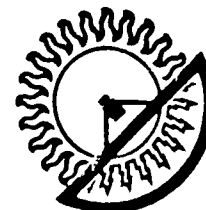
CONVENTIONAL
NEW POWER PLANTS
—— 8 MW OIL
(SMALL COMMUNITIES)
----- 1000 MW COAL
(UTILITIES)

- REGION
1. Catalina Island
 2. Pacific
 3. Texas & New England
 4. E&W North Central
 5. S. Atlantic
 6. W. North Central



Ford Aerospace &
Communications Corporation
Aeronutronic Division

SYSTEM COST CAVEATS

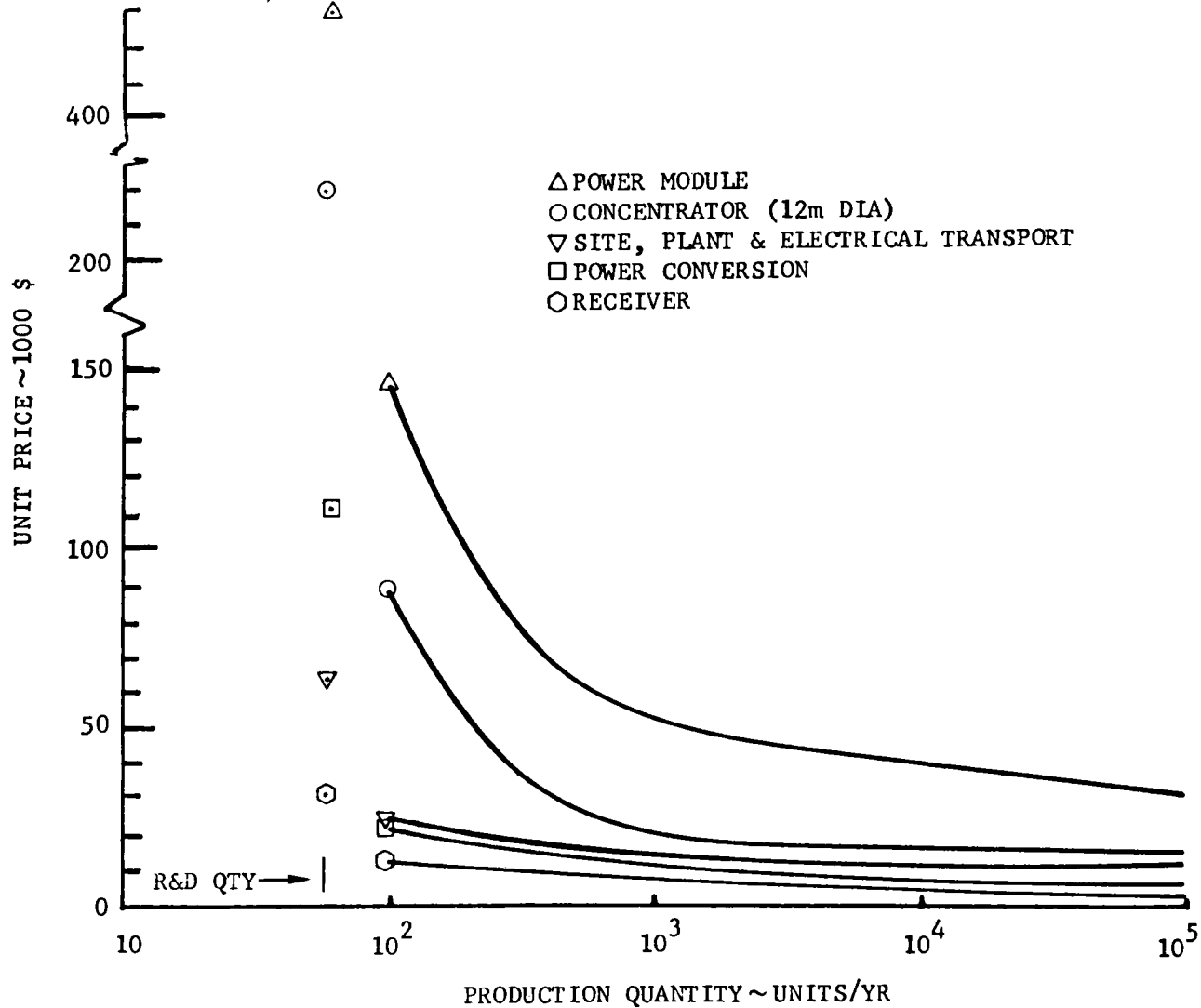
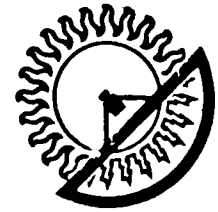


- CONCENTRATOR COSTS f (REFLECTIVITY, SLOPE ERROR, AND CONCENTRATION RATIO)
- HIGH TEMPERATURE ENGINE PERFORMANCE REQUIRES
 - HIGH CONCENTRATION RATIO
 - LOW SLOPE ERROR
 - HIGH REFLECTANCE
- SUN ACQUISITION, TRACK, DE-TRACK INFLUENCE
 - APERTURE FACE PLATE DESIGN
 - POWER CONVERSION STRUCTURAL INTEGRITY
 - SYSTEM SURVIVABILITY
- LOW LIFE CYCLE COSTS REQUIRE
 - FAULT TOLERANT SYSTEM DESIGN
 - UN-MANNED, COMPUTER-CONTROLLED SYSTEM OPERATION



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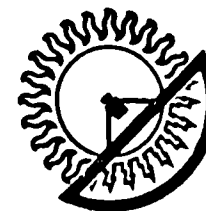
TYPICAL POWER MODULE COSTS





**Ford Aerospace &
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Aeronutronic Division**

POWER MODULE SCHEDULE



114

FY		'81	82	83	84	85	86	87	88	89	90	91	92	93	'94	
●1 MW EE-1		1		55												
●100 KW EE-2A					6											
●20 KW EE-3		2														
●STIRLING PON			1													
TOTALS		3	1	55	6											
● PRODUCTION PROTOTYPES								1st GEN. SYS.								
								600/YEAR		2nd GEN. SYS.						
										2,000/YEAR						
● PRODUCTION DECISION : FIRST GENERATION SECOND GENERATION								◇								
											◇					



**Ford Aerospace &
Communications Corporation
Aeronutronic Division**

MAJOR PROBLEMS INHIBITING
COMMERCIALIZATION



- INSUFFICIENT FUNDING AND IDENTIFIED PROGRAMS TO BRIDGE BETWEEN DEVELOPMENT AND PRODUCTION
- PFDR IDENTITY CRISIS RELATIVE TO MARKETS, AND RE-POWERING, RELATIONSHIP TO CENTRAL RECEIVER-CENTRAL GENERATION SYSTEMS AND TROUGHS
- WHAT IS THE LIKELY OUTCOME OF A COMPETITION FOR FUNDS BETWEEN THE THREE SOLAR TECHNOLOGIES?
- NEED TO DELINEATE THE APPROPRIATE MARKET AND OBTAIN CONGRESSIONAL COMMITMENT
- ECONOMIC NECESSITY TO DEVELOP IMPROVED CONCENTRATORS WITH INSTALLED COSTS BELOW \$100/M².

SANDERS ASSOCIATES

Daniel Shine

My emphasis will be on the philosophical issues. These issues have been alluded to in the preceding program or company discussions.

The first point I will mention is a theme recurrent in Paul, Worth, Walt and Cal's presentations: Program Continuity.

Whether you are in industry or you are with a national lab or in government, you must understand what Program Continuity is. It can mean different things, depending what your perspective is. We in industry will never reach that 1 quad by the year 2000 unless there is some Program Continuity. We cannot put together teams and keep them together without adequate funding. The point has been made over and over and over again that the programs are funded at woefully inadequate levels. We should take it upon ourselves to do something about that. It means educating the public, educating Congress, educating anyone who will listen. Those of us present in the room here represent everything from small businesses to Fortune 50 or perhaps Fortune 10 companies, and we have done a lousy job. With the size of the current program, we will not reach the 1 quad goal by the year 2050, if ever. We keep preaching as individuals and as companies to the government, to DOE and the labs about Program Continuity. There is nothing they can do about it if they themselves do not have the resources to pass through to industry for continuation of the development programs.

What I would like to do is lay down challenge number one: to take it upon ourselves to do something about this budget problem over the next several months. The budget cycle for 1982 has begun; hearings are being held on the Hill. It is up to us through our companies, through our labs, through whatever, to get the message across that we are not going anywhere at the rate we are going now. Most people in the public sector, most people on the Hill, do not understand what this program is. Solar to most means either a green house, heating water, or Barstow. That is all it means, and it is our fault. If we are really as interested as we indicate, and we are all interested since we are here, then we better do something about it. Maybe we will not be here next year or the year after--again it is our fault.

The second point I would like to make is that once we establish an adequate funding level there will have to be more demonstration projects. We all have our idea what the adequate funding level might be, and it is certainly inadequate now. Perhaps they do not all have to be at the megawatt level but there certainly must be more. That is all part of the education process. The more demonstration programs, the more publicity. As we have heard from speakers all day, and we will hear from them tomorrow, all of the technology and component development programs have been relative successes to this point. We need some system successes. That will generate more interest, more publicity, and hopefully, more funds. Maybe we will reach our 1 quad goal.

The third point I would like to make addresses the DOE JPL program. It is a point that several of us have made and it can be discussed forever. Simply put, it is the position of most of us in industry that there has been too much stress on technological advancement and coming up with the perfect

components: perfect component number 1 to be wedded to perfect component number 2, to be wedded to perfect component number 3, the sum to equal a perfect system. That is not how you get successful demonstration programs or additional funding. Who cares if it is 20 or 21 percent efficient? Nobody cares. Congress does not care. Certainly, as engineers and technologists, we do care. I am not disparaging that at all. What I am saying is that the stress in the program has been put in the wrong place.

Program stress must be on success, not on an additional percentage point of efficiency. This stress of efficiency, or additional points of efficiency, has presented industry with somewhat of a dichotomy. The programs often seem to be technologically ambitious, yet stretched out. We are looking for an additional percentage point, two percentage points, or three in a mirror program for instance. It turns out that the way the funding has been going, again our fault, over the recent years it will take 10 years to get there. By that time, everybody else will have passed us by and maybe we will be back to gas lamps or oil lamps. In any case, we have a problem.

Yogi is going to address one approach to resolving the problem. An organization now exists which requires the membership of all companies represented in the room. It is the Solar Thermal Energy Division of the Solar Energy Industries Association. Another approach might be looking at our own problem and getting better dialogue going with Washington and with the Labs responsible for our programs. We are not getting our message across; we fight one another. We do not understand what it is that we want. There has to be a better dialogue if this program is going to survive. We have seen from the General Electric presentation and the other presentations where solar thermal could go, what the costs could be, but my basic point is that we are never going to get there. We are never going to get there at the rate we are going now. Remember one thing from this panel presentation: You have to get out there and do your job on the Hill. We have not done it. Every one of our companies has other programs that take priority; we are all in some other business, if we are of any considerable size, with some small companies excepted. We have to integrate the solar program, particularly the dish program, into those overall priorities and see if we can get somewhere. At the rate we are going we are going nowhere. We will have some wonderful demonstrations in the desert and they will have very high efficiencies but it is not going anywhere. Who is going to buy them? This whole program is geared to developing products which can be sold in the commercial market place and displace oil. At the rate we are going we will not displace oil until all of the oil is gone.

It is our problem; it is up to us to do something about it.

ACUREX CORPORATION

Jorgen Vindum

A couple of subjects we will be discussing are the annual operating program for the dish program at DOE, some legislative action and anything else members would like to bring up.

I would like to talk briefly about the proper timing and mixture of dish technology. I think it is important to mention both timing and mixture since, as far as dish technology is concerned, this is not a normal evolution we are going through. We heard earlier about air conditioners. I will bring up additional examples of applications that have evolved. The market made them evolve at a particular pace; technology was not available to make them evolve any faster. We have the capability, I believe, to make the solar technology evolve too fast causing a serious problem. The mixture of the sizes, etc., of the programs could be wrong and that is what I would like to discuss.

The agenda is shown here (V-1). I want to talk about the requirements for proper technology evolution, the importance of timing, why I believe the dish program will be successful, and a few conclusions that have been reached.

Regarding the requirements of proper technology evolution (V-2) I will draw upon the experience Acurex has had in the trough business. We have gone through several generations and, as mentioned earlier, these generations are very critical. You sometimes learn the hard way from small projects, but at least you incorporate your knowledge into the next job and into the third or fourth generations. You continue to make improvements, and in this way you evolve. This is the way you get the performance up and get the hardware introduced until there is a real commercial market.

Secondly, I would like to draw on an experience in the aircraft industry. Again, they have all slowed by the pace of the commercial market. In some instances, they made some mistakes and I will discuss those. As far as the requirements, and system size, I think it is critical that we start out small and grow larger. Again, as I mentioned, the technology allows us to build a very large initial system. Should that particular program fail, solar would be in deep trouble. We must start with a single dish, two dishes, four, etc. I think that is a critical element to success.

System simplicity - again, make the first one simple and then get more complicated as we learn. Solar is generally very simple, but when you get hardware out there you learn that Murphy is still around and you still have problems. For that reason, start with the simplest and go to the more complex.

Improved generations, again looking at the airline industry, started with some very simple systems: The first Wright Brothers flight, the DC3. Many were built and a good deal was learned; the metal aircraft industry started, and we progressed to the DC8, DC9 and DC10 in a very orderly progression. If you had tried to build a 747 back in 1940, such as the Spruce Goose that is now located down in Long Beach, I think you would have gotten into serious trouble. We had the technology, but it was too premature an introduction of that sized aircraft.

The importance of timing (V-3). Competition: There are several competitive factors to consider right now. The first one is that of DOE or federal funding. We are competing with other solar technologies and we should recognize that. Those of us in solar thermal are unfortunate to be competing in three different solar thermal technologies. For that reason, it is important that we get dish technology out there where it can be seen, so that we can get our fair share. I do not think that dish technology is getting a third of the solar thermal budgets and I do not think that it is getting its fair share of the solar budget in general.

The second competition that we have to look at downstream is survival. Sooner or later, we will have to be in the commercial competitive market. However, if we do not get systems out there that the commercial customer can look at, he is not going to buy it. He wants to see some, and he wants to go kick some before he will buy the first one, and without the first one we will not have one quad or whatever by 2000.

Visibility: The number of installations and the size. I think it is very important to get many, many small systems across the country. Industrial and commercial clients have no idea what is going on. They do not go to Edwards to see them, they need to see them locally. There are trough systems around this country and yet when you talk to an industrial client they have never seen one. We must make sure that there is one in every state, and if we want congressional support for this program I think it is important that we put them around the country.

These first installed systems could be failures. If they are small, it is easy to replace them or improve them. Large failures are very visible. We need small systems that are all successful and lots of them.

Finally, we need to replicate systems with improvements from generation to generation. I think that the PV program within DOE has been very successful. They keep repeating the same thing, keep combing down the cost curve, and they have been very successful in getting funding for the PV program by replicating and showing cost improvements. If we develop just one of a kind forever we will never be able to show any cost curve and we will not get the support we so desperately need.

Finally, I will discuss why I think this technology will be successful and what characteristics it has (V-4) that will make a success of the program. Modularity: You can put out a single dish and make a complete system. It can be integrated to the grid. It could be a thermal system, it could be an electric system, but the modularity of point focus technology is very, very important if we wish to be successful. Again, when commercial customers come along, they can buy one - not umpteen megawatts. They can just buy one, two, three, etc., and we can get the commercial market going. Without those few buys (again an analogy of the movie theater) we will not get the commercial market going.

Repeatability and coming down the learning curve are very important. If you duplicate more of the same, we will come down to the magic cost number that is being thrown around now. We will never get there unless we start building one. You build one and two, four, eight, repeat it eight times, build about

500 systems, that's 10 megawatts. I think we would be a lot further down the learning curve if we did it that way rather than build one large 10-megawatt system.

Again, early market compatibility. The remote markets that exist for point focus technology right now require one, two, three dishes. Therefore, we are very compatible with those people who are likely to buy the first one.

In conclusion (V-5), let me point out that I believe dish technology should be accelerated relative to other solar technologies. We have great potential, we must spread that word and get it out in the field.

AGENDA

- REQUIREMENTS FOR PROPER TECHNOLOGY EVOLUTION
- IMPORTANCE OF TIMING
- WHY DISH TECHNOLOGY WILL BE SUCCESSFUL
- CONCLUSIONS

REQUIREMENTS FOR PROPER TECHNOLOGY EVOLUTION

- APPLICABLE EXPERIENCE FROM OTHER TECHNOLOGIES
 - PARABOLIC TROUGH
 - AIRCRAFT INDUSTRY

- REQUIREMENTS
 - SYSTEM SIZE
 - SYSTEM SIMPLICITY
 - IMPROVED GENERATIONS
 - AVOID PREMATURE TECHNOLOGY INTRODUCTION

IMPORTANCE OF TIMING

- COMPETITION
 - DOE/FEDERAL FUNDING
 - COMMERCIAL MARKET

- VISIBILITY
 - NUMBER OF INSTALLATIONS/SIZE
 - SUCCESS/FAILURES
 - REPLICATION WITH IMPROVEMENTS

WHY DISH TECHNOLOGY WILL BE SUCCESSFUL

- ADVANTAGES

- MODULARITY
- THERMAL AND ELECTRIC APPLICATIONS
- REPEATABILITY
- LEARNING CURVE COST REDUCTIONS
- EARLY MARKET COMPATIBILITY

CONCLUSIONS

- DISH TECHNOLOGY SHOULD BE ACCELERATED RELATIVE TO OTHER SOLAR TECHNOLOGIES
- SMALL SYSTEMS SHOULD BE INSTALLED FOR "COMMERCIAL" VISIBILITY
- ACCELERATED DEVELOPMENT OF DISH TECHNOLOGY WILL SUPPORT OTHER SOLAR TECHNOLOGIES

ADVANCO CORPORATION

Byron Washom

The present state of the art of the parabolic dish technology and the forthcoming changing of Administration makes this panel discussion on technology development most opportune. As all of us in the room are acutely aware, our business success is dually a function of our engineering achievements and the public policy support to enact our engineering progress. As witnessed this afternoon, the spokesmen for Garrett, United Stirling, General Electric, Ford Aerospace, Sanders, and Acurex have stated that the public policy is lacking, particularly in the form of direct appropriations for construction, and the consequence of such failing is retarding the commercialization of solar thermal technologies.

I have been asked by Dr. Lucas to provide a summary of the views presented thus far and address those pertinent areas possibly unmentioned. Additionally, I would like to speak to the subject of these technology development issues in context with the new Reagan Administration. My conclusions are those that I have drawn on my own, but with the assistance of colleagues about to assume various energy posts within the Reagan Administration.

As to the technical issues, it would be wise to segregate the issues into five areas: engines, receivers, concentrators, system integration, and component development.

If one agrees that the technical issues presented by this panel are in fact valid, then the future does not bode well for those anxious to see an early commercialization of parabolic dish technology. This present state of affairs, coupled with a decisive fiscal policy of the forthcoming Reagan Administration, will probably alter the course of the solar thermal technology development program, and this deviation is inexplicitly opposite to the present DOE program.

The present DOE program can be characterized as encouraging short term research and development of the energy technology and permitting the favorable effects of tax incentives and mass production to reach economic competitiveness.

When budget cuts have occurred in the solar thermal program, the Carter Administration has tended to preserve the policy of placing hardware in the field at the direct expense of the Research and Advance Development budget. The following table shows the forecasted Advance Technology Resource Requirements versus the budget allocations (in \$ millions):

	FY'79	FY'80	FY'81	FY'82	FY'83	FY'84
Forecast	13.5	22.0	34.0	38.0	42.0	42.0
Actual	13.5	22.0	11.0	N/A	-	-

The disparity is compounded when one considers that DOE and the government labs in a recent solar thermal multi-year plan identified Research and Development needs amounting to \$57 million starting in FY'82.¹ The present DOE policy has favored the central receiver technology the most, followed by line focus projects and lastly the parabolic dish market, but at least we have fared better than the research and advanced development program, albeit that the dish program is contained partially within it.

This rank order of priorities, I predict, will be reversed under the Reagan Administration, whereby research and advanced development will take a precedence in the solar thermal budget. Those technologies, especially the parabolic dish that will benefit the most from such R&D, will be placed in stronger competitive position. The basis for such a claim can be found in the existing information and policies of the Reagan team.

Foremost are the policies of David Stockman, Director-designee of the Office of Management and Budget, often referred to as the fourth branch of government. For those of you that have not read either his article in The Public Interest entitled "The Wrong War? The Case Against a National Energy Policy"² or the "Stockman Manifesto" in the Washington Post,³ I would encourage you to do so and draw your own conclusion. The Public Interest article reveals Stockman's belief (which is shared by President-elect Reagan and his energy advisor Harold Halbouty) that decontrol of oil and natural gas prices will simultaneously increase domestic production of oil, natural gas and coal, promote conservation via higher energy costs, and reduce oil imports.

Stockman stated that,⁴

In short, the force-feeding of new energy supplies into the economy (by such means as coal conversion, synthetic fuels, and solar technology), or the artificial withdrawal of energy from the economy (mandatory efficiency standards) at costs-equivalent above the world price are exceedingly bad economic bargains. Any attempt to displace the 3 to 5 billion barrels per year in imported liquid and gaseous fuels that will likely be required late in the next decade would impose a cost-penalty on the economy in the range of \$40 to \$70 billion per year. The result would be a substantial, unnecessary loss in national output, and an artificially high domestic-energy-cost structure which would reduce the competitiveness of our exports and increase the cost-advantage of imports. We obviously cannot improve our balance of payments or any other aspect of economic performance

1 Solar Thermal Program, Multiyear Plan, p. 92, August 28, 1979, draft.

2 Stockman, David A., "The Wrong War? The Case Against a National Energy Policy," The Public Interest, Number 53, 1978.

3 Stockman, David A., "The Stockman Manifesto," Washington Post, December 14, 1980.

4 Op cit., at 2.

by resorting to home grown, hothouse bananas. The same is true for energy. If autarky is a defensible policy it must have some other, non-economic justification.

This laissez-faire, free market approach suggests that new energy supplies must compete against these baseline technologies without the benefits of tax incentives, loan guarantees and grants, regardless of oil, coal and nuclear's historic subsidization by the Federal government of \$134 billion.⁵

The Washington Post article directly impacts the present commercialization strategy of the solar thermal industry, particularly the central receiver sector. Under Stockman's Fiscal Stabilization Component, he suggests that (1) public sector capital investments that accrue its benefits over 20-40 years be deferred, (2) low priority program cutbacks like DOE's commercialization program be applied, and (3) loan guarantees (on-budget and off-budget) be curtailed to relieve the borrowing pressure on the credit market. Such a fiscal stabilization program, if implemented, would significantly deflate any industrial strategy to establish a sufficient market to warrant mass production facilities.

I further believe that the Reagan Administration will be supportive of R&D, particularly in high efficiency engines like the Brayton and Stirling, unique high temperature materials and improved reflective surfaces. One confidant, who is to be named next week to a high post in the White House, informed me last week that they are painfully aware of the present reduction of \$154 million to \$90 million proposed FY'82 budget from that of the final days of the Carter Administration. His advice to me in the preparation of this paper was that a balance will be found to provide for a rational and timely introduction of solar thermal technologies. Furthermore, it will be incumbent upon private industry to assume more financial risks at all stages of development and be more selective as to the initial markets being pursued, i.e., markets that require the least subsidy to implement. His personal awareness of papers by Gregg, et al,^{6,7} on solar coal gasification, MX-RES program and solar enhanced oil recovery, illustrates that industry will be forced to think synergistically.

During this forecasted iterative period of RD&D, efforts will be underway to improve the institutional and financial environment for solar thermal technologies. Most notably will be the efforts of the Solar Energy Industry Association to achieve incentives that will:

- (1) Provide capital formation from sources other than direct appropriations for pre-commercial projects.

⁵ Cone, Bruce W., "An Analysis of Federal Incentives Used to Stimulate Energy Production," Battelle Northwest, May 1977.

⁶ Gregg, D.W., et al, "Solar Coal Gasification," Solar Energy, Vol. 24, pp. 313-321, 1980.

⁷ Gregg, D.W., et al, "Solar Retorting of Oil Shale," 88th AICHE Meeting, June 1980.

- (2) Prorate R&D financing to accelerate the R&D conducted in private industry without direct Federal funding.
- (3) Provide favorable depreciation schedules.
- (4) Provide more favorable investment tax credits.
- (5) Enact enabling legislation for repowering, solar thermal electric and industrial process heat.

In conclusion, I feel we will need to take to heart these technology development issues mentioned by the panel today, resolve them and work strenuously in Congress and the Administration for a solar thermal budget that will continue the research and development necessary and demonstrate the technology in sufficient magnitude at each significant step along the way.

Session III

**CONCENTRATORS AND
COLLECTOR SYSTEMS**

Session Chairman: W. Carley, JPL

INTRODUCTION

W. Carley, JPL

Concentrator and collector development activities managed for DOE by JPL are directed toward developing Point-Focusing Concentrator Technology with a major emphasis on low cost in large quantity production.

The work started in September 1978 with the contract to E-Systems for the modifications of a microwave antenna to meet the requirements of a versatile Test Bed Concentrator. Installation of two TBCs at the Parabolic Dish Test Site was completed in October 1979. The reflectors on these concentrators are rectangular facets of Corning 0317 glass mirrors bonded to spherically-contoured Foamglas^R, a technique developed by JPL.

Since that time, several contracts have been awarded for the development of integration of point-focus concentrators with receivers operating in the 1,000-1,500°F range. A few private companies have developed point-focus concentrators, generally for modules operating at somewhat lower temperatures. The following papers describe the concentrator development progress being made by companies contractually supporting the JPL Thermal Power Systems Project. The concentrators discussed come in many sizes and configurations. However, the prime goal for all must be to maximize the net useful thermal energy per dollar of concentrator cost for a given operating temperature. A high performance design that is expensive to build and install will lose out to one with lesser performance, but which is less expensive to build and install.

CHARACTERIZATION OF POINT FOCUSING
TEST BED CONCENTRATORS
AT JPL*

D. J. Starkey, Jet Propulsion Laboratory**

ABSTRACT

This paper briefly describes the Solar Test Bed Concentrators that E-Systems installed at Edwards Air Force Base near Lancaster, California, for JPL. It describes the characterization work that has been accomplished on the test units thus far and provides the test results. The characterization data has been measured using both a flux mapper and a cold water calorimeter. The flux mapper uses a Kendall Radiometer as the sensing device. It is mounted on an x, y, z motor-driven positioning mechanism that allows the sensor to take an x-y flux raster at several Z planes in the vicinity of the concentrators nominal focal plane. Various concepts were tried to protect the concentrator structure from being damaged by the sun's energy during sun acquisition and deacquisition. A description of both the passive and active protective systems is presented.

INTRODUCTION

Point Focusing Concentrator evaluation is evolving as part of the Solar Thermal Power Systems (TPS) Project assigned to the Jet Propulsion Laboratory (JPL). The objective of the Concentrator Development Task is to develop, via contracts with industry, technology and designs that will result in concentrators which are characterized by high kWth per dollar of cost for solar energy into a cavity receiver.

PURPOSE

The Test Bed Concentrators (TBCs) were developed as an early tool for use in the solar energy development program to provide a precise, consistent, and highly reliable source of thermal solar energy for testing a variety of receiver and/or power conversion subsystems. The TBC test data to date has substantiated that the TBCs have fulfilled their design purpose by providing flux densities well in excess of those required for nominal testing sequences. In fact, the peak fluxes measured with the initial mirror alignment have been purposely reduced by defocusing a part of the central mirror facets. This was done in order to minimize thermal damage to the TBC receiver mounting structure and the receiver components. The defocusing did not significantly reduce the overall available energy even though the peak flux is down almost threefold.

CONFIGURATION

Two papers describing the TBCs were presented at the first Annual Review meeting. In way of a brief review, E-Systems has installed two TBCs at the

* The development described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology, and was sponsored by the U.S. Department of Energy through an agreement with NASA.

** Test Bed Concentrator Technical Manager, Solar TPS Project, Energy Technology Engineering Section, Applied Mechanics Division.

Parabolic Dish Test Site (PDTS) located at Edwards Air Force Base near Lancaster, California. These TBC dishes have a plan form diameter of nominally 11 meters, are parabolic in shape with a reflector having 224 JPL-developed, rectangular shaped, second surface, back silvered, long radius, spherical contoured mirrors. Each mirror facet is individually aligned. The concentrators are of the Elevation over Azimuth tracking type with an azimuth wheel and track design and a jack screw elevation design. The sun sensor/control loop keeps the concentrators pointed to within 0.05° of the sun's true position.

CHARACTERIZATION

The characterization process for the TBCs was conducted in discrete steps to minimize any thermal damage from the sun's image and to provide the test team with low level solar operational experience. These steps consisted of uncovering the concentrator mirrors in five discrete groups. The process was additive in that the previously tested group of mirrors was not re-covered when the next group was uncovered. A complete set of flux mapping data was recorded using a Kendall Radiometer for each step in the mirror uncovering process. A set of data included a minimum of three rasters. Each raster consisted of 1056 discrete data points. For several of the mirror configurations, rasters were taken one inch in front of and behind the nominal focal plane and then every two inches along the Z direction thereafter (concentrator axis). Each raster took approximately 45 minutes to complete if everything performed smoothly and when this time is added to the TBCs' sun acquisition and normal operational sequence time, one complete raster consumed at least one and a half hours. An overall view of the TBCs with the flux mapper installed on the right hand unit is shown in Picture 1. A close-up of the flux mapper from the outer end is shown in Picture 2 and from the inner end is shown in Picture 3.

INSULATION

To preclude damaging the receiver mounting structure of the TBCs, during sun acquisition and deacquisition, this area was covered with an insulating material. An aluminum oxide material, Fiberfrax^R Hot Board, was chosen initially. This material has a melting point of 1260°C (2300°F). This material worked well on the inside of the receiver ring but deteriorated very rapidly on the front face of the ring where it was normal to the sun's image. As more and more mirrors were uncovered, the ablation rate of the Fiberfrax^R went up rapidly. The Fiberfrax^R was supplemented in the high heat area with a pure Zirconia held together with a Yttria binder. This material was far more expensive (by an order of magnitude) but has a greater melting temperature of 2593°C (4700°F). The ablation rate of this material was much less, however, with the full 224 mirrors the rate was still a problem because the molten material was dropping on the concentrator mirrors and causing damage. An active water-cooled plate was installed in the area where the sun spot traverses the receiver ring structure. The plate was made of 1/4 inch aluminum with a single pass water flow at a flow rate of 11 to 15 gals/minute. This plate, in conjunction with the Fiberfrax^R used in the less critical heat areas, solved the thermal protection problems in the TBCs.

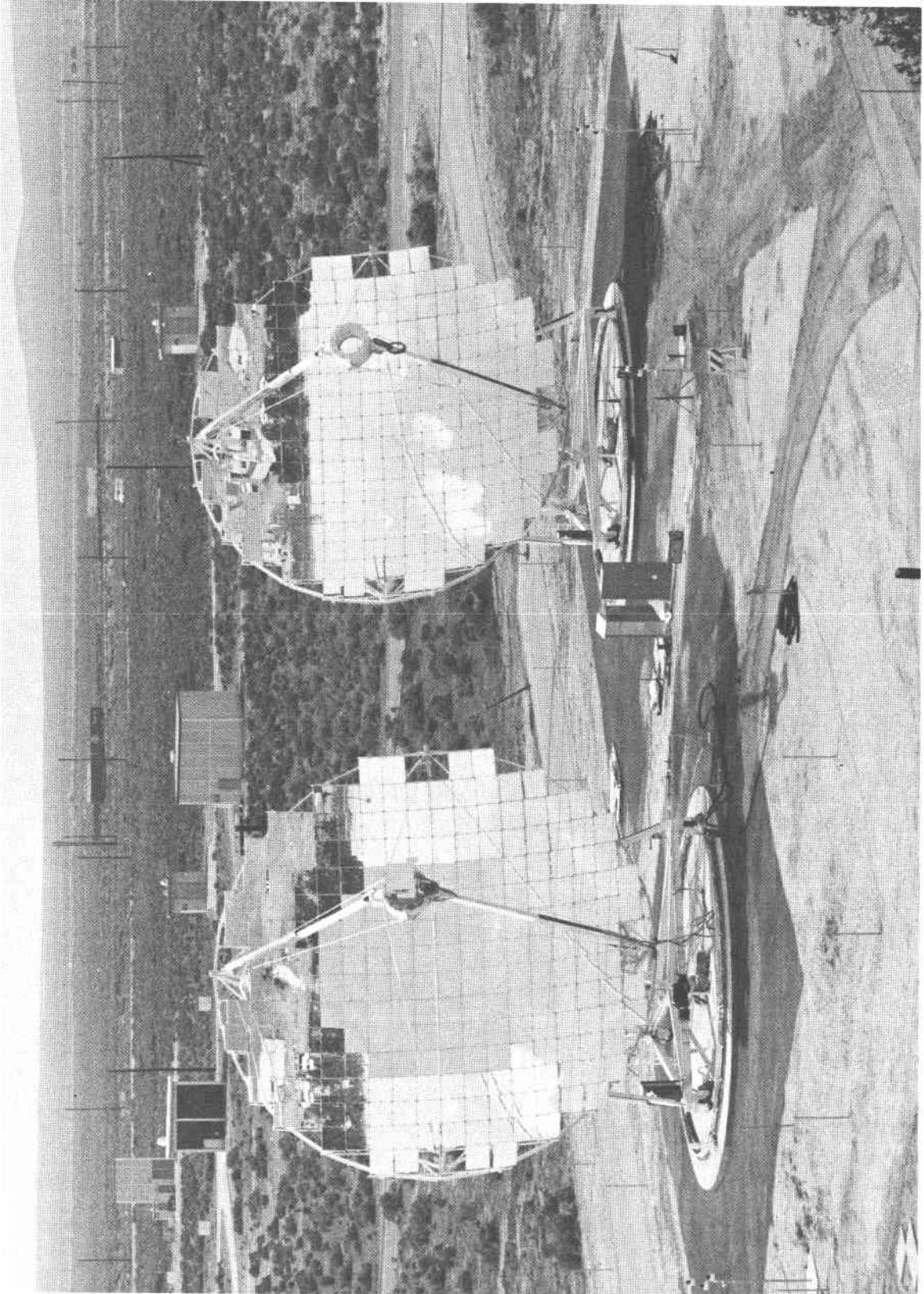
RESULTS

The initial flux mapping results indicated that the TBCs, with the initial mirror alignment, where all the mirror facets were focused on the center of the target at the nominal focal plane, produced a peak flux of 1500 watts per

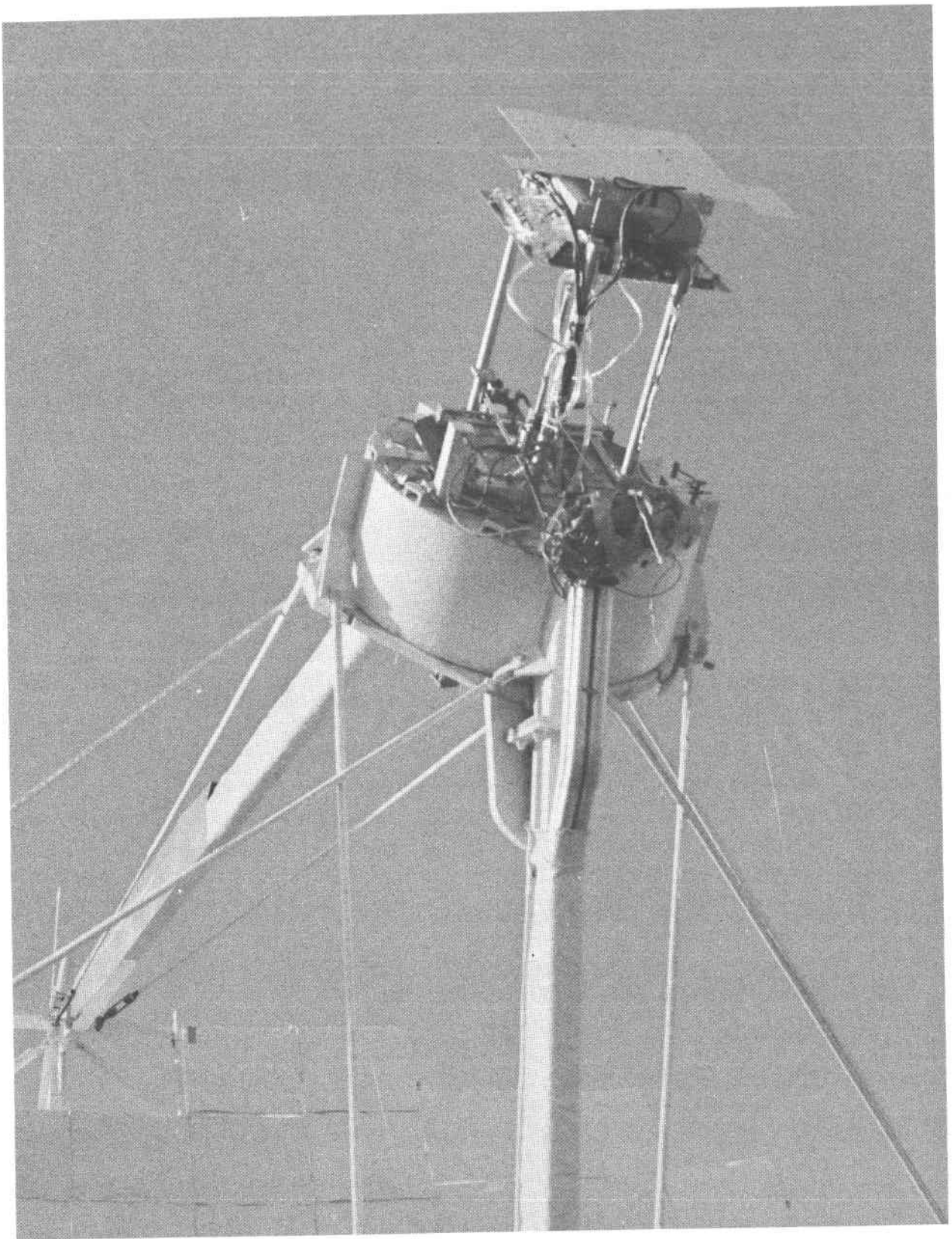
square centimeter when the insolation was normalized to 1000 watts per square meter (see Figure 1). Flux densities of this magnitude produce almost instantaneous temperatures in excess of 2760°C (5000°F) which would severely damage most passive receiver aperture materials. It should be noted from the figure that 98% of the energy is within a 20.3 cm (8 inch) diameter aperture. Flux mapper results also indicated that the majority of the peak flux was being produced by the center mirror section which totaled 68 facets. In addition to being nearly on axis, these 68 mirror facets had focal lengths very close to their geometric nominal requirement. It was concluded that by readjusting these center mirror facets, the peak flux could be reduced, thereby reducing the possible thermal damage to the TBC structure and the receiver cavities. During the second mirror alignment, all the images from the center 68 mirrors were centered on a fifty-one (51) millimeter (2 in.) diameter circle on the target at the nominal focal plane. This produced a slightly reduced peak flux of approximately 1250 watts per square centimeter (see Figure 1). This was still too high for our initial testing requirements so a third mirror alignment was undertaken. The center mirrors were realigned so that their image was geometrically on the opposite side of the target as compared to their physical location on the dish. Their images were centered on a one hundred two (102) millimeter (4 in.) circle but across the center of the target. This alignment change drastically reduced the peak flux down to the 550 watts per square centimeter range but kept the total energy through the 20.3 cm (8 inch) aperture essentially constant (see Figure 1).

After the third mirror alignment, the flux mapper was operated at several "Z" locations. The data from this test sequence indicated that the actual focal plane is closer to the dish surface than the nominal or geometric focal plane (see Figure 2). This difference is primarily attributable to using a finite-distant light source to align the mirror facets. It is also obvious that with the cross defocused mirrors, the sun's beam is highly converging diverging. Currently the technique for determining the flux on a receiver wall is to extrapolate the x-y plane data from several "Z" positions of the flux mapper, plotting constant flux lines, and estimating where they will intersect a receiver. The development of a direct flux receiver wall measurement device is being evaluated.

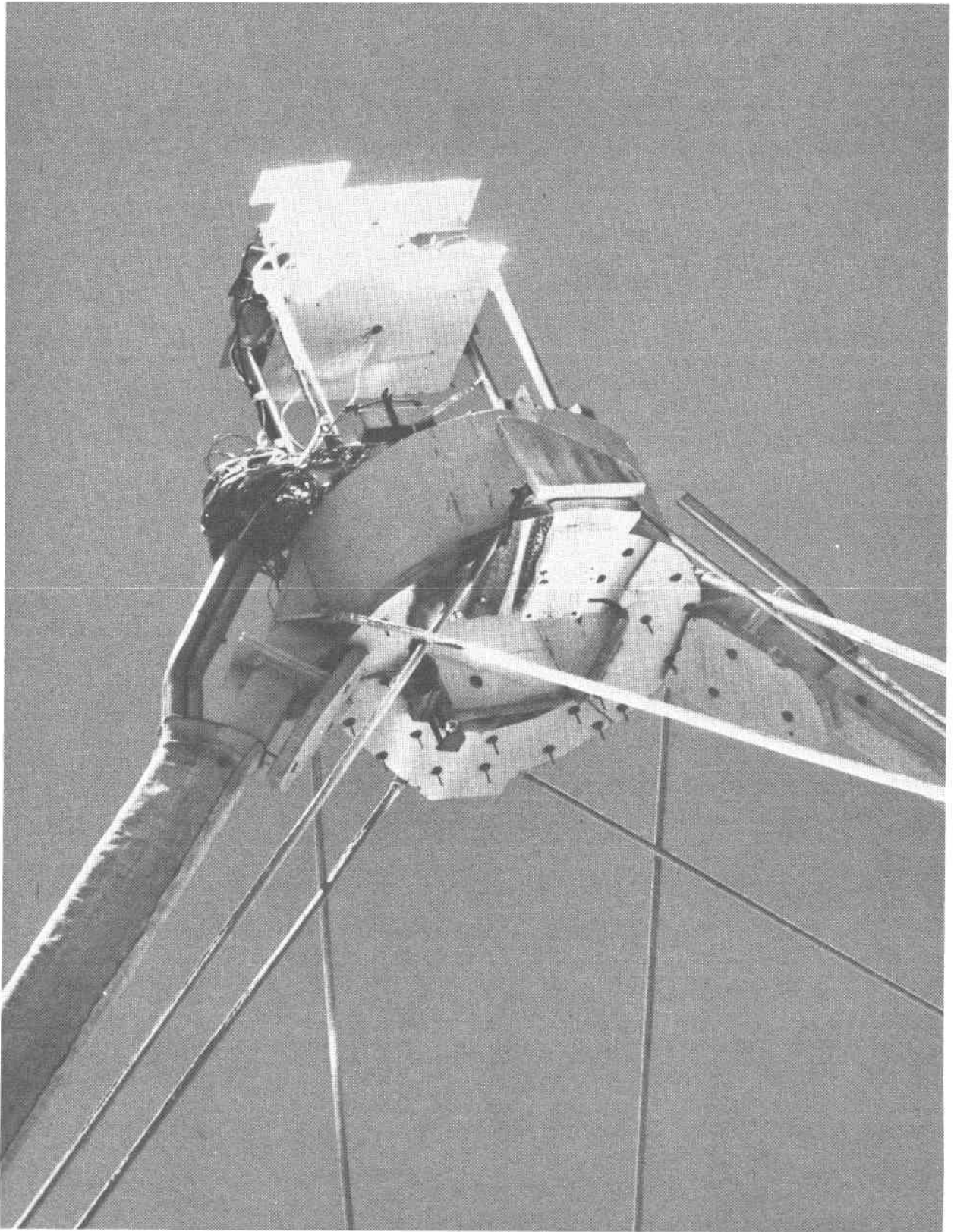
The initial calorimeter results to date have established that each concentrator will produce a maximum of 82 kWth with 1000 watts per square meter of insolation through a 56 cm (22 inch) and a 25.4 cm (10 inch) diameter aperture, Picture 4 shows the calorimeter installed on the TBC. The energy measurement data from the calorimeter will be measured as a function of the various aperture sizes in future tests. The apertures will range from the totally open sunlit end down to a 15.2 cm (6 in.) diameter hole.



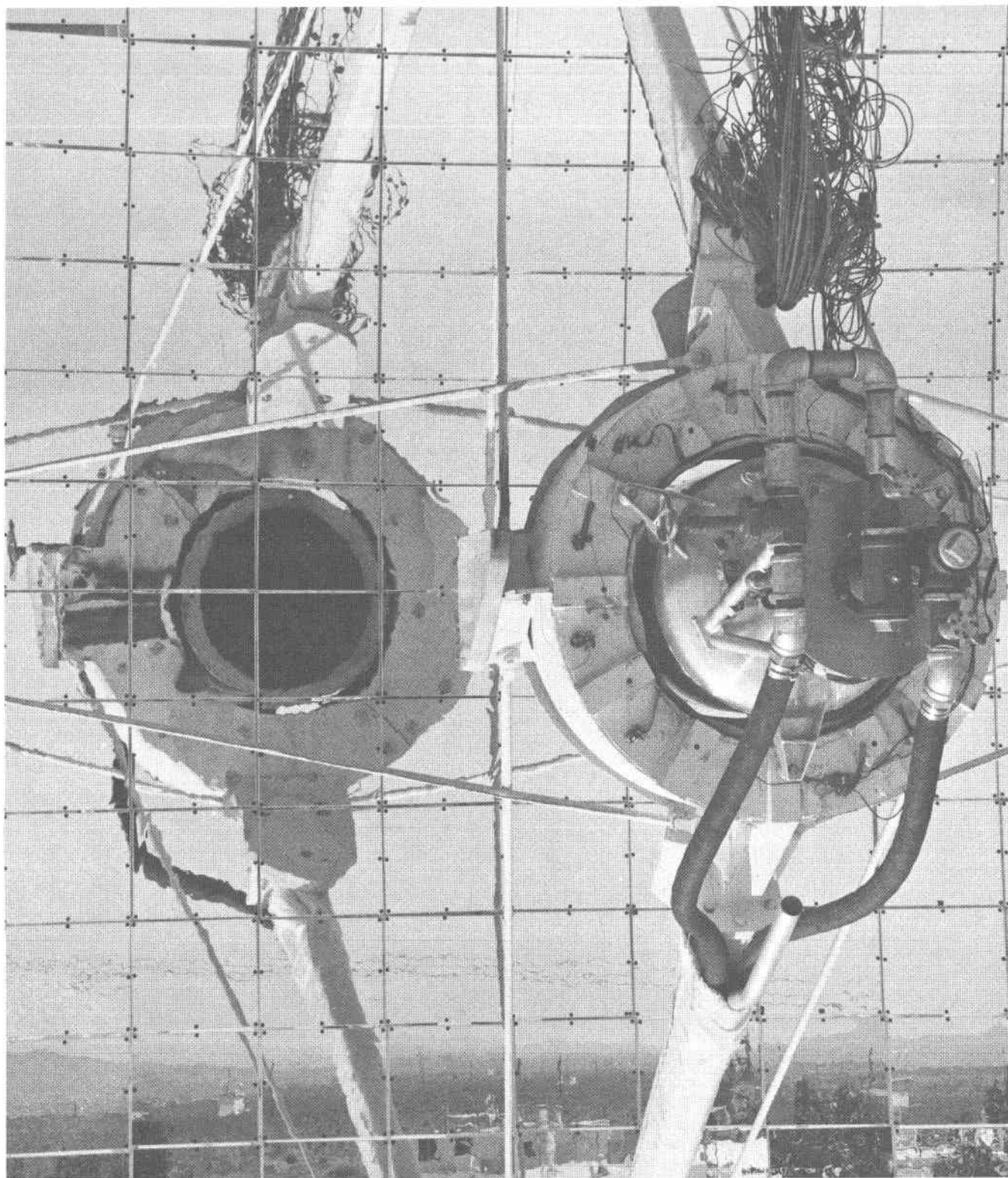
Picture 1: TBCs WITH FLUX MAPPER INSTALLED ON RIGHT-HAND UNIT



Picture 2: CLOSE-UP OF FLUX MAPPER FROM OUTER END



Picture 3: CLOSE-UP OF FLUX MAPPER FROM INNER END



Picture 4: COLD-WATER CALORIMETER INSTALLED ON TBC

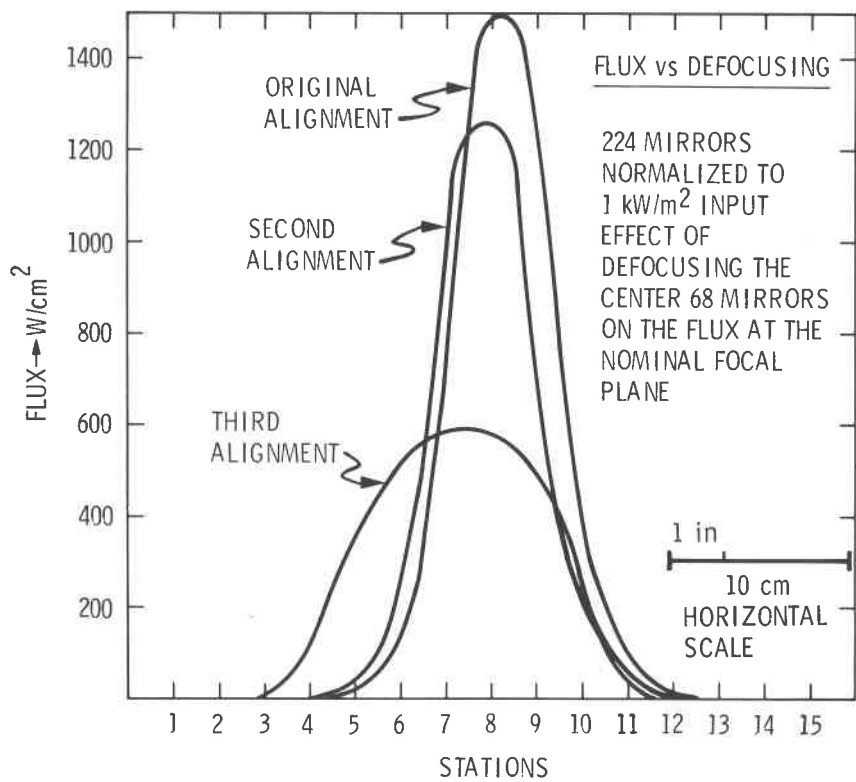


Figure 1. Solar Flux Measurements On Test Bed Concentrators

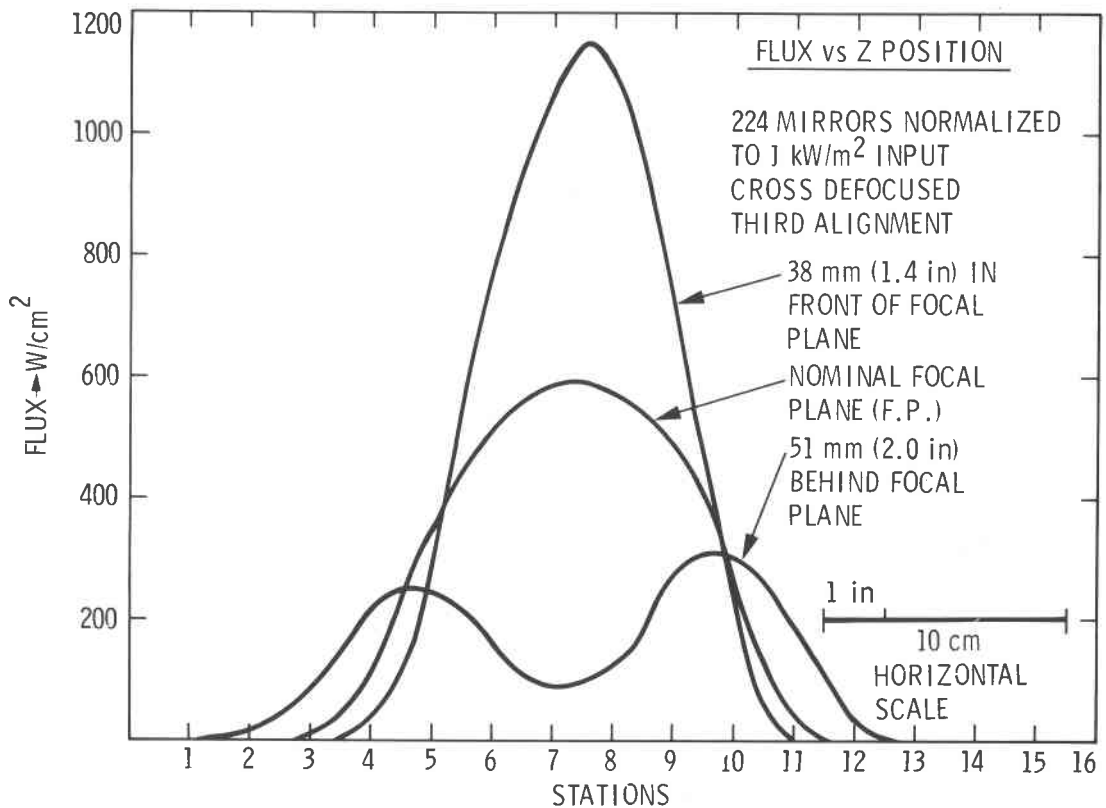


Figure 2. Solar Flux Measurements On Test Bed Concentrators

GENERAL ELECTRIC POINT FOCUS SOLAR CONCENTRATOR STATUS

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ABSTRACT

The General Electric Company is currently under contract to the Jet Propulsion Laboratory to design, fabricate, install and test a point focus solar concentrator that, given a high volume of production, will optimize the ratio of performance to cost. The concentrator design approach has evolved by a systematic process of examining the operating requirements particular to the solar application, minimizing material content through detail structural design and structurally efficient subsystem features, and utilizing materials and processes compatible with high volume production techniques. This paper briefly describes the design approach, the present concentrator configuration and the status of the hardware development.

INTRODUCTION

The General Electric Company is currently under contract to the Jet Propulsion Laboratory to design, fabricate and test a prototype 12-meter diameter point focus solar concentrator. A feature of the analysis and design phase of the program has been to include a value engineering iteration which has examined the cost and function of the concentrator subsystems and their components relative to the design requirements and the operating environment. Such an iteration was conducted early in the preliminary design phase; however, several important factors necessitated another iteration after completion of the detail design. Early performance and operating environmental requirements were established based on sensitivity studies which incorporated simplified models for both the optical performance of the design and the weight and cost of the subsystems. As the detail design evolved, complex structural/optical relationships arose, necessitating the need for more sophisticated analytical and design tools. Use of these tools soon identified the fact that small decreases in performance could result in large cost reductions and that costs could be reduced by better matching several component designs to both the structural requirements and manufacturing processes.

DETAIL DESIGN ITERATION

The approach for the detailed design "value engineering" iteration consisted of utilizing the first iteration detail design as a baseline description for function, weight, cost and producibility (this baseline design is described briefly in Reference 1). Cost saving designs were incorporated and the resultant performance effects evaluated. In addition, several environmental requirements were relaxed to test the cost sensitivity. Figure 1 depicts the new concentrator design. Major variations from the baseline design that were studied and eventually incorporated include the use of a skinned core gore

segment, use of steel corrugated internal ribs with a simplified gore joint design, and implementation of a new mount frame design which utilizes less material, simplified joints, and eliminates the upload structural requirement on the foundation.

The analysis methodology, as depicted in Figure 2, consisted of modelling each of the design changes, determining the optical effects of these changes and then altering the structural stiffness and material content until appreciable performance degradation was indicated. The analytical tools consisted of a detailed finite element structural model (NASTRAN) which determines loads, stresses and deflections for multiple orientations and environmental load cases, a ray trace optical program (POLYPAGOS) which mapped the focal plane flux profile for the deformed concentrator, and an optics program that further spread the focal plane energy due to reflector specularity and finite solar energy distributions. Included in the tradeoff optical studies were the distortion effects due to orientation, seismic loads, asymmetric wind loads, gore manufacturing tolerances and the thermal expansion characteristics of the various materials used throughout the concentrator.

The resultant performance characteristics are shown in Figure 3. These trends show the intercept factor variation with receiver aperture and wind speed and the thermal performance as a function of receiver aperture, wind speed and ambient temperature variation. The thermal performance predictions are based on a receiver loss model that considers radiation, conduction and convection thermal losses. As a result of this design iteration, the rated wind speed has been reduced to 15 mph from 22 mph and the recommended aperture size has been increased from 11.25 inches to 12.5 inches. The resultant usable thermal energy available to the heat engine is $58.5 \text{ kW}_{\text{TH}}$ versus $60 \text{ kW}_{\text{TH}}$, a 2.5% performance decrease.

As shown in Figure 4, however, substantial reductions were made in both the concentrator weight and cost. The baseline design weight was 172 lb/m^2 of concentrator aperture. The prototype weight, which consists of many of the design improvements identified, weighs 123 lb/m^2 . The potential weight of 108 lb/m^2 reflects including weight reduction designs that were not incorporated due to the near-term prototypical nature of the concentrator. Similarly, substantial cost reductions were realized as a result of reduced material content, use of lower cost materials and changes in the manufacturing approaches.

Clearly, as a result of this detailed design "value engineering" iteration, significant improvements in the concentrator cost-to-performance ratio were realized.

HARDWARE STATUS

The concentrator design as discussed above is currently in the initial stages of fabrication. The structure and foundations are in the procurement cycle while the control system and gore/reflector development is nearing completion.

A major effort on the program has been the design, material and process development, and tooling fabrication of the molded plastic gores. This activity has been divided into two areas: process development of a parabolic pilot mold facility and the design and fabrication of the prime gore segments and their molds. Figure 5 depicts several aspects of the pilot mold, including the resultant molded gore segment both as molded and with its reflector system applied. This pilot mold has been used to evaluate material and process parameters, and to provide specimens for structural and environmental testing.


The design of the prime gore segment molding facility has been completed, fabrication of the mold handling and support equipment is nearing completion, and fabrication of the master gore segment patterns has begun. Figure 6 depicts the sweep tooling that has been constructed to generate the parabolic contours. Also shown are the early stages of the outer gore segment master pattern fabrication.

Present schedules call for site installation, commencing with the foundations, occurring in the first quarter of 1981, with testing early in the third quarter of 1981. The resultant design alterations will determine the readiness of the concentrator for system applications.


REFERENCES

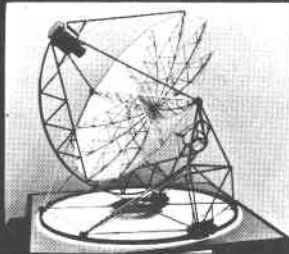
1. Zimmerman, J. J., "1st Generation Low Cost Point Focus Solar Concentrator," JPL Report 5105-8, pp. 63-67, April 1980.

FIGURE 1



LOW COST POINT FOCUS SOLAR CONCENTRATOR






SUBSYSTEM FEATURES

- AZ-EL MOUNT FOR MINIMUM WEIGHT, INVERTED STOW
- INTERNAL RIBS FOR INCREASED DISH STIFFNESS, PANEL ALIGNMENT
- MOLDED REINFORCED PLASTIC SANDWICH GORE SEGMENTS
- ALUMINIZED PLASTIC FILM REFLECTOR
- CABLE/DRUM DRIVE
- ON-BOARD COMPUTER CONTROLLED TRACKING SYSTEM


PHYSICAL CHARACTERISTICS

- 12 METER DIA; 6 METER FOCAL LENGTH
- 1500 CONCENTRATION RATIO
- 58.5 KW_{TH} THERMAL ENERGY TO ENGINE
- 1500 LB RECEIVER/ENGINE WEIGHT

FIGURE 2



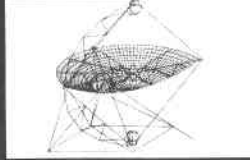
DESIGN ALTERATIONS STRUCTURAL/OPTICAL ANALYSIS



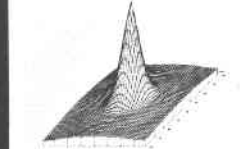
DESIGN APPROACHES

SUBSYSTEM	ALTERNATIVES CONSIDERED	RATIONALE
DISH ASSY	<ul style="list-style-type: none"> • PINNED VS. FIXED JOINTS • UNLOCK GORES • 1", 1/2", 1/2" CORES, .05" FACE 	<ul style="list-style-type: none"> • ELIMINATES COMPLEX FITTING • SIMPLER GORE DESIGN • MATCH LOAD PROFILE
INTERNAL RIBS	<ul style="list-style-type: none"> • CORRUGATED PANEL • STEEL VS. ALUMINUM 	<ul style="list-style-type: none"> • REDUCES NO. OF PIECES • LOWER \$/LB
MOUNT & BASE FRAME	<ul style="list-style-type: none"> • PINNED VS. FIXED JOINTS • NEW GEOMETRY 	<ul style="list-style-type: none"> • REDUCES COMPLEXITY OF FITTINGS • ELIMINATES UPLOADS • REDUCES COST

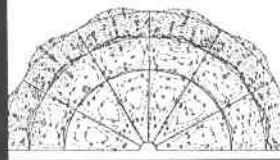
FINITE ELEMENT MODEL



OPERATING FLUX PROFILE




GORE DEFLECTION PATTERNS




COMBINED WIND AND THERMAL DISTORTIONS


FIGURE 3



PERFORMANCE SENSITIVITY CONCENTRATOR PERFORMANCE CHARACTERISTICS

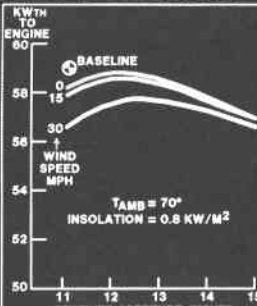


INTERCEPT FACTOR



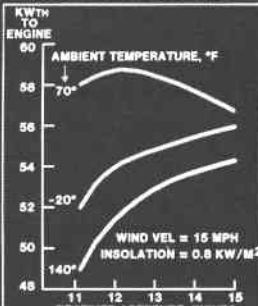
- INSENSITIVE BETWEEN 0-15 MPH
- MODERATE SENSITIVITY BETWEEN 0-30 MPH FOR LARGER APERTURES

KW_{TH} VS APERTURE



- RECEIVER THERMAL LOSS MODEL BASED ON RADIATION AND CONVECTION, 1500°F CAVITY
- MODERATE SENSITIVITY BETWEEN 11.0- 14.0 INCHES

KW_{TH} VS APERTURE



- DIFFERENTIAL THERMAL EXPANSION EFFECTS
- MODERATE SENSITIVITY TO AMBIENT TEMPERATURE AT LOWER APERTURE RANGE
- LOW SENSITIVITY TO AMBIENT TEMPERATURE AT HIGHER APERTURE RANGE

FIGURE 4

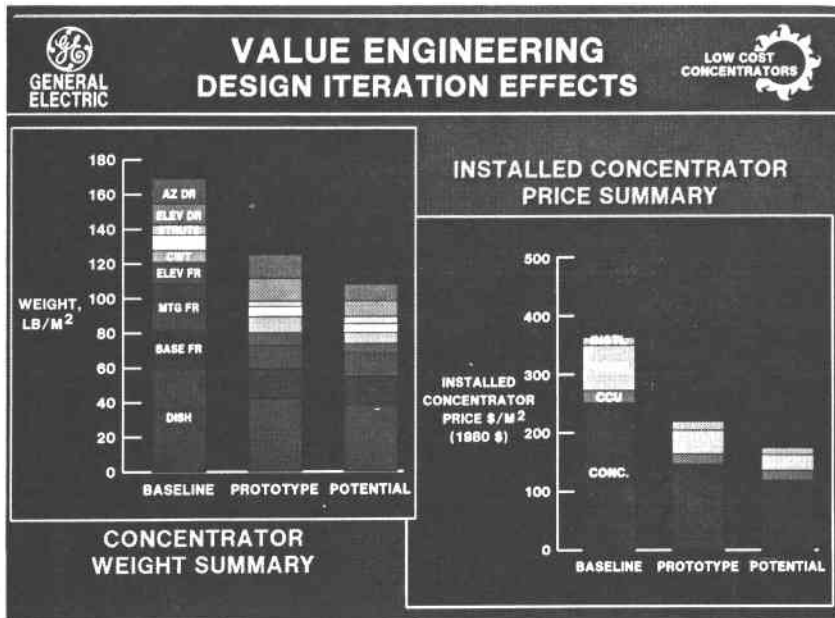


FIGURE 5

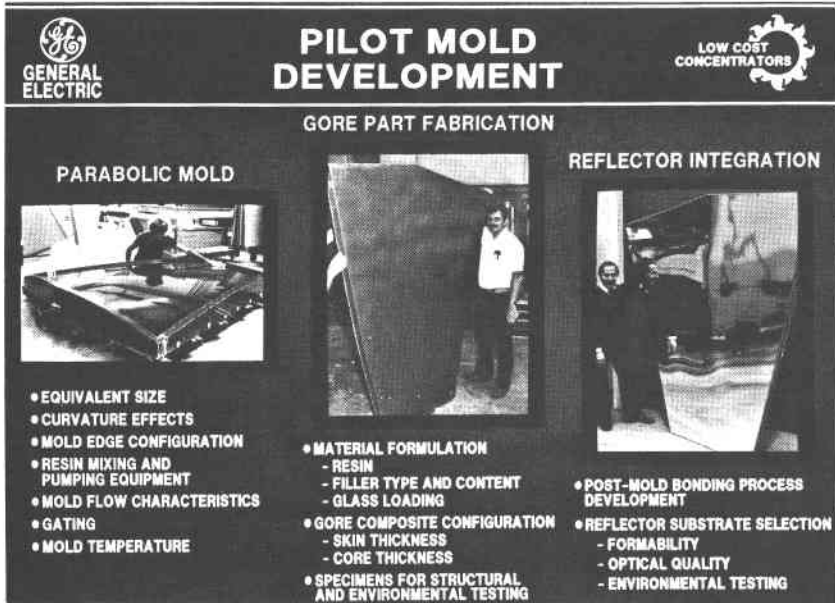
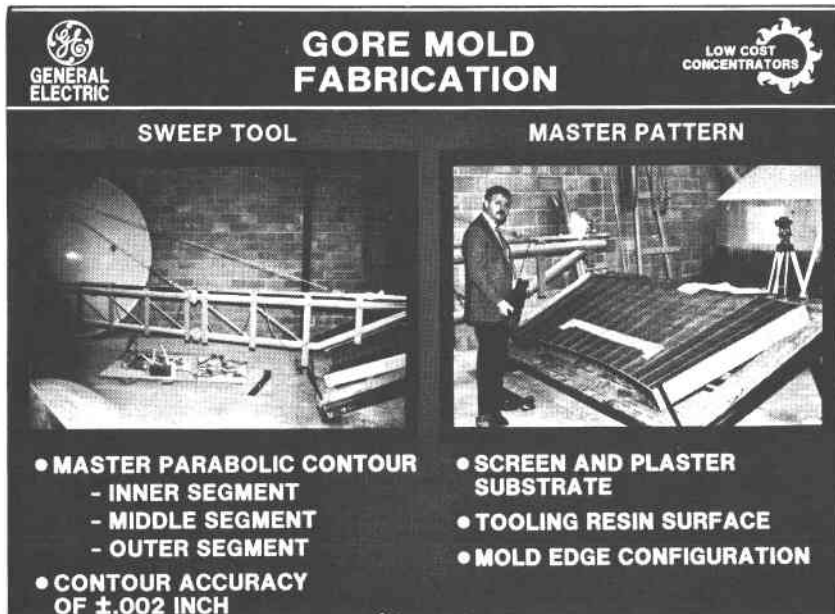


FIGURE 6



LOW COST CONCENTRATOR

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P. Overly
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ABSTRACT

The Acurex Corporation is under contract to the Jet Propulsion Laboratory to design, fabricate, install, and test a cost-effective point focus solar concentrator. The key to concentrator cost effectiveness is the proper design of the reflector surface panels. The low cost concentrator reflective surface design is based on the use of a thin, backsilvered mirror glass reflector bonded to a molded structural plastic substrate. This combination of reflective panel material offers excellent optical performance at low cost. This paper briefly describes the design approach, rationale for the selected configuration, and the development status. Reflective panel development and demonstration results are also presented.

INTRODUCTION

The overall objective of the low cost concentrator project is to develop and demonstrate a state-of-the-art technology concentrator which is cost effective in high volume production and has a 30-year life under wide environmental extremes. The development project is structured into a three-phase effort. Phase I, completed in March 1979, encompassed the concept selection, preliminary design and cost assessment, and demonstration of the mass production reflective panel fabrication approach. The Phase II efforts, which began in September 1980 and are currently underway, encompass detailed design and analysis and demonstration of the prototype reflective panel fabrication approach. Phase III includes fabrication, installation, and testing of three prototype concentrators and is scheduled for completion in May of 1982.

DESIGN SUMMARY

The design of the 11 meter diameter (95 m² gross aperture area) Low Cost Concentrator is shown in Figure 1. The concentrator is a two-axis tracking system designed to interface with a 1,500 lb thermal receiver/power conversion unit package. Predicted performance of the concentrator is 63 kWt at the receiver aperture based on the following design conditions:

- 800 W/m² insolation
- 1,700°F receiver operating temperature
- 95 percent reflectance
- 30 mph operating wind

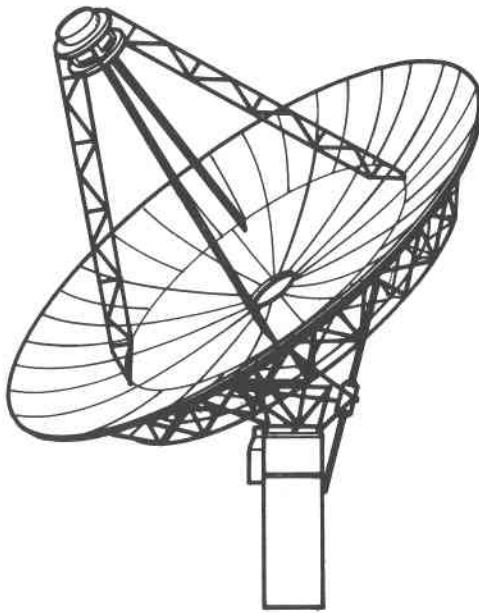
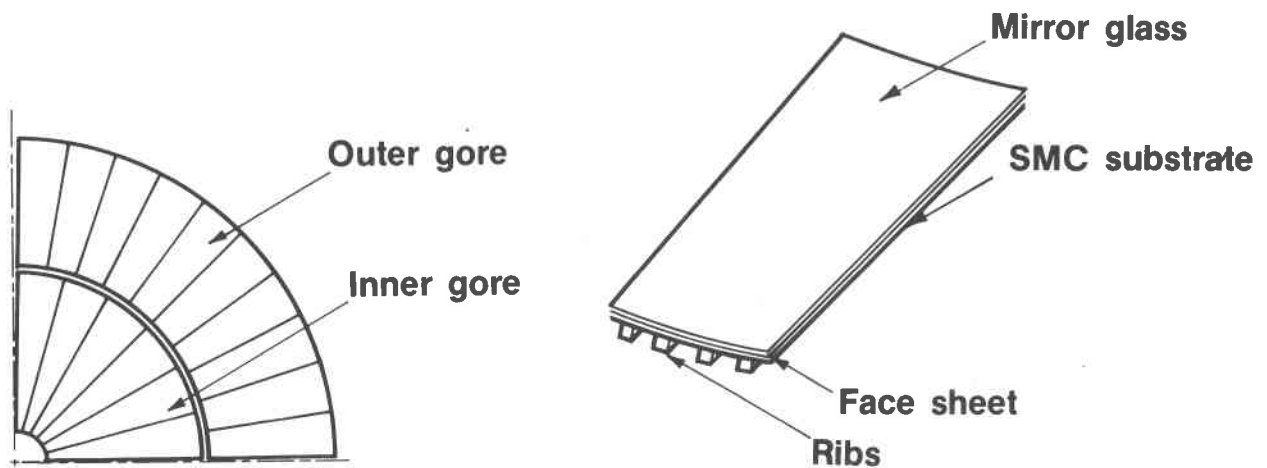


Figure 1. Design Description

The major design features of each of the subassemblies of the mass production concentrator are discussed in the following paragraphs. Prototype-specific modifications for the reflective panel subassembly are also presented.

Reflective Panel Subassembly

The reflective panel subassembly consists of inner and outer groups of reflector gores forming a complete but physically discontinuous reflective surface. As shown in Figure 2, a concentrator consists of 40 outer and 24 inner gores. The reflective gores are a composite construction of thin (0.028 in), backsilvered mirror glass with a sheet molding compound (SMC) supporting substrate. A thin glass reflector was chosen because of high performance and long life characteristics. In terms of performance, backsilvered mirror glass provides the highest practical solar hemispherical reflectance (0.95) and has excellent specularly. Glass is highly abrasion resistant and environmentally durable. The reflective panel substrate is a compression molded material generically referred to as SMC. SMC is a ready-to-mold polyester resin material with chipped fiberglass reinforcement processed in continuous sheet form. Parts of SMC are typically molded at 300°F and 1,000 psi in 3 to 5 min cycle times. SMC molding is a high volume production process and offers the potential for low cost reflective panel substrates. The reflective panel substrate design consists of a thin (0.15 in) face sheet with an intergrally molded rib structure. The glass mirror is bonded to the SMC substrate.



a. Reflective Surface Configuration

b. Typical Gore Configuration

Figure 2. Reflective Panel Design

Support Structure Subassemblies

The three support structure subassemblies are:

- Panel support structure
- Receiver support structure
- Intermediate support structure

The lightweight space frame subassemblies feature welded steel shop subassembly construction using standard size, commercially available steel tubing. Finite element analysis techniques were used to optimize the support structure for minimum weight.

Foundation and Drive Subassemblies

The foundation design features simple installation and adaptability to sloping or rough terrains. The foundation consists of a single cast-in-place, reinforced concrete pier with an azimuth turret mount. The single pier foundation was selected in order to minimize site preparation and foundation installation labor costs. It does result in a slightly higher weight concentrator than would result with a wide base foundation. However, because of reduced installation labor, total installed cost is minimized. Hydraulic power units were selected for both azimuth and elevation drive systems. The azimuth drive is a hydraulically-powered gear drive. The elevation drive is a single stage, double-acting hydraulic cylinder actuator. Emergency power is provided by a pressurized gas accumulator.

Tracking and Control System

A hybrid, two-axis, sun tracking control system based on microprocessor technology, has been selected. Coarse synthetic tracking is achieved through a microcomputer based control system to calculate sun position for transient periods of cloud cover as well as sundown and sunup positioning. Accurate active tracking is achieved by two-axis sun sensors.

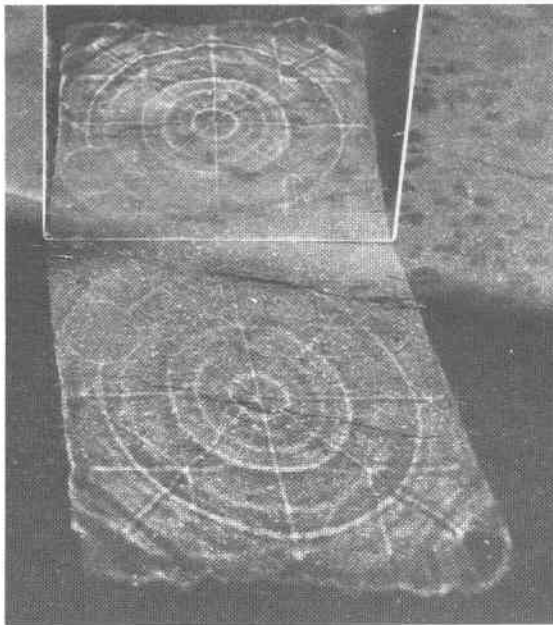
Reflective Panel Prototype Modifications

Prototype-specific modifications to the mass producible reflective panel design are being made to reduce prototyping cost. The most significant modification is in the area of the compression molded SMC substrate. The cost of a full-size mold is prohibitive for prototyping purposes. The prototype panels will be fabricated by hand layup of glass-reinforced polyester (GRP) on a contoured epoxy tool. The panel face sheet will be fabricated on this tool in a similar manner as boat hulls. The ribs will be cut from GRP sheet stock, assembled, and bonded to the face sheet. The mirror glass will be bonded to the assembled substrate.

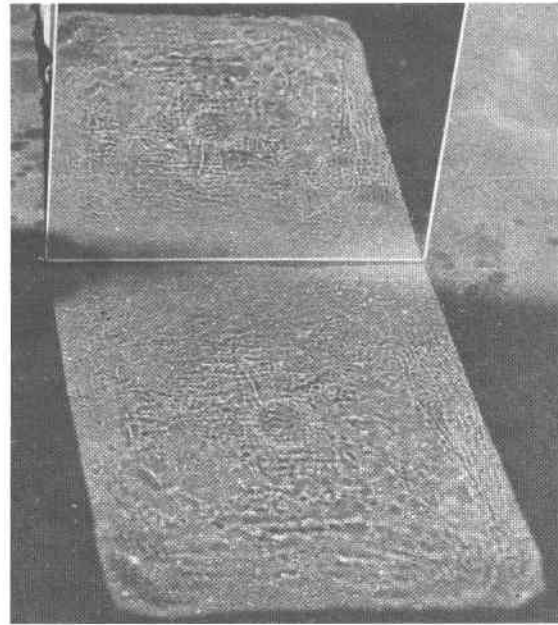
Reflective Panel Development and Demonstration

Two-foot square compression molded SMC-Mirror Glass panels were fabricated and tested in the Phase I effort. Compliance with the requirements of the low cost concentrator has been successfully demonstrated. Both subsized and full-size hand layup GRP-Mirror Glass prototype panels will be fabricated and tested in Phase II of this project. Panel testing will consist of dimensional verification, slope error, hail impact, thermal cycling, and structural deflection tests.

The primary objective of the Phase I compression molded SMC-Mirror Glass test panels was to demonstrate the optical surface quality attainable with present state of the art. Test panels were fabricated with both a single-step molding process and a two-step, molding-bonding approach. The single-step process integrally molded the SMC-Mirror Glass panel in one molding cycle. The two-step process involved molding of the SMC integral face sheet-ribbed substrate followed by adhesively bonding the mirror glass using the female portion of the mold as the bonding fixture. Qualitative and quantitative evaluation of test panel optical quality was performed. Representative panels produced with each manufacturing method are shown in Figure 3. The reflected light patterns from each panel provide a very sensitive qualitative evaluation of mirror surface topography. The single-step molded panel exhibited discernible rib print-through (the diagonal line patterns crisscrossing the mirror surface). This effect is related to material shrinkage at the rib/face sheet junction during molding and curing. A second observable feature in the single-step molded panel is a system of concentric ripples progressing outward from the center of the panel. This pattern was traced to a system of concentric ripples in the tool. The patterns were impressed into the glass sheet by the high molding pressure of the compression molded



a. Rib Print-Through
Circular Tool Pattern



b. No Rib Print-Through
Subtle Circular Pattern
0.95 mrad Slope Error

Figure 3. Compression Molded SMC-Mirror Glass Test Panels

process. The two-step, molded-bonded panel was visually superior to the single-step molded panel, showing no trace of rib print-through and only subtle traces of the concentric tool markings. Reflected light patterns from these panels revealed a relatively featureless surface, with a low amplitude, random oriented ripple uniformly covering the surface. This ripple is believed to be caused by variations in the bond joint thickness. The two-step molded-bonded panel was then tested at the Sandia Laboratory ray trace facility. The resulting slope error standard deviations for the surveyed area was 0.95 mrad, well below the target value of 2.4 assumed for initial performance estimates. From these experimental results, it can be concluded that composite reflective panels of SMC-Mirror Glass can be manufactured with required precision using current state-of-the-art methods. Bonding of the mirror glass to a premolded SMC substrate would be used for initial panel production. The impact of the additional processing time is small. In the long term, further developments in single-step molding will allow panels of comparable quality to be produced.

KEY RESULTS

The key results of this development project to date are:

- A state-of-the-art point focus solar concentrator based on SMC-Mirror Glass reflective panels has been shown to be highly cost effective in mass production
- SMC-Mirror Glass reflective panels manufactured with required precision using current state-of-the-art methods have been demonstrated

ADVANCED CONCENTRATOR PANELS

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ABSTRACT

Acurex Corporation, under contract to the Jet Propulsion Laboratory (JPL), has completed the prototype fabrication of a lightweight, high-quality cellular glass substrate reflective panel for use in an advanced point-focusing solar concentrator. The reflective panel is a gore shaped segment of a 11-m paraboloidal dish.

This paper briefly describes the overall concentrator design and the design of the reflective panels. Prototype-specific panel design modifications are discussed and the fabrication approach and procedure outlined. The optical quality of the prototype panels appears to be excellent, although no quantitative results are yet available.

BACKGROUND

JPL first developed the concept of using cellular glass in conjunction with thin backsilvered mirror glass to form lightweight, structurally efficient reflective panels for high-flux solar concentrators. Cellular glass is a low-cost, noncritical material with a very high stiffness-to-weight ratio. It is easily machinable and can be formulated to provide an excellent coefficient of thermal expansion match to most glass types. Gore shaped reflective panels (Figure 1) fabricated from a composite of cellular glass and sheet glass form the basis of the JPL Advanced Concentrator concept first proposed in 1977. The largely self supporting gores are used to displace much of the structural framework normally required to maintain an adequate dish stiffness.

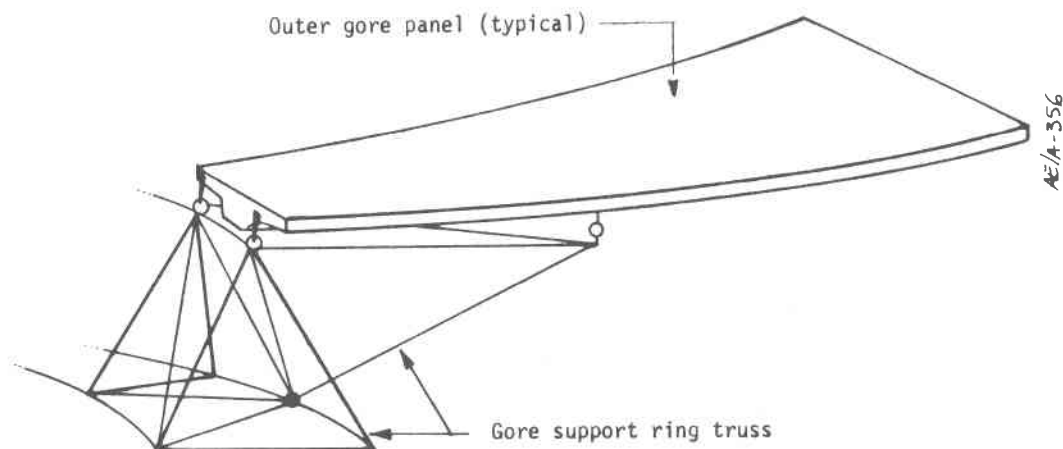


FIGURE 1. CELLULAR GLASS GORE

Acurex, under contract to JPL, performed the preliminary design of the Advanced Concentrator and carried the design of the outer reflective gore through the detailed level. A preliminary cost assessment confirmed the cost-effectiveness of reducing the structural framework required for the reflective dish, but also identified a problem with regard to the balance of the concentrator design. The installation costs associated with site preparation, foundation installation, and field erection of the wide-base/perimeter drive configuration accounted for a major fraction of the total installed concentrator cost.

A concept-level trade-off study resulted in a more cost-effective design which retains the advantages of the cellular glass panels, but eliminates the costly wide base configuration.

CONCENTRATOR DESCRIPTION

The resulting Acurex/JPL Advanced Concentrator concept is shown in Figure 2. It consists of 64 lightweight cellular glass substrate gores (40 outer and 24 inner gores), simply supported from a tubular steel ring truss which is hinged in elevation from an intermediate space frame structure. The intermediate structure is mounted to a motor driven turret azimuth drive which sits atop a single concrete column. The reflective dish is driven in elevation by an electric ball screw actuator which couples the gore support ring structure to the intermediate structure. A guyed truss-legged quadripod receiver support structure provides a rigid support for the power conversion package while providing a minimal amount of shading or blocking of the incident and reflected insolation.

The turret drive/pedestal mount configuration requires a more massive and more costly drive unit than the original wide-base/perimeter drive configuration. The significant reduction in site assembly and foundation installation costs more than offset this penalty, however. It is estimated that the installed cost of the single pedestal configuration will be 10 to 20 percent less than the wide base design.

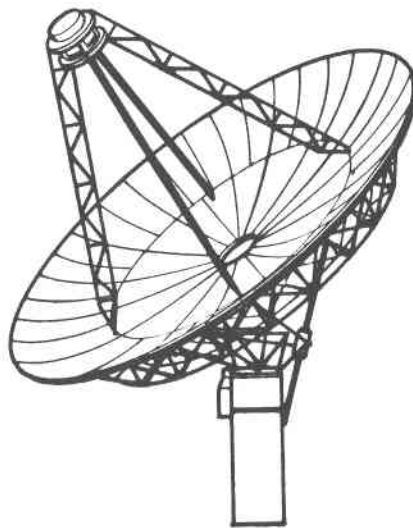


FIGURE 2. ACUREX/JPL ADVANCED CONCENTRATOR

REFLECTIVE PANEL DESIGN

The key element of the Advanced Concentrator is clearly the cellular glass substrate reflective gore. As shown in Figure 3, each gore is fabricated from a composite of 1.0-mm Corning Glass Works 7809 borosilicate glass and a Pittsburgh Corning Foamsil® 75 cellular glass core. The Foamsil® 75 has been specially formulated to match the thermal expansion characteristics of the 7809 sheet glass. A single sheet of backsilvered thin glass is continuously bonded to a contoured substrate of the cellular glass material. A narrow strip of unsilvered thin glass is bonded to the outer face of the cellular glass spar running longitudinally along the backside of the gore. The face sheets and the cellular glass core form a composite structure in which the mirror glass and the spar cap carry a significant portion of the aerodynamic and gravitationally induced bending loads. Three compression molded glass reinforced polyester (GRP) pads are bonded to the gore to serve as attachment points for the interface with the support structure.

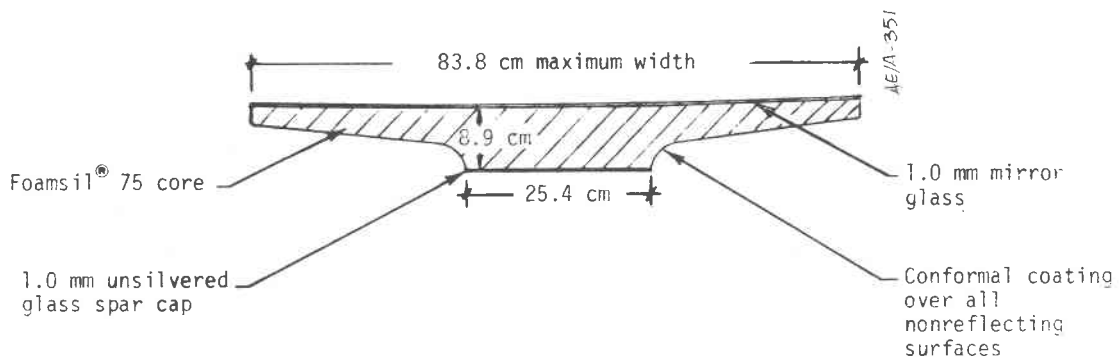


FIGURE 3. OUTER GORE CROSS SECTION

Two panel types form the paraboloidal surface. Forty outer gores and twenty-four inner gores are required. The masses of the outer and inner gores (less attachments) are 23.2 kg and 15.8 kg, respectively. The width of each gore type is limited by the maximum steady-state curvature stress which the sheet glass can withstand. A maximum panel width of 84 cm for the outer and inner gore limits the steady-state stresses to 14.9 MPa.

A detailed design was developed for the outer gore type only. The resulting gore is stress limited with a 5 percent probability of failure in the cellular glass core under a governing load condition of a 1 minute cumulative exposure to a 110 km/hr wind at the worst-case orientation. The peak tensile core stress is 275 kPa under this condition with a corresponding mirror glass stress of 20.1 MPa. Under worst-case operating conditions, the outer gore panel yields a peak deflection slope error of less than 0.3 mrad and an area weighted rms deflection slope error of less than 0.2 mrad.

Due to current manufacturing limitations, the maximum block size for the Foamsil® 75 material is 46 cm by 61 cm by 10 cm. Near-term production therefore requires the bonding of several blocks of cellular glass into a large core blank prior to machining. Future developments in cellular glass production may lead to full size monolithic core blanks or even foamed to shape cores.

PROTOTYPE PANEL FABRICATION

To verify the fabricability and integrity of the gore design, Acurex has fabricated several full-scale prototype gores. These gores will be tested by JPL to determine the structural and optical characteristics of the design.

Prototype Design Modifications

Several prototype-specific design modifications were incorporated to reduce cost. Due to limited availability of the 1.0 mm Corning 7809 sheet glass and the Pittsburgh Corning Foamsil® 75, the prototype gores were fabricated from 1.5 mm Corning 0317 glass and Pittsburgh Corning's standard Foamglas® material. While these materials are not ideally thermally matched, and the thicker sheet glass provides a shorter panel life, much insight into the gore design has still been gained. Steel weldments were substituted for the compression molded GRP attachment pads at a penalty of approximately 2.3 kg per gore.

In addition to these prototype material changes, two significant dimensional changes were also incorporated. To simplify the core machining operation, the rearside contour was modified from a constant edge thickness configuration to a constant contour angle design and the spar depth was increased to avoid a local bond joint problem. This change added approximately 10 percent to the core mass, but allowed the use of a simplified contouring scheme. The frontside contour was also modified to simplify the prototype machining operation. In lieu of the more perfect paraboloidal contour, a compromise of a parabolic contour in the radial direction and a constant radius of curvature in the circumferential direction was selected. The effective area-weighted slope error impact of this modification is approximately 0.3 mrad rms.

Fabrication Approach

To minimize prototype fabrication cost, Acurex developed a simple contouring scheme which allows accurate, repeatable substrate fabrication with a minimal investment in tooling. The prototype gore fabrication procedure is essentially a ten step operation:

- Cut cellular glass blocks
- Bond blocks to form core blank
- Cut core blank to planform
- Machine core backside
- Bond sheet glass spar cap
- Machine core frontside
- Bond mirror glass
- Bond attachment pads

- Apply conformal coating
- Package and ship

Since the optical accuracy of the gore is directly dependent upon the accuracy of the substrate contour, the core contouring apparatus was a key element of the prototype fabrication effort. As shown in Figure 4, the cellular glass contouring apparatus consists of a pair of reversible precision parabolic rails which support a hand-drawn cutter carriage. The carriage is designed to accept several interchangeable contoured scraper blades. Two blade configurations are required to generate the rearside contour, while only one constant-radius blade configuration is required for the frontside contour.

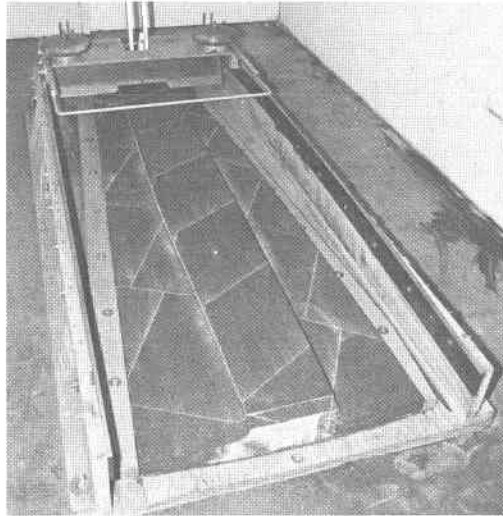


FIGURE 4. CELLULAR GLASS CONTOURING APPARATUS

Preliminary Results

While no quantitative data have yet been taken, the optical quality of the prototype gores appears to be excellent. Visual inspection does indicate a slight "print-through" of the bond lines where the cellular glass blocks were joined, but the total distorted area is very small. Simple hand held imaging tests with the sun as the light source provide a clearly defined image on the order of 10 cm at a focal distance of approximately 6.6 m. This corresponds to roughly a 60 percent increase over the sun's theoretical image as would be expected for a 1 mrad rms mirror.

Continued developmental work is required in the fabrication and processing of cellular glass as a structural material. Much can be done to expand upon the prototype gore fabrication technique. The labor intensive contouring operation could easily lend itself to increased automation. Further refinements in machinable cellular glass bonding agents could improve machinability and reduce print-through.

With adequate effort expended on its development, the cellular glass substrate reflective panel appears certain to have a significant impact on the future of point-focus solar technology.

DOE PARABOLIC DISH SOLAR THERMAL
ANNUAL PROGRAM REVIEW

DEVELOPMENT AND TESTING OF THE
SHENANDOAH COLLECTOR*

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ABSTRACT

The test and development of the GE-designed 7-meter Shenandoah parabolic dish collector incorporating an FEK-244 film reflective surface and cavity receiver is described. Four prototypes tested in the Midtemperature Solar System Test Facility indicate, with changes incorporated from these development tests, that the improvements should lead to predicted performance levels in the production collectors.

*This work supported by the U.S. Department of Energy, SAND81-0028A

A parabolic dish solar collector was selected for the Shenandoah Solar Total Energy Project application because it could supply the design loads throughout the peak electrical demand period of the utility and do this from a limited (5-acre) field and under moderate (Atlanta area) insolation conditions. The collector was designed by the General Electric Company under a DOE contract for the design of the Shenandoah Solar Total Energy System.

The initial model upon which the final collector design is based evolved from a 5-meter diameter communications dish antenna which Scientific Atlanta had developed. A solar collector, which was called the engineering prototype collector, EPC, was fabricated by the expedient of applying a reflective film to the "petals" of the communication antenna and attaching a solar receiver where the cassegrain reflector was normally located. This EPC model was evaluated at the Sandia Solar Collector Module Test Facility, and it indicated the feasibility of adapting the low cost fabricating technique of die-stamping petal sections to produce solar reflectors. These tests also led to modifications to the original receiver design resulting in improved receiver operation.

The reflector surface was originally conceived to be a glass surface over polished aluminum. The aluminum was a magnesium alloy which would polish to a high reflectivity. Alternatives were investigated, and an RTV silicone substitute for glass was developed when proprietary issues could not be resolved with the use of the GE glass process. An anodization scheme was carried on as an alternative. Both reflector approaches were eventually replaced by a reflective film (FEK-244, a 3M product). This change provided an improvement in reflectivity, enhancing the collection of solar energy to provide the thermal energy needs of the project. The change also indicated a protracted wash cycle could be considered over the other reflector approaches, making reduced operation and maintenance (O&M) costs possible. Since the aluminum was no longer the reflecting surface, the aluminum was changed to a lower cost alloy.

A key element in adapting the reflector film for dish collector use was the process development for applying FEK-244 to a compound curved surface. On the earlier EPC, the film was applied to the individual "petal" sections using the squeegee/detergent hand application method which is recommended by 3M for laminating the film to flat panels. This was the first time the film had been applied to a compound curved surface so no historical precedent could be cited which would provide confidence as to the long term integrity of the film (remaining attached to the substrate) under all environmental conditions. The film was only a temporary expedient to convert a communications antenna to a solar collector. Thus, alternate approaches for a reflector were encouraged.

When it became evident, however, that the FEK-244 film offered significant advantages over the RTV or anodized alternatives, the problem of applying the film to a compound surface was readdressed. The solution turned out to be relatively simple. The FEK film was laminated to the flat aluminum substrate material prior to die-stamping into the "petal" shape. To protect the reflective film, an opaque premask film was laminated over the FEK. An additional benefit accruing from the easily peeled premask is that it also permits collector assembly outdoors without creating a concern over eye hazards. Both film and premask are

applied using a roller applicator which reduces the time and labor over that associated with the hand application method. Environmental tests of two petals processed by the roller method disclosed the tendency of the FEK film to "tunnel." "Tunnelling" is a consequence of FEK expansion when exposed to hot, high humidity conditions and is the term applied to localized ridge-like lifting which occurs, especially at stress sites. FEK has a coefficient of thermal expansion of about 45 microinch/inch/°F. Resolution of this problem was effected by cutting the FEK every two feet to reduce the size of the laminated film sections. Subsequent environmental tests on petals with enlarged film sections (3-foot cuts) indicate no tendency toward tunnelling. This will reduce the number of cuts required in each "petal." Whether this phenomenon is associated primarily with the double curvature of a parabolic dish surface or is common even in a planar configuration, if the film sections are large enough, or whether roller application causes differences from hand applications is not known.

Four 7-meter diameter pre-production prototype dish collectors were fabricated for testing and evaluation in a quadrant of the Sandia Midtemperature Solar System Test Facility (MSSTF). Initially, the collectors had RTV-coated reflectors. One of the four was subsequently replaced with an anodized surface and another with an FEK surface. All of the reflectors were assemblies of 21, 8-foot long "petals" and a 29-inch wide center annulus section. The two-part reflector was a consequence of the petal fabricator being limited to a press size which would only accommodate an 8-foot die. With the acquisition of a 900-ton press the fabricator can now stamp full-length petals, eliminating the need for the annulus section. The annulus was fabricated by a spinning operation. An improvement in the collector efficiency is expected with the extended petal design. On the quadrant test collectors, the annulus accounts for about 10 percent of the reflector area but contributes much less than the expected reflected energy due to the non-specularity of the spinning.

The collector to be installed at Shenandoah will incorporate several design changes as a result of the quadrant tests.

Difficulties evidenced in the assembly of the reflector to the declination axis prompted the change from trying to align two horizontal holes for attachment to the frame, to mating the flat surfaces to effect assembly.

The large amount of field welding of the frame assembly led to the use of a base support frame to permit the frame assembly to be shop welded and be field installed as a finished section. This procedure also permits the polar drive motors and jackscrews to be shop welded to the collector frame assembly and the entire assembly checked for proper polar rotation prior to shipment.

The difficulties encountered in maintaining the reference orientation for the position indicating potentiometers has led to a redesign of the mounting bracket and a change in the attachment to the rotating axes.

The mechanical stop on the jackscrews will be strengthened to prevent the gear motors from driving through the stops and causing the reflector to freely pivot about the polar axis.

Each time the receiver was brought into or taken out of focus, the aperture plate (made of stainless steel) received a healthy thermal input causing the aperture plate to buckle. The heating also led to the malfunctioning of the optical fibre solar tracking system. A thicker steel sheet was not totally satisfactory. A quartz refractory pad is now used to insulate the aperture plate.

The receiver coil through which the heat transfer fluid is circulated has been changed from a double coil to a single coil. At flow rates slightly less than 1 gal/min through the double coil receiver, it was noted that a transition to laminar flow appeared to be occurring. The tubing diameter for the single coil has been enlarged to maintain the pressure drop at about 15 psi while maintaining the tube wall to fluid ΔT at less than 100°F at the minimum flow rates to keep the Reynolds number above 8200. The new coil was tested in a quadrant test collector and indicated improved operation in effecting heat transfer at low flow rates.

The hub, which is the centrally located element to which the reflector petals are attached, had been changed from an aluminum weldment to a steel weldment as a cost saving measure. Solicitations from potential fabricators now indicate that the hub can be made from an aluminum casting at an even greater cost savings, so this avenue is being explored further.

The collector was designed to meet the requirements indicated in Table 1. An operational characteristic which is distinctive to this dish collector is that the full temperature differential (from 500°F input to 750°F output) is accommodated in contrast to troughs where a number of collectors make up a ΔT string. The minimum operation level of 50 Btu/hr-ft² is the level at which the system losses (parasitic and thermal) are just met. The other requirements listed are common to other concentrating distributed collector systems. The design requirements were translated into collector optical and receiver thermal parameters and incorporated into a collector system analysis model. This model was used to analyze the collector performance in terms of key variables. These variables are shown in Figure 1.

The f/d ratio was selected on the basis of optimizing the concentration ratio without an undue increase in the receiver heat losses. Figure 2 shows the efficiency was maximized at a f/d ratio of 0.5

The sensitivity of the concentration ratio (CR) from 250 is shown in Figure 3. The collector for Shenandoah will have a CR of 234 with an 18-inch diameter receiver aperture.

The indicated reflectivity, Figure 4, is the level which, in conjunction with the intercept factor and receiver efficiency, was thought to be required to provide the overall collector efficiency needed to meet the collector design requirements. The FEK-244 surface on the environmentally tested panels has manifested a reflectance of about 0.85 after washing after degrading to about 0.82. On the Quad Test units, exposure to the elements for 3 months resulted in a reduction in the specular reflectivity (35 mr), but the level was recovered after washing.

TABLE 1. SHENANDOAH COLLECTOR DESIGN REQUIREMENTS

Type:	Concentrating, Two-Axis Tracking, Parabolic Dish		
Coolant Fluid:	Syltherm 800		
Output:	1.09 x 10 ⁸ Btu/Yr		
Operating Conditions:	● Ambient Temperature Range	:	17 ^o F - 95 ^o F
	Fluid ΔT	:	250 ^o F
	● Max. Working Fluid Bulk Temperature	:	750 ^o F
	● Wind Loads	:	30 mph
	● Tracking Range: Polar Axis	:	180-210 ^o
	Declination Axis	:	15-90 ^o
	● Insolation Levels	:	Design - 200 Btu/ft ² -hr Max. - 300 Btu/ft ² -hr Min. - 50-75 Btu/ft ² -hr
Non-Operating Survival Conditions:	● Ambient Temperature Range	:	-3 ^o F to 104 ^o F
	● Wind Loads	:	90 mph
	● Hail Impact	:	0.6 inch diameter
	● Lightning strike	:	100 kA peak current 1 Microsecond rise time
	Maintenance, Routine:	● Reflective Surface Washable	}
● Receiver Cleanable without removal			
● Control Calibration			
Maintenance, Unscheduled:	● Disk petals replaceable	}	Design provisions
	● Receiver replaceable		
	● Receiver/dish alignment		
	● Controls removable		
Hazard Shutdown:	● Defocus time	:	2 ^o /sec minimum
	● Over temperature	:	Automatic
	● Loss of fluid flow	:	Automatic
	● Power loss	:	Stand-by-power
	● Environmental	:	Manual override

f/d	Focal Length to Dish Diameter Ratio
Concentration Ratio	Collector Aperture/Receiver Aperture
Reflectivity	Total Hemispherical and Specular Distribution
Slope Error	Deviation from a Paraboloid
Tracking Error	Receiver Offset from Solar Flux

FIGURE 1. COLLECTOR DESIGN VARIABLES

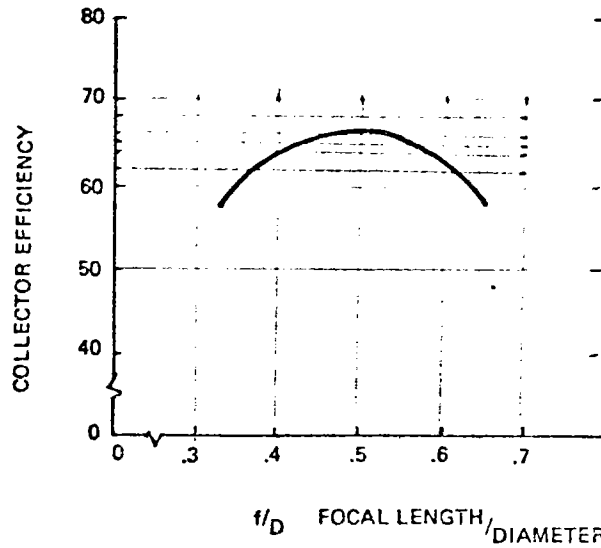


FIGURE 2. FOCAL LENGTH OPTIMIZATION

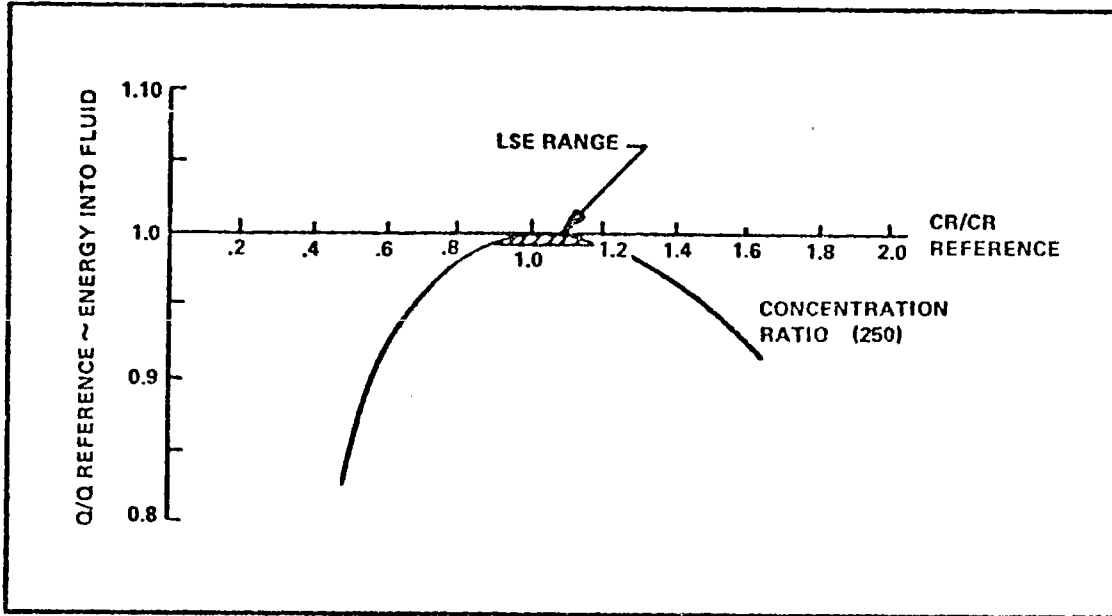


FIGURE 3. CONCENTRATION RATIO SENSITIVITY ANALYSIS

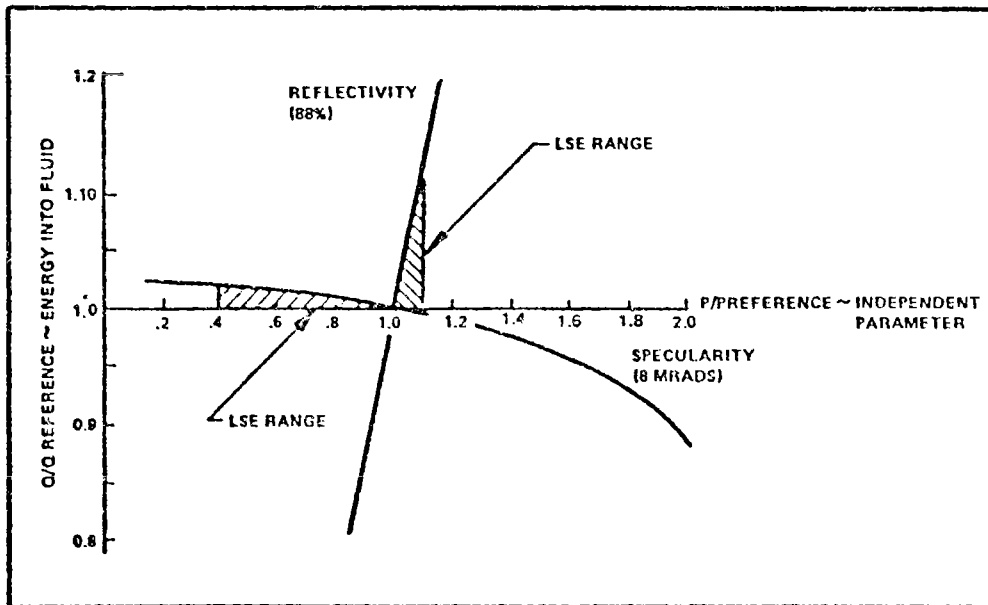


FIGURE 4. REFLECTOR SURFACE PARAMETER SENSITIVITY ANALYSIS

The intercept factor, which is defined as the percentage of the reflected energy incident at the receiver aperture, is a function of the specularity, slope errors, and tracking errors associated with the collector and is required to be about 0.96 to achieve the collector performance requirements. A slope error of 1/2 degree was considered a design parameter and its sensitivity relative to energy collection is shown in Figure 5.

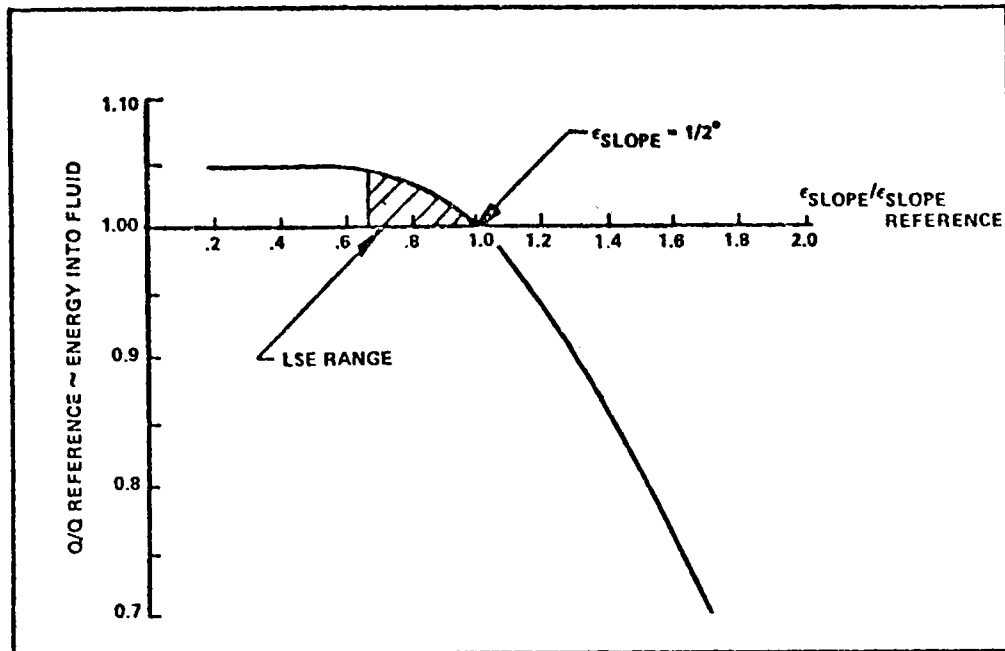


FIGURE 5. SLOPE ERROR SENSITIVITY ANALYSIS

The sensitivity of the tracking error on the energy collection is shown in Figure 6. The tracking bias of 1/4 degree was used as the collector design parameter.

The dish diameter of 7 meters was selected on the basis of being the best compromise considering collector cost, field cost, collector efficiency, and fluid heat losses. The diameter optimization results are shown in Figure 7. A collector field cost per unit of delivered energy versus collector diameter plot can be constructed for various projected collector costs. For our case, the optimal diameter lies in the 7-meter range. If collector costs can be reduced, other field component costs become more important, and the trend is toward optimizing at larger diameters.

These collector design parameters are shown in Figure 8, and the collector performance curves are indicated to show the expected off-design characteristics.

Quadrant test results from the FEK-244 collector indicate that these early prototypes are achieving operational levels very close to design levels. Production collectors, incorporating improvements suggested from the quadrant tests are expected to provide performance levels predicted.

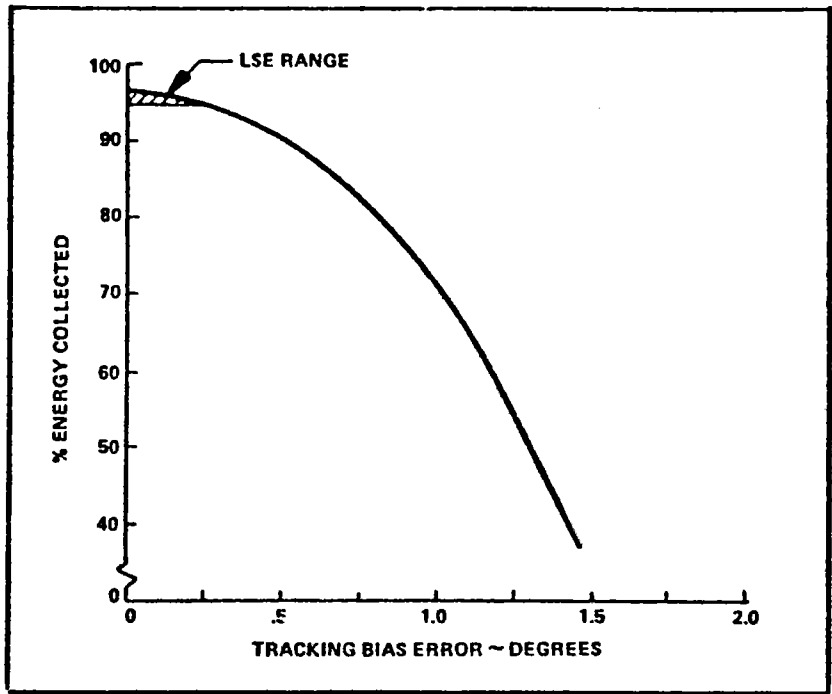


FIGURE 6. TRACKING BIAS ERROR SENSITIVITY ANALYSIS

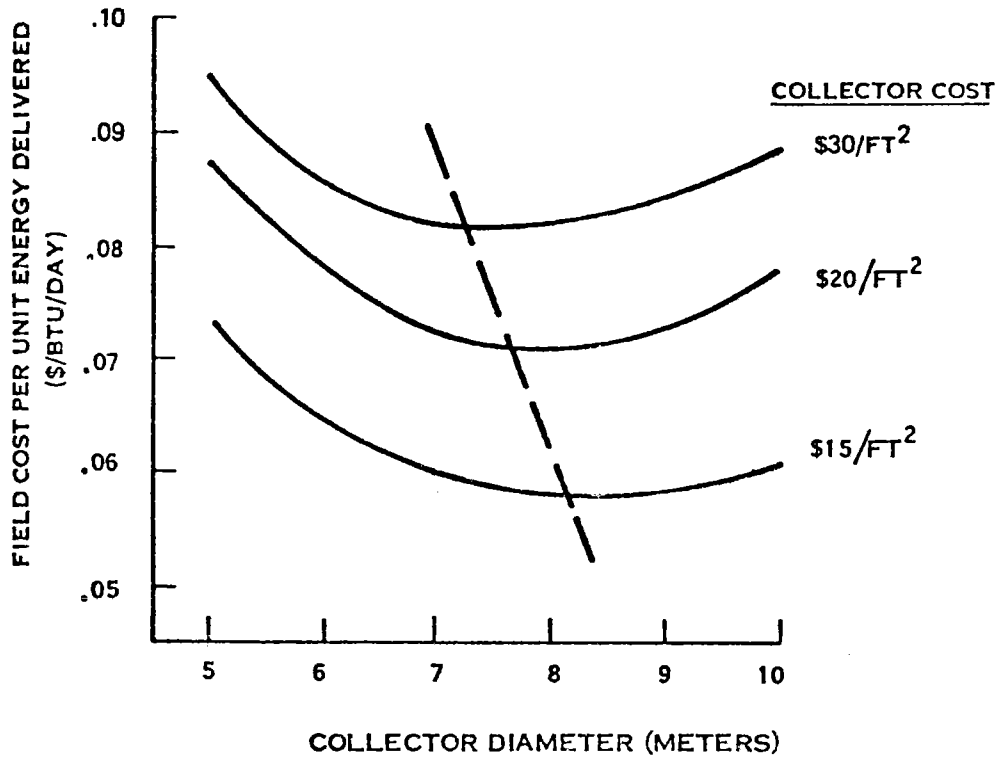


FIGURE 7. OPTIMIZATION RESULTS - COLLECTOR DIAMETER VS. COST/BTU DELIVERED

COLLECTOR PARAMETERS	
PARAMETER	NOMINAL VALUE
D_{DISH}	7 METERS
CR	250
F/D	0.50
REFL	88%
σ_{SPEC}	8 MRADS
σ_{SLOPE}	8.7 MRADS ($1/2^\circ$)
σ_{TRACK}	4.4 MRADS ($1/4^\circ$)
INSULATION	200 BTU/HR-FT ²
T_{IN}	500°F
T_{OUT}	750°F
$T_{AMBIENT}$	50°F

NOMINAL DESIGN POINT PERFORMANCE	
% CAPTURED BY RECEIVER	= 96%
$Q_{RADIATION LOSS}$	= 7410 BTUH
$Q_{CONVECTION LOSS}$	= 3890 BTUH
$Q_{CONDUCTION LOSS}$	= 930 BTUH
$Q_{INTO FLUID}$	= 55,500 BTUH
COLLECTOR EFFICIENCY	= 67%

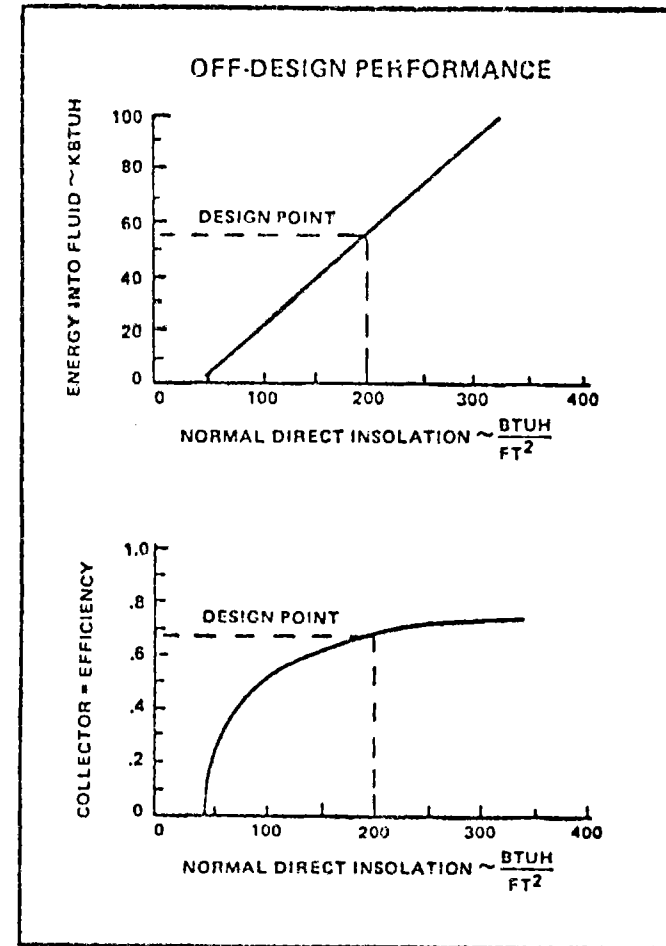


FIGURE 8. NOMINAL COLLECTOR PERFORMANCE AND DESIGN PARAMETERS

FRESNEL CONCENTRATING COLLECTOR

Power Kinetics, Inc.

William Rogers
David Borton
Mark Rice
Robert Rogers

INTRODUCTION

During the oil embargo of 1973-74, the Northeastern part of our country was shown to be particularly vulnerable to shortages of fossil fuels which, for the most part, were coming from overseas sources. Other energy technologies had to be found. To displace fuels in many applications, though, alternative energy sources had to be able to deliver high quality energy reliably. Therefore, even though the direct sunlight available in the Northeast may only total one half that available in the sunniest region of our country, there appeared to be a real potential for cost effective solar hardware even seven years ago. The energy user who could diversify into alternative energy sources could reduce the impact of sudden fuel price increases and also reduce the risks of having to shutdown operations because of a lack of sufficient heat, process steam or conventional cooling.

The two major hurdles we had to overcome before we could begin an extensive effort to produce active alternative energy equipment were:

1. To provide solar energy even during the harsh cold weather for which the northeast is infamous, and
2. To provide this alternative energy at a price competitive with traditional fuels.

With energy consumption increasing worldwide we believed that, in a reasonable amount of time, prices of traditional fuels would increase sufficiently to make focused solar energy a viable alternative.

Concentrating the sun allows heat losses to be minimized once the energy has been captured. Therefore, even sunlight during the winter months could be utilized. With the sun's energy being reflected from 864 square feet of mirrored surface onto a few square feet of heat transfer material, subzero temperatures become less of a factor in useful energy production.

Although focusing the sun overcame our first perceived hurdle without difficulty, it tended to amplify the effects of the second hurdle. Any complexity added to solar energy equipment increases the already large front-end costs associated with equipment which gathers significant quantities of low density energy. Our research efforts over the last seven years,

for the most part, were directed towards the need to develop mechanical and procedural methods for reducing hardware costs. See figure 1.

HARDWARE DESIGN

Major goals which directed our efforts in engineering cost effective designs for concentrating solar energy were:

1. The minimization of the overall weight of the solar energy collection equipment, while utilizing inexpensive materials;
2. The simplification of components and optimization of the number of different parts along with the manufacturing procedures needed to produce them;
3. The embodiment of designs which can be readily shipped, rapidly assembled and optically aligned, easily tested and quickly repaired by available labor; and
4. The incorporation of features and components which augment reliable, safe and durable operation.

Minimizing the weight of the collector prescribed the implementation of two concepts:

1. The distribution of forces from wind and gravity loading on the equipment, and
2. The use of a Fresnel concept.

Distributing the forces of wind and gravity over many parts allows lightweight components to be adequate for bearing the six tons of force anticipated from a 90 mph wind. The Fresnel concept is complementary to the concept of distributed loading. Eight thin one foot square mirror tiles treated for outdoor use have been supported by lightweight aluminum stressed-skin support panels which are pivoted on their centers of gravity to produce the motion necessary for elevation tracking. Using the Fresnel mirror concept and distributed loading permits wind to pass through the collector structure when the mirrored columns are positioned to "feather" in the wind like open Venetian blinds. The small surface area of each column allows common materials and construction techniques to meet the demands on these parts for stability and durability. Consequently, material weight is minimized and the corresponding cost associated with material quantity avoided.

The simplification of components and their material manufacturing processes was aided by several iterations of design, and construction of several generations of prototype equipment. Our current designs use large numbers of identical parts. Because the demands for strength in any one of these parts is small, exotic materials are avoided. During the

installation of equipment at a site, special erection equipment is usually unnecessary due to the manageable size of individual parts. We found these choices in design promoting our goals for reducing the overall installed cost of equipment.

The embodiment of practical aspects of design which provide the packer, shipper, site erection crew and operator with items which make their jobs easy, promotes acceptance of the technology and enhances its cost/benefit ratio.

We have found that by incorporating operational schemes, such as keeping the reflector surface upside down except during operation, limits reflector exposure to dust, ice, snow and vandals and enhances safety. Upon loss of power or occurrence of other stop parameters, the unit returns the mirrors to this inverted position "over the top" so that the intense focused radiation at no time comes below the receiver. The design of other components and software subroutines incorporates this kind of failsafe orientation. We have found that "add on" safety packages are seldom as reliable, and have an undesirable "add on" cost.

Although developing the objectives for our goals demanded more common sense than any other resource, the technical capabilities of Rensselaer Polytechnic Institute, the organization within which we performed our research, were essential to every stage of finalizing and testing component designs. With the right combination of simplicity and complexity, we believe we have achieved a design for collecting solar energy which is compatible with the special needs of our region of this country.

SYSTEM TESTING

Based on the preliminary work and receiver heat transfer analysis, two receiver designs were selected for manufacture and testing. The first was a conically wound copper monotube boiler with 30 degree cone half angle, and the second, a steam unit heater employing steel tubes with aluminum fins. (See Figs. 2 & 3).

Solar energy input was determined by an Eppley normal incidence pyrhelometer with a 5 1/2 degree aperture which had been recently calibrated by the Atmospheric Sciences Research Center in Albany, N.Y. This was coupled to a strip chart recorder which provided a record of instantaneous insolation readings. Integrated values corresponding to the discrete time periods for collector output measurements are utilized to calculate collector efficiencies throughout the day.

Output was determined by measurement of the quantity of water converted to steam and the pressure of the saturated steam transferred to the RPI steam system. System efficiency figures include losses from 120 feet of insulated steam line. Water flow was calculated by two methods: 1) by a Badger Recordall Flowmeter and 2) by measurement of lost weight from the boiler feed tank. The test fluid loop is illustrated in Figure 4 . Note

that steam condensate is returned to the boiler feed tank from the steam trap. In the test of the fin tube boiler, the variation of efficiencies to some extent are a function of water source. That is, part of the time water is fed directly to the boiler from the city water supply at 60F. When sufficient condensate accumulated in the feed tank, the water source was switched to the feed tank at >150F.

The results of performance testing of these boilers are presented in Figures 5 and 6. The fin tube boiler exhibited an average daily efficiency of 57%. The conical monotube boiler had an average daily efficiency of 68% and a peak efficiency of 79%. The graph of the test results indicates the dependence of efficiency on solar conditions. The collector has an effective aperture much less than the pyrhelimeter. Thus the pyrhelimeter accepts a greater amount of circumsolar radiation.

Significant improvements in performance can be expected when the department store mirror tiles are replaced by thin low iron glass mirrors with 10% better reflectivity. Also, the forming of the curves of the reflector columns to more precise tolerances are now possible which will result in an additional improvement in performance. The fin tube boiler had very wide fins between and in front of the fluid tubes, which contributed to enhanced convective losses. The use of copper fins would improve the performance of this type of receiver.

CONCLUSION

This advanced point focusing solar technology has demonstrated potential for near term commercialization as an effective renewable energy technology. The unique design features combine to produce a highly-efficient, low cost, safe, adaptable, durable system which is simple to manufacture, install and maintain.

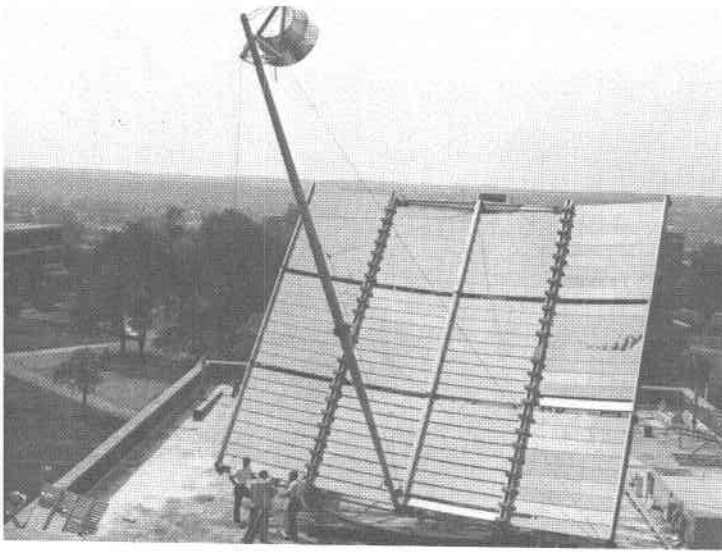


Figure 1: 80 SQUARE METER FRESNEL
CONCENTRATING SOLAR
COLLECTOR

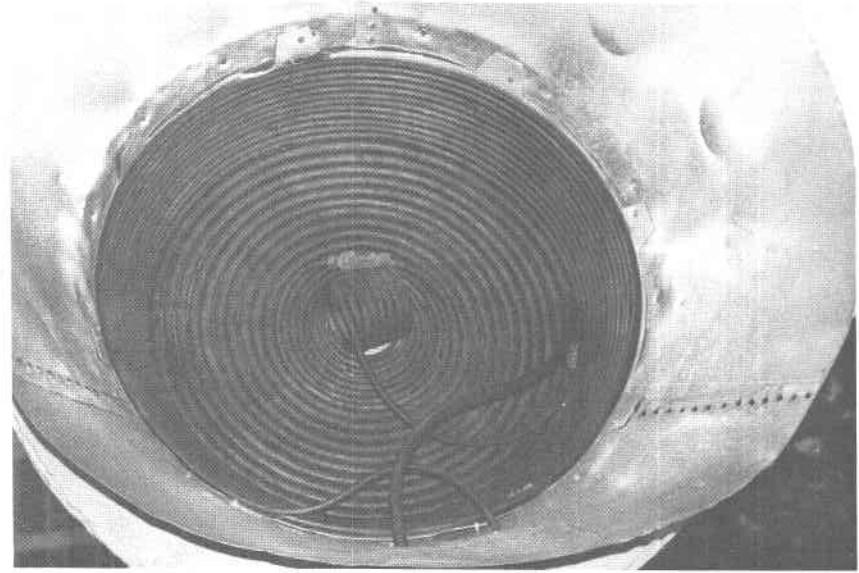


Figure 2: CONICAL MONOTUBE RECEIVER

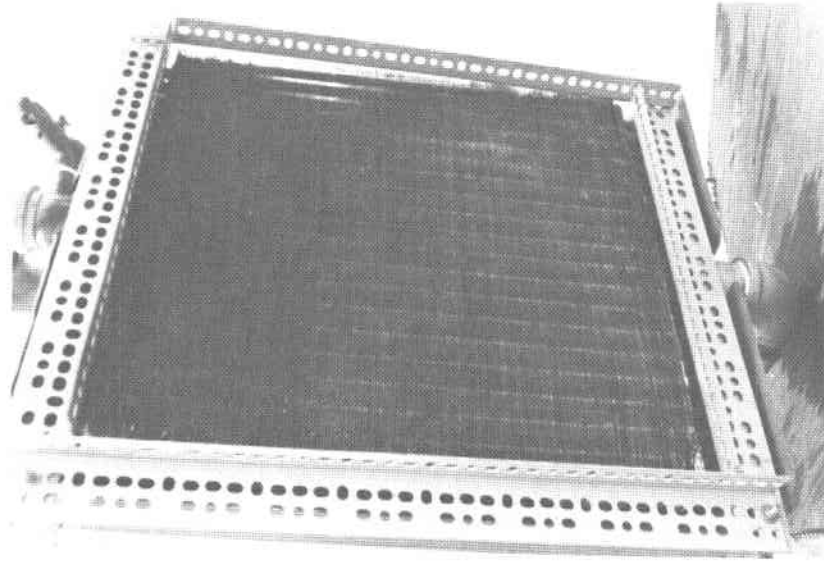
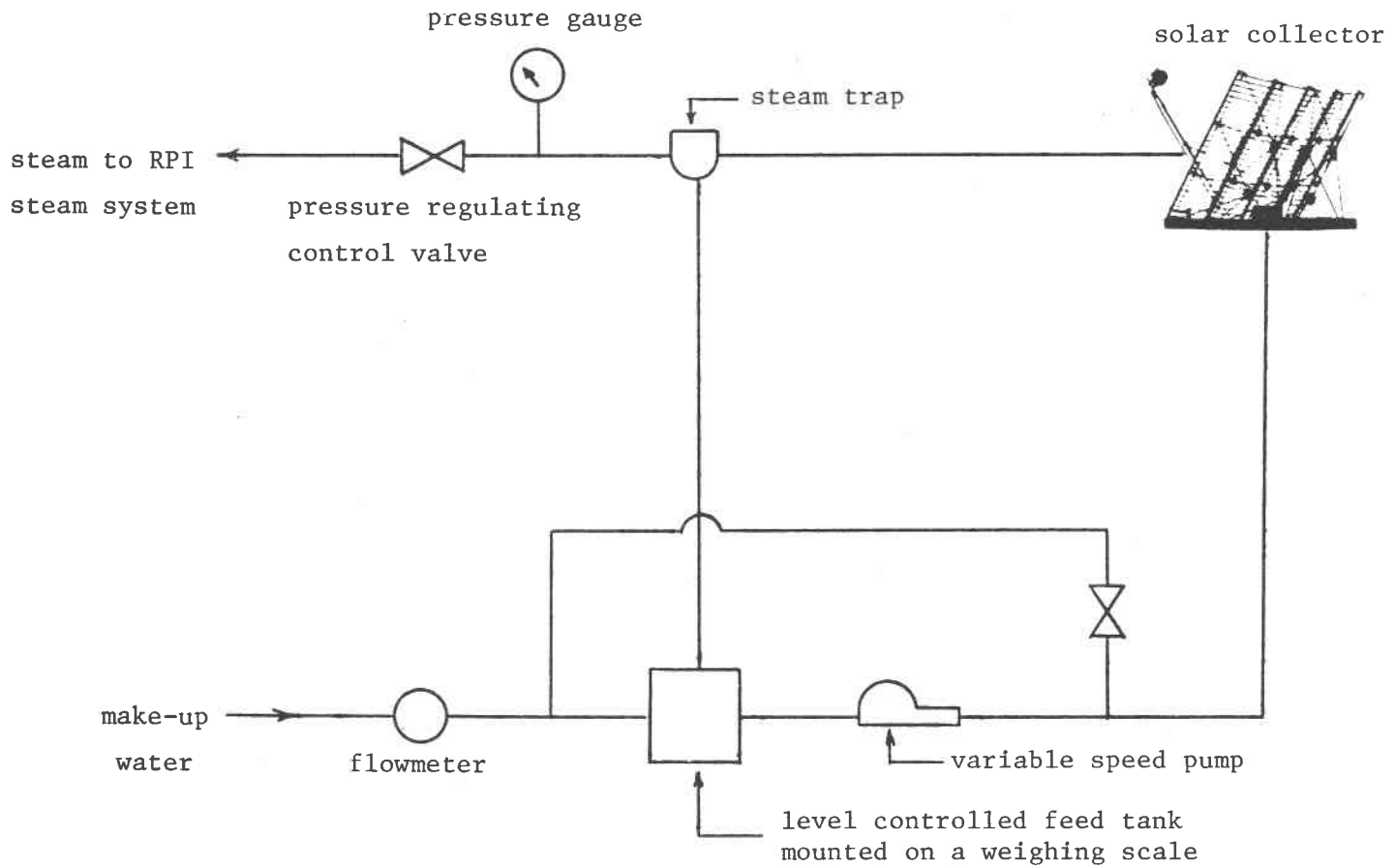


Figure 3: PARALLEL FIN TUBE RECEIVER



NOTE: Feed control for the monotube boilers is provided by the variable speed pump. For the fin tube boiler a level control valve maintains fluid level in the boiler and steam is taken off the top header.

Figure 4: POINT-FOCUSING SOLAR COLLECTOR TEST FLUID LOOP

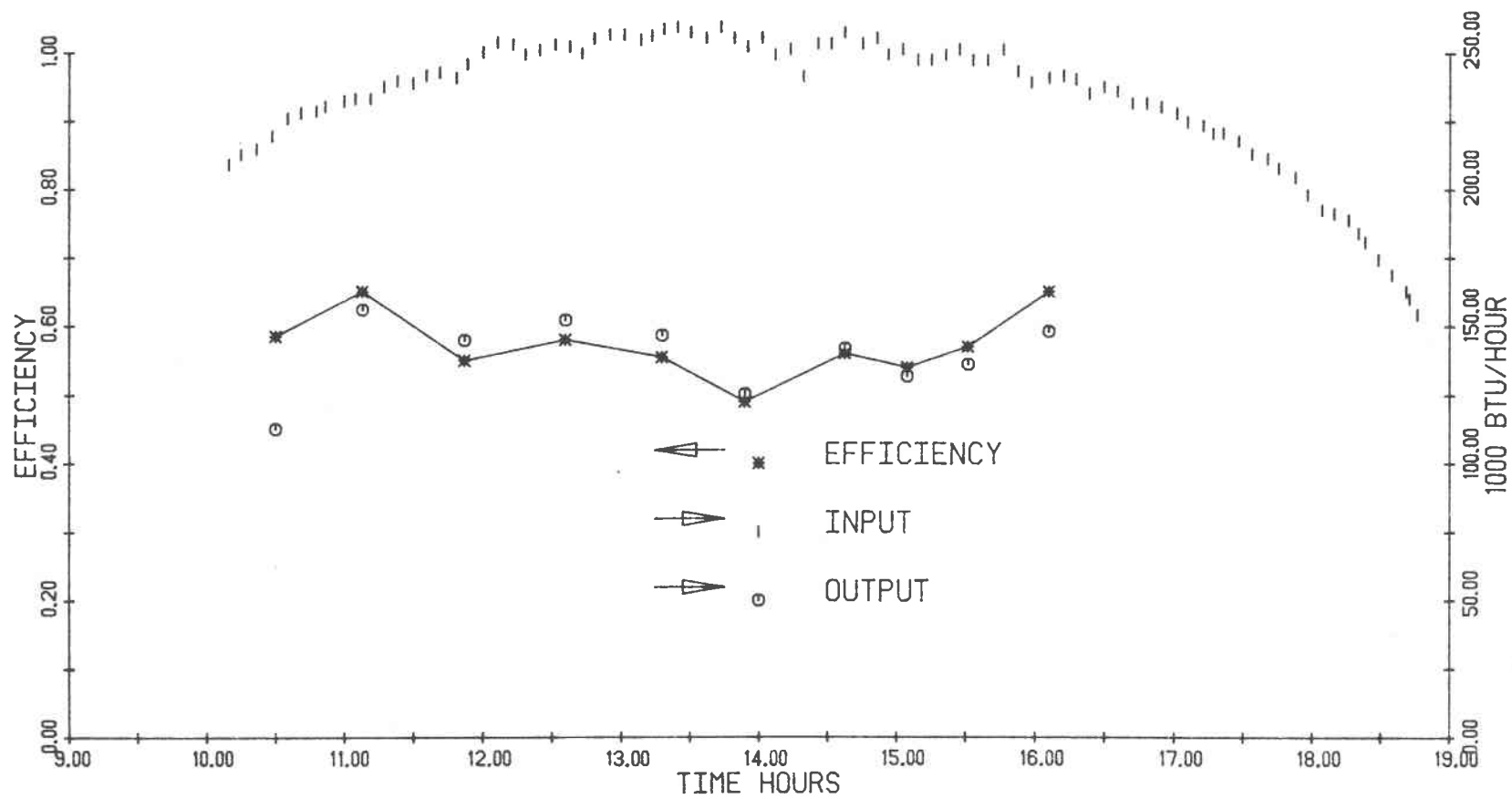


Figure 5: AVERAGE EFFICIENCY VS TIME 250 F STEAM OUTPUT, OCTOBER 9, 1980

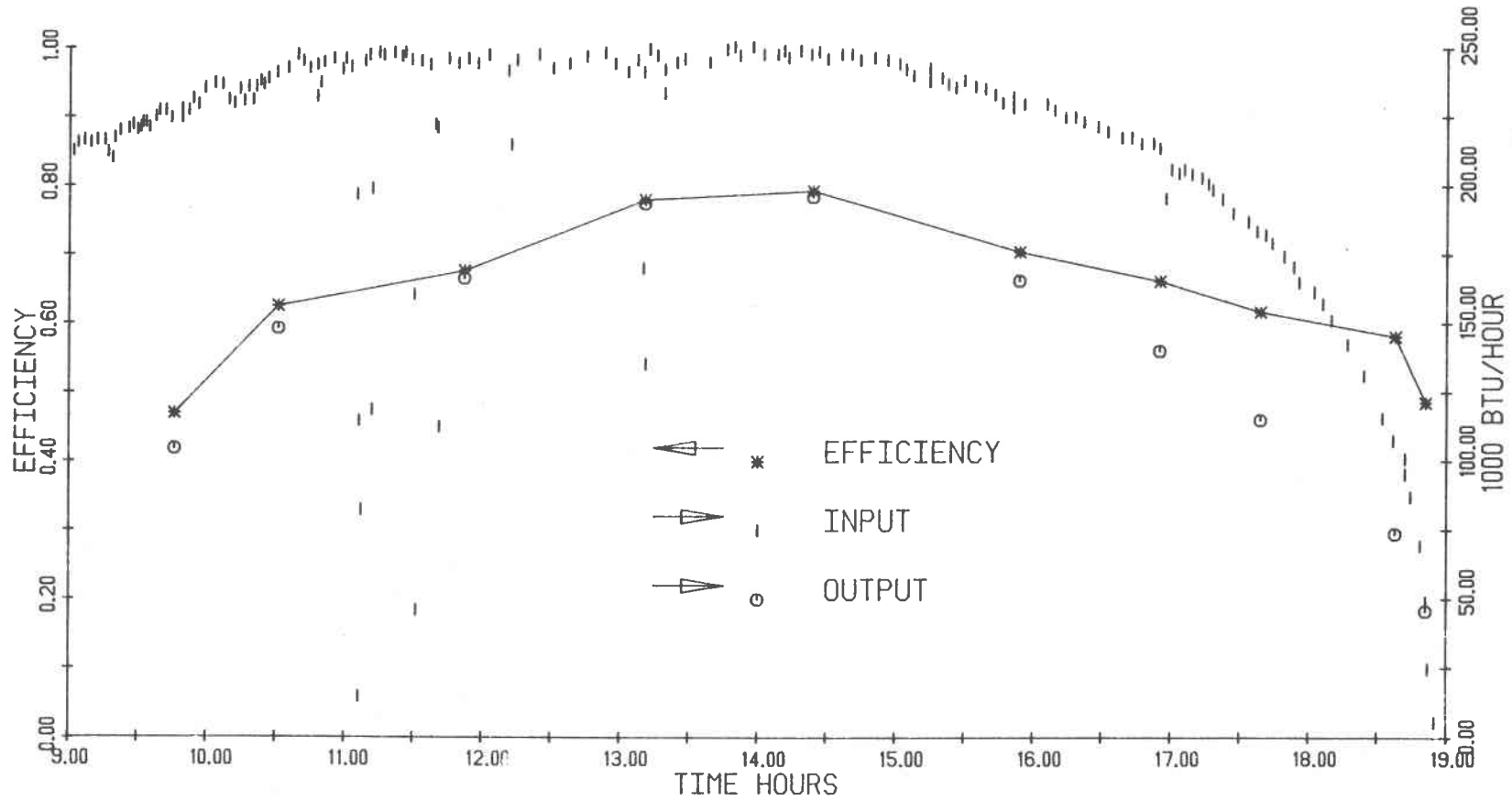


Figure 6: AVERAGE EFFICIENCY VS TIME 250 F STEAM OUTPUT, SEPTEMBER 8, 1980

LUNCHEON SPEAKER:

Marshall E. Alper

I spoke to Rusty Schweickart just before lunch and, as one might expect, the good old sun came out and burned off the fog in its old reliable way. But man, in his institutions and organizations, was not able to get the aircraft on the ground at Sacramento down here in time for Rusty Schweickart to be with us today. And that perhaps may be indicative of the real problems we all face. The sun is there, as we all know, and as Pogo once said, "we have met the enemy and (collectively) he is us." What Rusty and I thought might be an acceptable thing to do in his absence is to first let me introduce him to you, because should you ever have an opportunity to be someplace where he is speaking, I hope this introduction will encourage you to go out of your way to hear him.

Rusty Schweickart received a Bachelor and Masters Degree in Aeronautics and Astronautics at MIT, and stayed there in the research lab at the experimental astronomy laboratory where he worked as a research fellow. After leaving school, he joined the Air Force and logged over 3,500 hours in jet aircraft. In 1963, he was one of the 14 astronauts in the astronaut corps selection. He was command pilot for the Lunar Module for Apollo 9, which was only the third flight in the Apollo series. I believe during that series he logged some 48 or 50 minutes outside the vehicle. So in addition to 3,500 hours at supersonic speeds, he has got almost an hour of floating in space. He was also the backup commander for the first Skylab mission. As the backup commander, he was directly responsible for coming up with the technical and procedural workarounds that managed to get the sunshield into place, and managed to get the solar power system in place. He has had some interesting and exciting times, and some significant responsibilities in all of his endeavors. He served time at NASA headquarters, so he understands what a headquarters program office is like. I have observed that it is an experience which deserves our utmost respect. He was director of User Affairs in the Office of Applications. There, he had two primary responsibilities. One was the transfer of technology from space applications to other activities. The second was the responsibility of making sure that the applications activities of NASA appropriately understood and reflected the user's requirements. That experience is very relevant to our perspective today. He has served on Governor Brown's staff as an assistant for Science and Technology, a rather unusual position for a Governor to have. I think he performed that role most effectively. In August 1979, he was named by the Governor as Chairman of the California Energy Commission. This commission has responsibility for power plant siting, estimating California's energy supply and demands in the future, sponsoring and instigating conservation activities, and developing alternative energy supplies.

In that position, of course, he has had to worry a lot about technology, economics, and the politics of energy in a state the size of California, which is a big responsibility. I am truly sorry that he could not be here today. I have heard him speak at meetings two or three times in the past 9 months. He has some useful and interesting insights into the future, which are very challenging. He did ask me to make a few points, which I could attribute to him, and then for the rest of my comments, he asked if I would please take responsibility for myself.

He was going to talk about his perspective of the energy picture in California as an indicator of things to come in the rest of the country. He considers that picture and its evolution over the past several years as an energy challenge. He suggests that the past 4 or 5 years--and the next 5 or 10 years perhaps--have been and should be devoted to the questions which concern the types of energy investments, capital investments, or people investments one should make to begin future world change. He feels that the effort is successful, and recognizes clearly that it is not something that happens rapidly and that the payoff will come in the '90s, when we will see a large number of potentially attractive energy options from which people will be able to choose. In a biannual report to the legislature and the Governor, which his commission is obliged to do by legislation, he indicated that the problems will concern the many options to be chosen, which option the regulatory bodies will find favorable and public cost. We will find ourselves with a plethora of choices, which in a democracy may, in fact, make the situation worse, not better.

Rusty feels that with a number of alternatives started, we then have to face another very strong and pressing reality. That reality is our excessive dependence on sources of oil over which we have no control. He feels that a two-pronged approach consisting of substantial reduction in that dependence, in parallel with preparing for what we do in the eventuality that some major interruption occurs before that substantial dependence is eliminated, is necessary. His comment was that he feels the likelihood of having a substantial interruption before we have substantially reduced our oil dependence increases every day.

Clearly, these are problems to which any new, developing technology is not going to provide an immediate solution. Specifically, with respect to solar, he feels that it is coming eventually for a number of reasons. We have a need to reduce our use of combustible fossil fuels in the environment in order to reduce the production of carbon dioxide and acid rain. Several years ago acid rain was something you read about in the papers in Sweden; now you read about it in the papers in New York State and Connecticut. Clearly, the switch to potentially new fossil, that is, bioenergy sources, as opposed to old fossil, will help alleviate the carbon-dioxide problem, but it still does not help to reduce the acid rain.

Rusty also would have reminded us that, of course, in California as in most of the country, the primary short term problem is portable fuels for transportation, and not electricity. So, if we bring our problems as electric producers to him, forgive the fact that he has some other things that are perhaps more pressing on his mind. In that case, of course, solar-thermal technology has a very distinct advantage over some of its competition in the solar energy world. Solar thermal technology can produce either electricity or thermal energy which is useful in a variety of processes to produce fuels and chemicals. The comments just concluded are the things that Rusty would have said. He would have used some personal experiences in the space business, which of course I cannot duplicate, and will not try to. He also would have added some other insights which come from his very special position as chairman of the Energy Commission.

Let me now try to add some observations of my own. I will draw on two speeches I heard Rusty give in the past 6 months, a series of seminars at Caltech held last spring, and since we are a Caltech-influenced organization,

a series of internal seminars which we periodically hold for people from venture capital companies, public utility commission staffs, and similar organizations. We have, as an institution, an ability to develop some different perspectives. Let me try to form some pictures for you based on some of those perspectives.

Let me project a future, let me look at it, and then from that position, let me look back a little bit with you. Suppose we are successful. We, in fact, have a set of value-oriented goals. Our success reflects itself in a viable commercial industry of suppliers who sell for a profit and users who buy because supposedly what they buy provides them some value. That raises some interesting questions. Will the profit potential in that future be adequate to command the capital investments on the part of the supply side of the equation? From the other side of the equation, will the benefit be enough to make an adequate market for that supply side? We can have some interesting markets that make suppliers interested; in terms of the technology, we can have some interesting benefits which make users interested. However, will the scale of the market of those interested users match the scale of the market which those interested suppliers require in order to be able to make a marriage? Clearly, both of those questions have lots of interesting issues associated with them.

From the supply side of the equation, the adequacy of the profit potential has to be considered, and this very much depends on the company that is involved in the consideration. Let me be oversimplistic and, with no offense to anyone, try to divide the supply side into three classes of companies. One is a large successful manufacturer who now has a successful business and now uses production technology that is required to build our kind of distributed dish solar technology. Another company is perhaps middle size, got into the solar business some years ago and like in so many of the other solar options, some nice oil company provided capital in return for a substantial controlling interest. Finally, we have the very small struggling company, which has always been the source of some of the most innovative ideas and new developments in American technology. The question of adequate ROI is obviously very different to each of those companies. You can be big and successful, but unless you are in the position of the oil companies, you do not have the same tax considerations. If you are very small, you probably worry a lot more about cash flow than ROI. So, at least in that perspective, the adequacy of profit potential can be viewed with a number of different perspectives. When somebody says, "This is what our program has to do to help," I would hope that DOE and the project office do not forget that we have to recognize that spectrum of you out there.

Because the users see a substantial return in having bought our products, there are also a number of issues. The users reflect a variety of capital availability situations, a variety of tax situations, and a variety of regulatory situations. As a result of these different situations, one sees the potential for third party ownership where neither the seller nor the user owns the hardware. I do not know how many of us think about third party ownership. I do not know how relevant it is and I have not thought about it too much with respect to our particular technology. But I know other places that have. There was a proposal made to Hawaii using windmill technology, which was a third party ownership situation. If it is applicable for wind technology, it would seem to me that the supply side in the dish technology business ought to be thinking about that also.

Another question is the cost of energy to the user. Here the cost depends on who the user is, and it ultimately depends on how 50 state energy commissions and public utility commissions will interpret PURPA, the law that was passed last year which affected the privately owned utilities. It requires that the utility pay a cogenerator and/or an independent generator for electricity produced, and the utility must charge the user a reasonable rate when the utility provides them with electricity. Those terms were not specifically defined, and it will be up to the 50 state Public Utility Commissions during the next 2, 3, 4, 5, or 10 years, to define them. Those definitions will have a large impact on how the user sees our technology and the benefits it can provide him.

Finally, there are the user's characteristics in terms of his demand for energy and the availability of sun. A couple of years ago we studied the electricity demand in the San Fernando Valley in relation to the sun availability. We did it on a disaggregated basis. We looked at it on a Department of Water and Power substation-by-substation, service territory basis. In some of those territories, the coincidence between demand for electricity and availability of sunshine overlapped at the peak by about 90-95 percent. In other areas, the mismatch was to 50-60 percent. Again, we found that a distributed technology makes us think in terms of disaggregated requirements. Looking at it from this disaggregated way, we are very likely to open up some very interesting business opportunities which we might not see if we did not have to look at our problems in that manner.

Assume that all these pieces fit together and we, in fact, do wind up a success. What character can that success have? Let me postulate two alternatives again for simplicity's sake. The first alternative is one of small, specialized markets where there is a match between the technology, its price, the demand, and its value. This will be extremely beneficial to some of the smaller companies in the business. Some of the larger companies will eventually decide that if that is all there is it is not for us, and they will leave. Some users, who otherwise would be in a very tight bind, will be served by the companies which stay and will be very much relieved. I personally feel that this state of affairs is a very important one because the isolated users are part of this country also. The fact that they hurt a lot and that there are not very many of them, does not mean we should ignore their needs. They are still part of the country. It clearly becomes a Headquarters problem to consider how much public investment we make to satisfy those needs. That is what politics is all about.

The second alternative is the opposite end of the spectrum: A technology, highly successful from a price and value point of view, and a technology consistently used. A nice future? Let us look further. If we are that successful, it is safe to presume that some of our competition will also be successful. When that happens what would the user look into? He looks into a utility. I will describe what I think that utility might be in a few minutes because it is going to change also. But the competition will have our dish technology and the space power satellite technology. He may have small power towers, trough collectors, solar ponds, very advanced cost batteries, fuel cells, and natural gas-fired engines of various sizes. Those engines, under certain conditions of electricity and heat production, may be the best of both

possible worlds, particularly if the gas was locally generated from biosources which otherwise would be wasted, or if the gas has to be burned to contribute to the carbon dioxide content of the atmosphere.

The message is that if we are successful, it is likely that the competition will also be successful and that some of that competition is going to be outside the solar business. Take those other successes and add modern electronics. Let me specifically say two kinds of things that modern electronics can deliver. One of them is clearly an order of magnitude change in the character, quantity and utility of communications. The second is the absolutely staggering increase in capacity as a function of cost of small local computing. These characteristics could very easily lead to an energy-market place situation in which the utilities evolve to where they, in fact, become the energy stock-market, so to speak. They arrange the transactions, they take 5 percent off the top to arrange all the buying and selling, and they provide the pathways through which the energy flows. Some of those energy flows come from what they still own in the way of a central station here and there. The rest comes from 200,000 people who own one of those sets of technologies I mentioned earlier. You, as an individual, whether it be in the home or a company, have your local electronic controller of energy sales. You plug some of your criteria into this convenient computer which has an interactive display, and you see what the energy price is currently for electricity. You make a real time decision about keeping your solar generator going, or shutting down something in operation and selling the electricity instead.

That scenario is sort of far out and speculative but I think it is indicative of the character of change we have to be able to think about. Certainly, I am not predicting it is going to come next year or in the 1990s. I do not think anybody can predict when that will come. It will come when we need to use it, because it is better than the alternatives. Certainly its coming will be governed by how fast and how efficiently we provide some of those alternatives. It also depends on how fast some of the outside pressures that relate to natural gas, oil, coal and nuclear sources begin to make these alternatives look less attractive than the solar alternatives which we are working on.

With that as a potential future to look forward to, I think you will agree with me that being part of this program turns out to be a lot of fun and very exciting. And, if we are successful, our work will prove to be extremely important to the future stability of the democracy in which we live. How we get there from here is clearly a question we need to address, and without solving that question, anything I have said thus far is interesting but also pointless.

I think the workshop sessions last night, and the ones we have tonight, are an important initiation of a formal dialogue between us at the laboratory representing the program office, and you all out there who are the industries participating in the program one way or another. I think it is a very important dialogue, and we would certainly like to hear from you on how effective you think these kinds of sessions are, or what we can do to improve them. I can promise you one thing, we will listen to you. I can also promise you another thing. We will not always be able to do what you require or request

of us. We have an obligation to take the best information we can get, and provide it to the program management people at the Albuquerque Operations Office and at Headquarters. We provide them options, our best estimates of costs. They make decisions. They usually involve us in the decision making and then we stand ready to help implement those decisions.

From my perspective, you can help best if in your own meetings, and in your participation in the workshops such as the one last night and the one tonight, you recognize your own diversity. Recognize that we have an awful lot of trouble responding to a single voice in that sea of companies out there. We have to digest the information from a diverse set of voices. When advising Headquarters we must recognize that we do have a spectrum of companies, a spectrum of circumstances, and the more balance we can put into the advice we give to Jim, the easier it will be for him and the other people in the program office to defend, to rationalize, to sell and to provide all of us with a program that permits us to get to that future I talked about.

Session IV

APPLICATION EXPERIMENTS

Session Chairman: A. Marriott, JPL

THE SMALL COMMUNITY SOLAR THERMAL POWER EXPERIMENT

The Small Community Solar Thermal Power Experiment had its beginnings in 1977 when Congress, in response to strong and continuous community pressure, sought to provide alternative electric power supplies which demonstrated reduced dependence on non-renewable sources. To help meet this problem, Congress appropriated funds for a five-megawatt solar thermal demonstration, but the proposed plant was reduced in size to one megawatt when it was decided that this smaller facility provided a valid model at lower cost. The technical programs undertaken at JPL were augmented by market and commercialization studies to establish cost goals to which engineering decisions and achievements could be compared.

To insure that all solar thermal technology options would be considered, a concept definition phase was initiated in which competitive studies were to be performed in each of three categories. These categories were:

- Category A General (to include, but not be limited to, central receiver and line focusing systems).
- Category B Point-focusing, distributed collector, central power conversion.
- Category C Point-focusing, distributed collector, power conversion at the collector.

A multiphase approach was adopted as the best means of meeting the objectives of the experiment in the shortest period of time. Phase I addressed the problem of exploring all competitive technologies for this application and recommended those which should be studied in greater detail. Competitive bids were received in each of the above listed categories, and awards were made on the basis of merit. One contractor was selected in each category.

Within Phase I the contractors were asked to develop a preferred system concept, to perform sensitivity analyses, and to outline recommended approaches for the follow-on Phase II design program.

The systems recommended by the contractors in each of the categories were:

McDonnell-Douglas Astronautics Company: Central tower with field of south-facing heliostats.

General Electric Company: Field of parabolic dishes with steam piped to a central turbine-generator unit.

Ford Aerospace and Communications Corporation: Field of parabolic dishes with a Stirling cycle engine/generator unit at the focus of each dish.

A brief description of each of the proposed experimental plants follows:

A. McDonnell-Douglas Astronautics Company (MDAC)

The system proposed by MDAC is similar in principal to the 10 MW central tower solar plant now being constructed near Barstow for Southern California Edison, but the plant and tower are smaller in size, and the field of heliostats is distributed south of the tower, rather than surrounding it as it does in the Barstow plant. The tower assembly is a guy-wire supported lattice structure 131 feet high supporting the receiver as well as the thermal transport fluid (HITEC) riser and downcomer.

Steam produced from the steam generator drives a steam Rankine cycle turbine which in turn drives an electrical generator to produce electricity. A power plant building contains the entire power conversion subsystem with the exception of the cooling tower and waste water pond. The balance of plant equipment employs state-of-the-art equipment and techniques.

B. General Electric Company (GE)

The General Electric concept was derived in great part from the plant being designed by them as a total energy system for the Bleye plant at Shenandoah, Georgia. This design makes use of a field of G.E. Low Cost Concentrators to generate steam which is then transported through low loss piping to a central steam turbine generator unit. The collector field is split into two parts: those dishes which carry saturated steam and those which extend the heating into the superheat range. The central steam turbine and balance of the plant are adaptations of existing, well proven components.

C. Ford Aerospace and Communications Corporation (FACC)

The system concept selected by Ford Aerospace and Communications Corporation in the Phase I study is composed of multiple dish concentrators employing a Stirling cycle heat engine with direct-coupled AC generators for power conversion at the focal point of each concentrator. Each module includes the parabolic concentrator and a cavity receiver with an integral sodium pool boiler, the sodium thermal transport hardware, and the engine/generator assembly. The proposed parabolic dish concentrator is a front-braced design with an Az-El mount and tripod structure with a reflector surface composed of back-surfaced, high-reflectivity drawn fusion glass mirror segments.

Soon after the completion of the Phase I studies, the Department of Energy directives and ongoing technical studies at JPL and elsewhere resulted in the decision to employ Category C, parabolic dishes with distributed generation for this experiment. This decision meant that Ford, the successful contractor in this category, was to continue in Phase II. On the basis of energy cost, the energy conversion subsystem recommended by Ford made use of the Stirling cycle, with the Rankine cycle engine ranked second. In the light of ongoing engine studies at Lewis Research Center and at JPL, (which indicated that Stirling engine technology was not yet ready for field experiments) it was decided to incorporate the Rankine cycle engine in the configuration selected for design and test in Phase II and III.

Also, budget constraints combined with promising and timely results in the Point-Focus Distributed Receiver Technology (PFDRT) development program forced the decision that subsystem development within the experiment be minimized. Instead, designs for appropriate subsystems were to come from ongoing development work or from other existing sources. The G.E. Low Cost Concentrator was thought to be the most promising candidate for use with the experiment.

In August 1979, a sole source RFP was issued to Ford Aerospace and Communications Corporation soliciting its participation to act as system contractor for Phase II of the experiment. The contractor was asked to conduct a preliminary design, component and subsystem development, subsystems and system level verification testing, and detailed design. Ford was also asked to complete the plans for site preparation and hardware implementation. As indicated above, the technology was restricted to distributed energy conversion using the Rankine cycle.

DEVELOPMENT OF THE SMALL COMMUNITY
SOLAR POWER SYSTEM

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ABSTRACT

This paper presents the status of the Small Community Solar Thermal Power Experiment (SCSE Program). Current activities on the Phase II single/module development effort are presented, together with plans for the Phase III 1 MW_e demonstration plant. A description of the various subsystems and components is given with particular emphasis on the unmanned microprocessor-based plant control subsystem. Latest performance figures are given for the 1 MW_e plant, based on 56 power modules, each consisting of a G.E. 12m Low Cost Concentrator, a FACC cavity receiver, a Barber-Nichols Organic Rankine power conversion subsystem and a ground-mounted solid-state rectifier. Overall plant efficiency at rated conditions is 15.8 percent. Advanced glass concentrator designs yield 20 percent overall efficiencies.

INTRODUCTION

The Aeronutronic Division of Ford Aerospace & Communications Corp. (FACC) has been under contract (1) to JPL since 27 December 1979 for Phase II development of the Small Community Solar Thermal Power Experiment (SCSE). This program is the first experiment (EE-1) in the Engineering Experiment series of the Parabolic Dish Project managed by JPL for the U.S. Department of Energy (DOE). The EE-1 concept is classified as a Point-Focusing Distributed Receiver (PFDR) system with Distributed Generation. It is a modular system, comprised of multiple power modules interconnected by a conventional electrical system, with provision for utility grid-connected operation. During Phase II, a single power module is being fabricated and subsequently will be tested at the JPL Parabolic Dish Test Site (PDTs) at Edwards AFB, California. In the follow-on phase (Phase III), a complete 1 MW_e plant, composed of approximately 56 power modules, will be fabricated and installed for test at a site to be selected by DOE.

Each power module, as shown in Figure 1, is comprised of a parabolic dish concentrator with a Power Conversion Assembly (PCA) mounted at its focus. The PCA shown in Figure 2 consists of a cavity receiver and a Power Conversion Sub-system (PCS) comprised of an organic Rankine cycle (ORC) engine and a high-speed, direct-coupled permanent magnet alternator; a solid-state rectifier is located at the ground. Maximum gross weight of the PCA is 680 kg (1500 lb.); over-all length is 2.38 m (7.8 ft.) and maximum diameter is 1.124 m (3.7 ft.). The PCA and its associated support structure block approximately 1 percent of the incoming solar power.

(1) Contract No. 955637

PROGRAM STATUS

The SCSE master schedule is shown in Figure 3; a Preliminary Design Review (PDR) was successfully completed on 27 June 1980 and the System Design Review (SDR) is scheduled for 28 January 1981. As currently planned, the PCA will be shipped to the Edwards PDTs by mid 1981, after thorough testing of the receiver at Aeronutronic and subsequent testing of the combined PCS and receiver - on electrical heat - at the Barber-Nichols facility. The Plant Control Subsystem and associated electrical interface equipment will also be tested at Aeronutronic, then delivered to the PDTs for integration (with the PCA and the General Electric Low Cost Concentrator [LCC]) into a functioning EE-1 power module. The hardware will be tested under field conditions for 5 months under the existing contract; the intent of the field test operation is to verify the EE-1 design as a prerequisite to fabrication/installation/demonstration of the complete 1 MW_e EE-1 plant during Phase III of the SCSE program.

A second power conversion unit is being procured from Barber-Nichols for the parallel Design Maturity Testing (DMT) program. This unit will be in continuous operation at the Barber-Nichols facility - driven by an electrically heated boiler - primarily to ascertain long-term durability on all power conversion components. The test rig will also simulate the effect of engine attitude orientation - in real time - and achieve accelerated life testing. The lessons learned from the DMT program will be incorporated into the PDTs test unit as required, either in the form of hardware replacements, changed operating procedures, revised maintenance procedures, etc.

SYSTEM DESCRIPTION

The LCC, the ORC-PCS and the FACC receiver are presented in detail elsewhere in this Program Review and will not be repeated here. The Energy Transport Subsystem (ETS) and Plant Control Subsystem are also important elements of the EE-1 system, however, and are discussed below.

Energy Transport Subsystem (ETS)

The ETS is comprised of 1) a conventional dc electric system which interconnects each power module, 2) central static dc-to-ac inverter(s) for power conditioning and voltage/load control and, 3) associated equipments for grid interfacing and synchronization. The system is designed to operate at 600 volts, interfacing with a 4800 volt (typical) utility distribution line. Facility power is used to drive the individual concentrators, PCS accessories and the control room; an uninterruptable power supply (UPS) is provided for power when the grid is out and self-generated power is not sufficient to operate the system. A load bank is also provided to dissipate stored energy during grid out/concentrator de-track operation. The major benefit of the dc approach is that it permits the speed of the ORC engines to be varied with the change in solar insolation in order to achieve high part-load efficiency and hence high annualized performance. In addition, the use of the central inverter(s) for voltage/load control eliminates any need for individual field control of the alternators, as discussed below. Finally, grid synchronization in frequency and phase is much easier,

since an ac system would require synchronization of each engine whereas this system is accommodated at the central point of grid contact.

The ETS is being modified for the Phase II tests at the JPL-PDTS to accommodate certain differences in the grid interface and existing JPL equipment at the site as well as the fact that only a single module will be tested. However, basic principles of the Phase III design will be demonstrated

Plant Control Subsystem

The SCSE plant control subsystem is being designed for automatic, totally remote (unattended) operation. Manual control capability will be provided for installation, check-out, testing and maintenance. General functions are 1) automatic/manual control of all plant subsystems, 2) coordinated sequencing of plant subsystems for all operating modes, 3) failure protection and 4) status monitoring.

Operating Principle

The plant control system will operate the plant with high efficiency under continuously varying solar energy input. It is also simple in concept and provides totally stable operation in all possible modes. There are three elements of the concept: 1) concentrator control, 2) fluid control and 3) turbine speed control.

Concentrator control consists of 2-axis tracking and associated sequencing, e.g., start-up, shut-down, emergency de-track, etc. The essential feature of the LCC tracking concept is its dual operation, i.e., 1) coarse tracking via computer-stored ephemeris data and concentrator angular position sensors and 2) fine tracking via auto-nulling of optical (sun) sensor signals.

The fluid control loop operates the coupled receiver and ORC engine to make certain that 1) the net thermal energy absorbed by the receiver is transmitted to the engine in concert with the time-varying solar energy input, and 2) high part-load efficiency is achieved. These requirements are met by adjusting the working fluid (toluene) flow rate - via a flow control valve at receiver outlet - to maintain virtually constant turbine inlet temperature. The combination of constant turbine inlet temperature and optimum turbine speed (as discussed below) serves to maintain nearly constant PCS efficiency over a very wide range of solar input.

An additional control requirement is to maintain the turbine speed at near optimum so as to maximize turbine/alternator overall efficiency. This is done by providing a constant-voltage load for the individual alternators, (or, equivalently, a constant alternator output voltage is maintained), and the speed is then controlled by the balance of the power applied to the turbine and the power absorbed by the alternator. The constant-voltage load is produced by the inverter, which has an active circuit that senses its input voltage and varies the duty cycle of the SCRs so that the effective input impedance is

varied so as to draw the current required to keep the alternator output (or inverter input) voltage constant. The resulting turbine speed is very close to optimum if the appropriate alternator impedance is selected. With multiple power conversion units connected to the inverter(s) in a parallel electric circuit, the voltage across each generator's terminals is the same and is determined by the equivalent impedance of the complete circuit, which includes the inverter. The inverter impedance can thus be varied to maintain constant voltage in the face of continuously varying solar input. Power output variations among 1 or more engines are thus represented by current variations in the electrical circuit. Individual alternator field control is thus avoided and all power units are controlled by the central inverter. Additionally, alternator and turbine torque/speed characteristics are matched by careful design of the equivalent alternator impedance so that the imposition of constant voltage assures operation at or near the speed which yields highest turbine efficiency.

Hardware Implementation

A central digital microprocessor or Master Power Controller (MPC) is provided for mode control, sequencing, protection and monitoring of all plant subsystems. The flow control loop and other PCS control functions are mechanized in the Remote Control Interface Assembly (RCIA) microprocessor which is located at each power module and slaved to the MPC. As currently envisioned, concentrator pointing control will be shared between the RCIA and the MPC, with the latter providing the sequencing and coarse tracking commands while the RCIA performs the fine suntracking control.

SYSTEM PERFORMANCE

Each module will produce approximately 18.3 kW_e of ac power at rated conditions (1000 W/m^2 and $T(\text{amb}) = 28^\circ\text{C}$) at the output of the central inverter (19.6 kW_e dc output at the rectifier). At these conditions, a 56 module plant will produce about 1 MW_e when all plant losses (ETS, parasitics, etc.) are included. Table 1 summarizes performance by component and includes annualized figures for the Barstow, California site based on 15-minute environmental data tapes for 1976.

Peak output for a 56 module plant, corresponding to a solar insolation of 1100 W/m^2 , is approximately 1118 kW_e .

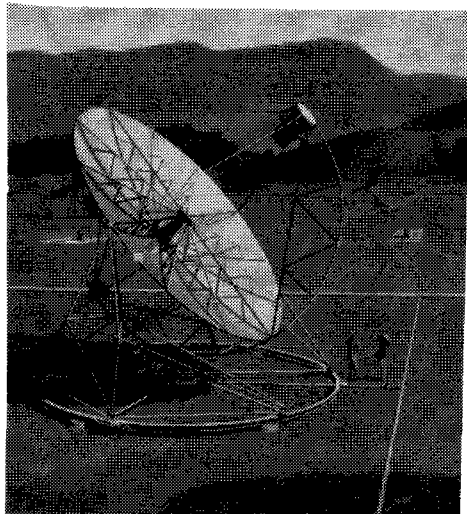


FIGURE 1 EE-1 POWER MODULE

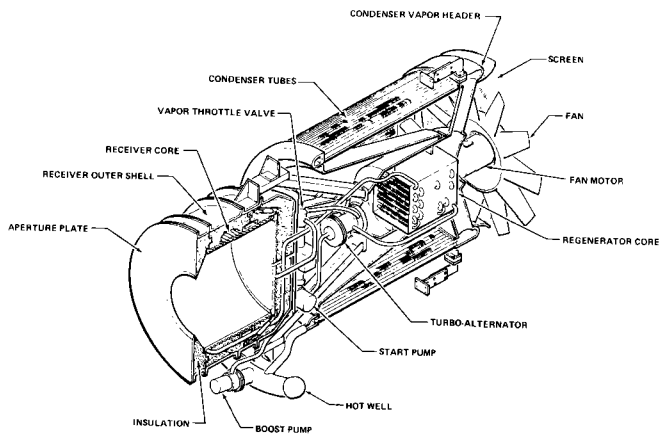


FIGURE 2 EE-1 POWER CONVERSION CONVERSION (PCA)

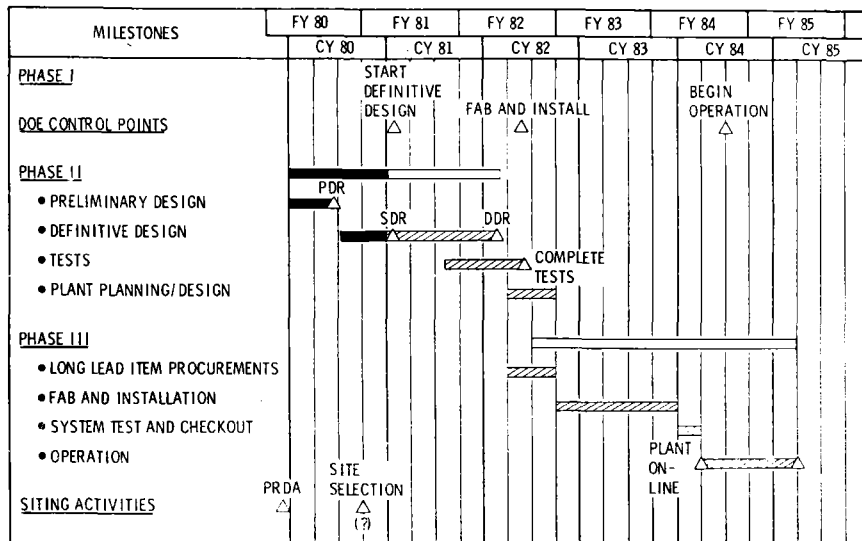


FIGURE 3 EE-1 MASTER SCHEDULE

TABLE 1 SCSE SYSTEM PERFORMANCE

Parameter	Value	Conditions/Comments
<ul style="list-style-type: none"> • Net power delivered to grid 	1001 kW _e (56 modules)	At rated conditions: <ul style="list-style-type: none"> • Insolation = 1000 W/m² • T_∞ = 28°C
<ul style="list-style-type: none"> • Plant efficiency (end-to-end) 	0.158 (plastic reflector) 0.200 (glass reflector)	At rated conditions and average LCC reflectivity
<ul style="list-style-type: none"> • Component/subsystem efficiencies 	<ul style="list-style-type: none"> • Collection Eff.=0.669 (= 0.817 with glass reflector) <ul style="list-style-type: none"> -Concentrator (0.691) -Receiver (0.971) -Intercept (0.998) • PCS Eff. = 0.258 • ETS Eff. = 0.935 • Plant Parasitics = 0.978 	<ul style="list-style-type: none"> • Concentrator Eff. includes: Reflectivity = 0.78, Dust = 0.95, Blockage = 0.932 • Concentration Ratio = 1000 Barber-Nichols calculation System Analysis 8 kW _e + 250 W/module for A/C, stationkeeping, drives, etc.
<ul style="list-style-type: none"> • Annual performance (plastic reflector) 	<ul style="list-style-type: none"> • Output = 2621 MWh/yr • Annual Capacity Factor (ACF) = 0.298 • Annualized Plant Efficiency = 0.147 	1976 Barstow data

SITE PARTICIPATION IN THE SMALL COMMUNITY EXPERIMENT

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ABSTRACT

The Small Community Solar Thermal Power Experiment (SCSE) has been planned to test a small, developmental solar thermal power plant in a small community application. The baseline plan is to install a field of parabolic dishes with distributed generation to provide 1 MWe of experimental power. Participation by the site proposer is an integral element of the experiment; the proposer will provide a ten-acre site, a connection to the electrical distributional system serving the small community, and various services. In addition to the primary participant, site study efforts may be pursued at as many as five alternative sites.

In 1980, 44 proposals for site participation in the SCSE, representing 24 states, were received by the U.S. Department of Energy (DOE). The extent and quality of the responses provide a great deal of encouragement regarding public interest in alternative energy in general and particularly in this solar thermal experiment. The 44 proposals represented a wide variety of potential site participants with respect to size, type of community, utility characteristics and geographic distribution. Following evaluation, DOE selected six geographically-dispersed site finalists and completed further evaluation of sites in mid-1980. Site selection by DOE has been delayed pending programmatic considerations.

SITE PARTICIPATION PLANS

Application experiments of parabolic dish solar thermal systems are intended to provide information on the operation of these experimental systems in a realistic field environment. The SCSE has the objective demonstrating the interaction of the experiment with the small community and its utility as well as on the technology itself. Site participation, then, is an important aspect of the experiment, and the site participant will be a partner in the experiment.

The general baseline characteristics of the experiment are for a 1 MWe plant, consisting of approximately 55 parabolic dish collectors, each approximately 12 meters in diameter with power conversion occurring at the focal point of each dish. The combined, rectified panel from these generators is inverted and transformed at the experiment/utility interface. The technical aspects of the SCSE are described in another conference paper and will not be repeated here.

The experiment will be located in a distinct small community, preferably one which has a peak electric load less than 20 MWe. The site participant must

represent the community itself as well as the owner of the local electrical distributional network.

The site participant as a cooperative partner will provide support including:

1. A suitable 10-acre site with appropriate zoning and permits for experimental plant activities.
2. Access roads and utility service to the site.
3. An electrical interface to the participant's distributional network.
4. Various data, maintenance, and operational support services.

The selection of the site participant is based on:

1. Community characterization and support
2. Insolation resource
3. Need for solar energy
4. Utility interface and generation experience
5. Site and permit acquisition
6. Site suitability
7. Site development characteristics
8. Environmental impact
9. Extent of participation
10. Organization and management

The baseline plan called for site participation to begin in July 1980 with construction activities beginning in October 1981 and experimental operation commencing in April 1983. Due to programmatic consideration, this schedule is now delayed at least one year. Six of the 44 site participation proposers have been selected by the DOE as site finalists. One of these finalists will be designated for the prime site. Up to five of the remaining sites may be designated for study activities which will involve, among other things, the deployment of field data systems. The purpose of these systems is to assess the site-specific insolation and system performance-related weather characteristics. These data will be used to examine a number of environmental variables that directly impact plant operation. The insolation data will enable system designers to characterize the solar resource of each site and to examine the frequency and effect of power dropouts due to clouding. Used in conjunction with temperature data, estimates of system performance can also be derived. The wind speed data can also be used to determine how often the system will have to be stowed due to high winds.

Each of the data systems will employ the following instruments:

1. Tracking pyroheliometer (direct normal insolation)
2. Pyranometer (total insolation on a horizontal surface)
3. Wind speed indicator
4. Ambient temperature

The flow of site data is described in Figure 1.

The instrument package is sampled by the data logger which converts the data signal from the analog to the digital form and stores the value with the corresponding time of sample. The values are accumulated throughout the day in electronic storage, on a five-minute basis; each evening the central unit transmits the data to the central site via telephone. The capability also exists to access the intermediate computation registers and obtain short-term data. These data can be transmitted to the central system in parallel to the site operation. The data are edited and stored in engineering unit form on floppy diskettes. A standardized report will then be generated from the data.

GENERAL DESCRIPTION OF THE PROPOSERS' SITE CHARACTERISTICS

A high degree of diversity among the proposers was manifest by the varying demographic characteristics of the communities and by the range of proposal combinations of utility types coupled with small communities. These proposer characteristics reflected an interest in the application of the technology over a wide range of supply and demand situations. This diversity is illustrated in Table 1.

In Figure 2, the locations of all proposal sites are identified. The six finalist sites selected by DOE are noted by stars, while the remaining 38 sites are shown by dots. The 24 represented states extend from the far western location in Hawaii to New Jersey in the northeast; South Carolina on the east coast; Washington, North Dakota and Minnesota as northern boundaries and Florida as the most southern location. Almost two-thirds of these locations may be considered to lie outside the sunbelt.

Utility ownership is particularly diverse as shown in Table I, with municipal utilities representing the largest number of proposers. 16 of these municipals have some degree of self-generation and 12 municipals rely entirely on purchase power. Eight of the total utilities are investor-owned, six small community proposers have combined with rural electric cooperatives and two proposers are teamed with irrigation districts. In addition to utility combinations with small communities, two of the above utilities (one municipal, one investor-owned) are teamed with academic institutions.

The average customer cost of electricity reported for a residential usage of 500 KWh per month at 1979 rates varied among utilities by a factor of five. Similarly, a wide range of values appeared for peak demand, even though the median peak value of 6.25 MWe reflected the stated preferred peak electrical power requirement of less than 20 MWe. The resulting peak values thus ranged from a low of 1 MWe to a high of 68.4 MWe.

These 44 small community proposers continue to show interest and confidence in solar thermal dish applications. Based on their varied generational experience and other characteristics as discussed here, solar thermal electric power uses by small communities offer a broad spectrum of opportunities.

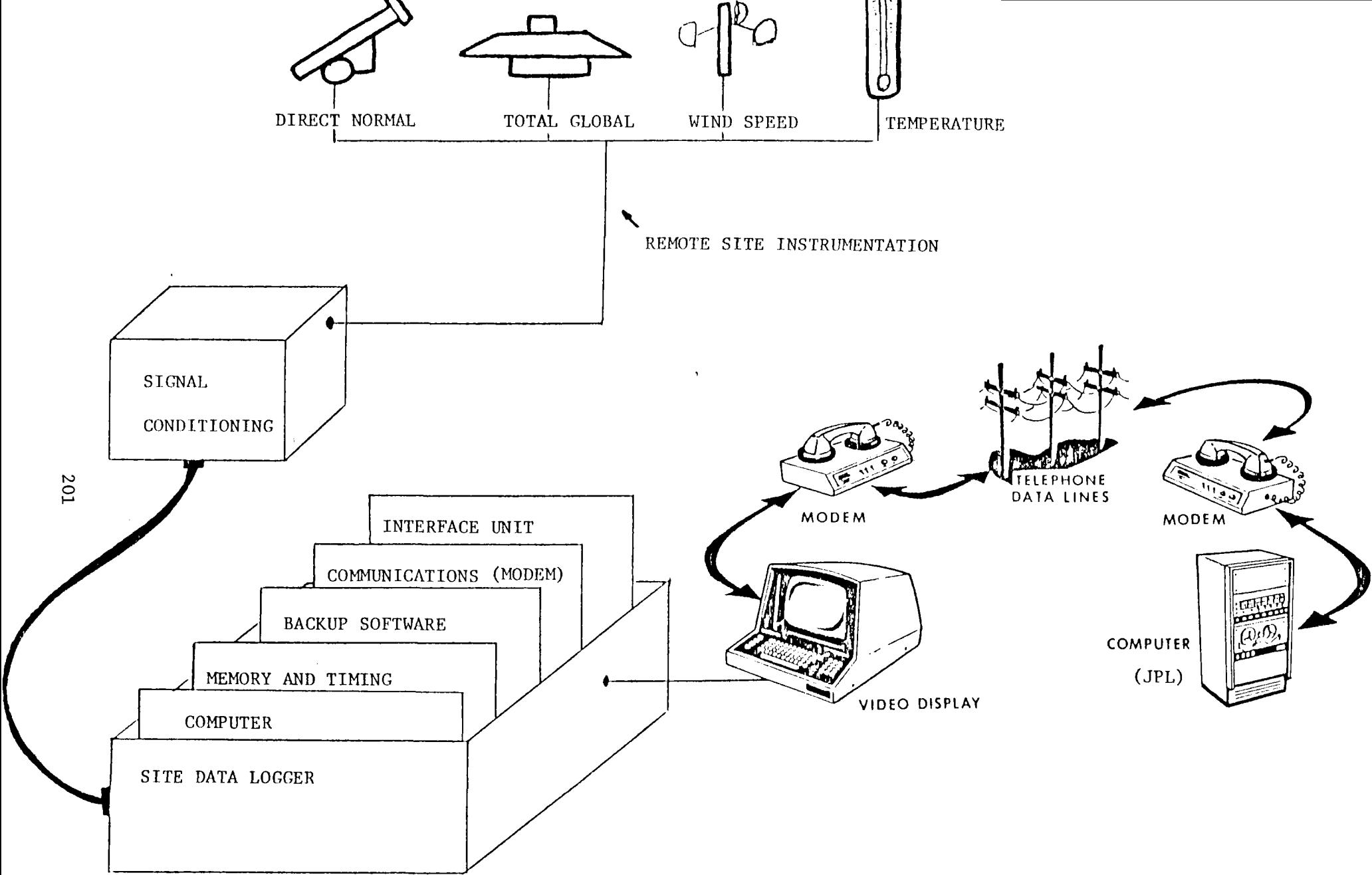


Figure 1. Small Community Instrumentation and Data Acquisition System.

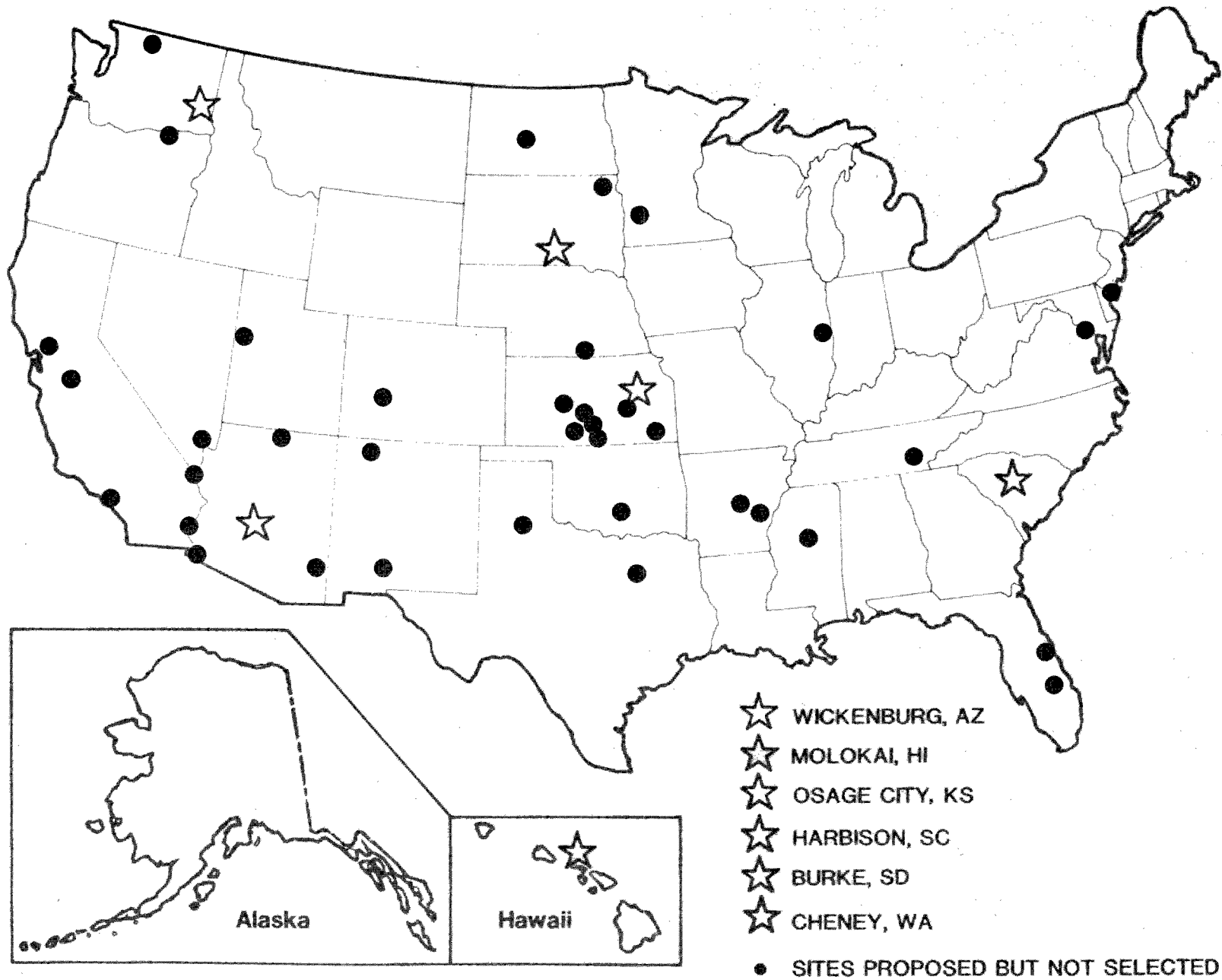


Figure 2. Finalists in SCSE Site Selection

Table I

Generic Summary of the 44 Site/Respondents

Utility Ownership*:	28 Municipal 16 Municipals with self-generation 12 Municipals with purchase only
	8 Investor-Owned
	6 Rural Electric Cooperatives
	2 Irrigation Districts
Median Peak Demand**:	6.25 MWe
Mean Peak Demand**:	15 MWe
Mean Electricity Cost: (Mean 1979 Customer Cost)	5¢/KWh

* Two academic institutions submitted proposals, one in conjunction with a municipal, one in conjunction with an investor-owned utility.

** Figures available for only 40 sites.

DEFINITIVE DESIGN OF THE SOLAR TOTAL ENERGY
LARGE-SCALE EXPERIMENT AT SHENANDOAH, GEORGIA*

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ABSTRACT

The U.S. Department of Energy, with Sandia National Laboratories providing technical support and management, is now starting construction of a Solar Total Energy Large Scale Experiment at Shenandoah, Georgia. The Solar Total Energy System (STES) is designed with capacity to supply electricity and thermal energy to a knitwear plant at the Shenandoah site. The system will provide 400 kilowatts electrical and 3.5 megawatts thermal energy.

The STES is a cascaded total energy system configuration. It uses parabolic dish collectors and a steam turbine-generator. The electrical system will be grid-connected to the Georgia Power Company system.

*This work supported by the U.S. Department of Energy, SAND81-0029A

INTRODUCTION

The Solar Total Energy Project at Shenandoah, Georgia, (Figure 1) is a prototype of a cascaded energy system using solar energy. Through system operation, definitive performance, cost, and O&M data will be obtained and an industrial solar total energy capability evaluated.

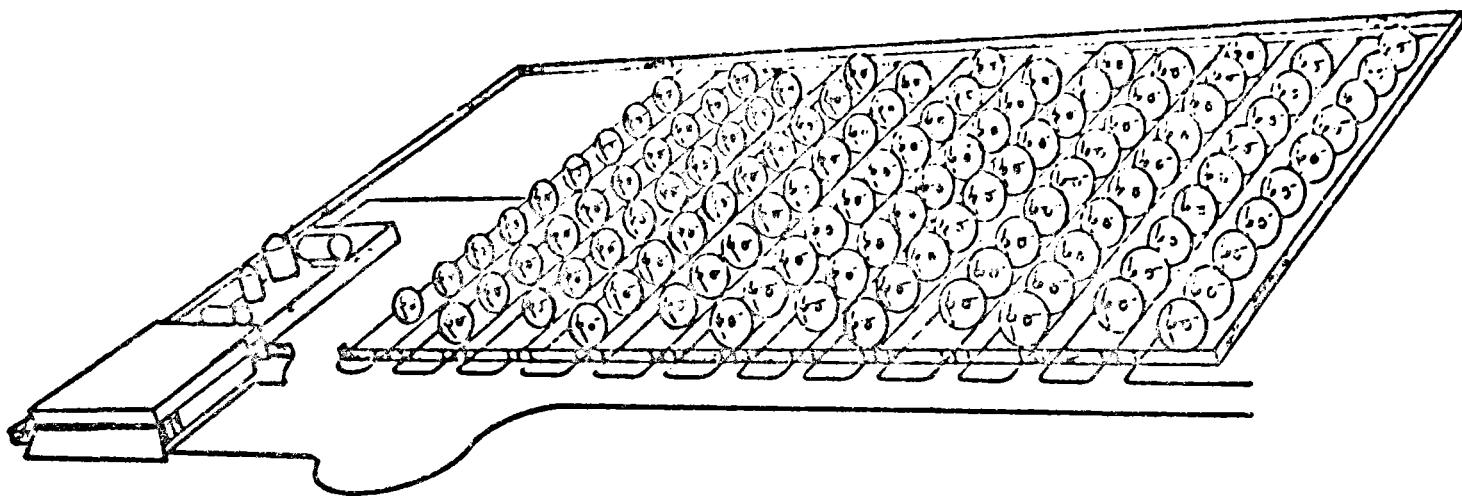


FIGURE 1. ARTIST'S CONCEPT, SOLAR TOTAL ENERGY PROJECT, SHENANDOAH, GA

A silicone heat transfer fluid is used to transport solar energy from the parabolic dish collectors to thermal storage or a steam generator. The power conversion system employs a high speed, steam, Rankine cycle turbine.

The system has the flexibility to operate in either a stand-alone or peak shaving mode while providing the electrical, steam, and heating and cooling needs of the nearby Bleyle Knitwear plant. Shenandoah, about 35 miles south of Atlanta, is an industrial-residential planned community. Sun right easements have been obtained on the land bounding the STES site to prevent future shading of the collector field.

SYSTEM DESCRIPTION

The STES consists of three major loops: solar collection and storage, power conversion, and thermal utilization, Figure 2.

One hundred and fourteen parabolic dish solar collectors, in parallel branches, form the collector field with a peak energy delivery rate of 1.2×10^4 MJ/hr (11×10^6 BTU/hr). Energy is either transported to storage or supplied to a steam generator by a high temperature silicone heat transfer fluid. The temperature range of the solar collector field is 260°C (500°F) inlet, 400°C (750°F) outlet. To permit operation during transient weather conditions, a thermal storage capacity

3.33 MW

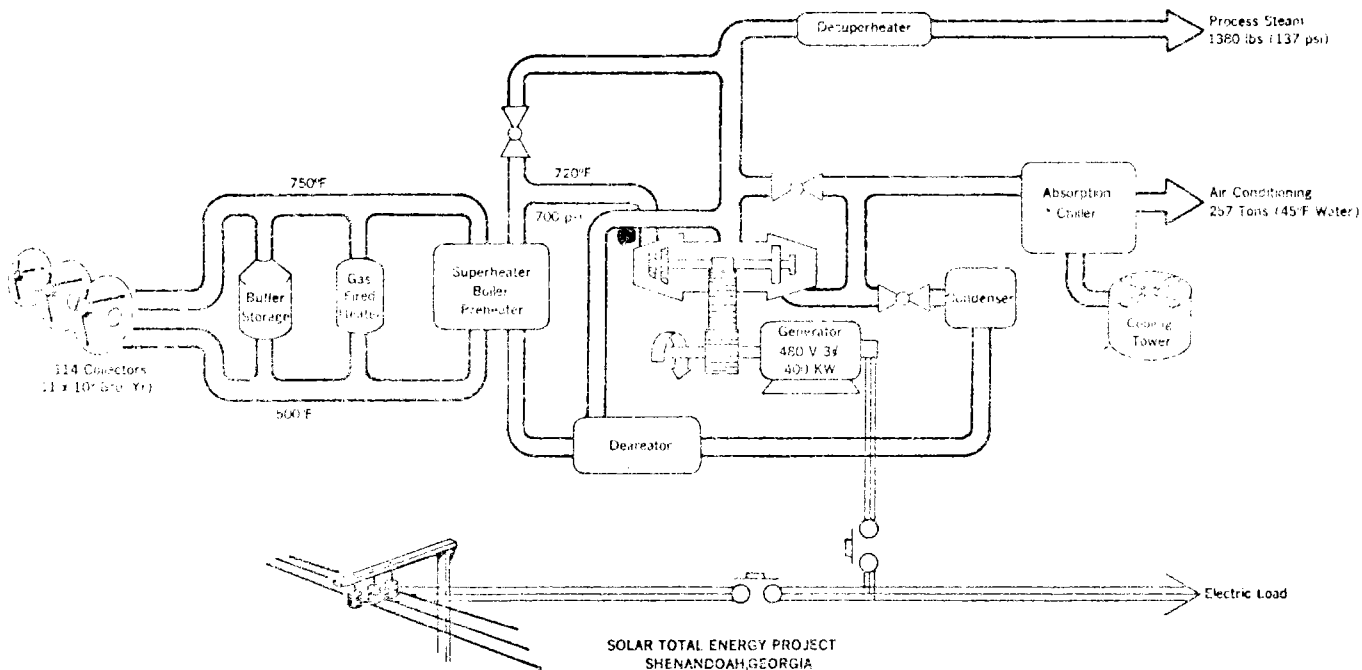


FIGURE 2. BLOCK DIAGRAM, SOLAR TOTAL ENERGY PROJECT, SHENANDOAH, GA

of 1.2×10^4 MJ (11×10^6 BTU) has been incorporated in the system. The solar collector is a 7-meter diameter paraboloid with a cavity receiver. Reflected solar energy is focused onto a coil of blackened stainless steel tubing within the receiver. The total field temperature rise occurs in each receiver (250°F).

The power conversion loop employs a high efficiency/high speed (42,500 RPM) steam Rankine cycle turbine, capable of providing 400 kW_e . Process steam at 630 Kg/hr (1380 lbs/hr) for the knitwear plant is extracted at an intermediate turbine stage. Thermal energy from the turbine exhaust is transferred to the thermal utilization loop for cooling of the Bleyle plant. An absorption air conditioner operating on 230°F steam provides chilled cooling water. In the peak shaving mode, the STES operates with a baseload provided by the Georgia Power Company. Table 1 lists the energy capabilities of the STES.

TABLE 1. STES ENERGY OUTPUT CAPACITY

Electrical:	400 kW_e	
Cooling:	22,000 MJ	174 tons
Process Steam:	630 Kg/hr	1380 lbs/hr (114 psia, 377°F)

High temperature storage is provided in an ASME code carbon steel tank. The tank is 3.04 meters (10 feet) in diameter and 5.47 meters (18 feet) high with a capacity of 41.6 cubic meters (11,000 gallons). Thermal energy storage is provided in 400°C (750°F) heat transfer fluid in a thermocline mode. Approximately

one hour of storage is provided for solar transient conditions. Storage for extended operation is not intended.

The Control and Instrumentation Subsystem initiates, regulates, and terminates collector tracking, energy storage, power generation, and thermal utilization for heating and cooling of the Bleyle plant. When operating in the peak shaving mode, the CAIS will monitor and regulate the generation of power to satisfy system requirements.

The CAIS consists of a central control console, a central minicomputer, and two remote microprocessor control units. The control system has the flexibility to be operated in a manual or automatic mode, and permits the operator to monitor or control the system functions from the control panel. Color graphic CRTs are employed for data display. Data archiving is performed with magnetic storage tapes and in hard copy form on the computer line printer. The remote microprocessors are programmable from the central minicomputer to allow a high degree of system control and versatility.

SUMMARY

A solar total energy system that uses parabolic dish collectors is being constructed that will have the capability to provide various energy forms, electrical and thermal, to a contemporary industrial facility with 25,000 square feet of floor space. Collector tests have demonstrated that existing fabrication techniques could produce an efficient parabolic dish solar collector. Performance measurements on the 7-meter dish have shown that the specified fabrication tolerances and performance of the full-scale unit can be realized in hardware.

THE JPL ISOLATED APPLICATION EXPERIMENT SERIES

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ABSTRACT

The goal of the Applications Element of the Thermal Power Systems Project is to establish the technical, operational, and economic readiness of parabolic dish power systems for a variety of applications in the power range below 10 MWe. Power systems are being developed and tested to the point where commercialization efforts can lead to successful market penetration. A key element in this strategy is the use of experiments to test hardware and assess operational readiness. The JPL Isolated Application Experiments are described and their objectives discussed.

BACKGROUND

The three successive milestones required in the development of a new technology to the point of commercial readiness are: 1) demonstration of technical feasibility, 2) verification of readiness of the technology, and 3) achievement of cost goals required for commercial readiness. The three phases in the evolution of a new technology can be described as creation, development, and commercialization. Participation by both government and the private sector may be necessary, with increasing activity by the latter as the commercial readiness phase is approached. Potential users are involved early in the design phase to the maximum extent possible.

A key element of the program strategy is first the identification, and later the penetration, of near-term markets that will provide a stimulus for establishing a manufacturing industry. This, in turn, will lead to cost reductions as a result of improved manufacturing methods, coupled with an increasing volume of production as lower cost markets are penetrated. The importance of this program element lies in the belief that design improvement alone will not result in a sufficiently low price to penetrate the utility market. A combination of mature technologies and mass production, however, offers the potential for economically competitive power systems with a significant environmental advantage.

Potential users will be sought that fall into two broad market categories: 1) the near-to-mid-term market, which is smaller, and for which costs are higher; and 2) the far-term market which largely corresponds to the utility sector for which a mature solar thermal technology is needed before penetration can be expected. Application studies and system analyses are being conducted to develop candidate system configurations best matched to the users in each category. Selected system design concepts will be developed through contracts let to private industry.

THE ISOLATED APPLICATION EXPERIMENTS

The Isolated Applications Experiment Series is the second major activity within the Applications Element of the Project. The Series will be a set of small (approximately 60-150 kWe) solar thermal power experiments, each of which is meant to address a separate isolated load application.

These experiments will employ point focusing distributed receiver technology with emphasis on electric power applications. The program is closely integrated with the Technology Element of the Project with the objective of utilizing the technologies being developed under that program.

The first experiment in the Series is co-sponsored by the Dept. of Energy and the U.S. Navy under the auspices of the Civil Engineering Laboratory (CEL). CEL and JPL have worked together to develop system requirements. The experiment, designated as the Military Module Power Experiment, will be a modular system using a hybrid fired Brayton cycle energy conversion. Subsequent experiments will test different versions of similar hardware in different applications which are now being selected.

Primary considerations in implementing the series are to:

- o Test the readiness of suitable solar power technologies at the system level in a number of different applications.
- o Economically provide testing of both technologies and markets, thus meeting principal program objectives without large expenditures.
- o Involve a large constituency of industrial suppliers and users.
- o Address the potential for near-to-mid-term market for small power systems that is needed to provide the initial incentive to manufacture these systems.
- o Increase programmatic flexibility by employing a number of small and varied experiments.

Emphasis will be on:

- o High reliability and safety.
- o Early plant deployment.
- o Low program cost.
- o Complete test and evaluation.

The engineering experiments will be designed, installed, and operated to permit JPL to better understand solar thermal plant applications and technical feasibility.

The objective of the engineering experiments is not to maximize the kWh of energy generated by the solar plant or to lower the electric power costs of the site participants. Rather the objectives are to:

1. Verify that the solar thermal plant can produce power from solar radiation supplemented by fossil fuel to meet energy requirements for this application during designated test periods.
2. Verify that the solar hybrid plant concept can be considered as a firm power resource for this application during designated test periods.
3. Characterize the total performance of the plant (site preparation, components, subsystems, modules, and plant) as a function of load characteristics, insolation, weather, operations and maintenance activities, safety regulations, environmental regulations, seismic factors, and legal and socio-technical factors.
4. Identify and understand plant failure modes.
5. Identify and quantify the impact of solar hybrid plant operations on the daily operations activities of user personnel and on user manning requirements.
6. Identify and quantify the impact of solar hybrid plant installation and operations on the local environment.
7. Identify and quantify the impact of solar hybrid plant installation and operation on the acceptance of solar power plants by local public officials, local power system officials, and the local public.

SCHEDULE

The MMPE will enter design phase in FY81. The schedule for the first experiment now calls for a test and evaluation of two different modules to begin in CY83. Tests will be conducted at the PDTs at Edwards AFB. Two contracts will be awarded for system design, and this effort will culminate in a test program lasting for approximately 12 months (summer '82-summer '83). Severe cutbacks by DOE in the funds requested by the Thermal Power Systems Project have impacted the MMPE. The extent of the impact has been a slip of approximately 18 mos. in the module test completion date.

TECHNICAL FEATURES

The degree of MMPE module self-containment will be driven by both economics and reliability. Each module will contain (at a minimum) 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 completely self-contained module is desired with only the true plant functions located centrally. These will be power combination and conditioning equipment, module and plant performance indicators, grid interconnection equipment, computing and data recording facilities, instrumentation, plant safety and control equipment.

The normal mode of module operation will be unattended, however each module will be equipped for safety or emergency shutdown, both manual and automatic. Although a fixed installation is expected, individual modules must be transportable, field erectable and field serviceable.

Long term thermal storage will not be included in the plant. No thermal buffering will be provided except by the heat capacities of the installed components and working fluid. The hybrid combustor control system and/or engine controls will provide the desired transient response characteristics.

MMPE CONTRACT STRATEGY

Past performance of DOE solar thermal system integration contractors plus ordinary good business practice argue strongly for the creation and maintenance of a competitive environment for both subsystem development contracts and system integration contracts for the JPL Engineering Experiments. Competition can be introduced in several ways, although the best and most effective method is to finance it directly. This means the parallel development of alternative subsystems and/or interchangeable technologies, any one of which could meet the stated requirements for the system being developed. Competitive developments can then be pursued and final selections deferred until cost, performance, or schedule considerations dictate termination of all but the leading candidate or until the happy moment when one candidate demonstrates the assured achievement of acceptable cost, schedule, and performance.

The most obvious results of competitive, parallel, development is reduced program risk. A less obvious result is that competitive development does not necessarily increase total program costs. Competing contractors constantly strive to minimize cost and optimize performance particularly when a very large potential market is the ultimate prize. An optimum strategy is one which introduces and maintains competition as inexpensively as possible for as long as possible, ensuring maximum program benefits.

JPL's strategy is therefore to establish and maintain a competitive environment for the MMPE.

MMPE SITE SELECTION

Site selection for MMPE has been a U.S. Navy responsibility. It will be conducted in parallel with the system integration control activities and basically independent of the technical tasks. The Marine Corps Air Station at Yuma, Arizona, has been tentatively selected as the site for the experiment.

FUTURE EXPERIMENTS

Additional small scale experiments are being planned for inclusion in the Series. They will be designed to test developing solar thermal hardware with emphasis on economy and modularity. Future Program Reviews will afford the opportunity to present the details of these experiments.

INDUSTRIAL APPLICATION EXPERIMENT SERIES

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ABSTRACT

This paper discusses two procurements within the Industrial Application Experiment Series of the JPL Thermal Power Systems Project. The first procurement, initiated in April 1980 has resulted in an award to the Applied Concepts Corporation for the Capitol Concrete Experiment: two Fresnel concentrating collectors will be evaluated in single-unit installations at the JPL Parabolic Dish Test Site and at Capitol Concrete Products, Topeka, Kansas. The second procurement will be initiated in March 1981 through the release of an RFP titled, "Thermal System Engineering Experiment B." The objective of the new procurement is the rapid deployment of developed parabolic dish collectors. Two or more awards are intended. At least one award will be made to a team involving small business.

INTRODUCTION

The Industrial Application Experiment Series assists industry-directed new initiatives in the commercialization of parabolic dish systems. Experiments funded through the Industrial Series utilize industrial involvement and expertise to the maximum possible degree. Industry is responsible for proposing collector system, application, and site. JPL does not specify site, application, or hardware. Each experiment results in the design, fabrication, verification testing, installation, check-out, operation, maintenance, and twelve-month evaluation of a collector system providing energy to a load at a user's site.

The Industrial Application Experiment Series' initial procurement took place in 1980 and resulted in the award of a contract to Applied Concepts Corporation for the Capitol Concrete Experiment. The second procurement will take place in 1981.

This paper discusses the first procurement, which resulted in the Capitol Concrete Experiment, and presents the implementation plan of the new procurement, to be initiated through the release of an RFP in March 1981.

FIRST PROCUREMENT

JPL released an RFP on April 3, 1980, for procurement of Thermal System Engineering Experiments. Proposals were received on May 29. One award was made in December 1980. Although JPL intended to make multiple awards and entered into negotiations with three proposers, a combination of technical and cost factors led to the decision to make a single award. The experiment which resulted from the first Thermal System Engineering Experiment procurement is

called the Capitol Concrete Experiment. The user, Capitol Concrete Products, is a masonry block producer in Topeka, Kansas, where the collector will be operated to provide industrial process heat (IPH) in the form of hot water and steam at 150°C (302°F) for the autoclave curing of concrete blocks. The collector manufacturer, Power Kinetics, Incorporated, of Troy, New York, will provide one unit for installation by July 31 at the JPL Parabolic Dish Test Site for extended (14 months) verification testing and one unit for installation by September 30 at the Topeka site for twelve-month evaluation. The plant integrator for this experiment is the Applied Concepts Corporation. The purpose of the experiment is to prove the system feasibility of the PKI Fresnel concentrating collector in an operational industrial environment and in an application, IPH less than 290°C (554°F), suitable to its performance capabilities.

For more information on the Experiment and the collector, the reader is referred to other papers submitted to this conference: "A Fresnel Collector Process Heat Experiment at Capitol Concrete Products," and "A Fresnel Concentrating Collector-Power Kinetics, Incorporated."

SECOND PROCUREMENT

The second procurement in the Industrial Series will be initiated through the "Thermal System Engineering Experiment B" RFP to be released in March 1981. (An announcement of this RFP has been placed with the "Commerce Business Daily.")

The objective of the contract is to secure systems and services necessary for the planning, implementation and operation of an experiment involving one or more parabolic dish solar thermal collectors integrated with a load to establish the system feasibility of a relatively low cost, low risk system in a near-term application. JPL intends to make two or more awards, including one award to a small business. Each proposer should provide a system supplier, a system integrator, and a user.

The preliminary implementation schedule has the following major milestones: Release RFP-March 6, 1981; Receive Proposals-June 2, 1981; Award Contracts-December 1, 1981; Complete Installation at PDTS and Begin Verification Testing-September 1, 1982; Complete Installation at User's Site and Begin 12-Month Evaluation-January 1, 1983; Receive Final Report-May 1, 1984.

Since the first procurement resulted in an award for evaluation of an IPH application at an application temperature less than 550°F, it is preferred that the second procurement result in awards for more complex or higher temperature applications. Examples of such applications are agricultural pumping and processing, air-conditioning, emulsion pumping and processing, Enhanced Oil Recovery, fuel-grade alcohol production, furfural production, and water treatment and pumping. (This list is not intended to limit proposers. The RFP does not designate specific application categories.)

Users should be performing agricultural, commercial, or industrial functions in the public or private sector. Laboratories owned by or operated for the Federal government are excluded from participation.

A FRESNEL COLLECTOR PROCESS HEAT EXPERIMENT
AT CAPITOL CONCRETE PRODUCTS

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ABSTRACT

Applied Concepts will plan, conduct and evaluate for JPL an experiment to determine the feasibility of using a Power Kinetics' Fresnel concentrator to provide process heat in an industrial environment. The system user will be Capitol Concrete Products of Topeka, Kansas. The plant will provide process steam at 50 - 60 psig to two autoclaves for curing masonry blocks. When steam is not required, the plant will preheat hot water for later use.

A second system will be installed at the JPL parabolic dish test site for hardware validation and experiment control. Both plants will be instrumented to provide technical performance data. Experiment design will allow for the extrapolation of results to varying demands for steam and hot water, and will include a consideration of some socio-technical factors such as the impact on production scheduling of diurnal variations in energy availability.

A final report in December 1982 will evaluate technical performance and operational feasibility based on 12 months' operational experience at the industrial and test sites.

BACKGROUND

Applied Concepts and its subcontracted partners will conduct for JPL an experiment to evaluate the feasibility of a Fresnel mirror solar thermal conversion system to provide process steam and hot water in an industrial facility. Applied Concepts will provide experiment planning and supervision and will evaluate experimental results. Power Kinetics, Inc. will be a major partner in the experiment. They will manufacture and install the solar conversion systems. They will also provide engineering services in support of experiment planning and evaluation. Capitol Concrete Products of Topeka, Kansas, will operate and maintain the system for one year subsequent to plant installation and check out. They will also be responsible for site preparation to receive the solar energy system. The University of Kansas Research Center, Inc. will provide Capitol Concrete with expert assistance in experiment planning and reporting.

The experiment, which involves the installation of the PKI system in a fuel-saving mode at the Capitol Concrete Plant, is designed

to evaluate the technical performance of the solar hardware in an industrial environment. It will also evaluate those socio-technical factors which are created when a new technology is first introduced into an industrial application where it places new demands on the user.

THE APPLICATION

Capitol Concrete Products is a manufacturer of masonry blocks. Concrete blocks, once formed, must be cured to attain the strength necessary to their use in load bearing construction. Such curing can be done over a period of months by exposure to rain and weathering, over a period of days by exposure to hot water, or over a period of hours by exposure to pressurized steam. According to a SERI study (Ketels and Reeves), nationwide, this process consumes some $1.6 \cdot 10^9$ KWh (thermal) or $5.4 \cdot 10^{12}$ BTU per year, or about one per cent of all U.S. medium temperature industrial steam.

Capitol Concrete has two 60 psig autoclaves which are served by a 6000 pound/hour capacity, natural gas-fired boiler. The process, which requires approximately 10 hours at pressure, is currently utilized five days per week, and produces some 16,000 blocks per day.

The current production schedule at Capitol Concrete did not evolve for the utilization of solar energy. It is not optimal for its application. Blocks, which are made during the morning hours, are loaded into the autoclaves in the early afternoon. The first autoclave is brought up to pressure about 2:00 PM. Pressure is maintained overnight, and at 6:00 AM, the first worker to the plant releases pressure and prepares for unloading.

There is no technical reason for the current schedule. Blocks, once formed, could be stored until next morning and cured on a ten hour schedule consistent with maximum insolation. Under experimental conditions, we do not propose to alter the manufacturer's operational procedures. The relatively small contribution which a single module will make to overall consumption does not warrant such a change.

Experiment design, however, incorporates the extrapolation of results to evaluate the value of a change in operational procedures to match the availability of energy. Moreover, during morning hours, Capitol Concrete plans to utilize the solar conversion system in a water pre-heat mode. This full utilization of the system during daylight hours will allow the extrapolation to full-time steam production to be made. It also offers the advantage of extrapolating results for those masonry manufacturers who utilize a hot water curing system. It allows the testing of the PKI system in a dual mode configuration.

The Capitol Concrete site is in an industrial area near the north shore of the Kansas River. Annual direct normal insolation

is about 1850 KWh/m². The major local environmental factor which is anticipated to impact on system performance is a sand pile on an adjacent lot from which the wind blows sand particles toward the Capitol Concrete site.

The precise location of the energy conversion system will be selected in January 1981. It may be roof mounted over the boiler room, or ground mounted in a nearby block storage lot. PKI has also proposed mounting the collector on an elevated frame with room underneath for block storage or parking. The best option will be selected based upon a consideration of cost versus program resources.

PLANT DESIGN

The PKI Fresnel concentrating collector was discussed in an earlier paper, and therefore need not be described in detail here.

The system to be installed at Capitol Concrete will provide, at nominal capacity and full insolation, some 170 pounds per hour of 50 psig steam. This is three per cent of the total plant load. When steam is not required, the system will be used to preheat water for later use. Figure 1 presents a conceptual design of the proposed Capitol Concrete plant. It should be noted that a small, fuel displacement design was chosen to help assure that experimental system downtime will have a minimal impact on normal production operations.

Before the Capitol Concrete system is installed, a complete, instrumented PKI system will be erected and tested at JPL's Parabolic Dish Test site at Edwards AFB, California. Prior to its installation, the Capitol Concrete conversion system will be tested at the subassembly level at PKI. Applied Concepts will provide engineering design of the plant interface, and will supervise installation, plant integration and check out to be accomplished at the site prepared by Capitol Concrete by a team of Applied Concepts, PKI and Capitol Concrete personnel.

THE EXPERIMENT

Capitol Concrete will operate and maintain the experimental system for a period of twelve months after installation and check out, under the supervision of Mr. Joe Perry, Production Manager. The University of Kansas Research Center will provide plant personnel with expert assistance for reporting experimental results and with trouble shooting, if necessary. Applied Concepts and PKI will be on call should major problems develop.

PKI is designing an automated data gathering system which will integrate with the standard control system of the collector

APPLIED CONCEPTS CORPORATION

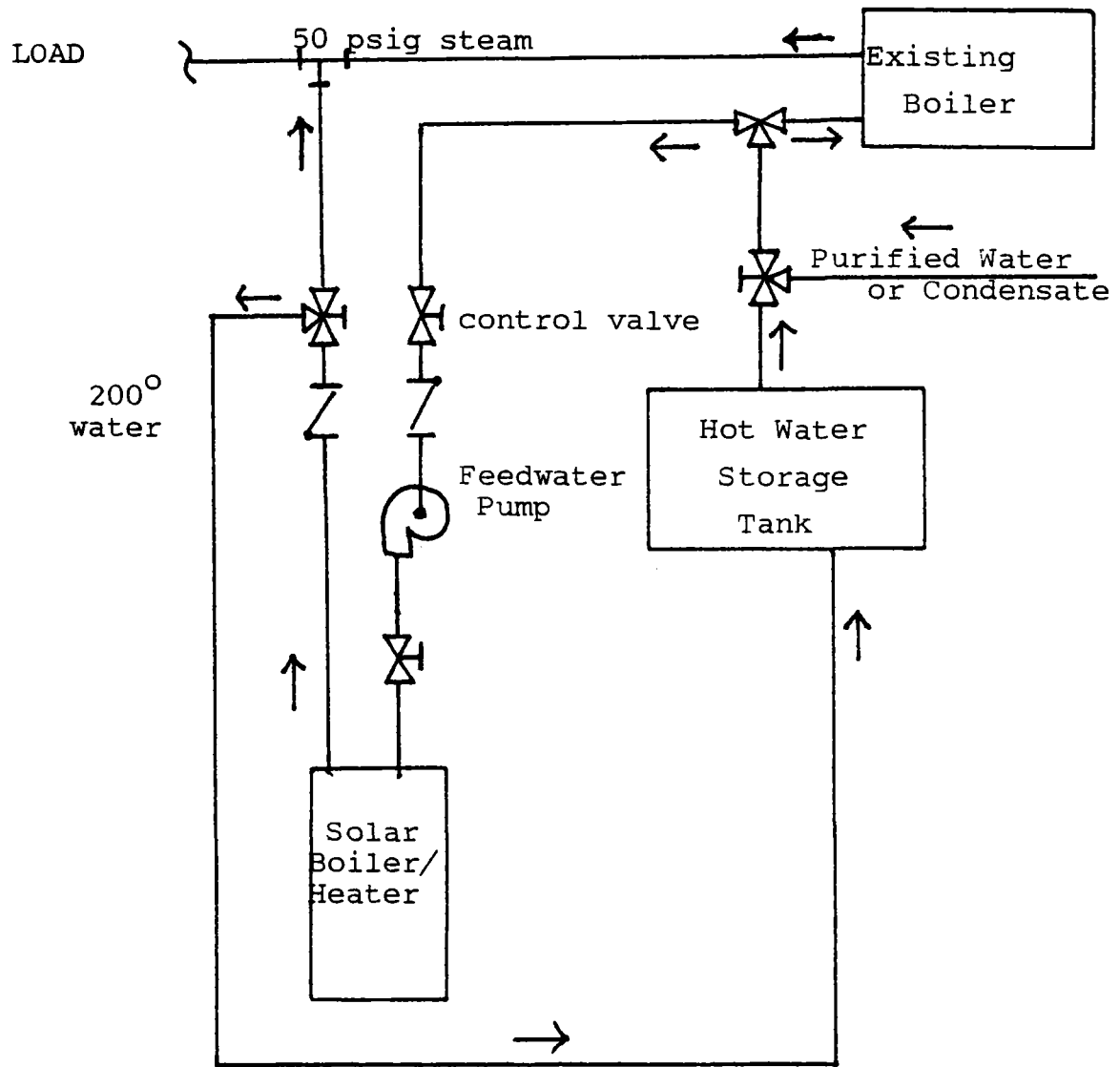


Figure I Conceptual Design, Capitol Concrete Plant

to provide technical performance data. In addition to 27 system variables which are currently monitored through the control system, instrumentation will record direct and total horizontal insolation, feedwater flow and temperature, system pressure, output temperature, ambient temperature, load steam status, condensed water run off, and parasitic power consumption. Data tapes will be collected and evaluated monthly.

It is the intention of Applied Concepts that the system to be installed at the JPL PDTs serve as an experiment control. It will be instrumented in the same way as the Capitol Concrete system. Applied Concepts will provide JPL with an experiment operation plan for its implementation. Data provided by JPL will be analyzed and compared with the results of operations in Topeka.

In addition to evaluating technical performance data on the PKI hardware, Applied Concepts will work with Capitol Concrete and the University of Kansas Research Center to evaluate the operational impact of system use. Results should be meaningful for the larger industrial environment. The energy products of the experiment (medium pressure steam and hot water) have broad industrial application. A fuel saving plant configuration is no doubt the most general one for realistic industrial application. Capitol Concrete was not chosen to be an "ideal" user as might be appropriate to a demonstration project, but as a representative user as is more appropriate to an industrial application experiment. The experiment is designed to provide us with information therefore on both the technical performance of a parabolic dish type system in an industrial environment and also on the interaction between the system and the environment in which it is to be used.

A final report is anticipated in December 1982.

Panel Discussion II

APPLICATION / USER NEEDS

Moderator: R. R. Riordan, University of Kansas,
Center for Research, Inc.

UNIVERSITY OF KANSAS, CENTER FOR RESEARCH, INC.

Robert F. Riordan

Good afternoon, ladies and gentlemen, and welcome to today's panel on "Applications and User's Needs." Before proceeding into the panel presentations, I would like to lay a little groundwork on what this panel is all about and how we see it fitting in to the overall program.

When I was first contacted by JPL to moderate the panel on user's needs and applications, I must say that I was a little bit intrigued as to what exactly the term "user needs and applications" meant. It seemed to me that this could be taken for a variety of things, depending upon one's particular viewpoint toward the problem, which I will elaborate on later in my comments.

This panel, as I see it, fits into a very logical progression in the flow of development of the Parabolic Dish Solar Thermal Program. Over the better part of the last two days, we have heard a number of presentations and panels on the technical aspects of the Parabolic Dish Solar Thermal Program, specifically, presentations on the scientific research that have been going on with relationship to the various subsystems, energy storage, engines, the collectors, and so forth.

We have also heard presentations on the different experiments that are being conducted throughout the country in this program.

The question now is: How do we use the results of these experiments as they progress? Also: Are these experiments addressing the needs of what we shall call "the user," whomever that might be? From my standpoint, I think that this is an extremely important facet of any long-range R&D program that is addressing specific applications. You might say that we are now moving from the basic research area into the applied research area and as we do that, we need to ascertain if there are needs out there that this research can address and solve through the application of the technology being developed?

This raises a series of questions to address:

- (1) Who is the user?
- (2) What applications might meet some of his needs?
- (3) How do you determine what his needs are?
- (4) Will these applications actually meet them?

At times, answering these questions can be rather interesting. We may find that applications may work technically but do they really meet the needs of the user? Or, more importantly, does the user perceive that they will meet his needs? May I say that unless the user perceives that an application meets his needs, we are faced with the fact that no matter how well an application works, it is not going to develop into a commercial product. The user must believe that an application does meet his need.

We are also faced with the question that is of some interest, not from a technical standpoint but from a management standpoint and planning. That is, how does the user:

- (1) Determine if an application will meet his needs?
- (2) Deliver the information to the R&D community that he has a need he thinks an application can meet?
- (3) Deal with all the ramifications of these situations?

I am not going to belabor the point, but I think we should think about developing a mechanism to find out what the user's needs are. How do we find out what needs he has that these technical applications may meet? Consequently, I would like to plant a seed today so that as you listen to this panel discussion, you keep in mind how we can continue to do this on a continuing basis and how we can bring more people in to address the specific needs of the user community.

From my standpoint on the panel, I would like to discuss the transfer of information and briefly give an example using a project you have heard something about today. That was with the Small Community Solar Power Program. JPL, I think very accurately and farsightedly, held a meeting in Aspen in 1977, where they had a number of small municipal utilities attend and provide inputs. Very little was heard by the attendees from JPL on the results of that meeting for the next 2 years until about a year ago last October when the RFP came out.

It was an excellent RFP from the standpoint that it had been written to meet the user needs. The RFP was written in such a manner that a small municipal utility, without too much difficulty, could respond to the RFP. I think JPL is to be commended. They identified a user which was a small municipal utility and they had identified the needs of that group. Oddly enough, it was not only a need for power generation, but also a need for how they were going to acquire information on the technology and make their needs known. In the state of Kansas, nine cities responded to that RFP. Personally, I am quite proud of that because it shows that informed municipal utilities will respond. In fact, if we would have had a little more time, Kansas would have probably had more response.

I would like to go over briefly with you what transpired in Kansas, to give you an example on involving the user. After the Aspen meeting, I met with Kansas Municipal Utilities every year at their annual meeting, and briefed them on the Small Community Solar Power Program at JPL. We had also met with their Board of Directors and their Executive Director so that when the RFP did come out in October a year ago, the people there were familiar with what was being proposed and they understood that it was an experiment.

At the same time, the Kansas Energy Office met a very serious need of those municipal utilities. They needed someone who could work with them in filling out the simplified RFP format, and Dave Martin did that. Once again, a need of consumers, in this case the municipal utilities, was met and fulfilled.

Dave Martin of the Kansas Energy Office is not on the panel, but he deserves much of the credit for the response from Kansas. I have just gone through this very briefly to show you that if we identify the user needs, whatever they may be, and operate under a system that the user understands, we can make things happen.

Also, I think that we are in a unique position here today because we are thinking about the user, or at least talking about the user. Unfortunately, I have yet to see how we are going to incorporate the user into the program; on that point, I would like to make two comments.

One, I suspect a number of people are thinking about inviting more users to these types of programs. Before doing that, I think you should give some serious consideration to the fact that this type of meeting is a technical review and may not be the best type of meeting if you are going to invite users. You may want to keep these two types of meetings apart.

The other point is credibility and reliability. In this instance, I am going to talk about the credibility of the people that are out marketing solar thermal systems to the user. They need to be credible. Many of you may be well aware of this, but I would like to re-emphasize this point. When talking to an industrial firm or utility company, you must have a very credible reputation with the user. Other panel members will address this point. When we talk about reliability, it is more than reliability of the system. It is the reliability of the maintenance system, and the support system. If something goes wrong, the user knows someone will be there to back up the system. Those are some factors that the user is looking at.

At this time, I would like to introduce the panel and ask each one of them to go through their presentation. We will start off with Mr. Charles Strong, who used to be with Johnson & Johnson. He is now with Acurex, and in effect is working with industrial customers; he is out in the field, down in the trenches, addressing the needs of the customer or client. The next speaker will be Mr. John Bigger* from EPRI, and he will be talking about the electric utility industry. The speaker after that will be Mr. Jerry Lohr, whom some of you may know, from Pasadena Water and Power. He will be talking from the municipal utility viewpoint. The next speaker will be Mr. Richard Zanard, from Morgan Guaranty Trust. I think his presentation will be interesting, because it will present some facets on the financial side--basically on the financing of municipal utilities. The last speaker will be Mr. Harry Bernstein,* with Aerospace Corporation, and he will talk about the MX-RES program.

In summary, the objectives of this panel are to focus in on some of the things that I have just been talking about in broad terms. In particular, this panel is an initial forum for users and potential users to provide input to this program regarding their needs and an opportunity for all of you to receive these comments and interact with the user.

*Transcript is unavailable.

ACUREX

C. Strong

I am going to review for you the industrial experience that I have come across over the last year as a result of a number of surveys that I have been involved in and also had the opportunity to review. The information covers about 300 different industrial people in about 150 different industrial classifications. Basically, these surveys were done for the type of user information that you, as technical people, are looking for in order to pick out potential commercial users. The first area that I will discuss before commercialization is technology and data development to be disseminated to the industrial population. Demonstration programs are of the utmost concern as far as the long range user goes. As far as the demonstration programs go, you have to tie up with a user partner and make sure that the user is involved from the beginning of the design of the system right up until its operation and data collection phases. First you go through the demonstration program and collect a suitable amount of data so that you feel confident the system is going to work on a commercial basis. Then you have to explore the avenues of getting the data disseminated to various parts of the industrial classifications where you feel the applications exist. I think this is one of the prime things that we in the technical business sometimes overlook. You find out you are weak in data disseminations when you try and sell an industrial user a system and he throws the questions back at you and all of a sudden you wince and say, "Well, I think I can get that information for you." And there you are, back to the point where education is required before you can even spend any time trying to show the person what the application is, what it can do for his operation, and all that. So, communication and education are paramount in the demonstration phase of the program.

Once you have gone through the demonstration part of the program and you feel that the hardware that you are developing and have demonstrated is to the point where its manufacturing costs and installation capability is equal to or better than the existing fuel sources, then you are probably ready to try a commercial marketing program. From that standpoint, I am going to highlight some of the areas as a result of the face to face contacts that the industrial people usually throw back at you when you are trying to discuss with them what the applications are for a system, whether it be for solar heat, or for power generation. Usually, the discussions will fall into two categories. They are very simple and stick out like a sore thumb. The first one of course, is economics. No matter whether it is a large corporation doing 5 to 10 billion dollars worth of sales, or a small corporation doing 5 to 10 million dollars worth of sales, you are going to get a number of standard questions in the area of economics. The other area is the technology credibility. This includes the credibility of the person that they are talking with: How much background in the business does the vendor have and how reputable and reliable is his equipment?

The first area I will cover is economics. One of the initial things that you have to recognize is that all corporations, no matter how big, have a certain size capital improvement budget. And, of course, a solar system to be used for power or heat generation to replace fossil fuels would fall into a capital improvement. You can specify for an individual system that may give

them a payback within their economic return ranges, but you may tell them that the initial investment is \$12 million dollars. If their capital improvement budget is only \$13 million they're going to tell you, "Sorry, I can not do that because I have got a number of other projects that I have got to consider." So the first thing you have got to remember is that the upfront capital cost is the major cost in the whole program, and the industrial user is going to be limited by how much he is going to be willing to invest.

Secondly, in the current marketplace, and I am sure it will exist in the future too, there is a natural gas industry telling all the industries in the nation that there is an unlimited supply of gas. One thing that they will not tell them is what the price is going to be. So when you talk to the industry, that question is going to come up and you have to dwell on the fact that the gas may be available, ad infinitum, but note the price paid for it. And, you are going to have to price your product against the price of gas in that particular region at that particular time.

The other thing, of course, that you are going to be asked about is the tax incentives for solar in the various regions of the country. And, of course, right now they vary depending on what state you are located in. You have got some states that have tax incentives, and other states that do not have any taxes, so as a result, there is a certain incentive in those states too.

You have got some industries with a cost improvement project (and the size of the industry does not seem to matter) and they are looking for a 3-year payback. With the solar technology as it is right now, that is a hard criterion to meet. There are a number of industries that have looked at energy projects with other than their normal cost improvement payback and they are willing to accept a payback in the area of 5 to 10 years, and in some areas of solar right now that is a payback that can be met. These are areas that are being explored by individuals that are in the position that I am in right now.

When economic analyses are run for the various industries a lot of them are looking at life-cycle costing, and generally they are using an accelerated 7 year depreciation. The big question, of course, when you do economic analyses and you try and price out a system which probably would have 20 to 30 year life, is: What is the fuel escalation going to be in that time period? Right now, an acceptable escalation percentage for analyses in most of the industry seems to be in the 15 to 20 percent range. Most of the publications that are being put out right now seem to think the escalation in the very near future will be in the 18 percent range.

One of the questions you will get thrown back by some of the financial people in the industries is: If you use that type of escalation, the U.S. economy can not afford to exist with those rates, so what is the credibility of the economic analysis? I think you have to be ready to counter those. The fact of the matter is, if you look at the last 10 years at fossil fuel rate escalation, you will come out with an average of 26 percent a year. I think you have to be prepared to have those curves with you when you talk to industrial people.

The other factor that generally comes out in an economic discussion which does not come into any economic analysis, but yet relates to an economic

impact on the industry, is the value of the positive public relations that the industry picks up by using an alternate fuel source. Also, by being adventurous in alternate energy, industry credibility increases. So, that summarizes the economic impacts that the industrial potential user is going to look at. You must answer those questions for him before he will consider it from a financial standpoint.

Next you get down to the product technology of the system that you are trying to sell the industry. There are really two things that jump right out at you when you start getting into the technology and the system that you are recommending to the industry.

The first thing you have to recognize is that the system that you are going to supply the industry with is going to produce an end product. Whether it be X-amount of pounds of steam or X-amount of Btu's of heat, or so many megawatts or kilowatts of power, that is all the industry is interested in. They want to know what the end product is going to be. They want to know what the cost of the end product is, for instance what is the cost of one million Btu.

Once you are beyond that, then they will start asking you questions about what the hardware is going to be. They are going to insist on a high quality hardware that can stand up in the industrial environment. They will want to know what the life of the components is going to be. What kind of performance they can expect? How easy is it to maintain the equipment? Most of the industries today in the production of process heat or power are not going to accept anything but better than 96 percent uptime as far as equipment operating when sun shines. If you come in and tell them you can guarantee that it will run 80 percent of the time, they will throw you out the door.

The other thing that they want to know is how it is going to interface with the existing equipment that they have? If there is an interface problem, then they are going to be leery of even looking at it. They are going to want to make sure that their current skilled people can maintain the equipment. They do not want to be getting into advanced technology that is different than what their people are used to. If they feel like it is different they are going to be a little bit skeptical about getting into that type of equipment.

I think the best way the industries respond relative to technology and interface with their equipment, is the old kiss theory. Keep it simple. If you start telling them that you are going to put sophisticated control systems and sophisticated new upgraded electronics and all that, my experience has been that more often than not you are going to turn them off. We, as technical people, may consider some of the parts of solar high technology, but the industrial people are not really interested in that. They are interested in the fact that you are replacing fuel that they are using right now with their existing equipment with solar energy.

What they want to know is, when you make that replacement, can you do it without disrupting the operation, or requiring them to add any additional people. They do not want any cost increases in order to do it. As I mentioned, they are going to insist that the control systems be very simple, that the instrumentation be minimal.

The only thing that they are going to want to know about a system is what the output of the system is. They are not going to be interested in you telling them the pressure here is such and the pressure over here is that, and the temperature over here is that. They could care less about that for the most part. You also have to recognize that once you talk with the corporate or planning engineering group, most of the people that are involved in the decision-making are not technical people. They are business oriented and they are not going to want to hear anything relative to a technical discussion.

In summary, whether they be big industries or small industries, the major industrial user applications are in areas where they want a simple interface system that will give them a cheaper output energy than what they have already. Beyond that they do not want any disruptions to their operations.

MORGAN GUARANTY TRUST COMPANY

R. Zanard

I have spent most of the last 10 years helping finance tax exempt electric utilities. Thus, I thought I would provide you with some insight into that aspect of the utility industry.

The good old days for electric utilities in this country were certainly over before Three Mile Island. The decline probably started with the northeast blackout in 1965, when for the first time in the memory of many people, the invincible electric utility industry was no longer invincible. By the time of the 1973-1974 oil embargo, the decline was well underway.

In those good old days, the utility industry enjoyed a large measure of public confidence. Equipment manufacturers could be counted on to stretch the frontiers of technology and produce steadily increasing efficiencies at steadily lower costs. Utility common stocks and bonds were market favorites. Money was plentiful and cheap. Electric utilities were considered growth stocks and some sold at 30 times earnings or more. Investor-owned utilities (IOUs) generated about two-thirds of their capital requirements internally and had no trouble raising the balance through the sale of securities.

A loss of investor confidence, the international oil situation, rampant inflation and a litany of other bad news has taken its toll. Today, a number of IOUs generate only 20-25 percent of their capital requirements instead of the old two-thirds. With declining margins and slowed load growth, bond ratings have been reduced. One result was higher interest costs, and in a few instances, no open window to borrow funds.

This decline in projected load growth and in the financial condition of investor owned utilities has brought about a major restructuring in the relationship between the IOUs and the consumer owned utilities. Perhaps this can be illustrated in no more dramatic way than a simple statistic: In 1974, the volume of tax-exempt electric revenue bonds, that is the debt sold by municipal electric systems, was \$1.5 billion. By 1978, that number reached nearly \$6 billion, and has been around \$5 billion during each of the last 2 years.

Although municipally owned generating facilities have been around for a while in California, the Northwest, Nebraska, and a few other places, the traditional relationship has been for an IOU to produce power and sell it to a municipal distribution system for retail to consumers, you and me. Regardless of how this relationship is described, it is greatly altered today and in many parts of the country it is more accurately described as a partnership, not a fifty/fifty partnership yet, but definitely a new arrangement.

An offshoot of this new arrangement, and let me say that this new relationship is not accepted with even a modicum of good spirit in some places, is that consumer-owned utilities have had to assume a new role...a role previously provided by the IOUs or in some cases, by hydroelectric facilities built by the Corps of Engineers.

This new role requires the municipal utilities to plan for that future growth in power supply and to participate in the development and implementation of new and improved technologies. Faced with the new demands placed on them, and the vastly increased responsibilities many municipal systems have banded together to form joint action agencies. One of the oldest is the Washington Public Power Supply System. Here in California, two such entities recently formed: the Northern California Power Agency and the Southern California Power Agency. In many instances these joint action agencies have entered into the formal joint ventures with investor owned utilities and rural electrical cooperatives to build and jointly own new generating and transmission facilities. In addition to the Supply System in Washington, a number of these joint action agencies have sold bonds: agencies in Texas, Georgia, Massachusetts, Colorado and Michigan just to name a few. In every instance, the bonds have been sold not on the credit of the agency, but on the basis of the underlying contracts between the agency and its members. Now, what does all this mean as far as some of you concerned?

It means, of course, that whereas you might historically have considered IOUs as the proper people to pursue in trying to sell some new technology, you probably should begin paying increased attention to the municipal entities. These include not just the new and proliferating via joint action agencies but such large local systems as those in Pasadena and Los Angeles. One of the attractions to a municipal entity undertaking its own generation is its lower-cost capital. This results not only because it can sell bonds with tax-exempt interest but also because it does not need to earn a return sufficient to attract equity investors. I will mention one other aspect that might be of interest to some of you, particularly those of you who are working with industrial users. Under Section 103 of the Internal Revenue Code, it is conceivable for example, that in a given municipality, an arrangement could be made to finance a solar facility entirely on a tax-exempt basis if the benefits of that facility are available both to the public and to a business located therein. If the benefits to the business do not exceed 25 percent of the output of that facility over the life of that facility, the entire unit could be financed on a tax-exempt basis. At times, though not necessarily right now, this ability to finance with tax exempt bonds has meant savings of over 500 basis points to the industrial user.

There is also a situation where tax exempt financing could be available to an industrial user even though its benefits greatly exceed the 25 percent limitation. This is the so called "two-county" rule; however, rather than get into that technical area I would like to respond to questions on the subject. Thanks for your attention and for the invitation to be here.

PASADENA MUNICIPAL UTILITY

J. Lohr

In thinking about this panel, what I am going to do is pose a lot of questions, most of which you have probably thought about and hopefully have the answers to. They are only representative questions, but I think they will define the kind of questions that must be answered by someone, whether it be you or whether it be manufacturers or producers. The end user, the consumer or the utilities, in our case, will want to know these things. They are nuts and bolts type things. What I am asking here today are only representative questions, but I think that you will want to know them early on in the game. Most of what I have to say will accompany these other gentlemen. Looking at your information on parabolic dishes, and I am just repeating some of those things, one question that comes to mind is, "What kind of space do we need for these devices? For a field of them?" Now I assume we are practically speaking of 50 to 1000 of these dishes. Certainly just to supply Caltech in town here, I think we would need approximately 350 of them. How much space do we need, not just in dishes, but control buildings for the auxiliary equipment, for the interconnection, and for the interface? One other thing I notice is the lack of exclusion area, which might be appreciable. Just here in Pasadena, children love our insulators and buses. They love to shoot at them and they love to throw rocks at our insulators and I think they will just be fascinated by those big mirrors. We must acquire some space in order to keep people away from them. I do not think you want to cover them up.

As an end user, we have to worry about erecting these mirrors. Along the way, of course, the question is: Who is going to erect them? Will a utility erect them or will a contractor erect them? Are we going to get an overgrown erector set? We have gotten some devices like that, with a million pieces, and it takes us two months to figure out what we have. Or, for instance, are we going to have six pieces that can be bolted together? Looking at dishes up there at Edwards, it certainly looks like it lends itself to a very nice set of sub-assemblies, which should not be too much of a problem. What kind of people must we employ to put these up if we should choose to do so ourselves? If we were to put up these kind of devices on a regular basis, I think we would seriously consider doing it ourselves. But, can the ordinary tradesman that we have do it? Now here again, let me say, I am speaking from a generating utility perspective, so we have generating capacity. Therefore, we have welders, we have machinists; we have those types of people which you might not find in the average city utility, which has only lines. This must be considered in the design. If a contractor is going to do it, where are these contractors? What contractors are going to be knowledgeable about having information to erect solar dishes? What kind of tolerances are necessary? Is this going to be a watch put up, or is it going to be cast-iron? Again, looking at the tests at Edwards in aligning mirrors, what kind of tolerances must you have on that foundation on the ring? Can you bend some railroad rail or do you have to use a theodolite or an optimum system to get everything in alignment? These are the kind of things we worry about, if we have to put them up and make them work.

Operating questions: If we have these erected, we have to live with them operating. In some of the information I have read it is suggested to make them unattended stations. That is fine, but presumably they will have to be monitored in some fashion. How is that going to be done? Is it going to be monitored at the station and the information displayed at the station, or is it going to be taken to some remote spot? Again, in our case, being larger small utilities, if that makes sense, we have a dispatching center that we man 24 hours a day and we have people that respond to the alarms. But what about the general case given the small utility? Is someone going to have to look at these things on a regular basis--once a day, once an hour, once a week? What kind of person, how many people are going to have to do that? What should he be able to do when there is a malfunction (and I am sure there will be malfunctions)? And if there is a malfunction, what will the device itself do? Will it shut down? Will the dish shut itself down and somehow datalog it, or say "I am sick" and tell the responsible person, whoever he is, that "I am the one that is sick?" We have a large data acquisition system. It was large in its day, which was approximately 15 years ago, for our steam plant. If there was trouble with the unit, the instruction manual said "Find faulty module and replace." That is fine when you are facing 300 identical modules that all look almost identical and you are not an electronics type. How would you find the problem? I have 350 dishes sitting there; how do I know which one is the sick one? Would it show itself and say, "Here I am?" If you had a dc system with inverters, do you have standby inverters, or just one inverter? Do you take into account how it affects economics? If the whole thing trips off, which could happen, what do you do? It is not an easy thing, particularly on isolated systems, or even on a grid system, to take a generating source that has gone completely off and put it back in service. If you try to pick up a cold load, you have problems. You may pick up a current something like five times your operating current and you have to keep that in mind in the interface design, and so forth, on the full load pickup. We have a maintenance problem that has been alluded to. How are we going to maintain this thing? And, again, what kind of people and how many people? Surely, it is going to take some kind of preventive maintenance. There are a lot of bearings and this kind of thing can not sit there for 20 years without someone looking at them, greasing them, oiling them, or whatever is necessary. Special tools may be needed, special test instruments, and trained people. What kind of training do they have to have? Spare parts: How many spare parts do we have to inventory? Who is going to do the maintenance? Again, maybe this deals with contracts. I can see a service industry devoted to erecting and maintaining solar dish fields.

The last detail is the one that I, perhaps, am more concerned with: How do you interface one of these solar plants with an existing utility system? I wonder how much you have thought about that! Again, just in some of the things that I have read, 4,800 V are mentioned for being the end voltage out of it. That might be fine in some cases, but certainly in a lot of cases that would be too low a voltage. We are talking probably more like 69 kV, 115 kV or 230 kV, which gets to be a problem, with a very small 1MW or 2MW station, of transforming it up to this higher voltage. It certainly may be necessary. In a utility such as ours here in Pasadena, we do not want to hook into our distribution system, which would be an old 4kV system and a 27 kV system. There is also the problem of protection. If there is a fault inside the station, will those devices take the fault current which the utility will deliver to them?

I think of the inverters in particular. If a fault occurs on the high or low side of the inverter we would say to the fault engineer, "What have you got in mind to protect those devices?" Or, conversely, if there is a fault right outside the station, can the devices keep that kind of fault from damaging the inverters? Can we dispatch the things? For some reason we may want to take power from someone else and back down on the dish generating source. How do we back this thing down? It is capable of putting out 5 MW but we only want to take 2 MW out. Is that dealt within the design and if so, how do we do it?

Those are all the nitpicking questions I am going to pose. The big question is, how do we get the answers to all these little questions? We need a dialogue instead of a monologue. The information that you have published is fine, but do we get it? Do we see it? Do we have time to read it? Often, we do not. The meeting in Aspen was a good example of getting utility people involved and I think the utility people should be involved right now as much as possible because of the types of questions I have been asking. And together we will have to supply some of the answers. You will have to supply some of the answers, and the manufacturers will have to supply some of the answers. Better start talking with us. Good luck. Thanks.

Session V

ECONOMICS AND APPLICATIONS

Session Chairman: K. Terasawa, JPL

MARKET ASSESSMENT OVERVIEW

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Market assessment was refined during FY 1980 with analysis disaggregated from a national level to the regional level and to specific market applications, resulting in more accurate and detailed market estimates.

The development of an integrated set of computer simulations, coupled with refined market data, has allowed tremendous progress in our ability to evaluate the worth of solar thermal parabolic dish systems. It is now possible to perform in-depth analyses of both electric and thermal market applications of these systems.

The following market assessment studies were undertaken in 1980:

- Regional analysis of the near term market for PD systems
- Potential early market estimate for electric applications
- Potential early market estimate for IPH/cogeneration applications
- Selection of thermal and electric application case studies for FY 1981

Regional Analysis

A computer simulation program was used to evaluate the effect on the levelized busbar energy cost of increasing production levels of two types of solar thermal electric power plant systems in each of 13 U.S. regions. The first-generation solar thermal reference system was a parabolic dish with a Brayton engine, with a production level of up to 25,000 modules per year; the second generation case used an improved dish and a Stirling engine, with production levels from 25,000 to 100,000 units per year.

The input data for the two generations were held constant while the direct normal insolation resources of each region were changed to obtain the effect of regional insolation on the levelized busbar energy cost (BBEC). The levelized busbar energy costs for three conventional power generation systems were estimated region by region for the years 1985, 1995 and 2000. Then the BBEC for the three conventional power systems were compared to the PD electric option to determine potential early markets. The results were that PD could be competitive with oil-fired power plants before 1990 in Western and Southwestern regions. The second generation of technology, even with annual production of 100,000 modules/year will not be competitive with intermediate and large coal power plants before the year 2000 in many states.

Regions	Breakeven with Small Oil Power Plants		Breakeven with Small Coal Power Plants		Breakeven with Large Coal Power Plants	
	Year	BBEC	Year	BBEC	Year	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

Regional Breakeven Cost
(1980 Dollars)

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

Electric Application

As the first step in estimating the electric application market size, it was determined that BTU's of oil and gas burned was a more relevant market size estimate than existing oil and gas capacity. Further, relying on the SAI case study results, the near-term (1985-1990) market for PD electrical applications will be limited to isolated utilities and utilities with favorable financing: municipals, rural electric cooperatives, and federal installations. An inventory was then compiled of oil and gas-fired generating plants used by electric utilities in high insolation states in the U.S. Based on this inventory and the above assumptions, the maximum near-term electrical application market size is 470 trillion BTU's or 890,000 dish modules.*

	<u>OIL & GAS CAPACITY DISPLACEMENT (MW)</u>	<u>OIL & GAS FUEL DISPLACEMENT (10¹² BTU)</u>	<u># OF EQUIVALENT*² DISH MODULES (10³ MODULES)</u>
MUNICIPALS	11,880	280	520
REC	2,340	20	50
FEDERAL	1,800	30	60
ISLAND	<u>4,360</u>	<u>140</u>	<u>260</u>
TOTAL	20,380	470	890

*¹ The marginal values of solar generation displacing oil and gas in these markets in 1985 are expected to range from 120 mills/kWh to 320 mills/kWh (1980 \$).

*² This column merely represents the number of solar modules required to generate the same amount of electric energy currently generated by the oil and gas units in these utilities.

* Note that this is the total replacement figure, not an annual market size. It is assumed that conventional systems have a heat rate of 12,000 Btu/kWh, and that the electrical output of a dish ranges from 32 to 52 thousand kWh/year, depending on the regional insolation.

Non-electric (IPH) Application

It was assumed that the industrial market would also be limited to areas of high insolation. Within these areas, industries with annual energy consumption of 5 trillion BTU's or more offer the highest potential market penetration. Representatives of industries identified in these areas were contacted to determine the constraints, if any, on the use of solar for specific IPH applications. Industry responses prompted the removal of applications in petroleum refining and iron and steel foundries from the market estimates: land constraints were prohibitive in both applications; the foundries needed direct heat rather than heat derived from steam. There were five industries which did not have any significant barriers against the use of solar thermal systems in the near future: industrial inorganic chemicals, agriculture chemicals, sugar refining, hydraulic cement, and enhanced oil recovery. The near-term maximum potential market in these industries is estimated to be 450 trillion BTU's, or an equivalent of 880 thousand dishes.

NEAR TERM POTENTIAL MARKET FOR PARABOLIC DISH
NON-ELECTRIC APPLICATIONS

INDUSTRIAL APPLICATIONS		OPERATING TEMPERATURE	ENERGY CONSUMPTION* 10 ¹² BTUs (1985)	EQUIVALENT NUMBER OF DISHES (000's)
SIC CODE	INDUSTRY			
281	INDUSTRIAL INORGANIC CHEMICALS	1100° - 2500°	100	200
287	AGRICULTURAL CHEMICALS	350° - 550°	100	200
206	SUGAR REFINING	550° - 1100°	30	60
324	HYDRAULIC CEMENT	1100° - 2500°	50	90
	ENHANCED OIL RECOVERY		170	330
TOTAL			450	880

- *SOURCES: (1) "MARKET CHARACTERIZATION OF SOLAR INDUSTRIAL PROCESS HEAT APPLICATIONS," SERI/PR 353-212, DECEMBER 1979, STATES: CALIF. TEXAS, LOUISIANA: INDUSTRIES WITH ENERGY USE OF 5 x 10¹² BTU'S OR MORE.
(2) DATA RESOURCES INC., ENERGY REVIEW, WINTER 1980, PP. 138 (INDUSTRIAL ENERGY CONSUMPTION; AVERAGE ANNUAL GROWTH RATE OF 1.5% DURING 1980-1990.
(3) HEAT RATE FOR CONVENTIONAL SYSTEM IS ASSUMED TO BE 3414 BTU/KWH AND THE OUTPUT OF THE DISH RANGES FROM 110,000 KWH TO 170,000 KWH.

Thus, the total potential new market for PD systems in electrical and non-electrical applications is about one quad, or equivalently, 1,770,000 PD modules.

These estimates, as noted previously, are the maximum potential market for solar systems. Two important issues consequently arise: first, how much penetration will be achieved by solar thermal technologies in general, and second, how much of this penetration may be achieved specifically by parabolic dish systems?

The latter issue involves defining the comparative advantages of PD systems over trough and central receiver systems. PD systems have some advantages over both troughs and central receivers in industrial applications. Dishes are more efficient than troughs, and are able to operate in higher temperature ranges (above 550° F). Close to 80% of the IPH market requires temperatures above 550° F. Although efficiency alone does not make a technology more attractive, solar thermal is a land intensive technology. High efficiency in this case implies smaller land requirements and thus mitigates one of the critical barriers to entry into this market.

Land constraints as well as thermal transport costs are also potential problems with central receiver systems. Because of their modularity, PD systems not only require less land for the same expected effective output, but the land need not be contiguous.

For electric applications, PD systems are again not only more efficient than troughs, but they also show more flexibility in dispatch options. The two-axis tracking allows optimal adjustment to seasonal demand and insolation variations, and thus different sun-following or load threshold dispatch strategies may be adopted at any time.

The major advantage of a PD system over the central receiver lies in the system's modularity; not because of land constraints, but because of the different patterns of capital costs. Central receivers require a much higher initial cash outlay, since the entire system must be installed before any power is generated. The capital costs of an equivalent PD system, on the other hand, may be spread out over many years as the system's capacity is increased.

Case Studies

Case studies performed with computer simulation models will be used to estimate market penetration in specific applications over time.

Documentation, testing, and integration of the models were performed in FY 1980.

These studies were selected to represent a broad range of sizes, ownership, insolation, utility load characteristics, and utility generation mix. At present, case studies for Molokai, Hawaii, Osage City, Kansas, Burbank, California, the Salt River Project in Arizona, and the Southern California Edison Company in California are planned for FY 1981.

COST GOALS

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Abstract

This paper reports the cost goal activities for the point focusing parabolic dish program. In general, cost goals involve three tasks. First is determination of the value of the dish systems to potential users. Secondly, the cost targets of the dish system are set out. Finally, the value side and cost side are integrated to provide information concerning the potential size of the market for parabolic dishes. This paper reports on the latter two activities.

Introduction

One crucial aspect of technological development is whether or not there will be a market for the technology once it is developed. If there is no market, one reason for development is eliminated. Some view of the potential market is essential. The cost goal exercise attempts to address this question.

There are two aspects to determining whether or not there is a market. First, we have to know what value consumers of the good place on that good. In short, how much would users be willing to pay to obtain the good. Secondly, we need to know something about how much it costs to produce the good. But these pieces by themselves do not yield answers. What if the amount people are willing to pay is lower than the cost, but the number of units people want will not be sufficient to drive the cost that low? In short, some synthesis or integration is required. This paper reports on cost targets and synthesis.

Cost Targets (or Attainability Based on System Cost Targets)

The cost targets are viewed as just that: reasonable targets which can be achieved. There is much challenging technical work to be done toward the achievement of the goals. The goals are initially stated in dollars/square meter for various levels of production. The numbers can then be inverted into other units for easy comparison to the value numbers. In particular, it would be desirable to obtain dollars/unit of output. For the consumer of power, dollar per peak output is not a satisfactory measure since the unit does not always operate at peak. A more desirable measure would be mills/kWh or dollars/MMBTU. To obtain the output (kWh or MMBTU) of the unit, we need to know something about efficiency of the unit of converting sunlight to usable energy and something about insolation. Thus, the cost goals are translated into numbers which are region-specific. The actual cost to the potential user will also depend on what financing arrangements and what unusual tax aspects the user faces. Thus, financial parameters also enter the picture.

Synthesis

These attainability based cost targets need to be integrated with the value base information to see if some potential market size can be determined.

In the following graph, a start toward that synthesis is made. We shall discuss the electric application and similar remarks held for the process heat case.

In this picture, the lines sloping gently upward are the value-based cost goals. The cross hatched areas are the attainability-based numbers. The fact that the attainability-based numbers seem to lie below the value numbers for distillate oil, gas peaking and residual oil seems to suggest that solar power could compete with those fuels. Of course, that would only be true if the utilities used only one kind of fuel, load perfectly matched insolation, if

there are plants of the kind assumed in that region, and if the number of units that people want is large enough to support those costs. In other words, if 10,000-100,000 modules/year are not needed in the 1990-2000 time frame, then there is no way to be sure that these costs can be attained. If that happens, utilities will not find it attractive to utilize solar devices. The point is that value below cost is a necessary condition for success of the solar program, but it is not sufficient.

Since modeling of the subtle economic aspects of the various fuel mixes and load match is very difficult, some case study work is planned to attack these problems. It seems unlikely that insight into these problems will be obtained without such work.

Summary

The size of the market for the device is a matter of considerable interest and importance. The calculation of market size includes both a value based number and an attainability based number. But these numbers by themselves, while necessary, are not sufficient to gauge market success. To correctly understand the nature of the market, finer, more micro studies must be done on a case-by-case basis.

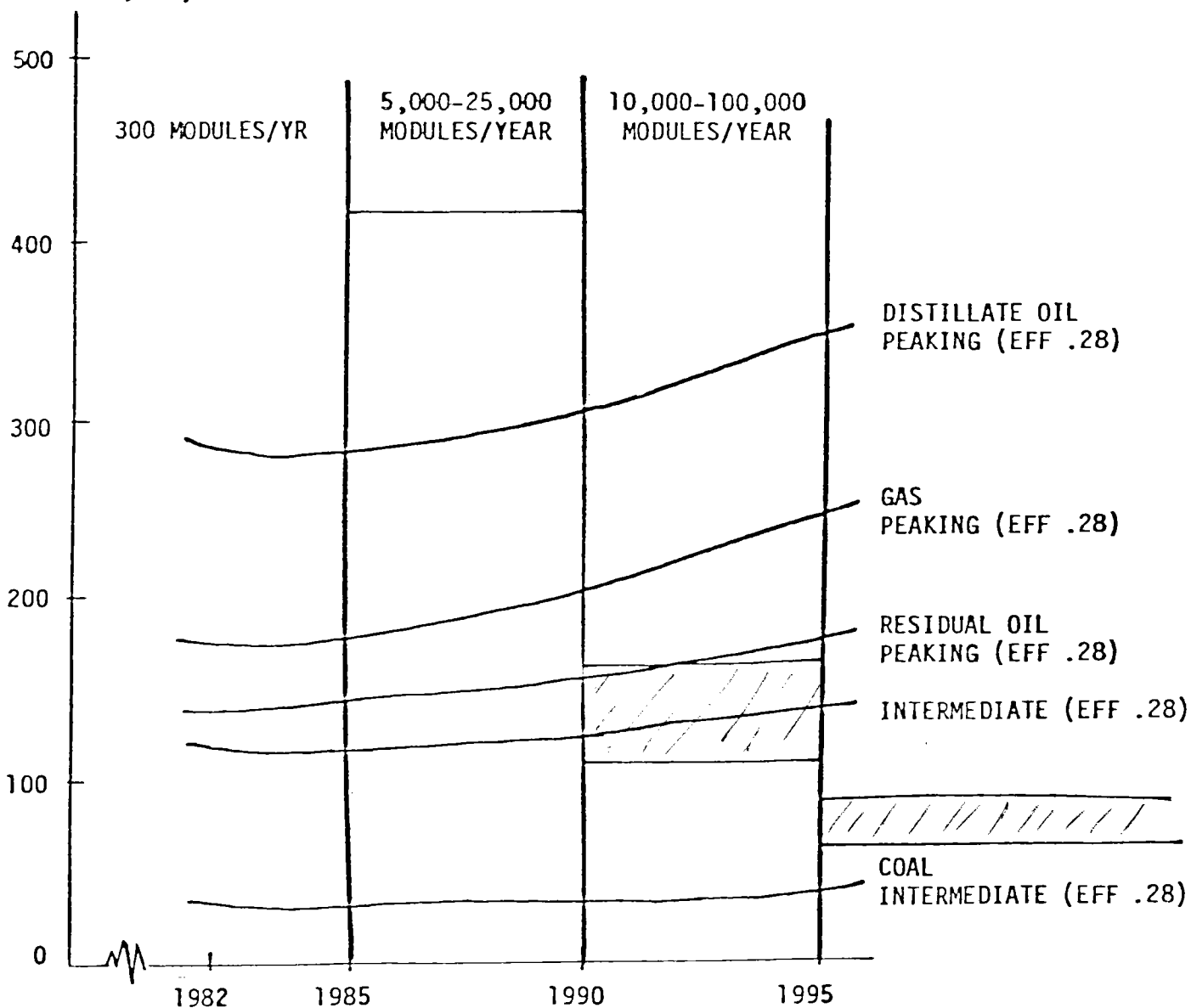
DISH

ELECTRIC UTILITY APPLICATION

BASE CASE

— BASE CASE: ALBUQUERQUE
INVESTOR-OWNED
DRI REAL ESCALATION
FUEL SAVER

LEVELIZED DELIVERED
ENERGY COST
REVENUE REQTS
(1980 MILLS/KWH)



ON-LINE YEAR

AN ASSESSMENT OF THE INDUSTRIAL COGENERATION
MARKET FOR PARABOLIC DISH SYSTEMS

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APPROACH

The Federal Energy Regulatory Commission (FERC) acting under authority of the Public Utilities Regulatory Policies Act (PURPA), has ruled that electric utilities must purchase electric energy from qualifying cogenerators and small power producers at rates reflecting the costs the purchasing utility can avoid by obtaining energy and capacity from those sources. The FERC rules also require sale of back-up electricity at nondiscriminatory rates, interconnection of qualifying cogeneration facilities to the grid, and "wheeling" of cogenerated power outside the local service area if a contract cannot be achieved between the cogenerator and the local utility.

Science Applications, Inc. (SAI) is examining the value for parabolic dish solar thermal systems in cogeneration applications in the southwestern United States under these circumstances. In this sense, the study is an attempt to approximate the economic demand curve for parabolic dish cogeneration systems, showing a potential amount sold as a function of price. Price estimates will be based, insofar as possible, on analysis of the benefit streams created by a reference cogeneration system, serving industry-specific steam and electricity loads, under region-specific weather conditions. In addition, the rates for back-up power and electricity buyback used to monetize the energy flows from the cogeneration system will be based on utility-specific filings of intent where possible.

The estimation of potential quantity sold as a function of price is a famous problem in new technology market potential studies. This study does not try to develop support for the existence of a large cogeneration market, but instead tries to identify the "top" (in a price sense) of that market. Thus, SAI will look for the most advantageous (for dish system value) correspondence between steam-electric energy loads, dish system output, and expected rates for back-up and exported power. The credibility for these findings will rest on the ability to verify the relevance of the conditions modeled, and on the analysis technique used to derive system value from those conditions.

METHODOLOGY

The value analysis technique used for this study is simple and straightforward. Maximum allowable life-cycle system cost for the cogeneration system is determined as the sum of the present value of fuels displaced plus the present value of revenues from exported power. Each conventional fuel displaced is described by a unit cost in the first year, a uniform annual consumption rate, and a uniform annual escalation rate for unit cost. Because the effects on after-tax earnings of a \$1 increase in revenues, are assumed to be the same as those of a \$1 decrease in costs, exported energy flows are treated the same as displaced energy.

The question of interest for this study is: how much can a cogeneration system cost and still be competitive with conventional energy technologies? An absolute upper bound to this question is defined by the "breakeven" system cost, defined as the highest installed system cost for which the cogeneration project can avoid a negative net present value (NPV) when all project-resultant cash flows are considered. All of the application-specific characteristics mentioned above, plus the operations and maintenance costs of the cogeneration system, are represented in the project NPV.

The technique for determining potential quantity sold is much more empirical than the discounted cash flow methods used to determine value. Subjective criteria were used to limit the survey population to service territories of eight investor-owned utilities in six major metropolitan of the southwestern United States. Use of the utility service territory as the basic unit of analysis has several operational advantages. First, the relevant rates for back-up and exported power will be utility-specific. Thus the utility service territory is a logical unit for the value analysis described above. Second, service territories are easily related to the regional manufacturing activity data used in estimating potential cogeneration system sales, and to other region- and site-specific influences on prospects for solar thermal cogeneration (insolation, projections of industrial growth, land availability, transmission line availability, etc.). Finally, the large utilities generally have substantial in-house knowledge of the load characteristics of their industrial customers. If this preliminary analysis were to be disaggregated and extended, visits to the eight utilities might be a cost-effective alternative to site visits to all prospective cogenerators.

Within a given service territory, the gross population of prospective cogenerators is determined from lists of local manufacturing activity as reported in state manufacturing registers. Initial screening is applied to eliminate manufacturing activities whose energy requirements are obviously incompatible with parabolic dish systems. The remaining plants are retained for further analysis. Performing this process for each service territory results in a matrix of "feasible" manufacturing establishments, tabulated by utility service territory.

Using energy load profiles typical of the industries selected, and local insolation and utility rate data, breakeven costs for parabolic dish cogeneration systems are computed for each application/service territory combination in the matrix. The results, ranked from high to low by breakeven value, represent a value-stratified list of potential cogeneration applications for the sample analysed. The last step is to estimate the quantities of potential sales of parabolic dish cogeneration systems corresponding to the respective value strata. This is done from local data on manufacturing sector energy use. This data is used to estimate, for each service territory, the total energy use by each manufacturing activity modeled. The portions of that total use corresponding to the process conditions modeled are estimated from "typical plant profiles" for the appropriate industries.

EXPECTED RESULTS

Because they will be synthesized from average data, the potential sales data are obviously "soft." Furthermore, the important attrition mechanisms separating attainable sales from gross potential are not modeled at all. The value of the study must rest, therefore, on the value stratification results. From this perspective, the quantity results should be indicative of applications meriting the cost of gathering more detailed information on technical requirements and potential energy displacement.

Session VI

ADVANCED DEVELOPMENT

Session Chairman: J. Becker, JPL

ADVANCED DEVELOPMENT - FUELST†

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ABSTRACT

This paper describes the solar thermal fuels and chemicals program at JPL. The primary objective is to develop and apply high technology to displace fossil fuel (oil) use in the production/processing of valuable fuels and chemicals; it is the aim to demonstrate the technical and economic feasibility to an extent that enables the industry to participate and commercialize the product. A representative process, namely Furfural production with a bottoming of acetone, butanol and ethanol (ABE), is described. Experimental data from all solar production of furfural is discussed. Estimates are given to show the attractiveness of this process especially considering its flexibility to be adaptable to dishes, troughs or central receivers. Peat, lignite and low rank coal processing, heavy oil stripping and innovative technologies for process diagnostics and control are mentioned as examples of current projects under intensive development.

FURFURAL AND ABE BOTTOMING

As part of the SUNFUELS program sponsored by the U.S. Department of Energy, JPL has demonstrated the technical feasibility of producing liquid fuels. The general philosophy has been one of maximizing the utility of the solar application; instead of producing one fuel or one chemical in the process, several fuels and chemicals are produced in the overall process. A brief description of the background, proven test results and the future plan is outlined here.

BACKGROUND

Solar energy processed fuels and chemicals are expected to gain prominence in the mid (1985-1990) and the long (2000) range future of the United States if not the world. Solar energy processed fuels and chemicals are of course available in nature as plants and derivatives. In an attempt to identify transportable and storable liquid fuels and to displace fossil fuels (Example: imported oil) in their processing, FURFURAL is identified as an important candidate; conventional furfural production from biomass is seen to offer possibilities of simultaneously producing valuable alcohols and acetone at little extra energy cost.

At the present time 10^8 kilograms ($\approx 2 \times 10^8$ lb.) of furfural are produced in the U.S.A. annually. Practically all of this is produced by Quaker Oats. The feedstock is biomass that have hemicelluloses in them (corncobs, peanut shells, soft woods....). The theoretical maximum yield is in the range of 10% - 20% by weight of the feedstock. Furfural can be used as a liquid fuel (≈ 5550 kcal/kg or 10,000 Btu/lb. of energy release upon complete combustion in air), although there exist more valuable uses such as feedstock for furan resins. (The Germans used furfural as a Diesel fuel

† Work funded by DOE and performed at JPL as part of NASA Contract NAS7-100.

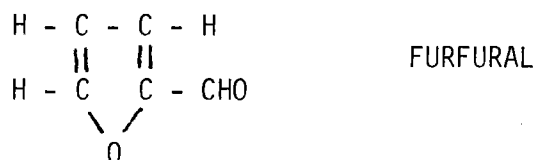
during the second World War.) The 1980 price is nearly 1\$/kg or (\$0.45 per pound). It takes nearly 9992 kcal/lit (150,000 Btu per gallon) of furfural produced. The feedstock is acid hydrolyzed and steam "cooked" to release the furfural which is subsequently extracted from the water by dichloromethane. Hence, the use of solar produced steam in the process would displace at least 0.75×10^{12} kcal/yr (3×10^{12} Btu/yr) worth of fossil fuels (mostly oil and natural gas in the U.S.A.). This number of 0.003 Quad*/yr is just the proverbial tip of the iceberg.

The acid hydrolysis process (with typically 5% dilute H_2SO_4) prepares the cellulosic portion of the biofeedstock also ideal for fermentation to acetone, butanol and ethanol (called ABE, for short). Since the cellulosic portion consists of at least 50% of the typical feedstock, while the hemicellulose is typically 15%, the product breakdown may be expected to be:

0.15 kg Furfural
 0.45 kg of alcohols
 0.2 kg of solid spent mass

per kilogram of feedstock. Even if the difference (0.2 kg) is not recovered, 0.45 kg. of alcohols yield an equivalent of $(\frac{0.45}{0.15}) \times 2 \times 10^8 \times 10^4 = 0.006$ Quad/yr in energy. The solid spent mass can be used as cattlefeed after deacidification, or just burned to augment the steam production. This ABE "bottomer" also enables the production of furfural on a continuous basis (as opposed to solar dependence always). Thus 0.009, or nearly 0.01 Quad/yr. is the *minimum* fossil energy displacement to be expected.

With the dwindling petroleum supplies the furfural derived chemicals can possibly provide the plastics feedstock and pseudo aromatics.



The chemical structure of furfural suggests that furfural could be a potential additive to engine fuels for knock suppression. After the elimination of tetraethyllead from the fuels, aromatics are being used to raise the octane numbers to acceptable values. With the natural petroleum derived aromatics becoming increasingly expensive, furfural could rise to meet the demands. Even at a conservative rate of 1% addition to gasoline (synthetic or natural) the demand for furfural (in furfural derived pseudo aromatics) potentially is seen to be $10^9 - 10^{10}$ kg/yr.

* 1 Quad = 0.25×10^{15} kcal.

THE PROCESS REQUIREMENTS

Furfural production requires steam in the pressure range of 3.4-6.8 atm (50-100 psi) and temperature range of 422-533°K (300°-500°F). Typically 30 kg of steam are used per kg of furfural produced or 30 kg for nearly 7 kg of feedstock. These rather mild conditions show that the process steam can be obtained by troughs, dishes, or central receivers. This flexibility is particularly valuable considering that the solar collector technology (viz, troughs vs CR's vs. dishes) has not been finalized yet.

THE RUNS AT JPL

Four successful runs were conducted at JPL (Pasadena) with 9.08 kg (20 lb) feedstock of corncobs each and electrically produced steam. The pressure and temperatures used were 3.4 atm (50 psig) and 422°K (300°F). The runs lasted 1-1 1/2 hrs. Electrical preheat was used to raise the temperature before the steam cooking.

After these initial tests the reactor was tied to the steam generator at the Test Bed Concentrator - 1 at the Edwards Test Station at JPL. This *all solar* production of furfural was highly successful even at the very first attempt. It should be mentioned that the design capacity of 80 kw (thermal) of TBC-1 was far in excess of the small reactor requirements. One half of the reflector area was blocked off during this run.

FUTURE PLANS

The reactor exists to handle nearly 10 kg feedstock per batch. The runs last typically 1-2 hrs. A reactor properly matched to the TBC is in design and will be matched with the TBC-1 later in FY81. Runs will be conducted at the trough facility of Albuquerque, New Mexico. Process optimizations will be performed. The furfural will be tried as a fuel in the diesel engine and as a fuel additive in a gasoline engine. Fermentation of the spent mass is in progress to prove the ABE process.

TRANSITORY SUMMARY ON THE FURFURAL PROCESSES

It is interesting to note that after the JPL effort got underway three important developments have taken place with regard to furfural in the world.

1. Cetus Corporation and Standard Oil of California have entered an agreement to produce large quantities of furfural. The production is expected to start in the next three years (ref. Chem. Eng. 28 July 1980).
2. Mitsubishi Company in Japan is setting up a huge plant in Japan for making a derivative of furfural (tetrahydrofuran).

3. Quaker Oaks and IITRI have jointly submitted to JPL a proposal for a feasibility demonstration of solarization of furfural production on a commercial basis.

The future looks bright for furfural.

LOW RANK COAL, PEAT AND LIGNITE PROCESSING

It is estimated that the deposits in the USA correspond to 1443 quads of peat, 3082 quads of lignite and 3534 quads of subbituminous (low rank) coals (Ref. 1). The high moisture content (frequently in excess of 50% by weight) of these fuels poses special problems. Transportation in wet form is not economical and drying them invariably introduces severe problems of spontaneous reactivity. Utilizing the energy content of the peat/lignite/low rank coal to process them would diminish their heating value. A process is sought to obviate all of these problems simultaneously.

An innovative process developed at JPL is shown in Fig. 1 here. The as-mined material is mixed with a heat transfer fluid in which it is wet ground. The heat is supplied in a heat exchanger that circulates solar steam. A flash separator gets out the high BTU vapors which can be directly fed into a gas pipeline or used as a feedstock for making liquid fuels. Preliminary economics calculations show that 3.25×10^9 Kcal/1000 kg can be recovered in transportable, storable high BTU fuel with this solar assist process. Laboratory experiments are underway to prove the process.

HEAVY OIL STRIPPING

The solar derived steam is ideally suited for the stripping of heavy oil that occurs in a distributed manner in many parts of the U.S.A. (example: California). A reactor is being built to utilize the TBC-1 steam at 811°K (1000°F) for this purpose. It is expected that the same reactor can be used for processing synthetic crudes also.

INNOVATIVE PROCESS DIAGNOSTIC TOOLS

Acoustic imaging is being developed to diagnose in real-time local details in processes. The acoustic field can be mapped locally with non-interfering Ellipsoidal Acoustic Mirror Microphones (EAMM). Details of spatial and temporal resolutions are being worked out.

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THE PROCESS MODIFIED WET OXIDATION

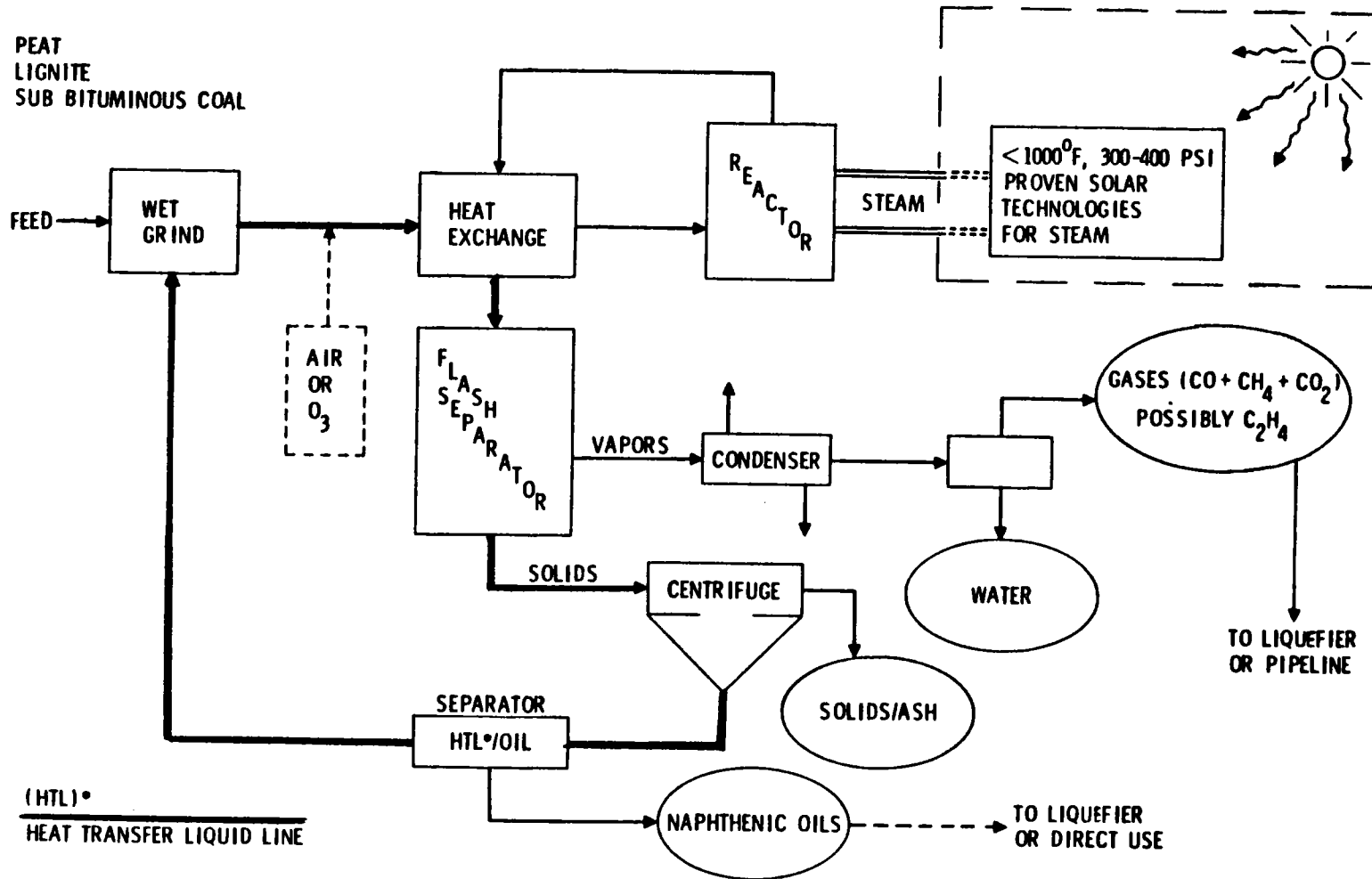


Fig.1 The proposed modified wet oxidation process to convert peat/lignite and low rank coals to high BTU fuels.

FUELS AND CHEMICALS FROM BIOMASS USING SOLAR THERMAL ENERGY

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ABSTRACT

In the manufacture of fuels and chemicals from biomass, a significant fraction of the energy input to the processes is derived either from fossil fuels or from a portion of the biomass feedstock itself. Since there is a strong motivation for the U.S. to reduce where possible the use of fossil fuels for process energy, and since the use of biomass simply as a fuel is a suboptimal use of this feedstock, the employment of solar heat for process energy represents genuine conservation of these valuable resources. The most significant nearer term opportunities for the application of solar thermal energy to the manufacture of fuels and chemicals from biomass are summarized in this paper, with some comments on resource availability, market potential and economics. Special consideration is given to the production of furfural from agricultural residues, and the future role of furfural and its derivatives as a replacement for petrochemicals in the plastics industry.

INTRODUCTION

Agricultural wastes offer a large source of available biomass. The Quaker Oats Co. has been active since the 1920's in the utilization of such waste products as a source of the chemical furfural. Current furfural processes convert only a portion of the collected raw material to the desired product with resultant by-production of large amounts of residues which on burning give sufficient energy to drive the process. The use of solar thermal energy for biomass processing would allow complete utilization of these residues for further conversion to higher value liquid fuels and chemicals.

Solar energy is considered to be the most viable source of process energy for totally integrated biomass plants in the future. Since most, if not all, of the biomass is to be converted to furfural and other chemical derivatives, or to high utility value convenience fuels for transportation, an alternate source of energy is needed. Since it is anticipated that these plants will be relatively small, to minimize collection costs of the biomass, coal does not appear to be a viable heat source because of transportation and pollution control problems. Solar energy therefore is considered to be the most viable long-term energy source.

The study presented in this paper is part of a proposed project aimed at determining the feasibility and optimum design of an integrated process for the production of fuels and chemicals utilizing agricultural residues. An important feature of fuels and chemicals based on furfural and its co-products is that the feedstocks are agricultural wastes and, as a result, do not compete with the food supply. The proposed study, to be conducted by IIT Research Institute with the cooperation of the Quaker Oats Co. and the consultation of Prof. M. Wayman of the University of Toronto, will indicate the best approaches for maximizing the energy yield of the biomass with the

use of concentrated solar heat as the primary source of process energy. The potential of furfural and its derivatives as "renewable resource" chemicals to replace petrochemicals in the production of plastics and elastomers is also considered.

SOLAR POWERED BIOMASS CONVERSION PROCESS

Biomass, regardless of source, consists primarily of three principal ingredients, namely, hemicellulose, cellulose and lignin. Agricultural residues such as corncobs, sugar bagasse and oat hulls, as well as hardwoods, give hemicelluloses which contain relatively large amounts of pentosans (C-5 sugars) which can be cleaved and dehydrated to give furfural, a pseudo-aromatic chemical which has the potential of replacing petroleum derived benzenoid chemicals and resins. Softwood hemicelluloses, by contrast, consist essentially of hexosans (C-6 sugars) which do not yield furfural, but which can be fermented to alcohol, usable as a liquid fuel. These hemicelluloses are rather easily hydrolyzed to a mixture of fermentable sugars such as glucose and mannose. Cellulose, by contrast, consists of essentially 6 carbon glucose units linked together by β linkages which permit the molecules to orient to give highly crystalline structures which are quite resistant to hydrolysis to simple sugars.

Lignin consists primarily of propenylphenol moieties linked by a number of different bonds, including ether linkages and carbon-carbon bonds. The lignin is closely associated with the cellulose portion, possibly with direct chemical bonds, so much so that some researchers in the field regard lignin as a "glue" that holds the cellulose structure together. Once isolated by mechanical/chemical means, lignin is soluble in alkaline solutions via salt formation with the phenolic hydroxyls.

Currently two industries process large quantities of biomass for non-food uses: The forest products industry pulps wood to separate the cellulose from the hemicellulose and lignin fractions, primarily for use in making paper, but also for chemical conversion to rayon fibers, cellophane film, and acetate plastics. The Quaker Oats Company processes agricultural residues so as to convert the pentosan hemicellulose fraction into furfural. These industries use different fractions of the collected biomass and convert only a portion of the huge amount of biomass they process into useful products. From 50 to 90% of the total biomass collected is burned as fuel. The challenge of a solar powered biomass conversion process is to maximize the energy yield of the biomass by complete utilization with the use of concentrated solar heat as the primary source of process energy for the production of chemicals and liquid fuels.

An integrated biomass conversion process would separate the components in an undegraded state so that subsequent processing would result in liquid fuels and chemical products of greater value. Unavailability of by-products as fuel, however, would require substitution of energy from another source. Solar-thermal energy can provide the steam needed for biomass processing and energy for product distillation and purification.

The critical aspect of such a biomass conversion process is the separation of biomass into hemicellulose, cellulose and lignin under conditions which do not degrade these fractions during separation. An effective pretreatment is "autohydrolysis" (ref. 1), which consists of steaming the

biomass at about 200°C for approximately 20 minutes. This breaks up the crystallinity of the cellulose, renders the hemicellulose soluble in hot water, and partially depolymerizes the lignin which becomes soluble in dilute sodium hydroxide solution from which it can be separated by acidification. The cellulose freed from hemicellulose and lignin is separated in a partially decrystallized form suitable for hydrolysis. The hemicellulose filtrate would be diverted to an existing Quaker Oats plant, the lignin would be sent to a conversion unit for the production of useful chemical intermediates, and the cellulose would go to a saccharification/fermentation plant for conversion to alcohol fuel. A tentative process flowsheet is shown in fig. 1.

For continuous operation during cloudy or non-daylight hours, in the absence of a thermal storage system, some of the residual lignin, which has a high heat of combustion (~11,000BTU/lb), could be effectively utilized as supplemental fuel for hybrid operation.

BIOMASS RESOURCE AVAILABILITY

Agricultural crop residues in the US amount to about 1 billion tons annually. While a portion of this is re-used in agriculture itself, the potential is there to produce 5-10% of the nation's energy needs from these wastes. Thus, biomass now existing can provide substantial amounts of feedstocks to processes such as the one described here.

Corncocks are the preferred material because of optimum furfural production and relative ease of grinding and processing. However, widespread use of combines to harvest corn has drastically reduced the availability of cobs. A possible future raw material would be the "corn stover" which exits from the combine when corn is harvested. Alternate feedstocks might be sugar bagasse or aspen chips. For the longer term, processing of guayule bagasse after extraction to remove rubber-like hydrocarbons will be considered. Guayule has been proposed as a viable source of "rubber latex" which can be grown on currently nonproductive arid regions in the southwestern U.S. Since these are areas of high insolation, application of solar thermal energy to the processing of guayule may be particularly advantageous. The fibers extracted from guayule bagasse contain relatively high levels of pentosans which could be converted to furfural. Subsequent removal of lignin would yield fibers suitable for paper (based on USDA studies) or for saccharification and fermentation to alcohol.

ALTERNATIVE FUELS AND CHEMICALS

In addition to developing alternative fuel sources, alternative chemical process feedstocks must be developed if dependence on petroleum imports from OPEC nations is to be eliminated. Furfural is a very versatile chemical which can be utilized in a variety of synthetic organic processes. Furfural is used as is as a selective solvent for refining motor lube oil, but is used more extensively as a feedstock for producing other chemicals such as furfuryl alcohol, tetrahydrofurfuryl alcohol, furan, tetrahydrofuran, and polybutylene glycol ethers. Until fairly recently, THF via furfural was the feedstock for du Pont's Nylon 6/6. Currently the largest market for chemicals based on furfural is for furfuryl alcohol which on condensation gives a resinous binder.

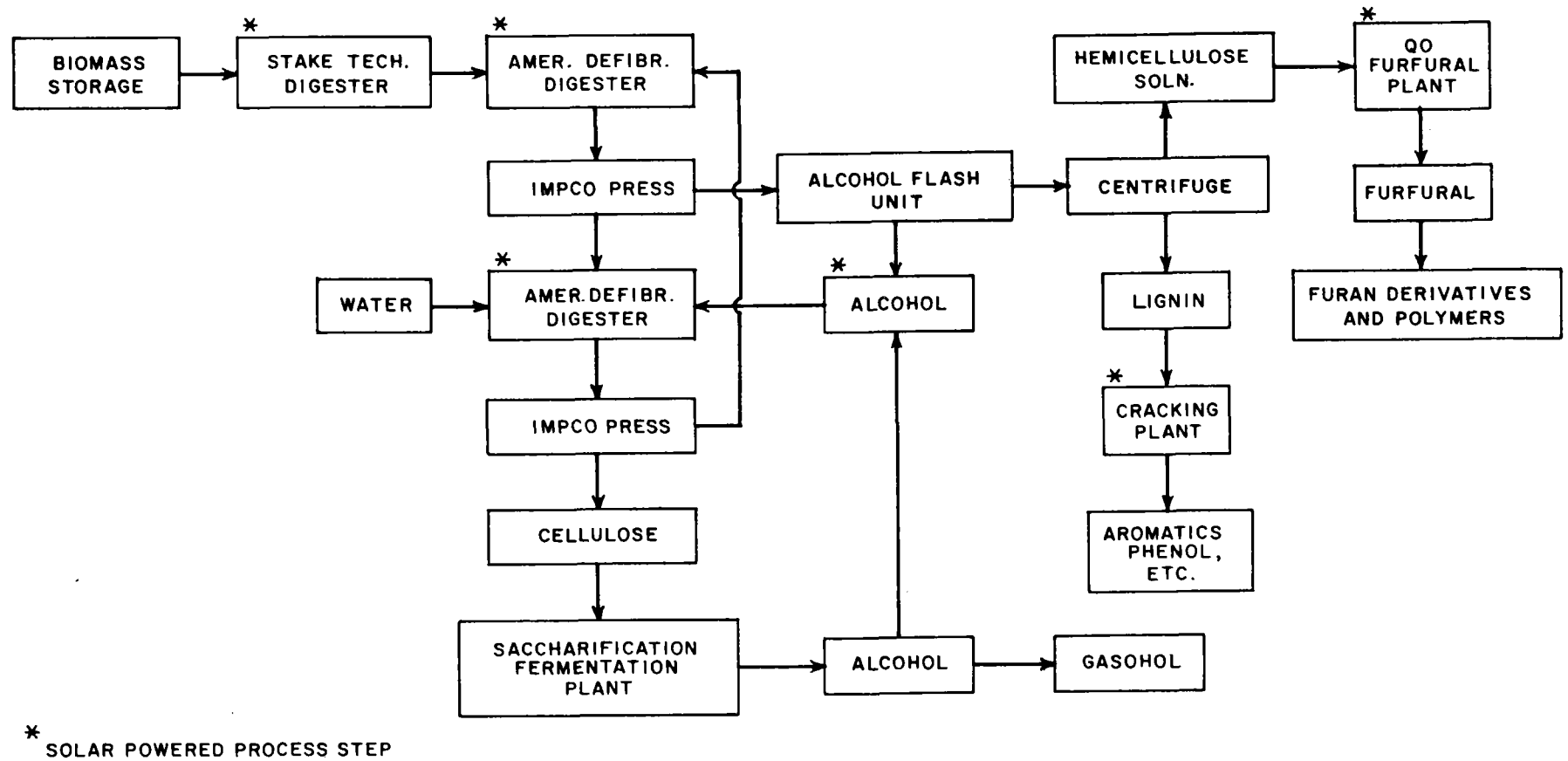


FIGURE 1. SOLAR-POWERED BIOMASS CONVERSION FLOWSHEET

The furan ring is pseudo-aromatic and undergoes many of the reactions of analogous aromatic compounds. Furfural and derivatives therefrom offer great potential for replacement of benzenoid chemicals such as styrene and phenol widely used in polystyrene and ABS plastics, in SBR elastomers, in phenolic molding compounds and plywood adhesives, and in polyester laminates. The pseudo-aromatic furan ring contributes many of the physical and chemical properties resulting from the aromatic benzene ring in petroleum based derivatives. Furfuryl alcohol resins could be used to replace phenolic resins as binders for particleboard and glue for plywood. With the price of phenol rapidly increasing and continued supply of phenol uncertain, the forest product industry currently is seeking a "renewable resource" adhesive to replace phenolics. Preliminary laboratory studies indicate that a furan resin can indeed be readily substituted for currently used phenolic adhesives. In order to supply this market, however, current production capacity of furfural/furfuryl alcohol, which is currently ~200 million lbs/yr, would need to be expanded by a factor of at least 10. Another potential large volume market for furfural is the production of vinylfuran as a replacement for styrene. Styrene, which is vinylbenzene, is a vital chemical intermediate for polystyrene plastics, insulating foams, elastomers and polyester resins for fiberglass laminates.

Thus, furfural appears to be a viable "renewable resource" alternate for the plastic industry. Potential large volume markets exist for the replacement of oil-derived aromatic chemicals. This increased volume of furfural could only be produced economically by development and construction of plants designed for the total utilization of biomass. It would appear that the economics and future outlook for such plants depend upon the availability of a source of energy not involving either fossil fuel or the combustion of the biomass itself. Solar heat has a contribution to make by providing the source of energy required for biomass conversion.

REFERENCE

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SOLAR THERMAL MATERIALS RESEARCH AND DEVELOPMENT¹

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The primary objectives of the Materials Research and Development effort are 1) to understand the behavior and interaction of different materials used in solar thermal technologies so as to create a sound technical base for future system and component designs and 2) to develop materials to extend the application potential of systems by either making materials more reliable in difficult operating environments or by offering lower cost alternatives to presently used materials.

Solar thermal systems are being designed aimed primarily at electric power, industrial process heat from low to high temperature, and fuels and chemicals applications. Another application not discussed here is building climate control such as passive and active heating and cooling. Systems which concentrate, collect, and transport solar thermal energy are of primary interest for these potential applications.

Concentration ratio corresponds to the ability of a solar collector to deliver high temperature thermal energy. Figure 1 shows the progression from point focusing systems (both parabolic dishes and heliostats), through line focusing systems such as parabolic troughs, CPC, evacuated tubes, to solar ponds. This figure depicts their primary application focus while also displaying other potential applications for which these systems may be equally well suited.

The materials research and development effort is divided in two categories: 1) optical materials which include reflectors, transmitters, and optical structures; and 2) thermal materials for receiver

¹This effort is managed by SERI for the U.S. DOE, Division of Solar Thermal Energy Systems

and energy transport subsystems which consist of absorber materials, ceramics, metals, alloys, and heat transfer fluids. The relative importance of materials in the two categories to the solar thermal systems of interest is also displayed in Figure 1, more dots meaning greater importance.

The materials requirements are derived from the system concepts and expected application environments. These requirements have been established for the current generation of solar thermal systems and the perceived needs of the initial markets. A great deal of effort remains to establish the systems requirements and market needs for systems that would have to meet the stringent first cost and economic criteria of the industrial sector where the larger potential may exist for modified versions of current or entirely new concepts of future solar thermal energy systems.

Materials research and development includes the four critical steps; namely, a) generating new ideas and concepts, b) assessment of its potential from economic and system performance viewpoints, c) pilot fabrication of promising materials and evaluation both in laboratory and field experiments, and d) adaptation of the new or improved materials to the wide range of components and systems. This program is structured to allow these steps to be conducted with a maximum utilization of the available university, national laboratories, and industrial scientific and production capabilities. With this combined effort, it is hoped that the most promising concepts and materials nurtured through research and development will ultimately emerge in the commercial marketplace.

The development of optical materials has the highest priority because they account for a significant portion of the solar thermal system cost and also, being new and unique to solar systems, presents the

largest unknown in calculating their operational reliability and life cycle costs from the ultimate users perspective. Optical systems, which consist of reflecting, transmitting, and structural materials, when further developed, can lead to concentrators with lower initial cost, improved performance, or longer life. One of these criteria is important in each unique application or system depending on whether higher temperature, minimum maintenance, low first cost of installed systems or some combination is required by the purchaser of the system.

In the following, some examples of the research projects in the concept laboratory evaluation stages are polymers and mirrors. An example of the research at the concept stage is the development of polymers which are UV stable over a long period, say up to 10 years. Polymers offer the potential to reduce the cost or extend the life of a variety of solar energy systems. Another example is the evaluation of alternate mirror fabrication techniques which offer the possibility of more durable mirrors on glass and polymers.

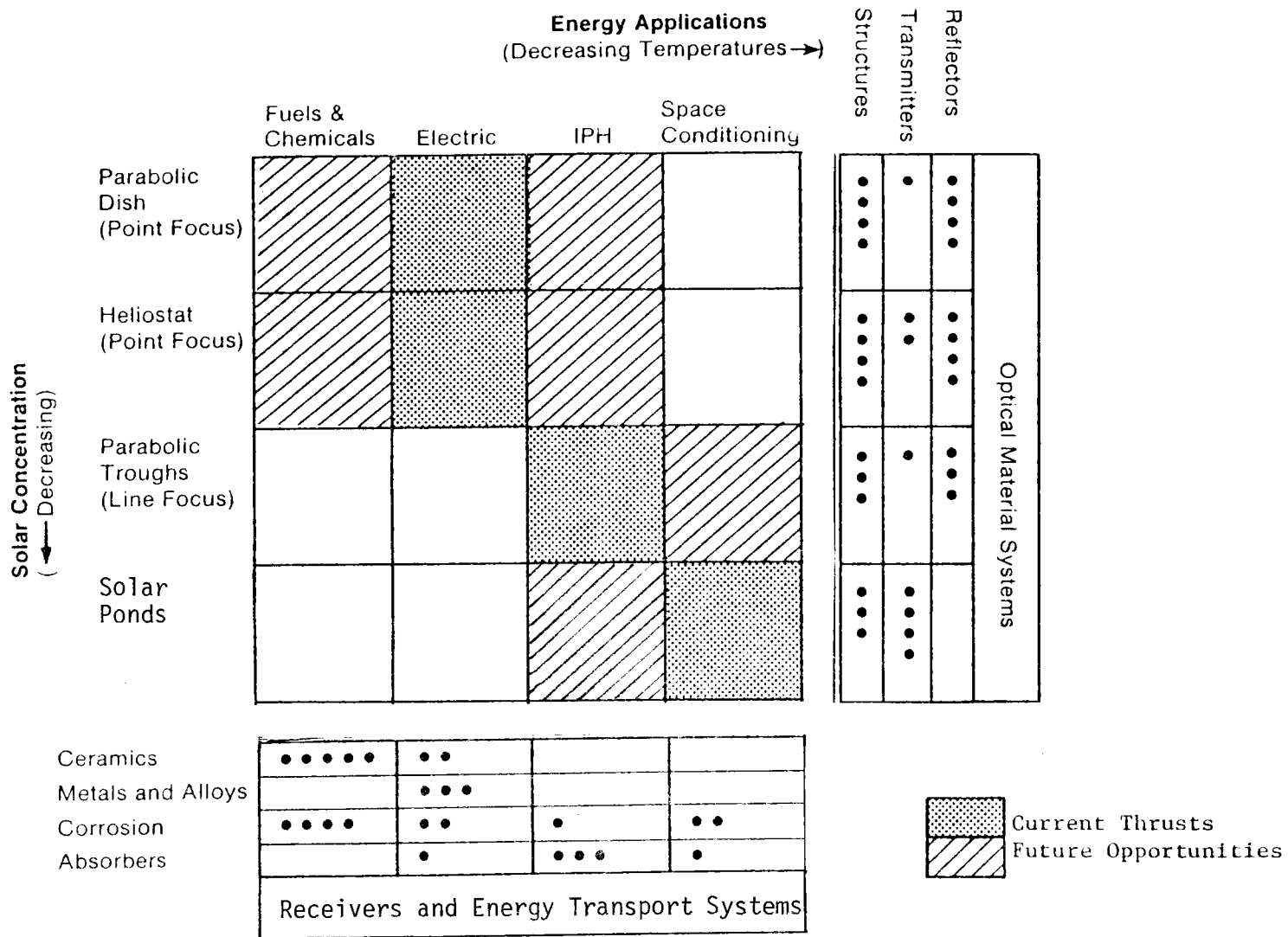
Examples of the materials in pilot fabrication and adaptation are cermet coatings and thin glass. A concept being assessed for its large scale production is the cermet selective absorber coating with platinum and aluminum oxide. This material, developed as a university concept, showed desirable performance characteristics in the laboratory and is now being evaluated by industry using production equipment and techniques.

The evaluation of thin glass produced by industry on a pilot production basis represents an example of another materials development effort. Glass with high transmission coupled with desirable characteristics such as good strength and low weight is undergoing field evaluation by a variety of solar system fabricators. This evaluation by equipment designers and system engineers is critical to the success of the materials research and development since this represents the initial

step to future product improvement and industry commitment for large scale production.

The materials development is a foundation upon which future solar systems will be built. Guiding the availability of these reliable materials with adequate data to designers and system suppliers through the commercial sector is the measure of success of this effort.

Figure 1



Materials Application to Solar Thermal Systems and Applications

SOLAR ENERGY WATER DESALINATION IN THE UNITED STATES AND SAUDI ARABIA

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Five solar energy water desalination systems are being designed to deliver 6000 m³/day of desalted water from either seawater or brackish water. After the system definition study is completed in July 1981, two systems will be selected for pilot plant construction. The pilot plants will have capacities in the range of 100 to 400 m³/day.

1.0 BACKGROUND

In October 1977, Saudi Arabia and the United States signed a Project Agreement for Cooperation in the Field of Solar Energy (SOLERAS) under the auspices of the United States-Saudi Arabian Joint Commission on Economic Cooperation. The objectives of the agreement are to:

- cooperate in the field of solar energy technology for the mutual benefit of the two countries, including the development and stimulation of solar industries within the two countries;
- advance the development of solar energy technology in the two countries; and
- facilitate the transfer between the two countries of technology developed under this agreement.

The Solar Energy Research Institute (SERI), as the Operating Agent, is responsible for implementing SOLERAS in accordance with directives of the SOLERAS Executive Board who has approved a five-year technical program plan.

As part of this technical program plan, an area of Industrial Solar Applications for solar technology has been identified. A specific objective is to demonstrate the use of solar energy in desalinating water. Water desalination is needed in both Saudi Arabia and the United States. In Saudi Arabia, water is needed principally for municipal and agricultural applications. In the United States, desalination is mainly required to control river salinity and provide potable water to selected communities that have critical water quality problems or water shortages.

2.0 PROJECT PLANS

To accomplish the objective of the SOLERAS solar energy water desalination project, a 3-phase activity is planned. The phases are as follows:

- Phase 1: Preliminary System Design and Cost Analysis
- Phase 2: Detailed Pilot Plant Design and Construction
- Phase 3: Pilot Plant Operation and Training of Personnel

Phase 1: System analyses and economic analyses will be performed by several companies on a solar energy desalination system of their choice for either seawater or brackish water desalination. The systems will each be for an average daily product water capacity of 6000 m³. The main criterion for the analysis will be the product water cost. Each system will be designed for a specific site and application. The site, application, and technology will have broad applicability to general water desalination needs in either the United States or in Saudi Arabia. It is the intent of this project to encourage innovation without unduly affecting performance and reliability. Subsystems and their interfaces will be defined during Phase 1 and product-water cost projections will be made for commercial plants of a range of capacities.

Finally, a development plan for Phase 2 will be generated including detailed cost estimates for the design and construction of a pilot plant with a capacity of 100 to 400 m³/day using the technology of the baseline system.

Phase 2: Of the several systems designed in Phase 1, one system in each category (brackish and seawater desalination) will be chosen for pilot plant construction. The criteria for selection will include levelized cost per unit of product water for the commercial sized plant, design and construction cost for the pilot plant, consistency in cost between the commercial sized plant and the pilot plant, maturity of system design and projected plant reliability. Each pilot plant will have a product-water output capacity of 100 to 400 m³/day. The pilot plants will be designed in detail and constructed on specific sites.

The size of the pilot plant was selected to be within the budget limitations of the SOLERAS Program and is of a capacity that provides useful technical and economic data for planning, design, and construction of a commercially-sized plant. A pilot plant delivering 400 m³/day of desalted water would provide water to 2,000 people or could provide irrigation water for about 8,000 m² of greenhouse agriculture. If the ratio of the ultimate plant capacity to the pilot plant capacity becomes too great, less useful technical and economic information for application to the full scale plant can be extracted from the pilot plant construction and operation.

Phase 3: The pilot plants will be operated and performance measurements made to provide the information essential for designing commercial-sized desalting plants. Local personnel will be trained in the operation and maintenance of the plant so they can make performance measurements.

The schedule for Phase 1 is from October 1980 to July 1981. Phase 2 is expected to start in October 1981 with the pilot plant construction completed by July 1983. Phase 3 will start at the completion of Phase 2 and will continue until the end of 1983.

The five companies that have been awarded contracts for Phase 1 and their team members are shown in Table 1. The technologies involved in the five systems, the water type, and projected plant locations are given in Table 2. The table shows that the five contracts represent six different desalination technologies (seawater and brackish water reverse osmosis are regarded as two different processes), and five different solar energy technologies.

The two companies which utilize point focus thermal collectors are discussed in more detail in the next section.

Table 1. CONTRACTORS FOR PHASE 1

Prime Contractor	Team Members
Boeing Engineering & Construction Co.	Resource Conservation Co. International
Catalytic, Inc.	Science Applications, Inc.
Chicago Bridge & Iron Co.	Foster-Miller Associates, Inc. Arabian Chicago Bridge & Iron Co.
DHR, Inc.	Science Applications, Inc. Ionics, Inc. Al-Radwan
Exxon Research & Engineering Co.	Permutit Co., Inc. Ecodyne-Unitec Div. Martin-Marietta Badger Energy, Inc. Saudi Investment Development Center

Table 2. WATER TYPES, PLANT LOCATIONS, AND TECHNOLOGIES FOR FIVE SYSTEMS

Prime Contractor	Water Type	Plant Location	Desalination Technology	Solar Energy Technology
Boeing	Brackish water	Upton County, Texas, United States	Reverse osmosis, 2 stages in series, 2.4 and 5.9 MPa.	Heliostats and central receiver
Catalytic, Inc.	Brackish water	Brownsville, Texas, United States	Reverse osmosis, 2 stages in series, 2.9 and 5.6 MPa, and vertical tube distillation	Wind generators and line- and point-focus thermal collectors
Chicago Bridge & Iron Co.	Seawater	Al Jubayl, Arabian Gulf, Saudi Arabia	Indirect Freezing	Point-focus thermal collectors
DHR, Inc.	Seawater	Uquair, Arabian Gulf, Saudi Arabia	One stage reverse osmosis in series with electrodialysis	Line-focus thermal collectors and photovoltaics
Exxon	Seawater	Rabigh, Red Sea, Saudi Arabia	Two stages of reverse osmosis in parallel with 24-effect distillation	Heliostats and central receiver

3.0 POINT FOCUS SYSTEMS

The Catalytic solar energy collection subsystem consists of three types of solar thermal collectors, having a total area of 64,000 m². The collectors include high temperature point-focus Omnium-G thermal collectors, medium temperature line-focus Fresnel thermal collectors, and low temperature Winston thermal collectors. In addition, 12 wind generators provide a total of 2.4 MW of electric power.

Energy storage is provided using a high-temperature air thermal storage system over the range of 290°-430°C, and medium temperature and low temperature thermal storage with a range of 45°-120°C and 180°-290°C, respectively. The medium and low temperature thermal storage systems use a liquid medium. The total capacity for the thermal storage system is 60 MWh. The electric storage capacity is 725 kWh.

Energy conversion is obtained through a steam turbine with a 560 kW electric generator and through the use of a power recovery turbine. Backup power is obtained through a motor with a 207 kW electric generator.

The brackish water is pre-treated and uses 18,000 m³ storage tanks. The desalination subsystem consists of two stages of reverse osmosis units in series, operating at 2.9 MPa and 5.6 MPa and operating in series with a multiple effect vertical tube evaporator. The brine is disposed in 93,000 m² surface area evaporation ponds. The water recovery ratio is 0.98.

The Chicago Bridge and Iron system uses 37,000 m² distributed point-focus thermal collectors with two axes tracking. Energy storage is obtained through two tanks containing HITEC molten salt operating over a temperature range from 286°-565°C and having a capacity of 148 MWh.

The energy conversion subsystem uses a steam turbine with a 560 kW electric generator and a turbine driving the 1,216 kW primary refrigeration compressor. Backup power is obtained from a 7.5 MW boiler. There is no waste disposal subsystem as the brine is rejected directly into the sea.

Figures 1 and 2 are block diagrams of the point focus system and show the interaction of the subsystems.

4.0 PROJECT STATUS

Subcontracts for the projects were awarded in October 1980. The efforts to date have focused on the definition of system specifications and trade studies for alternate subsystem configurations and components. Simulation models have also been developed for the plant performance analysis.

The subcontracts for Phase 1 are all firm fixed price. Financial performance is, therefore, the total responsibility of the subcontractors.

The technical performance of the project teams is on schedule. No slippages of major milestones are identifiable at this time. The Phase 1 system studies will be completed in August 1981.

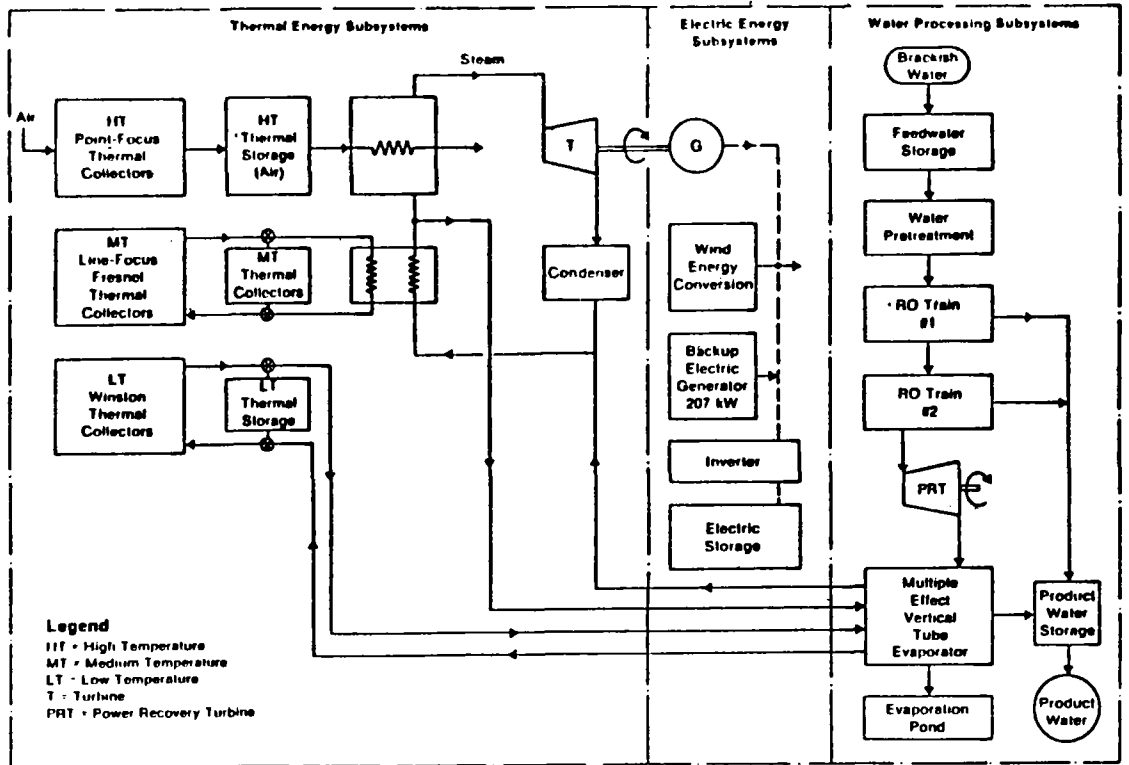


Figure 1 Block Diagram of the Catalytic System

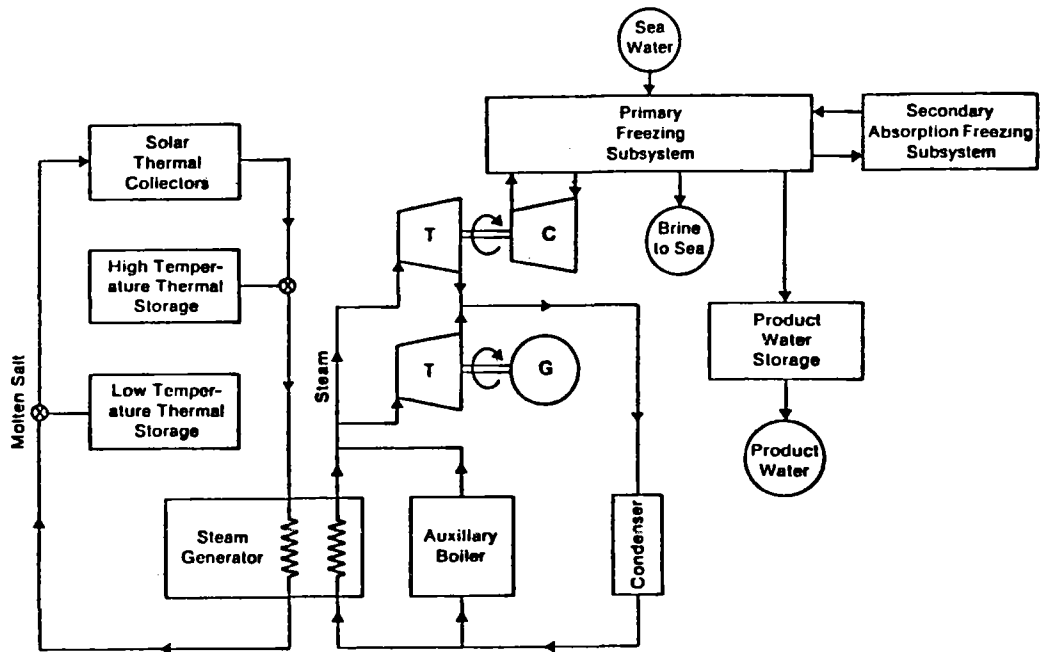
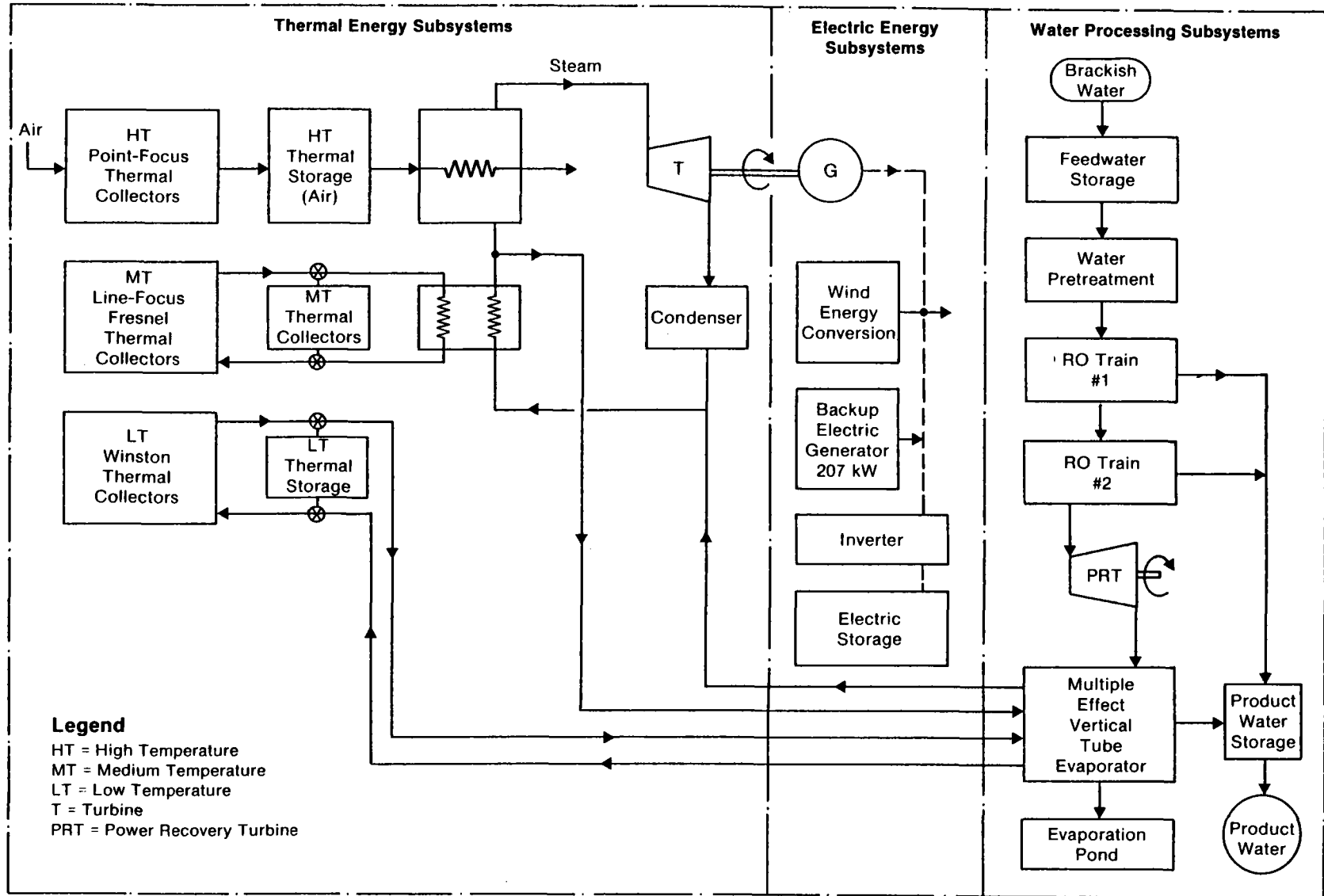
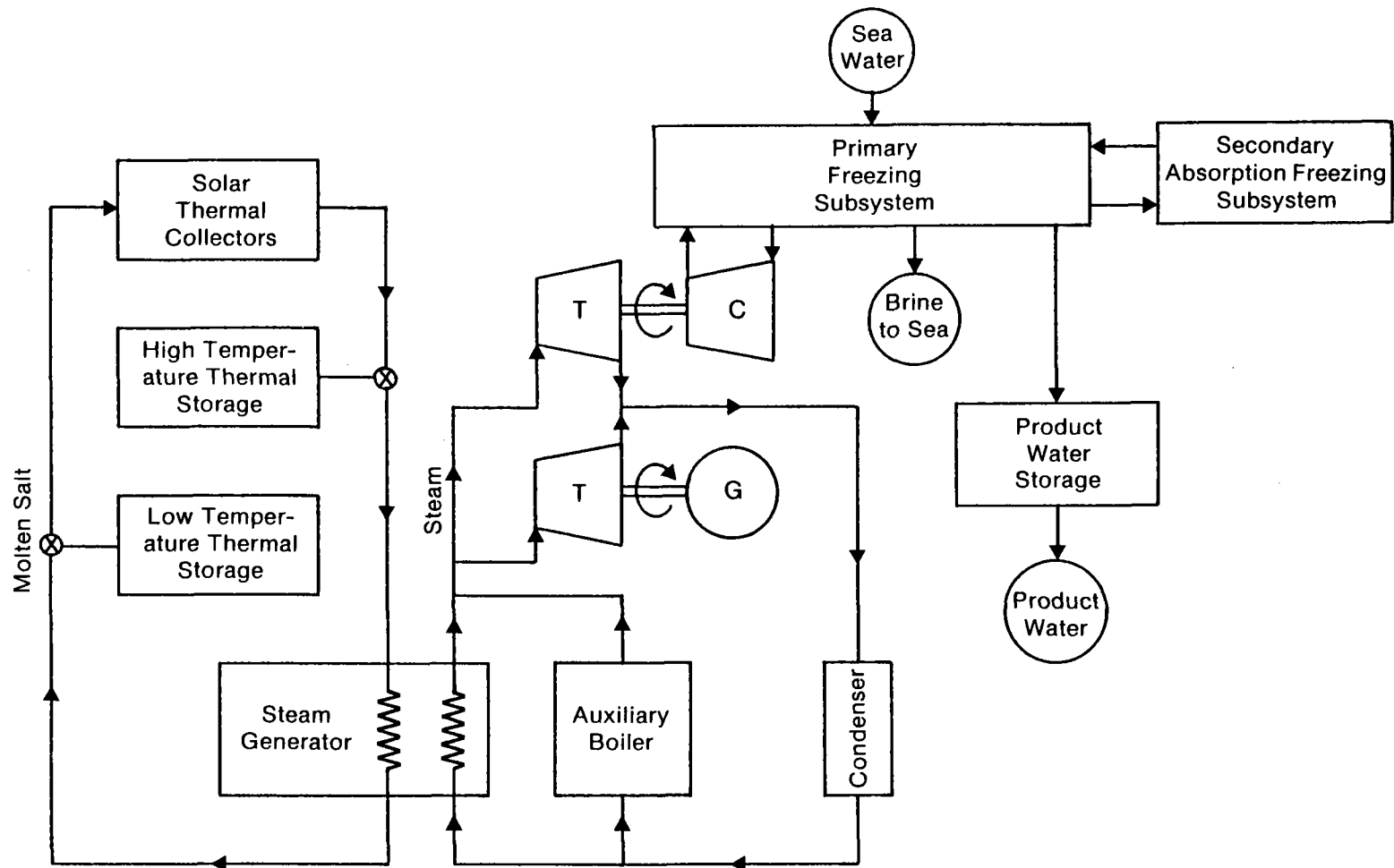


Figure 2 Block Diagram of the Chicago Bridge & Iron System



Catalytic Inc. System



Chicago Bridge & Iron Co. System

APPENDIX

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