DOE/ET/20255-T2(Vol.4)
(DE84002710)

THE CROSBYTON SOLAR POWER PROJECT (PHASE I)

Technical Report of Work Accomplished from September 1, 1976–
February 15, 1978

February 1978

Work Performed Under Contract No. AC04-76ET20255

Texas Tech University
Lubbock, Texas

TECHNICAL INFORMATION CENTER
U. S. DEPARTMENT OF ENERGY

This report has been reproduced directly from the best available copy.

Available from the National Technical Information Service, U. S. Department of Commerce, Springfield, Virginia 22161.

Price: Printed Copy A05
Microfiche A01

Codes are used for pricing all publications. The code is determined by the number of pages in the publication. Information pertaining to the pricing codes can be found in the current issues of the following publications, which are generally available in most libraries: *Energy Research Abstracts (ERA); Government Reports Announcements* and Index (*GRA* and I); *Scientific and Technical Abstract Reports (STAR);* and publication NTIS-PR-360 available from NTIS at the above address.

DOE/ET/20255-T2(Vol.4)
(DE84002710)
Distribution Category UC-62b

THE CROSBYTON SOLAR POWER PROJECT

(PHASE 1)

TECHNICAL REPORT OF WORK ACCOMPLISHED

FROM

SEPTEMBER 1, 1976 TO FEBRUARY 15, 1978

BY

TEXAS TECH UNIVERSITY,

E-SYSTEMS, INC.,

AND

FOSTER WHEELER ENERGY CORPORATION

SUBMITTED TO

THE

DEPARTMENT OF ENERGY

DIVISION OF SOLAR ENERGY

BY

TEXAS TECH UNIVERSITY

UNDER

CONTRACT NO. EY-76-C-04-3737

DR. JOHN D. REICHERT
PROJECT DIRECTOR

DR. HERBERT J. CARPER, JR.
PROJECT MANAGER

VOLUME IV MAIN TEXT

The work reported here was performed by:

TEXAS TECH UNIVERSITY: Project Director - J. D. Reichert

Project Manager - H. J. Carper, Jr.

R. M. Anderson
C. A. Bell
R. M. Bethea
L. D. Clements
J. R. Dunn
W. T. Ford
A. L. Goldman
D. L. Gustafson
N. Guven
D. R. Haragan
D. P. Jordan
C. H. Keho
A. P. Kwatra
J. R. McDonald
W. M. March
C. M. Parrish
R. J. Pederson
T. L. Simpson
M. L. Smith
C. V. Vallabhan
F. P. Wagner
F. Williams

E-SYSTEMS, INC.

Program Director: W. E. Erikson

Program Manager: R. R. Walters

M. J. O'Neill
S. L. Hudson
D. E. Yakel
D. Muzzy
A. J. O'Dannel
J. L. Perry
L. Wilson
J. Smith
B. Sheard
A. Anderson
M. Quan
D. Halsey
D. Schools
V. Goldberg

FOSTER WHEELER
ENERGY CORPORATION

S. M. Cho
R. Anderson

The Project Director and Manager greatfully acknowledge our indefatigable secretarial and support staff:

Carolyn Barrier

Toni Smith

Tina Watts

Judy Clare

Fran Dupre

Lana Reed

Donna Cates

Nancy Birney

Sue Willis

Flo Meyers

Julio Treveno

Fran Schuessler

H. S. Leung

D. M. Barrett

S. Majumdar

D. A. Courtney

R. Callicutt

S. Chin

TABLE OF CONTENTS FOR VOLUME IV

SECTION

I. OVERVIEW OF THE PROJECT AND THIS REPORT

In this report the work performed in Segment I of Phase I of the Crosbyton Solar Power Project (CSPP) is described. The period of performance was 18 months, from September 1, 1976 to February 28, 1978. The work of the first six months by Texas Tech University, with E-Systems, Inc., was reported in Volumes I, II, and III, the Interim Technical Report of February 19, 1977. The present report is a continuation of that report so that details from that report will not be reapeated here. This report is organized into two volumes: IV and V. Volume IV is an overview of the work and results of Segment I and is supported by Volume V, a collection of appendices summarizing the research program.

The plan of the overall CSPP program is given in Table I-1. The central organizing theme of the CSPP is the continuing development of an FMDF solar thermal electric power system through the NPS and RPS stages to the SPS for construction at Crosbyton. The work of Segment I, Part B shown in the table consists of conceptual design of an RPS, continuation of the research program, design specification of the ATS, and design of a plan for incorporating the ATS into the research program. As may be seen in the table the work of Segment II is simply the implementation of the work and planning of Segment I.

The conceptual design of the RPS has central importance because it has great impact on the design specification of the ATS. It is necessary to have an RPS conceptual design to constrain and provide a design framework for the ATS. The selected RPS specification produced in Segment I is given in Section II of this report.

TABLE I-1 THE STAGED CSPP PROGRAM

Phase I, Segment I

Part A, First Six Months of Segment I (Reported in Vols. I, II and III; Panel Review, February, 1977)

- Select parameters defining a Nominal Power System (NPS), approximately 5 MWe appropriate for Crosbyton, Texas, including strategies, procedures, materials, and cycles. Use best initial engineering judgement, based upon experience with the FMDF Concept and preliminary site data at Crosbyton.
- Evaluate the expected cost, performance, and economic value of the NPS to set bounds for system performance and cost.
- Initiate an R, D, T, & E Program for effective study and evaluation of the Fixed Mirror Distributed Focus (FMDF or Solar Gridiron) Concept.

Part B, Seventh through Eighteenth Months of Segment I (Reported in Vols. IV, V; Panel Review, February, 1978)

- Continue the R, D, T & E Program with special emphasis on the receiver/boiler subsystem and experimental evaluation of components and parameters.
- Revise and improve the NPS to provide the preliminary conceptual design of a Recommended Power System (RPS) for Crosbyton. The RPS is to be suitable as a module for Solar Thermal Electric Power Systems (STEPS) of larger capacity.
- Devise an Analog Test Plan for evaluation and testing of the RPS conception, including the design specification and cost estimate for an Analog Test System (ATS) to be constructed and operated in Segment II.

TABLE I-1 (continued)

Phase I, Segment II

Part A, First Twenty Months of Segment II

- Continue the R, D, T, & E Program with special emphasis on the use of the ATS in confirming and extending the understanding of FMDF systems. Continue to develop analytical/theoretical predictions for ATS performance. Reconcile any significant differences between predicted and actual ATS performance. Develop analytical/computer capability for extrapolating ATS results for more accurate prediction of cost and performance of the full-scale RPS for Crosbyton.
- Produce the final design for and construct an ATS capable of simulating the operation of a large scale FMDF system.
- Make a revised overall assessment of the applicability and usefulness of the FMDF concept for solar thermal electric power generation.

Part B, Last Six Months of Segment II

- Continue the R, T, D, & E Program with special emphasis on accurate prediction of the cost and performance of the full-scale RPS for Crosbyton.
- Develop a final conceptual design and design specifications for the RPS for Crosbyton.
- Submit the defined RPS as a candidate for the Selected Power System (SPS) at Crosbyton.

Phase II

- Construct, test, and evaluate the SPS at Crosbyton, Texas and put it on-line for the production of electricity for the Crosbyton load.

The relevance of the RPS to the ultimate SPS depends upon its expected cost and performance and, hence, upon its economic evaluation. These matters are discussed in Section III.

The research program of Segment I, Part B was necessary to provide the basis for the RPS conceptual design and its expected performance and cost. In addition, the research program was required to determine parameter values, evaluate options, and identify possible problems. A part of the research was devoted to devising an ATS tool so as to best continue the research, testing, and evaluation program in Segment II. The research of Segment I has involved theoretical, analytical, and experimental effort. The experimental testing and evaluation featured in Segment I, Part B is surveyed in Section IV. A survey of the theoretical and analytical work is scanned in Section V, but that section has intentionally been kept brief in this summary in deference to the featured work reported in Section IV.

The ATS must be responsive to the RPS conception in order to provide adequate modeling and testing of the behavior of the full-scale RPS system. The ATS is primarily a research tool allowing the study of all subsystems, interfaced in the proper way with each other and operating under realistic conditions. The ATS design given in Section VI offers enough flexibility and versatility that all essential aspects of the RPS operational strategy can be simulated and studied. For example, in some roles the RPS system management may rely heavily upon the use of a thermal storage subsystem, so the ATS design allows study of the collector/storage/load interfaces. The actual ATS construction will also allow evaluation of techniques of fabrication preassembly, sequencing, erection, and construction. The description of the Analog Test Plan for effective R, D, T, and E use of the ATS, after construction in Segment II, is given in Section VII.

This volume is intended as a summary and emphasizes the experimental program of Segment I and the ATS. All aspects of the results, plans, and designs produced in Segment I rest on the foundation of the underlying Research Program. The companion Volume V of appendices is organized according to the twelve research areas of that program. Thus, Volume V gives the research support for the present summary. The organization of the research program (and of Vol. V) is given in Table I-2 along with mention of a few of the currently emphasized topics. Each appendix specifically discusses the relationship of the ATS to the RPS and to the research program.

Various conclusions from this report are given in Section VIII along with a review of the present project status. The RPS, the experimental results, the planning for the ATS, and the overall R, D, T, and E Program of the CSPP are commended to the reader.

TABLE I-2 RESEARCH PROGRAM AND VOLUME V

Appendix A. Optical-Thermal-Fluid Analyses and Experiments

(boiler fluid behavior, internal heat transfer, helical flow, thermal/hydraulic analyses, wall temperatures, pressure drops, boiling flow stability, heat transfer oils, radiant testing, solar simulator tests, non-uniform heating, losses, transients, receiver design and fabrication, absorptive receiver coatings, optical concentration: misaligned receivers, multiple bounce radiation; angle of incidence of light on receiver, FOM of mirror elements, role of mirror imperfections, effective sun size model, stochastic concentration patterns and moments, optical receiver sizing.)

Appendix B. Receiver Subsystem

(tubing and cone materials, structural considerations, thermal stress analysis, support structure analysis, flexible fluid loop connections, oil receivers, fabrication)

Appendix C. System Management-Control and Tracking Subsystems

(tracking control, process control, emergency control, data acquisition and communication, site management, transient operation, production design, software requirements, hardware requirements, modeling, simulation, and analysis, operational modes)

Appendix D. Mirror Surfaces and Mirror Panels

(panel structural analysis, fabrication, sizes, focal testing, load testing, thermal testing, hail impact testing, reflectivities, materials, surface weathering, mirror cleaning, selection criteria, alignment error)

Appendix E. Concentrator Support Structure

(structure loads, Crosbyton environmental condition, wind loads, snow loads, structure design, superstructure, substructure, alternate configurations, excavation configuration, foundations, concentrator error analysis, error budget)

Appendix F. Survivability, Manintenance, and Safety

(mirror panel hail damage, receiver tubing hail damage, dust and radiation effects on mirrors, mirror surface maintenance, survivability of oil used for thermal storage, safety of concentrator design, environmental impact, lifetime of panels)

TABLE I-2 (continued)

Appendix G. Energy Storage Strategies and Options

(thermal storage: hot oil, molten salts)

Appendix H. Power Cycle, Electrical Production, and Distribution Options

(cycle selection and evaluation, system configuration, management and operational requirements, performance evaluation, cycles for larger systems, alternate system concepts)

Appendix I. Analysis of Site Dependent Factors

(general climatological data: total insolation, direct normal insolation, temperature, relative humdity, barometric pressure, wind velocity components, particulates, storms; soil, foundations)

Appendix J. System and Economic Modeling and Simulation

(economic models, efficiency trains, operational system concepts, economic value of storage, transient thermal analysis of receiver, use of heat transfer oils in receivers, receiver operation during periods of reduced insolation)

Appendix K. Instrumentation and Data Processing for the ATS

(instrumentation categories, hardware requirements by category, data acquisition system, use of the data in the R, D, T, and E program)

Appendix L. Concentrator/Receiver Wind Tunnel Tests

(wind load tests, receiver thermal loss tests, effect of wind velocity, effect of berm, surface pressure patterns, wind forces)

II. RPS DESCRIPTION

The Recommended Power System (RPS) for the Crosbyton Solar Power Project has evolved through successive stages of concept definition, subsystem design, engineering analysis and simulation, and experimental research and development. The specifications of the RPS have evolved from a prior definition of the Nominal Power System (NPS), but with refinements based on additional detailed analyses and key experimental tests. The current design and operational specifications are not considered optimal and will continue to be refined on the basis of design, construction, and experimental results from the implementation of the Analog Test System (Section VI) and a continuation of related experiments and analyses in Segment II into a design recommendation for the Selected Power System.

Specifications for the RPS are given in Table II-1 and significant aspects of the design are discussed in the following paragraphs.

II-A SYSTEM CONFIGURATION

As seen in Figure II-1, the power generation cycle is a solar hybrid in which a water-steam simple Rankine cycle, solar loop, has been combined with a regenerative Rankine cycle, conventional boiler loop. As discussed in Appendix H, the system is

TABLE II-1. SPECIFICATIONS FOR RECOMMENDED

FMDF STEPS POWER SYSTEM

SYSTEM/SUBSYSTEM	SPECIFICATIONS
SYSTEM SIZE-CONCEPT	
Nameplate	5 MW (electric)
Plant Type	Solar hybrid - includes: auxiliary oil-fired boiler; 10 FMDF solar collectors; oil storage; two-2.5 MW_e turbine-generators.
Thermodynamic Cycle	Water-steam, regenerative Rankine cycle; Turbine inlet-850 psia, 900°F (Optional-600 psia, 750°F); Condenser pressure - 2 in. Hg.
CONCENTRATOR SUBSYSTEM	
Configuration	Fixed, 120°(60° rim angle); spherical segment mirror; 115 ft radius; north-south tilt-15°; 200 ft. aperture dia.
Mirror Surface	Modular panels; 1/8", second surface, silvered glass; reflectivity-88%; spherically curved; bonded integrally to paper honeycomb core; enclosed in steel case with mounting and alignment capabilities.
Mirror Support	Prefabricated steel trusses forming a steel matrix mounted to a rigid frame steel column network in an excavation. Trusses installed to form a hemispherical grid with mounting pads for attachment of mirror panels.
Civil Works	Civil works will employ a trench excavation for the east-west row of collectors. Excavated material will be used to form a continuous berm running east and west along the north side of the collectors.

SYSTEM/SUBSYSTEM	SPECIFICATIONS
RECEIVER SUBSYSTEM	
Receiver	Truncated support cone, 0.25 in. wall thickness, 57 ft. long, diameter varying from 1 ft. to 2 ft. with a bundle of 20 tubes helically wrapped around support cone. Tubes are 400 ft., 0.375 in. O.D. and 0.25 in. I.D. Water/steam receiver: manifolded at both ends with an intermediate manifold at beginning of two-phase flow region for flow stabilization. Oil receiver: tubes are 0.70 in. O.D. and 0.50 in. I.D.
Receiver Materials	Support cone: Incoloy 800; flow tubes: water-steam receiver-Inconel 617 or 625; oil receiver-stainless steel; absorptive coating; high temperature, flat black paint (brand name "Pyromark") $\alpha=\varepsilon=0.9$.
Receiver Operation	Once-through flow with preheating, boiling, and superheating occuring successively as water flows from the wider to the narrower end of the conical receiver. Oil receivers operate single phase in once-through or multiple pass options.
Flow Distribution	Insulated stainless steel piping and control valves for superheated steam; Insulated carbon steel piping for condensate return and oil lines.
Receiver Support Structure	Cantilevered polar mounted receiver, two-axis tracking using diurnal and declination drives. Structure consists of steel space frame and pipe construction with a walkway to permit access to the polar tracking mount. Articulated fluid transfer achieved with flexible couplings.
POWER GENERATION SUBSYSTEM	Two multi-stage, multi-valve turbine-generators, 2.5 MW_e each; 900^{o}F, 850

SYSTEM/SUBSYSTEM	SPECIFICATIONS
	psia inlet (optional 750°F, 600 psia), 2 in. Hg exit; generator rating: 4160V-Y, 3φ 60 Hz, 278A @0.8 pf.
STORAGE SUBSYSTEM	
Thermocline	Caloria oil and rock. Operating temperature range: 125°-600°F.
CONTROL SUBSYSTEM	
System Management	Dual microcomputer control system; includes interactive displays, printer, status panel and magnetic disks. Provides operator interface and control of total installation. Interfaces with conventional power plant control system. Includes provisions for emergency procedures to safeguard collector operations.
Tracking	Hybrid digital control and analog drive using distributed processing and stabilized velocity position servo. Auto-track positon command provided by the microcomputer. Active-track position command generated by the analog control loop electronics and monitored by the microcomputer. Active tracking sensors are photosensitive.
Process Controls	Mode 1-Normal Operation:Digital Control of flow distribution in quasi-steady operation to maintain design delivery conditions. Microcomputer senses system conditon changes and adjusts pneumatic control valves as required. Mode 2-Transient Operation:Digital control of flow distribution, to a). Track slowly varying transient insolation and maintain design delivery condition or b). Flood receiver under rapid transients to protect thermal integrity.

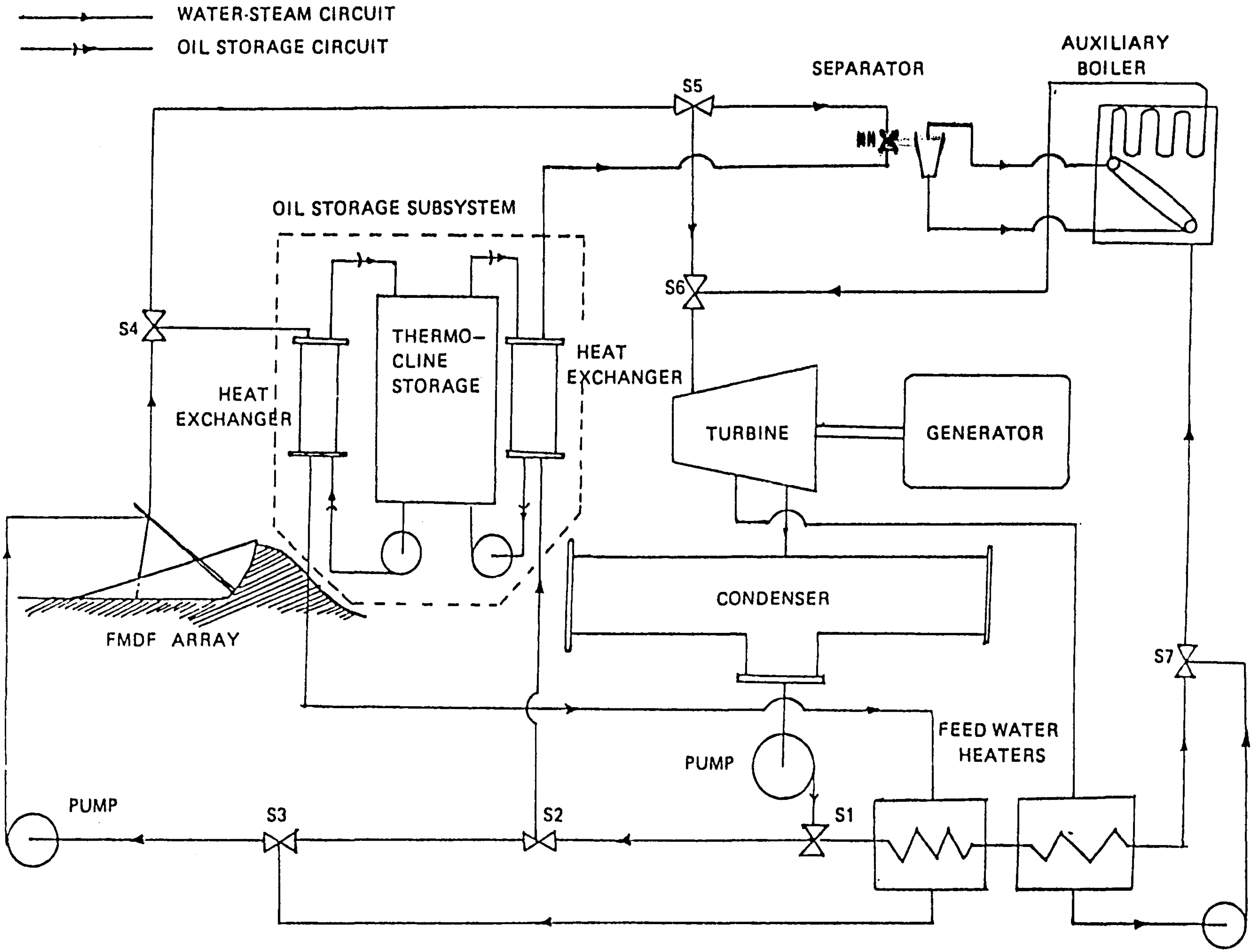


Figure II-1. SYSTEM POWER CYCLE FLOW SCHEMATIC WITH STORAGE designed to operate in the following modes: (1) Normal Solar Operation (quasisteady insolation), (2) Normal Conventional Operation (zero insolation), and (3) Transient Solar Operation (intermittent insolation) with specific requirements for start-up, normal shutdown and emergency shutdown.

II-B CONCENTRATOR SUBSYSTEM

The present concentrator subsystem specification is based on the results of a continued review of available mirror materials; analysis, design, fabrication and testing of full-scale reflective panels (Appendix D and F); wind tunnel verification of concentrator wind loading (Appendix L) and application of the data in a refined structural analysis; and analysis of accumulated concentrator optical errors.

The recommended mirror panel design using 1/8 in. thick second surface silvered glass curved and bonded to a paper honeycomb core and enclosed by a steel facing, Fig. D-1 of Appendix D, was fabricated and tested in sizes ranging from 1 ft. X 1 ft. to that required for a full-scale concentrator. Structural testing (to determine deflection characteristics), thermal testing, focus testing (to determine image quality), and hail impact testing (at velocities in excess of 125 mph), demonstrate that this panel design meets the structural, optical and environmental requirements for the concentrator subsystem.

The recommended support structure design of prefabricated steel trusses mounted to a rigid frame steel column evolved from consideration of several different designs and structural modeling on the SPACE computer program. Environmental factors considered in the design recommendations (Table E-1) include maximum and minimum ambient temperatures, operational and survival wind velocities, survival snow loads, survival seismic loads, extreme frost penetration, and rainfall. The cumulative optical error predicted for this design is 0.414°.

Trade-off studies were performed to determine a cost-effective construction procedure including a review of using an east-west trench for embedding the concentrators as opposed to individual spherical excavations.

II-C RECEIVER SUBSYSTEM

The receiver subsystem consists of the receiver, its support structure, the drive unit and fluid transfer loop. Engineering tasks contributing to the design include independent thermo-optical-fluid analyses by Texas Tech and E-Systems, structural and experimental tests of receiver tube movement (found to be negligible), dynamic modeling of the complete receiver structure (Appendix C), and a detailed experimental program to confirm, under a radiant heat flux environment, the steady-state thermodynamic, fluid dynamic and heat transfer characteristics (at ATS scale) predicted by the theoretical analyses. It is noted that for those tests conducted to date, neither fluid dynamic instabilities, nor conditions under which receiver damage would be expected to occur have been observed. Additional effort supporting the receiver design included a design, manufacturing and performance evaluation by Foster Wheeler Energy Corporation.

The cantilevered receiver support concept is presented as the recommended concept. The difference in performance and cost between the cantilevered support and simple support concepts is small and no aspects of the design requirements or analysis, i.e., resonant frequency, have eliminated one or the other from consideration. Therefore, both receiver support concepts are retained as candidates at this point. Additional refined analysis and empirical data from the Analog Test System will aid in the selection of one of these concepts for the Crosbyton 5 MW_e module collectors. The recommended receiver support structure has been modified slightly from the nominal system to compensate for requirements imposed by the dynamic analysis. The primary change was an increase in diameter of the compression support leg and the polar mounted support bearing.

II-D CONTROL SUBSYSTEM

The recommended control subsystem has evolved as a refinement of the nominal system through continued design studies and computer control modeling. The main features are a single microprocessor at each collector with management control redundancy within the power plant. Performance characteristics for off-the-shelf hardware were incorporated in the control system computer model along with the receiver support structural characteristics. The analysis indicated that the receiver dynamics during wind gust load conditions and emergency stow procedures, can be readily and satisfactorily controlled.

III. RPS PERFORMANCE AND COSTS

III-A. OVERALL SYSTEM EFFICIENCY

The overall system efficiency has been evaluated from consideration of

Concentrator Errors (Appendix E)

Receiver Support Structure Errors (Appendix B)

Control System Errors (Appendix C)

Receiver Efficiency (Appendix A)

Optical Input Losses (Appendices A, E)

Using the improved receiver profile (Sec.V), the annual average performance for a 5 MW_e RPS is summarized in Fig. III-1. A net annual average solar-to-electrical efficiency of 10% is achieved. The peak overall efficiency would be over 16%.

The effect of system size is illustrated in Fig. III-2. [The curve labeled Statistical Optics refers to the improved receiver design (Sec. V) and the other curve refers to the receiver sized to double the actual sun size.] Because turbine efficiency increases with nameplate capacity rating, substantial improvement in system efficiency is possible for larger systems. (Appendix H).

The effect of system location is shown in Fig. III-3. The Crosbyton site is "ideal because it's typical, not ideal."

III-B. RPS COST ANALYSIS

A detailed cost analysis of the RPS has been conducted using the EPRI/ERDA Work Breakdown Structure (WBS) as the basic costing

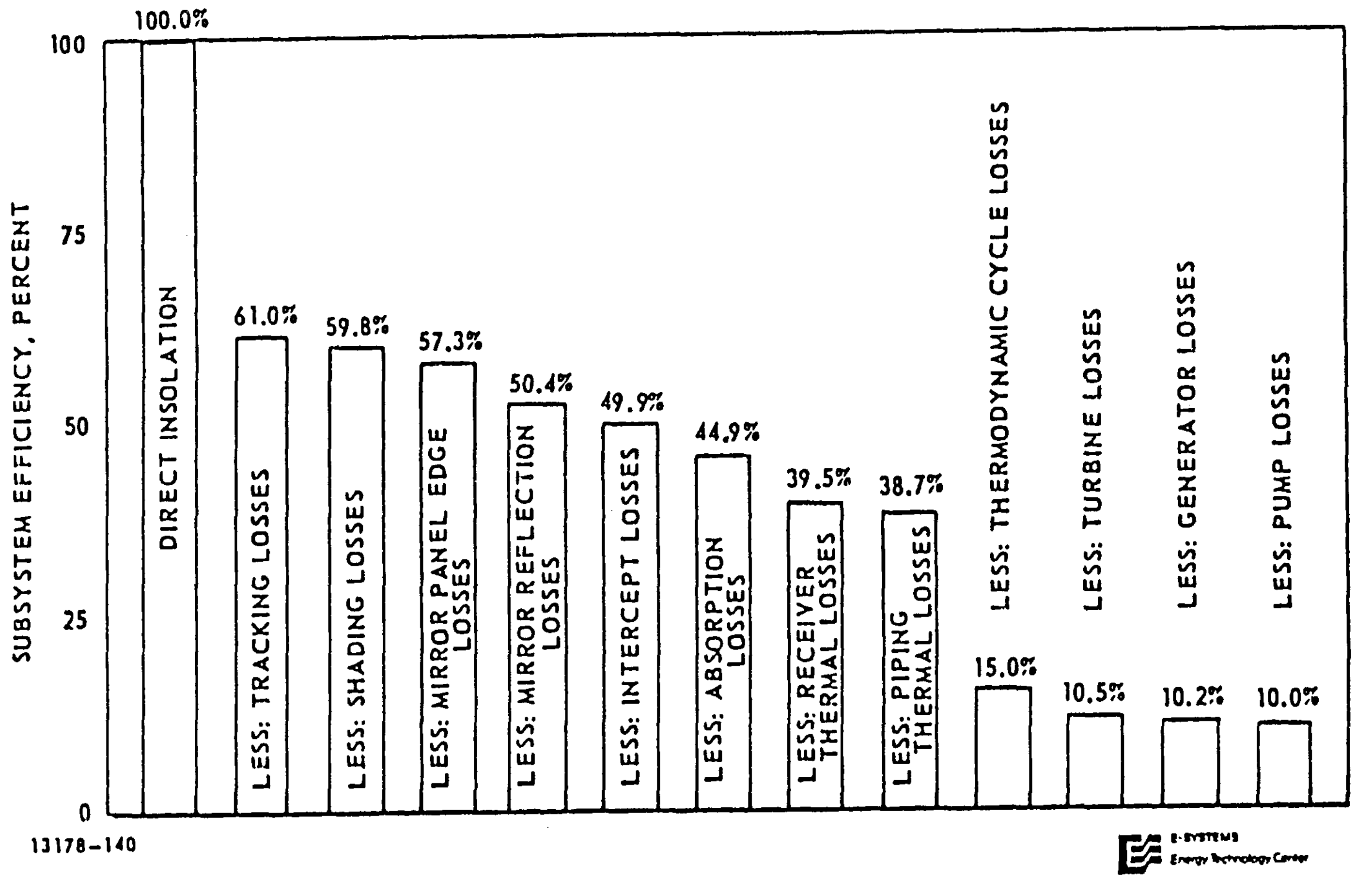


Figure III-1. Typical Annual FMDF-STEPS Performance for 5 MW_e System Without Waste Heat or Storage

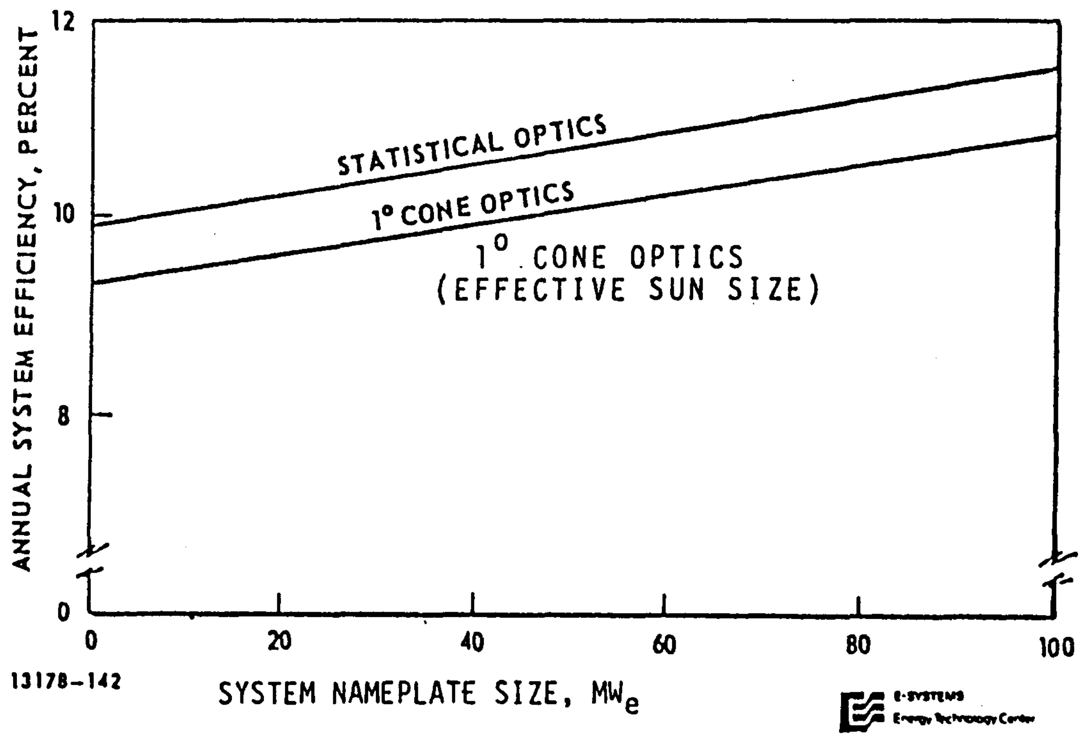


Figure III-2. FMDF-STEPS Annual System Efficiency Vs. Size

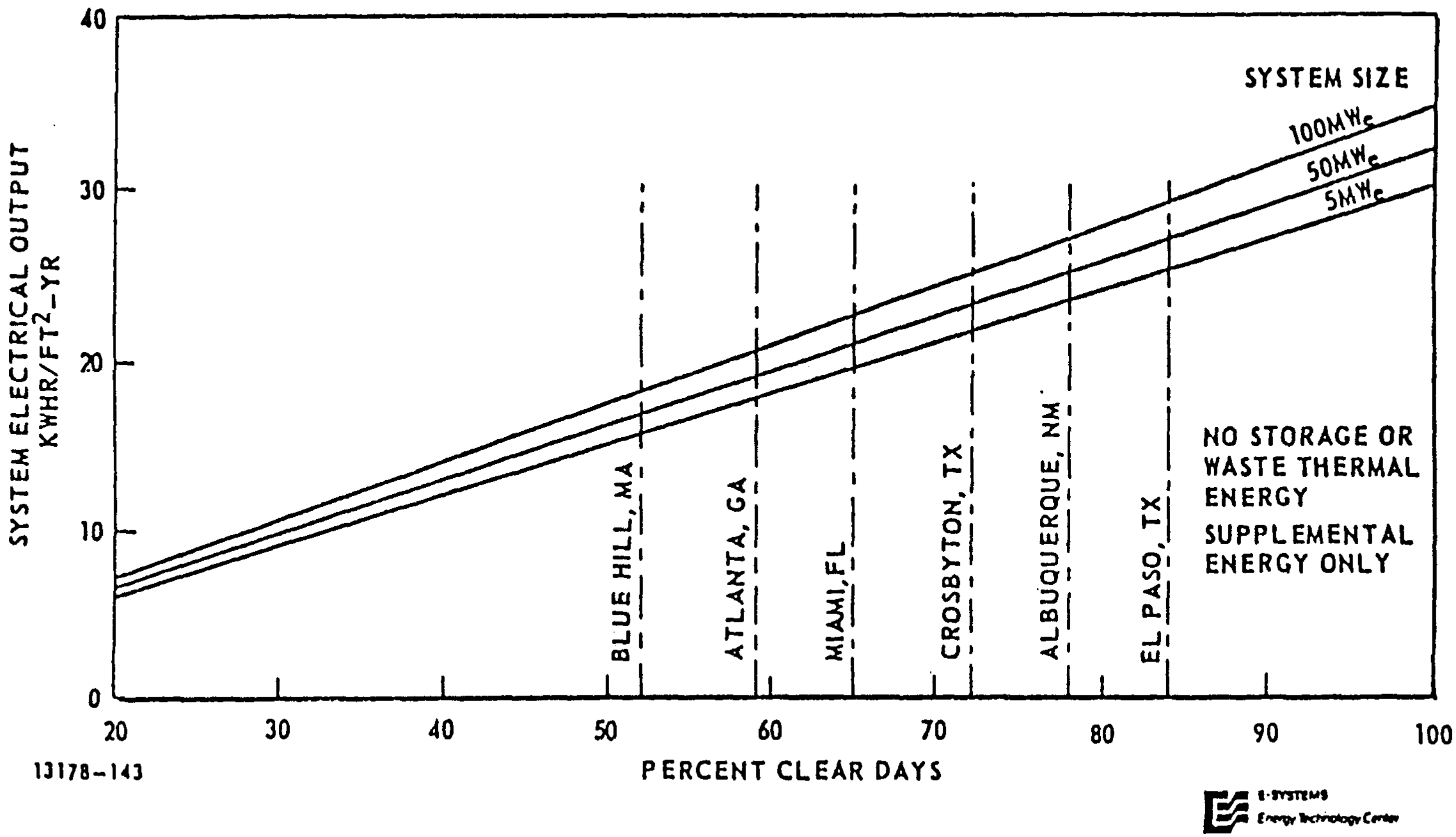


Figure III-3. FMDF-STEPS Annual System Output for Various Locations format, modified to conform with the hardware content of the FMDF concept.

In Table III-1 the results of the cost analysis are presented for two quantity weighted systems. One of the cost structures represents the 10 collector Crosbyton system; the other provides representative costs for a large production system employing a value engineered module of the same configuration. The cost of a storage subsystem is not included in Table III-1.

The Crosbyton system costs project the relative impact of non-recurring costs, temporary tooling, high shipping costs, proof by construction in a first time effort, and other similar cost inefficiencies inherent in limited quantity prototype activities. Moreover, since the program to date is heavily weighted toward analytically determining collector functional criteria, the costs are based upon conceptual documentation rather than detail design. Thus the costs can be considered accurate only within the limits of the estimator's abilities to envision the detail cost elements. In Segment II, Part B of the CSPP program, the conceptual design will be converted into detailed definition from which more refined pricing data can be developed.

The production system costing takes advantage of the economic prudence of on-site fabrication facilities, bulk material procurement, and learning curve progression, while minimizing the impact of non-recurring costs. It is also noteworthy that the production system costs are predicated on collector sizing and configuration data developed to date. Thus, in the interest of conservatism, no provision has been made in these costs for dramatic design improvements that may be

TABLE III-1
RPS COLLECTOR COST WORK BREAKDOWN STRUCTURE

		200 FT CROSBYTON		200 FT PRODUCTION	
		$/FT^2	$/M^2	$/FT^2	$/M^2
(WBS)	TOTAL COST	39.66	426.66	21.59	232.23
WBS NO	DESCRIPTION				
2700	CONCENTRATOR	23.86	256.63	14.09	151.55
2710	REFLECTOR	10.20	109.71	6.43	69.17
2711	Mirror Element	8.40	90.30	5.05	54.29
2713	Support Structure/Panel Interface	.17	1.83	.07	.75
2714	Panel Attachment	.87	9.36	.55	5.91
2715	Flushing System	.76	8.18	.76	8.18
2716	Focus Calibration	<.01	.04	<.01	.04
2750	SUPPORT FRAMEWORK	3.70	39.79	2.45	26.36
2753	Main Truss	.44	4.73	.35	3.76
2754	Intermediate Truss Unit	1.63	17.52	1.30	14.00
2755	Support Columns	.63	6.78	.55	5.91
2756	Support Structure Bracing	1.00	10.76	.25	2.69
2760	DESIGN & ANALYSIS	.87	9.29	.14	1.51
2761	Structure Analysis	.29	3.12		
2762	Optical Sys. Analysis	.12	1.29		
2763	Mirror Design	.09	.97		
2765	Adjustment Design	.01	.11	(1% of WBS 2700)	
2766	Framework Design	.12	1.22		
2768	Column-Footing Design	.22	2.37		
2769	Flush System Design	.02	.21		
2770	ASSEM. INST. & CHECKOUT	9.09	97.84	5.07	54.51
2771	Column Foundation	.90	9.69	.90	9.68
2772	Site Prep., Excavation & Drainage	4.92	52.96	2.10	22.58
2773	Structure Erection	1.54	16.58	1.15	12.36
2774	Mirror Panel Install.	.53	5.70	.40	4.30
2775	Mirror Adjust/Alignment	1.05	11.30	.37	3.98
2777	Flushing Install.	.12	1.29	.12	1.29
2778	Focus. Cal. Install.	.03	.32	.03	.32
2800	RECEIVER	9.42	101.37	4.69	50.47
2810	RECEIVER UNIT, CANTILEVER	5.17	55.65	2.13	22.91

TABLE III-1

(Continued)

WBS NO.	DESCRIPTION	200 FT CROSBYTON $/FT^2$	200 FT CROSBYTON $/M^2$	200 FT PRODUCTION $/FT^2$	200 FT PRODUCTION $/M^2$
(WBS)	TOTAL COST	39.66	426.66	21.59	232.23
2811	Boiler	3.02	32.51	.77	8.28
2813	Piping & Insulation	.08	.86	.08	.86
2814	Boom	.21	2.26	.17	1.83
2815	Boom Pivot & Support Structure	1.69	18.19	1.09	11.72
2816	Counterweight	.01	.11	.01	.11
2817	Thermocouples	.16	1.72	.01	.11
2820	DRIVE UNIT	.89	9.58	.73	7.85
2821	Diurnal Drive	.29	3.12	.25	2.69
2822	Declination Drive	.05	.54	.05	.54
2823	Motors & Gear Boxes	.49	5.27	.40	4.30
2825	Drive Support Structure	.06	.65	.03	.32
2830	TRACKING AND CONTROL	.30	3.23	.21	2.26
2831	Detector System	.02	.21	.02	.21
2833	Electric Controller	.07	.75	.05	.54
2834	Position Generator	.01	.11	.01	.11
2836	Power & Signal Lines	.08	.86	.05	.54
2837	Manual Controls	.01	.11	.01	.11
2838	Structure & Housing	.02	.22	.02	.21
2839	Interface Electronics	.09	.97	.05	.54
2840	FLUID LOOP	.80	8.60	.55	5.91
2841	Piping to Load	.51	5.49	.35	3.76
2842	Flex/Rotary Joint	.07	.75	.04	.43
2843	Utility Piping	.02	.21	.02	.21
2844	Valves	.15	1.61	.10	1.08
2846	Flow Meters & Transducers	.05	.54	.04	.43
2850	ASSEM. INST. & CHECKOUT	1.82	19.58	1.02	11.00
2851	Erect Boom Support Structure (Tripod)	.78	8.39	.35	3.76
2852	Inst. Boom Drive & Align	.42	4.52	.30	3.23
2853	Assemble & Install Boom and Receiver	.42	4.52	.23	2.47
2854	Inst. Contr. Systems	.15	1.61	.09	1.00
2856	Test & Calibrate	.01	.11	.01	.11
2857	Inst. Fluid Loop	.04	.43	.04	.43

TABLE III-1
(Continued)

(WBS)	TOTAL COST	200 FT CROSBYTON $/FT^2	200 FT CROSBYTON $/M^2	200 FT PRODUCTION $/FT^2	200 FT PRODUCTION $/M^2
		39.66	426.66	21.59	232.23
2860	DESIGN & ANALYSIS	.44	4.73	.05	.54
2861	Heat Transfer	.19	2.04		
2862	Structures	.03	.32		
2863	Kinematic/Dynamic	.02	.22		
2864	Receiver/Boom Design	.03	.32	(1% of WBS 2800)	
2865	Boom Support Design	.03	.32		
2866	Boom Drive Design	.02	.22		
2867	Tracking & Control Design	.07	.75		
2868	Fluid Loop Design	.05	.54		
9000	INDIRECT COSTS	6.00	64.50	2.75	29.56
9010	OVERHEAD	3.52	37.84		
9020	CONSTRUCTION EQUIPMENT	1.33	14.30		
9030	SMALL TOOLS, SUPPLIES, EXPENDABLES	1.03	11.07		
9040	CIVIL WORKS ENGRG SERVICES	.12	1.29		
3100	MASTER CONTROL EQUIP.	.09	1.01	.02	.22
3110	Computers	.02	.22		
3120	Peripherals	.02	.22		
3130	Displays	.04	.43	(All < .01)	
3140	Console, Racks, etc.	<.01	.03		
3150	Interface Equipment	.01	.11		
3200	TEST INSTRUMENTATION	.22	2.40	0	
3201	Instrumentation Design	.05	.54		
3202	Instrumentation Installation	.03	.32		
3210	Thermocouples	.01	.11		
3220	Pressure Gages	.01	.11		
3230	Fluid Flow Meters	.01	.11		
3240	Air Flow Measuring	.01	.11		
3260	Temp. Pyrometer	<.01	.02		
3270	Data Recording	.07	.75		
3280	Data Processing	.02	.22		
3290	Strain Gages	.01	.11		

TABLE III-1
(Continued)

	200 FT CROSBYTON		200 FT PRODUCTION	
	$/FT²	$/M²	$/FT²	$/M²
(WBS) TOTAL COST	39.66	426.66	21.59	232.23
4000 SPARES	.07	.75	.04	.43
4030 CONCENTRATOR	(1% of WBS 2810 thru 2840)		(1% of WBS 2810 thru 2840)	
4040 RECEIVER				

achieved in the next phase, nor for the consequent cost reductions resulting therefrom. Due to the site sensitivity of the earthworks, variations in production systems costs can be anticipated dependent upon the installation locale.

III-C. ECONOMIC VALUE OF THE RPS

In order to update the economic forecast for the RPS, E-Systems made a comparison of levelized busbar costs for the options of purely fossil fueled, pure solar (15.4% plant capacity) with no storage, pure solar with storage, and hybrids of solar with storage and fossil fuel. The results given in Appendix J-1 are summarized below.

a) Under the financing constraints of a privately owned utility, it will require a fuel price escalation rate in excess of 12% in order for a purely solar or a hybrid system to be competitive.

b) Under the financing constraints of a municipal utility, a purely solar system without storage is attractive for a fuel cost escalation rate of 10% or greater.

c) For a fuel cost escalation rate of 8%, both the hybrid plant and a pure solar plant with storage are economical for a municipal utility.

These results are based upon a 30 year life plant, solar costs of $\$10/ft^2$, and storage costs of \$0.02/Btu of storage.

Another way of comparing solar and conventional options is on the basis of target costs. The basis of the results cited above were based upon solar collector costs of $\$10/ft^2$.

For a fuel cost escalation rate at or below the general inflation rate, the target cost for a solar collector drops to $\$2/ft^2$. Conversely, if the fuel escalation rate is allowed to rise to 12-15%, the target for solar cost competitiveness rises to $\$15/ft^2$.

The cost estimate of $\$21.59/ft^2$, from Table III-1, for a system like the RPS (in production) is presently 30 to 100% greater than a suitable target value. Once actual performance data and cost data are determined from the ATS in Segment II of the CSPP, it should be possible to refine the target estimate. The present RPS, considered as a 5 MW_e solar module, becomes more attractive for larger systems with higher energy conversion efficiencies of the order of 30-35%.

IV. SURVEY OF EXPERIMENTAL PROGRAM

A major portion of the effort expended during Part B of Segment I has been devoted to the experimental program mentioned in Section I. This experimental program has been broad in scope, and was designed to address those systems and subsystems of the RPS design considered to be the most crucial components. The nature of these experiments, along with the major findings and conclusions, are surveyed in this section of the report.

IV-A THERMAL ASPECTS OF RECEIVER/HEAT TRANSFER FLUID

IV-A.1 Receiver Heat Transfer Experiments

Solar Simulation Tests on an FMDF Receiver

A solar simulator employing quartz infrared lamps for the heat source was constructed at E-Systems for the purpose of testing a working model of an FMDF receiver. A test receiver was fabricated by Glitsch, Inc. for use in the experiment. This receiver consisted of a single tube, 461 ft. long, coiled around a 1^0 cone with an overall length of 13.8 ft and outside end diameters of 3 and 6 in. This receiver size corresponds to a concentrator with an aperture diameter of approximately 50 ft. The tube material was Inconel 600 with 0.375 in. O.D. and 0.245 in. I.D. The receiver was coated with Tempil Pyromark 2500 flat black paint. The test facility and receiver were fully instrumented with thermocouples, pressure gauges, flow meters, and other instrumentation necessary to determine the thermal behavior of the test receiver under the simulated solar flux.

The main objective of the receiver tests was to show proof of the concept, that a complete receiver in the form of a helically wound, once-through boiler would work under the anticipated operating conditions of the ATS and RPS. Desired outlet steam conditions are 500 to 1000 psig and 500° to 1000°F, with a stable flow in the receiver.

The results of the preliminary experiments show the desired outlet superheated steam conditions can be met. Under steady radiant flux, outlet steam conditions ranging from 500 to 1000 psig and 500° to 1000°F were obtained under stable flow conditions. The regions of liquid, two-phase, and superheated flow in the receiver, as well as the axial temperature profiles,match closely those predicted by computer simulation by TTU, E-Systems, and Foster Wheeler. Higher than expected pressure drops were observed, and are attributed to the helical flow geometry.

The equipment and test results summarized here are described in detail in Appendix A.

High Heat Flux Tests on FMDF Receiver Sections

The high heat flux radiant test facility at Texas Tech described in Appendix A is designed to provide an experimental evaluation of the thermal-fluid performance of individual sections of the FMDF solar receiver. Since the purpose of the facility is to provide an opportunity to isolate individual receiver sections, provision is made for feeds to the test section to vary in thermodynamic state from a subcooled liquid, to a vapor-liquid mixture, to a superheated vapor. The radiant heat source is quartz tube lamps with a lamp power up to 132 KW available.

Initial tests, currently underway, are being directed toward an evaluation of the effect of coil radius of curvature on pressure drop. Initial measurements will be in the single-phase regime, with subsequent tests in the two-phase regime.

Joule Heating Heat Transfer Experiments

The joule heating, two-phase flow heat transfer experiments being conducted at Texas Tech are the first part of an attempt to sort out effects of flow channel geometry and heat flux asymmetries on the heat transfer in the FMDF receiver. The approach is to use joule heating, with the tube itself being the heater, as a means of providing an easily controlled, easily measured heat source. Also, the individual effects of flow path geometry and heating asymmetry may easily be separated. Important variables for the helical flow tests are the radial acceleration component (affected by coil radius and pitch), the tube L/D ratio, the degree of liquid subcooling, and the imposed heat flux. The prime factors in the study of axial asymmetry of heat flux are the period of the asymmetry (affected by heater geometry and fluid flow rate) and the amplitude of the heat flux swings.

Preliminary data have been obtained with a helical test section constructed using a 93 in. long 304 stainless steel tube, with 0.25 in. O.D. and 0.028 in. wall thickness. The tube was coiled to a 1 ft. diameter helix, with a pitch equivalent to having 20 tubes coiled in parallel thus simulating a portion of the RPS receiver.

For a water/steam flow through the test section, measured wall temperatures and calculated heat transfer coefficients show the same behavior as predicted in the earlier Interim Report. The most important feature of the results is that the heat transfer coefficient along the outside wall of the helix is consistently about 20% higher than on the inside wall. This is a very preliminary indication that the heat transfer along the outer wall is enhanced by the helical flow path. Indeed, heat transfer coefficients both along the inside of the coil and along the outside of the coil are higher than expected for straight tubes.

A more detailed discussion of the experiment is included in Appendix A.

IV-A.2 Tests with Heat Transfer Oil

During Part B of Segment I an analysis has been conducted where the TTU receiver heat transfer simulation computer program was applied to the case of oil flow through the receiver. This analysis has demonstrated the feasibility of circulating oil directly through the receiver for application to sensible heat storage in oil. A prime candidate oil is Caloria HT-43, a relatively inexpensive heat transfer oil that has been used for many years in various industrial applications. The experiments discussed in detail in Appendix A, and briefly described below, were conducted at TTU for the purposes of establishing stability characteristics of this oil.

A static stability test was designed and run using samples of Caloria HT-43 as a means of evaluating the oil's short term degradation properties. Samples of fresh heat transfer oil were encapsulated in containers made of stainless steel tubing about 3-1/2 in. long, closed at both ends.

Samples were exposed to elevated temperatures of 500° and and 750°F for periods of 24 to 48 hrs. Three of the samples exposed to 750°F exploded, consequently tests at that temperature on the remaining samples were aborted.

Ultraviolet spectrographs were run on samples of fresh and the exposed oil. The results showed that there was very little degradation of the sample exposed to 500°F. However, comparing the spectrographic results for the oil exposed to 750°F to those for the fresh oil showed that there had definitely been a shift in the ultraviolet absorption pattern, indicative of changes in physical composition. In addition, the fresh oil is a clear, yellowish liquid while the oil after exposure at 750°F is a very dark brown, having the consistency and the appearance of a well-used motor oil. The simple static experiments rather dramatically indicate that exposure for even relatively short times at conditions well in excess of the stability limit of the oil is apt to cause considerable deterioration.

IV-A.3 Receiver Convective Heat Loss

Wind Tunnel Tests

Thermal loss tests were conducted using a heated scale model receiver in a wind tunnel to provide data for a firm empirical base to be used for receiver heat loss calculations. A 1/75th scale model of the receiver and concentrator were constructed and tested by E-Systems in the Vought Corporation low-speed (<240 mi/hr) wind tunnel in Grand Prairie, Texas. Parameters varied included wind direction relative to concentrator, wind speed, receiver temperature, and receiver location within the concentrator.

Data were obtained for wind velocities of about 90 to 300 ft/sec, and flow directions were varied to represent north, south, east, and west winds on an FMDF concentrator. The most interesting feature of the results are that for any given value of Reynolds number, based on the mean receiver diameter and the free stream velocity, the Nusselt number for the case where the receiver is placed in the concentrator is always less than the Nusselt number for the case where flow is normal to the receiver. Thus, the presence of the concentrator actually attenuates the cooling effect of winds, and the use of heat transfer data for flow normal to cylinder has been conservative.

A detailed discussion of these experiments and results is included in Appendix L.

Heat Loss Tests of a Receiver in Free and Forced Convection

An additional part of the experimental receiver thermal performance program was to evaluate the convective heat transfer loss coefficients for a helically wrapped coil under conditions of free and forced convective heat flow. The specific purpose was to determine if the non-uniform surface resulting from the exposed 3/8" O.D. tubes caused significant deviations from smooth cylinder convective heat loss predictions. The potential effect would be analogous to surface roughness in internal pipe flow.

The test section is a D.C. joule heated, helically wrapped length of 3/8 in., 304SS tubing, close packed, with varying outside coil diameters. Both polished and flat-black painted surfaces are being tested to evaluate the radiation contribution. Coil surface temperatures range from 300°F to 600°F and the ends are capped and insulated to minimize internal and end convective heat loss. Initial data for free convection conditions indicate an increase in the heat transfer coefficient of from 10 to 20% over predicted smooth cylinder results. (Appendix A)

IV-A.4 Receiver Coating Absorptivity

As mentioned previously, the prime candidate for the receiver coating is Pyromark 2500. Some data on the emissivity of this coating are available in the literature. However, for the purposes of evaluating the receiver thermal performance, data are also needed on absorptivity as a function of angle of incidence.

An experiment was initiated at TTU to determine the absorptivity of Pyromark 2500 applied to an Inconel 617 substrate. The experimental device used to obtain the absorptivity actually measures the energy reflected from a square plate, coated with Pyromark, which is viewed by the sensing device mounted above the sample. The measurements are made using the sun as the light source. The hemispherical reflectivity of the sample can be determined for different angles of incidence by changing the angle of the sample relative to the sun. The incident flux is first determined by aiming the sensor at the sun, then the sensor is rotated 180° to face the sample, and the reflected energy is measured. The absorptivity is then calculated from the reflectivity.

The results of preliminary experiments with an 8 in. by 8 in. sample show an absorptivity of 0.92 for radiation at normal incidence. This supports the value of 0.9 used in previous analyses by TTU and E-Systems. The measurements also show that the absorptivity only drops from 0.92 at normal incidence to about 0.87 at an angle of incidence of 60°. For angles of incidence greater than 60°, the data show a rapid drop in absorptivity to a value of 0.7 at an angle of incidence of 80°. For these higher angles of incidence, the error introduced by the finite size of the sample will, of course, be greater. Experiments are continuing at TTU with different sample sizes to determine the size effect. Typical results are presented in Appendix A. See Appendix A-7.1 for angle of incidence study.

IV-B. MECHANICAL ASPECTS OF RECEIVER

IV-B.1 Fabrication Techniques for Receiver

The fabrication of the 13.8 ft long single-tube receiver described earlier in this section has served to provide information on fabrication and welding techniques. It was constructed of Inconel 600 tubing which was obtained in straight sections and butt welded together before wrapping the tubing around a mandrel.

Prior to welding the sections, Inconel tube samples were welded using the tungsten inert gas technique with a semi-automatic feed rotary welder. These samples were sectioned to examine weld penetration and quality and were found to be satisfactory. This technique was then used to weld the sections of Inconel tubing together before wrapping. After wrapping the welded sections, the welds were visually inspected and hydrotested at a pressure of 20,000 psi with penetrant dye. Again, all welds were found to be satisfactory.

Data were also obtained concerning the elastic behavior of the tubing after the wrapping process. Upon release of the winding force on the tubing, the diameter of the helix will increase, the axial length will decrease, and the number of turns around the mandrel will decrease. A mandrel design must compensate for these changes. The elastic behavior information gained during the fabrication of the 13.8 ft receiver can be thus used for the design of a mandrel for larger receivers.

IV-B.2 Unwinding of Helically Coiled Tubes

An ANSYS computer model of a helically wound tube was constructed by E-Systems, and computer runs based on this basic model indicated a negligible tendency for the tubes to buckle or unwind due to pressure and thermal loadings.

Computer analysis confirmed that deflections due to temperature could be determined analytically without computer aids by using the coefficient of linear expansion. In other words, configuration of the material was found to have no effect upon the expansion or contraction of the material due to temperature gradients. Therefore, a pressure test was required to verify the pressure deflections detertermined by the computer analysis.

The pressure test was conducted on a four-turn single tube helix constructed from readily available 321 CRES seamless annealed tubing. Helix outside diameter was 12.1 in. and pitch was 7.5 in. Flattening of the tube due to forming was measured to be 0.8 percent of the outside diameter (0.003 in.).

The helical tube was fixed at the fitting end to a surface table and the remainder of the helix was left freely standing. Six dial indicators were mounted to rigid structure attached to the surface table and extending upward along the helical tube. Although the actual operating pressure of the receiver tube assembly is approximately 900-1000 psi, the helical tube was tested up to 2000 psi to increase the magnitude of the readings.

The results of the pressurization tests indicated that the average measured deflection was negligible, well below 0.001 in., in agreement with computer analyses.

IV-B.3 Receiver Absorptive Coating

Application of Coating

Preliminary experiments were conducted at both E-Systems and TTU to develop satisfactory application techniques for the Pyromark 2500 coating. Various samples of substrate metals were used, including aluminum, stainless steel, Incoloy 800H, and Inconel 600 and 617; and different methods of surface preparation such as wire brushing and sandblasting were employed. The coating was sprayed, cured, and vitrified on all samples in accordance with the coating manufacturer's recommendations. No problems were encountered with the coating adhering to the stainless steel and aluminum. However, problems were encountered with adherence of the coating to the Incoloy and Inconel substrate materials.

The nature of the problem was that, after the curing and vitrifying step of the procedure, the coating would flake off or could easily be rubbed off of the Inconel or Incoloy. Through various additional experiments at E-Systems and at Glitsch, and through consultation with the coating manufacturer,Tempil, it was determined that good adherence of the coating to Inconel 600 could be obtained. This technique includes wire brushing the substrate, applying two very thin sprayed coats of Pyromark 2500, followed by curing at 480°F for one hour, and finally vitrifying at 1000°F for one hour. The resulting dry coating thickness is approximately 0.001 in. or less.

Survivability

The application technique developed as described above was used to coat the 13.8 ft receiver tested by E-Systems in the solar simulator test facility. In those experiments the coating has been subjected to temperatures in excess of 1200°F with no apparent deterioration.

A flat sample of Inconel 617 coated with Pyromark 2500 was subjected to iceball impacts using the TTU hail test facility. Test results show no observable damage from impacts of 2-in. diameter ice-balls with velocities of up to 97 mi/hr.

IV-C MIRROR SURFACES AND PANELS

IV-C.1 Mirror Surfaces

Reflective mirror materials of various types identified in the previous Interim Report as candidates for the concentrator surface were obtained and deployed at the Crosbyton site beginning in February, 1977, to determine the effects of weathering.

The objective of the weathering experiment was to determine the nature and degree of temporary and permanent deterioration of the samples from the environmental effects of radiation, dust, temperature, moisture, hail, etc. Deterioration and cleaning maintenance requirements with respect to reflectivity are discussed in detail in Appendix D. Deterioration with respect to warpage, debonding of reflective material, scratching from wind blown dust, cracking, etc. is discussed in Appendix F. Salient features of the experiment are discussed below.

Experimental Procedure

The mirror samples were attached to the tops and sides of cubical mounts with approximately 8 in. sides. Some of these cubical mounts were attached to poles about 7 ft. above the ground. Others were attached approximately 100 ft. above the ground on a tower. In all, 180 samples were deployed. On-site observations were made at regular intervals and in October 1977, all samples were removed from the site for laboratory examination.

The principal problem with Scotchal 5400 and Kinglux was debonding of the reflective material from the substrate. In addition, Kinglux was dented significantly by hailstones. The Alzak and RAM Acrylic samples were scratched, apparently due to windblown dust, and warping was prevalent. Some warping occured with the Plexiglas samples, and some degradation of the reflective surface was noted. The Donnelly glass mirror samples showed severe deterioration of the reflective surface because the protective paint was not suitable for outdoor use.

Of all the materials subjected to the exposure tests, the Carolina glass mirror material appears to be the most promising candidate for the concentrator mirror. After eight months of exposure, only one of the samples showed even faint scratches from wind blown dust. No warping was observed on any of the samples. Examination by optical microscope showed no pitting or scratching resulting from the hailstorm which damaged some other material samples as mentioned above.

Reflectivities and Mirror Cleaning

Reflectivity measurements of the new unweathered samples were made at TTU and reported in the previous Interim Technical Report. Reflectivity measurements were also made at TTU on the weathered samples, and the effectiveness of various cleaning techniques was evaluated. The results are summarized briefly below and are discussed in detail in Appendix D.

Reflectivity was measured as a function of the angle of incidence for all mirror samples in the as-received condition from the site. Considering all types of samples as a group, the average reflectivity loss in the uncleaned condition at normal incidence ranged from about 5 to 12 percent. At an angle of incidence of 70°, the average reflectivity loss ranged from about 9 to 16 percent.

Cleaning the mirror samples by a gentle rinse in water or in water containing a laboratory detergent solution restored at most about half of the reflectivity loss. When the same samples were gently scrubbed with cotton soaked with the detergent solution, the reflectivity for most samples was restored to within one to two percent of the value measured when the sample was new.

IV-C.2 Mirror Panels

Four types of experiments are conducted on the mirror panels. These are static load tests, focus tests, thermal tests, and hail impact tests. These tests with results are discussed in detail in Appendices D and F.

Static Load Tests

For the static load tests, conducted at E-Systems, a 6 ft by 4 ft panel constructed of 3 in. resin-dipped paper core honeycomb with 1/8 in. thick glass mirror and 0.036 in. thick sheet facings was used. The panel was simply supported at the four corners and dead weight loads of up to 650 lb, uniformly distributed, were applied. The maximum panel deflection measured was 0.059 in. The essential result was that no damage or permanent deformation was observed during the tests.

Focus Tests

Preliminary focus tests yielding a broad measure of panel surface accuracy have been conducted with the mirror panels. In these tests, also conducted at E-Systems, the sun's image was focused on a target at a known distance from the panel and photographed. Through the use of an intensitometer and the negative of the photograph image, the diameter of the image that represented 95 percent of the energy was determined and compared with the known theoretically perfect image diameter. These preliminary tests have shown small values of panel surface error. More accurate tests of panel accuracy using laser techniques are planned.

Thermal Tests

For the thermal tests, a 1 ft by 1 ft panel was fabricated and instrumented with thermocouples. A 6 ft by 4 ft panel and a 2 ft by 2 ft panel are placed along with the instrumented panel in an environmental test chamber. The instrumented panel is used for purposes of estimating the temperatures of the larger panels. The panels are subjected to cyclic variations of various frequencies and temperature amplitudes, and thermal shock is introduced by spraying with cool water.

At this writing, the thermal tests were still in progress at E-Systems. Results will be included in the final version of this report.

Hail Impact Tests

An extensive experimental program was conducted with the

TTU hail test facility to determine data on the survivability of the mirror panels under hail impacts. This program and the results are discussed in detail in Appendix F.

During this program, a pneumatic gun was used to fire iceballs of various diameters with various velocities at glass panel targets. The glass panel targets included unbacked flat glass, flat glass backed with paper core honeycomb, and curved glass backed with paper core honeycomb. The thickness of the glass was also a variable.

One extremely interesting finding is that curved panels tend to have a higher resistence to hail impact than flat panels. This is, of course, gratifying since the RPS and ATS panels will be curved. As an example of the increased resistance, the results for impacts with 1.5-in. diameter iceballs are as follows. For flat glass panels with 1/8-in. thick glass backed with 2-in. thick paper honeycomb, the minimum velocity required to break the glass was 76 mi/hr and the average was 101 mi/hr. For curved panels with the same thickness of glass and paper honeycomb backing, the minimum breakage velocity was 116 mi/hr, and the average was over 120 mi/hr. The terminal velocity for a 1.5-in. diameter hailstone under no-wind conditions is approximately 65 mi/hr. Thus the probability is excellent that the recommended panel design will survive hailstone impacts from hail of diameters up to 1.5-in. in diameter.

For 2-in. diameter iceballs, the average breakage velocity was determined to be about 77 mi/hr, and the terminal velocity for a 2-in. diameter hailstone under no-wind conditions is approximately 75 mi/hr. Thus, the probability of a panel surviving impact from hail 2 in. in diameter or larger is not as good. However, the probability of 2-in. diameter or larger hail is very low as shown in Appendix F.

IV-D WIND LOADING ON CONCENTRATOR

Wind tunnel tests were conducted by E-Systems using a 1/75th scale model of a 200 ft diameter FMDF concentrator for the purposes of determining structural design information concerning wind effects. In these tests the concentrator surface pressures and wind forces were determined for various wind speeds and directions, concentrator tilt angles, and depth of embedment of concentrator below ground level. In addition, the effect of a north-side berm on the boundary layer velocity profiles and surface airflow patterns was determined.

The surface pressure and wind force data were used by E-Systems to check the accuracy of an existing computer program used to calculate airloads for structural analysis. This was done for the two cases of interest which include a concentrator with a 15° tilt, both with and without a ground plane. It was found that in general for both cases the computed drag was lower than the measured, the computed lift was higher than the measured, and the computed side force was approximately the same as the measured. At least a part of the discrepancy between measured and computed drag force can be attributed to the drag of the concentrator model mount.

Due to geometric constraints of the wind tunnel, the effect of the berm could only be tested for wind from the south and from the north. The results showed that the presence of the berm reduced the drag force in either case, but the reduction is only slight when the wind is from the south. The berm had very little effect on lift or crosswind forces.

Based on an analysis of all the data, it was concluded that the use of the surface wind pressure coefficients obtained in the tests to calculate the design wind loads will yield satisfactory results. Details of the experiment and results are included in Appendix L.

IV-E TRACKING CONTROL SENSORS

Two sensor concepts are being considered for automatic precise tracking of the receiver. One sensor concept involves the use of a pyramid shaped quadrated sensor head with a photovoltaic sensor accurately placed on each face. Tests run at E-Systems to determine the sensor's sensitivity proved that a change of one millivolt in differential signal was equivalent to 1.5 minutes of arc (0.025°). This is to be compared with the desire maximum tracking error attributable to the control system of 0.030°.

The second sensor concept being considered is a ring sensor that would be placed surrounding the caustic region of the receiver. The principle of operation is that the resistance of the total length of the wire ring is proportional to the solar insolation impinging on its length. By seeking the position of the ring which produces the greatest resistance of the wire, the optimum position of the reciever can be determined. The thermal averaging characteristic of the wire is such that the sensor will not tend to seek a local hot spot, but will seek a condition of maximum energy input.

Limited tests at E-Systems have proven this concept, but additional tests are necessary in an actual solar environment. Additional discussion with some test results is presented in Appendix C.

IV-F SITE DOCUMENTATION

Since the last Interim Technical Report was submitted, site documentation at Crosbyton by TTU has continued. Emphasis has been place on obtaining measured data on direct normal and total solar insolation, wind, and dust.

The direct normal solar insolation data has been studied and categorized according to the nature and degree of transient behavior. Sample transient insolation records were provided to E-Systems for use as input to a computer program for predicting transient behavior of the receiver.

Three-component (u,v,w) wind speed measurements have been made during storms to provide valuable input to the structural design of the concentrator structure. In addition, measurements of dust concentrations have been made during storms and at other times to provide data on the effects of dust on solar insolation and information relative to the survivability and maintenance of the concentrator.

Details of the site documentation instrumentation, procedures, and results are presented in Appendix I.

V. SURVEY OF ANALYTICAL WORK

Only the high points of the theoretical and analytical studies are listed here. Details and other work are described in the referenced Appendices in Vol. V.

1. Foster Wheeler Energy Corporation, Nuclear Department has contributed significantly to the understanding of the heat transfer and fluid flow in the water/steam receivers. Most important was evaluation of potential flow instabilities and a warning of the likelihood of encountering a dynamic density-wave instability. This work led to the insertion of a plenum in the receiver design to separate the subcooled heating and nucleate boiling regions. (Appendix A-1)

2. The E-Systems' transient analysis code predicts that after a step change in insolation from 250 to 275 Btu/ft^{2}hr, 80% of receiver's temperature change occurs in first 60 seconds. (Appendix J-2)

3. Analysis indicates that, below about 30% of peak insolation, steam mass flow rates from receivers may be so low that receiver output should be used for feedwater preheating. (Appendix J-4)

4. For oil receivers the trade-off between mass flow rate in the receiver and total energy loss leads to a true optimum region for operation. Also, studies indicate that two receivers working in series will heat up the oil adequately with only small losses and minimal risk of degradation. (Appendix J-2)

5. Analysis by E-Systems of receiver coils and support cone indicates only negligible tendency of coil to unwind. Either Inconel 617 or 625 in adequate to handle the expected thermal and pressure stresses. Support cone must be at least 0.1" thick if made of stainless 316 and at least 0.15" thick if made of Inconel to prevent buckling. (Appendix B)

6. Proposed Control System has been modeled by E-Systems and transient responses determined (Appendix C).

7. Cantilever supported receiver has natural frequencies ranging from 1.19 Hz (200' aperture) to 3.60 Hz (65' aperture). Simply supported receiver has natural frequency of about 1.8 Hz. (Appendix B)

8. Cycle performance calculations for eleven cycles show 20 to 27.5% efficiencies. (Appendix H)

9. In concentrator support structure, it has been found that the survival mode for a south wind dominates the structural configuration. Total concentrator error for survival level structure is determined by E-Systems to be $\Delta\psi_T = 0.104°$. (Appendix E)

10. Concentration distributions on misaligned receiver can be computed. (Appendix A-7.1)

11. Theory has been developed for computation of moments of optical concentration distributions resulting from mirrors bearing stochastic errors. (Appendix A-7.2)

12. A new receiver profile has been suggested by E-Systems, based upon sizing the receiver using stochastic mirror errors. For the same error budget, the new results indicate that the receiver can be 40% smaller in exposed area. Perhaps, then, thermal loss, pressure drop, weight, and cost penalties can be greatly reduced. (Appendix A-7.3)

VI. THE ANALOG TEST SYSTEM

VI-A PURPOSE AND OBJECTIVES

The fundamental purpose of the ATS is to provide data and results which will verify and reveal additional knowledge on the expected performance, cost, and economic impact of the RPS. The ATS is necessary to accomplish the following objectives:

1. Analytical and computer analyses will be tested; discrepancies will be reconciled and computer codes improved to provide a reliable basis for the RPS.
2. Several receiver options will be tested, and a final decision will be confirmed for the RPS receiver design.
3. Various subsystem concepts will be proven, and various backup concepts will be implemented as required to enhance the RPS.
4. The actual ATS construction will allow evaluation of the techniques of fabrication, preassembly, sequencing, erection, and construction to be used for the RPS.
5. Materials will be tested and evaluated under conditions that realistically simulate the RPS environment.
6. Strategies for managing and operating the system under transient conditions will be examined, and the best modes of RPS operation will be established.
7. From the operational characterisitcs of the ATS, data will be developed for realistic assessment of the economic value of the RPS in various roles and operating modes.

VI-B ATS DESIGN CHARACTERISTICS

The specifications for the ATS are given in Table VI-1, and a drawing showing major features of the concentrator/receiver assembly is presented in Fig. VI-1.

As can be seen by comparing the specifications for the

TABLE VI-1 SPECIFICATIONS FOR ANALOG TEST SYSTEM

SYSTEM/SUBSYSTEM	SPECIFICATIONS
SYSTEM	
Concentrator Aperture Diameter	65 ft. (Scaled from 200 ft. diameter RPS on basis of number of receiver tubes)
Thermodynamic Cycle	Water/Steam Rankine
Load Simulation	Simulated Turbine Expansion: Inlet Conditions: 900°F, 850 psia (Optional: 750°F, 600 psia) Condensor Pressure - 2 in. Hg
CONCENTRATOR SUBSYSTEM	
Configuration	Fixed, 120°(60° rim angle), spherical segment mirror; aperture diameter - 65ft.; north-south tilt-15°.
Mirror Surface	Modular panels; 1/8 in., second surface, silvered glass; reflectivity-88%; spherically curved; bonded integrally to paper honeycomb core; enclosed in steel case with mounting and alignment capabilities.
Mirror Support Structure	Prefabricated steel trusses forming a matrix mounted to a rigid frame steel column substructure in an excavation. Trusses installed to form a hemispherical grid with mounting pads for attachment of mirror panels.
Civil Works	Concentrator support structure will be placed in an excavation on a pier foundation similar to RPS system. A berm will be used to determine techniques of integrating the support structure with the foundation and berm. The berm and excavation will be formed to provide a simulation of wind flow patterns for the fullscale system. A security fence will be provided around the facility.

SYSTEM/SUBSYSTEM		SPECIFICATIONS
RECEIVER SUBSYSTEM		
Receivers	First Water/Steam Receiver:	Truncated support cone, 25 in. wall thickness; 10.76 ft. long, diameter varying from 0.33 ft. to 0.66 ft. Two tubes are helically wrapped around support cone. The tubes are manifolded at both ends of the receiver. Receiver connections are provided for ease of installation, alignment and removal. Tubing dimensions: 400 ft lengths of 0.375 in. O.D. and 0.25 in. I.D. as in the RPS.
	Second Water/Steam Receiver:	Decision on several options, to be made after first receiver.
	Oil Receiver:	Single tube dimensions: 0.70 in. O.D. and 0.50 in. I.D.
Receiver Materials		Inconel 617 or 625 for both the helically coiled flow tubes and conical support structure for the water/steam receiver. Stainless steel for the helically coiled tube and support structure for the oil receiver. Abosrptive coating: high temperature, flat black paint(brand name "Pyromark"), $\alpha = \epsilon = 0.9$.
Receiver Operation		Once-through flow the preheating, boiling and superheating occuring successively as water flows from the wider to the narrower end of the conical receiver. The oil receiver to operate single phase in either a once-through or a multipass option.
Flow Distribution		Insulated stainless steel piping and control valves for superheated steam and insulated carbon steal piping for condensate return lines and oil lines.

SYSTEM/SUBSYSTEM	SPECIFICATIONS
Receiver Support Structure	Cantilevered polar mounted receiver, two-axis tracking using diurnal and declination drives. Structure consists of steel space frame and pipe construction with a walkway to permit access to the polar tracking mount. Articulated fluid transfer achieved with flexible connectors. Back-up alternative: simply supported receiver on a fixed tripod center support and a moving azimuth-elevation track mounted on a fixed rail immeditely above surface of mirror.
TEST LOAD SUBSYSTEM	The test load will be provided by an appropriately sized expander and condenser system that can handle design temperature and pressure conditions for simulating an inline steam turbine/condenser unit. The oil storage subsystem also serves as a test load subsystem.
STORAGE TEST SUBSYSTEM Thermocline Storage (B is optional at present)	A. Caloria oil and rock. Operating temperature range: 125° - 600°F B. HITEC. Operating temperature range: 400° - 1000°F
CONTROL SUBSYSTEM System Management	Dual microcomputer control system contains interactive display, printer and magnetic disks. Provides operator interface and control of the ATS prototype. Provisions for emergency procedures are included to safeguard collector operations.
Tracking Control	Hybrid digital control and analog drive using ATS dual microcomputer configuration and stabilized velocity position

SYSTEM/SUBSYSTEM	SPECIFICATIONS
	servo. Autotrack position command provided by the microcomputer. Active-track position commands generated by the analog control loop electronoics and monitored by the microcomputer. Active tracking sensor is photosensitive.
Process Control	Mode 1-Normal Operation: Digital control of flow distribtuion in quasi-steady operation to maintain design delivery conditions. Microcomputer senses system condition changes and adjusts electromechanical values as required. Mode 2-Transient Operation: Digital control of flow distribution to a). Track slowly varying transient insolation and maintain design delivery condition or b). Flood receiver under rapid transients to protect thermal integrity.
Data Acquisition	Collector system data is sampled at a selected rate. Data is used by the control system and also formated and stored for historical use

<u>CONSTRUCTION NOTES</u>

The ATS is planned to be constructed at the Crosbyton site in Crosbyton, Texas. The on-site construction will be carried out in a manner that will provide significant baseline data for installing the larger 200 ft. aperture diameter collectors. However, it is anticipated that substantial parts, assemblies and subassemblies will be erected elsewhere for in-house testing and checkout prior to delivery at the Crosbyton site.

Information will be obtained on optimum site assembly sequencing, material handling, concentrator and receiver structures alignment, reflective panel installation sequence and alignment determination of techniques which would be limited by increased collector size, methods of protecting hardware (i.e., mirrors and receiver, during installation),

SYSTEM/SUBSYSTEM	SPECIFICATIONS
	safety precautions required that are unique to the FMDF system installation, and so forth.

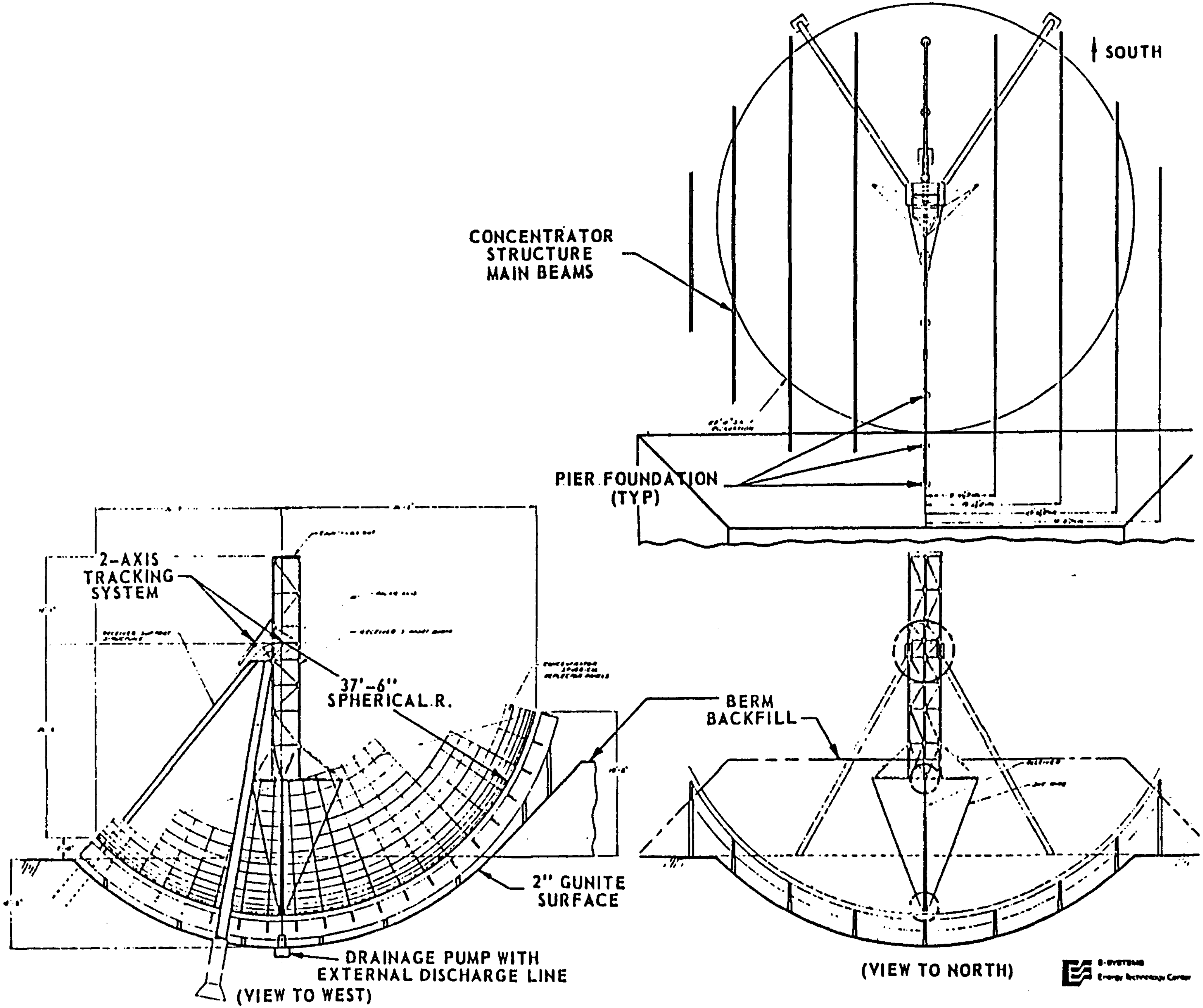


Figure VI-1. 65 ft. Aperture Diameter FMDF Analog Test System

ATS with those for the RPS given in Table II-1, the ATS is designed to be similar to the RPS in as many respects as possible. The ATS will not generate electric power, but a simulated turbine load on the system will be provided.

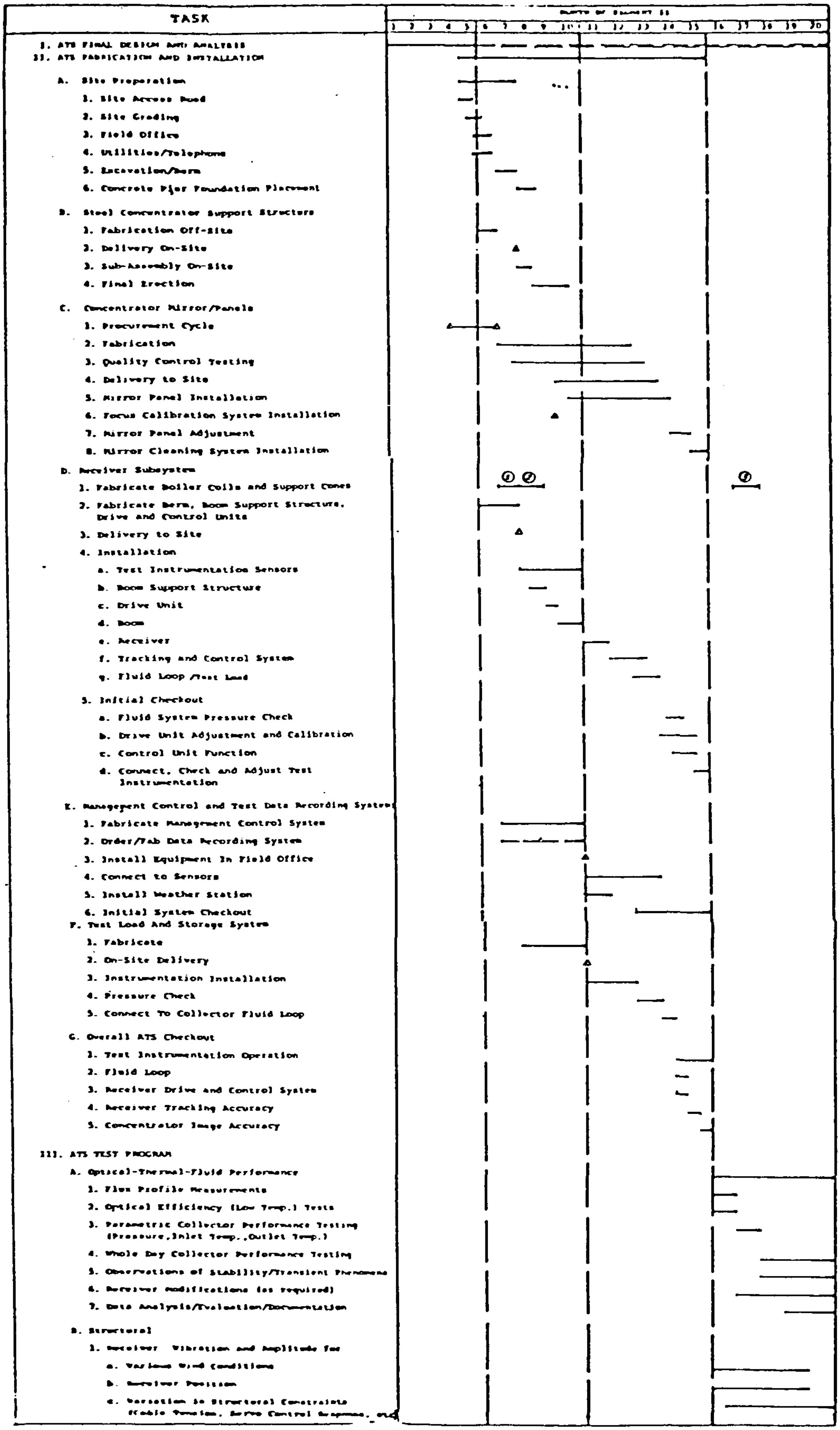
For the water/steam receivers, tube diameters and lengths have been chosen to be identical to those of the RPS in order to maintain flow and heat transfer similarity. Thermodynamic analyses have shown the possibility of flow instabilities resulting from a manifolded tube arrangement. Such transients are difficult to predict theoretically and therefore justify experimental study. Thus a two-tube receiver design has been specified, and this requirement, along with the specification of RPS-size tubes dictates a 65 ft. diameter aperture for the ATS.

In some roles, the RPS system management will rely heavily upon the use of a thermal storage system. Consequently, the ATS design includes provision for a thermal storage subsystem which will allow study of the collector/storage/load interfaces in a realistic fashion. A receiver designed for use with oil will also be tested in conjunction with the oil storage subsystem.

VI-C. SCHEDULE FOR ATS FABRICATION AND TESTING

The ATS timetable shown as Fig. VI-2 provides details of the design, installation, and testing schedule for the ATS. In particular, this figure shows the variety of fabrication and installation tasks, from site preparation to overall ATS checkout, and the required sequencing of these tasks to complete the construction within the established

Figure VI-2.   ATS TIMETABLE



time frame (the circled numbers on the timetable refer to the three receivers: 1 and 3 are water/steam receivers, and 2 is the oil receiver). The chart also presents similar information concerning the test program.

VII. INSTRUMENTATION, DATA PROCESSING, AND OPERATING PROCEDURE FOR THE ATS

The fundamental purpose of the ATS is to serve as a device to produce, under appropriately realistic conditions, data relevant to the performance, cost, survivability, and maintenance of the RPS. The instrumentation for gathering those data is described in the first subsection. The data acquisition system is considered next. Then the relationship of the data to various RPS subsystems is indicated and, finally, the nature of the knowledge to be gained is surveyed by R and D area.

VII-A INSTRUMENTATION CATEGORIES, HARDWARE, AND DATA ACQUISITION

The ATS instrumentation is divided into eleven categories (counting the general "dress rehearsal" information):

A.	Site Data	soil, insolation (total and direct normal), wind direction and speed, clouds, rain, dust, snow, and hail conditions, ambient temperature, humidity, barometric pressure
B.	Photometry	optical concentrations (receiver, mirrors, support structures), reflectivities, absorptivities
C.	Thermometry	receiver skin, mirrors and panels, support structures, fluid transfer loop, test load (expander/condenser), storage
D.	Odometry	strains, displacements of receiver, mirror surface, support structures
E.	Accelerometry	dynamic motions of receiver, receiver support, concentrator support
F.	Barometry	fluid pressures at receiver inlet, receiver outlet, stations in the transfer loop

G. Flow Metering — flow rates in the fluid loops

H. Wind Convection Measurement — nature of air flows at various points in the vicinity of receiver and support structures

I. Receiver Positioning — receiver location/alignment and rate of movement

J. Electrical Metering — pump and drive motor power, sensor signals, control signals, sensor and controller behavior

K. Dress Rehearsal Experience — general information about system construction, performance, and operation

The nature of the hardware is described below by category:

Instrumentation Hardware Requirements by Category

A. Site Data

Soil structure previously analyzed from extensive core samples obtained during first six months of Segment I. Additional information will be obtained from ATS excavation and construction.

Pyrheliometer and pyranometer for direct and total insolation measurement (already deployed and in use at Crosbyton)

Weather station type hardware for measurement of: wind, barometric pressure, relative humidity, dust, and ambient temperature (already deployed and in use at Crosbyton). Rain, snow, hail, and cloud data will not be gathered electronically

B. Photometry

Radiant flux sensors for measurement of optical concentrations

Reflectometer for periodic measurement of receiver and mirror surface reflectivities

C. Thermometry — Thermocouples deployed on: receiver (at least 50 stations), selected mirror panels (at least 20 stations), frame, boom, tripod structure, and at various stations in the fluid loops

D. Odometry — Weldable and/or general purpose strain gauges attached to support boom, tripod structure, main frame, and selected mirror panels (approximately 50 locations)

E. Accelerometry — Accelerometers for measurement of motions of boom support, receiver, tripod structure and main frame (approximately 10 locations)

F. Barometry — Pressure gauges (approximately 10) and pressure transducers (approximately 8) for fluid pressure measurement at receiver inlet and outlet, across flexible couplings, and at other locations in the heat transfer loop

G. Flow Metering — Turbine meters (3) and rotameters (3) for measurement of fluid flow rate in process and condenser water loops

H. Wind Convection Measurement — Probe-type anemometer for measurement of air flow patterns inside and around dish

I. Receiver Positioning — Data on receiver position and rate of motion will be available from the tracking control sensors. In addition, an optical television camera and a grid network on the mirror surface will be used to monitor movement in the boom and receiver. Results will be recorded on video tape

J. Electrical Metering — Wattmeters for measurement of power required for all motor-driven equipment

Sensor and control signals will also be recorded by data acquisition subsystem

Indication of some of the sensor locations is given in Fig. VII-1.

Specific instruments have been designated to acquire the required data. A survey of available instrumentation will be continued to obtain the sensors best suited for our application. The complete system will be capable of expansion as needed to fulfill the requirements of the test program.

Data Acquisition System

The data acquisition subsystem and the system control and management subsystems will be housed in an instrumentation trailer providing the necessary air conditioning, lighting, and environmental protection for equipment and personnel. Another trailer will be used for storage of equipment and supplies.

The system control and management subsystem will monitor the overall system performance in real time. It will include the displays and instrument readouts required to give the observer/operator all necessary information on system operation. Instantaneous solar insolation, fluid state and flow rates, temperatures, and other data will be monitored.

The data acquisition system, on the other hand, is concerned with data for subsequent analysis off-site; e.g., at the Texas Tech University Computer Center or at E-System, Inc. Energy Technology Center. The system will be programmed to scan the various sensors at various rates appropriate to the nature of the data requirements. The system will digitize and convert the raw data to more applicable formats and record the data as required for off-site analysis. This system will provide a permanent record of the pertinent parameters

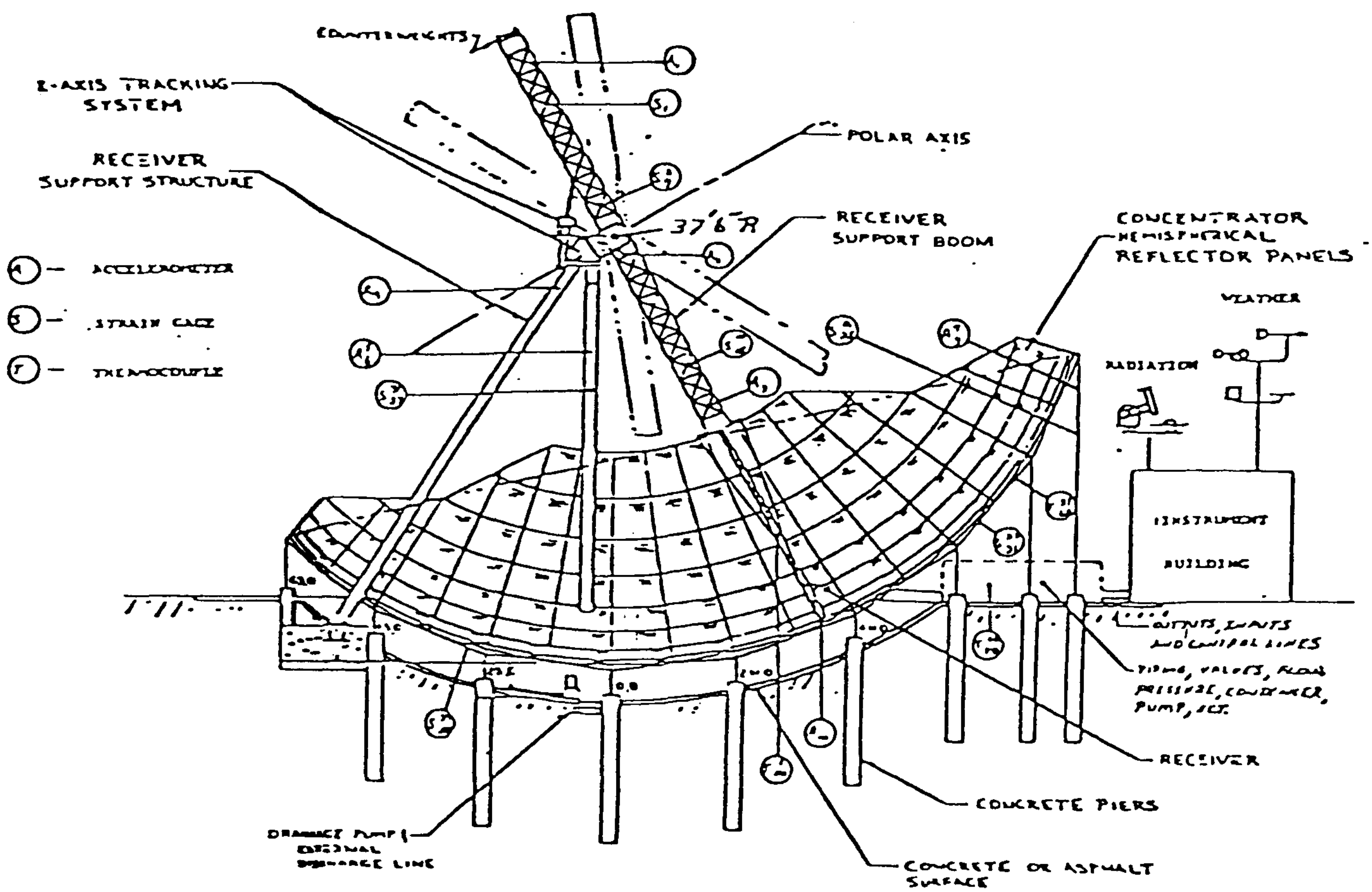


Figure VII-1. 65-ft Aperture Diameter FMDF Instrumentation during each test phase, independent of the system controller. This allows an independent analysis of problems associated with any and all aspects of the ATS operation.

The components of the data acquisition system will include signal conditioning interfaces with the sensors, scanners to time multiplex the sensor data for the digital conversion equipment, a magnetic tape system to record the data, a graphical display for monitoring of data during test setup and operation, and a programmable controller to manage the overall operation of the data acquisition subsystem.

VII-B RELATIONSHIP OF THE DATA TO THE R AND D PROGRAM

As documented above, a great amount of data of many types will be obtained from the ATS. These data are required so that the performance, cost, survivability, and maintenance can be estimated for the RPS. The R and D Program for the ATS can be conveniently divided into twenty-one R and D Areas. The following chart surveys the applicability of the eleven instrumentation categories described above to the twenty-one R and D Areas to be considered in the next subsection. The code number 1, 2, 3 used in the chart indicate the importance of the data to the R and D Area requiring that information.

R and D AREAS 1: 1st order requirement 2: 2nd order requirement 3: 3rd order requirement	1. Site Characteristics	2. Civil Works	3. Concentrator Support and Configuration	4. Reflector Surface &	5. Optical Concentratio	6. Receiver Support	7. Tracking & Tracking	8. Receiver Configuratio and Materials	9. Receiver Thermal-Flui Behavior	10. Heat Transfer Loop	11. Storage	12. Auxiliary Energy Sour	13. Turbine - Generator	14. Load, Demand	15. Process Control	16. System Management Psi	17. Safety, Survivability Maintenance	18. Instrumentation and Data Acquisition	19. System Costs	20. Construction Sequence Preassembly	21. Economic Strategy, In
A. Site Data																					
soil	1	1	1								2						2		1	1	1
insolation (total and direct normal)	1		2		1		2	2	1		1	1	2	1	1	1	2		2		1
wind direction and speed	1	1	1	1	2	1	1	2	1	2	3	3		2	2	2	1		2	3	2
clouds, rain, dust, snow, hail	1			1	1				1			1			1	1	1	2			
ambient temperature, humidity, pressure	1		1					1	1	1		2		1		2	2				
B. Photometry																					
optical concentrations (receiver, mirror, support structures)			1	1	1		2	1	1		1				1	1	1		1		
reflectivities and absorptivities				1	1			1	1		3	3			1	1	1		1		
C. Thermometry																					
receiver skin					1		3	1	1						1	1	1		1		
mirrors and panels			2	1	1											1			2		2
support structures		2	1	1	1	1	3		3							3	1				
fluid transfer loop					2				1	1	1	1	1		1	1	2				
test load (expander/condenser)									1	1	1	1	1	1	1	1					1
storage									1	1	1	1	1	1	1	1	1		1		1
D. Odometry																					
receiver								1	2							1	1		1		
mirror surface		1	1	1	1				2							2	1		1		
support structures						1	2	2	3							2	1		1		
E. Accelerometry																					
receiver					2	1	1	1	2						2	1	1		1		
receiver support		1			3	1	1	2	2							2	1		1		
concentrator support		1	1	1	1				1						2	1	1		1		
F. Barometry																					
receiver input/output								1	1	1	1	1	1	2	1	1	3				2
transfer loop stations									1	1	1	1	1	2	1	1	2				
G. Flow Metering																					
fluid loops									1	1	1	1	1	1	1	1					
H. Anemometry																					
wind flow patterns	1	1	1	1			1		1						2	2	1		2		
I. Receiver Positioning																					
location/alignment					1	1	1	2	1						1	1	2				
rate of movement						1	1	2	2						2	1	1				
J. Electrical Metering																					
pump and drive motor power							1		1	1	1	1	1	2	1	1	1		1		
sensor signals					1		1		1	1	1	1	1	1	1	1		1			
control signals					1		1		1	1	1	1	1	1	1	1					
sensor/controller behavior							2		2	2	2	3			1	1	1	1			2
K. Dress Rehearsal Experience	2	1	1	1	1	1	1	1	1	1	1	3		3	1	1	2	1	1	1	3

VII-C R AND D AREAS REQUIRING ATS DATA

As introduced in the chart above, the data from the ATS is required for twenty-one R and D Areas. Some of the issues to be studied in these twenty-one areas are surveyed in this subsection. In the table below, the left column lists the R and D Areas and some of the issued pertinent to each area. The use of the ATS data is presented in the middle column which indicates some of the topics to be studied. The third column points out the relevance of the 65 ft. ATS study to the 200 ft. RPS. It is this utility that justifies the ATS.

[Section VII-D follows table.]

R AND D AREAS	STUDY WITH 65 FT. DISH (ATS)	RELATION TO 200 FT. DISH (RPS)
Site Characteristics		
Insolation, wind, temperature, humidity, pressure, cloud cover, rain, dust, snow, hail, soil	Baseline of data continued	Completely appropriate baseline
Civil Works		
Excavation technique	(Not necessarily the same as for RPS)	Techniques well known
Berm on north for support	Soil stabilization requirements; relationship of berm to cost and concentrator stability	Some stabilization techniques to obtain required stability; cost model
Windbreak on southwest	Effects of size and shape on wind flow patterns	Can be extrapolated.
Concentrator Support and Configuration		
Static and dynamic stresses and strains	Effects of static and dynamic loads	Confirmation of computer codes at ATS scale to increase reliability of their RPS predictions
Environmental effects	Effects of thermal gradients and transients; diurnal cycling	Direct application of results
Materials	Adequacy of the selected materials	Direct application of results
Reflector Surface and Panels		
Attachment	Adequacy of attachment method to achieve desired accuracy in presence of static and dynamic structural strains	Direct application of observations

R AND D AREAS	STUDY WITH 65 FT. DISH (ATS)	RELATION TO 200 FT. DISH (RPS)
Reflector Surface and Panels (Contd.)		
Stability of alignment	Reliability of optical concentration in presence of static and dynamic loads	Direct application of results
Reflectivity	Average reflectivity of segments; changes in reflectivity due to environmental effects and cleaning	Direct application of results
Performance degradation	Effects of hail, moisture, temperature	Direct application of results
Lifetime	Various aging mechanisms for panels, bonding agents, and reflector surface	Direct application of results
Production characteristics	Variation of properties from segment to segment	Direct application of observations
Optical Concentrations		
Mirror imperfections	Effects of actual surface deviations on concentration patterns	Direct extrapolation of results
Alignment errors	Effects on concentration pattern; evaluate effective sun size model	Direct application of results
Cloud cover and dust	Effects of unsymmetrical reflection	Direct application of results
Transients	Effects of wind and other dynamic loads and various system responses	Direct extrapolation of results
Tracking errors	Implications for energy capture	Direct application of results
Receiver deformations	Thermal and mechanical distortions	Direct extrapolation of results
Signals to tracking control	Various methods for determining misalignment of receiver	Direct application of results

R AND D AREAS	STUDY WITH 65 FT DISH (ATS)	RELATION TO 200 FT. DISH (RPS)
<u>Receiver Support</u>		
Static and dynamic stresses and strains	Effects of static and dynamic loads	Confirmation of computer codes at ATS scale to insure reliability of their RPS predictions
Environmental and concentrator effects	Effects of thermal gradients and transients; diurnal cycling	Direct application of results
Materials	Adequacy of the selected materials	Direct application of results
<u>Tracking and Tracking Mount</u>		
Static and dynamic loads	Ability of the tracking system to detect receiver misalignments and respond effectively; survivability of components	Direct extrapolation of results
Optical concentration variations	Response of tracking systems to clouds and other perturbations on the nominal optical distributions	Direct application of results
Receiver support	Sensitivity of tracking control to receiver support strains	Direct extrapolation of results
Drive motors	Power and torque requirements	Direct extrapolation of results
Tracking control	Applicability and reliability of the control system	Direct application of results
<u>Receiver Configuration and Materials</u>		
Receiver flow channels	Effects of the thermal and mechanical loads on the local stresses and strains; relationship of attachment methods to channel deformations; various failure events that may occur; observations of channel dynamical motions	Direct extrapolation of results and direct application of observations

R AND D AREAS	STUDY WITH 65 FT. DISH (ATS)	RELATION TO 200 FT. DISH (RPS)
<u>Receiver Configuration (Contd.)</u>		
Receiver conical substrate	Observations of possible deformations and dynamical motions	Direct application of observations
Articulation	Behavior of flexible couplings	Direct application of results
Coil and substrate material	Behavior in presence of high temperatures and thermal cycling when subjected to the actual static and dynamic loads	Direct application and extrapolation of results
Absorber surface coating	Properties and behavior of Pyromark paint and other possible coatings	Direct application of results
<u>Receiver Thermal-Fluid Behavior</u>		
Steady heat transfer and fluid mechanics	Effects of two-phase internal heat transfer coefficients and friction factors by direct measurement of local channel wall temperature and inlet and outlet fluid temperature	Direct application of results Note: The ATS is modeled to give the same L/D, D and cone angle as the RPS. The number of tubes and total mass flow of the ATS is adjusted to give the same channel mass flow as the RPS. Under these conditions, the channel Reynolds number, average velocity, average heat transfer coefficient and total pressure drop will be the same for both designs. The radial accelerations are unavoidably different but the effect is considered secondary.
Heat transfer and fluid mechanics during transient insolation conditions	Effects of interactions between process control strategies and receiver integrity	Direct application of results
Channel flow instabilities	Effects and nature of instabilities in flow channels caused or aggravated by * two-phase flow * manifolding * process control strategy * time varying heat addition	Extrapolation of results Note: Due to the complex nature of two-phase flow instabilities, the relation between the ATS and RPS is not totally predictable at this time. However, if instabilities

R AND D AREAS	STUDY WITH 65 FT. DISH (ATS)	RELATION TO 200 FT. DISH (RPS)
<u>Receiver Configuration (Contd.)</u>		
Channel flow instabilities (contd.)		are found to occur in the ATS, techniques that are developed to alleviate the undesirable effects can be applied to the RPS design. Considerable information is to be gained from currently running experimental studies on the ATS channel configuration.
Degradation of interior heat transfer surface	Effects of scale and coking deposits on heat transfer and pressure drop; effects of corrosion and erosion	Direct application of results
Water chemistry	Effects of water treatment on rate of scale buildup in receiver	Direct application of results
Oil degradation	Effects of prolonged exposure to elevated temperatures on degradation of oil	Direct application of results
<u>Heat Transfer Loop</u>		
Flexible couplings	Effects of repeated thermal and mechanical cycling on survivability	Direct application of results
Conventional hardware	Effectiveness of standard components (valves, pumps, heat exchangers, insulation, etc.)	Direct application of results
<u>Storage</u>		
Thermocline	Effects of inlet design and flow rate on ability to maintain adequate thermocline	Direct extrapolation of results

R AND D AREAS	STUDY WITH 65 FT. DISH (ATS)	RELATION TO 200 FT. DISH (RPS)
Storage (Contd.)		
Storage/system interface	Integration of available storage strategies with system management policies	Direct extrapolation of results
Auxiliary Energy Source	Requirements for auxiliary fuel and energy sources (No auxiliary energy source included in ATS)	Direct extrapolation of results Note: Studies conducted under other R & D areas, e.g. 9, 14, and 16, provide results leading to design specs for the RPS auxiliary energy source.
Turbine-Generator	Requirements for turbine-generator, particularly off-design performance requirements (Load simulated in ATS by use of expander/condenser and by removal of heat from storage)	Direct extrapolation of results
Load, Demand	Compatibility of various load characteristics with system output	Direct extrapolation of results
Process Control	Adequacy of process control hardware and software to maintain desired receiver fluid temperature, pressure, and flow rate under various operating conditions including start-up, normal insolation, intermittent insolation, normal system shut-down, and emergency shut-down	Direct extrapolation of results
System Management Policies	Ability of management system to manage tracking orientation and process control effectively, optimizing energy capture while providing personnel safety and protection of equipment from catastrophic failure	Direct application of results

R AND D AREAS	STUDY WITH 65 FT. DISH (ATS)	RELATION TO 200 FT. DISH (RPS)
Safety, Survivability, Maintenance		
Safety	Nature of potential thermal, mechanical, and optical hazards; operational procedures to alleviate hazards	Direct application of results
Survivability	Effects of hail, wind, rain, and temperature on concentrator panels	Direct application of results
	Integrity of receiver coating; effects of internal corrosion of receiver; structural integrity of receiver after mechanical and thermal cycling	Direct application of results
Maintenance	Techniques of mirror cleaning and required time intervals; possible receiver coating and general receiver maintenance; requirements for maintaining soil stabilization; general system maintenance	Direct application of results
Instrumentation and Data Acquisition		
Instrumentation	Adequacy of optical sensors to provide desired tracking control accuracy	Direct application of results
	Adequacy of flow meters and pressure and temperature sensors to provide desired process control	Direct application of results

R AND D AREAS	STUDY WITH 65 FT. DISH (ATS)	RELATION TO 200 FT. DISH (RPS)
Instrumentation and Data Acquisition (Contd.)		
Instrumentation (contd.)	Adequacy of accelerometers and strain gauges to provide required information on receiver and concentrator support structure motions	Direct application of results
	Adequacy of instrumentation in heat transfer loop, storage tank, expander/condenser, and associated heat exchangers to provide required information for various system management policies	Direct application of results
Data acquisition	Adequacy of data acquisition system, procedures, and data handling techniques	Direct application of results
System Costs	Comparision between actual and predicted ATS costs	Direct extrapolation of results
Construction Sequencing, Preassembly	Feasibility of proposed RPS construction sequencing and preassembly concepts	Direct application of results
Economic Strategy, Impact	Total integration of system performance, possible system management policies, and present and future load characteristics to obtain maximum economic benefit	Direct application and extrapolation of results

VII-D OPERATING PROCEDURE FOR THE ATS

The ATS will be an expensive and relatively complicated apparatus. In order to protect the system, as well as the operating personnel, caution must be exercised during early stages of operation. A Start-Up Manual of Procedures will be developed prior to the time the system is first operated. Start-Up procedures will involve manual control of the various subsystems, with appropriate sequencing of operations designed to allow the operator to develop a "feel" for system behavior and control.

As experience is gained with the system during manual operation, the automatic control system will gradually be programmed and taught to operate the system. During this phase, an Operator/Experimenter's Manual will be developed to describe detailed procedures for start-up, normal and emergency shut-down, and operation under steady and transient insolation conditions.

The research program to be carried out with the ATS will involve operating the system under various insolation conditions to test the system's ability to respond appropriately to changing conditions. These data will be used in an iterative process to continue to refine and extend the dynamical model of of system behavior which will in turn be used to modify the control management scheme leading ultimately to a scheme which will optimize energy collection.

VIII. STATUS AND CONCLUSIONS

The CSPP has been conducted with sound planning and has been organized into effective steps and stages as indicated in Table I-1. The work is highly directed toward the mission of constructing a solar thermal electric power system at Crosbyton to serve as a module for larger systems and as a prototype for similar systems. The fundamental strength of the CSPP has been the broad R and D program. A great deal has been learned about the Solar Gridiron Concept. Further significant advance in the understanding of the concept requires a research tool, like the ATS, which allows realistic simulation of the operational characteristics of full-scale systems.

Certain experimental efforts, still underway, such as radiant testing of receiver models, will continue to produce interesting and relevant information. As indicated in Section VII, there is still much to learn about the operational behavior of some subsystems. The behavior of the boiler under transient conditions remains the most difficult area of prediction.

It is clear at this point that, under all conditions that have been simulated, the receiver design performs reliably, that the receiver can be supported in a cost effective and dynamically stable mode under operational conditions, that full-scale panels providing the design performance can be fabricated in a way that potentially lends itself to low cost mass production, and that known transients in the tracking and process control subsystems are on a time scale that can be easily controlled with available hardware. As mentioned in Section V, there is a strong possibility that the receiver can be resized without penalty in a way that reduces the exposed surface area by 40%, thereby reducing receiver thermal losses and receiver weight and cost.

☆U.S. GOVERNMENT PRINTING OFFICE: 1984- 746-081/2315 REGION NO. 4