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Proceedings of the Solar Thermal Technology Conference

Craig E. Tyner, Editor

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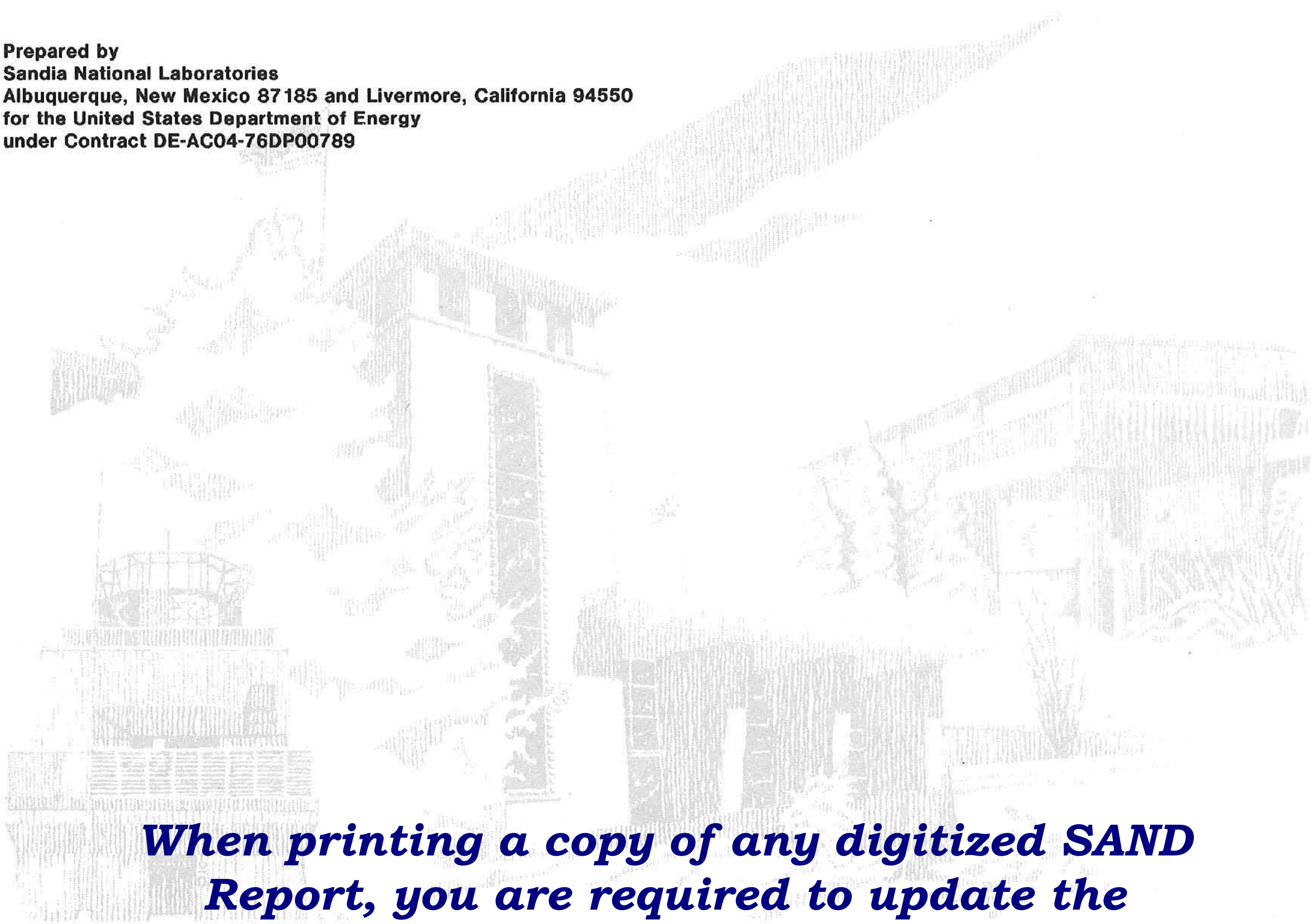

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Proceedings of the Solar Thermal Technology Conference

August 26 - 28, 1987

Albuquerque, New Mexico

Craig E. Tyner
Editor

Solar Energy Department
Sandia National Laboratories
Albuquerque, New Mexico 87185

ABSTRACT

The Solar Thermal Technology Conference was held on August 26-28, 1987, at the Marriott Hotel, Albuquerque, New Mexico. The meeting was sponsored by the United States Department of Energy and Sandia National Laboratories. Topics covered during the conference included a status summary of the Sandia Solar Thermal Development Project, perspectives on central and distributed receiver technology including energy collection and conversion technologies, systems analyses and applications experiments. The proceedings contain summaries (abstracts and principal visual aids) of the presentations made at the conference.

ACKNOWLEDGEMENTS

I would like to acknowledge and express my appreciation for the support provided by many individuals whose contributions were essential to the success of the conference. Special recognition and thanks are due to Kathleen Sena of the University of New Mexico Engineering Research Institute, who handled the logistics and arrangements for the conference, defined the various activities that had to be handled and set the deadlines, and generally insured that everything went smoothly both before and during the conference. Thanks are also extended to the Session Chairpersons: Dan Alpert, Gregory Kolb, Hugh Reilly and Doug Adkins, for securing speakers and organizing and conducting their sessions. Finally, thanks are due to Ken Boldt and the tour guides for organizing and conducting the tour of the Solar Thermal Test Facility.

Craig E. Tyner
Conference Chairman

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SESSION II - DISTRIBUTED RECEIVER SYSTEMS CONT'D

SOLAR THERMAL TECHNOLOGY CONFERENCE

MARRIOTT HOTEL ALBUQUERQUE, NM

AGENDA

WEDNESDAY, AUGUST 26

7:30 REGISTRATION

8:00 OPENING REMARKS
Welcome and Announcements, Craig Tyner, Sandia National Laboratories
Energy Program Perspectives, Dan Hartley, Sandia National Laboratories
Distributed Receiver Program Overview, James Leonard, Sandia National Laboratories

SESSION I DISTRIBUTED RECEIVER COMPONENTS

Chair - Doug Adkins, Sandia National Laboratories

8:40 Introduction - Doug Adkins
Sandia National Laboratories

8:50 Advanced Stirling Conversion System Conceptual Design Status
Richard Shaltens, NASA Lewis

9:10 Liquid Metal Thermal Electric Converter
Joseph Abbin, Charles Andraka, Laurance Lukens, James Moreno, Sandia National Laboratories

9:30 New Solar Receiver Concepts for a 25kWe Stirling Engine
Jim Kesseli, Sanders Associates, Inc.

9:50 Measurement of the Temperature Distribution in Solar Cavity Receivers by Scanning Radiometer
Eric Thacher, Clarkson University

10:10 **BREAK**

10:25 Point-Focus Concentrating Collector Technology Development
Thomas Mancini, Sandia National Laboratories

10:45 Stretched Membrane Dish Development Project
Monte McGlaun, LaJet Energy Company

11:05 Stretched-Membrane Dish Collector Development Project Phase One
Keith Armstrong, Solar Kinetics, Inc.

11:25 CIRCE: A Computer Code for the Analysis of Point-Focus Solar Concentrators
Art Ratzel, Sandia National Laboratories

11:45 SOL-GEL Planarized Flexible Solar Mirrors
A.R. Mahoney, C.S. Ashley, S.T. Reed, Sandia National Laboratories

12:05 **LUNCH (on your own)**

SESSION II DISTRIBUTED RECEIVER SYSTEMS

Chair - Hugh Reilly, Sandia National Laboratories

1:30 Introduction - Hugh Reilly
Sandia National Laboratories

1:45 Central Engine Study
Jane Diggs, Sandia National Laboratories

2:10 Design of the Phase I Closed-Loop Experiment (CLOE)
Tzvi Rozenman, RAI

2:40 Prevention of Carbon Deposition in the CO_2/CH_4 Thermochemical Energy Transport System
Jim Fish, David Hawn, Sandia National Laboratories

3:00 **BREAK**

3:15 Project Summary: Solar Total Energy Project (STEP) at Shenandoah, Georgia
Ed Ney, Georgia Power Company

3:35 Distributed Receiver Test Facility Activities
Christopher Cameron, John Strachan, Sandia National Laboratories

4:00 Small Community Solar Experiment at Osage City, Kansas
W.D. Batton, Barber-Nichols Engineering Co.

4:20 Power Kinetics SCSE #2 Molokai, Hawaii
Eugene Bilodeau, Power Kinetics, Inc.

4:40 LaJet Energy Company Update on SOLARPLANT 1
Monte McGlaun, LaJet Energy Company

5:00 **ADJOURN**

5:15 **SOCIAL HOUR**

7:30 Arizona Solar Thermal Task Force Dinner
(Contact Carlo LaPorta directly for details)

THURSDAY, AUGUST 27

7:30 REGISTRATION

SESSION III CENTRAL RECEIVER TECHNOLOGY

Chair - Daniel Alpert, Sandia National Laboratories

8:00 Program Technical Perspectives
A. C. Skinrood, Sandia National Laboratories, Livermore

8:15 Status - Central Receiver Technology
John Otts, Sandia National Laboratories

8:30 Molten Salt Subsystem/Component Test Experiment Receiver Test Results
David Smith, The Babcock & Wilcox Co.

8:50 Optimization of the Molten Salt Subsystem Component Test Experiment Receiver Performance
James Chavez, James Grossman, Sandia National Laboratories

9:10 MSS/CTE Pump and Valve Test Results to Date
Patricia Bator, The Babcock & Wilcox Co.

9:30 Thermomechanical Fatigue of Solar Central Receiver Collector Tube Alloys
W.B. Jones, R.J. Bourcier, J.A. Van Den Avyle, Sandia National Laboratories

9:50 Direct Absorption Receiver Development
Craig Tyner, Sandia National Laboratories

10:00 Direct Absorption Receiver Water Flow Tests
James Chavez, Sandia National Laboratories

10:20 **BREAK**

10:40 Development of a Low Cost Heliostat Drive
Werner Heller, Peerless-Winsmith

11:00 Large Area Heliostat Development
R.J. Thomas, D.N. Gorman, J.G. Halford, Advanced Thermal Systems, Inc.

11:20 Stretched Membrane Mirror Module Improvement at Science Applications International Corporation
Kelly Beninga, Barry Butler, Science Applications International Corp.

11:40 Stretched-Membrane Mirror-Module Design Improvement
Paul Schertz, Solar Kinetics, Inc.

12:00 **LUNCH (on your own)**

SESSION IV UTILITY STUDIES

Chair- Gregory Kolb, Sandia National Laboratories

1:00 Introduction - Sig Gronich
Department of Energy

1:05 Utility Solar Central Receiver Study - Alternate Utility Team
D.L. Thornburg, Arizona Public Service Company

1:40 Utility Solar Central Receiver Study
E.R. Weber, Arizona Public Service Company

2:10 Pacific Gas and Electric Company Utility Solar Central Receiver Study
T. Hillesland, Jr., Pacific Gas and Electric Company

3:00 **BREAK**

SESSION V CENTRAL RECEIVER SYSTEMS

Chair - Gregory Kolb, Sandia National Laboratories

3:20 Solar One Power Production Phase
Charles Lopez, Southern California Edison Co.

3:40 Solar One Future Plans
Charles Lopez, Southern California Edison Co.

4:00 Annual Energy Improvement Study
Daniel Alpert, Gregory Kolb, Sandia National Laboratories

4:20 Simulation of Solar Central Receiver Systems
Gregory Kolb, Sandia National Laboratories, T.L. Greenlee, M.R. Ringham, ESSCOR Corporation

4:40 Commercializing Solar Thermal Electric and Industrial Process Heat Projects: United States Market Experience
Carlo LaPorta, R & C Enterprises

5:00 **ADJOURN**

FRIDAY, AUGUST 28

8:30 Transporation to the Sandia Solar Thermal Test Facility
(bus in front of hotel)

9:00 Tour of the Solar Thermal Test Facility

11:00 Return Transportation to Albuquerque Marriott Hotel

SOLAR THERMAL
TECHNOLOGY CONFERENCE

CONFERENCE OBJECTIVES

The Solar Thermal Technology Conference provides a review and status update of Sandia's Central Receiver and Distributed Receiver Development Project. This project is sponsored by the United States Department of Energy as part of its Solar Thermal Technology (STT) Program. The objectives of this meeting are

- To provide an overview of Sandia's Solar Thermal activities and plans.

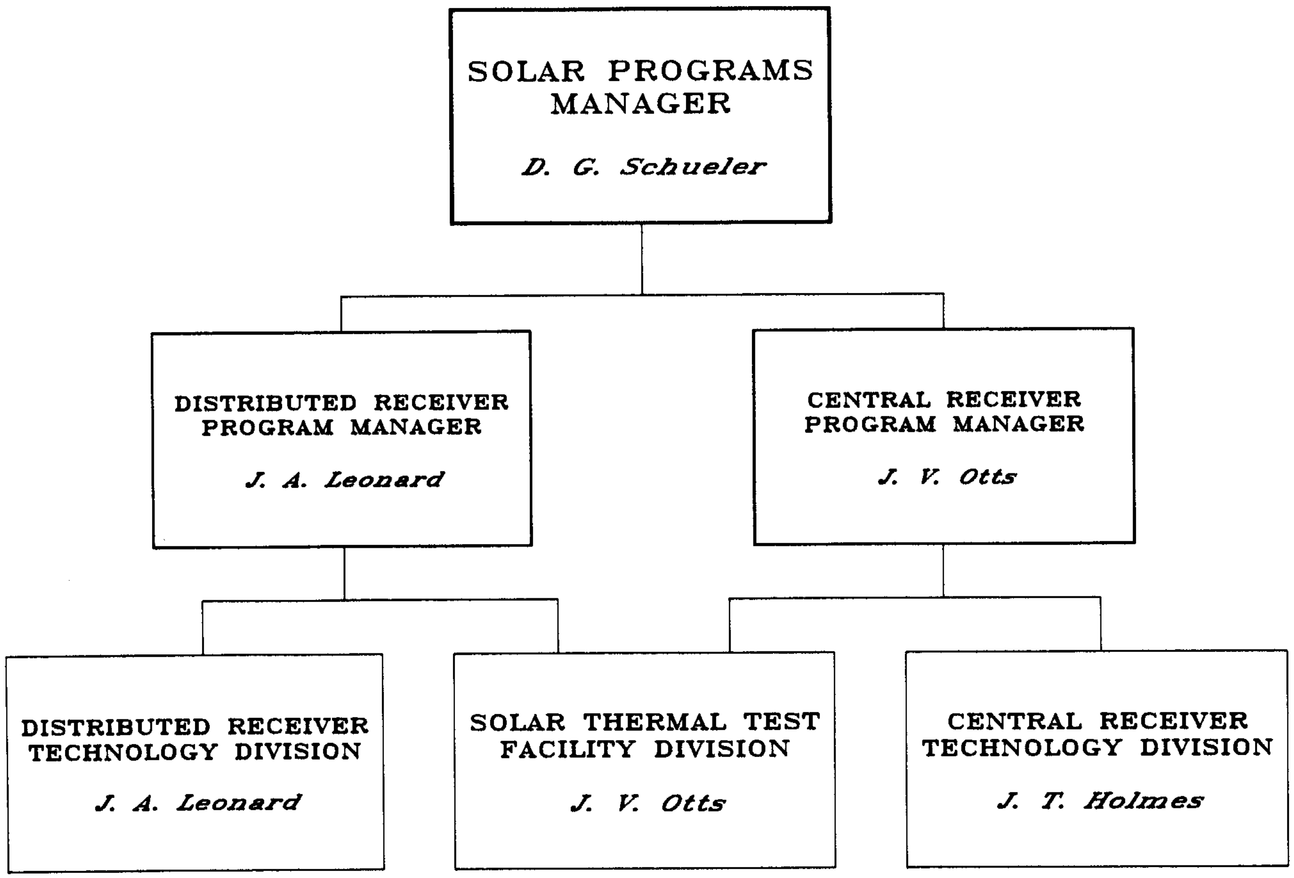
- To present results of these activities with emphasis on technical issues and details.

- To provide the latest operational experiences on various experiments.

- To disseminate solar thermal technology developed during the past year by both government and industry.

- To provide an opportunity for solar system technical investigators and potential users to meet and exchange technical information.

SANDIA SOLAR THERMAL PROGRAM ORGANIZATIONAL STRUCTURE



SANDIA SOLAR THERMAL DEVELOPMENT PROJECT PERSONNEL

AUGUST 1987

		Organization Number	Telephone 84X-XXXX
Manager Solar Energy Department	Schueler, Don	6220	4-4041
Project Managers			
Test Facility	Otts, John	6222	4-2280
Distributed Receiver	Leonard, Jim	6227	4-8508
Central Receiver Technology	Holmes, John	6226	4-6871
Distributed Receiver Task Leaders			
Concentrators	Mancini, Tom	6227	4-8643
Receivers	Diver, Rich	6227	6-0215
Heat Engines	Linker, Kevin	6227	6-7817
LMTEC and SOLGEL	Martinez, Jesus	6227	6-7508
Transport and Storage	Muir, Jim	6227	6-7818
Balance of Plant	Adkins, Doug	6227	4-0611
Systems Analysis	Diggs, Jane	6227	4-5203
	Fewell, Mert	6227	4-7120
	Reilly, Hugh	6227	6-5845
Central Receiver Task Leaders			
Concentrators	Alpert, Dan	6226	4-6982
	Strachan, John	6222	4-4141
Receivers	Tyner, Craig	6226	4-3340
	Chavez, Jim	6226	4-4485
Controls	Boldt, Ken	6222	6-8109
Storage	Kolb, Greg	6226	6-1976
Central Receivers	Kolb, Greg	6226	6-1976
Systems	Alpert, Dan	6226	4-6982
CRTF Molten Salt	Couch, Bill	6222	4-6770
Analysis	Grossman, Jim	6226	6-5482
	Kolb, Greg	6226	6-1976
Solar One	Baker,Al	8471	415 422-2171
New Applications	Tyner, Craig	6226	4-3340

SESSION I

DISTRIBUTED RECEIVER COMPONENTS

DOUGLAS ADKINS

CHAIRMAN

DISTRIBUTED RECEIVER COMPONENTS

Introduction

Doug Adkins
Sandia National Laboratories

(This page is provided for notes.)

ADVANCED STIRLING CONVERSION SYSTEM (ASCS) CONCEPTUAL DESIGN STATUS

Richard K. Shaltens

NASA-Lewis Research Center
Cleveland, Ohio 44135

The Department of Energy's (DOE) Solar Thermal Technology Program, Sandia National Laboratories (SNLA), is evaluating heat engines for terrestrial Solar Distributed Heat Receivers. The Stirling engine has been identified by SNLA as one of the most promising engines for terrestrial applications. The potential to meet DOE's goals for performance and cost can be met by the free-piston Stirling engine.

The National Aeronautics and Space Administration (NASA) Lewis Research Center (LeRC) is conducting Stirling activities which are directed toward a dynamic power source for the space application. Space power systems requirements include high reliability, very long life, low vibration and high efficiency. The free-piston Stirling engine has the potential for future high power space conversion systems, either nuclear or solar powered. Although both applications, terrestrial and space power, appear to be quite different, their requirements complement each other.

NASA LeRC is providing technical management for an Advanced Stirling Conversion System (ASCS) through a cooperative Interagency Agreement with DOE. Parallel contracts have been awarded to Mechanical Technology Inc. (MTI) of Latham, New York, and Stirling Technology Company (STC) of Richland, Washington, for the conceptual designs of an ASCS. Each design will feature a free-piston Stirling engine, a liquid metal heat pipe receiver, and a means to provide about 25 kW of electric power to a utility grid while meeting DOE's long term performance and cost goals.

The MTI design incorporates a linear alternator to directly convert the solar energy to electricity while STC generates electrical power indirectly by using a hydraulic output to a ground based hydraulic pump/motor coupled to a rotating alternator. Both designs for the ASCS's will use technology which can be reasonably be expected to be available in the 1980's. Both the MTI and STC concepts will be evaluated by the same, but independent contractor, to provide a manufacturing and cost analysis including life cycle cost. The ASCS designs using a free-piston Stirling engine, a heat transport system, a receiver and the methods of providing electricity to the utility grid will be discussed.

One of the conceptual designs will be selected for a competitive final design, hardware procurement, assembly and test of the ASCS at the SNLA test facilities in Albuquerque, NM by 1990.

ADVANCED STIRLING CONVERSION SYSTEM (ASCS)

- IAA WITH DOE - SNLA
- STIRLING A LEADING HEAT ENGINE CANDIDATE
- FREE PISTON STIRLING HAS POTENTIAL TO MEET DOE's LONG TERM GOALS:
  - HIGH EFFICIENCY
  - PERFORMANCE
  - COST

DESIGN OBJECTIVES

- DEFINE THE ASCS CONFIGURATION
- PREDICT ASCS PERFORMANCE OVER A RANGE OF SOLAR INPUTS
- ESTIMATE SYSTEM AND MAJOR COMPONENT WEIGHT
- DEFINE ENGINE AND ELECTRICAL POWER CONDITIONING AND CONTROL REQUIREMENTS
- DEFINE KEY TECHNOLOGY NEEDS NOT READY BY THE LATE 1980's IN MEETING GOALS
- PROVIDE A MANUFACTURABILITY AND COST EVALUATION FOR THE ENGINE-ALTERNATOR

ASC SYSTEM INCLUDES:

- RECEIVER
- HEAT TRANSPORT SYSTEM
- CONVERSION SYSTEM
  - STIRLING ENGINE
  - POWER OUTPUT DEVICE
- POWER CONDITIONING AND CONTROLS
- AUXILIARIES

Liquid Metal Thermal Electric Converter

Joseph P. Abbin
Charles E. Andraka
Laurance L. Lukens
James B. Moreno

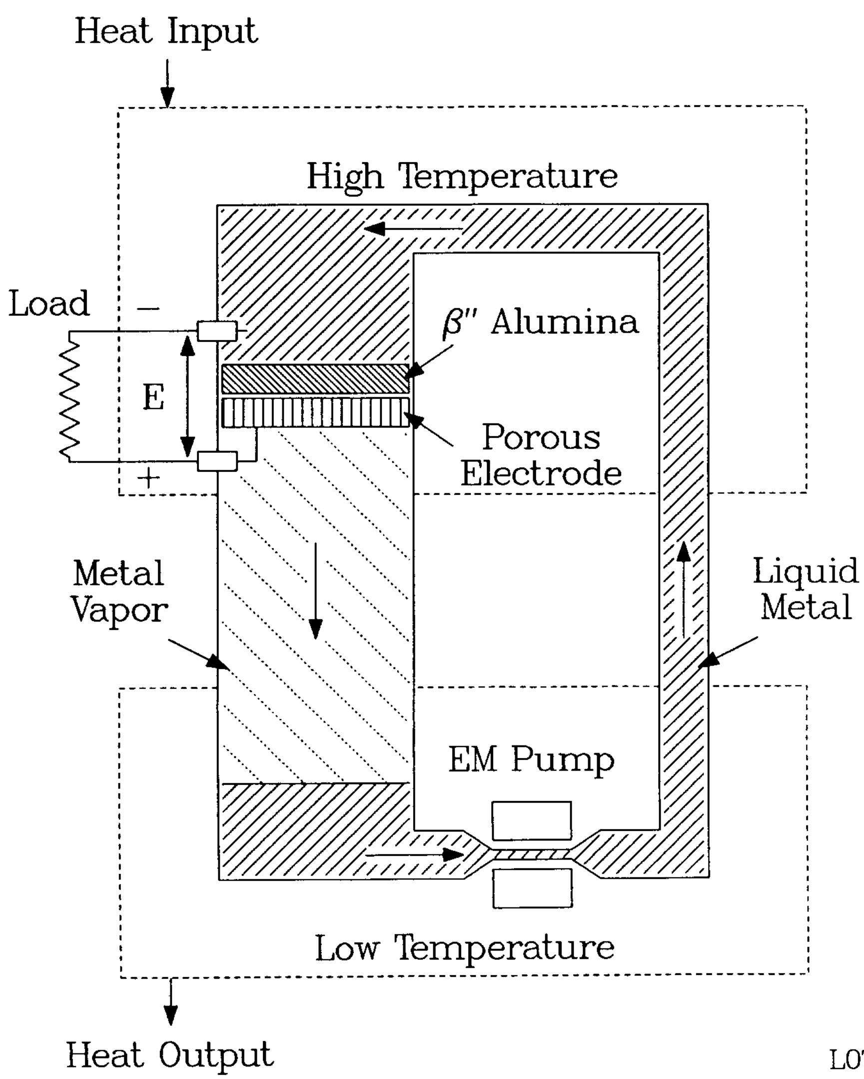
Sandia National Laboratories
Division 2541
Albuquerque, New Mexico 87185

Since October of 1984, Division 2541 at Sandia has been actively engaged in the evaluation and development of heat engine technologies applicable to dish electric systems. Our preliminary heat engine technology assessment identified the Liquid Metal Thermal Electric Converter (LMTEC) concept as having the potential to meet the Solar Thermal Technology Program's long term cost and performance goals but concluded that the concept required significant engineering development for terrestrial solar applications. The LMTEC concept is appealing because of its basic mechanical and electrical simplicity and because its ideal thermodynamic cycle efficiency closely approaches that of a Carnot cycle operating between the same temperature limits.

The LMTEC work at Sandia has concentrated on three major areas; the conceptual design of a 25 kW unit for mounting at the focus of a parabolic dish type solar collector, analytical modeling of the LMTEC to better understand its limitations and advantages, and the design, construction, and test of a 50 W bench test module to validate analytical models, evaluate design concepts, and gain experience with materials. Significant progress has been made in all of the above areas during the past year.

The LMTEC conceptual design study has resulted in a preliminary design which includes several innovative design changes developed at Sandia. This conceptual design has been used as the baseline for the analytical modeling efforts. Significant results have been obtained from the analytical modeling. Our work indicates that careful design will be required to minimize radiation and viscous flow penalties for a sodium LMTEC. The development of higher performance, more stable electrodes will be necessary for further consideration of the sodium LMTEC for terrestrial solar. A key finding from our modeling work is that an alternate working fluid, mercury, could offer significant performance advantages over sodium for terrestrial solar.

LMTEC Cycle Schematic



L078604

Liquid Metal Thermal Electric Converter Advantages

High Reliability and Low Maintenance (No Moving Parts)

Low Noise and Vibration

Theoretical Efficiency Near Carnot

Efficiency Independent of Power Level

L028701

JPA 2/87

Sandia National Laboratories

Solar Energy

LMTEC Development Plan

Conceptual Designs Of 25 kW Solar Powered Device

Design Assemble & Test LMTEC Bench Test Module

Solid Electrolyte Study for Hg

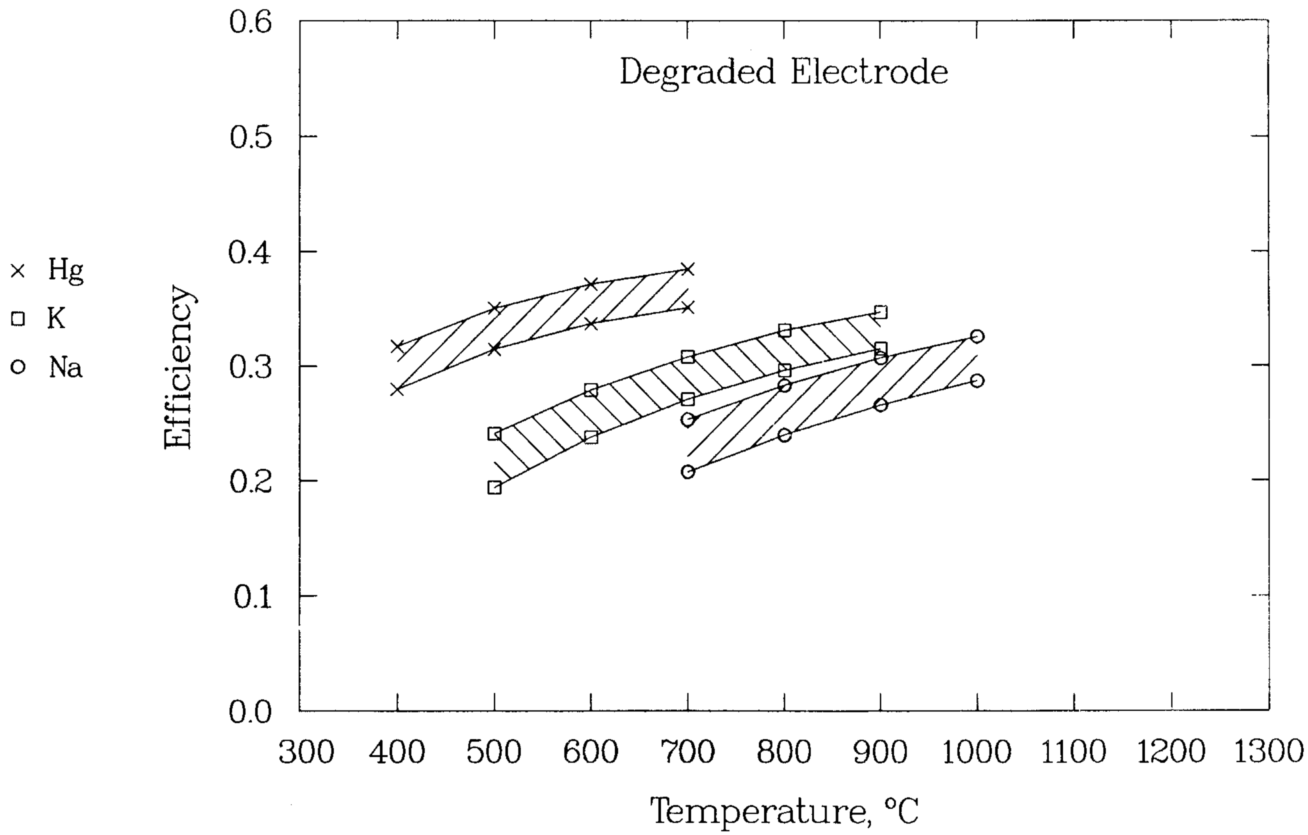
Electrode Research

Design Assemble & Test 1 kW Device Based On 25 kW Conceptual Design

Sandia National Laboratories

Solar Energy

LMTEC Peak Engine Performance



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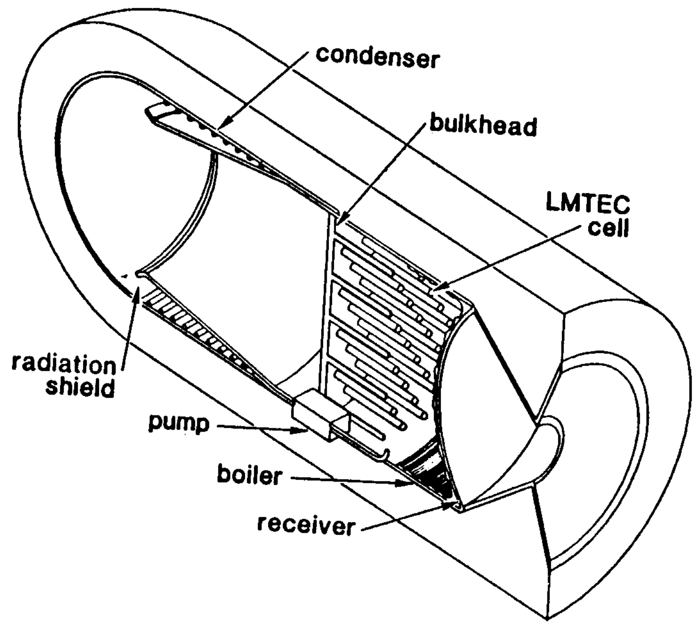
LLL 4/87

SCHEMATIC OF 25-KW LMTEC



SNLA LMTEC
Design Innovations

Refluxing Boiler
- Allows Series Connection of Cells
- Allows Isothermal Heat Input
- Simplifies Design

Internal Electrode
- Keeps Ceramic in Compression

Alternate Working Fluids (Hg and K)
- Higher Efficiency
- Lower Peak Temperatures

Remote Condenser
- Reduces Thermal Losses
- Allows Packaging Flexibility

Ceramic–to–Stainless Steel Seal
- Essential to Practical Engine

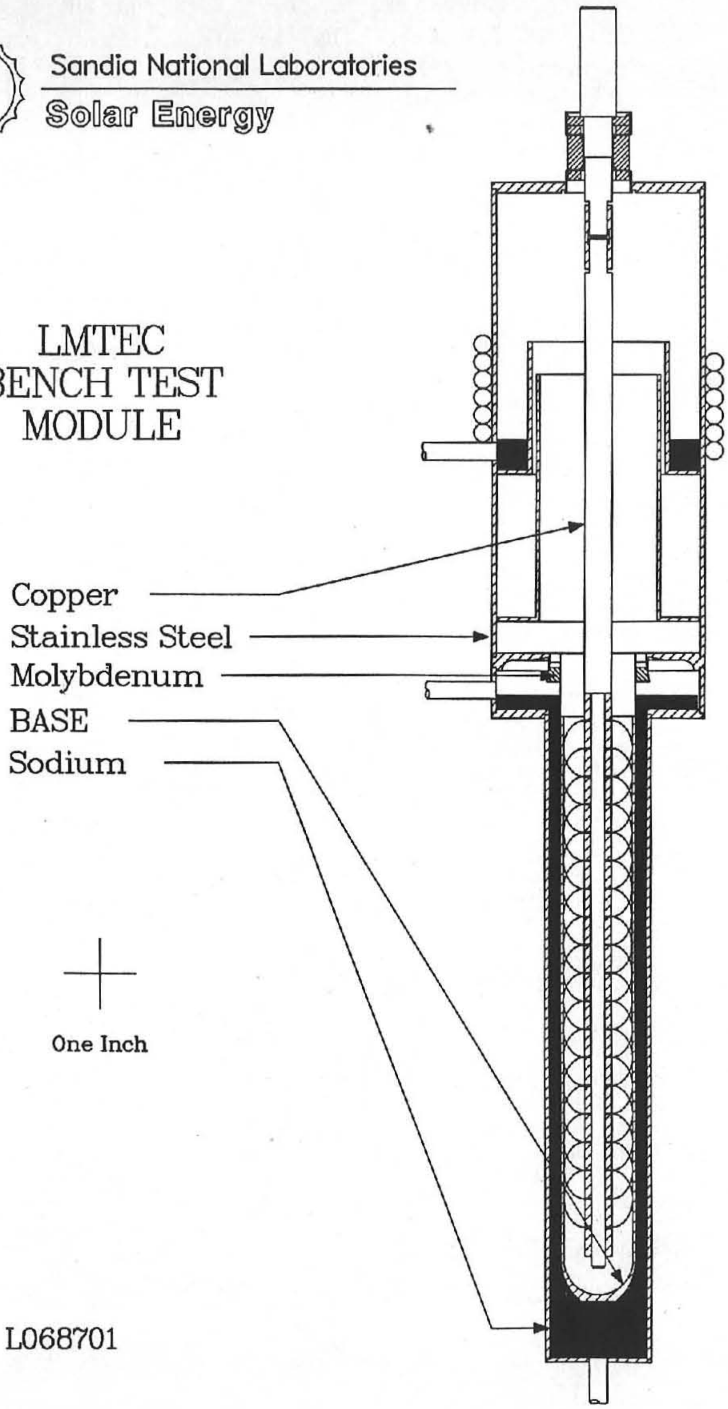
LMTEC/Rankine (Binary) Engine
- Very High Efficiency

JPA 3/12/87 L038704

Sandia National Laboratories

Solar Energy

LMTEC BENCH TEST MODULE



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LMTEC Bench Test Module Operation

March 26, 1987

The BTM Was Operated At Design Temperature, 800 °C

Open Circuit Voltage Was Slightly Lower Than Expected

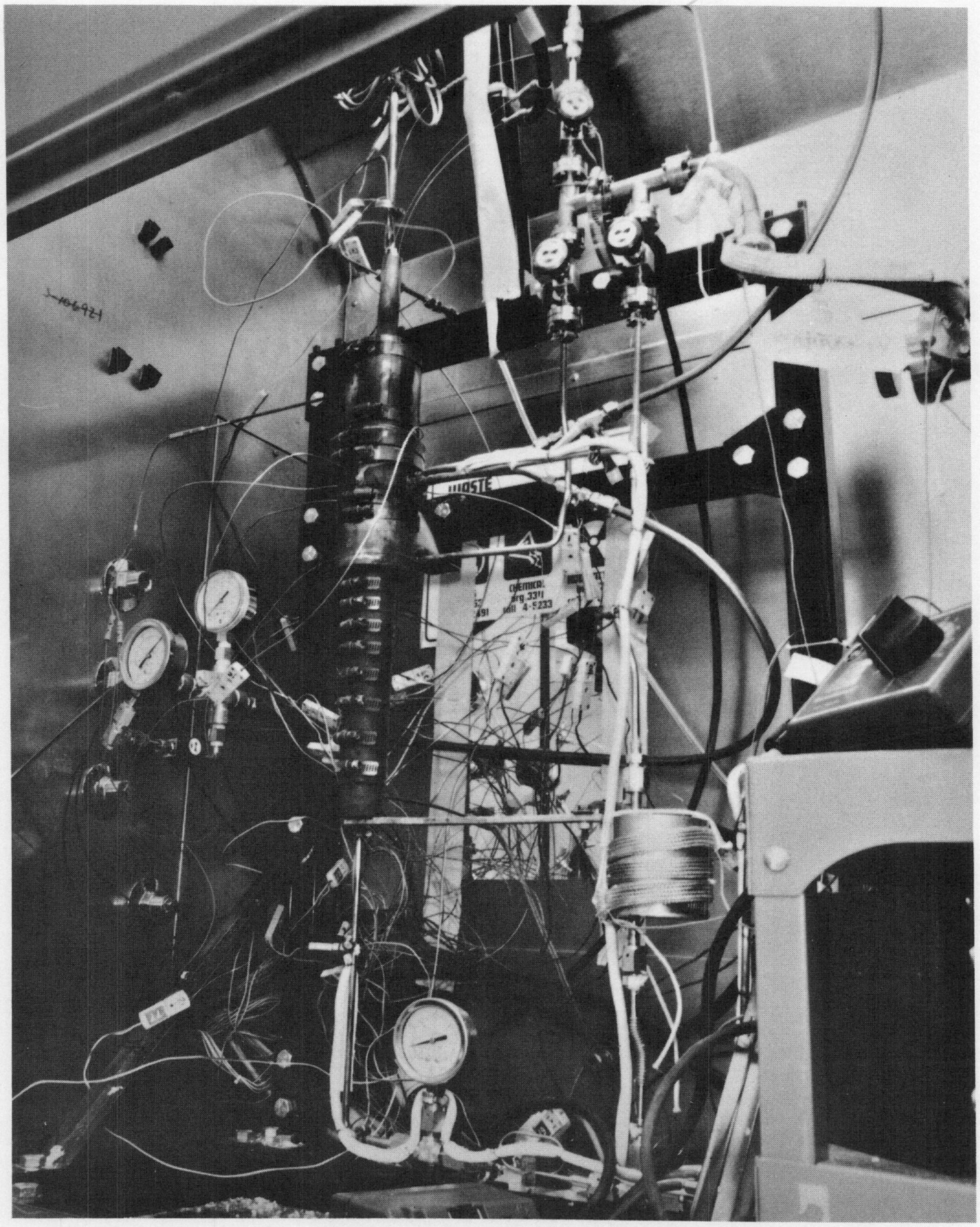
The Power Output Was Much Lower Than Expected

Demonstrated Computer Control And Data Aquisition System

Demonstrated Safe Operation Of An 800 °C Sodium System

Operation Terminated By Burnout Of Primary Heater

L048706 LLL 4/87



NEW SOLAR RECEIVER CONCEPTS FOR A 25-kWe STIRLING ENGINE

J.B. Kesseli
Sanders Associates, Inc.
Nashua, NH

This report contains a description of two solar receiver designs adapted for a Stirling engine. The prior history of problems associated with the first generation of heater head/receiver designs has led the DOE to solicit a more reliable, cost-effective solution. At the request of the DOE, MTI and STC have considered employing a heat pipe scheme to a free-piston Stirling engine (FPSE) design. Sanders was subcontracted to work with each of these prime contractors on the receiver portion of the engine module.

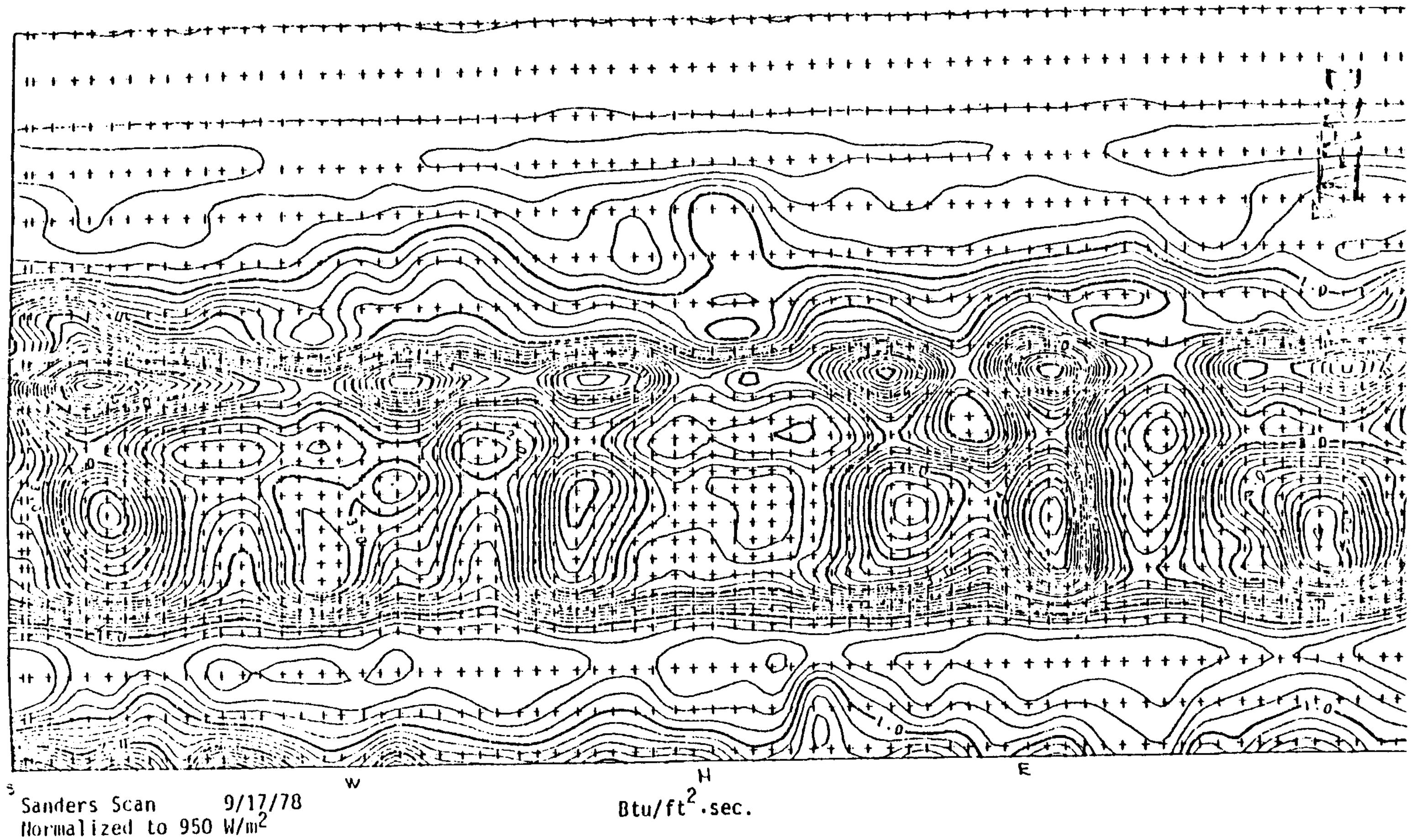
Over the course of the studies many concepts were considered. Two innovative receiver concepts emerged from these programs. The STC approach adapted a conventional, pool boiler behind the solar absorption surface. MTI chose to employ a wicked evaporator/absorber configuration. Both designs rely on a gravity refluxing of condensate from a multitubular engine heaterhead to a reservoir.

Why Absorber/Evaporator Design is Considered so Critical

- High solar flux environment (~ 40 W/cm^2) is not easily predicted
- Actual solar flux "hot spots" may be twice the theoretical prediction
- Large surface temperature gradients arise due to flux maldistribution
- Flux safety factors must also be applied to wick design from superheat considerations
- 20,000 extreme fatigue cycles in 20 years
- Potentially more numerous local cycles due to "flickering" hot spots
- Internal (Na) and external (enhanced oxidation) corrosion reduces safety factor by introducing stress concentration pitting
- Safety factors are difficult to apply because of the competing nature of stresses, wick requirements, and corrosion factors
- Few material candidates available with required temperature capability, corrosion compatibility, and cost.

Sanders
A Lockheed Company

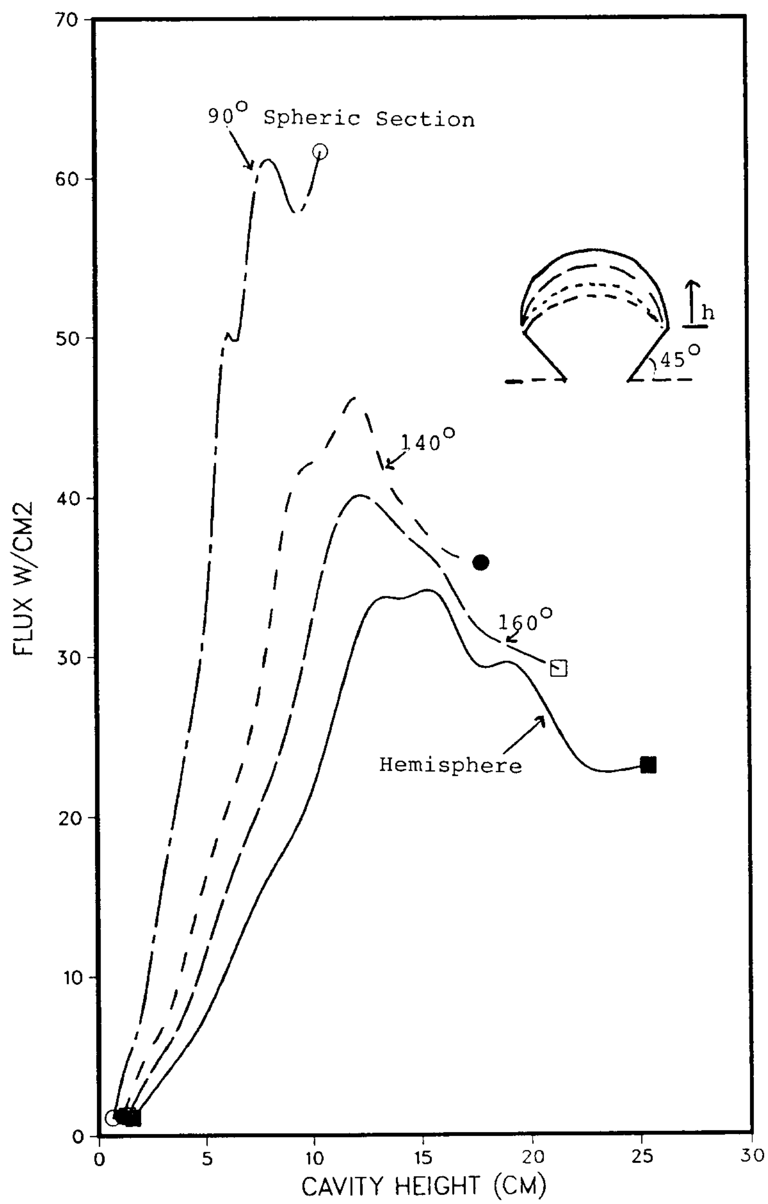
An Example of How Bad Solar Flux Profiles Can Be



Typical Sanders Rake Flux Map.

Multifaceted Low Cost Concentrators are Likely to be Worse than Pedigreed JPL/TBC

SOLAR FLUX PROFILE FOR 20 INCHES SPHERIC SECTIONS



STC Solar Receiver With Pool Boiler

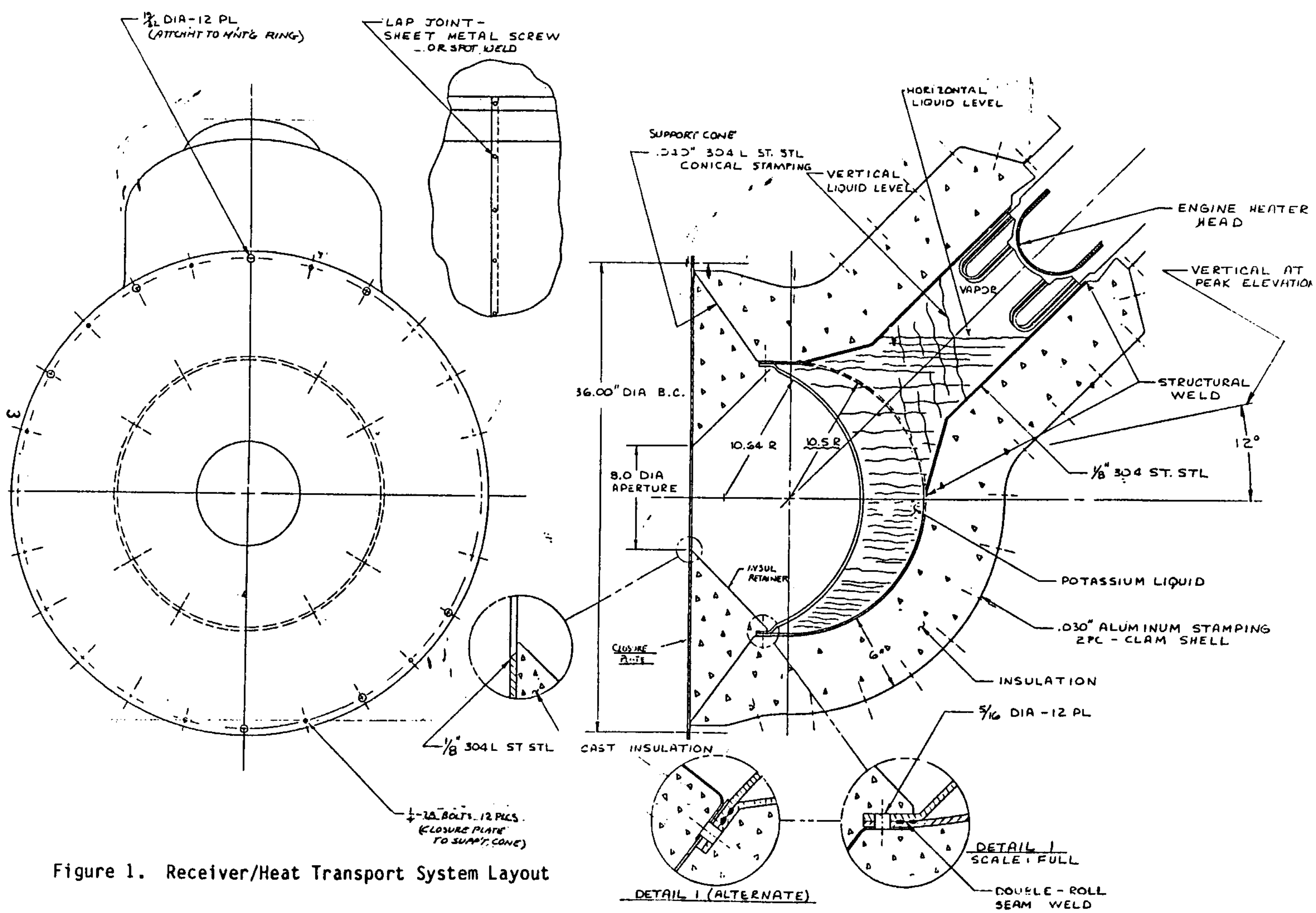
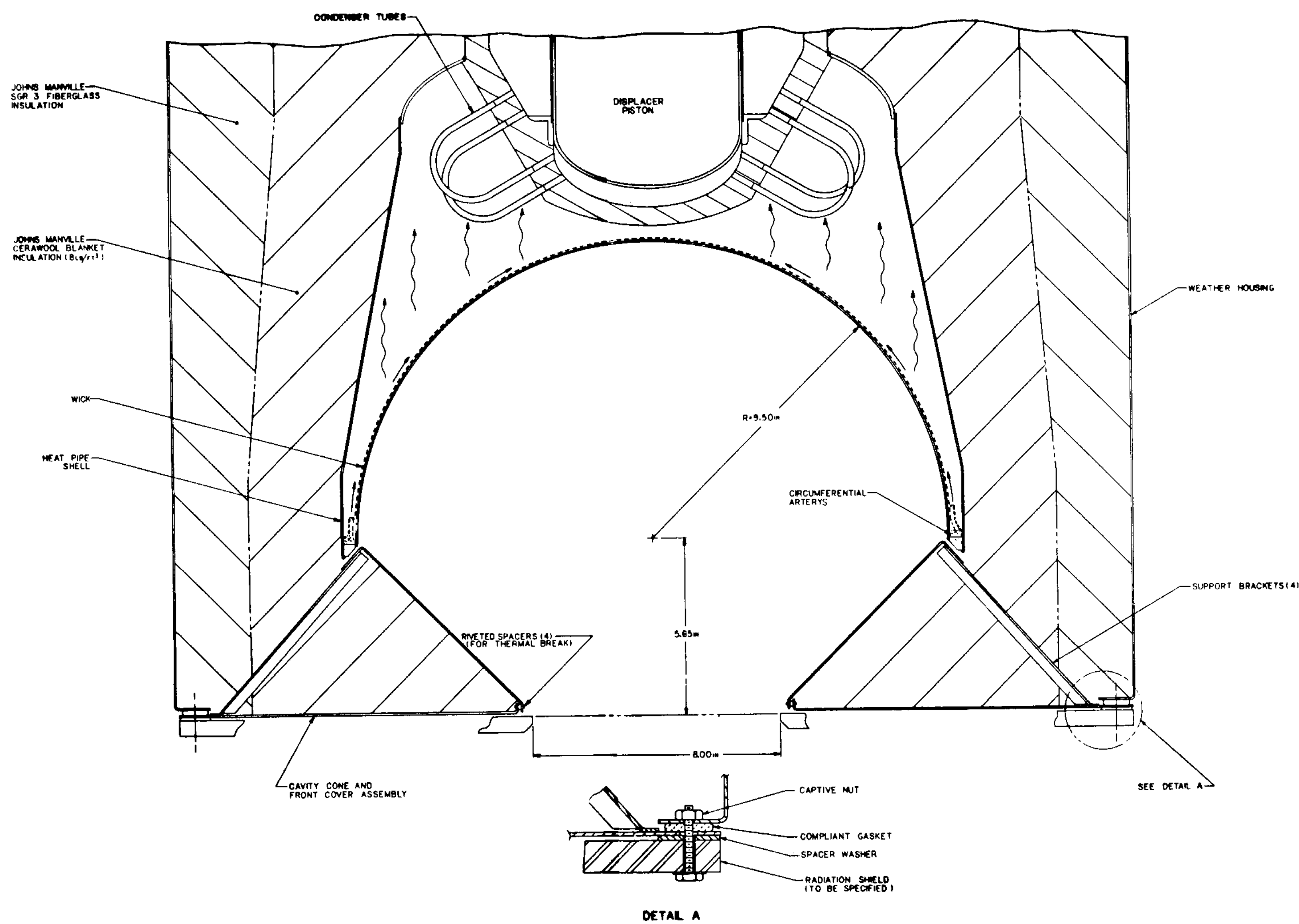
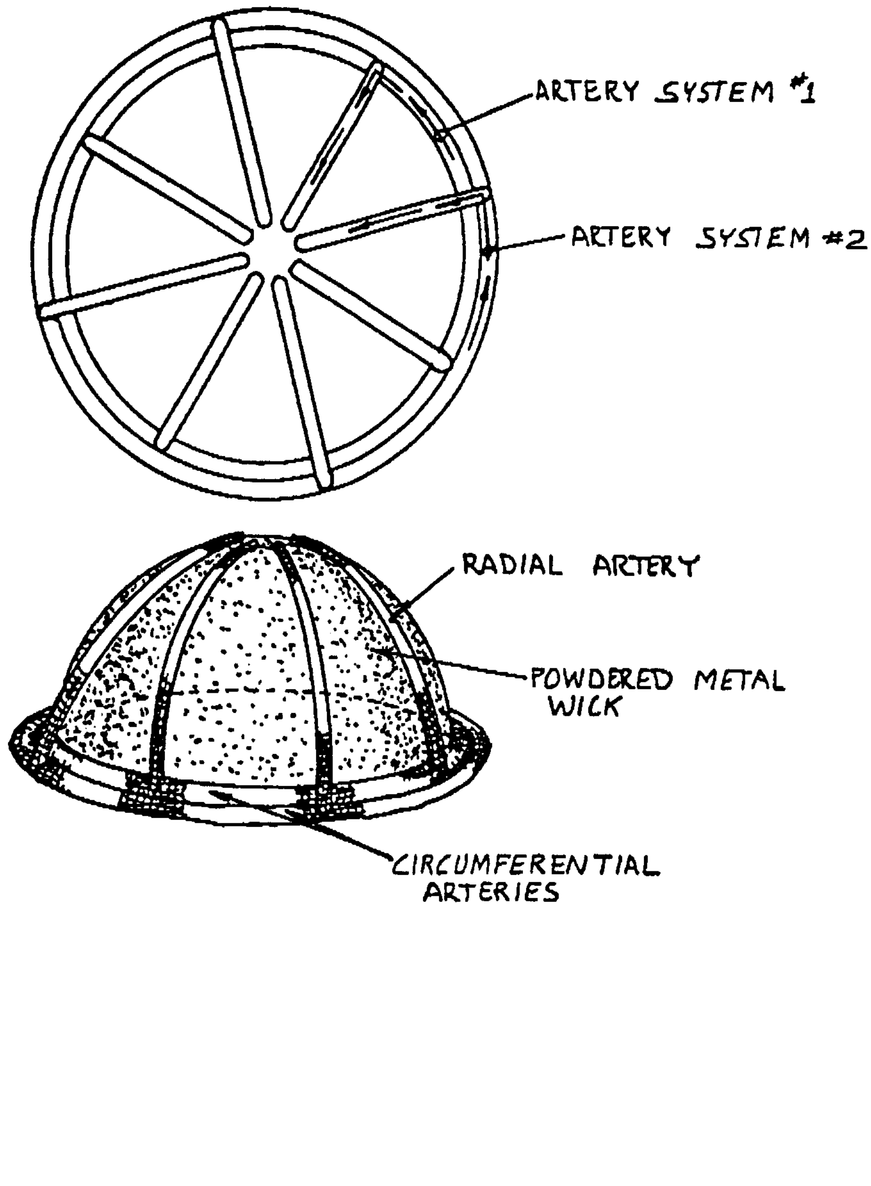


Figure 1. Receiver/Heat Transport System Layout

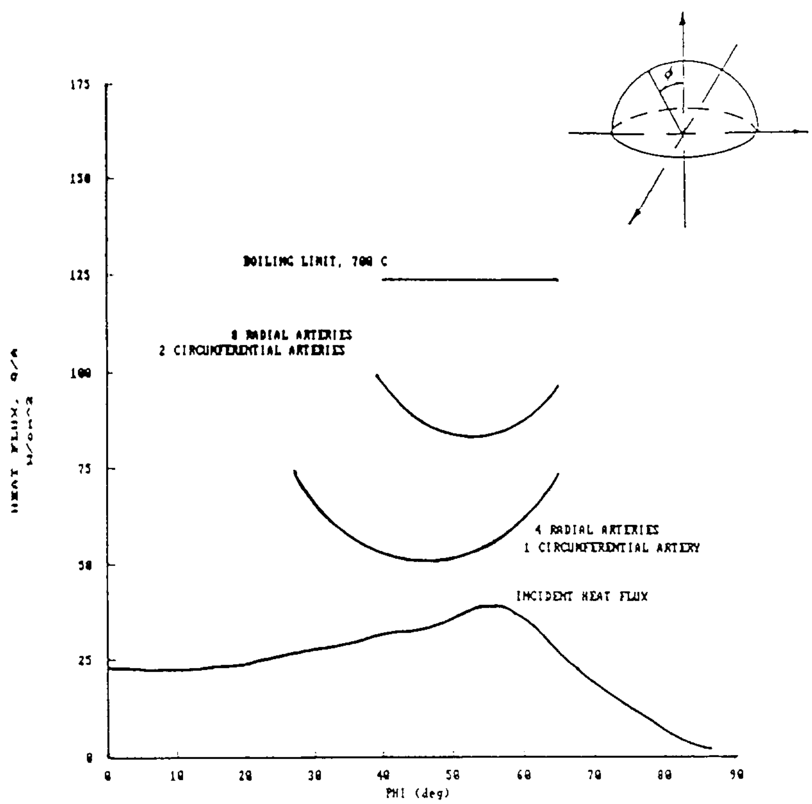
MTI Solar Receiver With Wicked Heat Pipe Evaporation



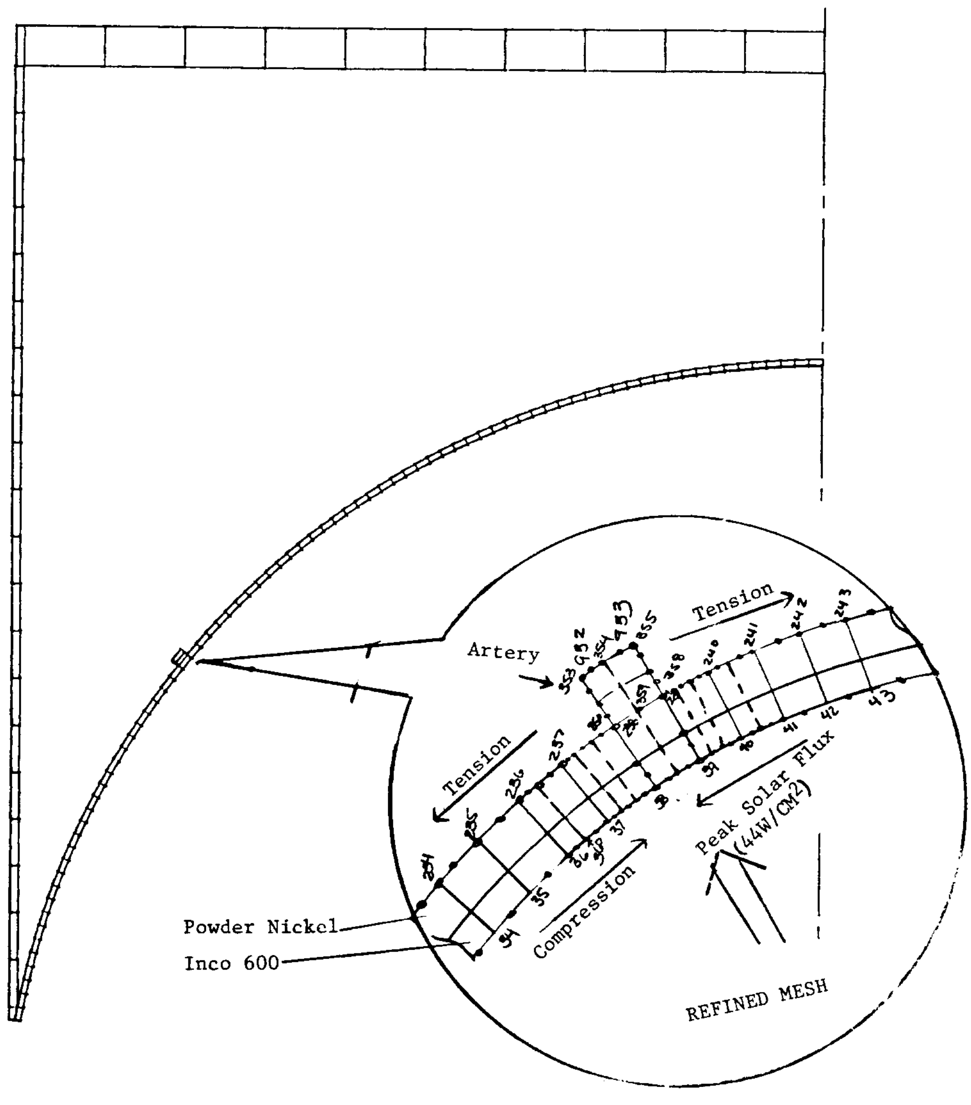
Thermacore's Sintered Powder Metal Wick Configuration



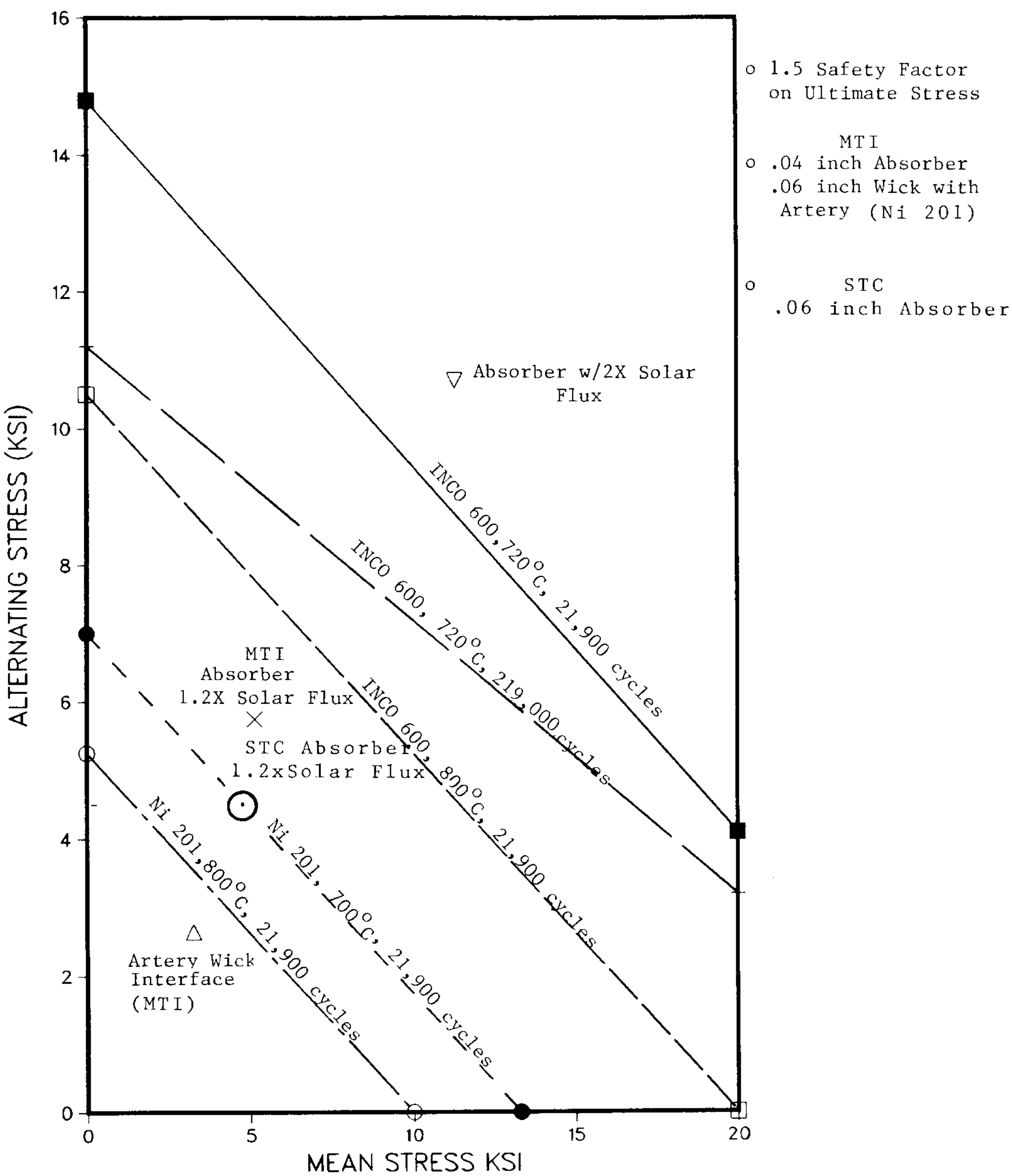
HEAT FLUX PERFORMANCE USING SODIUM



FINITE ELEMENT STRESS ANALYSIS OF ABSORBER/EVAPORATOR



FATIGUE STRESS ALLOWABLES BY THE METHOD OF UNIVERSAL SLOPES



Conclusion on Stress and Fatigue Life

- Absorber fatigue life is sufficient (> 1.5 safety factor)
  - 20,000 cycle
  - 20 years
  - 1.2 solar flux safety factor
  - no stress concentration factors
  - sharp thermal gradients do not introduce extreme stresses

- Fatigue/creep effects on wick should not affect operation
  - long term integrity should be verified experimentally due to combined corrosion/plastic effects

Sanders
A Lockheed Company

Starting Requirements and Issues

PDR Issue: Start up from frozen sodium state

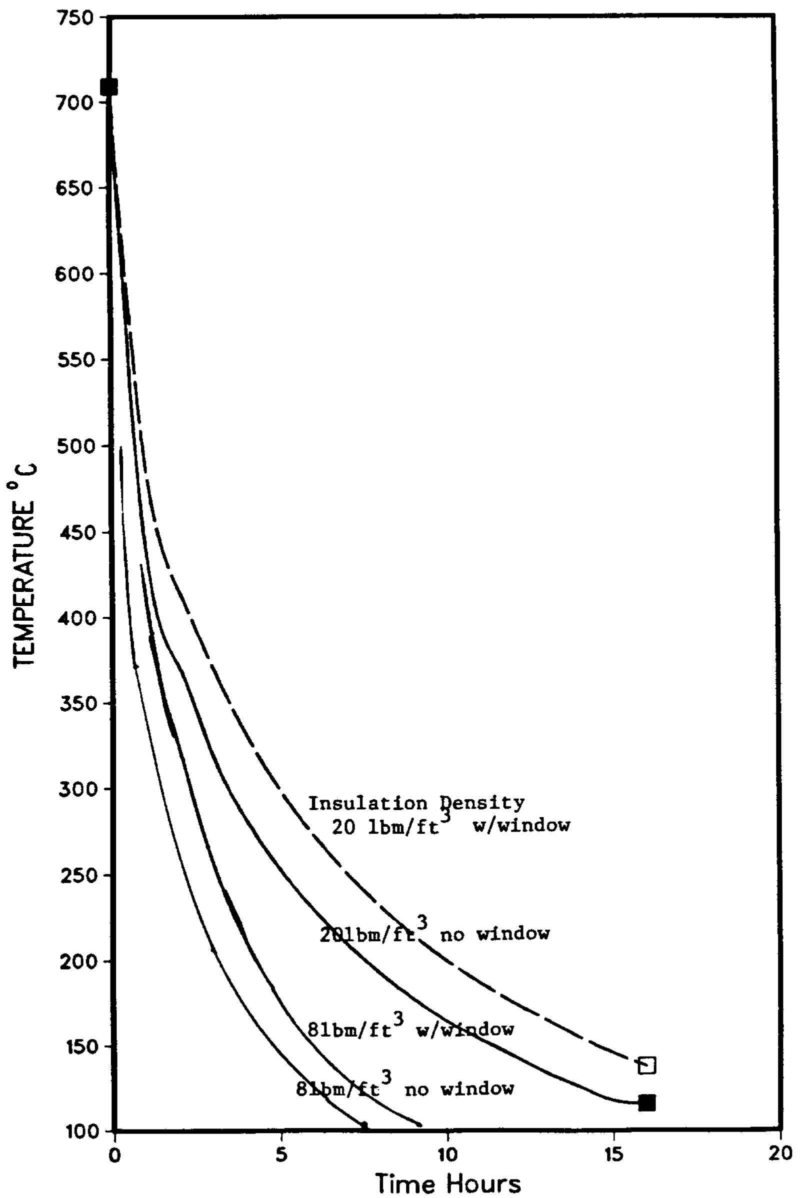
- Expansion in arteries and reservoir inducing stresses
- local dryout in wick

Solution:

- Preheat receiver with electric heater
  - without a window or shutter it will freeze daily
  - with a window it is possible to reduce the need for auxiliary heating
- Low solar power operation
  - evacuated membrane concentrators are controllable
- Hybrid fuel fired operation

Sanders
A Lockheed Company

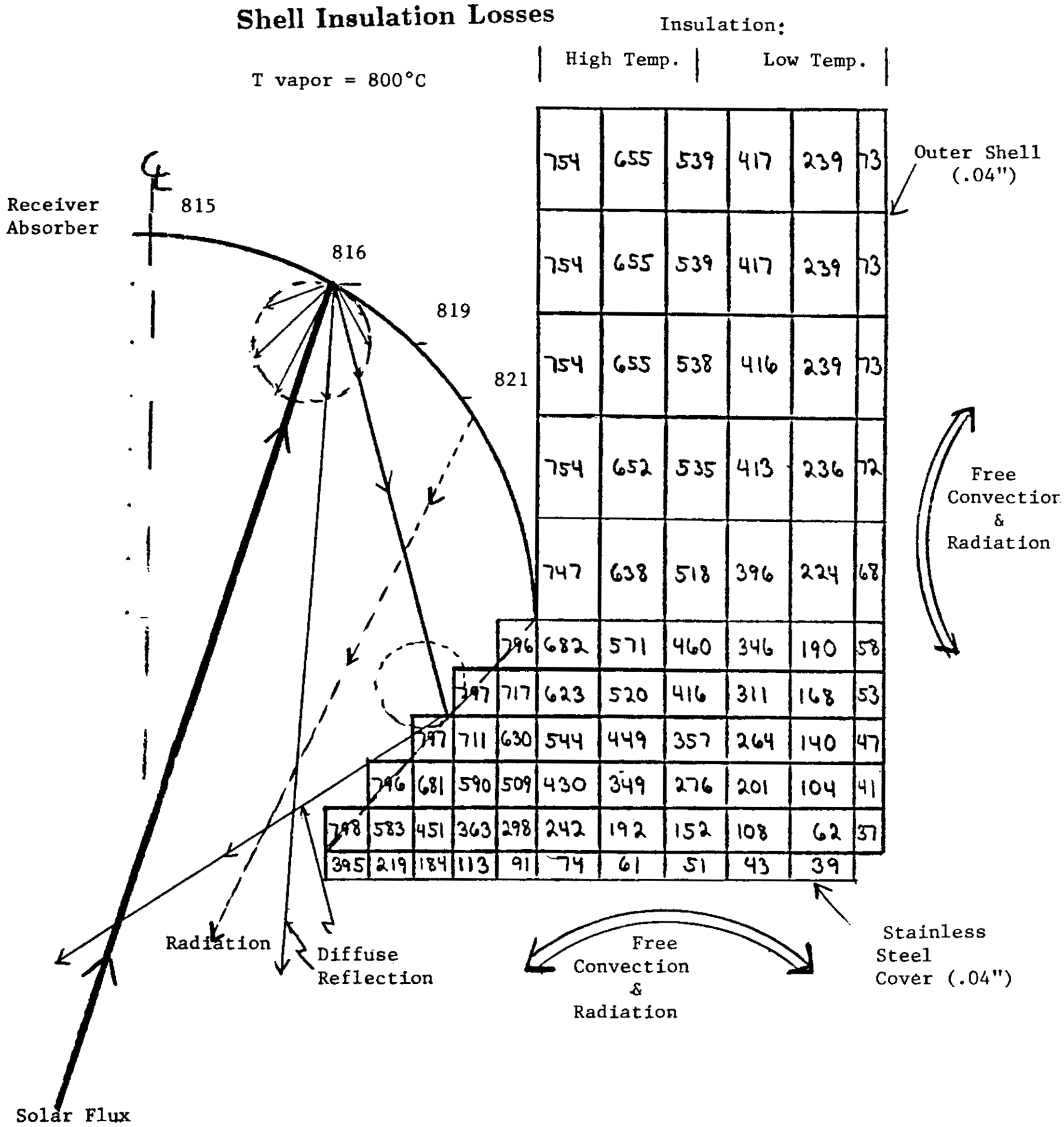
Transient Cool Down Rate of MTI Receiver



STC Potassium Reservoir Can Definitely Be Kept Molten Through The Night

Receiver Thermal Analysis

Cavity Radiation, Reflection, and Shell Insulation Losses



Temperatures in °C
Not to scale
Example for 6 inches of insulation

RECEIVER ENERGY LOSS MECHANISMS

	Percent of 75KW Thermal Input	
	STC	MTI
Shell Insulation	1.	1
Cavity Reradiation	2.6	2.5
Dish Shadeing	0.7	0.7
Transient Start-up*	2.	0.7
Diffuse Cavity Reflection	3.0	2.3
Cavity Convection		
- Horizontal	(?)	(?)
- Vertical	1	1
Net Receiver Efficiency (Vertical)	89.7	91.8

Assumed Conditions:

- T_{∞} =25°C
- T Vapor=700°C
- Total Solar Energy input on 950w/m^2 day =2.1x10^{5}KJ
- 6" insulation

Measurement of the Temperature Distribution in Solar Cavity Receivers by Scanning Radiometer

E. F. Thacher
Mechanical and Industrial Engineering Department
Clarkson University, Potsdam, NY 13676

A scanning infrared radiometer encodes the radiosity distribution on a receiver cavity's surface in a standard commercial television signal. This signal, when digitized and combined with knowledge of the geometry and emissivity of the cavity's surface, can be used to establish the temperature distribution in the cavity.

Two right circular cylindrical cavites were constructed of stainless steel and instrumented with thermocouples. The cavities were heated by a combination of a solar simulator and cartridge heaters and viewed by a scanning radiometer. One cavity was coated with a high emissivity paint and the other with a low emissivity paint. The error in the temperature measurement was expected to be smallest at high temperatures and high emissivities and largest at low emissivities and low temperatures.

Scanning radiometers operate in wavelength bands which span transmission "windows" in the atmosphere. The instrument used in this investigation operates in the 8 - 12 micron band. The emissivity of the two paints in this band was measured with the radiometer as a function of temperature and polar angle.

A computer program was developed to calculate the temperature distribution in a cavity from the radiometer's signal. The program discretizes the cavity's surface and uses the diffuse-gray model to find the irradiance distribution in the cavity.

Two other issues were also addressed experimentally and analytically. These were: (1) solving for the temperature distribution when only a portion of the cavity's surface is visible to the radiometer; (2) compensating for the system transfer function (STF). The STF contributes to the measurement error when a gradient in the radiosity distribution is present. It was shown experimentally that this contribution can be large and increases as the gradient increases.

INFRARED RADIOMETER CHARACTERISTICS

> TYPE: INFRAMETRICS 525L

> 8 - 12 MICRON BAND

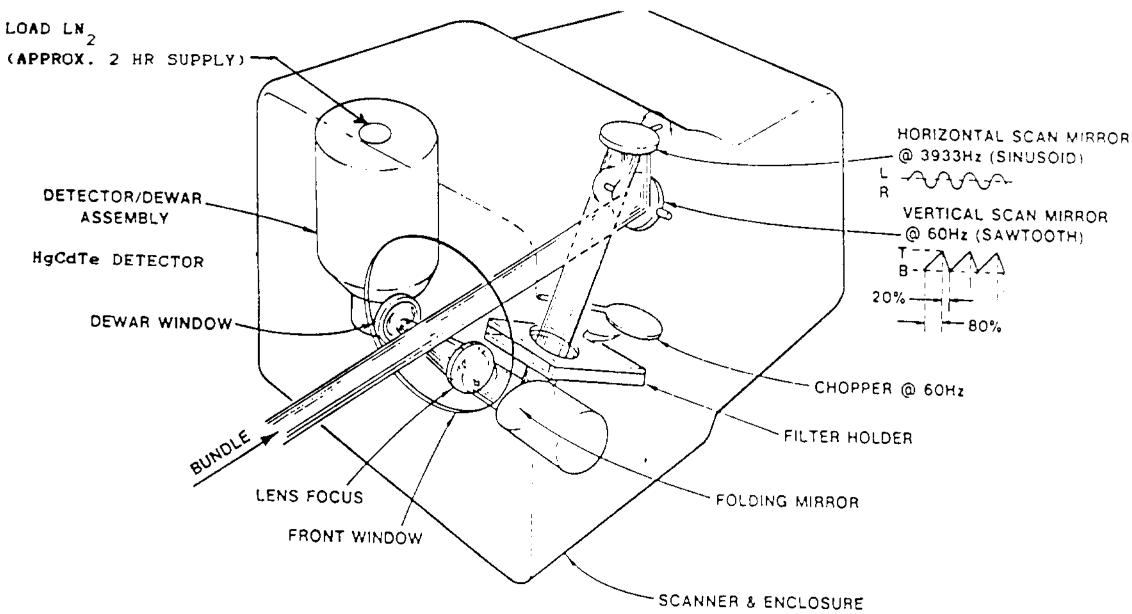
> 2 MR X 2 MR IFOV SCANS 14° X 18° FOV (4:1 ZOOM)

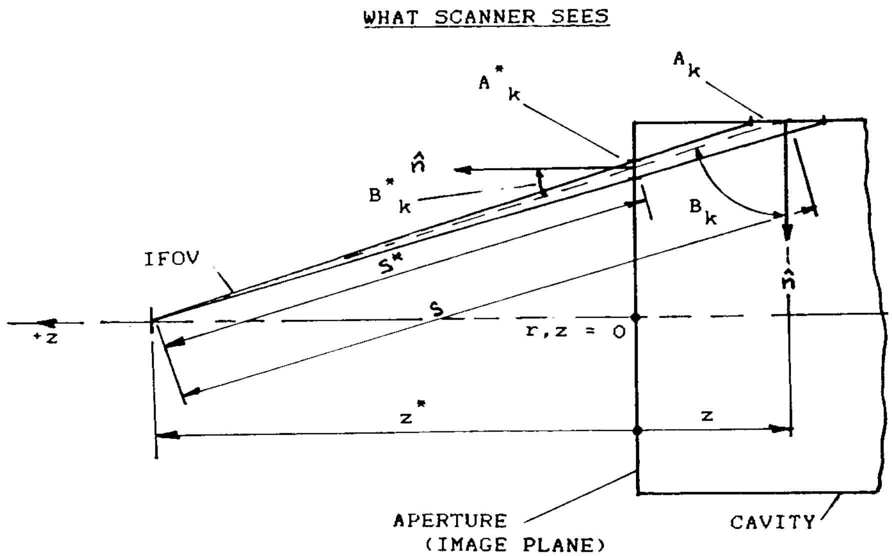
> C & E UNIT PRODUCES RS170 VIDEO

> SIGNAL PROPORTIONAL TO RADIOSITY

> TO 1300°C WITH FILTERS

> TELESCOPIC OPTICS AVAILABLE





$$IFOV \simeq (A^*_k \cos B^*_k / S^{*2}) = (A_k \cos B_k / S^2)$$

$$A_k = A^*_k (\cos B^*_k / \cos B_k)(S_k / S^*_k)^2$$

> SIMILAR FOR EACH PIXEL IN THE CAVITY IMAGE

> B^*_k, S^*_k, A^*_k FROM IMAGE PLANE DATA

> B_k, S_k FROM IMAGE PLANE DATA & CAVITY SURFACE EQUATION

WHAT SCANNER MEASURES

$$J_k = e_k E_{bk} + (1 - e_k) G_k$$

WHERE J_k = BAND-DIRECTIONAL RADIOSITY
e_k = BAND-DIRECTIONAL EMISSIVITY
E_{bk} = BAND BLACK BODY EMISSIVE POWER
G_k = BAND-DIRECTIONAL IRRADIANCE

T_k, THE TEMPERATURE AT A PIXEL LOCATION

$$E_{bk} = [J_k - (1 - e_k) G_k)] / e_k$$

$$T_k = P_c^{-1} (E_{bk})$$

WHERE P_c IS THE SCANNER'S CALIBRATION POLYNOMIAL

IRRADIANCE FROM DIFFUSE-GRAY APPROXIMATION

$$J_i = (1/A_i) \sum_{k \text{ on } i} A_k J_k$$

WHERE J_i = AVERAGE RADIOSITY ON ELEMENT i
A_i = AREA OF ELEMENT i

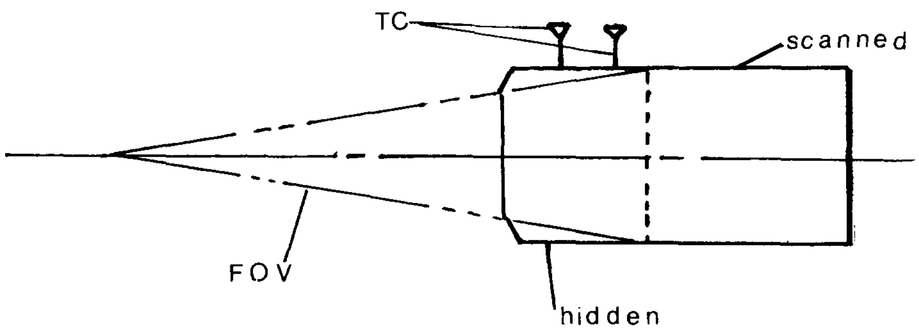
AND

$$G_i = \sum_{j=1} F_{ij} J_j$$

WHERE F_{ij} = VIEW FACTOR FROM i TO j
J_j = AVERAGE RADIOSITY ON ELEMENT j

> NEGLECT ATMOSPHERIC ABSORBTION

HIDDEN SURFACES



> E_{bi} ON HIDDEN SURFACE ELEMENTS KNOWN FROM FEW T/C BY INTERPOLATION

> J_i ON SCANNED SURFACE ELEMENTS KNOWN

>> ACTUAL RADIOSITIES FROM HIDDEN SURFACE ELEMENTS "FOLDED" INTO SCANNED RADIOSITIES

SOLUTION

$$\{ x \} = [A]^{-1} \{ b \}$$

WHERE { x } = COLUMN VECTOR OF UNKNOWN J_i'S AND E_{bi}'S

[A] = MATRIX OF WEIGHTED F_{ij}'S

{ b } = COLUMN VECTOR, ELEMENTS ARE LINEAR COMBINATIONS OF KNOWN E_{bi}'S, J_i'S, AND F_{ij}'S

> SUBSEQUENT FINER DISCRETIZATIONS CAN USE RADIOSITIES FROM PREVIOUS COARSER SOLUTIONS, TENDING TO "UNFOLD" SOLUTION

> MEASURED TEMPERATURES CAN BE USED TO CHECK CONVERGENCE

TEST PLAN

> MEASURE EMISSIVITY OF PAINTS

>> THURMALOX 270 (HIGH e)

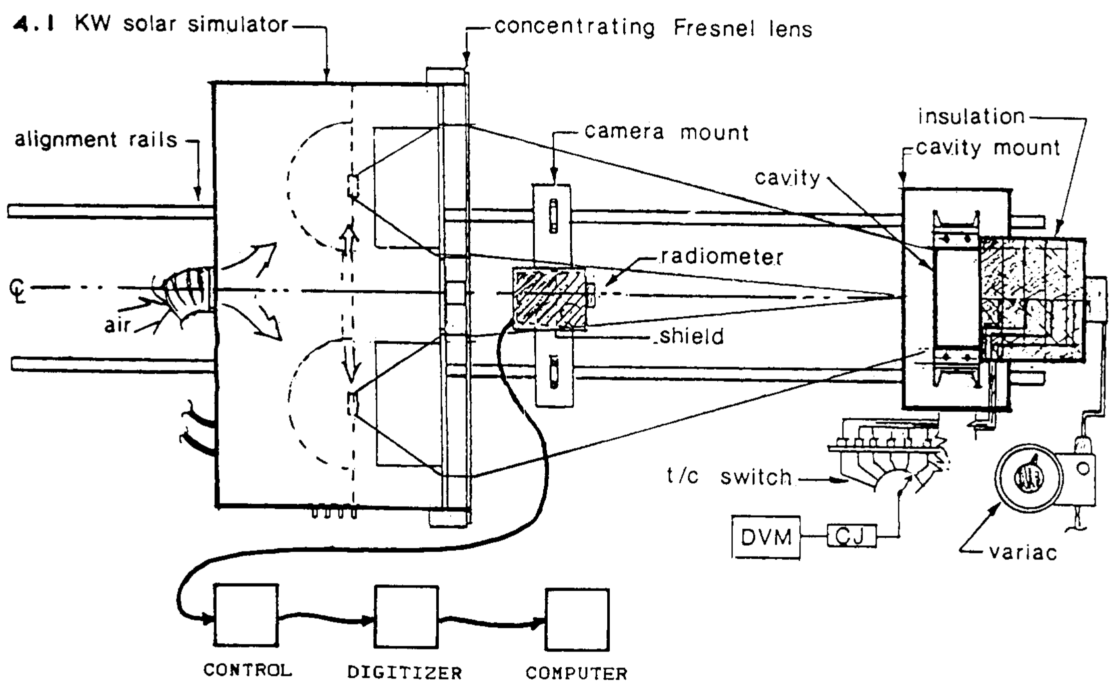
>> SOLKOTE HI/SORB II (LOW e)

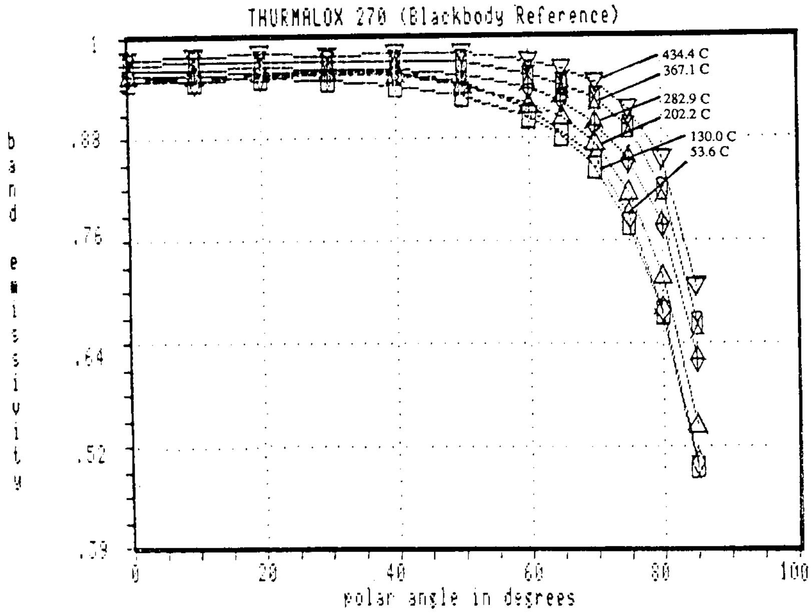
> TEST AT LOW e & T (WORST CASE) AND AT HIGH e & T (BEST CASE)

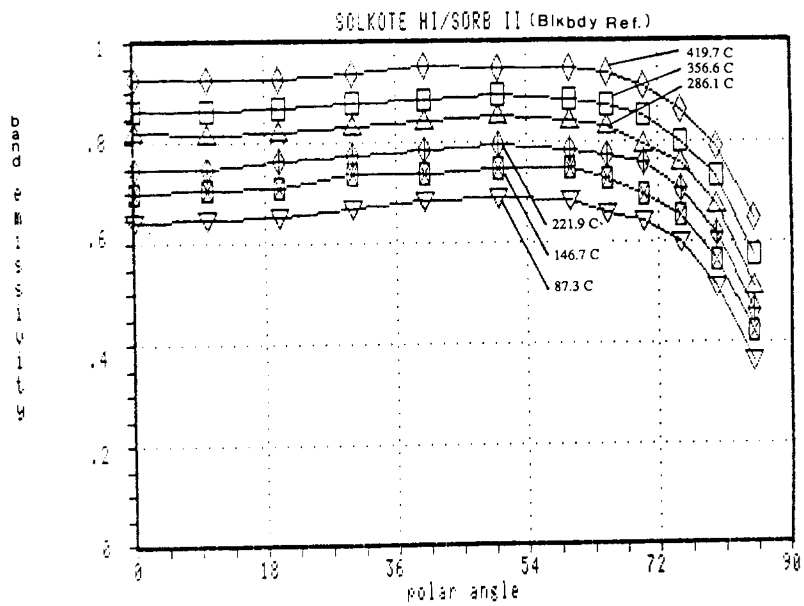
>> FULL VIEW OF CAVITY

>> HIDDEN SURFACES (HIGH e & T, ONLY)

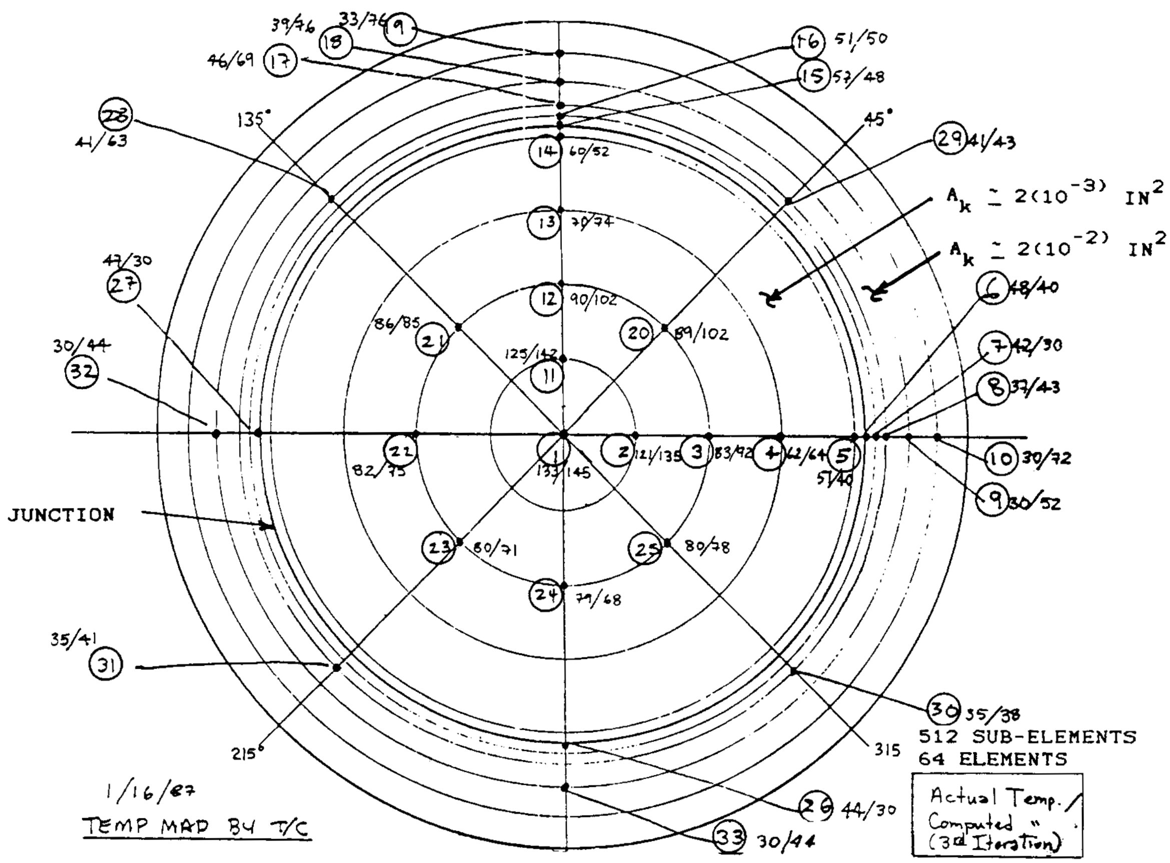
PLAN VIEW OF EXPERIMENTAL APPARATUS SETUP




THURMALOX 270 (Blackbody Reference)
434.4 C
367.1 C
282.9 C
202.2 C
130.0 C
53.6 C
band emissivity
polar angle in degrees


SOLKOTE HI/SORB II (Blkbdy Ref.)
419.7 C
356.6 C
286.1 C
221.9 C
146.7 C
87.3 C
band emissivity
polar angle

FIRST LOW e & T RESULT



SOURCES OF ERROR

> LOW J_k AT LARGE B_k (WALLS OF CAVITY)

>> USE B-AVERAGED e(T) TO FIND J_k FOR G_i

> ASYMMETRY

>> INTERPOLATE G

> SYSTEM TRANSFER FUNCTION

>> COMPENSATE RAW IMAGE

> DISCRETIZATION TOO COARSE

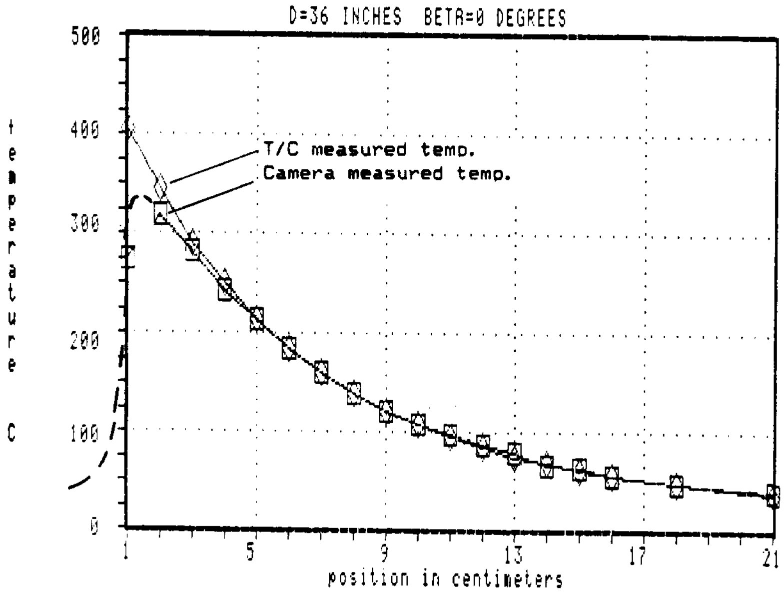
> e MEASUREMENT ERRORS

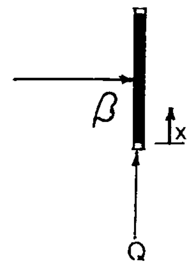
SYSTEM TRANSFER FUNCTION

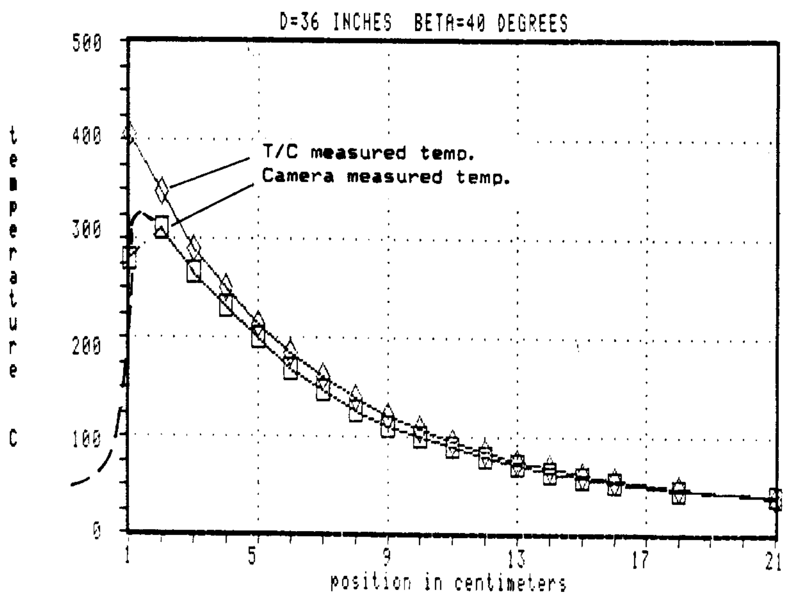
> RADIOSITY OUTPUT OF SYSTEM (RADIOMETER, DIGITIZER, COMPUTER) DIFFERS FROM ACTUAL RADIOSITY IN SPACE BECAUSE OF

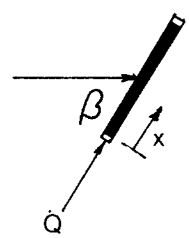
>> OPTICAL TRANSFER FUNCTION OF SCANNER OPTICS
>> CIRCUIT RESPONSE

SCANNER RESPONSE TO HEATED FIN









Point-Focus Concentrating Collector Technology Development

by

Thomas R. Mancini
Division 6227
Sandia National Laboratories
Albuquerque, New Mexico 87185

This presentation sets the background for the following four by defining the rationale behind the Point-Focus Development Project at Sandia National Laboratories. The emphasis which is placed on reducing the weight (cost) of the concentrating collector while, at the same time, maintaining high levels of performance is discussed. The importance of the sheet metal and stretched membrane concentrator projects and the sol-gel glass, stainless steel mirror development to the Point-Focus Development Project is described. Last, the status of the DOE Innovative Concentrator Project is presented.

August 26, 1987

POINT-FOCUS COLLECTOR TECHNOLOGY DEVELOPMENT

MEASURE OF COLLECTOR PERFORMANCE

The "best" performance measure for a solar collector is the annualized cost per unit of energy delivered, the Levelized Energy Cost (LEC).

$$LEC = \frac{\$}{kWT\text{-}HR}$$

COSTS: Capital plus Operation and Maintenance

ENERGY DELIVERED: Performance or efficiency of the system

ISSUES: Annualization of cost and performance
Absolute costs
Known -- peak performance
May perform comparative cost

TRM 8/26/87

POINT-FOCUS COLLECTOR TECHNOLOGY DEVELOPMENT

STATE-OF-THE-ART

The current state-of-the-art for point-focus (dish) collectors is represented by facetted, glass/metal technology. These solar collectors are characterized by highly accurate optics provided by rigid, relatively heavy support structures.

COLLECTOR	AREA SQ. M.	WEIGHT IN kG	PEAK EFFICIENCY
TEST BED	98.8	16,000	0.87
VANGUARD	88.7	10,430	0.83
McDONNELL	91.0	-----	0.88

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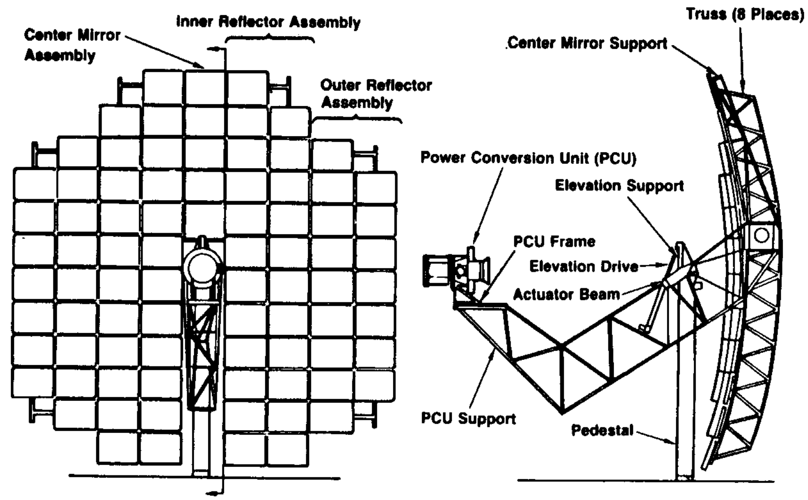
POINT-FOCUS COLLECTOR TECHNOLOGY DEVELOPMENT

THE McDONNELL DOUGLAS GLASS/METAL COLLECTOR



Front View

Section

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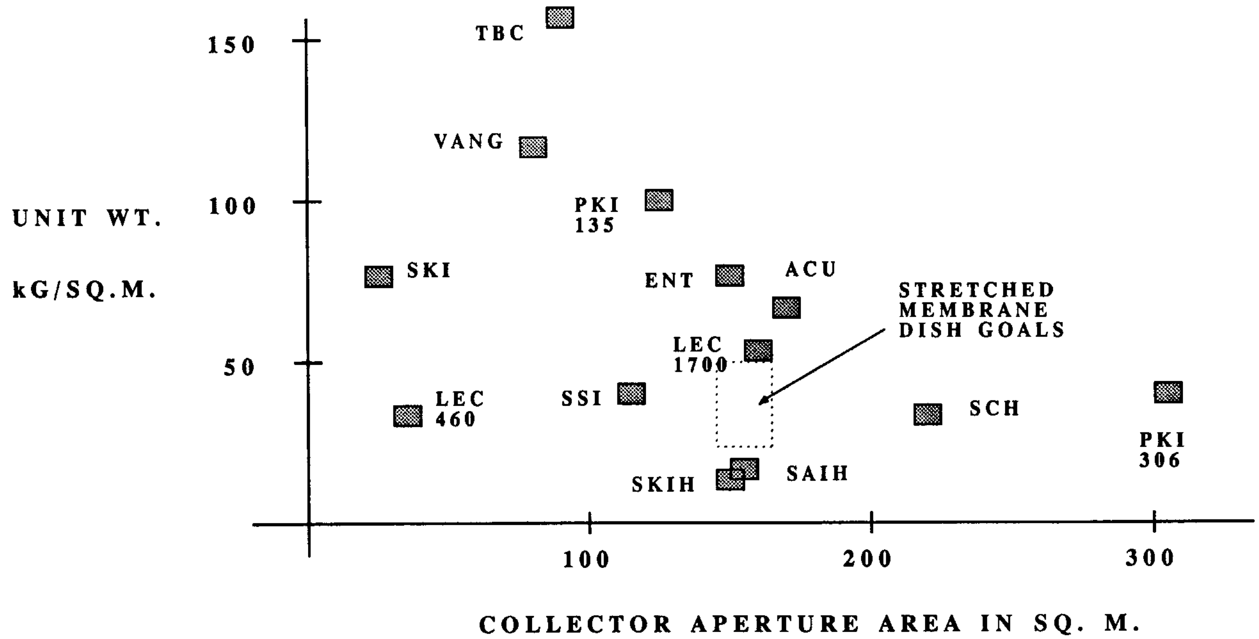
POINT-FOCUS COLLECTOR TECHNOLOGY DEVELOPMENT

COLLECTOR WEIGHT PER UNIT AREA VS. GROSS COLLECTOR APERTURE AREA



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POINT-FOCUS COLLECTOR TECHNOLOGY DEVELOPMENT

MAINTAIN HIGH LEVELS OF COLLECTOR PERFORMANCE

REDUCE SOLAR COLLECTOR COSTS (UNIT WEIGHT)

COLLECTION TECHNOLOGY PRIORITIES

- Fabricate and test a structurally integrated, sheet metal collector.
- Pursue the development of stretched membrane, dish solar collectors.
- Continue the development of sol-gel glass, stainless steel reflective surfaces for both sheet metal and stretched membrane solar collectors.

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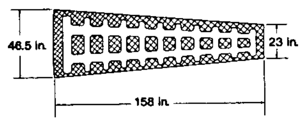
POINT-FOCUS COLLECTOR TECHNOLOGY DEVELOPMENT

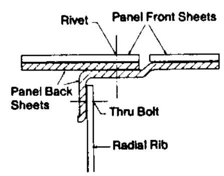
STRUCTURALLY INTEGRATED SHEET METAL COLLECTOR PANELS

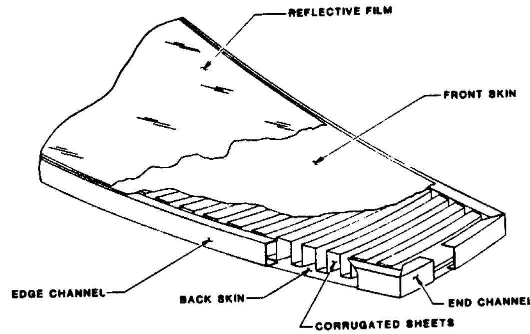
a. Outer Back Panel Detail



- Cross-hatched area is bonding surface
- Front/back sheet thickness = 0.030 in. each (nominal)

b. Inter-Panel and Rib Interfaces





ACUREX CORPORATION **SOLAR KINETICS, INC.**

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POINT-FOCUS COLLECTOR TECHNOLOGY DEVELOPMENT

STATUS
DOE INNOVATIVE CONCENTRATOR PROJECT

ACUREX CORPORATION INNOVATIVE CONCENTRATOR

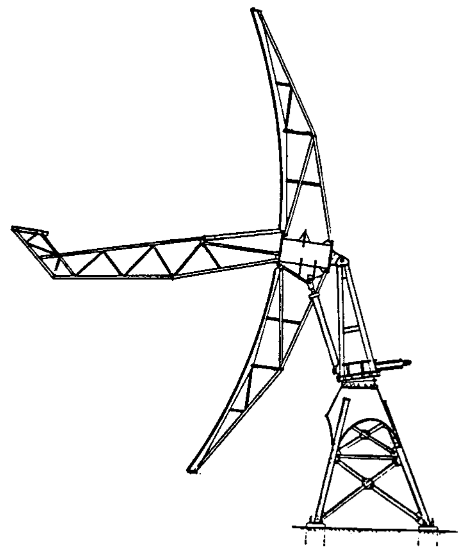
DEC 1986 -- Installed at DRTF

DEC 1986 -- Weld Failure

MAY 1987 -- Sandia will Fab.

AUG 1987 -- Pedestal RFQ

SEP 1987 -- Dish Repair Decision



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POINT-FOCUS COLLECTOR TECHNOLOGY DEVELOPMENT

STATUS
DOE INNOVATIVE CONCENTRATOR PROJECT

LAJET ENERGY COMPANY CONCENTRATOR

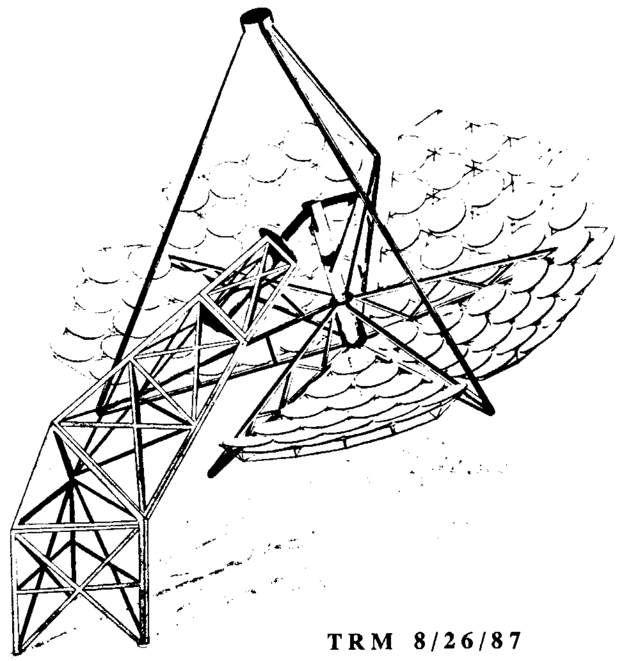
JAN 1987 -- Erect. at Abilene

FEB 1987 -- Test at Abilene

APR 1987 -- Design Mods.

JUL 1987 -- Ass. at DRTF

AUG 1987 -- Test at DRTF



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POINT-FOCUS COLLECTOR TECHNOLOGY DEVELOPMENT

OTHER DR COLLECTION TECHNOLOGY EFFORTS

COMPUTER CODE DEVELOPMENT: CIRCE

- Solar Concentrator Design/Analysis
- Design Trade-Off Studies
- Test Planning and Evaluation

STAINLESS STEEL MIRROR DEVELOPMENT

- Application to Sheet Metal Collector
- Application to Stretched Membrane Collectors and Heliostats
- Fabricated Mirrors on .025 and .005 mil Stainless Steel
- 0.91 to 0.94 Reflectivity at a 15 mr full cone measurement aperture

TRM 8/26/87

Stretched Membrane
Dish Development Project

Monte A. McGlaun

LaJet Energy Company
P. O. Box 3599
Abilene, Texas 79604

LaJet Energy has been investigating design options for very large stretched membrane concentrators under Sandia Contract 53-9663B. The Energy Control Products Group of 3M has been subcontracted to recommend and evaluate material systems.

A literature survey was conducted to locate mathematical modeling approaches, and a model was identified to predict the initial membrane position prior to pressurization. Additional models were developed using PC based finite element codes.

Initial material investigations were of Poly(ethylene terephthalate) (PET) laminates; however, these laminates are subject to severe creep in the adhesive interfaces. The most positive aspect of the PET investigations was the characterization of an ECP-300A to PET laminate that can serve as the primary reflective surface of the membrane.

Alternate material selections are in the composite family. The most realistic choices are E-glass fiber-matrix composites which are also the lowest cost and most attainable. There are several choices of matrix or resin systems; however, vinyl ester resins appear to be the best choice for ambient temperature curing. Mandrels for forming the desired membrane shape require a cost effective solution. Attempts are being made to form a male mandrel from low expansion tooling plaster by screeding the desired shape in plaster onto a reinforced wooden superstructure. Preliminary indications are that a satisfactory structural membrane can be developed and that a desired initial shape of the membrane can be formed with low cost tooling. Uncertainties in the use of composites are the accuracy of the mandrel, shrinkage control of the matrix, and print through of the fiber reinforcement pattern. A laser scanning video encoding system is being developed to assess the performance of the optical elements.

Lajet ENERGY COMPANY
3130 Antilley Road
P.O.box 3599
Abilene, Tx. 79604
(915) 698 - 8800

LAJET ENERGY STRETCHED MEMBRANE CONCENTRATOR PROJECT

LITERATURE SURVEY & MATHEMATICAL MODELING

From Literature:

Kydoniefs Model determines the unpressurized membrane shape as a function of the desired pressurized shape.
Kydoniefs Model Adapted into an APL code for Neo-Hookean materials nd Poissonian materials.

Finite Element Models (FEMs):
PC based IMAGES3D axisymmetric solid.
ANSYS verification (U of Nebraska), axisymmetric conical shell

The FEMs predict larger deflections than the Kydoniefs approach.
Both FEM show similar magnitudes of deflections.
All modeling approaches predict low stress levels that are well within the elastic range of PET's and composites.

Laurel(?) ENERGY COMPANY
3130 Antilley Road
P.O.box 3599
Abilene, Tx. 79604
(915) 698 – 8800

MATERIAL INVESTIGATIONS

ORIGINALLY PROPOSED OPTIONS:

Poly(ethylene terephthalate), PET Laminates were considered the best option initially.

Scotchply Composites were considered to be an expensive option due to requirements for high temperature curing (ie, autoclave).
High performance (used for nose cones of Trident class submarines).

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P.O.box 3599
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MATERIAL INVESTIGATIONS

FINDINGS OF INVESTIGATIONS OF POLY(ETHYLENE TEREPHTHALATE) LAMINATES

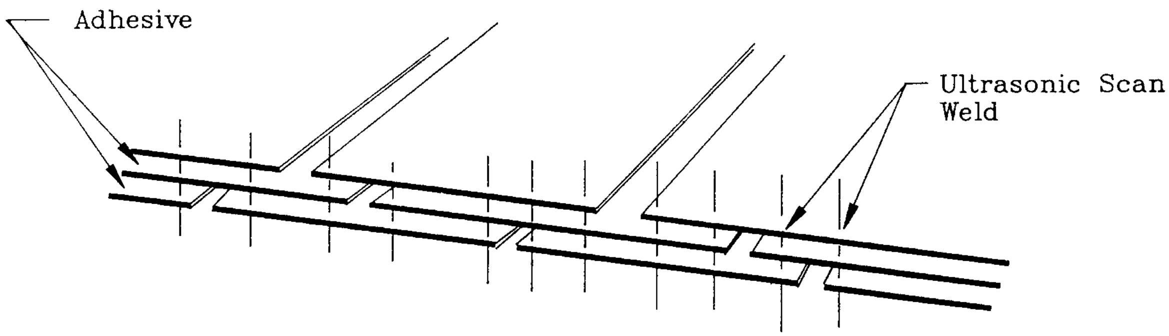
Requires adhesive interface between PET layers with mechanical attachment joints between gore pieces (mechanical attachments considered are fusion welding and high strength adhesives). PET's are highly anisotropic.

Acrylic adhesive interface between layers of PET display creep problems (the basic PET structures are reasonably stable against creep).

Reasons for Seeking Alternate Solutions to PET Laminates:

* Mechanical attachments distort the membrane surface,
* High strength adhesives are difficult to apply & fixture,
* Materials do not lend themselves to uniform stress distribution,
* Although stress levels are low, creep tendencies are unacceptable,
* Surface treatments of PET's are inconsistent for adhesive bonding.

SEAM FABRICATION



Objective: provide uniform strain through joint

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3130 Antilley Road
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MATERIAL INVESTIGATIONS
FINDINGS ON THE USE OF COMPOSITE MATERIALS

Fiber reinforcement options:

***Configurations available are chopped, plain weaves, basket weaves, woven rovings, harness satins, twills, lenos, unwoven continuous fibers**

***Materials available are E-glass, S-glass, graphite, aramid, boron, quartz, ceramic**

Matrix (resin) options:

***Polyester, vinyl ester, epoxy, phenolic, polyimide**

Initial choices:

***Vinyl ester matrix with E-glass - commonly available, ambient temperature lay-up, flexes without crazing, low cost compared to graphites and epoxies.**

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3130 Antilley Road
P.O.box 3599
Abilene, Tx. 79604
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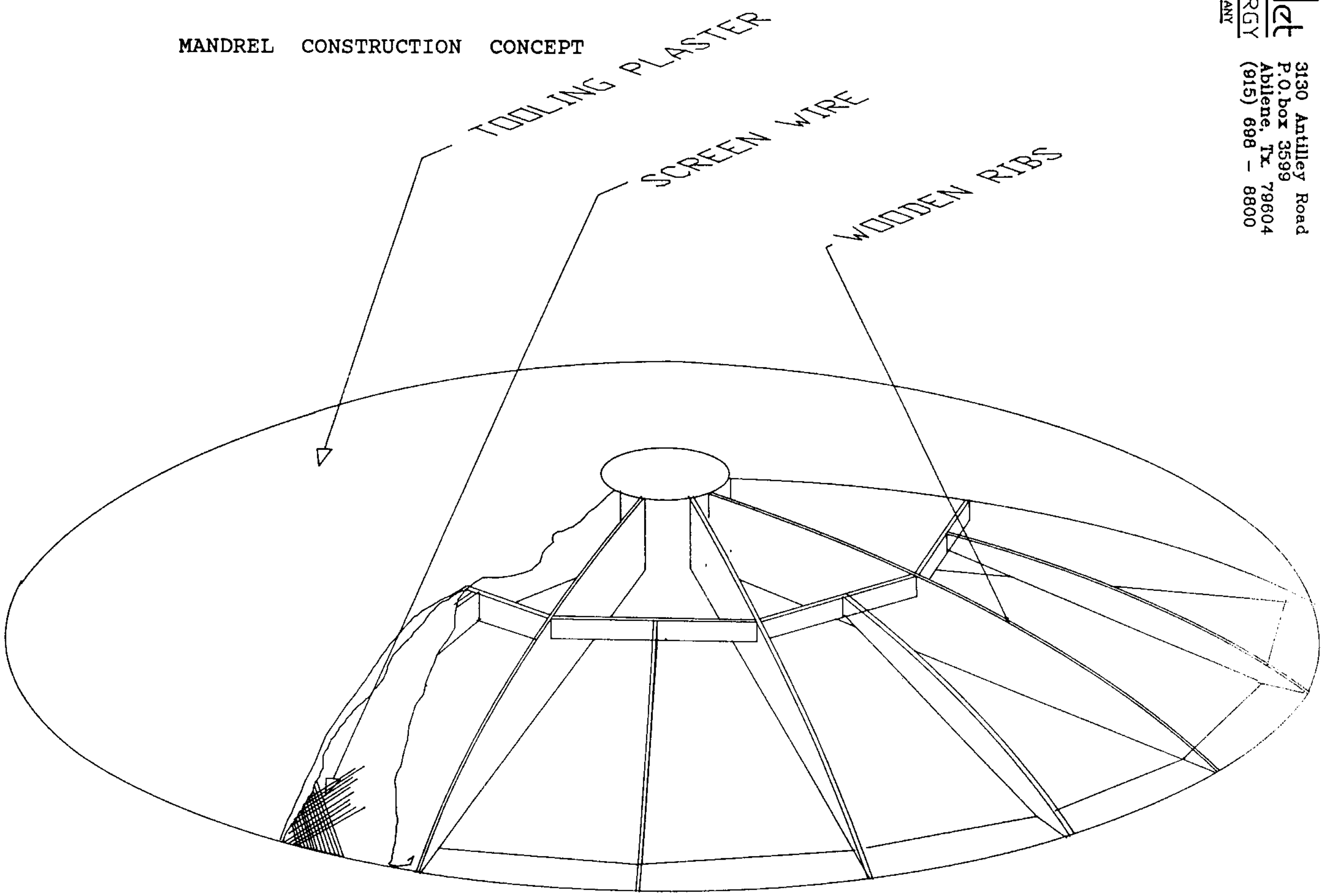
MANDREL CONSTRUCTION

Accurate lay-up surface required
Low expansion tooling plaster used over reinforced wood structure.
Proper curvature screeded into plaster during plastic state.
Conventional sealers used to condition finished surface.
Initial attempt with 5 foot diameter membrane.
Target diameter for Phase I prototype membrane was 20 feet,
but facilities limit diameter to 15 feet maximum.
Control of screed variations is a major concern.
Templates are used to gauge the surface accuracy of the mandrel.

MANDREL CONSTRUCTION CONCEPT



ENERGY COMPANY
3130 Antilley Road
P.O.box 3599
Abilene, Tx. 79604
(915) 698 - 8800

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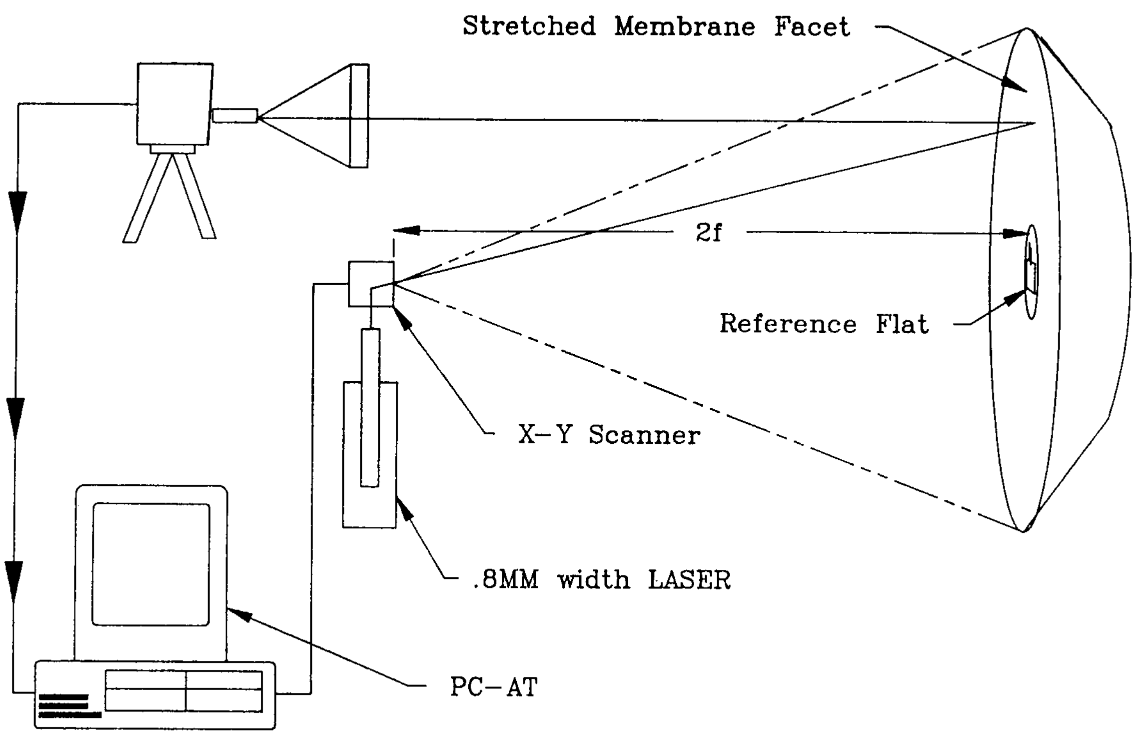
OPTICAL ELEMENT EVALUATION PROCEDURE

Laser ray tracing from the 2f position with 10 mw Helium Neon laser pointed by two axis servo driven scanner mirrors. Reflected rays are intercepted in the 2f plane with a translucent screen.

The position of the ray is digitized with a video imaging system. Algorithms are used to calculate slope error at the test point. Post analyzer routine predicts the location of the minimum circle of confusion.

STRETCHED MEMBRANE TESTING



STRETCHED-MEMBRANE DISH COLLECTOR DEVELOPMENT PROJECT PHASE ONE

Keith Armstrong

Solar Kinetics, Inc.
10635 King William Dr.
Dallas, TX 75220

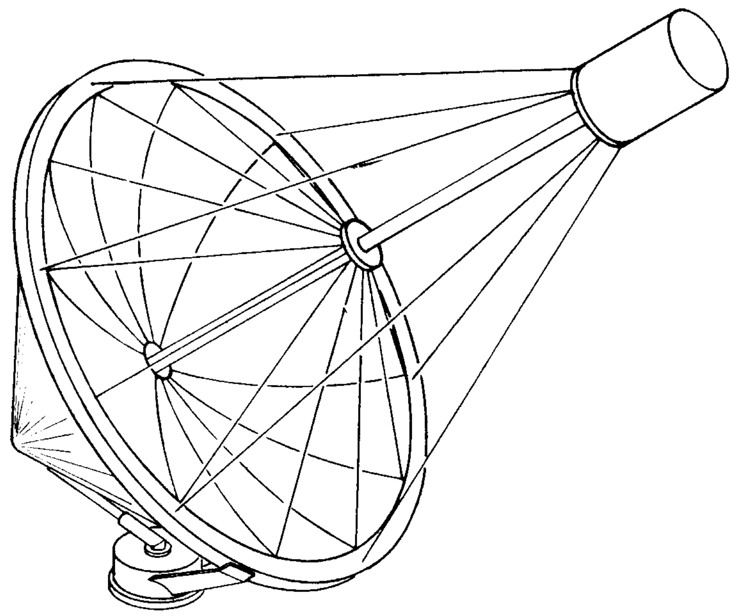
The purpose of the Stretched Membrane Dish (SMD) project is to apply membrane technology to the development of a point-focus dish solar concentrator. The potential benefits are significant reductions in collector weight and cost. The major concerns of Phase I have been with the membrane formation techniques, membrane material, and the size and f/D of the optical element.

In Phase I, SKI was allowed to consider an optical element comprised of between one and five facets. Analysis with Sandia's new optical code, CIRCE, has shown a single facet to be desirable from the standpoint of collector thermal efficiency. Conceptually, a single facet approach also enjoys an economy in structural mass. A single facet approach dictates an f/D between 0.6 and 0.8.

In SKI's previous experiences with stretched membrane collectors, large reductions in collector weight were possible due to the structural coupling between the membrane and supporting ring. Coupling exists at small f/D's. The f/D of the collector is predominant in determining the magnitude and nature of this coupling. When the preformed deflections are large, the coupling phenomenon is much less clearly understood. Most of the analysis on structural coupling has been done with finite element models.

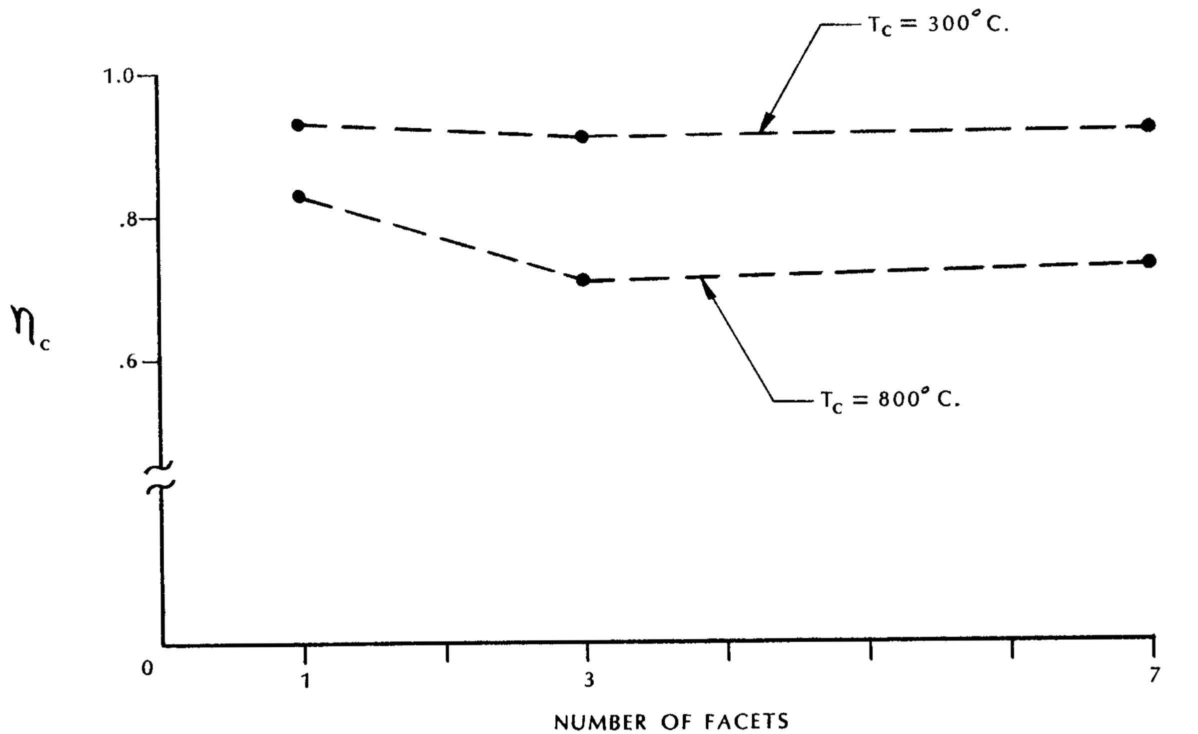
One of the major achievements of Phase I was the development of a forming process that resulted in desirable membrane contours. Under ideal conditions, the deformed shape under a uniform load is spherical. A spherical concentrator does not result in the required collector thermal efficiency. Under actual conditions, membranes deform under uniform body forces to a "canoe" shape as a result of diaphragm tension. Optically, this shape is too flat in the middle and too steep near the edges. A process has been developed for modifying the formed shape to approximate a parabola. The result is concentrators with potential collector efficiencies equal to the more conventional approaches.

STRETCHED MEMBRANE DISH COLLECTOR DEVELOPMENT PROJECT PHASE ONE



SOLAR KINETICS INC.

COLLECTOR EFFICIENCY VS.
NUMBER OF FACETS



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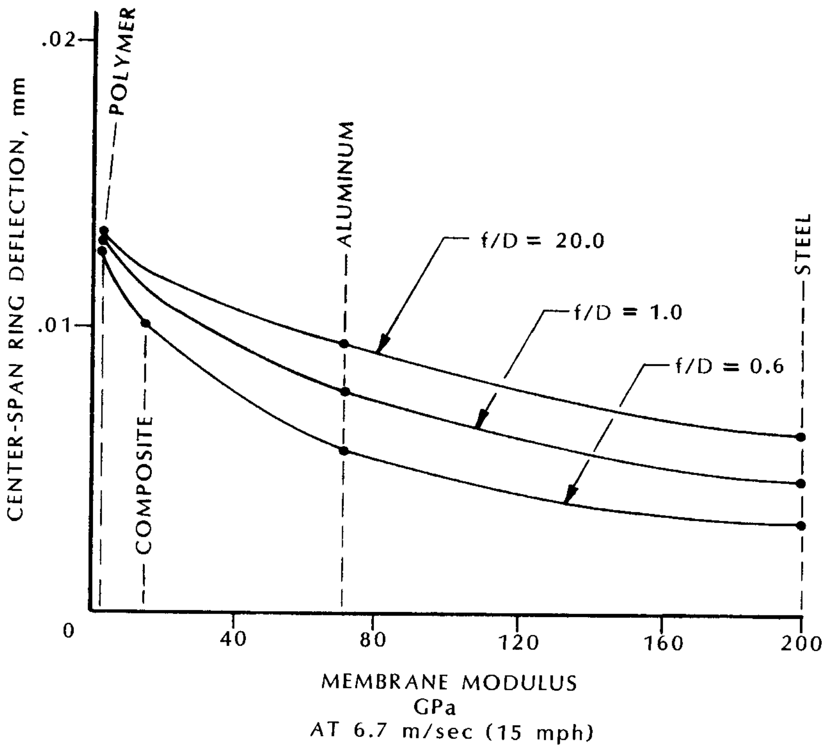
CENTER-SPAN RING DEFLECTION VS. MEMBRANE MODULUS



BASE LINE

RING PROPERTIES

RING DIAMETER, R = .686 m
CROSS-SECTIONAL AREA = 2.032 E-4 m^2
MATERIAL
MODULUS OF ELASTICITY, E = 200GPa
POISSONS RATIO, ν = 0.3
MODULUS OF RIGIDITY, G = 77GPa

MEMBRANE PROPERTIES

THICKNESS, t = .2mm (.007")
POISSONS RATIO, ν = 0.3
MATERIAL

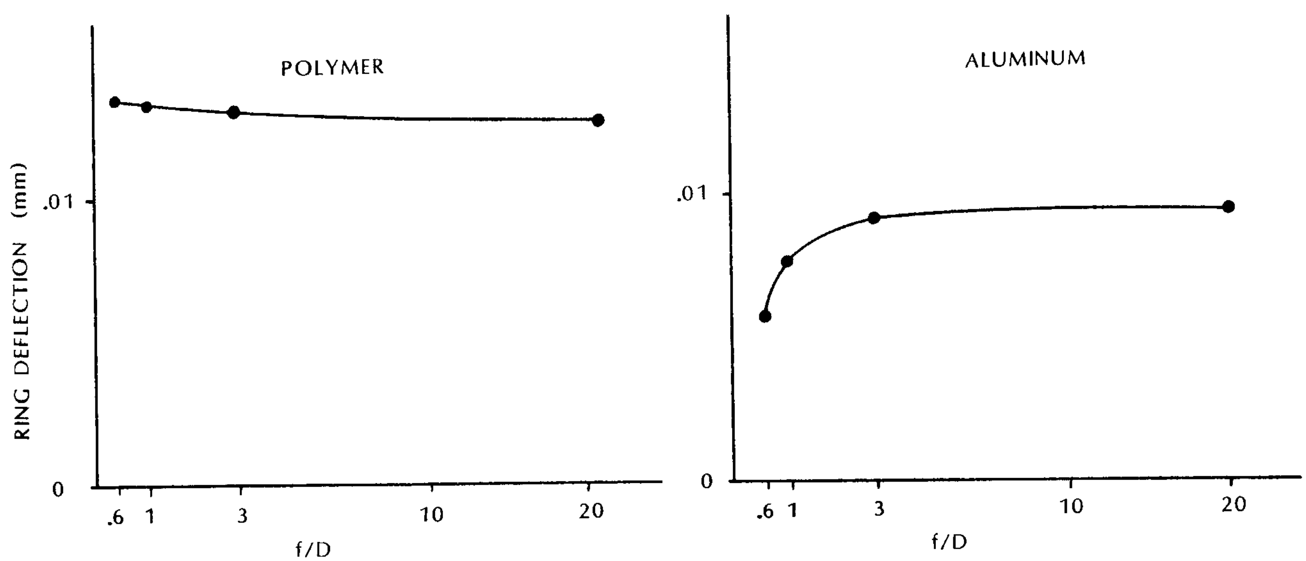
	MODULUS OF ELASTICITY
STEEL	200GPa
ALUMINUM	71GPa
COMPOSITE	15.6GPa
POLYMER	3.4GPa

LOAD

PRESSURE EQUIVALENT OF 22m/s WIND (50 mph)

SOLAR KINETICS INC.

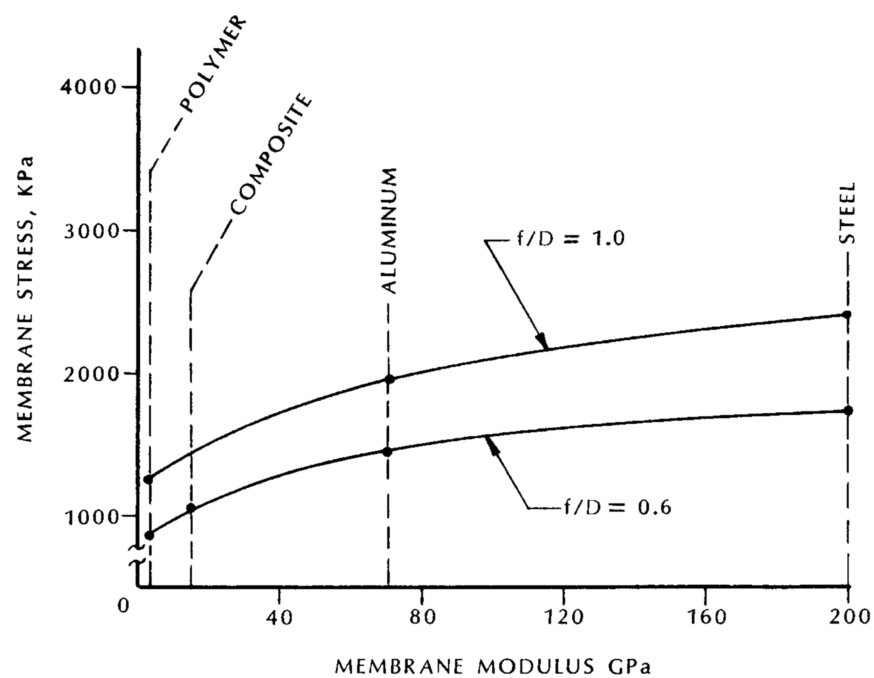
MAXIMUM RING DEFLECTION vs f/D



BASE LINE AT 6.7 m/s (15mph) WIND

SOLAR KINETICS INC.

MEMBRANE STRESS AFTER FORMING VS. MEMBRANE MODULUS



BASELINE CONDITIONS

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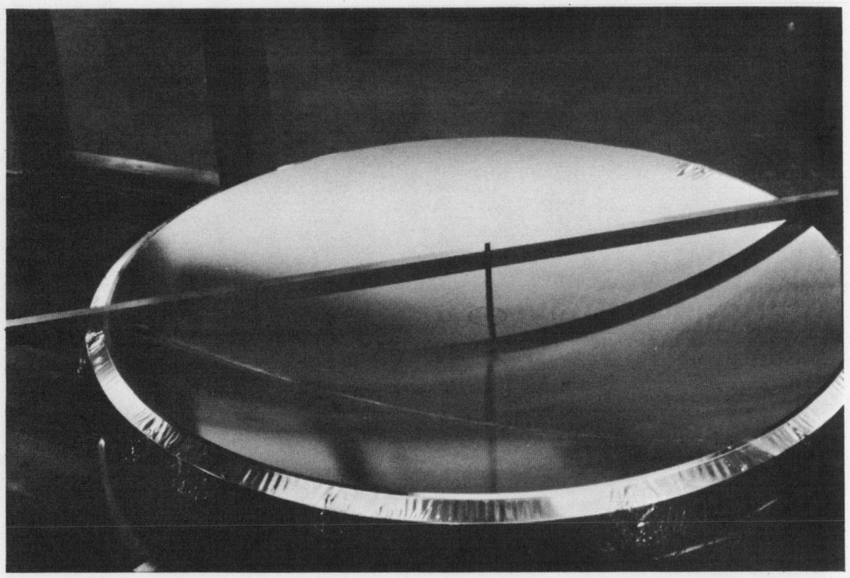
FREE-FORMED MEMBRANE



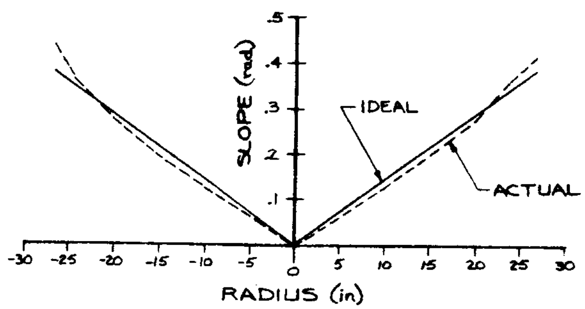
54 INCH DIAMETER

f/D = 0.6

ALUMINUM MEMBRANE

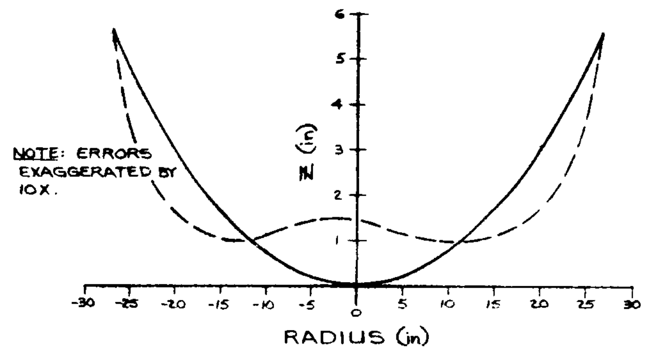
SOLAR KINETICS INC.

IDEAL VS. ACTUAL SLOPE

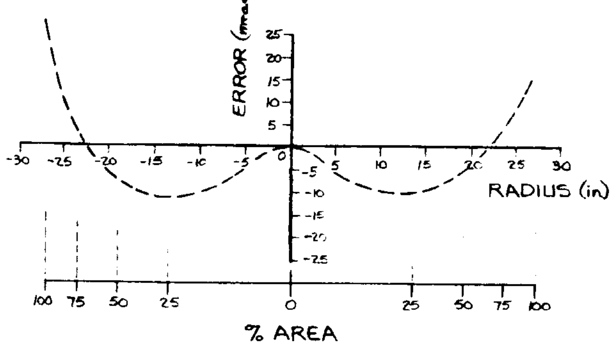


NOTE: ERRORS EXAGGERATED BY 10X.

IDEAL VS. ACTUAL PARABOLA



ACTUAL SLOPE ERROR



MEMBRANE #6

MATERIAL: 1145-O ALUM., 2 mil

ATTACHMENT: SOFT

BLADDER PRESSURE:

DURING FORMING - 82" H_2O

DURING STABILIZATION - 0" H_2O

f/D = 0.597

STABILIZATION PRESSURE: 1.25" H_2O

AXIS OF SCAN: Y

DATE: 5-5-87

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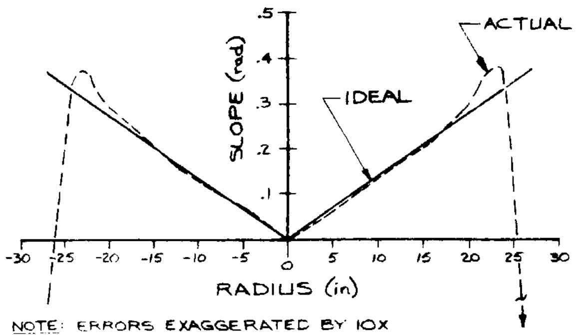
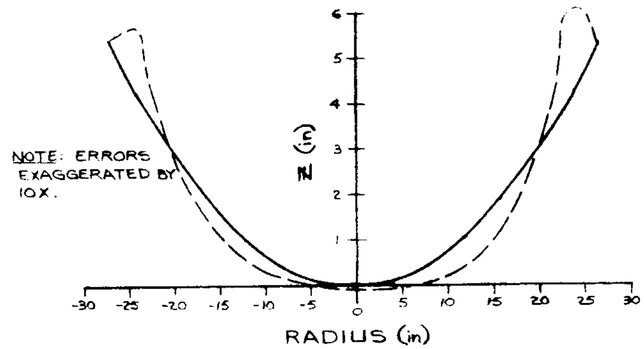
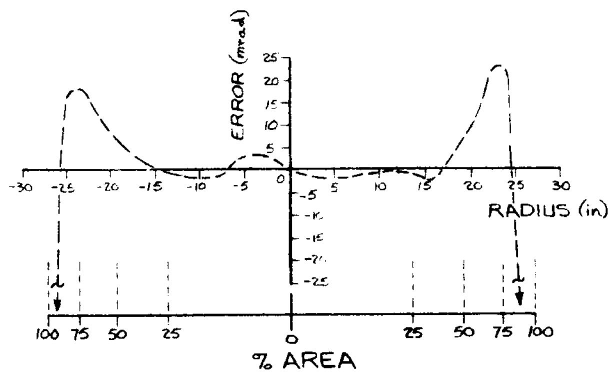
IDEAL VS. ACTUAL SLOPE



IDEAL VS. ACTUAL PARABOLA



ACTUAL SLOPE ERROR



MEMBRANE #6

MATERIAL: 1145-O ALUM., 2 mil

ATTACHMENT: SOFT

BLADDER PRESSURE:

DURING FORMING - 82" H_2O

DURING STABILIZATION - 82" H_2O

f/D = 0.627

STABILIZATION PRESSURE: 1.25" H_2O

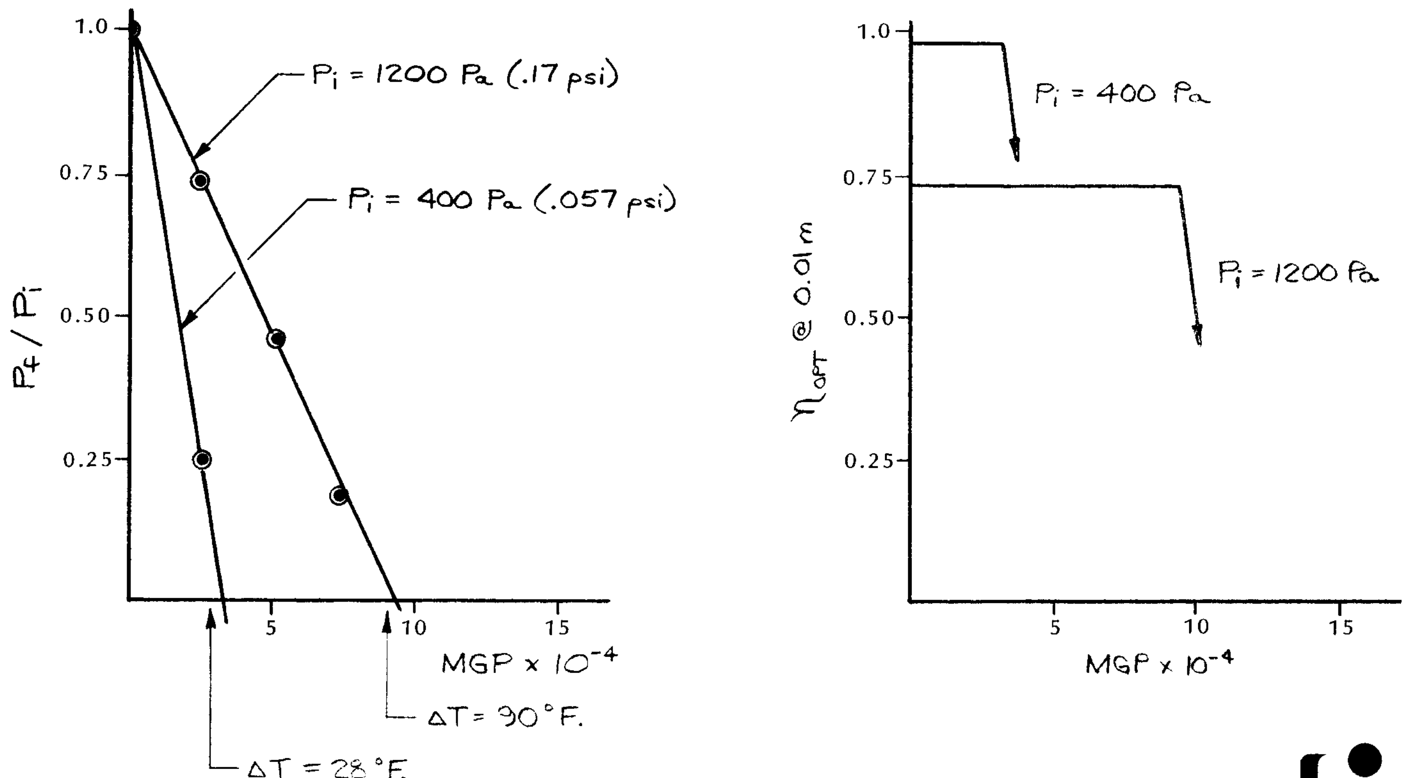
AXIS OF SCAN: Y

DATE: 5-5-87

SOLAR KINETICS INC.

"MEMBRANE GROWTH PARAMETER"

CONTROL SYSTEM KEEPS MEMBRANE POSITION CONSTANT
VARIES PRESSURE



SOLAR KINETICS INC.

MEMBRANE MODEL RESULTS

- MEMBRANE GROWTH PARAMETER (MISMATCH IN EXPANSION COEFFICIENTS, HUMIDITY COEFFICIENTS, OR CREEP) IS A CRITICAL PERFORMANCE ISSUE
  - HARD ATTACHMENT OF METAL RING/POLYMER MEMBRANE IS UNACCEPTABLE
  - POLYMER CREEP WILL SUBSTANTIALLY DEGRADE COLLECTOR OPTICAL EFFICIENCY
  - POLYMER CREEP OR THERMAL/HYGROSCOPIC MISMATCH WILL REQUIRE HIGH INITIAL OPERATING PRESSURES
- PARABOLIC INITIAL SHAPE IS ADEQUATE FOR LOW AND MODERATE OPERATING PRESSURES

SOLAR KINETICS INC.

CIRCE: A Computer Code for the Analysis of Point-Focus Solar Concentrators[*]

A. C. Ratzel

Sandia National Laboratories
Albuquerque, New Mexico

In this presentation a computer simulation code called **CIRCE** is discussed and examples of its application to several point-focus concentrating collector geometries are provided. **CIRCE**, an acronym for Convolution of Incident Radiation with Concentrator Errors, was developed from **HELIOS**, a large multi purpose cone optics computer code for the analysis of central solar receiver systems. **CIRCE** was developed with the objective of providing knowledgeable users with an easily used design tool which does not require a large investment of time to obtain results. In **CIRCE**, the concentrator errors are convolved with the solar intensity profile (sunshape) to produce the flux-density distribution on a specified target plane. **CIRCE** may be used to analyze reflectors that are spherical, parabolic, or flat and that are either continuous surfaces or faceted. The current version of the code is restricted to the analysis of reflector systems which have flat rectangular or circular targets; work is underway to allow for modeling axisymmetric cavity receiver geometries.

The important features of **CIRCE** are included in this presentation as are several examples of its use for the optical performance calculations for both faceted and continuous parabolic reflector systems. In particular, the sensitivity of the optical efficiency to concentrator errors and to sunshapes (which are a function of the solar intensity level) is investigated for circular targets centered in the concentrator focal plane. Results for a three facet concentrator are also presented and compared with those for an equivalent area continuous parabolic dish to demonstrate the capability of the code and the differences between these concentrators. In this last example, the performance degrading effects of astigmatic focusing are shown for the three facet reflector system. Some discussion of the validation of **CIRCE** using experimental results from the SNLA Test Bed Concentrator (TBC-1) will also be included.

[*]This work performed at Sandia National Laboratories supported by the U.S. Department of Energy under contract number DE-AC04-76DP00789

CIRCE: A COMPUTER CODE FOR ANALYSIS OF POINT–FOCUS SOLAR CONCENTRATORS

PRESENTED AT THE
SOLAR THERMAL TECHNOLOGY
CONFERENCE
AUGUST 26–27, 1987

A. C. RATZEL

Heat Transfer and Fluid Mechanics Division 1513
Sandia National Laboratories
Albuquerque, NM 87185

CIRCE

a.k.a. "DAUGHTER OF HELIOS"

Acronym for:

Convolution of Incident Radiation with Reflector Errors

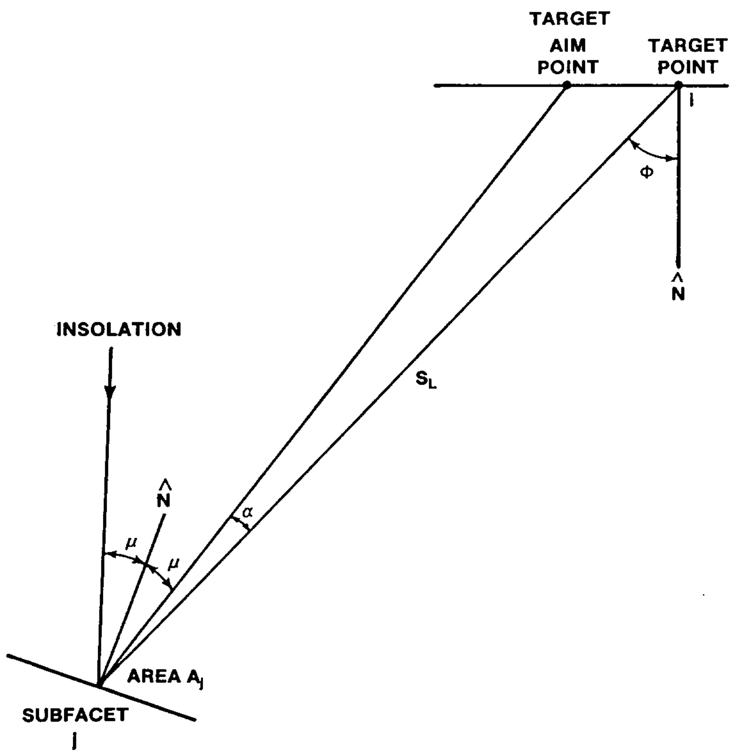
MOTIVATION FOR WORK

- Model Faceted as well as Continuous Surface Reflectors
- Model 2–D Axisymmetric Receivers with Option of Considering Reconcentrators at Aperture
- Easy to Use and Interface with a Receiver Heat Transfer Simulation
- Transportability (Possibly into a PC Simulation)

PRIOR WORK

- CAV
  - Developed at Ford Aerospace
  - Models only Continuous Reflectors
  - Difficult to Modify/Generalize
- COPS
  - Developed at Honeywell, Inc.
  - Monte Carlo Code
  - Difficult to Modify for General-Purpose Applications
- HELIOS
  - Developed at SNLA
  - General-Purpose Optics Code
  - Primarily Intended for Central Receiver–Heliostat Fields
  - Continuous and Faceted Reflector Options

CIRCE NUMERICAL MODELING



ABSORBED FLUX

$$F_i(x_i, y_i, z_i) = \sum_{j=1}^{N} F_{ij}.$$

$$F_{ij}(x_i, y_i, z_i) = \rho_s A_j (1 - B_j) I D_{ij}$$

$$D_{ij} = \left(\frac{cos\mu_j \ cos\phi_i}{S_l^2 \ cos^3 \alpha_j} \right) E_{sun}(x_i, y_i, z_i).$$

OPTICAL EFFICIENCY

$$\eta_{opt} = \frac{\int_{A_{target}} F dA}{I \sum_{j=1}^{N} A_j \ cos\mu_j}$$

AVAILABLE OPTIONS

- 1–D Sunshapes
  - Gaussian
  - Uniform Disk w/ 6 Limb Options
  - User–Specified Tabular Inputs

- Error Parameters
  - Reflector Errors
    Up to 5 "Slope–like" Errors
  - Tracking Errors
    about Horizontal and Vertical Axes

- Convolving Sun and Error Distributions
  - 1–D or 2–D Convolution
  - Numerical or Analytical Convolution

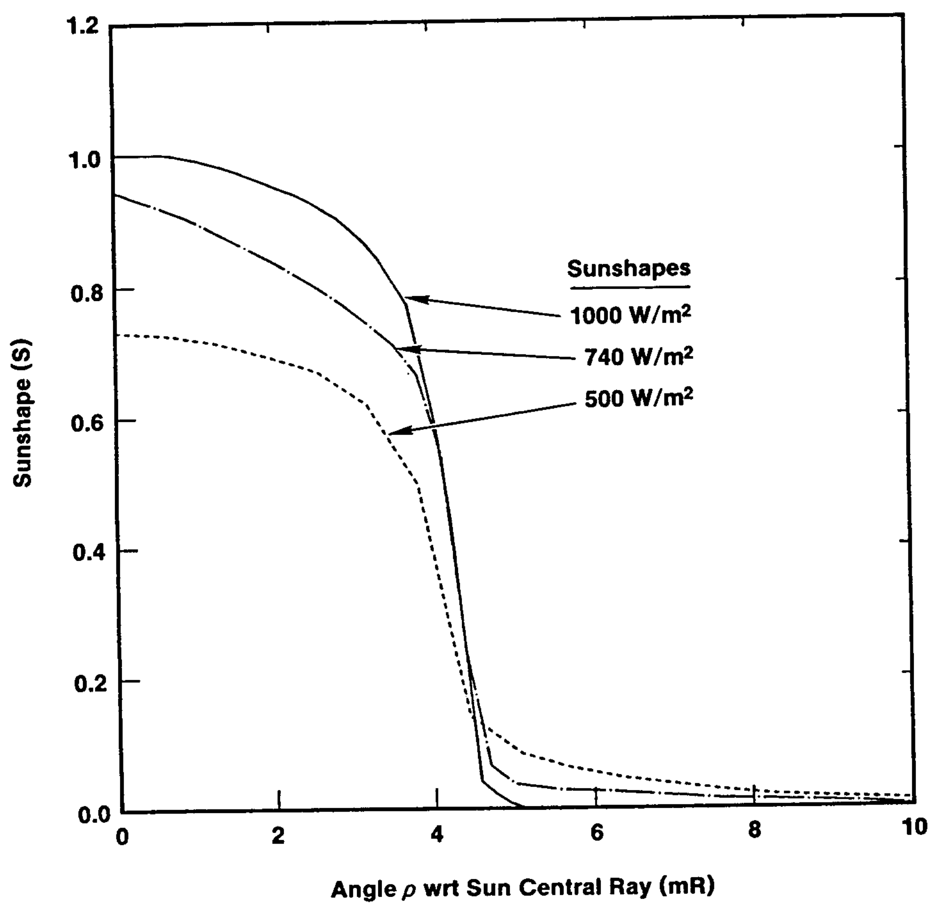
- Miscellaneous Options
  - Insolation Magnitude
  - Time of Day and Day of Year
  - Latitude of Dish
  - Reflectance of Facets/Dish

AVAILABLE OPTIONS (Contd)

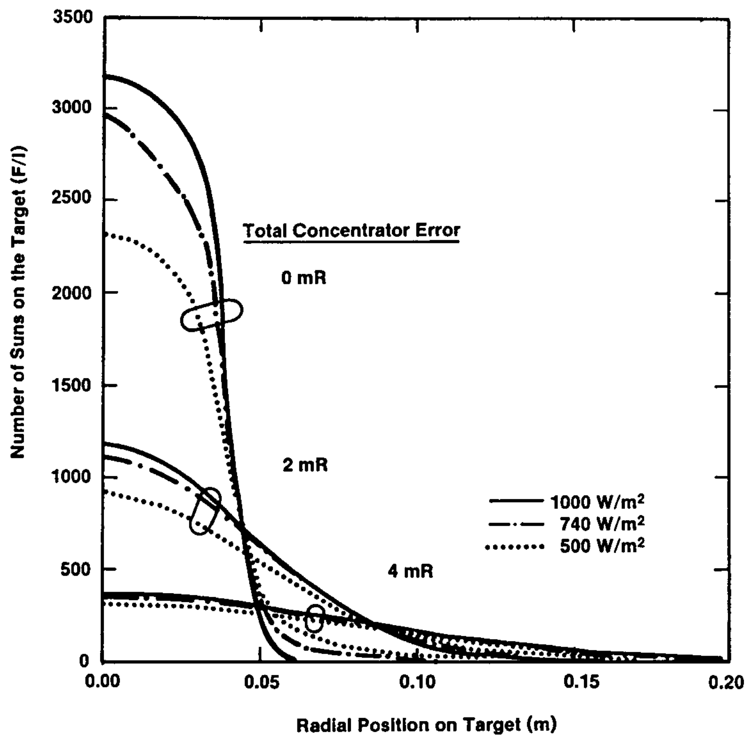
- Reflector Types
  - Single Continuous Surface
  - Faceted Surfaces
- Facet Shape – Projected Surface
  - Rectangular
  - Circular
- Facet Contour
  - Parabolic
  - Spherical
  - User–Provided Polynomial Fit
  - Flat
- Target Shadowing of Reflector
  - User–Input Blockage Factors
  - Internal Computation of Blockage
- Target Alignment
  - Target Can be Canted or Aligned Normal to Focal Plane
  - Target Center to be Specified
  - Up to 5 Aim Points on Target Allowed

EXAMPLE 1: SUNSHAPE VARIATION

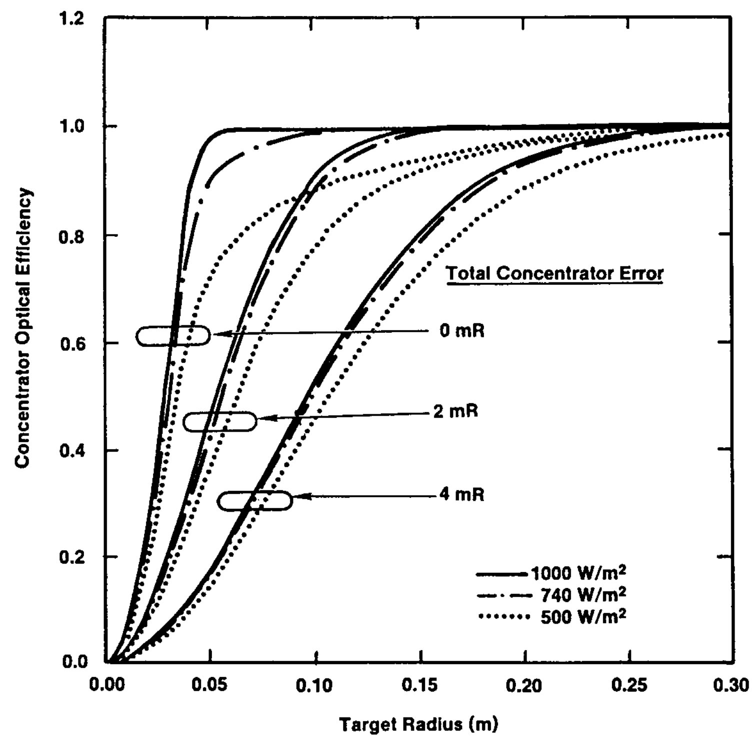
- Problem Constraints
  - 14–m Diameter 45 Degree Parabolic Dish With Circular Target at Focal Point
  - Three Sunshapes Analyzed
  - Three Total Concentrator Errors Considered



SUNSHAPE VARIATION



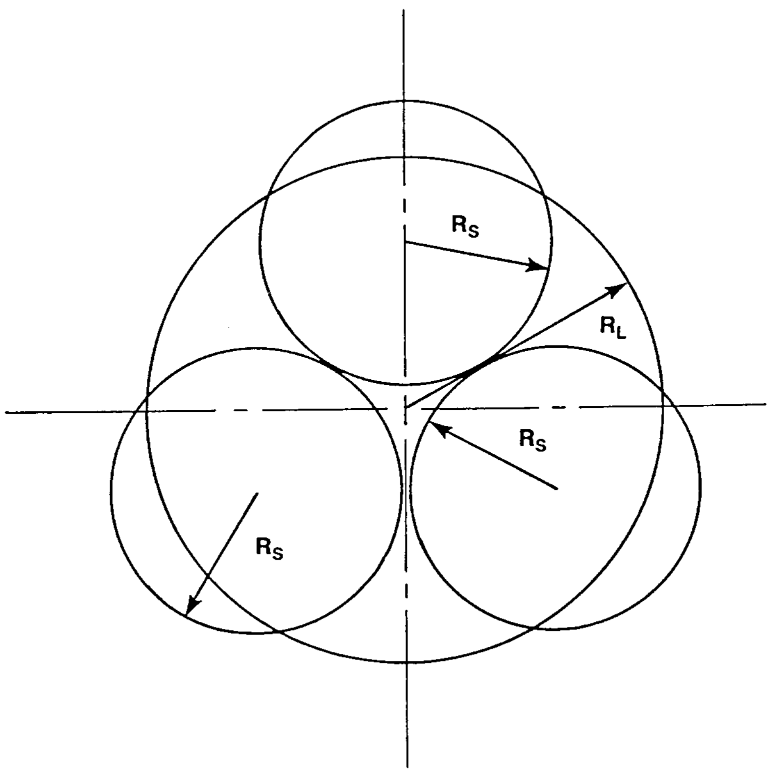
SUNS ON TARGET



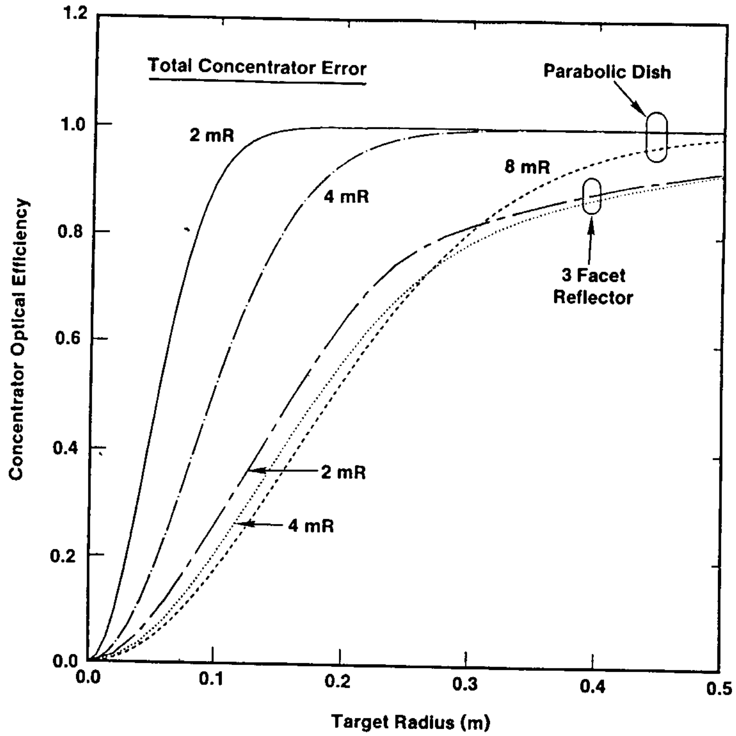
CONCENTRATOR OPTICAL EFFICIENCY

EXAMPLE 2: ONE VERSUS THREE FACET CONCENTRATORS

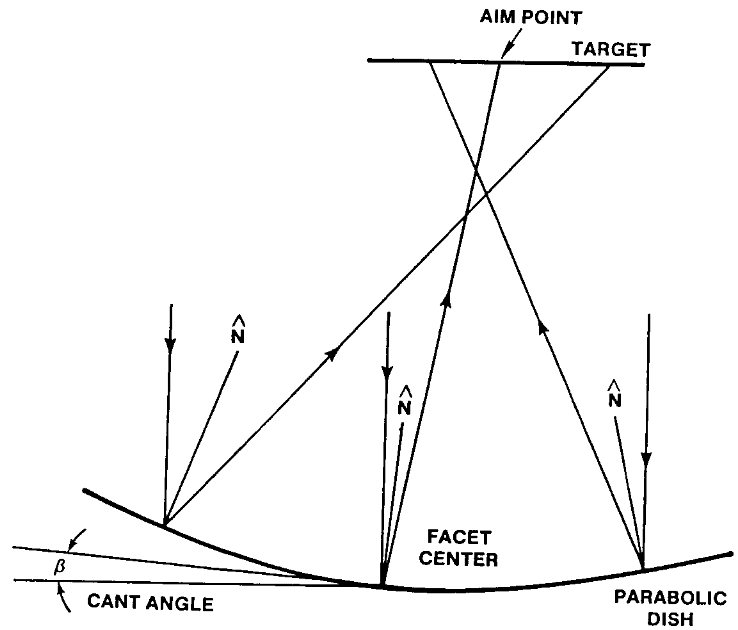
- Problem Constraints
  - 14–m 45 Degree Parabolic Dish Compared To Three 8.08–m Parabolic Facets
  - Circular Target Centered 8.45–m Above Vertex of Single Effective Dish
  - 1000 W/m^2 Sunshape Used
  - Total Concentrator Error Varied



ONE VERSUS THREE FACET CONCENTRATORS



COLLECTOR OPTICAL EFFICIENCY



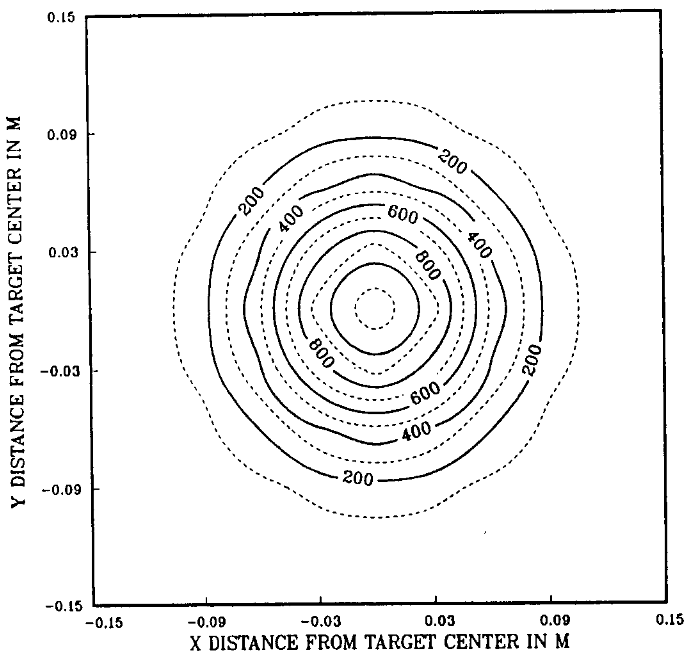
SCHEMATIC OF ASTIGMATIC EFFECT

Sandia National Laboratories

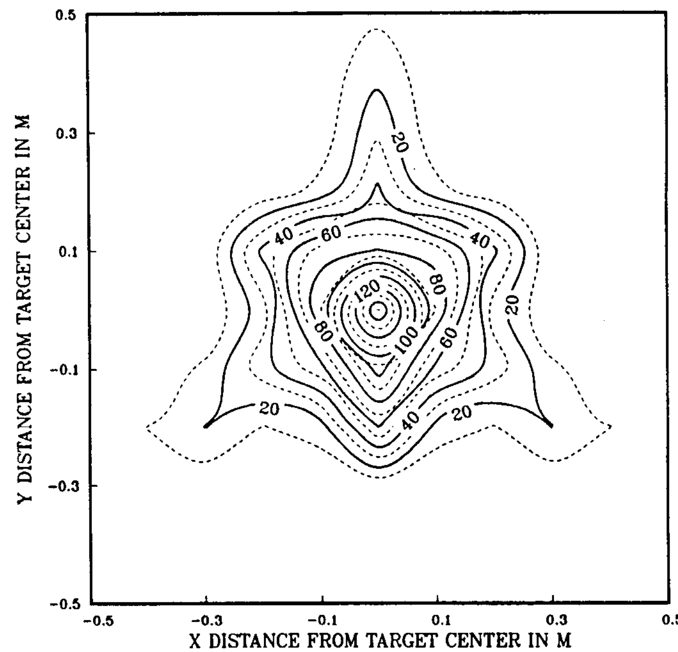
A. C. Ratzel (6/20/87)

ONE VERSUS THREE FACET CONCENTRATORS

ABSORBED FLUX CONTOURS

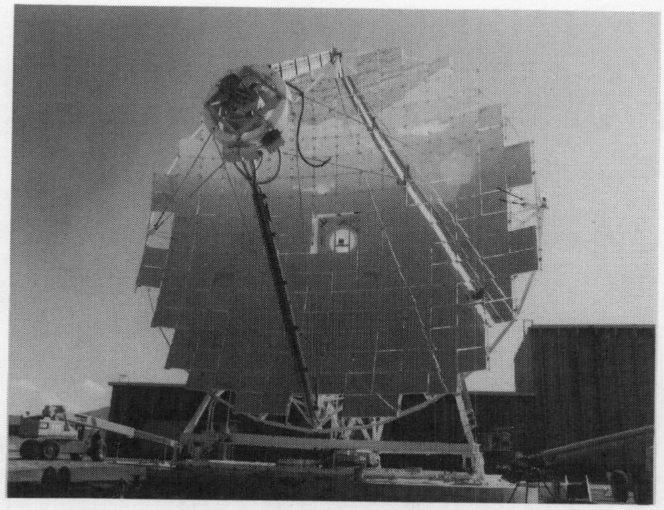


SINGLE PARABOLIC DISH



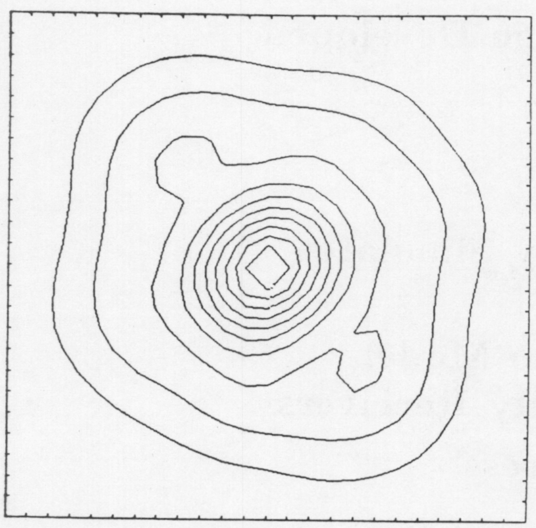
THREE FACET CONCENTRATOR

CIRCE VALIDATION

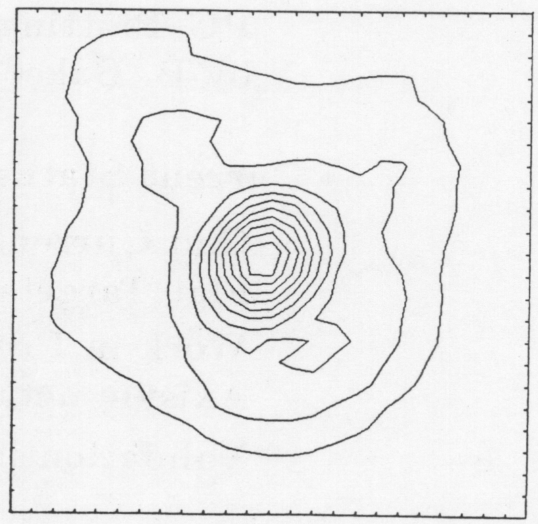


PHOTOGRAPH OF SNLA TBC–1

ABSORBED FLUX CONTOURS



CIRCE PREDICTION



MEASURED

SUMMARY

- CIRCE.001 Code is Operational and Available
  - VAX Version Can Model 250 Facets
  - PC Version Can Model 50 Facets
- VAX Usage
  - VAX–Specific Operating Procedures w/ Data File Generation and Graphics Output Possible
- PC Usage
  - PC–Specific Operating Procedures w/ Data File Generation
  - PC–Plotting Package Developed by B. Baker
- Current Status
  - Can Currently Only Simulate Flat Targets
  - Work in Progress to Model Axisymmetric Cavity Receivers
  - Validation in Progress

Sandia National Laboratories

A. C. Ratzel (6/20/87)

SOL-GEL PLANARIZED FLEXIBLE SOLAR MIRRORS †

A.R. Mahoney, C.S. Ashley and S.T. Reed
Sandia National Laboratories
Albuquerque, NM 87185

ABSTRACT

The current flexible mirror configuration consists of a 430 stainless steel (SS) substrate, a multiple coat sol-gel dielectric and planarizing layer, sputtered silver, sputter deposited SiO_x, and a final sol-gel environmental protective layer. The sol-gel coating process was investigated on a variety of SS substrates with differing surface morphologies. From these studies it appears that some types of microscopic surface defects severely limit the specular properties of the sol-gel planarized mirror. Each substrate required slight adjustment of process parameters which included sol-gel composition, thickness of the planarizing layer, and firing temperature. When optimized for a particular substrate, the sol-gel planarizing layer dramatically improved the specular reflectance properties by minimizing the wide angle scattering component of the reflected beam.

The sol-gel planarizing process was optimized and a scale-up demonstrated for a 0.025 in. thick SS substrate. Diffuse reflectance measurements indicated a significant reduction in wide angle scattering properties. The solar averaged diffuse reflectance for the silvered mirrors decreased from 0.086 reflectance units for the bare substrate to 0.006 reflectance units for the sol-gel planarized substrate. The specularly reflected beam profile was measured from 1 mrad to 15 mrad (full cone angle). The results showed a dramatic increase in the intensity of the reflected beam. These mirrors exhibited a specular reflectance increase of 0.12 reflectance units at a 6 mrad collection aperture with an accompaning increase in the solar averaged specular reflectance from 0.77 to 0.89. More recent process development efforts utilizing 0.005 in. thick SS foil substrates have produced mirrors with specular reflectance values as high as 0.95, compared to an estimated value of 0.78 for the non-planarized substrate.

Present studies are directed toward optimizing the environmental protective layer. Testing plans include both accelerated and real time exposure and abrasion resistance tests. Recent experiments have shown that the SiO_x layer is essential for silver protection during subsequent processing and to improve environmental stability.

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† This work performed at Sandia National Laboratories supported by the U.S. Department of Energy under Contract Number DE-AC04-76DP00789.

SOL-GEL PLANARIZED FLEXIBLE SOLAR MIRRORS

Rod Mahoney -Optical Properties
Carol Ashley -Solgel Chemistry
Scott Reed -Process Development

August 26, 1987

SANDIA NATIONAL LABORATORIES

SUMMARY OF FY 86 STUDIES

1. Variety of 430 SS substrates investigated

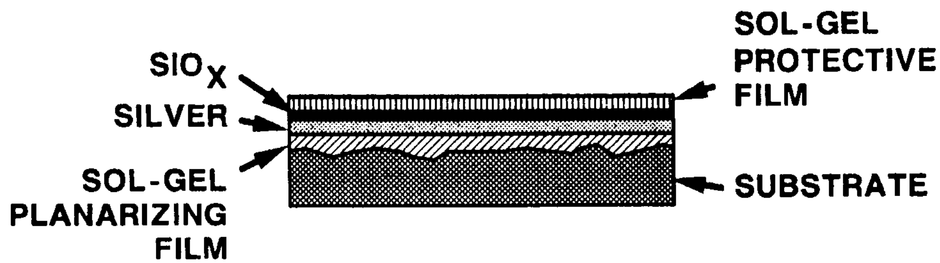
2. Identification of sol-gel coating process interactions

3. Optimized process for supplied substrate
   430 SS -- 25 mil thickness
   Scale-up to 18" by 20" sheet

4. Preliminary investigation of environmental overcoat

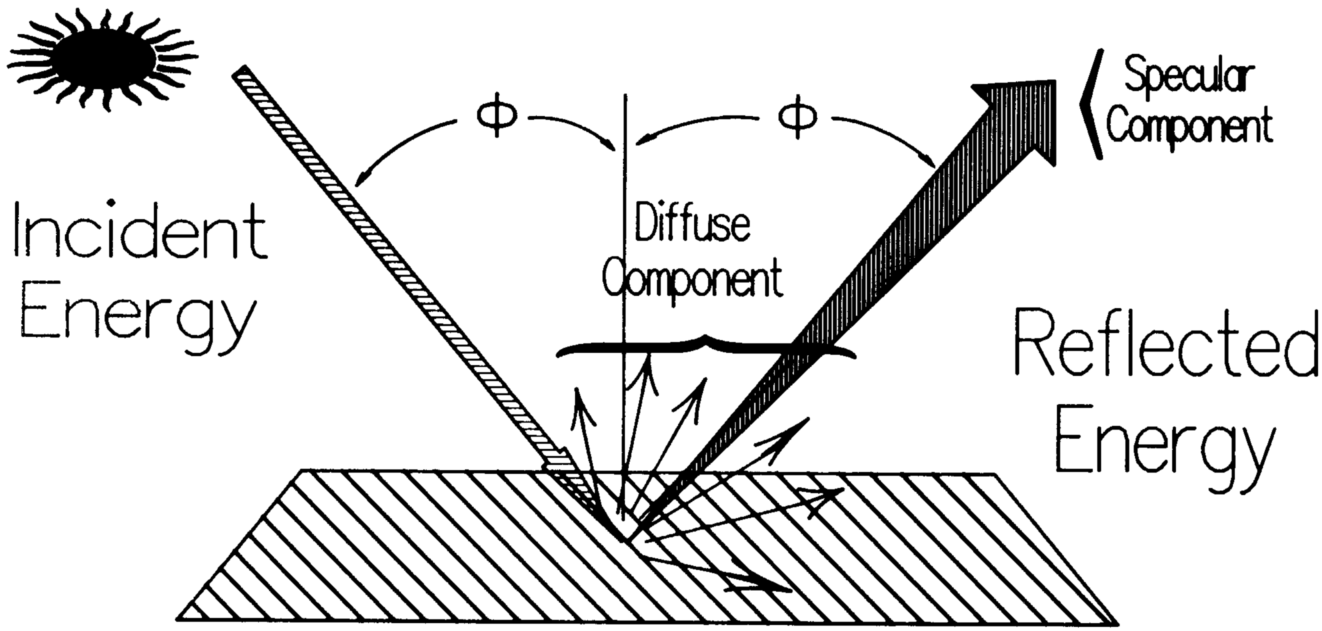
5. 5 mil SS foil process development

MULTIPLE ROLE OF SOL-GEL FILMS FOR FLEXIBLE MIRRORS



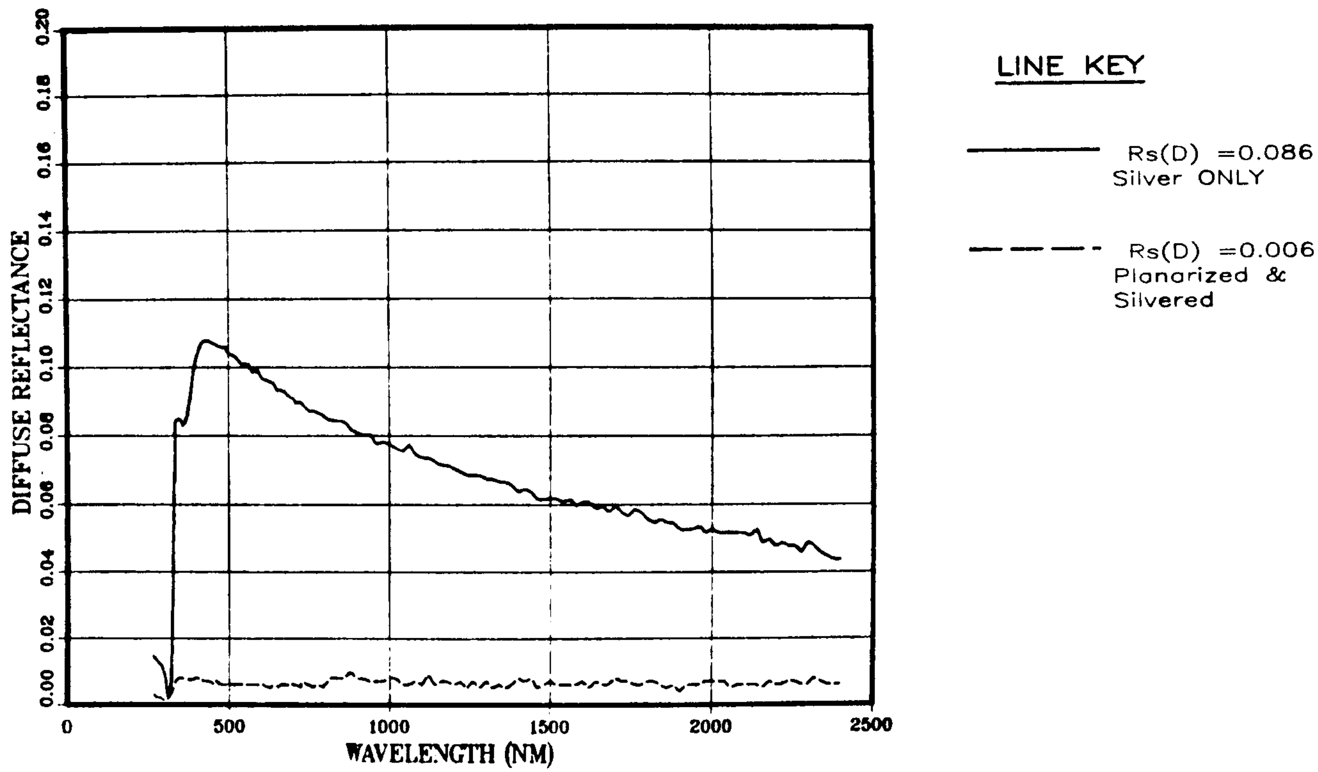
- IMPROVED SPECULARITY OF SUBSTRATE
- GALVANIC BARRIER (Fe-Ag)
- PROTECT SILVER FROM CORROSION

BI-DIRECTIONAL SPECULAR REFLECTANCE

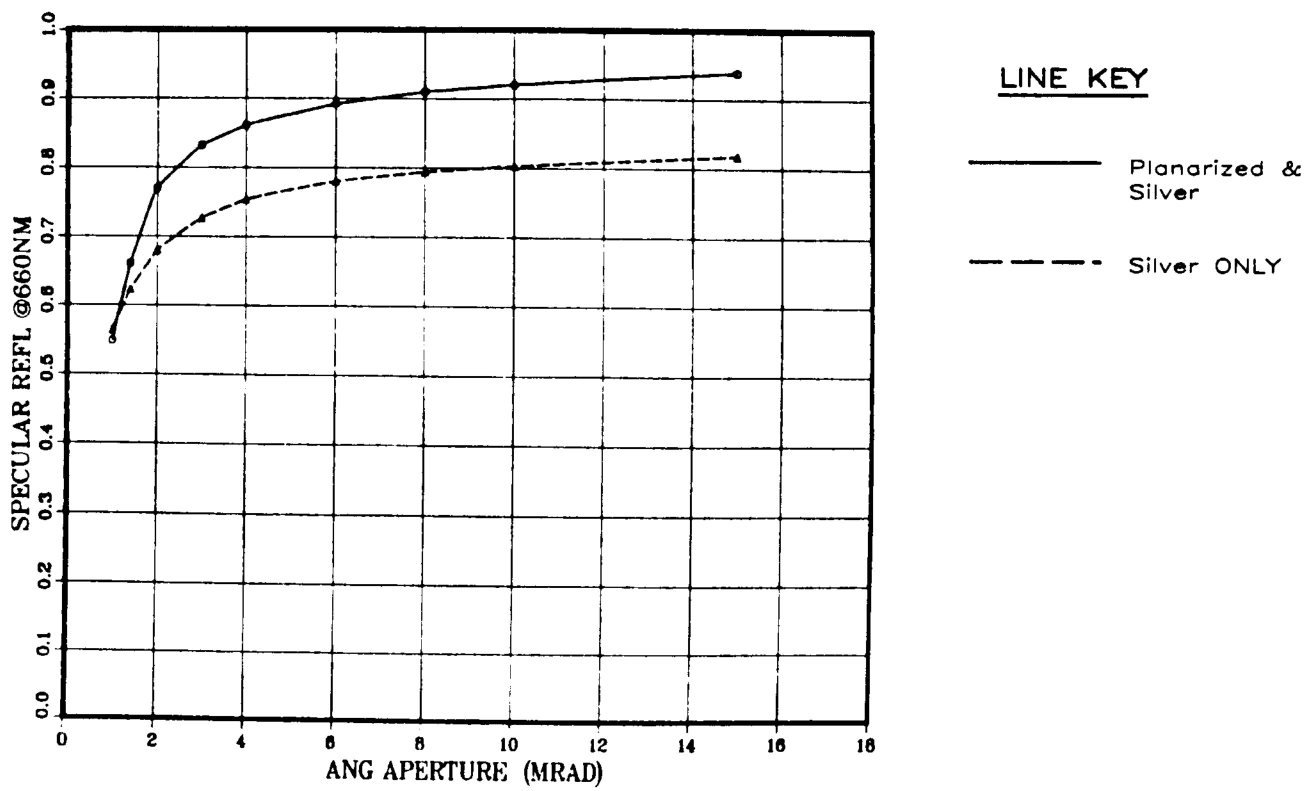


Hemispherical Reflectance = { Specular Component + Diffuse Component

SS SUBSTRATE: WITH & WITHOUT PLANARIZING



SS SUBSTRATE (0.025'') W & W/O PLANARIZER



SOL-GEL PLANARIZED FLEXIBLE SOLAR MIRRORS

- 430 Stainless Steel
- Multiple layer sol-gel planarizing coat
- Silver
- SiOx/Sol-gel environmental layer

SUBSTRATE	Rs(2)	Rs(6mrad)	Rs(15mrad)
25 mil As-recieved	0.96	0.77	0.81
25 mil Planarized	0.96	0.89	0.93
25mil Planarized/ Environmental	0.95	0.87	0.91

ENVIRONMENTAL OVERCOAT DEVELOPMENT

1. Primary protective layer ESSENTIAL
   - SiOx or alternative coating

2. Clear SiOx or optimum protection
   - Clear = SiO2
   - Minimal pinhole

3. Environmental Stability
   - Accelerated testing QUV, T/H, Salt fog
   - Abrasion resistance ASTM D 968-81

CONCLUSIONS

- **SOL-GEL PLANARIZED VARIETY OF STAINLESS STEEL SUBSTRATES**
  - Each substrate requires process optimization
  - Detailed substrate surface inspection (SEM) essential
    Open surface features necessary for optimum improvement
  - Specular Improvement >10% (15 mrad full cone values)
    25 mil substrate :: 0.82 to 0.94

- **SCALE-UP DEMONSTRATED**
  - Lab Samples 1" by 3"
  - Scale-up to 18" by 20"

- **ENVIRONMENTAL PROTECTIVE LAYER DEVELOPMENT**
  - Accelerated & real time testing
  - Abrasion resistance tests

SESSION II

DISTRIBUTED RECEIVER SYSTEMS

HUGH REILLY

CHAIRMAN

DISTRIBUTED RECEIVER SYSTEMS

Introduction

Hugh Reilly
Sandia National Laboratories

(This page is provided for notes.)

Central Engine Study

J. M. Diggs
Sandia National Laboratories
Albuquerque, New Mexico

This study was undertaken to investigate the potential of distributed dishes delivering energy to a central site for conversion to electricity by a standard Rankine cycle engine. Two methods of thermal connection between the dishes and the central site were considered: Thermochemical transport (CO_2 reforming of methane) and liquid metal sensible heat transport (NaK). To eliminate the time and funds required for new engine development, the conversion to electricity is achieved using current industrial technology. The range of operations of interest in this study were 500 kWe - 50 MWe size plants with turbine inlet temperatures of 750F -1000F.

The method of approach was to design the system, simulate its performance under solar conditions and superimpose cost and economics on top. The design phase consisted of gathering on and off design performance information on each individual component comprising the system. Thus, the turbine, boiler feed pump, and condenser on the conversion side and the receiver and piping on the solar side were modeled individually to the extent necessary to capture the interaction of components during simulation.

By simulating each system (conversion + transport) under solar conditions, the net daily electrical output was predicted. The SOLTES code provided the structure in which each designed component model acts upon the incoming solar energy as it cascades through the system. Effects of incoming state point changes and flow dependent efficiencies are included in each component model. Modeling of the transient response of the sensible system has been rudimentary to date. This simulation structure is sufficient to provide a medium for addressing control philosophies between the two transport methods.

Annual performance, as the ultimate goal of the simulation, was achieved by judicious extension of selected predictions of daily electricity output. For a thermochemical system, where the warm-up period is considered short, this method gives fairly representative annual performance. For a sensible system, however, the length of low or no solar insolation periods and their frequency of occurrence relative to each other have a major impact on the ability to extend daily performance simulations to approximate the annual system performance.

Sandia Laboratories
Solar Energy

Objective

To investigate the use of available conversion technology (Rankine cycle) in conjunction with distributed solar receivers.

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Solar Energy

Method

- Design the system
- Simulate the system under solar conditions
- Impose economics on the performance

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Solar Energy

Study Groundrules

Steam Rankine Conversion System
Size Range – 500 kWe to 50 MWe
Turbine Inlet Temperatures of 750F to 1000F
Transport Systems – Sensible and Thermochemical

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Solar Energy

System

Concentrator – "current" capability
Receiver – As needed for transport
Transport – TC or sensible
Conversion – Steam Rankine Engine–
current technology

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Solar Energy

Component Performance

Concentrator – 85%
Receiver –
Eff = 1.086 – 3.58E–14*T**4 – 6.15E–5*T (conv)
Eff= 0.982 – 3.58e–14*T**4 – 5.16E–5*T (DCAR)
Transport – derived from simulation
Conversion – Cycle efficiency is a function of Turbine Inlet Temperature and size and is derived from simulation

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Solar Energy

System Performance

Interaction of components is modeled to obtain daily electric output under varying solar conditions.

Annual System Performance is then estimated by extension of daily simulations with TMY data.

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Component Capital Cost

Concentrator – $200/m2
Receiver – $40/m2 (conv)
$41/m2 (DCAR)
Transport – derived from design
Conversion
500 kWe ≈ $2400/kWe
50 MWe ≈ $610/kWe

JMOD 8/87

DESIGN OF THE PHASE I CLOSED LOOP OPERATIONS EXPERIMENT (CLOE)

Tzvi Rozenman, Ph.D

Resource Analysis International (RAI), Inc.
Los Angeles, California.

The Closed Loop Operations Experiment (CLOE) is a field-scale thermochemical (TC) energy transport system based on the carbon-dioxide (CO_2) reforming of methane (CH_4). Its objective is to demonstrate the technical and practical feasibility of TC transport for high temperature distributed receiver solar thermal systems at larger than laboratory scale and under more realistic conditions. It will include multiple reformers (endothermic receiver/reactor units), both electrically and solar heated, and will utilize as many commercially available components as possible. As presently conceived, CLOE will be conducted in two phases. Phase I will involve conservative, state-of-the-art receiver/reactor designs that will ensure successful operation of the transport system. Energy will be input using electrical heaters to provide better control and more flexibility in performing the experiments. Phase II will involve advanced receiver/reactor design concepts capable of operating at higher temperatures, and at least one of these units will be mounted on a paraboloidal concentrator to demonstrate operation in a solar environment.

Resource Analysis International (RAI), Inc. of Los Angeles, California, is under contract to Sandia National Laboratories to provide a detailed design of CLOE Phase I. In this system, solar energy is absorbed in the reforming reactors where a mixture of methane and CO_2 is converted to hydrogen and carbon monoxide. This mixture is cooled and transported via a pipeline to the methanator. Energy is released as the gaseous mixture is converted back to the original feed in the methanation reactor. The gas is returned to the reformer, via another pipeline, to complete the cycle.

The CLOE Phase I design includes two electrically heated reformers. Each consists of 15 tube-in-tube reactor/recuperator units and is capable of absorbing 80 kW_{th}. Process conditions in the reformers are designed to heat the reacting gases up to 815°C (1500°F) at a maximum pressure of 20 atm.

The methanator consists of three adiabatic stages connected in series. Steam will be mixed with the methanator feed to create a favorable composition for the thermodynamics and kinetics of the methanation reaction and to maintain the first stage exit temperature at approximately 700°C.

CLOE Phase I will serve as an important test facility to study thermochemical energy transport for solar thermal distributed receiver applications such as electrical power generation and process heat.

PREVENTION OF CARBON DEPOSITION IN THE CO_2/CH_4 THERMOCHEMICAL ENERGY TRANSPORT SYSTEM

Jim D. Fish and David C. Hawn
Process Research Division 6254
Sandia National Laboratories
Albuquerque, New Mexico 87185

The thermochemical energy transport system, based on the reforming of methane with carbon dioxide, has the advantage that the transport components are all gases: CO and H_2 in one direction; CH_4 and CO_2 in the other. The major disadvantage of the system is a tendency for carbon deposition in the reactors and in the recuperative heat exchangers.

Experiments in the CLFA laboratory facility have shown that carbon deposition can be managed by a combination of starting system composition, water recycle around the methanator, appropriate startup and shutdown procedures, and material selection.

The system should be charged initially with a mixture of CO_2 and CH_4 with a CO_2 to CH_4 ratio of 1.1 or higher. On startup, the methanator should be heated to 350°C with circulating CO_2 and CH_4, and steam recycle should be established before the reformers are brought on line. On shutdown, the methanators should remain in operation after the reformers are valved out of the system until all of the CO and H_2 has been converted back to CO_2 and CH_4.

All metal surfaces exposed to temperatures less than 700°C and greater than 300°C and to high concentrations of CO should be plated or lined with copper. The exit piping of the reformers and the product side of the reformer recuperators are particularly critical locations.

MAIN REACTION

$$CH_4 + CO_2 = 2CO + 2H_2$$

POTENTIAL CARBON-FORMING REACTIONS

$$CH_4 = 2H_2 + C$$

$$2CO = CO_2 + C$$

RXN 1 PREVENTED BY EXCESS CO_2 IN REFORMER

RXN 2 PREVENTED BY WATER RECYCLE ON METHANATOR SIDE AND BY COPPER PLATING ON REFORMER SIDE

STARTUP AND SHUTDOWN PROCEDURES

* INITIAL $CO_2:CH_4$ GREATER THAN 1.1

$$CH_4 = C + 2H_2 \qquad CH_4 = C + 2H_2$$

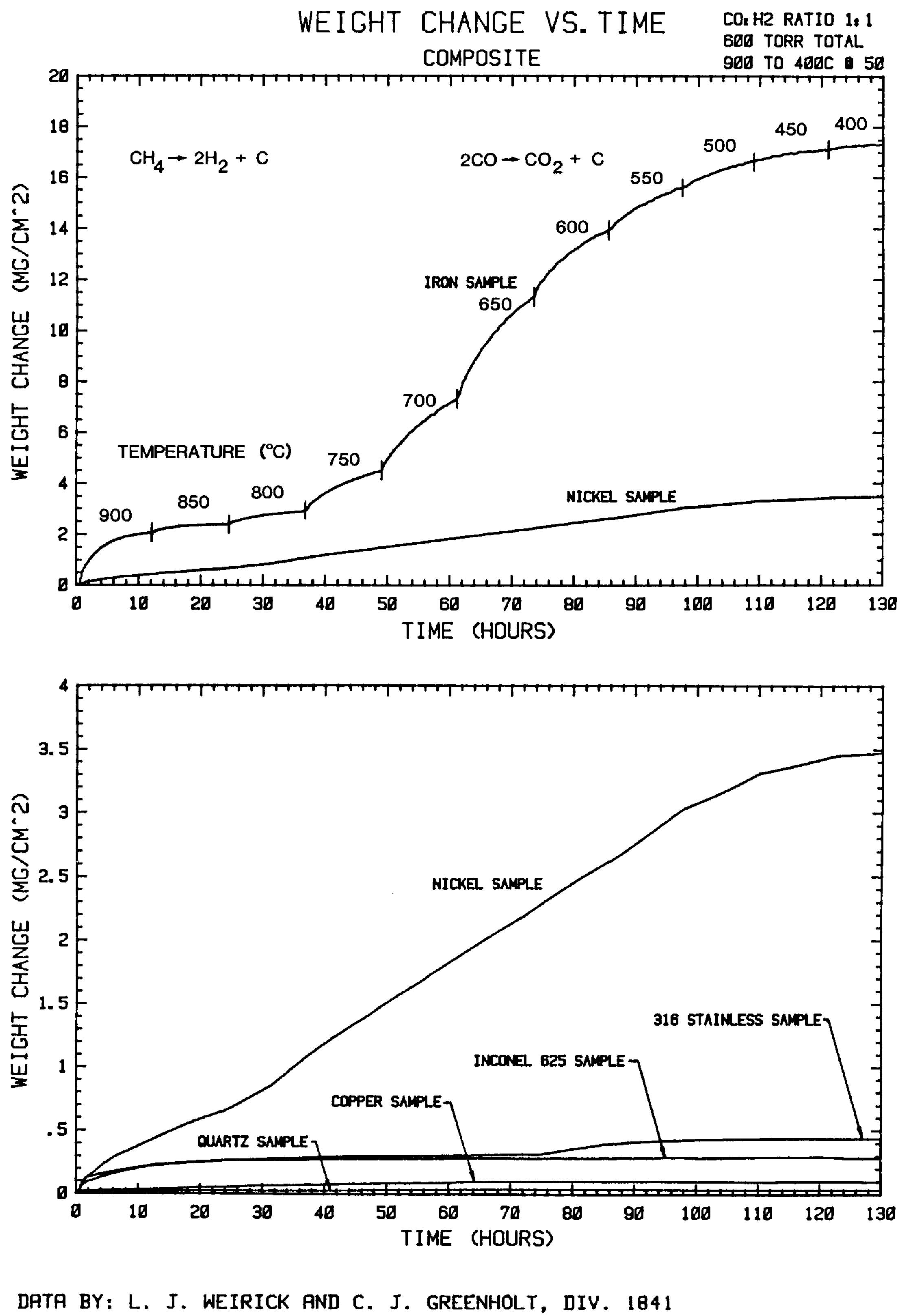
$$H_2O + C = CO + H_2 \qquad CO_2 + C = 2CO$$

* WATER RECYCLE ESTABLISHED AROUND METHANATOR BEFORE REFORMER VALVED INTO SYSTEM

$$2CO + 2H_2 = CO_2 + CH_4$$

$$H_2O + CO = CO_2 + H_2$$

* CONVERT CO AND H_2 TO CO_2 AND CH_4 BEFORE SHUTDOWN


WEIGHT CHANGE VS. TIME
COMPOSITE
CO:H2 RATIO 1:1
600 TORR TOTAL
900 TO 400C @ 50
$CH_4 \rightarrow 2H_2 + C$
$2CO \rightarrow CO_2 + C$
TEMPERATURE (°C)
900
850
800
750
700
650
600
550
500
450
400
IRON SAMPLE
NICKEL SAMPLE
WEIGHT CHANGE (MG/CM^2)
TIME (HOURS)
NICKEL SAMPLE
316 STAINLESS SAMPLE
INCONEL 625 SAMPLE
COPPER SAMPLE
QUARTZ SAMPLE
WEIGHT CHANGE (MG/CM^2)
TIME (HOURS)
DATA BY: L. J. WEIRICK AND C. J. GREENHOLT, DIV. 1841

PROJECT SUMMARY

Solar Total Energy Project
At Shenandoah, Georgia

Solar Thermal Technology Conference
Albuquerque, New Mexico
August, 1987

E.J. Ney, Manager, Solar Operations
Georgia Power Company

ABSTRACT

The purpose of this summary is to present the Key Operational Experiences of the Georgia Power Company (GPC) team during its participation in the Solar Total Energy Project (STEP) from May, 1977 to the termination of the Department of Energy (DOE) Cooperative Agreement in September, 1985. The original program between DOE and the GPC, and under the technical direction of Sandia National Laboratories (SNLA), was conceived to further the search for new sources of energy. STEP is continuing to supply valuable research data through support contracts from SNLA and funding from Electric Power Research Institute (EPRI) along with technical coordination with Solar Energy Research Institute (SERI) and other electric utilities and solar energy industries.

STEP is the world's largest industrial application of the solar total energy concept. The objective is to evaluate a solar total energy system that provides electrical power, process steam, and air conditioning for a knitwear factory operated by Bleyle of America. Solar energy generates a large part of the electricity and displaces part of the fossil fuels normally required to operate the factory.

Construction of the STEP system was completed in 1982. After the startup phase, operations were initiated under management of Georgia Power. The solution of electrical, mechanical, and system problems has produced significant information for subsequent system designs. These problems are discussed according to the following categories:

- Startup Anomalies
- Hardware and Software Controls
- Environment
- Heat Transfer Fluid
- Thermodynamic Performance
- Power Parasitics and Manpower
- Solar Energy Source/Demand

The STEP is viewed as an absolute success as a concept demonstration and experimental facility. Although portions of the system were derated and the expected loads never developed, the overall system worked well and continues to operate. Most of the problems encountered were solved. The technical achievement and lessons learned at STEP should be considered for use by other solar technologies in the national and international communities.

DISTRIBUTED RECEIVER TEST FACILITY ACTIVITIES

Christopher P. Cameron and John W. Strachan
Solar Thermal Test Facility Division 6222
Sandia National Laboratories
Albuquerque, New Mexico 87185

The purpose of the Distributed Receiver Test Facility (DRTF) is to support development and testing of point-focus concentrators and associated solar-powered heat engines for electrical generation and thermochemical transport systems for thermal applications. The facility also includes line-focus systems, developed under the Modular Industrial Solar Retrofit project, and other line-focus test capabilities. The DRTF is located at the Solar Thermal Test Facility, which also includes the Central Receiver Test Facility and the Flux Gauge Calibration Station (solar furnace).

A significant portion of the effort at the DRTF over the past year has been devoted to development and test activities associated with the Small Community Solar Experiment #1 (Osage City). Optical evaluation of the Power Kinetics, Inc. (PKI) concentrator was completed using cold water cavity calorimetery and the reverse illumination method. After Barber-Nichols completed installation and checkout of the organic Rankine cycle engine on the concentrator, evaluation of the module began. Following a decision by Barber-Nichols to select another solar concentrator for the project, the engine was moved to a test stand for evaluation with a 100 kW electric heat source until the new concentrator is ready for use. Over 200 hours of engine operation have been completed; however, a variety of difficulties such as leaks and control problems have precluded achieving routine operation of the engine.

Because of the importance of wind loads as a factor in solar collector design and the lack of conclusive information about actual loads, an experiment was performed at the DRTF to measure wind-induced strain on a LaJet Energy Corp. collector, the LEC-460. Measurements were obtained from strain gages mounted along the principal load-bearing path of the collector for numerous high velocity wind events, with the collector in several different orientations.

The radiometer-based fluxmapper was used to characterize Test Bed Concentrator #1 in support of a materials test for Johns Hopkins Applied Physics Laboratory. The fluxmaps obtained are also of value in validating the CIRCE optical code and will be compared with maps obtained with the video-based fluxmapper currently in development.

The Video-based Fluxmapper (VFM) is an instrument designed and built at the DRTF to permit detailed, accurate measurements of flux densities in the focal region of point-focusing collectors. The measurement technique involves placing a diffuse, highly reflective target in the flux field and viewing with a camera the image of the collected solar energy reflected from that target. The camera picture frame is digitized and then processed using a computer-based image analysis system. The instrument was designed for easy installation and the rapid optical evaluation of any point-focusing collector. The first fluxmap tests using the Video Fluxmapper are currently being performed at the DRTF.

Line-focus component evaluation has continued at a low level. Components evaluated include direct-imbedded collector pylons, evacuated receivers, and black-chrome coated stainless steel receivers.

SMALL COMMUNITY SOLAR EXPERIMENT #1 - OSAGE CITY
CONCENTRATOR PERFORMANCE SUMMARY

REVERSE ILLUMINATION METHOD (RIM)

Original Alignment Done On-Sun
RIM Indicated Alignment Could Be Improved
RIM Used By PKI as an Alignment Technique

COLD WATER CAVITY CALORIMETRY

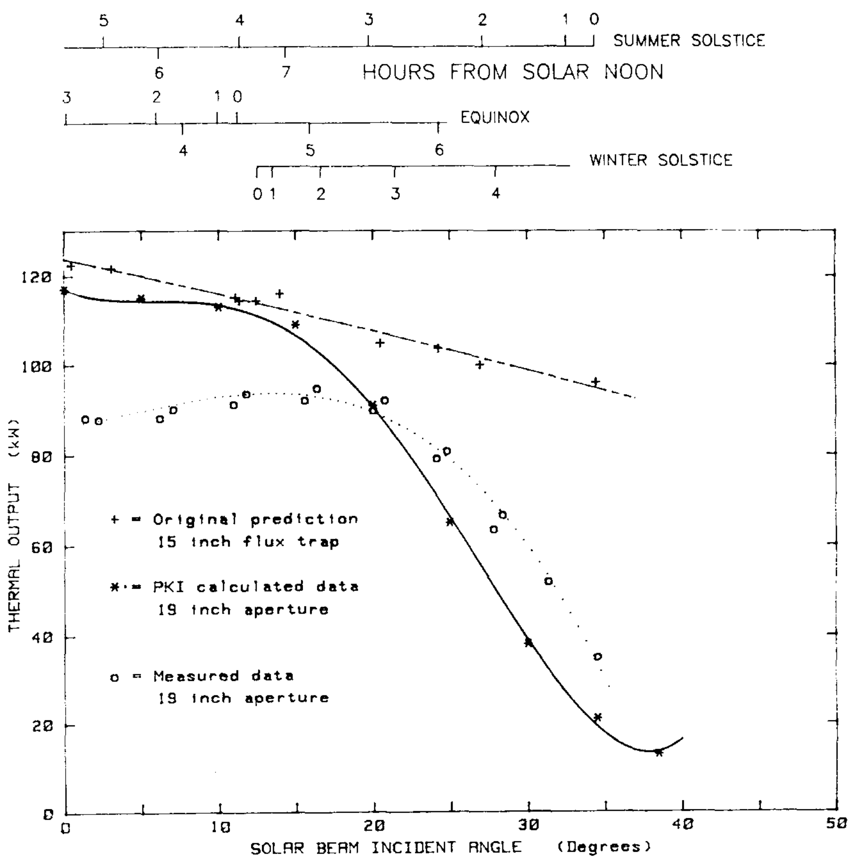
A Variety of Liquid-Cooled Secondary Concentrators (Flux Traps) and Flat Apertures were Used - Final Measurements Made with a 19 inch Liquid-Cooled Aperture

Peak Values near 90 kWth

Near Solar Noon on Summer Solstice at Osage City Only 20kWth Predicted to be Delivered into 19 inch Aperture

Engine Needs About 35 kWth to Run

Aperture Was Changed to 23 inches After Engine Installation



PKI Normalized Power Output vs. Incident Angle

SMALL COMMUNITY SOLAR EXPERIMENT #1 - OSAGE CITY
ORGANIC RANKINE CYCLE ENGINE PERFORMANCE SUMMARY

MAXIMUM SYSTEM OUTPUT DURING ON-SUN TESTING - 18 kWe

ENERGY BALANCE

Reflectivity of Clean Mirrors is about 94%. - Use 90% to account for soiling and blockage. Concentrator Area is 135 sq. m.

Measured input onto 23 inch aperture coil at 24 kWth

990 w/sq.m. • 135 sq. m. • .90 = 120 kWth
Less 24 kWth that misses = 96 kWth

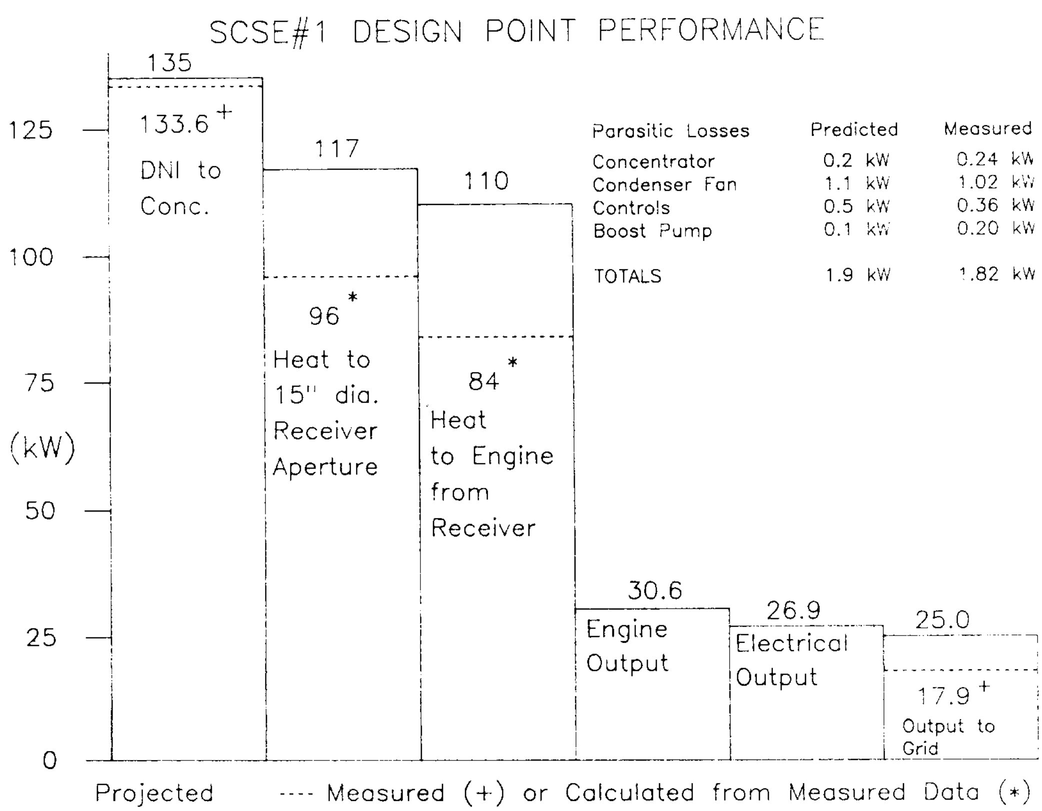
Based on lab tests with an electric boiler (no receiver), B-N predicts that the engine will produce 18 kWe net from 84 kWth input to the turbine

B-N calculated using our experimental data that they were getting only 84 kWth from the receiver

Ford reported receiver losses of 3.6kWth with a 15 inch aperture, but B-N predicted 7 kWth loss. Because of the larger 23 inch receiver aperture, the actual losses may be expected to be 2.3 times larger

Corrected for area: Ford - 8.5 kWth, B-N 16.5 kWth

Observed performance falls in between



SMALL COMMUNITY SOLAR EXPERIMENT #1 - OSAGE CITY
SYSTEM STATUS

CONCENTRATOR REPLACED BY ELECTRIC HEATER - Weld Failures at High-Load Areas of Concentrator Track

CONTROL PROBLEMS

- Problems with PKI Concentrator, Poor Control Labeling and Interfaces Plus Operator Error Led to Overheating of Receiver
  - Carbon Residue Removed with Endothermic Reaction On-Sun Using CO_2 Gas and High-Pressure Filter Installed at Turbine Inlet
- Unexplained Control Excursions During Testing on Concentrator
  - Control and Stability Problems Persisted During Checkout with Heater

VACUUM LEAKS

- Several Attempts Were Made to Locate Leaks while the Engine was on the Concentrator. Repairs Were Made but Leaks Persisted
- Removed Engine from PKI Concentrator and Leaked Checked Indoors - Most Leaks Were in Fittings in the Tubing From the Receiver to the Turbine - Replaced with Heavier Wall Tubing
- Leaks Continued During Tests with Electric Heat Source
  - Cracked Weld Found in Receiver. Repair will be Attempted. A Spare Receiver Coil is Available.

SMALL COMMUNITY SOLAR EXPERIMENT #1 - OSAGE CITY
TEST GOALS

TESTS WITH ELECTRIC HEAT SOURCE

- Find and Eliminate Control Problems and Vacuum Leaks
- Attain Fully Operational Status Before LaJet Concentrator Characterization is Completed
  - Controls Installed and Fully Operational Adjacent to LaJet IC Site
  - Engine #2 with Two Boost Pumps as Required for LaJet Concentrator Can Be Fully Operational
- Potential to Improve Efficiency Measurements (depending on accuracy of measurements of electric power to heater) - Measure Efficiency at Several Power Levels
- Demonstrate Feasibility of Two ORC Engines Feeding and Controlled by One Inverter as Designed for Osage, Using Osage Engine with Heater and ORC Prototype Engine on Test Bed Concentrator
- Evaluate Engines at Two Orientations
  - Engine #1: Morning/Afternoon - 45 Degree Roll at 10 Degree Elevation
  - Engine #2: Noon-time Elevation of 27.5 degrees

COMPLETE MODULE TEST WITH LaJET CONCENTRATOR

SUMMARY OF LINE-FOCUS COMPONENT TESTS

ACUREX DIRECT-IMBEDDED PYLONS AND SELF-ALIGNING BEARINGS

Installed and Life Cycling - 815 Cycles (2.2 years) Completed

ACUREX EVACUATED-ANNULUS RECEIVERS

Six Installed on a Drive Group - Two Damaged During Shipping and Installation

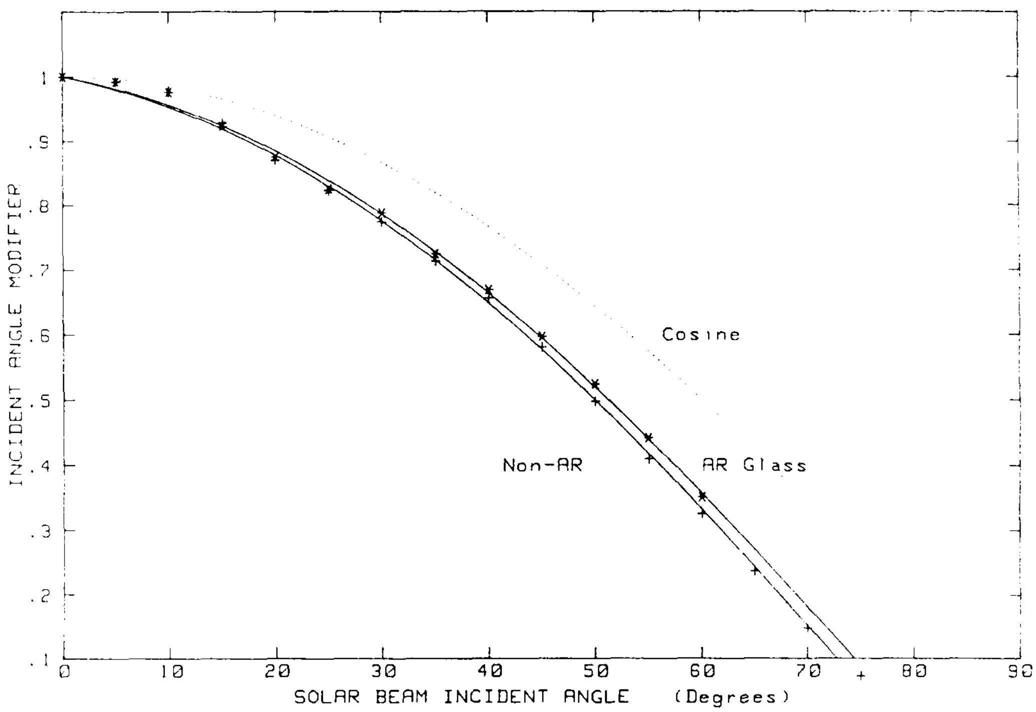
Remaining Four Have Completed 500 Operating Hours at Temperatures above 400F (200C), 830 Operating Hours Total

SOLAR KINETICS BLACK-CHROME/STAINLESS STEEL RECEIVER WITH GRAPHFOIL DUST SEALS

Incident Angle Modifier Evaluated with Anti-reflective Glazing and Plain Glazing on T-700A Collector

Efficiency Evaluated up to 750F (400C)

Graphfoil Dust Seals Do Not Have Enough Compressibility - Either Do Not Seal or Break Glazing



Black Chrome on S.S. Receiver, AR & Non-AR Glass

THE SANDIA FLUXMAPPER:
A TOOL FOR COLLECTOR DEVELOPMENT AND EVALUATION

USES OF THE FLUXMAPPER

Evaluate Collector Performance

- Flux distribution, Contour Maps, and 3-D Intensity Plots
- Collector Intercept Factor: Collected Energy as Function of Aperture Diameter

Validate Computer Models

Tailor Flux Profiles for Special Applications

SPECIFICATIONS FOR A FLUXMAPPING DEVICE

Obtain an Instantaneous Measure of the Flux Field

Be Able to Mount the Instrument on Collectors of Different Design

Have High Reliability and Low Maintenance

Survive the High Temperature / High Flux Environment

Ease and Speed in Testing

PRINCIPAL FUNCTIONS AND FEATURES OF THE SANDIA VIDEO FLUXMAPPER

1. THE FLUX TARGET:

   The Target's function is to provide a surface upon which to view an image of the collected solar energy.

   The Flux Target is a 2.5 cm thick, 48 cm diameter plate of T6061 Aluminum with cooling channels.

   The front surface is a diffuse (Lambertian) high reflectance ceramic coating applied to the aluminum with plasma spray technique.

   Quantitative measure of flux is based on the assumption that the light reflected from the target is linearly proportional to the light incident on it from the collector.

   An absolute measure of the flux level at two known points in the image is provided by two 1 cm diameter circular-foil flux gages set in the target.

   Boiling convection cooling is expected in the cooling channels. Water cooling channels designed against Critical Heat Flux.

2. TARGET POSITIONER:

   Stepper motor gives accurate linear motion to shaft-mounted target.

   Tripod-type mounting interface is adjustable to permit mounting of device on different collectors.

   Light Weight and Dust Proof

PRINCIPAL FUNCTIONS AND FEATURES (continued)

3. CAMERA & CAMERA FILTER WHEEL:

Sensor's gain must be fixed; Sensor output is linear.

Neutral Density Filters used to attenuate image brightness

The filters are set in motor-driven wheels to provide a range of filter selections.

4. COMPUTER:

Machine selected is an -AT with 20 Mb hard disk and EGA monitor.

Commercial hardware installed in slots to provide image acquisition, non-image data acquisition, and motor control; commercial software used where available.

The overall system design is parallel/compatible to the Receiver Temperature Mapping System being developed (R.B. Diver & E. Thatcher).

Frame Grabber:

- Frame Grabber (A/D converter) digitizes camera signal. Digitized image provides 512 x 512 picture elements (pixels). Result is a 1/4 million flux measurements.

* Pixel intensities are calibrated using the flux gages.

Non-Image Data Acquisition:

* 16 Input Channel / 8 Output Channel A/D converter

- Input channels read thermocouples, cooling channel flow switch, circular-foil flux gages, normal incidence pyroheliometer (NIP), and camera filter wheel position.

* Output channels for actuating camera filter wheel motors.

Motor Control:

* Movement commands are sent to and position feedback received from the motor indexer with RS-232 signals using a serial port. Short-haul modem used to facilitate signal over 400 meter distance.

Software System:

- Commercial image analysis software (ITEX-PC) consisting of a library of compiled "callable" subroutines was used for image capture and analysis functions.

* C-language subroutines were written and compiled by Sandia programmer to perform other functions.

* Overall program shell written in C-language to integrate commercial and homemade subroutines

* Data analysis and output uses commercial software (ASYST).

SMALL COMMUNITY SOLAR EXPERIMENT
AT OSAGE CITY, KANSAS

W. D. Batton

Barber-Nichols Engineering Co.
Arvada, Colorado 80002

The goal of this program is to provide 100 kWe (peak) using modules composed of point focusing concentrators and organic Rankine cycle engines (ORCE). The ORCE is mounted at the focal point of the concentrator. Each module will produce 25 kWe and uses an engine designed and manufactured by Barber-Nichols who is also the system integrator. The LaJet Energy Company's (Abilene, TX) innovative concentrator (IC) was recently selected as the concentrator to be used for the module.

The engine underwent development testing during the first half of 1986 and was delivered to the Sandia distributed receiver test facility (DRFT) in July of 1986. The engine was in test on the sun until April of 1987 when a ground-mounted, electrically heated test facility was constructed by DRFT personnel.

A second engine, whose design has been slightly modified to match the LaJet concentrator, is to be delivered to the SNL DRTF by August 1, 1987. This modified engine will be placed in the ground-mounted, electrically heated test facility for testing until the LaJet IC testing is completed. The engine will then be mounted on the concentrator for module acceptance testing.

The LaJet IC, using silver film, can potentially develop a heat input to the receiver of 147 kWt. The engine was originally designed for a heat input of 117 kWt, but has some additional capacity designed in. Because of the limited heat available in the test facilities used to date, the actual heat input limit to the engine remains undetermined. Therefore, the matching of the engine to the concentrator on a peak solar day has yet to be resolved.

The schedule for the program is to complete module testing during the fall of 1987 and to place the modules in the field (Osage City) in the spring of 1988. The goal is to have the field operational by June 1988.

SMALL COMMUNITY SOLAR EXPERIMENT AT OSAGE CITY, KANSAS

W. D. Batton
Barber-Nichols Engineering Co.

PROGRAM GOAL

Deliver 100 kWe (peak) Net to Grid
(Under Specific Conditions)

Requires Four 25 kW Modules

MODULE

EACH MODULE CONTAINS

- One Barber-Nichols Organic Rankine Cycle Engine (ORCE)

- One LaJet Energy Co. Innovative Concentrator

  - Engine is Mounted at Focal Point

  - Modules Deliver 600V DC to Inverters Which are Connected to Grid

ORCE

- Turbine Inlet 750°F and 465 psia
- Toluene Working Fluid (Subcritical)
- Air Cooled
- 60,000 rpm Turbine
- 60,000 rpm Permanent Magnet Alternator (PMA)
- Monotube Receiver (Boiler, Separator)
- Uses a Regenerator

MODIFICATIONS TO ORCE FOR LAJET IC

- Added Second Hotwell to Handle Large Roll Angle
- Provided More Drainage to Handle Roll and Pitch
- Modified Control Philosophy to Handle Rapid Focus Potential of IC

LAJET IC

- May Use Silver Film
- Will Have Active Aperture Plate Cooling
- Controls Modified to Track Off Axis Until Engine Has Completed Start Sequence

Osage ORCE in Test at SNL DRTF

PROGRAM SCHEDULE

JAN 1986	ORCE BEGINS DEVELOPMENT TESTING
JULY 1986	ORCE DELIVERED TO SNL DRTF
AUG '86 TO APR '87	ORCE IN TEST ON SUN
JUNE 1987	LAJET IC DELIVERED TO SNL DRTF
JUNE-JULY 1987	ORCE IN GROUND-MOUNTED TEST
AUG 1987	LAJET CONFIGURATION ORCE DELIVERED FOR GROUND-MOUNTED TESTING
FALL 1987	ORCE MOUNTED ON IC FOR MODULE TEST
SPRING 1988	MODULES DELIVERED TO FIELD
JUNE 1988	FIELD ON LINE

Power Kinetics SCSE #2
Molokai, Hawaii

Eugene A. Bilodeau
POWER KINETICS, INC.
415 River Street
Troy, NY 12180

Abstract

Power Kinetics, Inc. (PKI) is building a solar power station to be installed on the island of Molokai, Hawaii under a contract with the U.S. Department of Energy. The station will consist of five modules to produce 50 kW each. These consist of a 306m^2 point focus collector with polar axis tracking, a ground mounted steam engine driving an induction generator via a cam clutch, an oil fired boiler and superheater, and a water cooled condenser. The steam system will produce 363 kgm of steam per hour at 6.89 MPa. The temperature at the exit of the solar receiver will be 280°C and at the outlet of the superheater, 450°C. The boiler can produce the steam when there is no sun. The PKI Square Dish Solar Collector consists of 392 mirrors, 0.6 m (25") x 1.2m (48"), mounted on 28 identical open web triangular shaped mirror support beams, each of which supports 14 facets. The dish is aligned parallel to the earth's axis to simplify tracking. The rotating frame consists of three main girders extending from a central beam which is supported so that the girders clear the ground at all orientations. A 2-member boom extends from the frame to support the receiver 15m (50 ft.) from the mirrors. The collector can operate in an 18 m/s (40 mph) wind.

The system design for the Molokai Small Community Program optimizes flexibility. The heavy requirement for reliability because of the remote nature of the site, added significant engineering challenges, but most hurdles have been surmounted under the design phase of the program. The 306m^2 Square Dish is being manufactured at this time.

The design includes fired input for superheat and operation during low insolation periods. When the insolation value is between 500 W/m^2 and 700 W/m^2 the fire adds 100 kW of power to the steam and when it exceeds 700 W/m^2 the superheater operates alone, to provide 50 kW. The flow of feed water is controlled at all times to make the temperature of the steam leaving the superheater 450°C. The superheater is located below the saturated steam generator and is fired by its own smaller burner which is controlled separately.

The switching of the boiler and superheater fires is designed to use a combination of solar and oil whenever the system will produce more output than the same quantity of oil used in a diesel engine. In other locations, where waste biomass or crude or bunker oil is used for fuel, the strategy could depend upon the supply and cost of the fuel. The power needed from the burner to achieve this performance depends upon the insolation and the efficiencies of the boiler and engine.

Using a boiler efficiency of 0.85, and engine efficiency of 0.2 and a modern diesel engine efficiency of 0.33, the operations meets the condition that the oil is being used effectively when the solar input is equal to the power of the oil being used.

The power in the steam entering the engine needs to be 300 kW to produce 60 kW of shaft power. At 430°C and 800 psi this requires a flow of .0913 kgm/s (724 lbs/hr). With the 306m^2 collector and 40 kW from the superheater, that water flow results in the production of dry steam at 331°C when the insolation is 900 W/m^2. The flow will be controlled electronically to produce steam as near to 450°C as possible with oil used mainly for superheating.

SCSE #2 - MOLOKAI

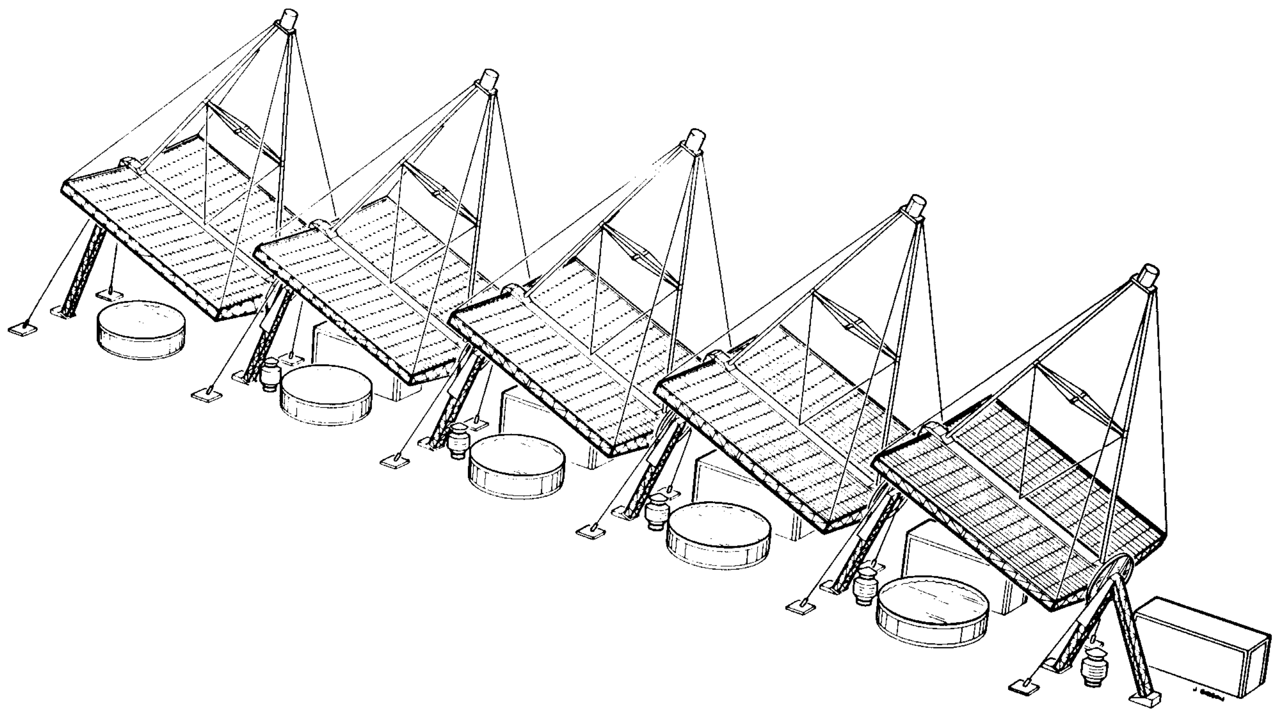
PROJECT DESCRIPTION

- COOPERATIVE AGREEMENT - U.S. DEPT. OF ENERGY/POWER KINETICS, INC.

- PARTICIPANTS - DOE, PKI, AUSTRALIA NATIONAL UNIVERSITY (ANU), SNLA, WG ASSOCIATES

- LOCATION - DEMONSTRATION UNIT (1-50 KW_E MODULE), SNLA, ALBUQUERQUE, NM
  - OPERATING STATION (5-50 KW_E MODULES), MOLOKAI, HI

SMALL COMMUNITY SOLAR EXPERIMENT
MOLOKAI, HAWAII



SCSE #2 - MOLOKAI

SYSTEM DESCRIPTION

- SOLAR COLLECTOR - PARABOLIC DISH, POINT FOCUS TYPE, POLAR MOUNT, TWO-AXIS TRACKING, SQUARE SHAPE, W/392 RECTANGULAR-SHAPED MIRRORS, 306 M^2 APERTURE AREA

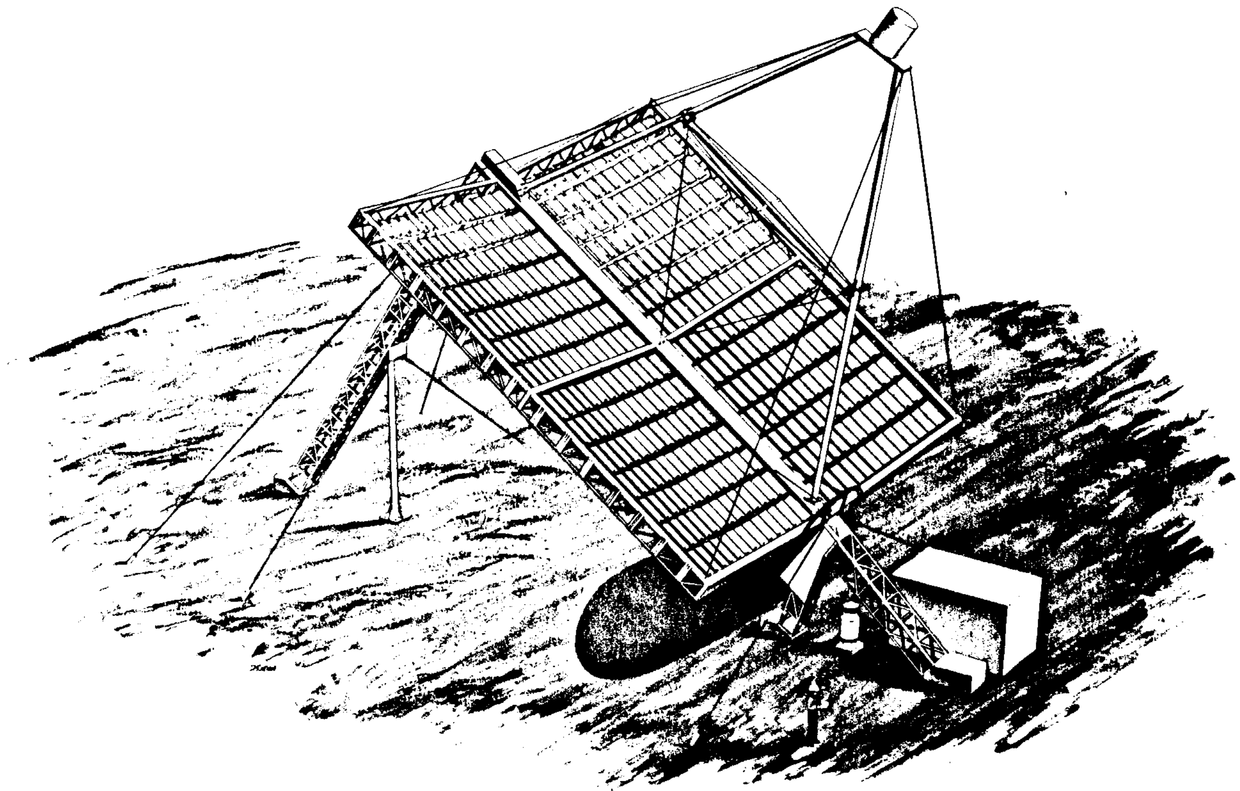
- RECEIVER - CYLINDRICAL CAVITY W/APERTURE COIL, BOILING WATER TYPE

- BOILER - OIL FIRED, TWO-LEVEL BURNERS W/SUPERHEATER, BOILER AND ECONOMIZER

- ENGINE/GENERATOR - ANU STEAM ENGINE/SPRAGUE CLUTCH/INDUCTION GENERATOR, 60 KW_E, 440 V

- CONTROLS - MICROPROCESSOR BASED FOR AUTOMATIC UNMANNED OPERATION

SMALL COMMUNITY SOLAR EXPERIMENT
MOLAKAI
(SANDIA EVALUATION UNIT)



SCSE #2 - MOLOKAI

CURRENT STATUS

1. DESIGN REVIEW - COMPLETED MARCH 4-5, 1987

2. MANUFACTURING DRAWINGS - NEAR COMPLETION

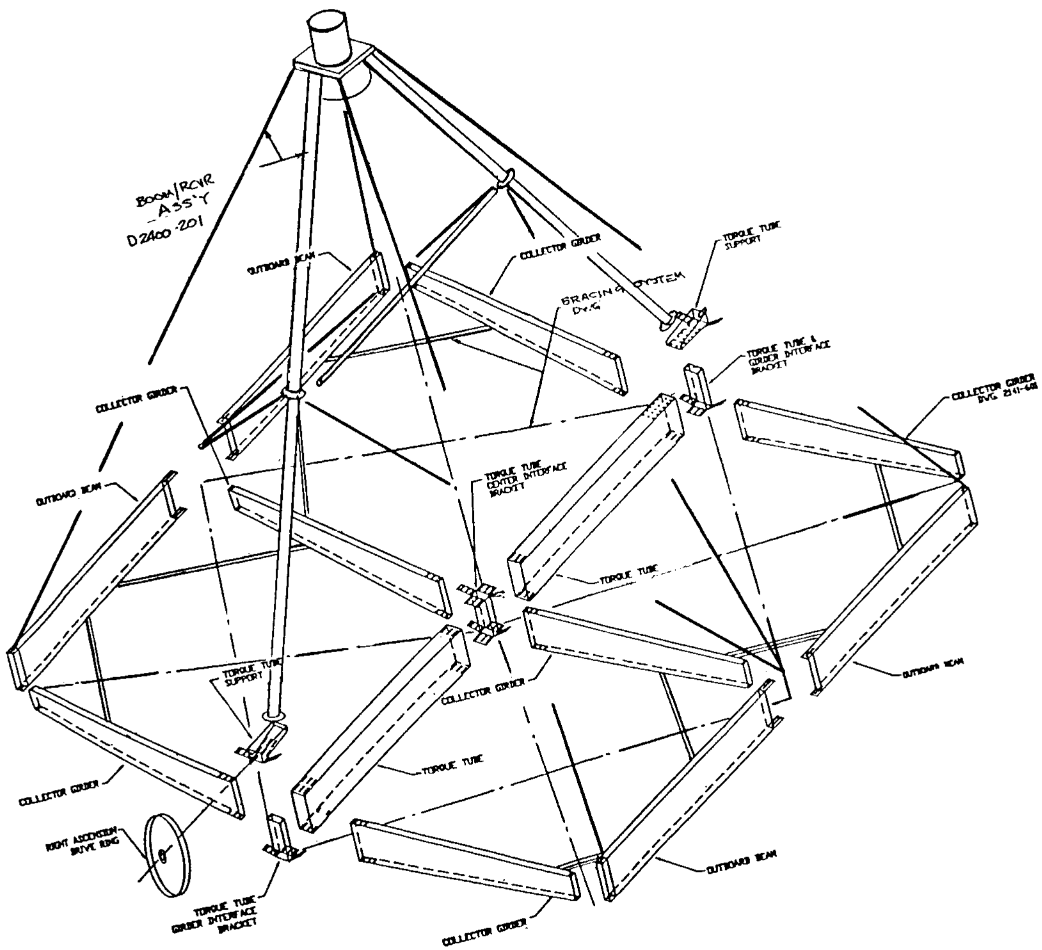
3. STRUCTURAL ANALYSIS - NEAR COMPLETION

4. ENGINE, BOILER, RECEIVER, ENGINE CONTROLS, AND MOST COLLECTOR CONTROLS - FABRICATION COMPLETE

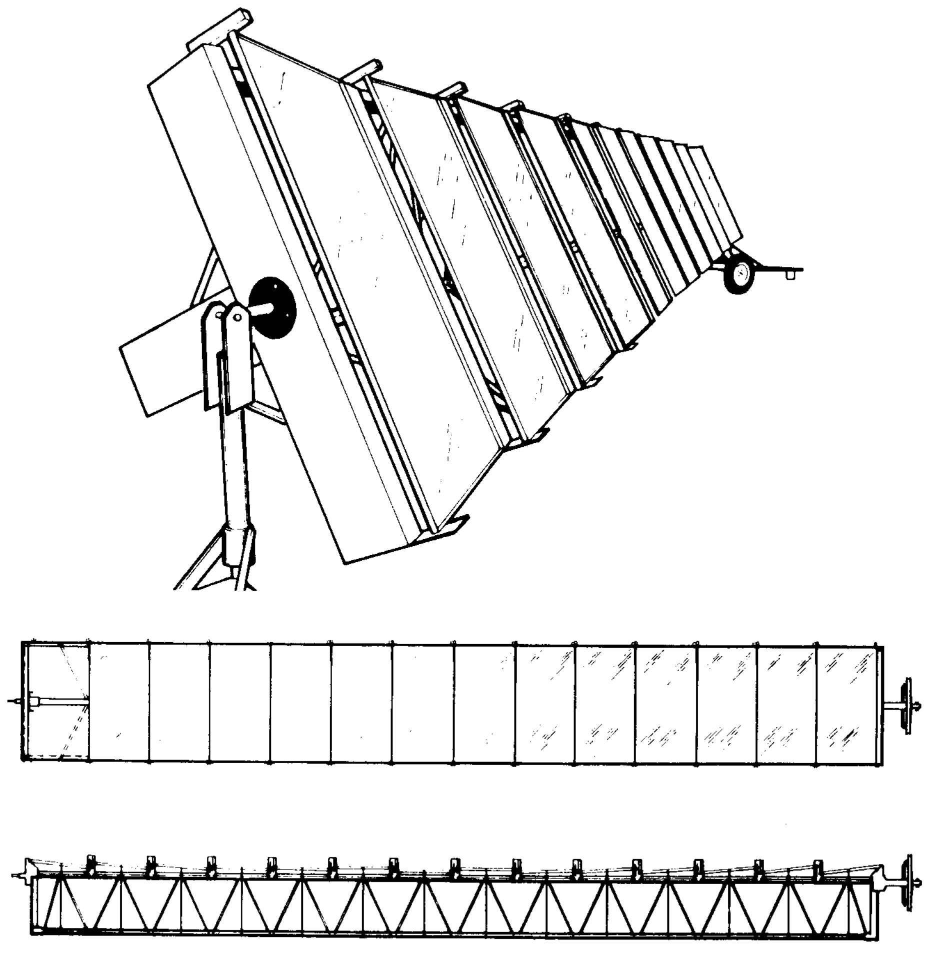
5. MIRRORS & MIRROR BEAMS - FABRICATION RELEASE, MAY 6, 1987

6. FOUNDATIONS (SNLA UNIT) - CONTRACT LET MAY 11, 1987

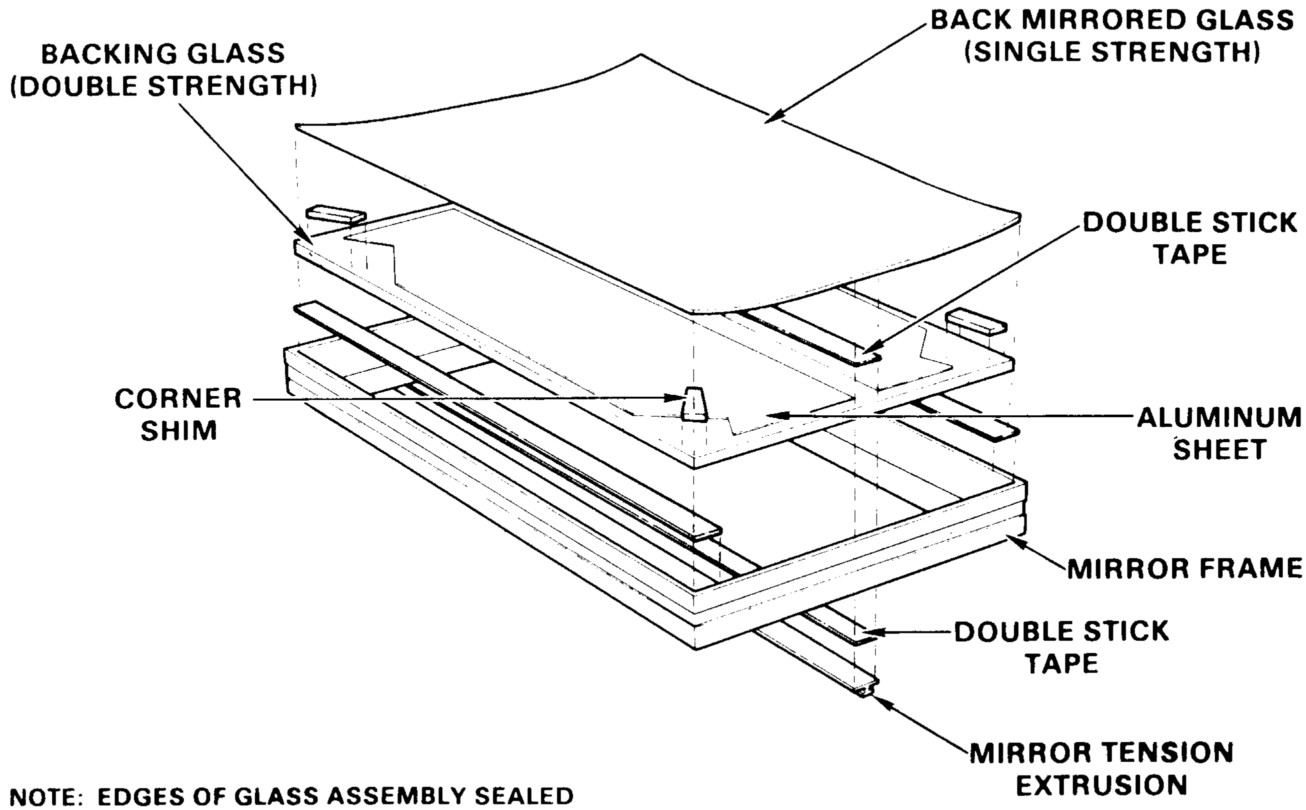
SCSE #2 - MOLOKAI
COLLECTOR FRAME ASSEMBLY



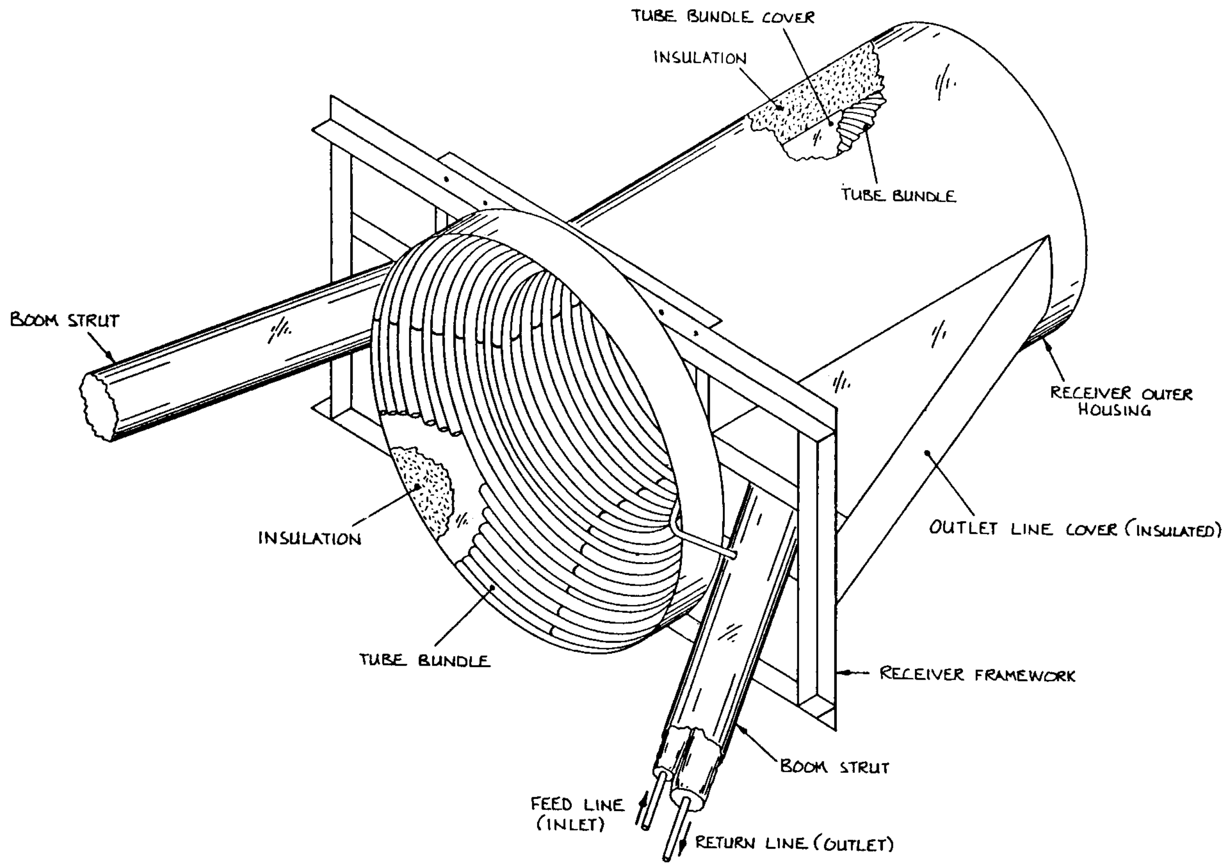
MIRROR BEAM ASSEMBLY



MIRROR FACET
(EXPLODED VIEW)

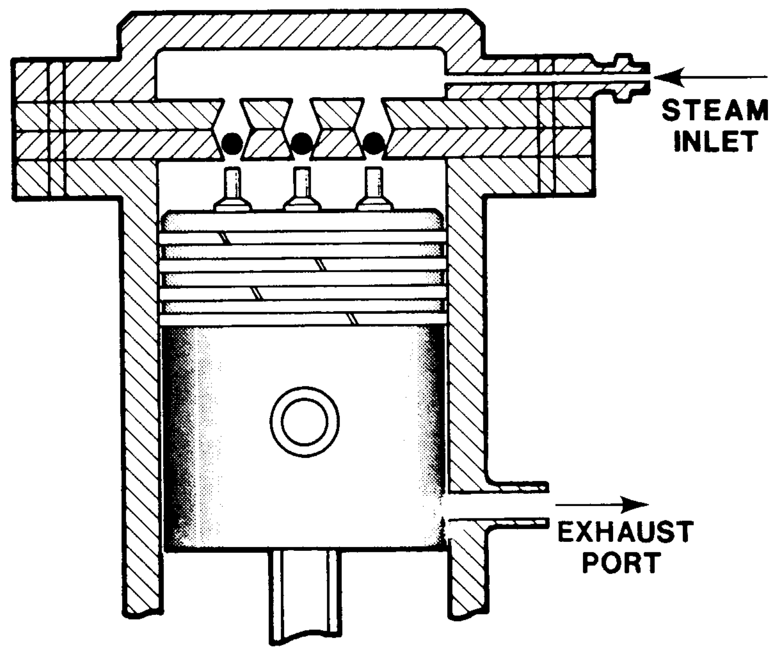


NOTE: EDGES OF GLASS ASSEMBLY SEALED
WITH HOT MELT BUTYL.
GLASS ASSEMBLY SEALED IN FRAME
WITH SILICONE.



SCSE #2 - MOLOKAI
RECEIVER ISOMETRIC VIEW

ANU STEAM ENGINE
(CYLINDER CROSS SECTION)



SCSE #2 - MOLOKAI

PREDICTED PERFORMANCE AT EQUINOX

	EFFICIENCY	POWER (KW)
DIRECT NORMAL	1.000	295.0
MIRROR REFLECTIVITY	0.870	256.7
SHADING & BLOCKING	0.994	255.1
TRACKING & STRUCTURE	0.990	252.6
RECEIVER ABSORPTION	0.977	246.8
RECEIVER THERMAL	0.987	243.5
PIPING THERMAL	0.992	241.6
OIL POWER ADDED		76.0
POWER IN FLUID		317.6
ENGINE EFFICIENCY	0.190	60.3
GENERATOR EFFICIENCY	0.930	56.1
PARASITICS (-6KWE)	0.107	50.1

PREDICTED PERFORMANCE AT SOLSTICE

	EFFICIENCY	POWER (KW)
DIRECT NORMAL	1.000	295.0
MIRROR REFLECTIVITY	0.870	256.7
SHADING & BLOCKING	0.994	255.1
TRACKING & STRUCTURE	0.970	247.5
RECEIVER ABSORPTION	0.977	241.8
RECEIVER THERMAL	0.975	235.7
PIPING THERMAL	0.992	233.8
OIL POWER ADDED		83.0
POWER IN FLUID		316.8
ENGINE EFFICIENCY	0.190	60.2
GENERATOR EFFICIENCY	0.930	56.0
PARASITICS (-6KWE)	0.107	50.0

LaJET ENERGY COMPANY
UPDATE ON SOLARPLANT 1

Monte A. McGlaun

LaJet Energy Company
P. O. Box 3599
Abilene, Texas 79604

LaJet Energy used internal dollars and private funding to design and build SOLARPLANT 1, a solar thermal electric-generating power plant at Warner Springs, California. SOLARPLANT 1 has 700 LEC 460 solar concentrators creating a 4.92-megawatt generating capacity. Superheat steam at 750F and 675 psi is produced to drive two traditional turbine-generator sets. A steam Rankine cycle thermodynamic closed loop process is used to transfer and convert solar energy to electric energy. Since starting operation in January 1985 considerable experience has been gained in plant operation and maintenance techniques. Presently a retrofit is underway on the reflective film for the mirror facets, electronic controls update, and selected drive assembly components. Structural performance in wind loading has been satisfactory; the only structural failures that have occurred were due to manufacturing defects and non-standard loading conditions. Daily start-up procedures represent most of the routine difficulties due to condensate in steam lines that must be dried prior to turbine roll. The most recent change is the installation of two 1 megawatt diesel generator sets with exhaust heat recovery as steam. The recovered heat augments the solar generated steam, increases the net efficiency of the diesel fuel, and permits revenue during night time and inclement weather. Significantly, the recovered heat preheats the turbine and steam headers and establishes condenser vacuum prior to acquisition of the sun by the solar side of the field, thereby, reducing the solar start-up time. The diesel retrofit was made possible by a joint venture between LaJet Energy and Cummins Engine Company.

LaJet ENERGY COMPANY
3130 Antilley Road
P.O.box 3599
Abilene, Tx. 79604
(915) 698 – 8800

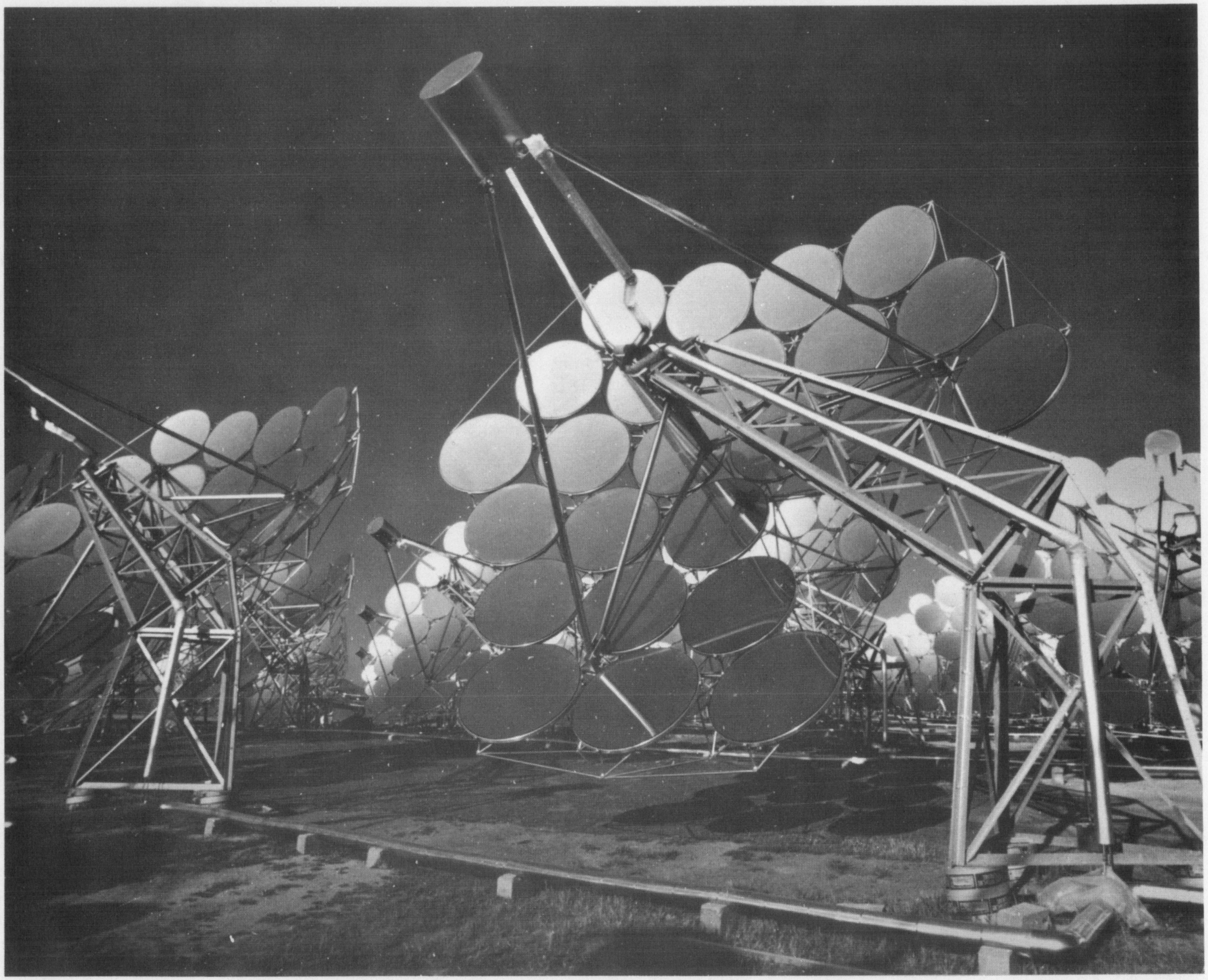
HISTORY OF SOLARPLANT 1

Started operation in January 1985

Privately funded

Located near Warner Springs, California
On a 40 acre site within site of Mt. Palomar

Based on the LEC 460 the 7th Model of LaJet Energy's Solar Concentrators



Lajet
ENERGY
COMPANY
3130 Antilley Road
P.O. box 3599
Abilene, Tx. 79604
(915) 696 – 6800

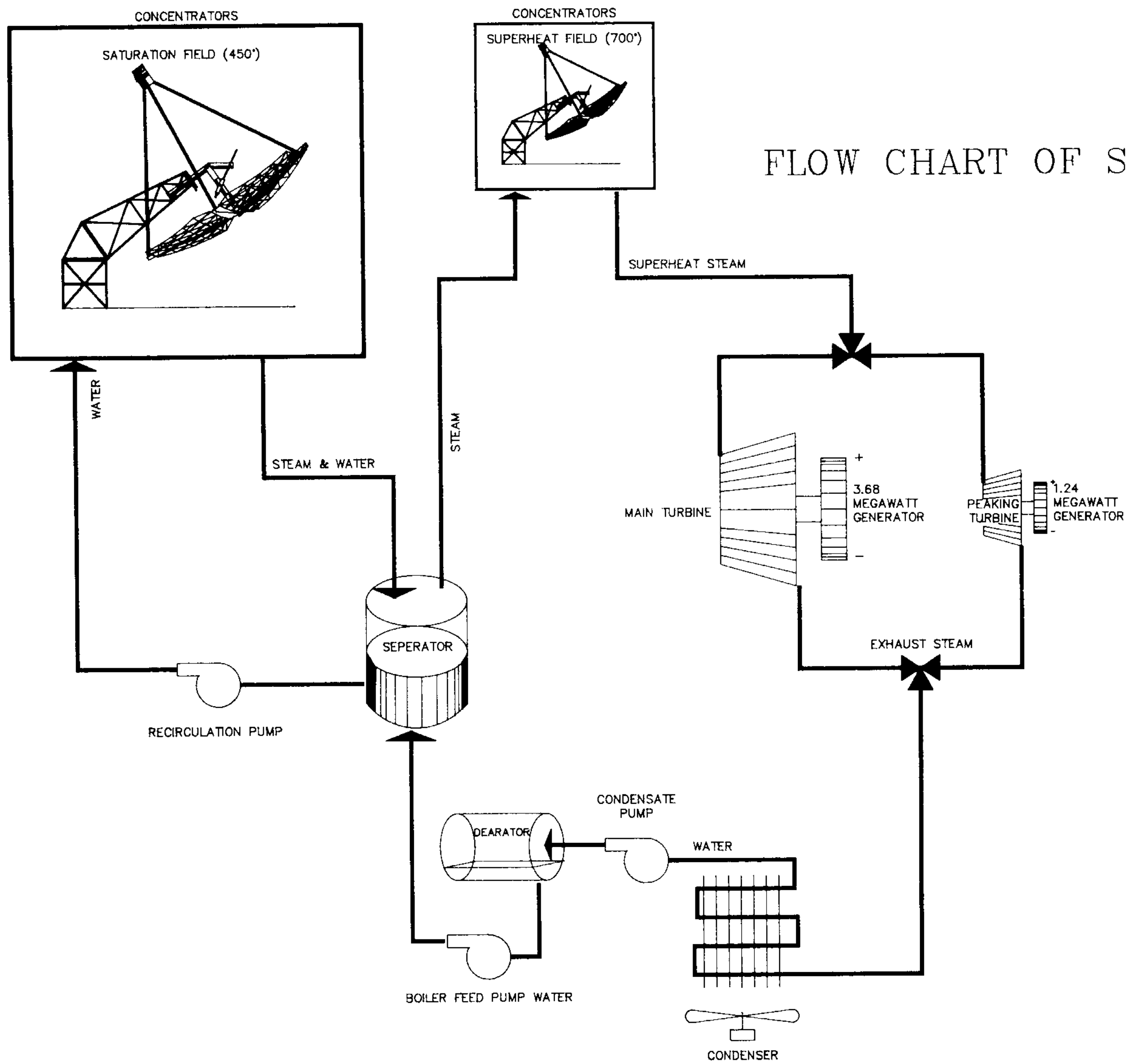
SPECIFICATIONS

**700 LEC 460's Arranged in Two Fields:
Saturated (450F) and Superheat (700F)**

**4.92 Peak Electrical Output
From Two Turbines**

**Designed Average Electrical Output
12,000,000 kwh/year**

FLOW CHART OF SOLARPLANT 1



Lauer ENERGY COMPANY
3130 Antilley Road
P.O.box 3599
Abilene, Tx. 79604
(915) 698 – 8800

SOLARPLANT 1 OPERATIONAL UPDATE

CHANGES TO THE SOLAR SIDE

Receiver redesign and installation to correct faulty welds
Flexible hose material change to resist chloride attack
Electronic & Electrical equipment update
Mirror reflective film change-out with higher strength substrate
Upper declination pivot support assembly change-out

CHANGES TO POWER CONVERSION SIDE

Piping changes to enhance dry-out in morning start-up by improving drainage and condensate collection

Laucet ENERGY COMPANY
3130 Antilley Road
P.O.box 3599
Abilene, Tx. 79604
(915) 698 – 8800

SOLARPLANT 1 OPERATIONAL UPDATE

OPERATIONAL CHALLENGES

SOLARPLANT 1 is required to start-up the steam system on a daily basis versus most industrial systems which may start-up twice a year.

Weather related delays can last for several days which cause piping to lose all residual heat.

Start-up after several prior days of operation takes 30 to 60 minutes.

Start-up after extended shut-down can take half a day

LaJet ENERGY COMPANY
3130 Antilley Road
P.O. box 3599
Abilene, Tx. 79604
(915) 698 - 8800

SOLARPLANT 1 OPERATIONAL UPDATE

CURRENT STATUS

Through a joint venture with Cummins Engine SOLARPLANT 1 has been modified to a solar/diesel combined cycle.

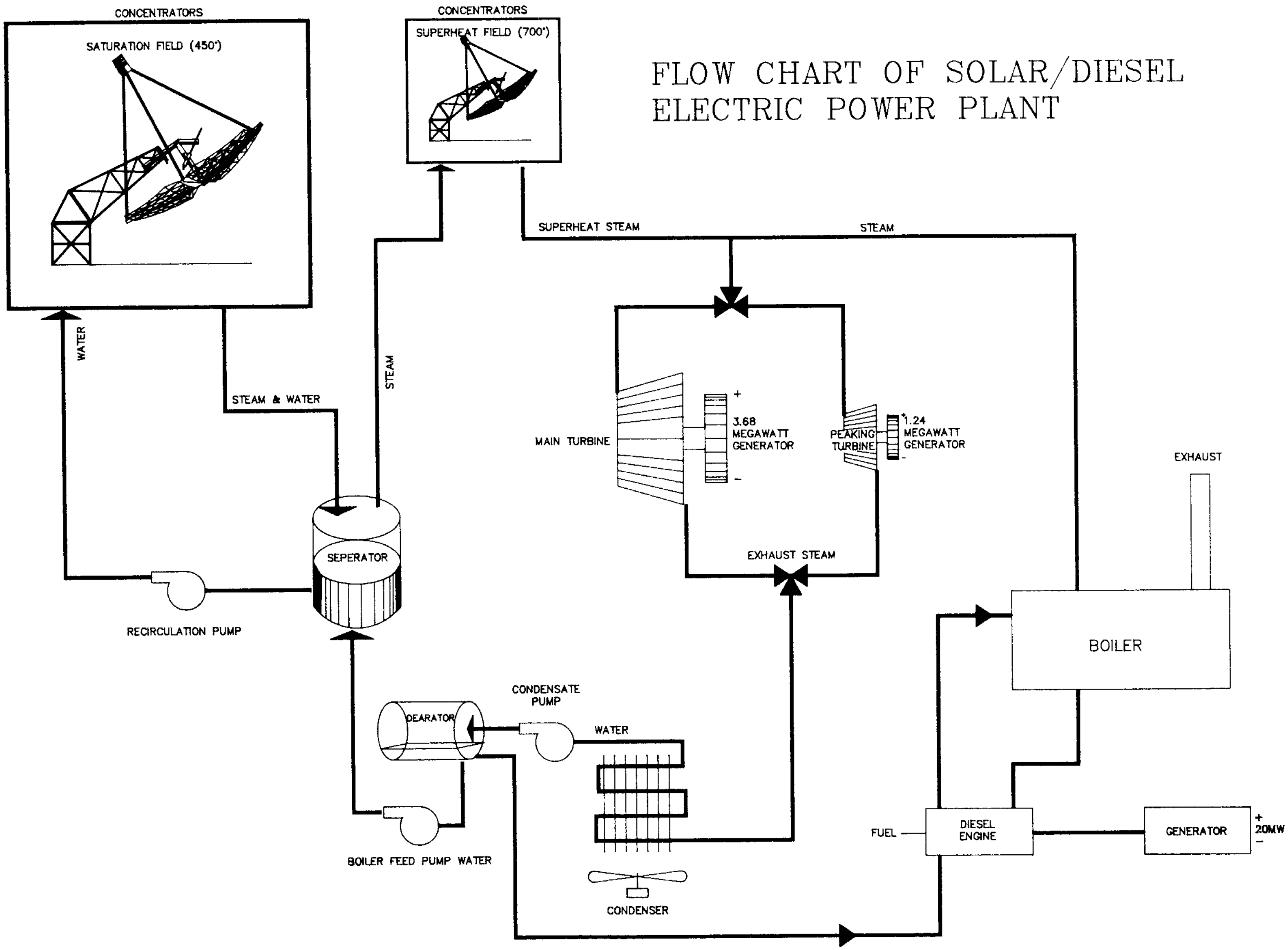
Two 1 mw diesel generator sets have been installed with exhaust heat recovery

Benefit of combined cycle are:

Recovered heat will keep headers and turbine warm,

Turbines will increase diesel fuel efficiency

Revenue stream continues during solar down-time



FLOW CHART OF SOLAR/DIESEL ELECTRIC POWER PLANT

SESSION III

CENTRAL RECEIVER TECHNOLOGY

DAN ALPERT

CHAIRMAN

STATUS - CENTRAL RECEIVER TECHNOLOGY

J. V. OTTS - SANDIA NATIONAL LABORATORIES

The current status of the Central Receiver Technology program will be presented by a matrix of components and subsystems vs. performance, life expectancy and cost.

This will be followed by a discussion of FY88-89 plans and objectives. Special emphasis will be placed on the concentrator and receiver tasks.

Molten Salt Subsystem/Component Test Experiment

Receiver Test Results

David C. Smith

THE BABCOCK & WILCOX CO.
91 Stirling Avenue
Barberton, Ohio 44203

The Molten Salt Subsystem/Component Test Experiment (MSSCTE) receiver is designed to incorporate key features of large scale commercial receivers. The receiver is a north facing "C" shaped cavity design with aperture wing panels to catch side spillage, and an insulated aperture door so that the cavity may be closed to minimize heat loss when the plant is not operating. The receiver is sized for an input of 5 MWt from the CRTF collector field, with a nominal output of 4.5 MWt. The test plan was designed to confirm the basic design of the receiver, measure its performance, and define the capabilities of the receiver for operation in clouds, and at sunrise.

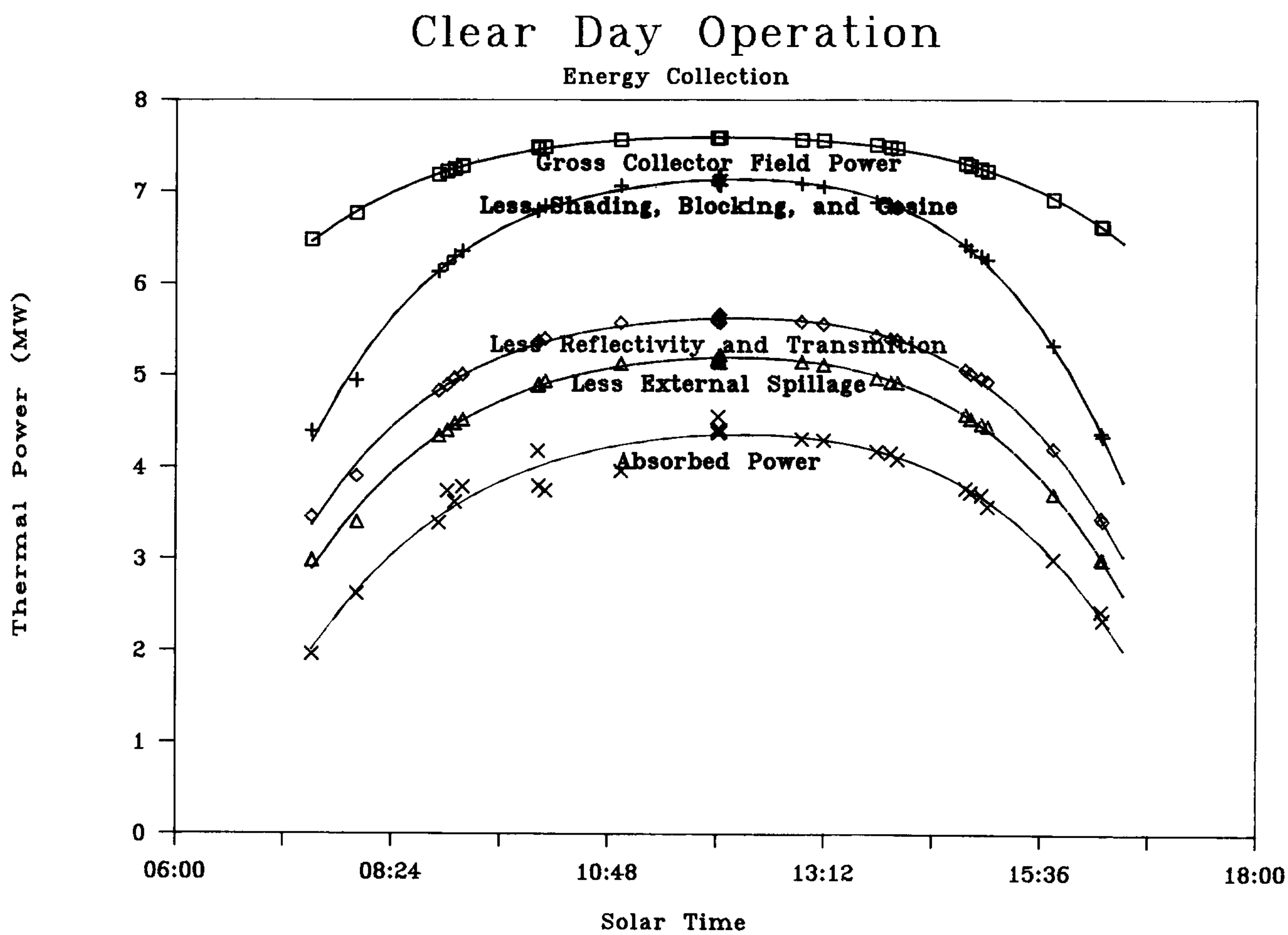
Six tests were performed to meet these objectives. Steady state operation results show a maximum receiver power of 4.4 MWt at solar noon, and the capability to absorb 3 megawatt hours on a typical 9 hour mid-April day. Transient testing demonstrated that good outlet temperature control can be achieved but that transient thermal stresses are significant. The receiver losses were measured by the method of complimentary field configurations, and calculated based on predictions of input power vs. measured absorbed power. Based on these, a receiver efficiency of approximately 90% is calculated. Morning startup of the receiver was demonstrated using cavity electric heaters to establish salt flow in the receiver before sunrise, allowing the full collector field to track the receiver at sunrise. Startup was also demonstrated starting with a cold receiver, using heliostats to warm the panel to above the salt freezing point, and then establishing flow and bringing the full field on target. This allows a comparison of the energy used, and energy collected by the two methods. Overnight conditioning of the receiver was also demonstrated by circulation of salt through the receiver panels and piping. This minimized the parasitic load of the heat trace system, and takes the place of cavity heaters.

No major problems with the receiver were uncovered in the test but several areas where improvement is warranted were found. These included: control features to minimize thermal stress, alternative attachments to the receiver tubes, and better instrumentation.

Olin
Black & Veatch Consulting Engineers
Babcock & Wilcox a McDermott company
APS
Southern California Edison Company SCE
McDONNELL DOUGLAS
FOSTER WHEELER
THE UNIVERSITY OF UTAH
Sandia National Laboratories

<u>**STEADY STATE OPERATION**</u>

LOSS ESTIMATES BY PREDICTION OF INPUT VS. MEASURED OUTPUT



Cosine, Shading & Blocking: .94

Reflectivity, Atmospheric Transmission: .79

External Spillage: .923

Receiver Efficiency: .86

RECEIVER DESCRIPTION

- "C" Shaped Cavity Receiver With
    - Door
    - Wing Panels
- Molten Salt Cooled
- 4.5 MWt (Absorbed) Rating
- 550F Inlet 1050F Outlet Temperature
- Alloy 800/304 Stainless Steel Panels

TEST OBJECTIVES:

- CONFIRMATION OF DESIGN
    - o Heat Flux within Limits
    - o Thermal Expansion System Working
    - o Controls Functioning
- MEASUREMENT OF PERFORMANCE THERMAL/HYDRAULICS
    - o Efficiency: Design Point
    - o Energy Collection
- DEFINITION OF CAPABILITIES
    - o Morning Startup
    - o Cloudy Operation
    - o Overnight Conditioning

TEST SUMMARY

1. Steady State Performance
2. Receiver Operations with Clouds
3. Receiver Thermal Loss Rate - Flux Off & Flux On
4. Maximum Transient Response
5. Receiver Optimum Startup Development
6. Overnight Thermal Conditioning

MOLTEN SALT SUBSYSTEM/COMPONENT TEST EXPERIMENT

RECEIVER TEST RESULTS

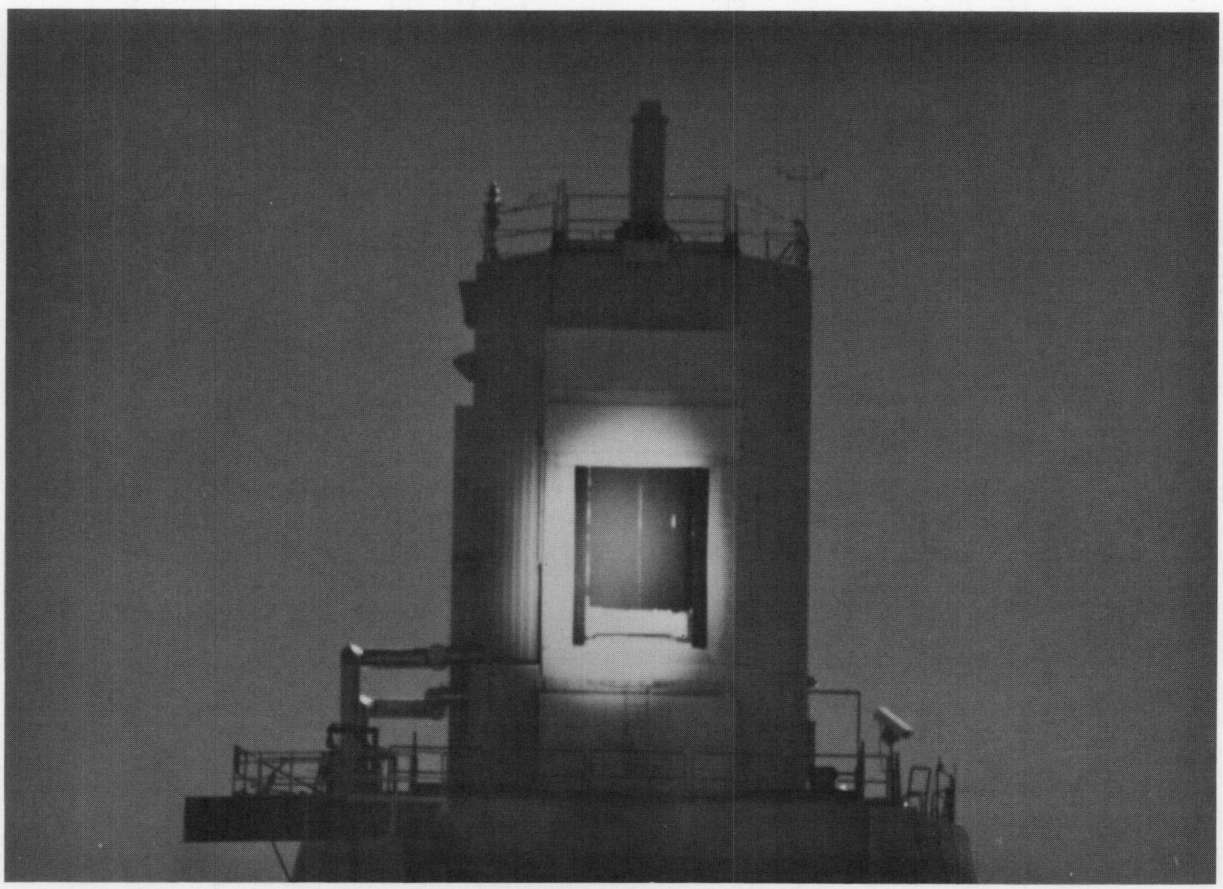
Presented at the

Solar Thermal Technology Conference

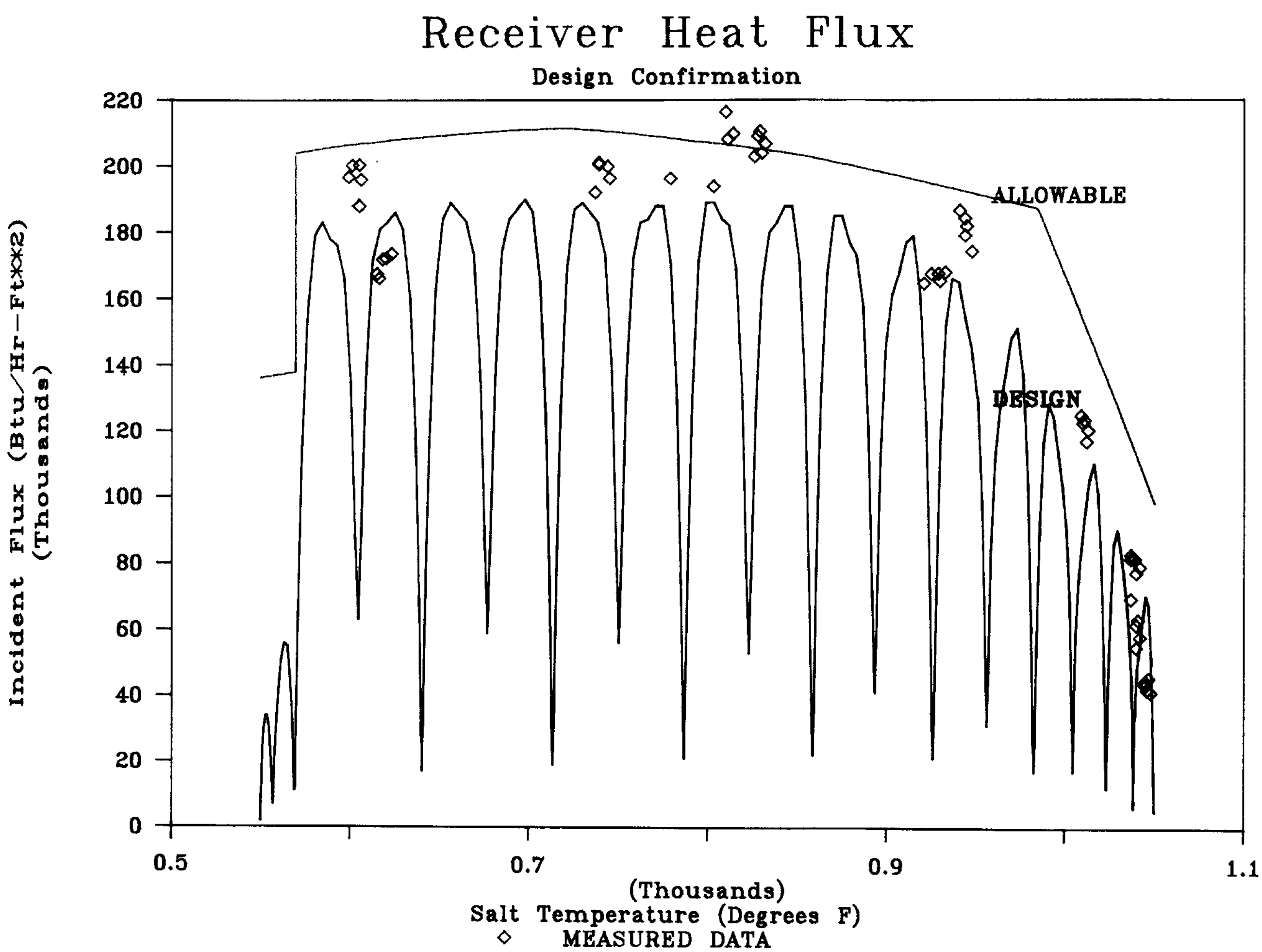
August 26 - 27, 1987

Albuquerque, New Mexico

David C. Smith
The Babcock & Wilcox Co.



STEADY STATE OPERATION



- Flux Data Higher Than Predictions
- Instrumentation is Inaccurate
- Large Margin or Risk Acceptance Required

TRANSIENT OPERATION

CONTROL OBJECTIVES

Maintain Rated Outlet Temperature

Maximize Energy Collection

Minimize Thermal Fatigue Damage

Maintain Safe Conditions

TEMPERATURE CONTROLLER DESCRIPTION

Control Valve Position Derived from

- Flux Feed Forward
- Back Tube Temperature Feed Forward
- Outlet Temperature Feed Back
- Flow Feed Back

RESULTS

Flux Signal is Essential

Good Temperature Control Achieved

Large Thermal Stresses Occur - Improvement Required

RECEIVER THERMAL LOSS TESTS

Door Closed Loss Test

10-20 KW (Function of Wind)

Flux Off (Door Open) Loss Test

115 KW - 200 KW (Function of Wind)

Complementary Field Partitions ("Method of Barron")

270 KW (94% Efficiency)

STARTUP TESTS

	Time Til Full Collector Field on Target	Time Til Rated Outlet Temperature From Both Zones	Energy Collection (First Hour)
With Cavity Heaters	0 Min	75 Min	1.47 MWH
With Solar Warmup	35 Min	75 Min	1.18 MWH

OVERNIGHT CONDITIONING

	PARASITIC POWER
ELECTRIC HEAT	
Electrical Heat Trace	35 kw
With Cavity Heaters	47 kw
WITH SALT CIRCULATION	
Electric Heat Trace	3.3 kw
Thermal Loss from Salt (Estimated)	44 kw
Pump Electrical Power (Projected)	13 kw

OPERATIONAL PROBLEMS

- Salt Leaks at Tube Welds
- Flow Instrumentation
- Pyromark Paint
- Water Cooled Flux Gages
- Heat Trace
- Salt Pumps & Valves

CONCLUSIONS

- No Major Problems Unresolved
- Design Confirmed for Scale Up
- Performance as Expected
- Receiver Fully Operated

IMPROVEMENT AREAS

- Control Features to Minimize Thermal Stress
- Panel Header Design
- Alternatives for Support Attachments
- Flow Measurement

Optimization of the Molten Salt Subsystem Component Test Experiment Receiver Performance

James M. Chavez
and
James W. Grossman

Sandia National Laboratories

The Molten Salt Subsystem Component Test Experiment (MSS/CTE) receiver was designed, constructed, and tested in a program funded by the United States Department of Energy. The MSS/CTE receiver is a 5 MWt partial cavity receiver which uses molten salt as the working fluid. In the receiver Operational Test phase (described in another presentation) the operational capabilities of the receiver were demonstrated and characterized. However, during the Operational Test phase no receiver optimization testing was performed. Therefore, additional receiver testing is needed to optimize the receiver performance.

The Optimization Testing is a continuation of the Operational Test phase recently completed and will consist primarily of receiver thermal loss tests, front surface temperature measurements, receiver control algorithm modifications, maximum energy production, and improved aiming strategies. The receiver thermal loss tests will complement similar tests performed in the Operational Test phase. Receiver front surface temperature measurements (to be obtained using an infrared camera) will be used to evaluate thermal losses and to compare with computer model predictions. Receiver control algorithm modifications are needed to refine the flow and temperature control algorithm and to reduce the flux/flow mismatch which can cause excessive thermal stresses in the receiver. The data from the maximum energy production testing will be used to predict the annual energy conversion from this type of receiver. Improving the heliostat aiming strategies will optimize receiver performance and energy production.

The Optimization Tests and key results will be described in this presentation.

Optimization of the Molten Salt Subsystem Component Test Experiment Receiver Performance

Presented at the Solar Thermal Technology Conference

August 26-27, 1987

James M. Chavez
James W. Grossman

Sandia National Laboratories
Albuquerque, New Mexico

Optimization Testing of the MSS/CTE Receiver

PURPOSE: CONTINUE TESTING OF THE MSS/CTE RECEIVER TO FURTHER CHARACTERIZE RECEIVER OPERATIONAL CAPABILITIES AND TO OPTIMIZE RECEIVER PERFORMANCE

TEST OBJECTIVES:

- REFINE DATA ON RECEIVER THERMAL LOSSES
- PROVIDE ADDITIONAL DATA FOR MODEL VALIDATION
- OPTIMIZE RECEIVER PERFORMANCE

Testing to be Conducted During the Optimization Test Phase

- Receiver Thermal Loss Testing
- Receiver Front Surface Temperature Measurements
- Receiver Control Algorithm Modifications and Tuning
- Maximum Energy Production
- Improved Aiming Strategies

MOLTEN SALT SUBSYSTEM/COMPONENT TEST EXPERIMENT
PUMP AND VALVE TEST RESULTS TO DATE

Patricia A. Bator

The Babcock & Wilcox Company
91 Stirling Ave.
Barberton, Ohio 44203

The Molten Salt Subsystem/Component Test Experiment (MSSCTE) Pump & Valve Test was designed to test commercial scale pumps and valves at commercial plant conditions using molten salt. The P&V consists of two loops, a hot salt loop (1050°F), and a cold salt loop (550°F). Each loop contains five valves and one pump designed to utility scale specifications, specifically the Saguaro solar power plant conditions. The test has been designed to test the pumps over design flow range, nominally 1000 to 2300 gpm; and the valves through typical control valve cycles, 0 to 80 percent. The test will run for six months, five days per week. The pumps will simulate approximately 800 cycles or two years of commercial pump cycling. The valves will accumulate about 1700 hours of service or a half a year of commercial operating time.

The construction of the P&V was completed in March and water tests performed to checkout pump and valve operation as well as the control system and instrumentation. The water tests on both loops have provided a baseline performance curve for each of the pumps and have shown good comparison with the manufacturer's curves. Cycling of the control valves has allowed for characterization of the valves and corrections in the control set points due to variations from the manufacturer's curve.

THERMOMECHANICAL FATIGUE OF SOLAR CENTRAL RECEIVER COLLECTOR TUBE ALLOYS*

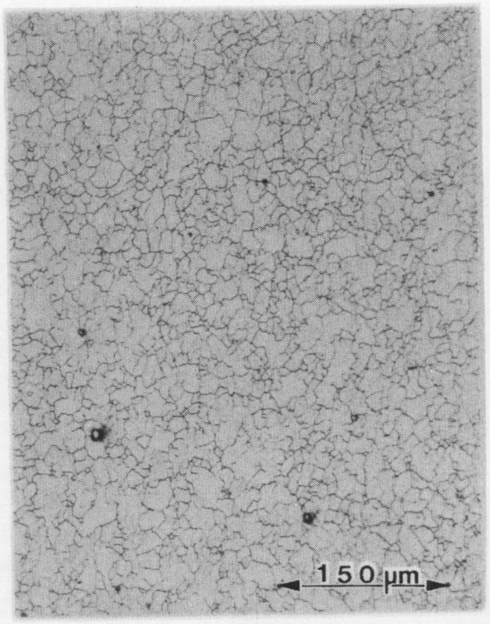
W. B. Jones
R. J. Bourcier
J. A. Van Den Avyle

Sandia National Laboratories
Albuquerque, NM 87185

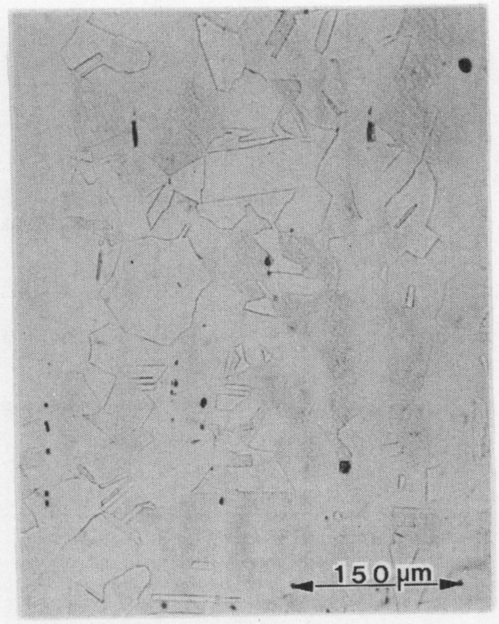
Thermomechanically induced fatigue (TMF) is known to be an important part of the service conditions present in solar central receiver plants. In conventional fossil and nuclear power plants, the number of thermal cycles is purposely kept small to minimize the damaging effects of thermomechanical deformation. In solar receivers the diurnal solar cycles and cloud passage make this impossible. The current baseline service condition established for central receiver design is 10,000 cycles accumulation in 30 years plant lifetime. The ASME Boiler and Pressure Vessel Code and Code Case N-47, which have been used to design stainless steel collector tubing, do not explicitly treat TMF effects. Rather, they assume that isothermal cycling at the peak temperature is a conservative estimate of fatigue lifetime under thermomechanical cycling conditions. We are carefully testing this assumption and examining the strengthening and fatigue crack growth mechanisms present during TMF.

Both Alloy 800 and 316 Stainless Steel have been examined under conditions of both isothermal low cycle fatigue (LCF) and thermomechanical fatigue (TMF). The TMF tests were conducted between 649 and 360°C with a carefully controlled triangular waveform. The LCF tests were performed at 649°C and both kinds of tests were subjected to a strain range of 0.5%. TMF shortens the fatigue life of both 316 Stainless Steel and Alloy 800 when compared to LCF cycling. This loss of fatigue life is more marked in Alloy 800 (95% life reduction) than for 316 Stainless Steel (60% life reduction). The microstructural evolution occurring in both alloys has been examined and we conclude these do not play a role in the life shortening caused by TMF. The TMF does produce asymmetric hysteresis loops with large tensile peak stresses in tests where the maximum temperature corresponded with the peak compressive stress. Differences in time-dependent flow characteristics between these alloys produce this effect. The influence of TMF on fatigue crack growth rates has been measured and it was found that TMF accelerated crack growth in Alloy 800 and slowed it down slightly in 316 Stainless Steel. The dominant influence of TMF appears to be in fatigue crack initiation, with the tensile peak stress development driving early crack initiation. This effect must be considered in the design of structures which see thermal cycling in service.

*This work was supported by the U.S. Department of Energy under contract number DE-AC04-76-DP00789.

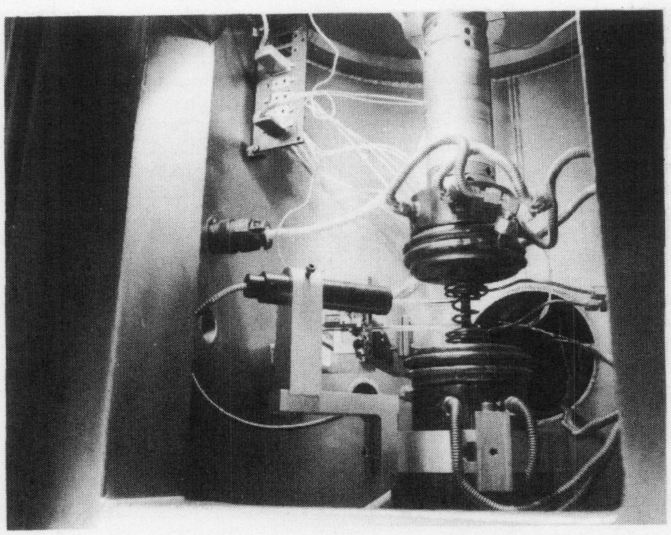


(a)

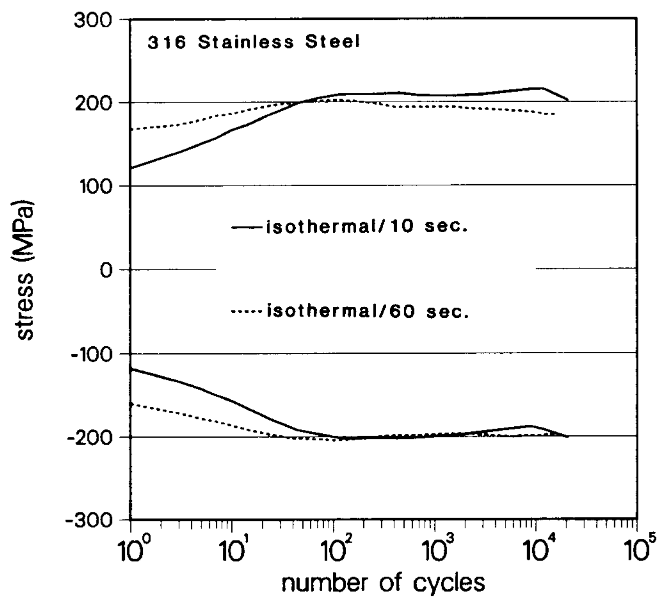


(b)

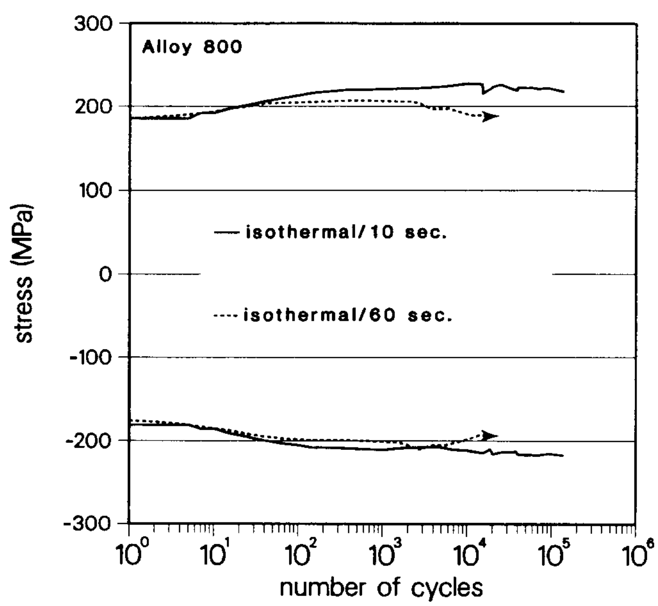
Optical microstructures of (a) Alloy 800 and (b) 316 Stainless Steel.



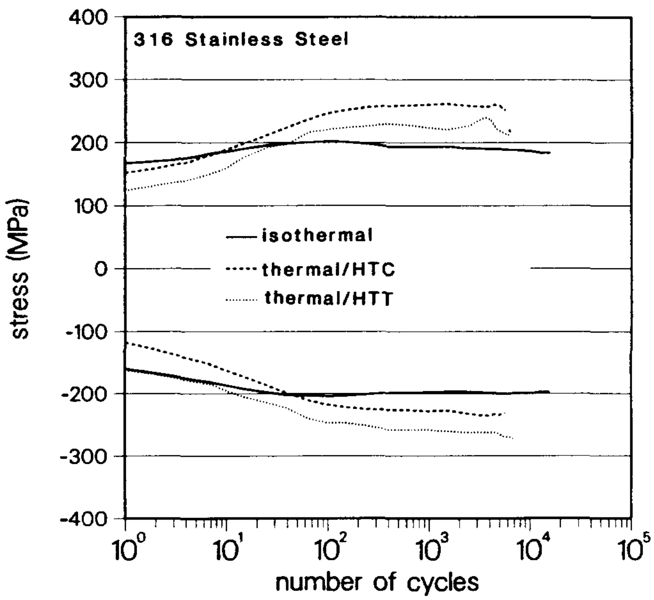
Testing configuration.



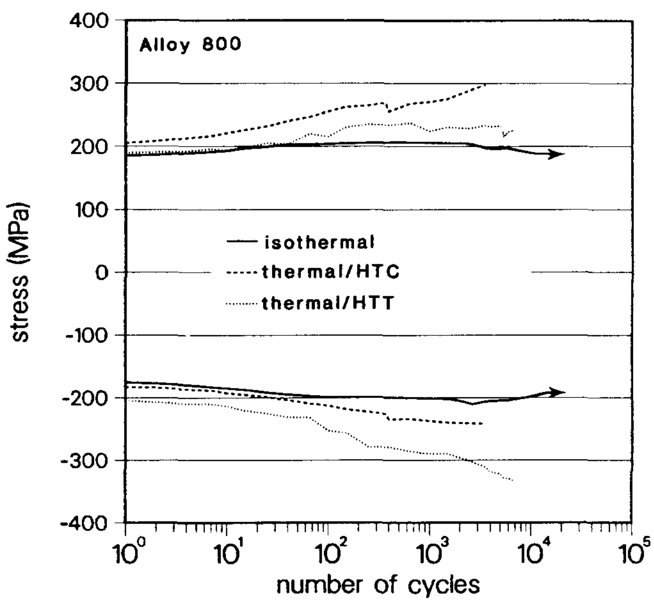
Cyclic hardening of 316 Stainless Steel in isothermal fatigue, 649°C, $\Delta\varepsilon$=0.5%.



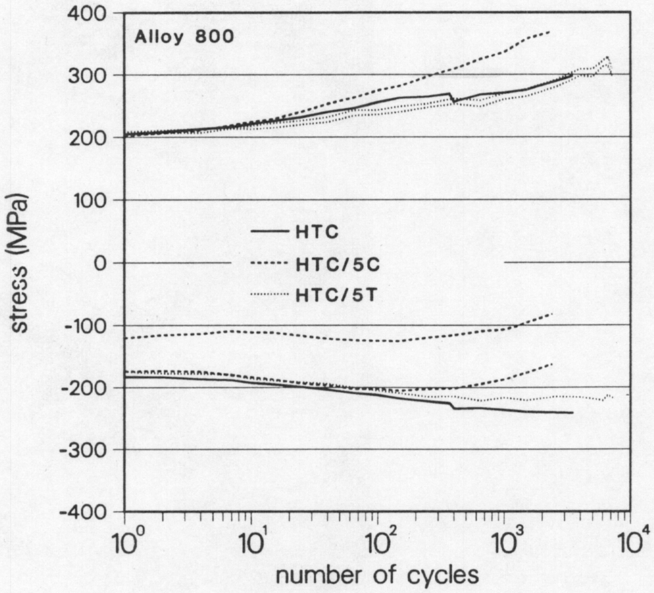
Cyclic hardening of Alloy 800 in isothermal fatigue, 649°C, $\Delta\varepsilon$=0.5%.



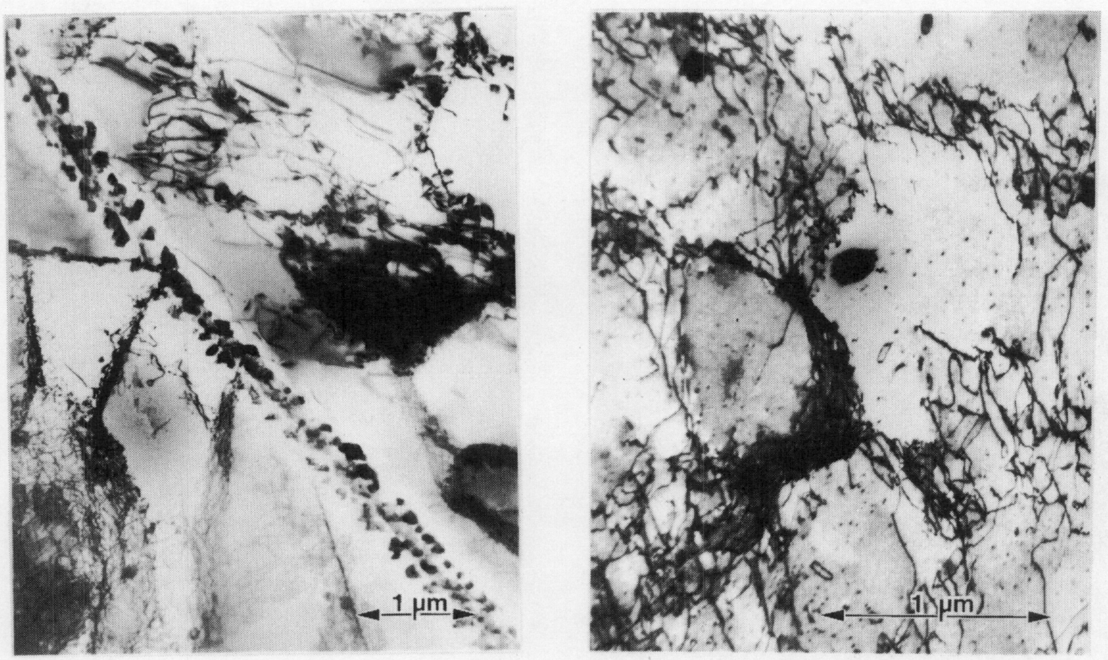
Cyclic hardening of 316 Stainless Steel in thermomechanical fatigue.



Cyclic hardening of Alloy 800 in thermomechanical fatigue.



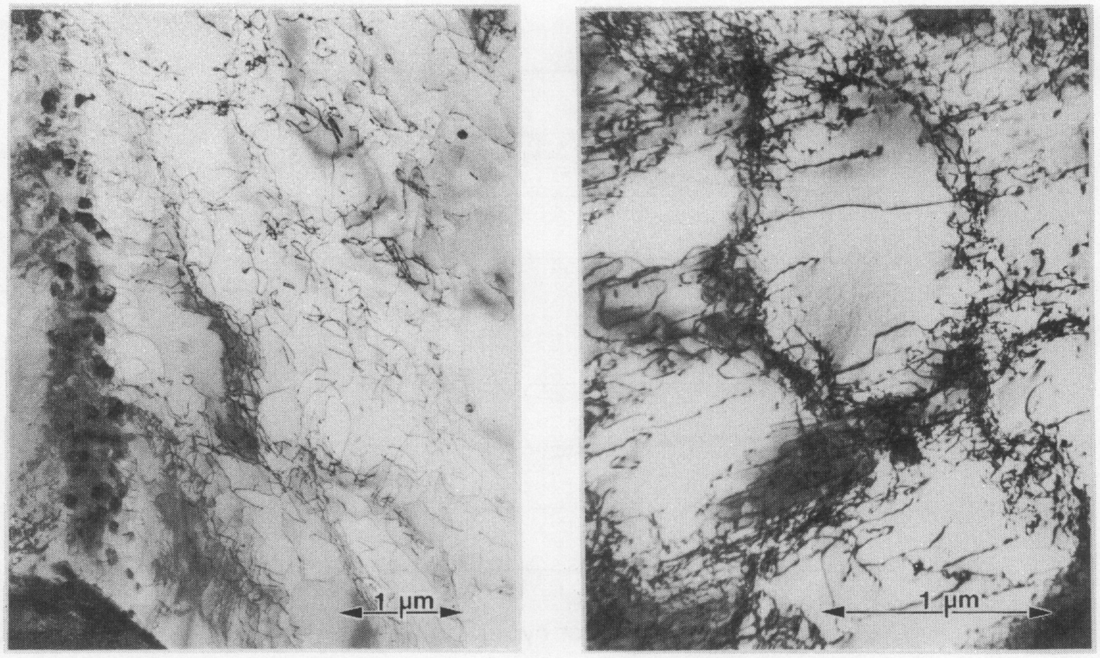
Cyclic hardening of Alloy 800 in thermomechanical fatigue with hold periods.



(a)

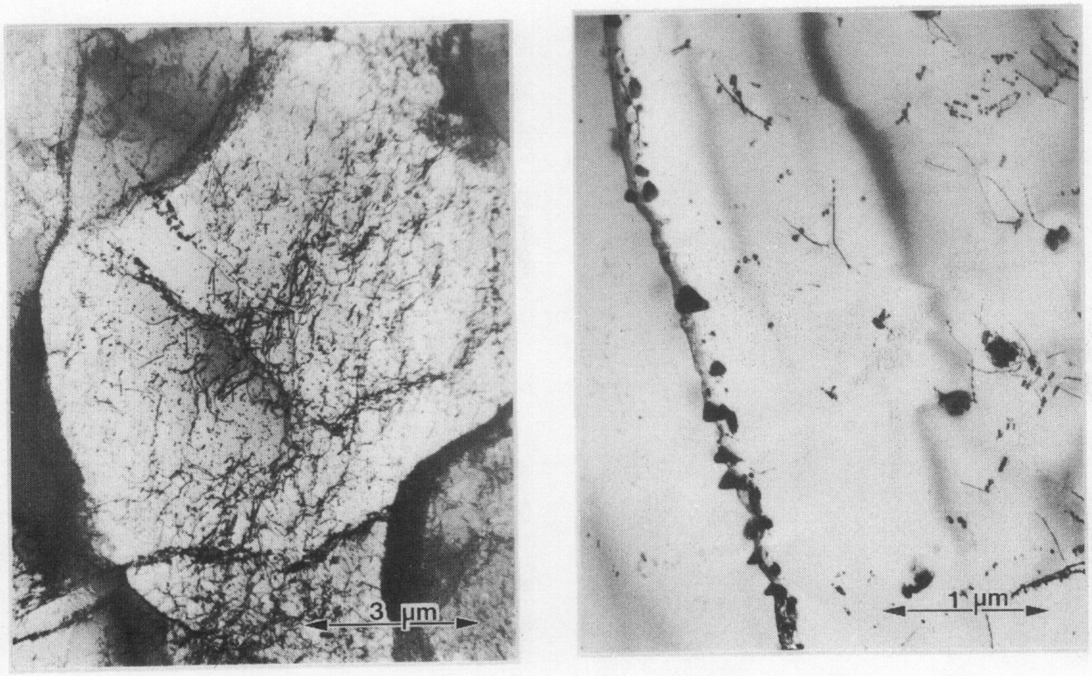
(b)

Transmission electron micrographs of 316 Stainless Steel isothermally fatigue cycled at 649°C, 6 s/cycle, 36 hr test duration.



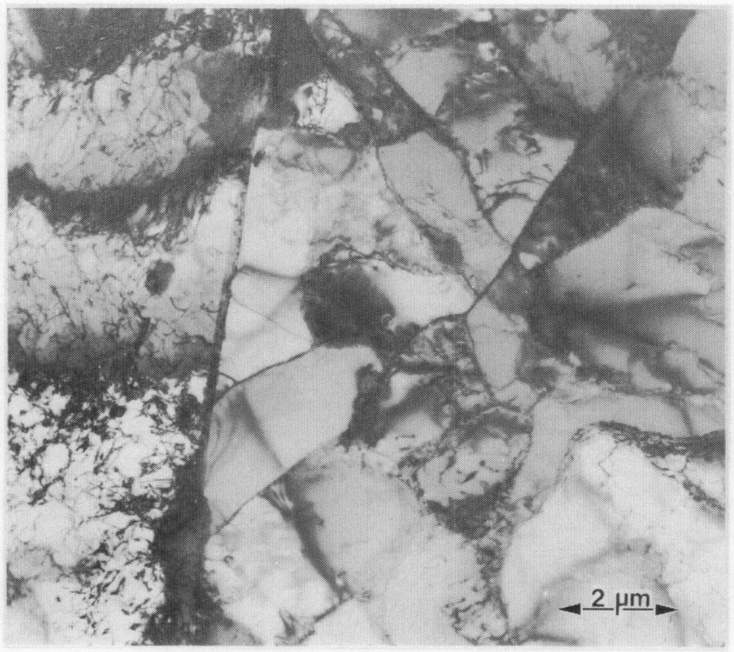
(a) (b)

Transmission electron micrographs of 316 Stainless Steel thermomechanical HTC cycled, 60 s/cycle, 117 hr test duration.



(a) (b)

Transmission electron micrographs of Alloy 800 isothermally cycled at 649°C, 60 s/cycle, 256 hr test duration.

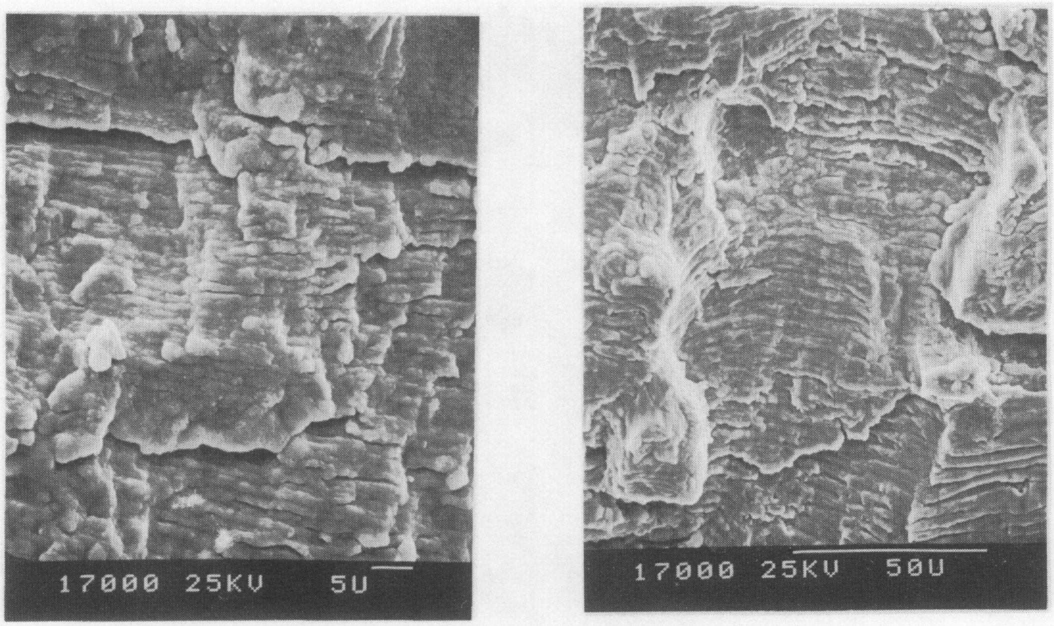


Transmission electron micrograph of Alloy 800 thermomechanical HTC cycled, 60 s/cycle, 75 hr test duration.

(a)

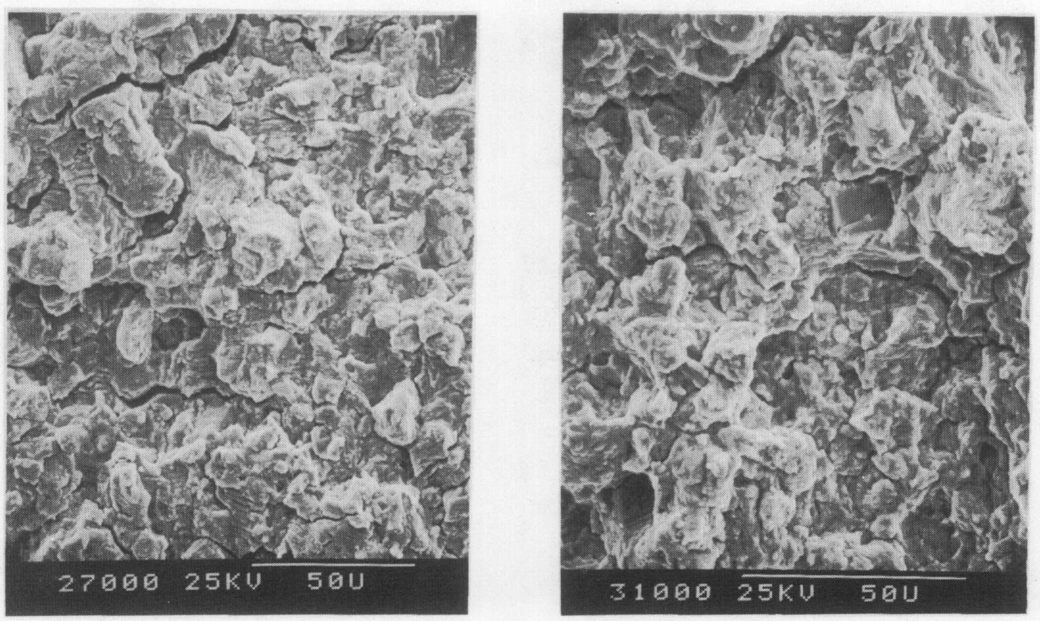
(b)

Transmission electron micrographs of Alloy 800 thermomechanical HTC cycled, 60 s/cycle; (a) 5 min. tensile hold, 120 hr test duration; (b) 5 min. compressive hold, 40 hr test duration



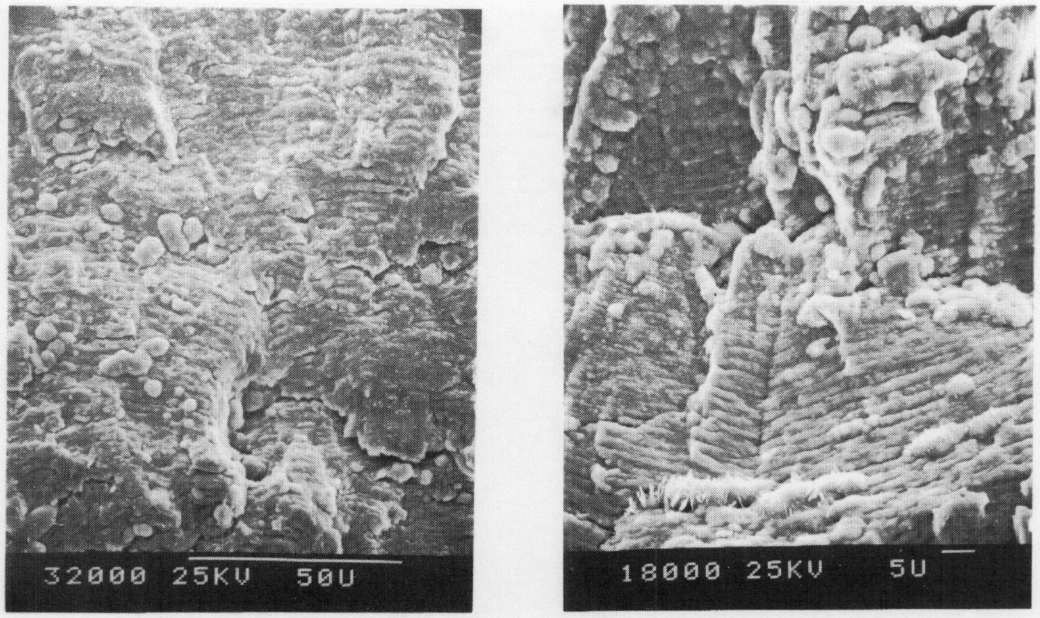
(a) (b)

Fatigue fracture surface of 316 Stainless Steel isothermally cycled at 649°C; (a) crack length = 1.33 mm; (b) crack length = 1.97 mm.



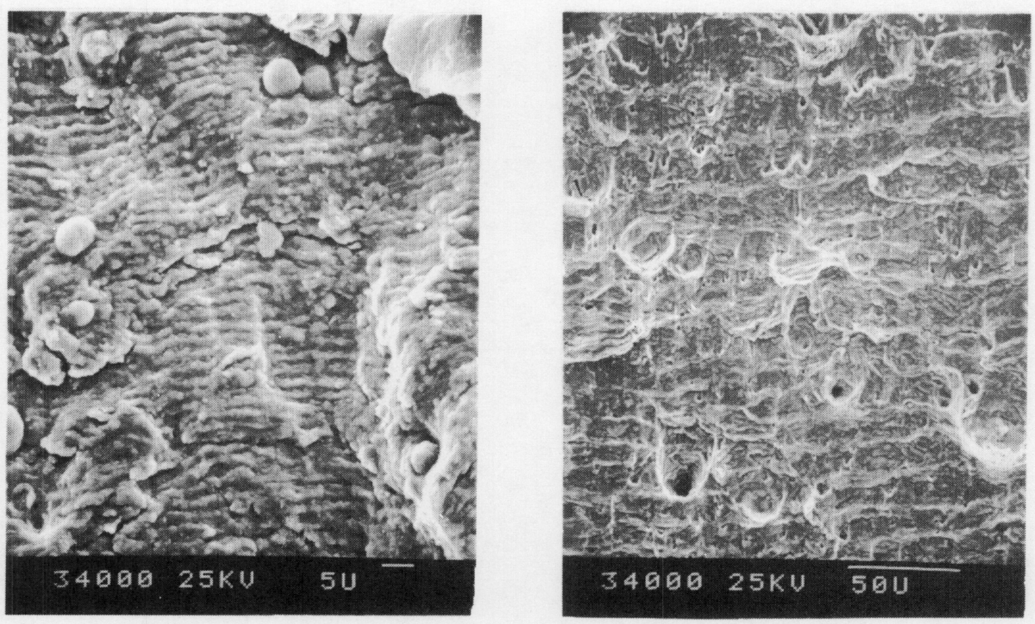
(a) (b)

Fatigue fracture surface of Alloy 800 isothermally cycled at 649°C; (a) crack length = 1.30 mm; (b) crack length = 2.02 mm.



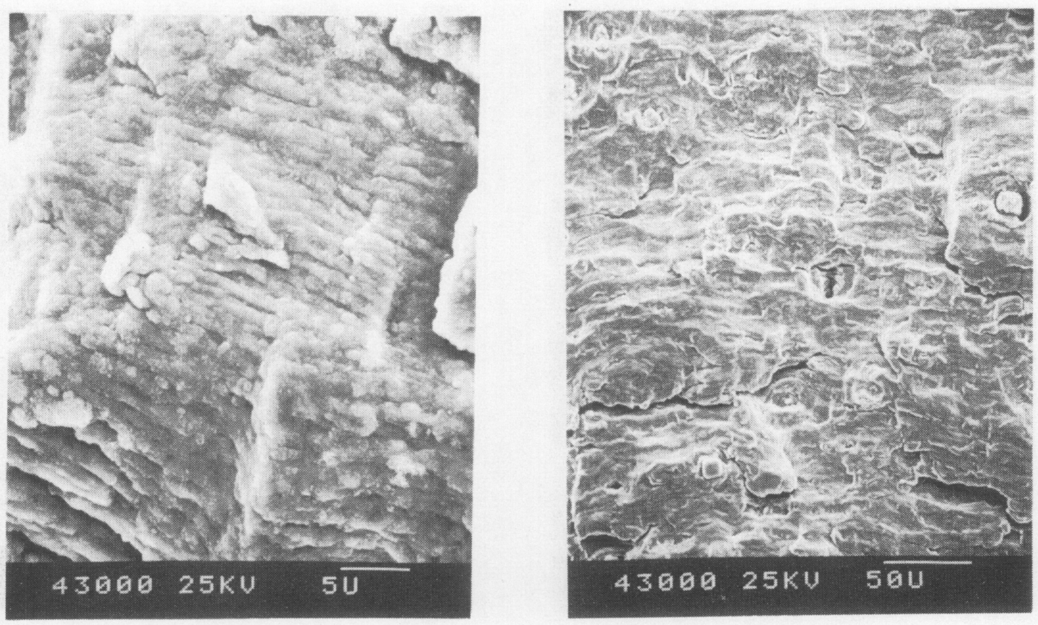
(a) (b)

Fatigue fracture surfaces of HTC thermomechanical fatigue cycled specimens; (a) Alloy 800, crack length = 1.00 mm; (b) 316 Stainless Steel, crack length = 2.22 mm.



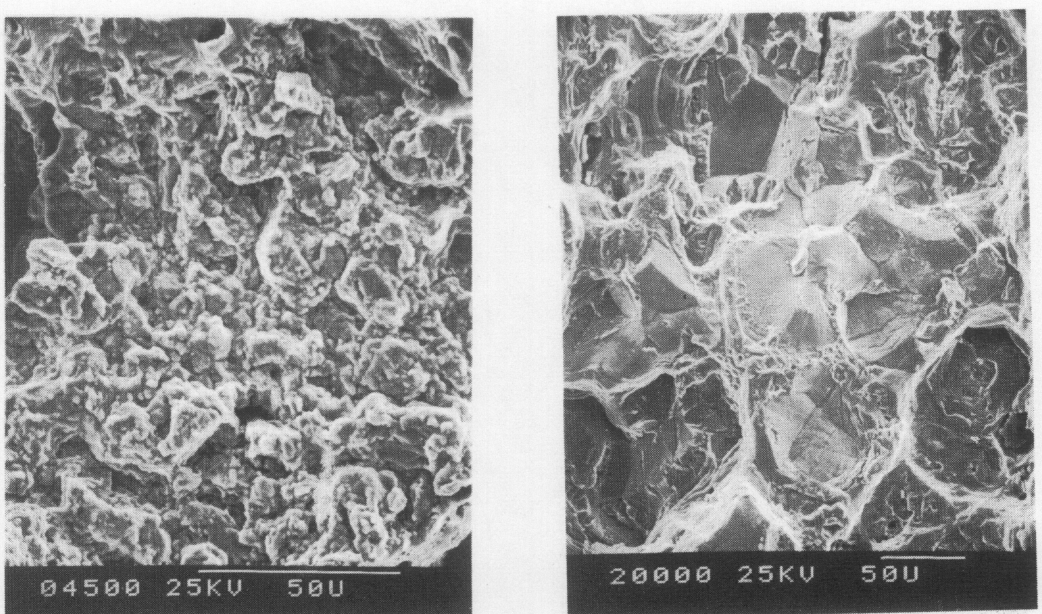
(a) (b)

Fatigue fracture surface of HTC thermomechanical fatigue cycled Alloy 800 with 5 min. compressive hold period; (a) crack length = 0.77 mm; (b) crack length = 2.00 mm.



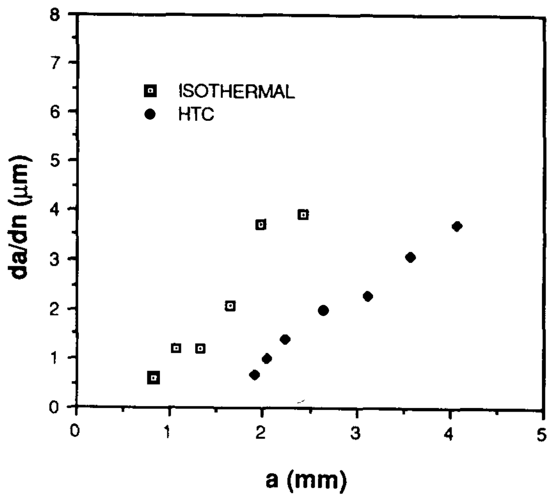
(a) (b)

Fatigue fracture surface of HTC thermomechanical fatigue cycled Alloy 800 with 5 min. tensile hold period; (a) crack length = 0.66 mm; (b) crack length = 2.84 mm.

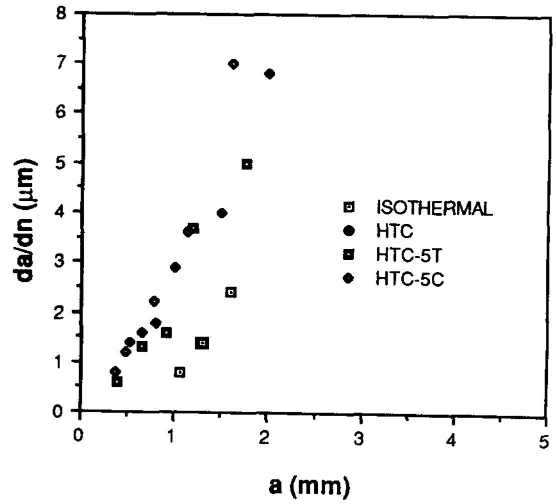


(a) (b)

Fatigue fracture surfaces of HTT thermomechanical cycled specimens showing regions of mixed intergranular and intragranular ductile fracture; (a) Alloy 800; (b) 316 Stainless Steel



(a)



(b)

Striation spacing crack growth rates versus crack length for isothermal and HTC thermomechanical cycling for (a) 316 Stainless Steel and (b) Alloy 800.

DIRECT ABSORPTION RECEIVER DEVELOPMENT

Craig E. Tyner

Central Receiver Technology Division
Sandia National Laboratories
Albuquerque, New Mexico 87185

ABSTRACT

In a solar central receiver system Direct Absorption Receiver (DAR), the heat absorbing fluid (a blackened molten nitrate salt) flows in a thin film down a basically flat, vertical panel (rather than through tubes as in conventional receiver designs) and absorbs the concentrated solar flux directly. Potential advantages of the DAR include a significantly simplified design, improved thermal performance, increased reliability and operating life, and decreased capital and operating costs. A joint Sandia/SERI three-year DAR research and development program to determine DAR feasibility is currently underway. Current development activities at Sandia include water flow testing to simulate DAR salt flow, design and fabrication of a solar DAR experiment, and preliminary design studies of a commercial solar central receiver plant using DAR technology.

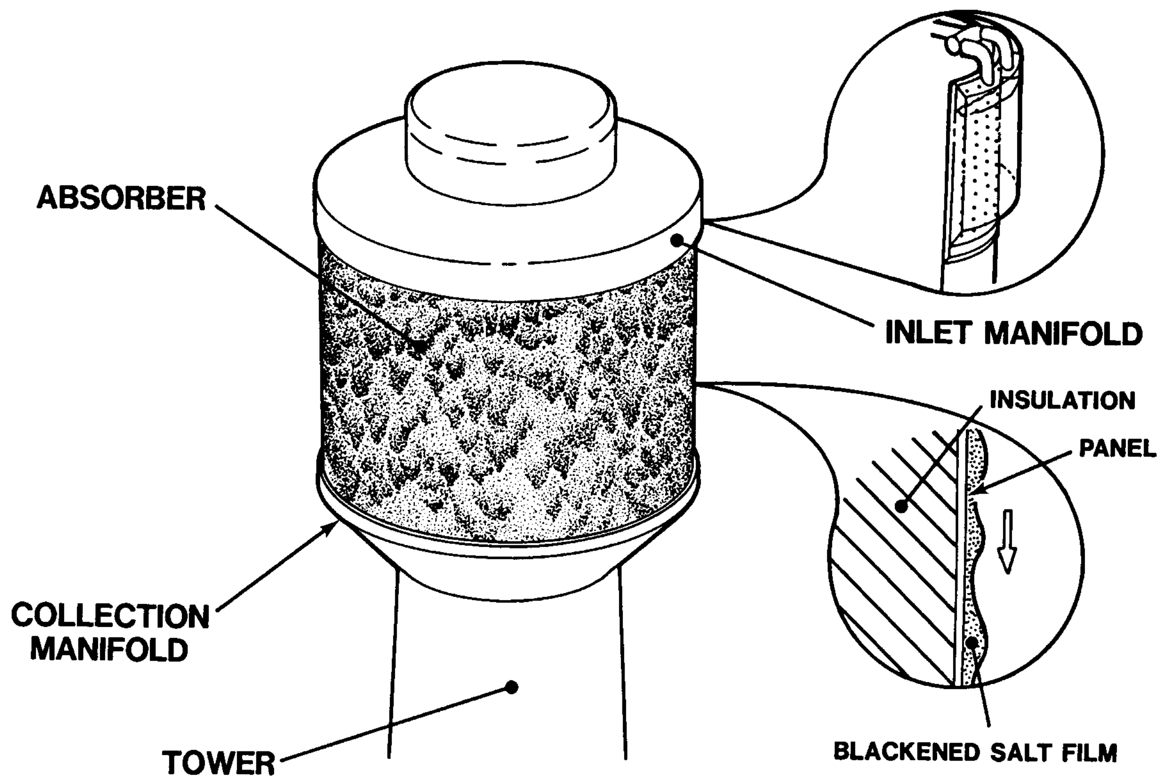
Because the flow properties of ambient temperature water are very similar to those of molten salt, water flow testing provides a cost-effective means of studying flow characteristics of DAR films. We are conducting water flow tests to develop effective manifolding systems for the DAR and to investigate film characterisitcs, including waves, in long flowing films. We are also assessing the effects of wind and natural convection on flowing films and determining control characteristics of multiple flow control zones.

To allow flow testing with nitrate salt and to provide a test bed for DAR testing in an actual solar environment, we are designing and fabricating a 2 MWt salt flow loop. The loop is capable of accommodating DAR panels up to 1m wide by 5m long at flow conditions typical of a commercial-sized DAR. Once fabricated, the system will be flow tested to verify similarity with results of the water flow tests and to fine-tune manifold and panel designs for use with molten salt. We will then add water-cooled shielding around the panel and an air-cooled heat rejection system to allow solar testing of the DAR on the CRTF tower.

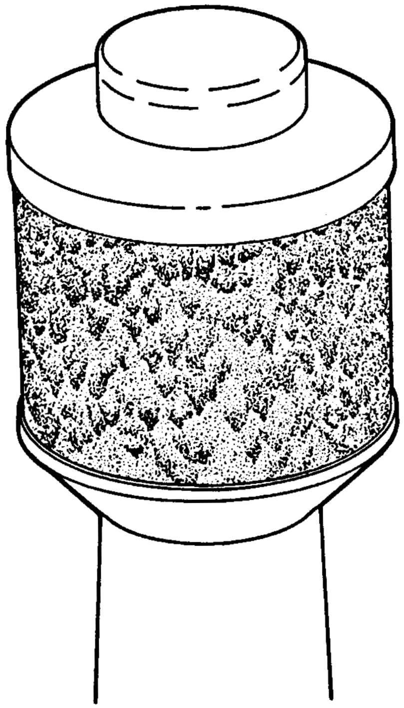
To help guide testing, DAR design studies are underway to examine receiver-specific aspects of a 320 MWt direct absorption receiver, emphasizing differences between previous salt-in-tube receiver designs and a DAR design. One of the major issues being addressed is panel and support design alternatives, including mechanical design of the receiver panels, thermal stress and deformation analyses of the panels during steady-state and transient conditions, and salt containment at panel edges. Preliminary cost estimates relative to salt-in-tube receivers are also being developed.

The status of these ongoing activities will be reviewed and key results to date presented.

External Molten Nitrate Salt
DIRECT ABSORPTION RECEIVER



Molten Nitrate Salt
DIRECT ABSORPTION RECEIVER



High Solar Flux Absorbed Directly in a Blackened Flowing Molten Salt Film

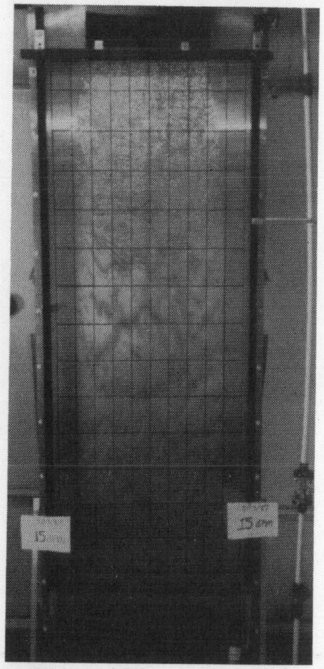
Advantages:

- High Efficiency
- Low Cost
- Simplicity & Reliability
- No Tube Life Considerations
- Simplified Control

Potential Problems:

- Flow Stability
- Panel Stresses & Deformation
- Wind
- Salt/Blackener Stability

Direct Absorption Receiver
WATER FLOW TESTS

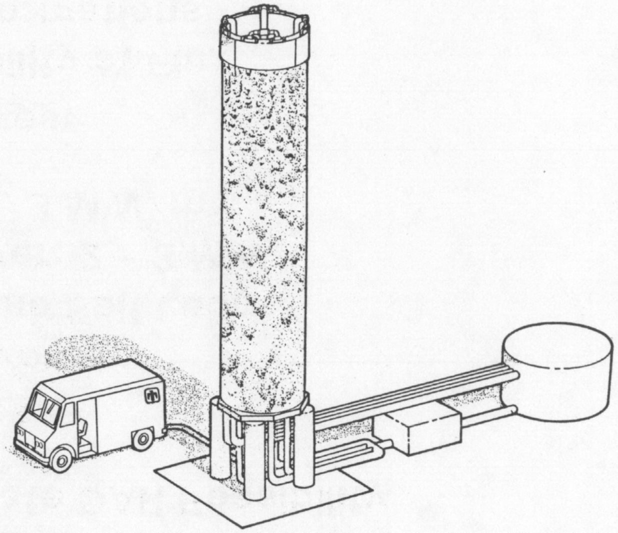


Manifold Development

Hot Salt Flow Characteristics Are Very Similar to Water.

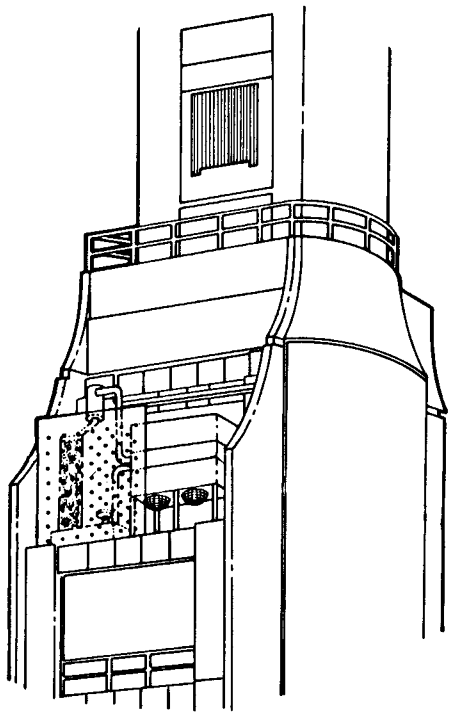
Test Objectives:

- Develop Effective Manifold Systems
- Assess Wind Effects and Control Requirements
- Test Full Length Panels in Full Flow



Long Flow & Wind Testing

Direct Absorption Receiver Solar Testing
PANEL RESEARCH EXPERIMENT



Objective:
- Demonstrate DAR Feasibility

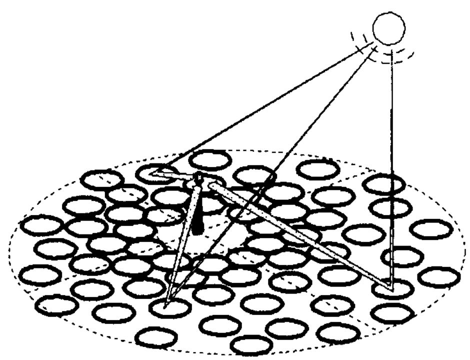
Test Features:
- CRTF Tower
- Stand-Alone Salt Loop
- Total Power: 2 - 3 MW_t
- Peak Flux: 3 MW/m^2

Test Objectives:
- Flow Stability at Flux
- Panel Deformations
- Wind Effects
- Blackener Performance
- Receiver Efficiency
- Control Effects

Direct Absorption Receiver
COMMERCIAL RECEIVER DESIGN STUDIES

Cooperative Industry/Sandia design studies are underway to examine receiver-specific aspects of a 320 MWt surround field/external DAR system.

Objectives:
- Guide for development testing needs
- Industry involvement in DAR programs
- Preliminary PRE panel designs



Key Issues:
- Panel & support design alternatives
- Panel stress and deformation analyses
- Salt containment at panel edges
- Blackener system performance and costs
- Critical fabrication and installation issues
- Costs relative to salt-in-tube receivers

Direct Absorption Receiver Water Flow Tests

James M. Chavez
Sandia National Laboratories

Abstract

The solar Direct Absorption Receiver (DAR) uses a blackened working fluid (molten salt), flowing down a flat vertical panel, to absorb energy directly from the incident concentrated sunlight. There are numerous advantages to a DAR, both performance and economic, when compared to a fluid-in-tube receiver. Most of the advantages arise because of the improved thermal efficency and the simplicity of the direct absorption concept. However, there are many issues that need to be addressed before the technical feasibility of the concept can be established. Therefore, a series of water flow tests have been performed to investigate some of the issues.

One of the critical areas in the development of the DAR is the method of distributing the heat transfer fluid on to the panel (using an "inlet manifold"). The inlet manifold directly affects the fluid uniformity and stability which in turn affects the heat absorption characteristics of the working fluid. The first step in resolving this issue was to construct a laboratory-scale panel test apparatus for conducting water flow tests. This test apparatus is 1 meter wide by 4 meters long. Water is used as the working fluid in place of the molten salt for cost and safety reasons. (The flow properties of room temperature water are very similar to those of molten salt.) The primary purpose of the laboratory-scale panel test apparuatus is to evaluate the various inlet manifold designs. However, it has also been used to investigate other technical concerns about the fluid flow on a DAR panel such as the effects of panel tilt, control zone interface effects, wind effects, natural convection effects, and panel surface effects. Instrumentation used in evaluating the inlet manifolds and investigating fluid uniformity and stability consisted of micrometer and ultrasonic measurment devices for measuring fluid film and wave thicknesses, a mass flow measurement device, as well as photography and high speed movies for evaluating fluid patterns and velocities.

Additional water flow testing of the DAR concept will include large-scale water flow testing in which a 2 m diameter by 10 m high cylinder will be used. This test apparatus will allow us to investigate wind effects, control zone flow effects, and wave phenomena for long vertical films.

The results from both the laboratory-scale and large-scale water flow tests will be described in this presentation.

Direct Absorption Receiver Water Flow Tests

Presented at the Solar Thermal Technology Conference

August 26-27, 1987

James M. Chavez

Sandia National Laboratories
Albuquerque, New Mexico

Why Perform Water Flow Test to Evaluate Direct Absorption Receiver Development Issues

- Water Tests Inexpensive and Easy to Perform Compared to Molten Salt Tests.
- Water Properties (at Room Temp) Similar to Hot Molten Salt.

Approach

- Perform Two Series of Water Flow Tests
  - Laboratory-Scale (1m x 4m Panel)
    - Manifold Evaluation
    - Fluid Stability Concerns
  - Large Scale (2m dia x 10m Tall Cylinder)
    - Fluid Stability Concerns

Sandia Laboratories

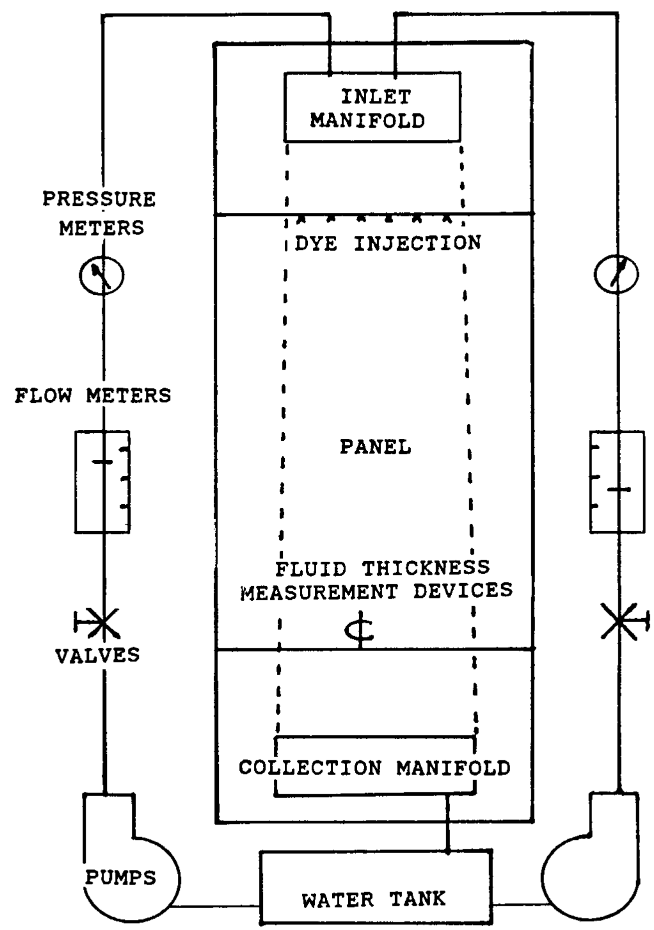
LABORATORY-SCALE WATER FLOW TEST

TEST APPARATUS SPECIFICATIONS

- 1M X 4M TALL ABSORBER PANEL (ALUM)
- WATER FLOW RANGES
  1-21 KG/S.M (5-100 GPM/FT)
  Re# = $4\,\Gamma/\mu$ = 2000 - 72,000
- PANEL TILT ANGLES
  85 - 95 DEGREES (FROM HORIZONTAL)

DAR REQUIREMENTS

- MANIFOLD OUTLET CONDITIONS
  <33 KG/S.M (121 GPM/FT)
  Re# = 0 - 24,000
- FLOW CONDITIONS AT BOTTOM OF PANEL
  RE# = 120,000
- CONTROL ZONE VARIATIONS
  0 - 30 PERCENT



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EVALUATION OF INLET DISTRIBUTION MANIFOLDS

- OBJECTIVES: QUALITAIVELY AND QUANTATIVELY EVALUATE MANIFOLD DESIGNS FOR:
  - SIMPLICITY OF CONSTRUCTION AND OPERATION
  - ADAPTATION OF CONTROL OVER WIDE FLOW RANGES (10 - 1 TURNDOWN)
  - UNIFORMITY OF FLUID DISTRIBUTION
  - POTENTIAL FLUID LOSS

- DESIGNED, BUILT AND TESTED OVER 10 INLET DISTRIBUTION MANIFOLDS

- EVALUATED NUMEROUS DISPERSION MATERIALS

Sandia Laboratories

Results of Inlet Distribution Manifold Evaluation

- Selected the "perforated plate manifold" with woven wire mesh as best choice

<u>Advantages</u>

- Reduced Head Height Requirements
- Simple to Construct
- No Air Entrainment in the System
- Fluid "Adhered" to the Panel with Wire Mesh
- Operates Effectively in Wide Range of Flows

Sandia Laboratories

MULTIZONE CONTROL EVALUATION

OBJECTIVE: EVALUATE MULTIZONE INTERFACE EFFECTS ON FLUID STABILITY

- BUILT "DUAL" MANIFOLD TO EVALUATE ZONE INTERFACE
  - EFFECT OF FLUID WASHOVER
  - VELOCITY WASHOVER EFFECTS
- INVESTIGATED ZONE DIFFERENCES FROM 0 - 50 PERCENT
  - ANALYSIS BY TYNER SHOWS MAXIMUM DIFFERENCES OF 30 PERCENT IN ADJACENT ZONES

CONCLUSIONS: CONTROL ZONE DIFFERENCES OF UP TO 50 PERCENT APPEAR TO BE CONTROLABLE WITHOUT PHYSICAL SEPARATION OF ZONES

- FLUID WASHOVER MINIMAL
- VELOCITY WASHOVER INSIGNIFICANT
- WAVE FORMATION LOCATION UNAFFECTED

EVALUATION OF FLUID STABILITY CONCERNS

- OBJECTIVES: FOR VARIOUS FLOW RATES AND PANEL CONDITIONS EVALUATE
  - FLUID UNIFORMITY AND STABILITY
  - WAVE EFFECTS
  - WIND AND NATURAL CONVECTION EFFECTS

- METHOD OF EVALUATING FLUID STABILITY CONCERNS
  - HIGHSPEED MOVIES
  - DYE INJECTION
  - STILL PICTURES
  - MICROMETER MEASUREMENTS OF FLUID THICKNESS
  - ULTRASONIC MEASUREMENTS OF FLUID THICKNESS

Sandia Laboratories

RESULTS OF FLUID STABILITY EVALUATION

- RESULTS BASED ON
  - MAXIMUM FLOW RATES RE# = 40,000
  - MAXIMUM PANEL LENGTH OF 2.75 METERS
  - ZONE VARIATIONS OF 50 PERCENT
  - SMOOTH PANELS
  - USED "PERFORATED PLATE INLET MANIFOLD" WITH SCREEN DIFFUSER

- CONCLUSIONS
  - NO APPARENT WAVE BREAKING
  - AT HIGH FLOW RATES WAVES NOT AT STEADY-STATE AT 2.75M
  - WAVE PEAK-TO-PEAK OF 1/2 - 3/4M COULD RESULT IN HOTTER BACK PANEL TEMPERATURES OR SUBSTRATE TEMPERATURES
  - RESIDENCE TIME ON PANEL IS LONGER THAN CALCULATED - LOWER VELOCITIES
  - FLUID SPREAD IS MINIMAL AT PANEL TILT OF 85 DEGREES

Sandia Laboratories

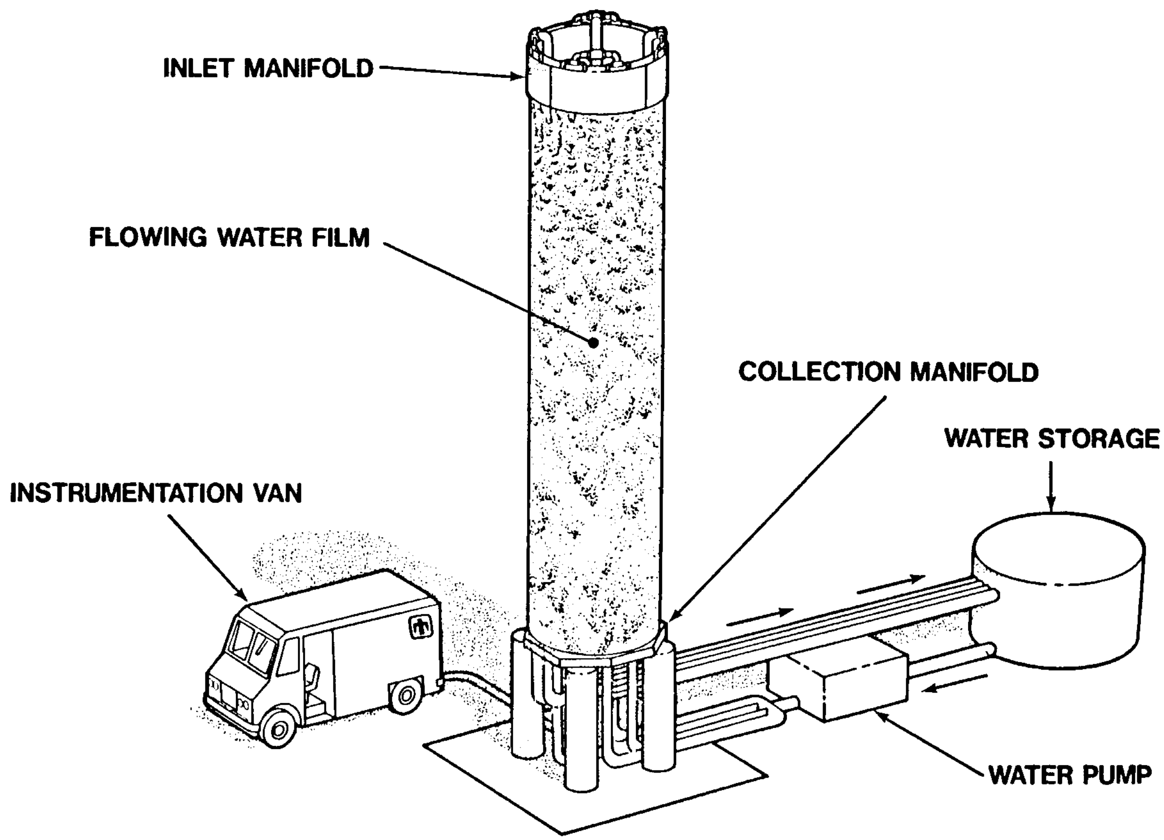
LARGE-SCALE WATER FLOW TESTS

- OBJECTIVE: ON A COMMERCIAL SCALE TEST APPARATUS, UNDER REAL WEATHER CONDITIONS INVESTIGATE:
  - UNIFORMITY OF FLUID DISTRIBUTION
  - LONG-PANEL WAVE EFFECTS
  - ZONE INTERFACE EFFECTS
  - REAL WIND EFFECTS

- LARGE-SCALE TEST FACILITY SPECIFICATIONS
  - ALUMINUM CYLINDER 2 M DIA X 10 M TALL
  - FOUR CONTROL ZONES (FOUR INLET MANIFOLDS)
  - FLOW RANGES - UP TO 211 KG/S (3350 GPM)
<33 KG/S.M (121 GPM/FT)
RE# = 120,000

Sandia Laboratories

DIRECT ABSORPTION RECEIVER
Large Water Flow Test



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CONCLUSIONS
FROM WATER FLOW TESTS TO DATE

- DEVELOPMENT OF A COUPLE INLET MANIFOLDS
- ZONE INTERFACE EFFECTS NOT SIGNIFICANT
- WAVES NOT A PROBLEM - MAYBE BENEFICIAL
- WIND AND NATURAL CONVECTION EFFECTS TO BE INVESTIGATED
- PANEL TILT HAS NO EFFECT ON UNIFORMITY OF FLUID DISTRIBUTION

Sandia Laboratories

DEVELOPMENT OF A LOW-COST HELIOSTAT DRIVE

Werner Heller
Peerless-Winsmith

In May 1986, Peerless-Winsmith received a contract to develop a heliostat drive with a cost goal of 11 dollars per m^2 of reflector area based on an area of 150 m^2 and a yearly production rate of 50,000 units for a 10 year period of time.

Design requirements were high pointing accuracy, ability to support wind induced loads of 90 mph, low maintenance requirements over a 30 year life, and ability to survive continuous operation in a desert environment without detrimental degradation of performance during the design life span.

It is believed that this proposed design can meet all design requirements and it can approach the cost goal very closely. This would represent a significant reduction of drive system cost compared to existing designs.

To derive at the proposed design, a number of alternative configurations were examined with the intent of selecting the most cost effective drive system designed to meet load, performance, and environmental conditions with small or no safety factors. Although all components of the drive are conventional, overall performance must be proven through a prototype construction and testing program. It can be expected that some components may not be capable of performing as required because of uncertainties inherent in analytical methods. However, it is expected that the proposed design can be developed to possess uniform strength with no costly excessive safety margins.

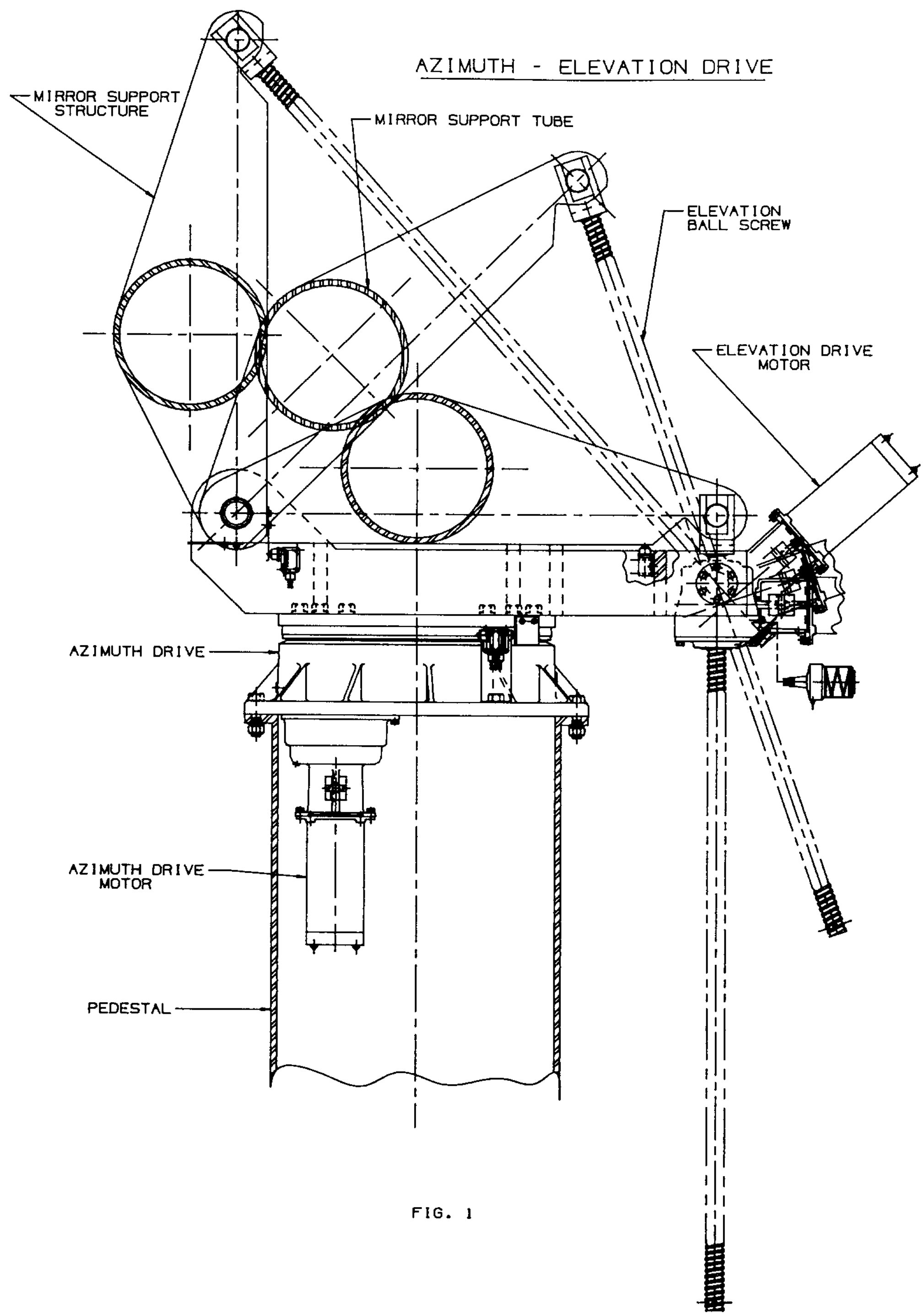

AZIMUTH - ELEVATION DRIVE
MIRROR SUPPORT STRUCTURE
MIRROR SUPPORT TUBE
ELEVATION BALL SCREW
ELEVATION DRIVE MOTOR
AZIMUTH DRIVE
AZIMUTH DRIVE MOTOR
PEDESTAL

FIG. 1

AZIMUTH DRIVE

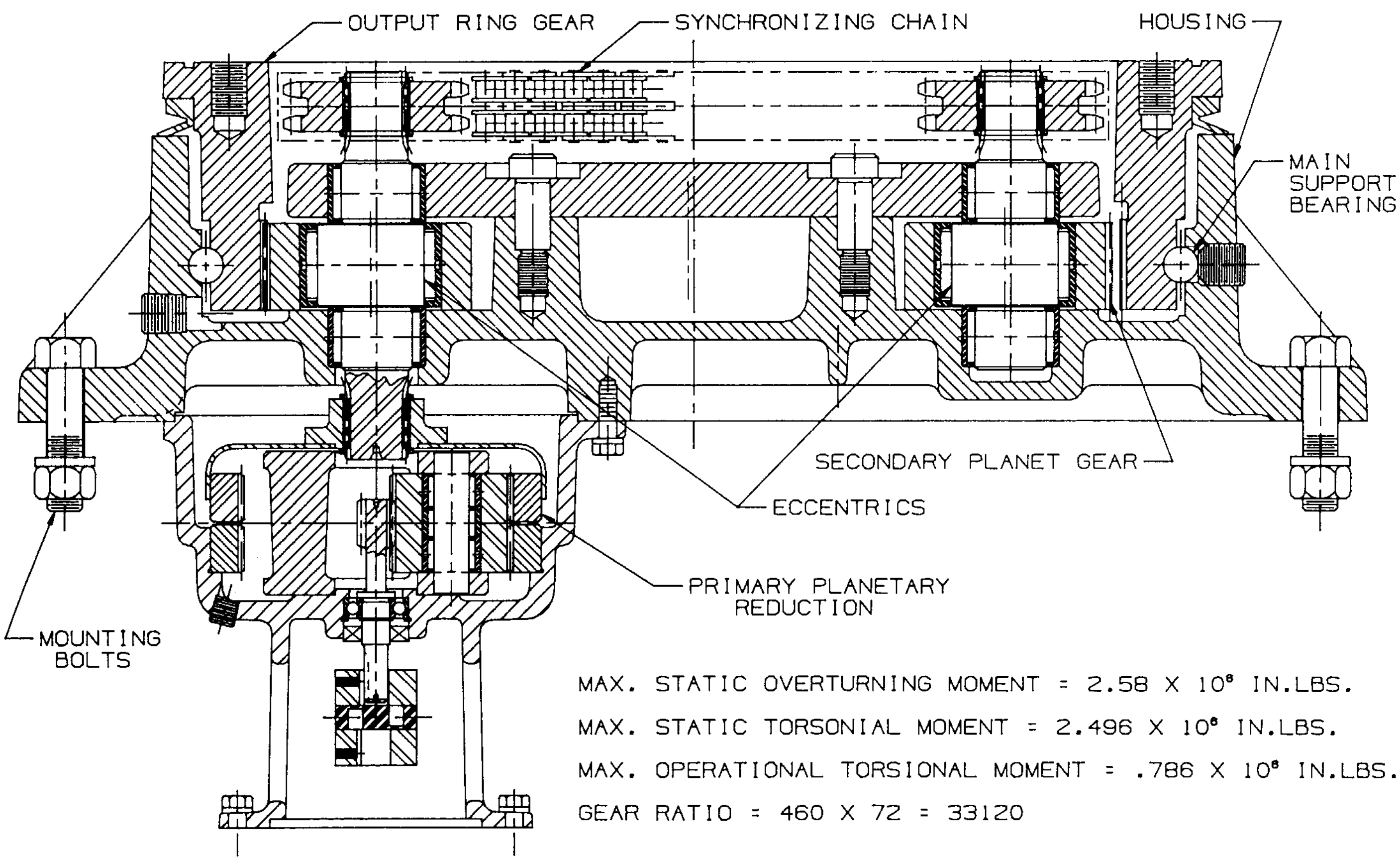
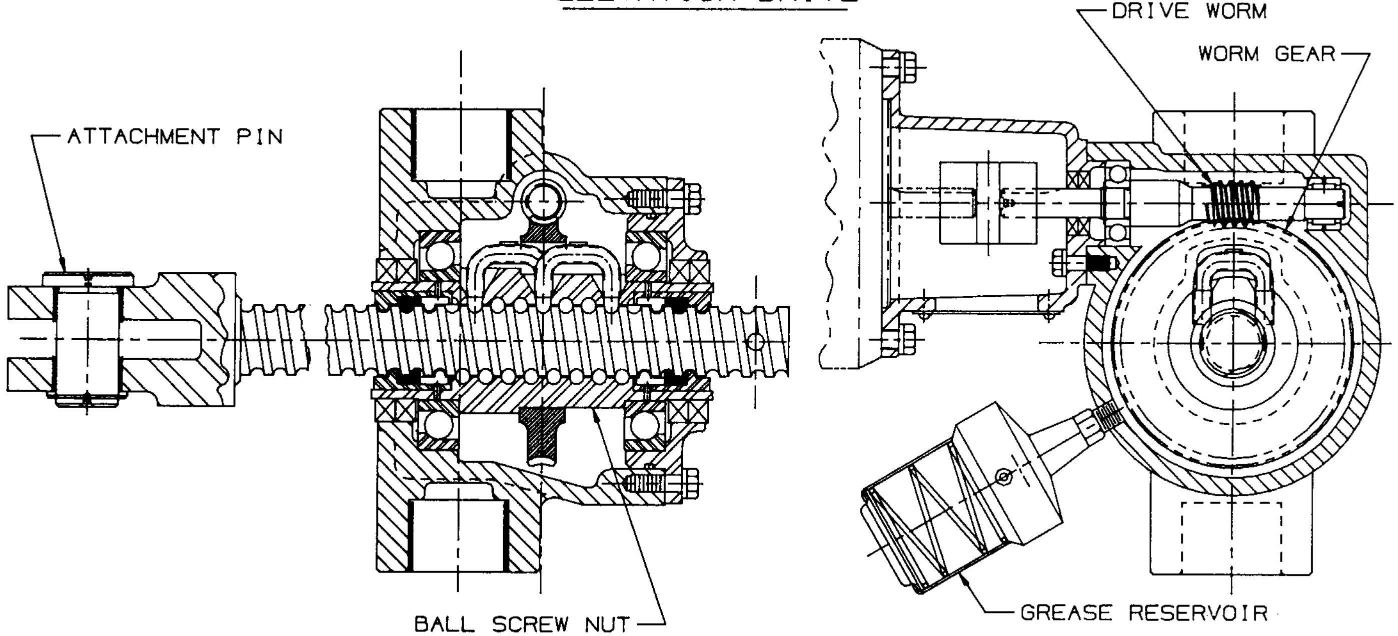


FIG. 2

ELEVATION DRIVE



MAX. STATIC MOMENT = 2.64 X 10^6 IN.LBS.

MAX. OPERATIONAL MOMENT = .787 X 10^6 IN.LBS.

FIG. 3

SUPPORT STRUCTURE

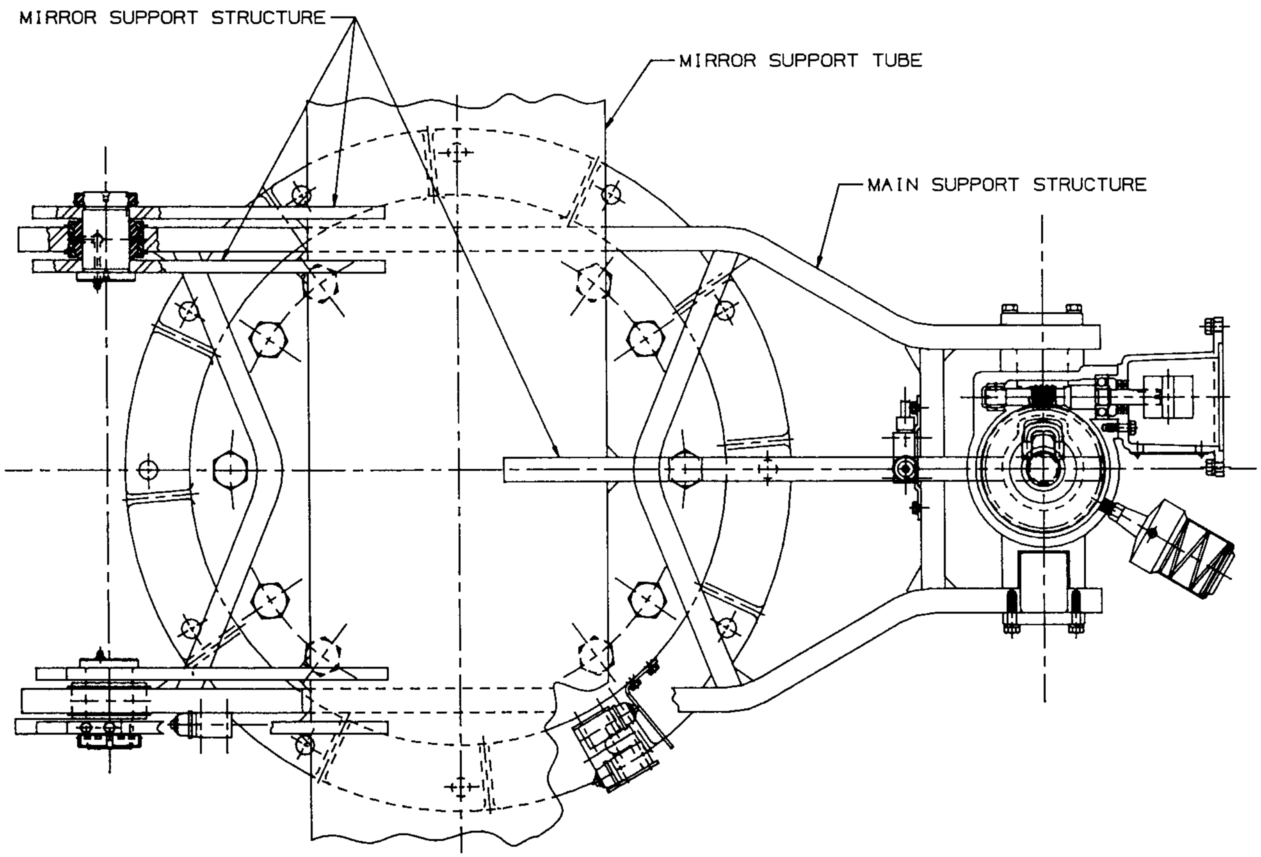


FIG. 4

MAJOR COMPONENT WEIGHTS

AZIMUTH ASSEMBLY	601.0 lbs.
ELEVATION ASSEMBLY	93.0 lbs.
MAIN SUPPORT STRUCTURE	376.0 lbs.
MIRROR SUPPORT STRUCTURE	95.6 lbs.
TOTAL	1165.6 lbs.

FIG. 5

MAJOR COMPOMEMT COSTS

	AZIMUTH DRIVE	ELEVATION DRIVE	MAIN SUPPORT STRUCTURE	MIRROR SUPPORT STRUCTURE	
EQUIPMENT AMORTIZED COST	29.53	13.30	5.76	4.63	
MATERIAL COAT	580.27	296.47	221.23	54.00	
MFG. COST	282.10	170.73	49.27	37.80	
EXP. TOOL COST	19.24	2.84	8.53	5.76	
CRATING/SHIPPING	14.37	8.37	-	-	
LUBRICANT	47.25	4.73	-	-	
TOTAL	972.76	496.44	284.79	102.19	1856.18

COST PER $M^2 = \frac{1856.18}{148} = 12.54$ DOLLARS/M^2

COST PER LB. $= \frac{1856.18}{1165.6} = 1.59$ DOLLARS/LB.

FIG. 6

LARGE AREA HELIOSTAT DEVELOPMENT

R. J. Thomas D. N. Gorman, and J. G. Halford

Advanced Thermal Systems, Inc.

The Advanced Thermal Systems, Incorporated, (ATS) large area heliostat prototype was installed at CRTF in March 1986. It has a reflective area of 148 m2 consisting of 20 laminated glass mirror modules 4 ft by 20 ft in size. The design was described at the 1986 Annual Solar Thermal Technology Conference.

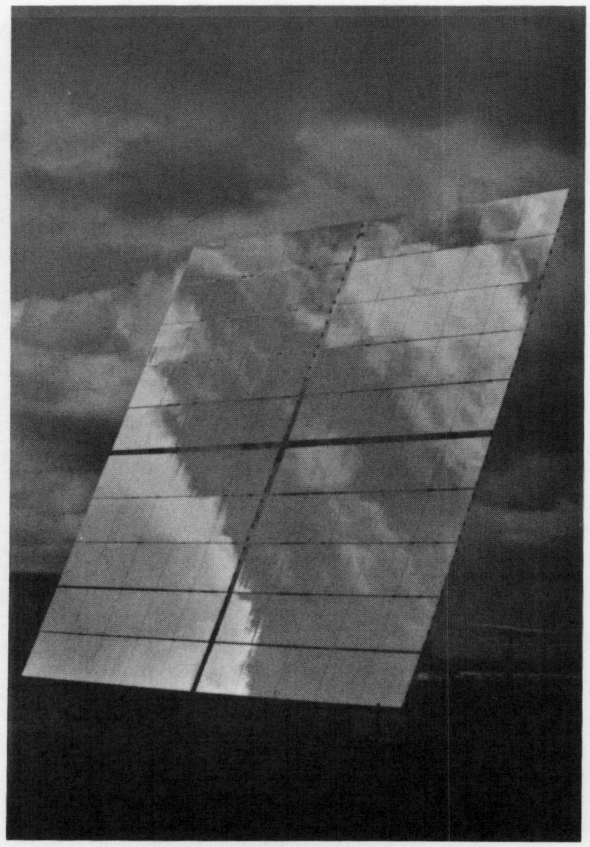
Initial mirror module canting for on-axis focus included an approximate correction for gravity sag of the structure. Early data from the BCS (with no heat flux intensity calibration) indicates additional sag correction is necessary for optimal beam focus. This will be accomplished using calibrated BCS data in conjunction with analytically produced image data.

The ATS control system is also used to operate other prototype heliostats at CRTF, using electronics supplied by Micro R&D and software provided by ATS. The control software haas been modified to accomodate different gear ratios for each axis of each heliostat, batch command execution, angular and linear aimpoint offset capability and other unique features useful to the Sandia test program.

ATS HELIOSTAT DESIGN FEATURES

SIZE:	40.5 ft. by 40.75 ft. 148 m2 Net Reflective Area
MIRROR MODULES:	Laminated Glass Mirrors Aluminized Sheet Metal Sections
STRUCTURE:	Single Pedestal, Torque Tubes Bar Trusses, Bracing
DRIVE:	Two-Stage Spur and Worm Gearing 18,615 to 1 Input/Output Ratio
CONTROLS:	Pedestal Mounted Electronics Battery Backed Memory Hall Effect Encoders Microcomputer Command

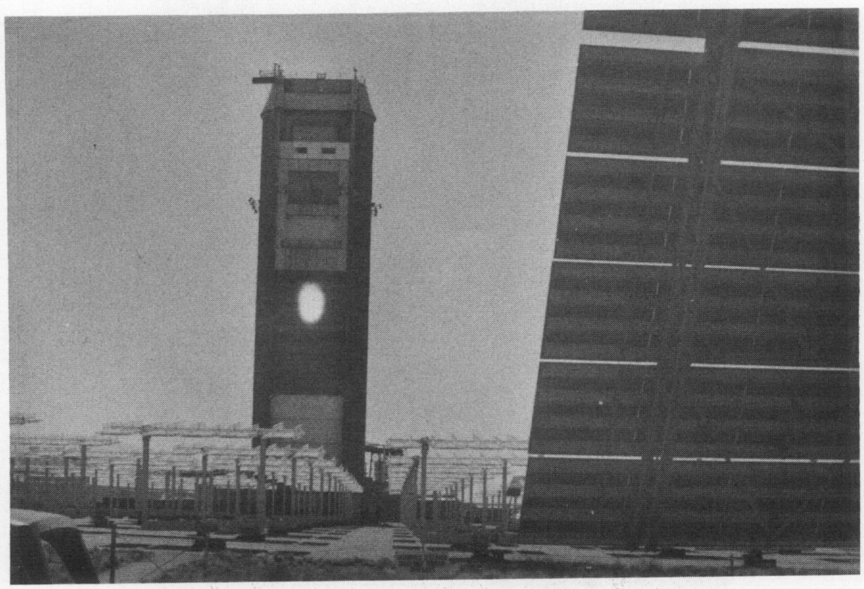
ATS HELIOSTAT - FRONT VIEW



PAGE ATS-2

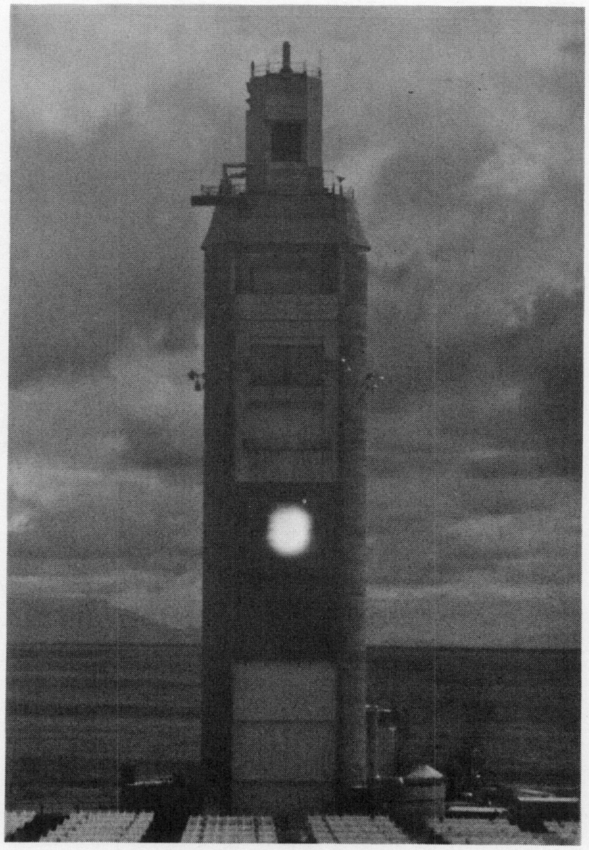
ATS HELIOSTAT - REAR VIEW

IMAGE PRIOR TO CORRECTION
FOR GRAVITY SAG
MARCH 27, 1986



PAGE ATS-3

IMAGE AFTER INITIAL CORRECTION FOR GRAVITY SAG MARCH 28, 1986

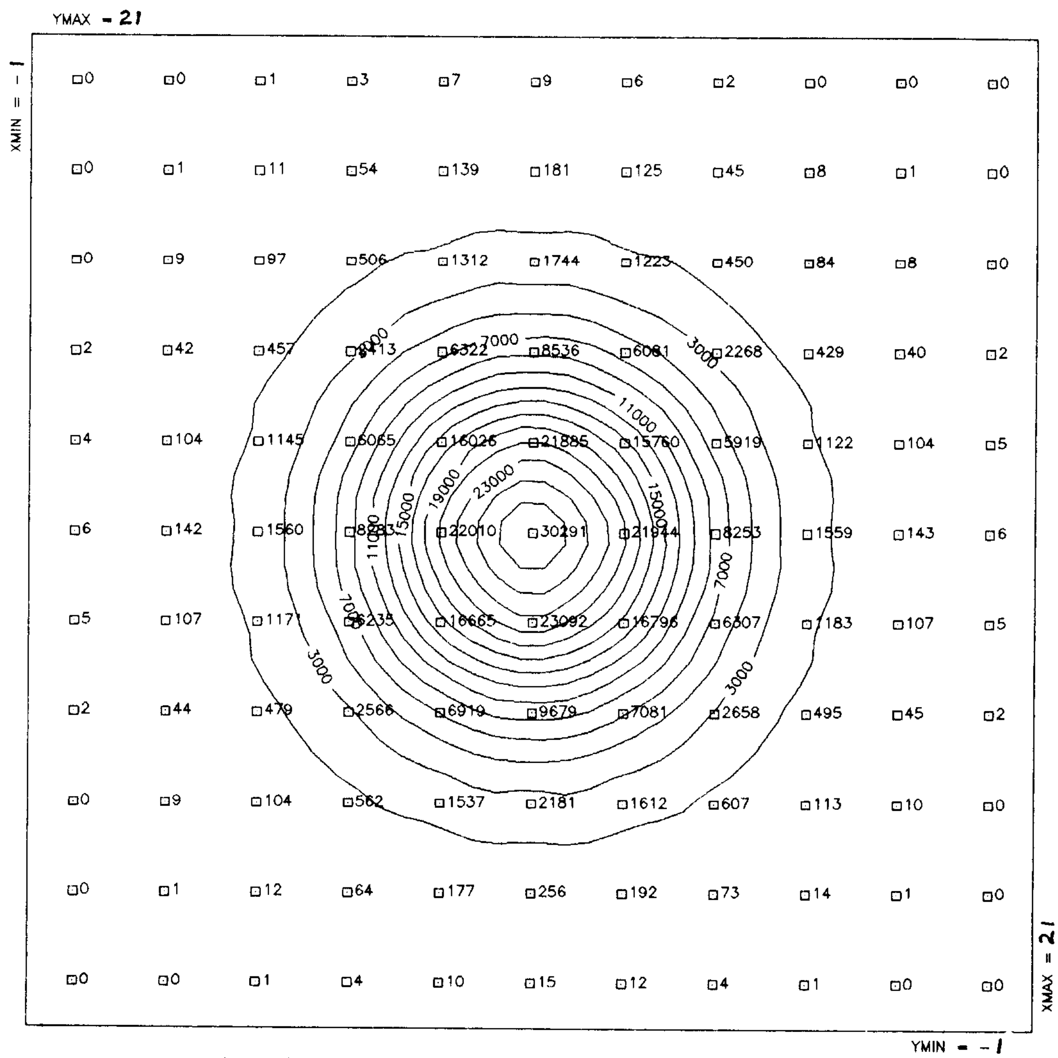


PAGE ATS-4

ADVANCED THERMAL SYSTEMS, INC.

LARGE AREA HELIOSTAT

PREDICTED BEAM CHARACTERISTICS



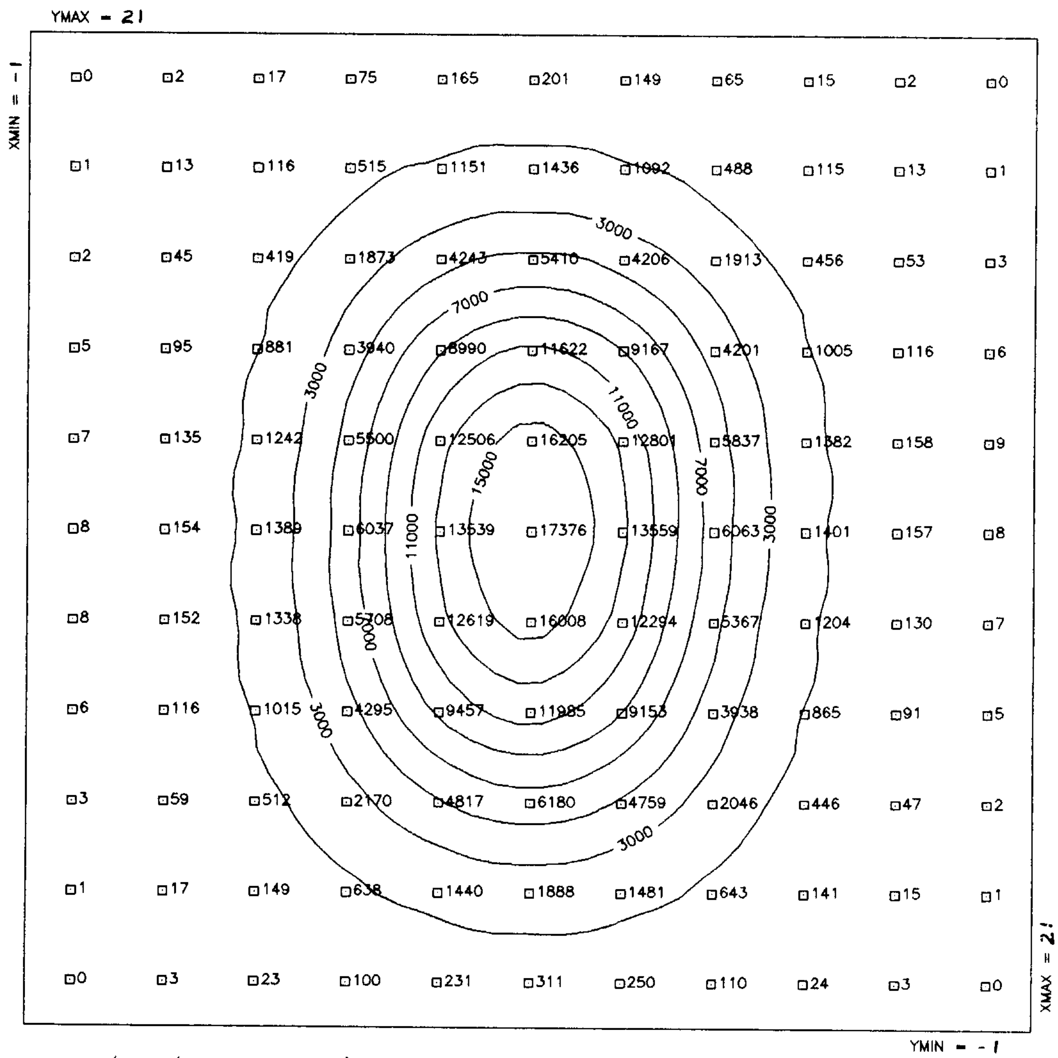
3/21/87 – NOON NO GRAVITY SAG

PAGE ATS-5

ADVANCED THERMAL SYSTEMS, INC.

LARGE AREA HELIOSTAT

PREDICTED BEAM CHARACTERISTICS



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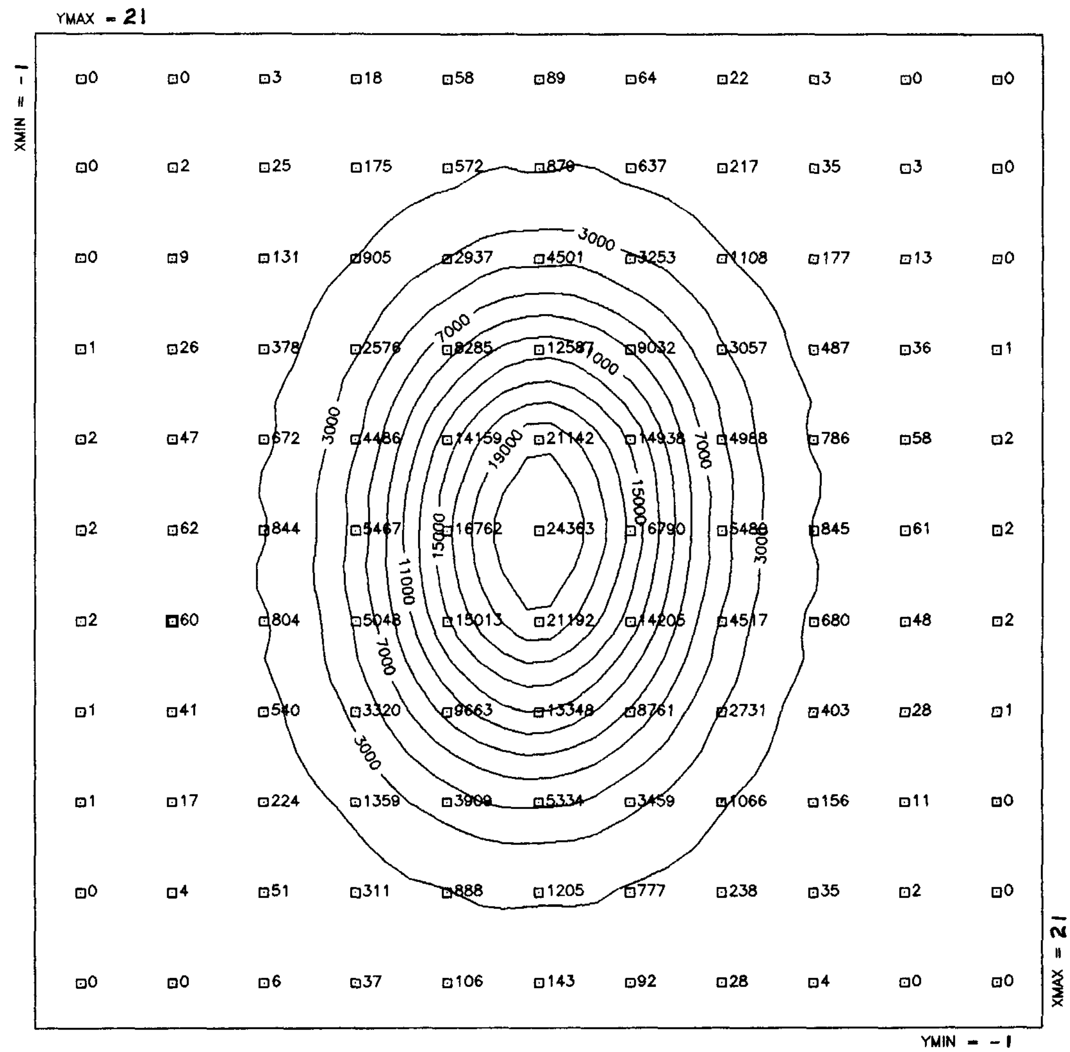
ADVANCED THERMAL SYSTEMS, INC.
LARGE AREA HELIOSTAT
PREDICTED BEAM CHARACTERISTICS



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ATS HELIOSTAT COMMAND CONTROL FEATURES

VERSATILE:	Currently used to control 3 Different Prototype Heliostats at CRTF
CAPABILITIES:	Multiple Aim Points
	Angular and Linear Aim Point Offset
	Different Gear Ratios for Each Drive and Each Axis
	Rapid Position Alignment and Trim Calibration
	Pedestal Tilt Correction for Two Mirror Module Canting Methods
	Batch Command Execution, Either Sequential or on a Time Schedule
	Optional Automated Startup, Sunrise, Sunset and Wind Stow Command Proceedures
	All Operating Parameters Easily Changed By Operator Input
COMPUTER USED:	Currently Operating on IBM PC and Compatibles
	Various Versions on HP 200 Series, HP 1000 and Others Using FORTRAN, BASIC and C Languages

STRETCHED MEMBRANE MIRROR MODULE IMPROVEMENT AT SCIENCE APPLICATIONS INTERNATIONAL CORPORATION[1]

Kelly J. Beninga
Barry L. Butler
Science Applications International Corporation (SAIC)
10401 Roselle Street
San Diego, CA 92121

ABSTRACT

Science Applications International Corporation (SAIC) has developed and fabricated a first-of-a-kind stretched membrane heliostat mirror module. Both a 150 m^2 commercial mirror module for mass production and a 50 m^2 prototype mirror module were designed. Fabrication of the prototype mirror module was completed in September 1986 at the Central Receiver Test Facility, Albuquerque, New Mexico.

The mirror module design consisted of a large toroidal ring of circular cross-section with stainless steel membranes on both sides of the ring. The membranes were made up of .0762 mm (.003-inch) thick, .61 m (24-inch) wide 304 stainless steel strips which were roll-resistance welded together. The pressure in the plenum between the front and back membranes was controlled to adjust the focal length of the mirror module by changing the radius of curvature of the membranes. A light source, reflector, and a photo detector were arranged so that the light beam was modulated by a knife edge which was attached to the inside center of the front membrane. The effect of wind pressure on the surface of the membranes could then be compensated for by adjusting the plenum pressure with the control system. The cost of an installed 150 m^2 commercial pedestal-mounted complete heliostat for a 50,000 unit per year mass production scenario is $65/$m^2$.

Much information was gained from the fabrication and testing of the first generation prototype mirror module. The out-of-plane ring distortions were greater than expected due to membrane stress non-uniformities caused by manufacturing and an undersized support ring. The stainless steel membrane was seam welded together at 60 inches/minute. Misalignment in one seam created a pie-shaped dart of material in the back membrane. The resulting stress non-uniformity in the back membrane caused ring out-of-plane bending forces which in turn caused the ring to saddle or "potatochip" as the membrane tension was increased. To improve the quality of the mirror module, the membrane was yielded while holding the ring planar to obtain better biaxial stress uniformity. The resulting membrane smoothness was exceptional. The membranes were not radially and circumferentially fixed to the ring so the membranes did not significantly increase the ring stiffness.

SAIC currently has a contract with Sandia National Laboratories for design and fabrication of an improved stretched membrane mirror module. Improvements to this second mirror module will include: use of a rectangular ring with increased out-of-plane moment of inertia; a revised membrane fabrication alignment procedure; elimination of the pressurized tensioning bladders; and welding of the membranes directly to the top and bottom of the rectangular ring to provide a stiffer ring-/membrane structure. A comprehensive finite element model of the mirror module including the ring, membranes, and support trusses is under development. This model includes the effect of ring out-of-plane imperfections and non-uniform tension in the membrane. This technique provides a more realistic assessment of the actual loads incurred in the mirror module which will provide an accurate tool for the design and sizing of various mirror module components.

[1] Work supported by Sandia/DOE contract.

STRETCHED MEMBRANE MIRROR MODULE IMPROVEMENT AT SCIENCE APPLICATIONS INTERNATIONAL CORPORATION

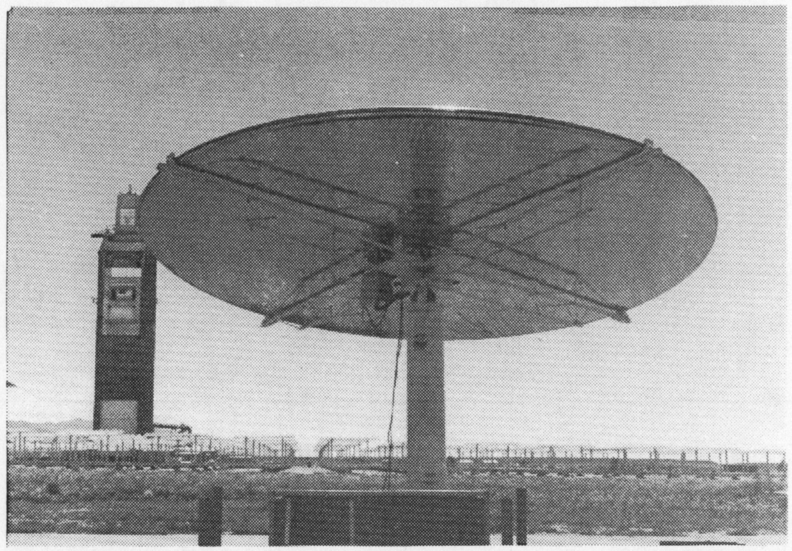
PRESENTED AT THE
SOLAR THERMAL TECHNOLOGY CONFERENCE

AUGUST 26 - 28, 1987

KELLY J. BENINGA
BARRY L. BUTLER

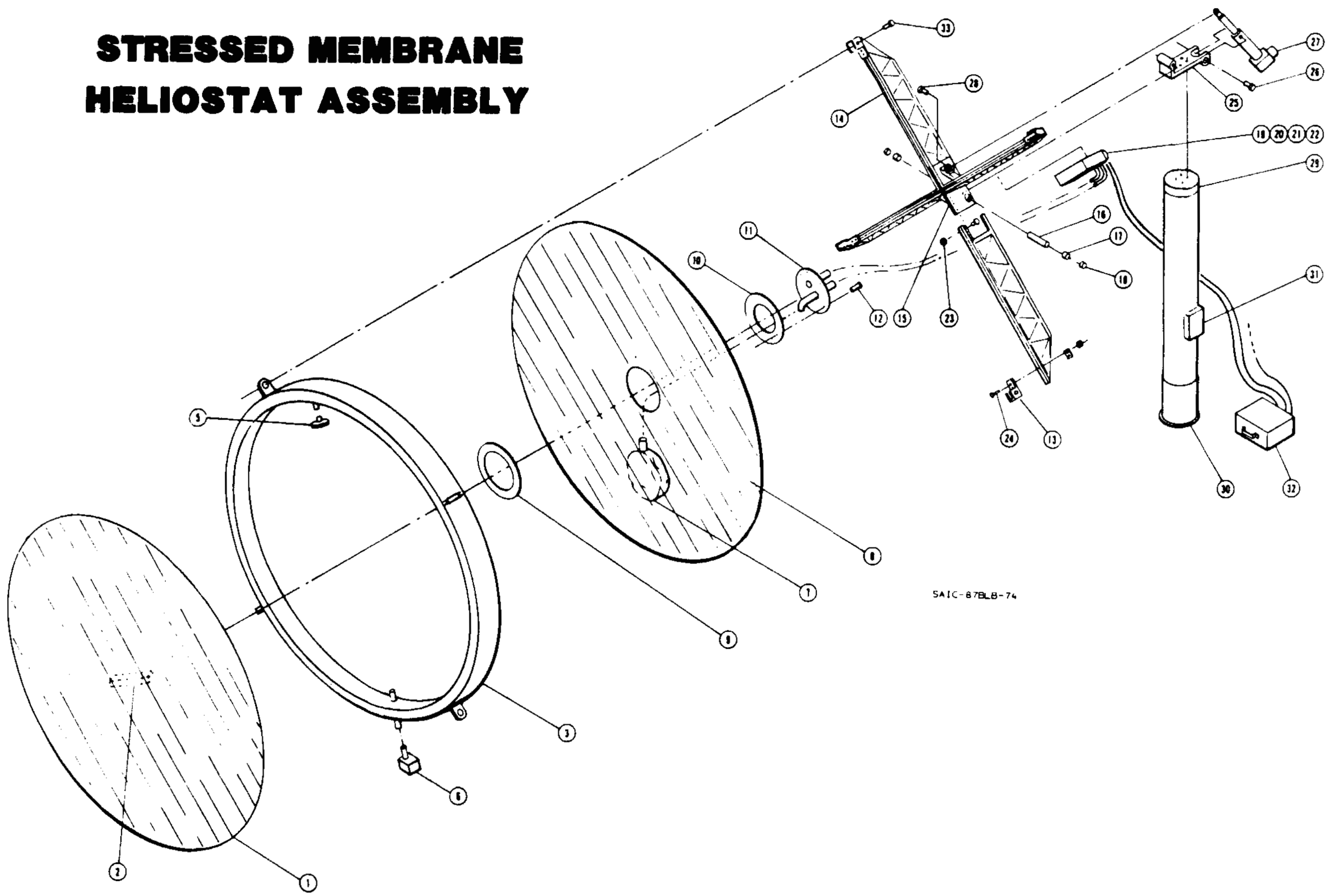
SAIC

HELIOSTAT INSTALLED 9/86 AT
CENTRAL RECEIVER TEST FACILITY TEST SITE



SAIC

STRESSED MEMBRANE HELIOSTAT ASSEMBLY



Science Applications International Corporation

FIRST GENERATION PROTOTYPE HELIOSTAT SPECIFICATIONS*

HELIOSTAT DIAMETER	7.92 m (26 ft)
AREA	49.3 m^2 (530.9 ft^2)
REFLECTIVE AREA	47.75 m^2 (514 ft^2)
SUPPORT RING TUBE DIAMETER	127 mm (5.0 inch)
TUBE WALL THICKNESS	1.651 mm (.065 inch)
TUBE CROSS SECTIONAL AREA	658.7 mm^2 (1.008 $inch^2$)
MEMBRANE THICKNESS	.0762 mm (.003 inch)
MEMBRANE PRELOAD	5.253 N/mm (30 lbs/inch)
MEMBRANE STRESS	68.95 M Pa (10,000 psi)
NUMBER OF RING SUPPORTS	4 each
SPAN	3.96 m (13 ft)
DEPTH OF SUPPORT	355 mm (14 inches)
WIND LOAD @ 50 MPH	18,842 N (4,236 lbs)
WIND LOAD PER JOIST	4,710 N (1,059 lbs)
MOMENT	15,227 Nm (11,233 ft lbs)
WIND LOADING 6° @ 90 MPH	4,897 N (1,101 lbs)
MOMENT	18,282 Nm (13,487 ft lbs)

*Fabrication completed 9/86

COMMERCIAL HELIOSTAT SPECIFICATIONS

HELIOSTAT DIAMETER	14 m (46 ft)
AREA	154.4 m^2 (1661.9 ft^2)
REFLECTIVE AREA	148.85 m^2 (1602.2 ft^2)
SUPPORT RING TUBE DIAMETER	254 mm (10.0 inch)
TUBE WALL THICKNESS	1.651 mm (.065 inch)
TUBE CROSS SECTIONAL AREA	1309 mm^2 (2.029 $inch^2$)
MEMBRANE THICKNESS	.0762 mm (.003 inch)
MEMBRANE PRELOAD	5.253 N/mm (30 lbs/inch)
MEMBRANE STRESS	68.95 M Pa (10,000 PSI)
NUMBER OF RING SUPPORTS	4 each
SPAN	7 m (23 ft)
DEPTH OF SUPPORT	762 mm (30 inches)
WIND LOAD @ 50 MPH	64,851 N (14,580 lbs)
WIND LOAD PER JOIST	16,213 N (3,645 lbs)

SAIC

STRESSED MEMBRANE HELIOSTAT INSTALLED AT CUSTOMER SITE
COST vs. SIZE (1985 $) 50,000 UNITS/YEAR - 12,500th UNIT PRODUCED
(LOW COST POLYMER REFLECTOR)

DIAMETER (m)	11 m		14 m		20 m	
AREA (m^2)	$95m^2$		$154m^2$		$314m^2$	
COST	$	$\$/m^2$	$	$\$/m^2$	$	$\$/m^2$
Mirror Module -						
Materials	2,280.95	24.01	3,800.79	24.68	10,811.02	34.43
Labor	501.66	5.28	604.58	3.93	725.50	2.31
Equipment + Interest	122.03	1.28	152.54	.99	213.56	.68
Consumables	19.94	.21	19.94	.13	28.26	.09
Mirror Module Subtotal	2,924.58	30.78	4,577.85	29.73	11,778.34	37.51
Drive & Pedestal -						
Drive Assembly	1,810.00	19.05	1,650.00	10.71	2,847.00	9.07
Pedestal	212.00	2.23	266.00	1.73	500.00	1.59
Assembly Drive/Ped./Elect.	107.00	1.13	107.00	.69	107.00	.34
Drive & Pedestal Subtotal	2,129.00	22.41	2,023.00	13.13	3,454.00	11.00
Foundation	614.00	6.46	934.00	6.06	1,600.00	5.10
Labor (Field Site)	250.83	2.64	302.29	1.95	500.00	1.59
Buildings (Incl. Interest)	13.56	.14	16.95	.11	30.00	.10
Field Wiring	434.00	4.57	434.00	2.82	434.00	1.38
Total Heliostat Cost	6,365.97	67.00	8,288.09	53.81	17,796.34	56.68
ROI + Taxes @ 20%	1,273.19	13.40	1,657.62	10.76	3,559.27	11.34
TOTAL HELIOSTAT SELLING PRICE	7,639.16	80.40	9,945.71	64.57	21,355.61	68.02

MATERIALS FOR ONE 150 m^2 UNIT

	50,000 UNITS/YEAR	
COST CENTER	$	$/$m^2$
POLYMER REFLECTOR	640.88	4.16
MEMBRANES	1,819.04	11.81
RING	477.87	3.10
STRESSING	175.00	1.14
FOCUS/DEFOCUS SYSTEM	100.00	.65
SUPPORT TRUSSES	238.00	1.55
MISCELLANEOUS	350.00	2.27
TOTALS:	3,800.79	24.68

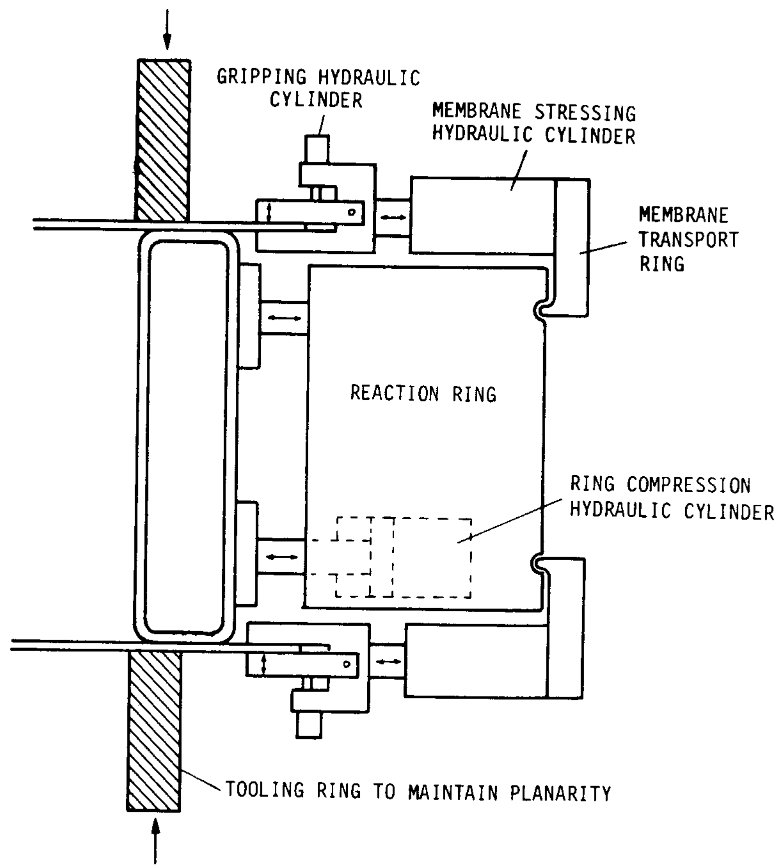
LESSONS LEARNED FROM FIRST GENERATION PROTOTYPE HELIOSTAT

- OUT-OF-PLANE RING DISTORTIONS WERE GREATER THAN EXPECTED
- MEMBRANE FLATNESS AND PRE-TENSIONING TECHNIQUES ARE CRITICAL TO QUALITY OF MIRROR MODULE
- HARD ATTACHMENT OF MEMBRANES TO RING IS REQUIRED TO TAKE FULL ADVANTAGE OF STIFFENING EFFECT ON RING
- EFFECT OF NON-UNIFORM MEMBRANE TENSION AND RING MANUFACTURING IMPERFECTIONS MUST BE EVALUATED IN DESIGN EFFORT
- INTEGRATED MODEL OF RING, MEMBRANES AND SUPPORT TRUSSES REQUIRED TO PREDICT PERFORMANCE ACCURATELY
- YIELDING OF THE STAINLESS STEEL MEMBRANES INCREASES SMOOTHNESS AND REDUCES MEMBRANE TENSION NON-UNIFORMITY
- PRESSURIZED TENSIONING BLADDERS ARE UNRELIABLE

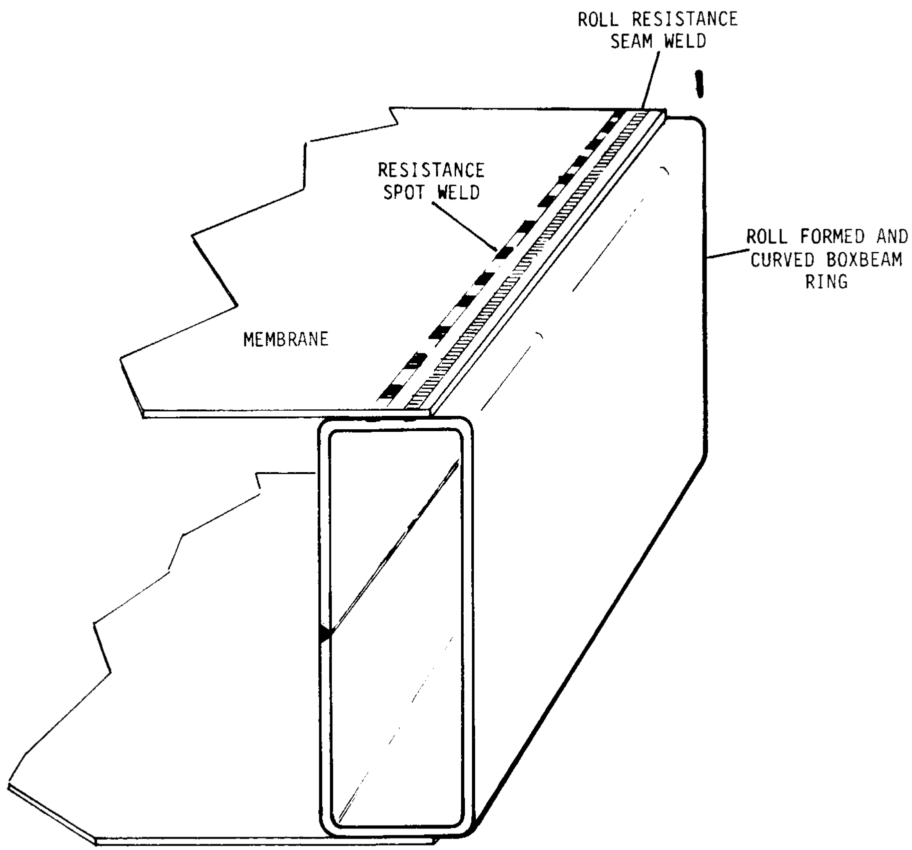
PLANNED IMPROVEMENTS TO SECOND COMMERCIAL/PROTOTYPE HELIOSTATS

- RECTANGULAR RING WITH INCREASED OUT-OF-PLANE MOMENT OF INERTIA
- REVISED MEMBRANE FABRICATION PROCESS
- ELIMINATION OF PRESSURIZED TENSIONING BLADDERS
- MEMBRANES ATTACHED DIRECTLY TO RING
- MEMBRANES TENSIONED AND RING COMPRESSED PRIOR TO ATTACHMENT
- POSSIBLE YIELDING OF MEMBRANES BEFORE ATTACHMENT TO RING
- COMPREHENSIVE FINITE ELEMENT MODEL OF MIRROR MODULE CONSIDERS FABRICATION IMPERFECTIONS

COMMERCIAL TOOLING CONCEPT FOR RING COMPRESSION AND MEMBRANE TENSIONING



DESIRED HELIOSTAT MEMBRANE TO RING ATTACHMENT



STRETCHED-MEMBRANE MIRROR-MODULE DESIGN IMPROVEMENT

Paul T. Schertz

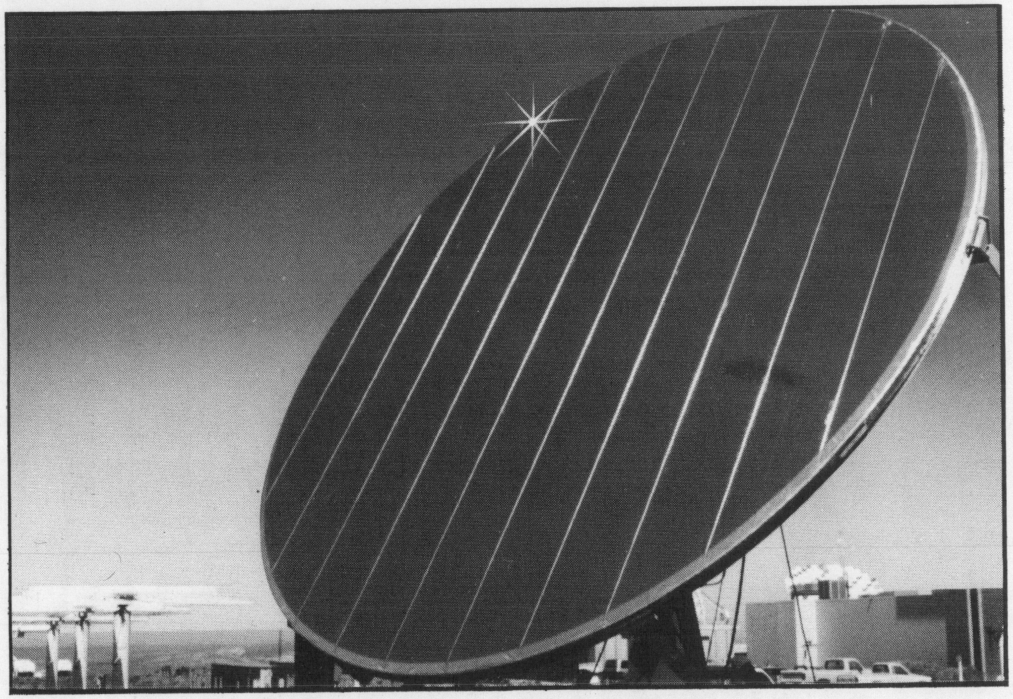
Solar Kinetics, Inc.
10635 King William Dr.
Dallas, TX 75220

Solar Kinetics, Inc. (SKI) is under contract with SNLA to enhance stretched-membrane heliostat (SMH) technology by refining the first generation SMH developed in FY86. The first generation SMH developed by SKI consists of an aluminum ring and membrane supported by six steel trusses which carry the loads to central drive connections. During the successful design and prototype development of this unit, several areas were identified where additional improvements in the design and manufacturing might be possible. The current work is not a complete redesign effort but rather a directed effort to improve these specific areas. The pedestal and drive are not a part of this contract; the mirror module must conform to a glass/metal heliostat type drive. The size has been defined as $150m^2$ with .010" aluminum membranes and a silvered acrylic reflective surface.

Planned improvements will decrease fabrication, material and O&M costs and increase performance of the heliostat. An open section, such as a channel, is being investigated to replace the rectangular tube of the previous heliostat. The open section may use material more efficiently and reduce fabrication costs. The steel trusses will be redesigned to decrease fabrication complexity and cost. The inflatable tube, used to achieve a portion of the membrane tension, will be eliminated in favor of a nonconsumable pretensioning approach. O&M costs arising from control system parasitics and reflective film degradation will be addressed. Rear membrane reaction to internal pressure changes dominates the parasitics demand and methods to restrict this motion will be investigated. A scalloped membrane material stock caused small areas of the first generation prototype aperture to be optically ineffective. This performance burden will be eliminated by leveling of the coil stock.

The period of work for this contract is April '87 through April '88 and will culminate with the installation of a $50m^2$ prototype at the CRTF.

STRETCHED-MEMBRANE MIRROR MODULE DESIGN IMPROVEMENT



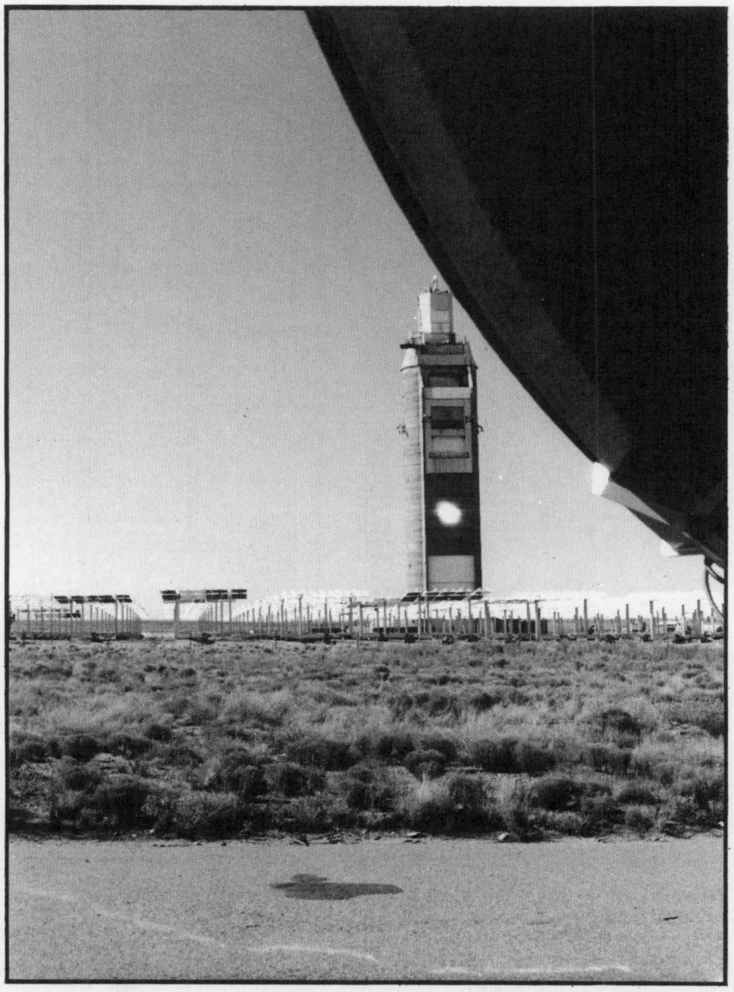
MAKE SPECIFIC IMPROVEMENTS TO DESIGN

BUILD PROTOTYPE MIRROR MODULE

APRIL '87 THROUGH APRIL '88

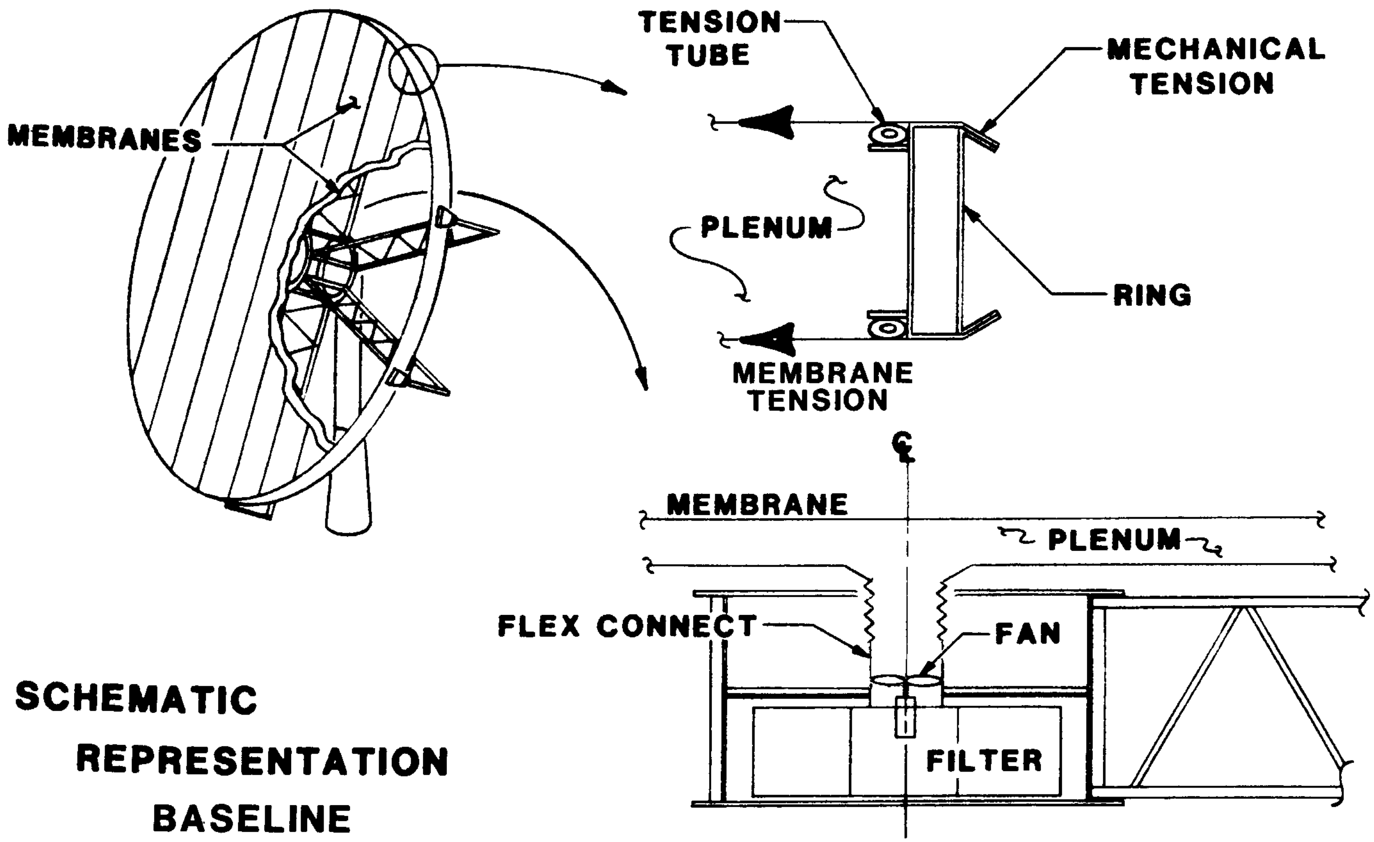
SOLAR KINETICS INC.

FIRST GENERATION
STRETCHED-MEMBRANE PROTOTYPE



FOCAL SPOT ON CRTF TOWER

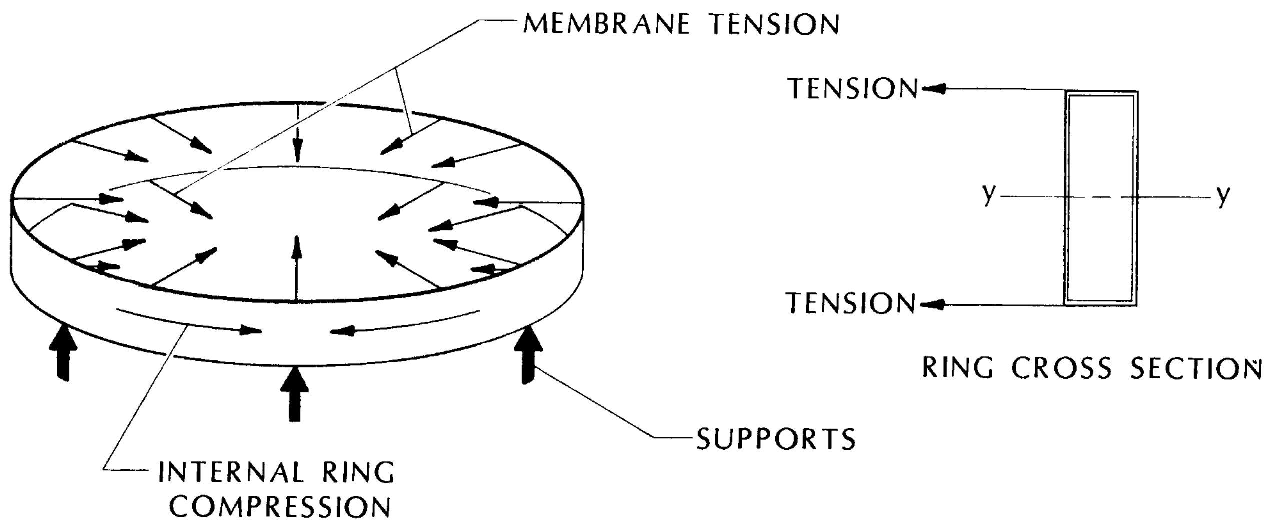
SOLAR KINETICS INC.



SCHEMATIC REPRESENTATION BASELINE

SOLAR KINETICS INC.

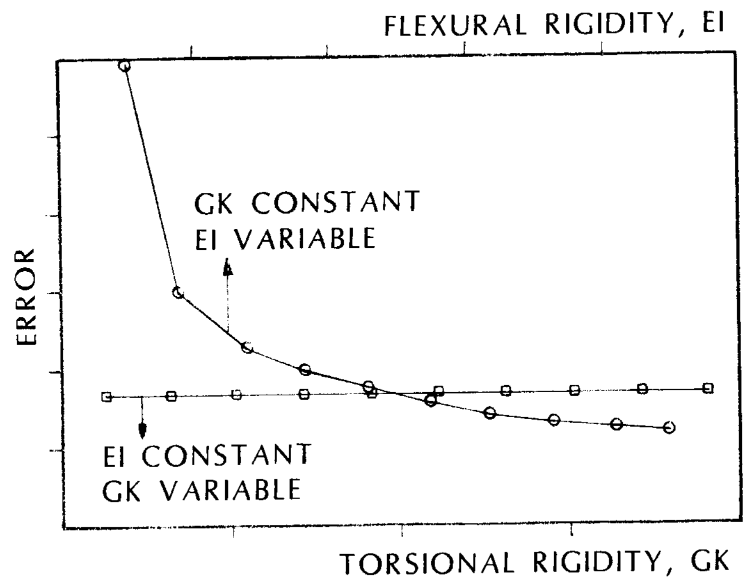
STRETCHED MEMBRANE CONCEPT

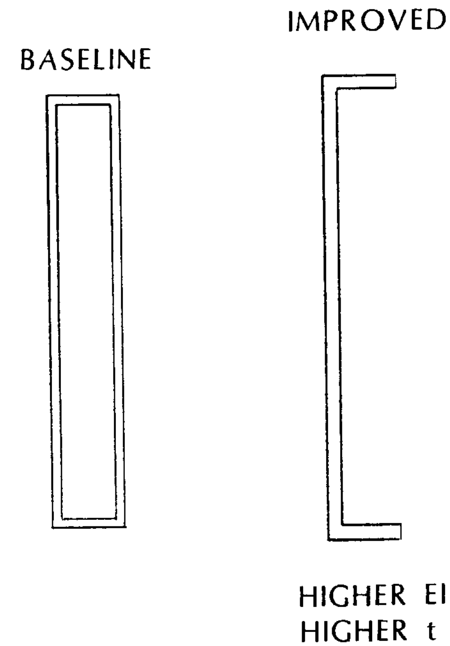


- AXIAL COMPRESSION IN RING AS REACTION TO MEMBRANE TENSION
- MEMBRANE INCREASES IN-PLANE STABILITY
- MEMBRANE INCREASES OUT-OF-PLANE STIFFNESS & STABILITY
  - DEFLECTION ACCOMPANIED BY ROLL
  - ROLL RESISTED BY MEMBRANES

SOLAR KINETICS INC.

RING WEIGHT REDISTRIBUTION

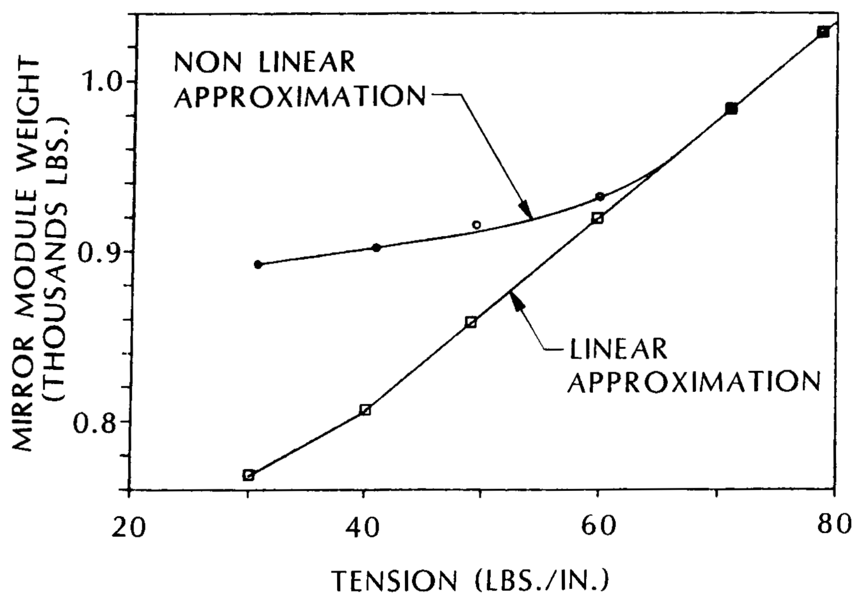




[REF. STRUCTURAL DESIGN CONSIDERATIONS...,
Murphy et.al., SERI/TR-253-2338, Ref 4]

SOLAR KINETICS INC.

MEMBRANE ITEMS

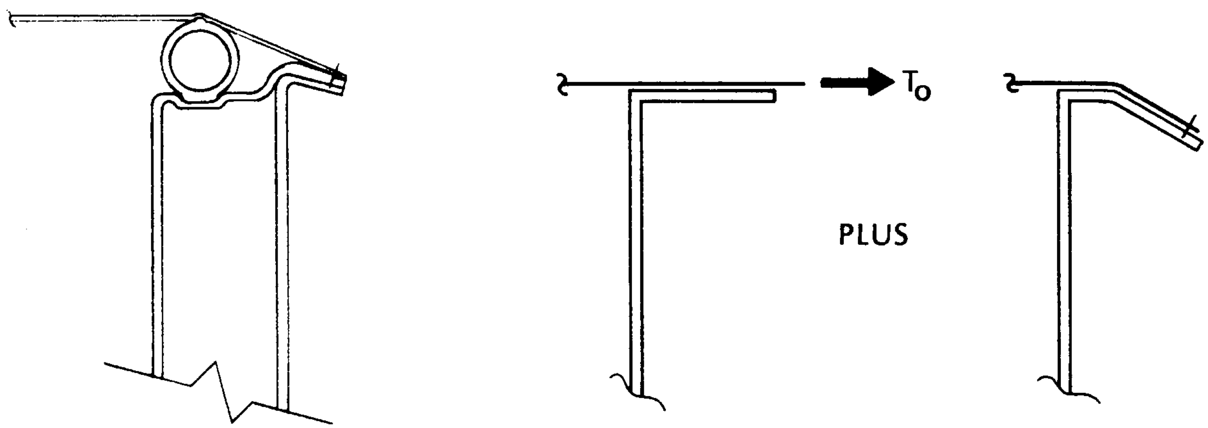


- INITIAL TENSION DEFINED BY DIAPHRAGM STRESS
- 0.010" ALUMINUM
- LEVELED STOCK
- REFLECTIVE MATERIAL DEGRADATION

SOLAR KINETICS INC.

MEMBRANE TO RING ATTACHMENT

BASELINE | IMPROVED



EDGE CRIMP AND TUBE INFLATION

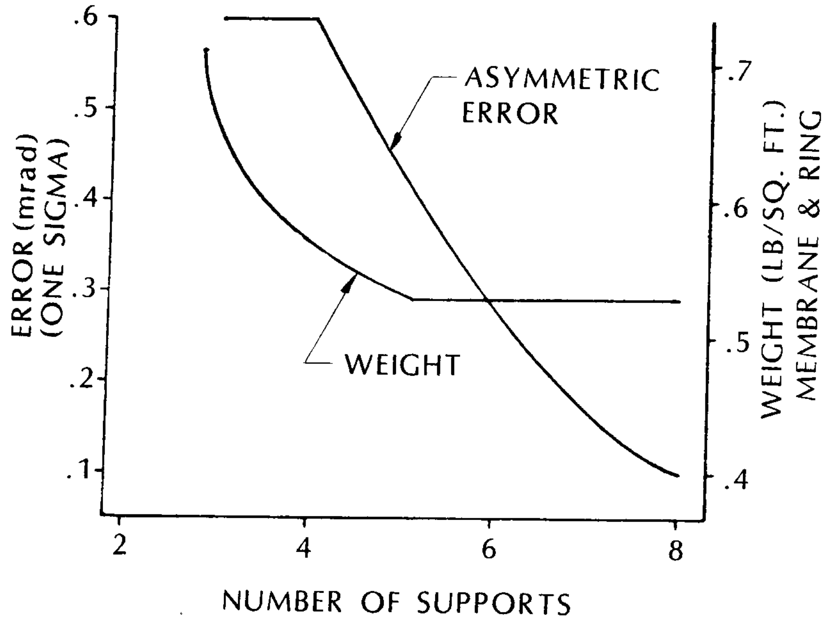
TENSION PRIOR TO ASSEMBLING

EDGE CRIMP

- REDUCE MATERIAL AND MANUFACTURING COST
- INCREASE RELIABILITY

SOLAR KINETICS INC.

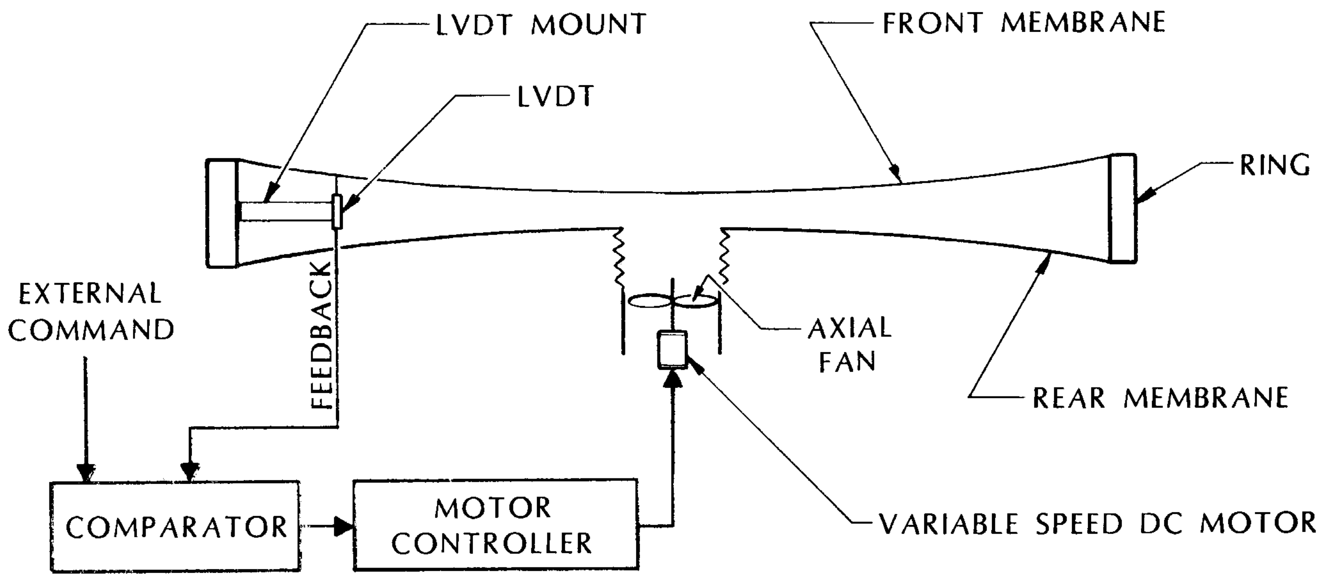
REAR STRUCTURE



- CONTRACT RESTRICTS TO SAME CONCEPT (CENTRALLY LOCATED DRIVE POINTS)
- SIX TRUSSES AND HUB
- REVISE ASSUMED LOAD PROFILE
- REDUCE MANUFACTURING COMPLEXITY/COST

SOLAR KINETICS INC.

FOCUS CONTROL



- REDUCE VOLUMETRIC REQUIREMENTS CAUSED BY REAR MEMBRANE MOVEMENT
    - FIX MEMBRANE NEAR CENTER
    - INCREASE REAR MEMBRANE TENSION
- HIGH EFFICIENCY FAN AND HOUSING

SOLAR KINETICS INC.

DESIGN OBJECTIVES SUMMARY

- IMPROVE PERFORMANCE
  - REDUCE INACTIVE APERTURE ASSOCIATED WITH MEMBRANE IRREGULARITIES
- REDUCE FABRICATION COSTS
  - CONSIDER OPEN SECTION FOR "RING"
  - EVALUATE ATTACHMENT STIFFNESS, MEMBRANE TO RING
- REDUCE MATERIAL COSTS
  - REVISE ASSUMED LOAD PROFILE
  - ELIMINATE POST TENSION TUBE
- REDUCE OPERATION AND MAINTENANCE COSTS
  - DECREASE PARASITIC DEMANDS
  - INVESTIGATE FILM PROTECTION AND LAMINATION PROCEDURES

SOLAR KINETICS INC.

SESSION IV

UTILITY STUDIES

GREGORY KOLB

CHAIRMAN

UTILITY STUDIES

Introduction

Sig Gronich
Department of Energy

(This page is provided for notes.)

UTILITY SOLAR CENTRAL RECEIVER STUDY - ALTERNATE UTILITY TEAM

Arizona Public Service Company
Utility Solar Central Receiver Study
D. L. Thornburg
Phoenix, Arizona 85072-3999

In addition to the Arizona Public Service (APS) and Pacific Gas and Electric (PG&E) U. S. Department of Energy agreements, APS was also funded to perform specific trade studies which were not included in the APS and PG&E agreements. The group of contractors formed for this work was designated as the Alternate Utility Team.

Prior studies and system experiments tested at the Solar Thermal Test Facility (STTF) had primarily used a cavity configuration with various receiver working fluids, namely water/steam, sodium or salt; the exception is Solar One which utilizes an external water/steam receiver. The European experience has also utilized cavity receivers.

The Alternate Utility Team, as a part of the trade studies, prepared designs of surround heliostat fields and external receivers for 100, 190, 343, 390 and 780 MWt receiver output using molten salt. In addition, a detailed examination of the 100 and 343 MWt receiver designs was performed and adjustments made to eliminate differences not unique to the cavity and external configurations. Costs and annual performance estimates were then prepared for both configurations over a range of plant sizes from 50 to 200 MWe.

The results from this study indicated that an external receiver should produce electric energy at a cost slightly less than that for the cavity in the range of 50 to 100 MWe. For plant sizes larger than 100 MW, the external receiver is clearly the preferred choice.

ALTERNATE UTILITY TEAM

UTILITY SOLAR CENTRAL RECEIVER STUDY
SOLAR THERMAL TECHNOLOGY CONFERENCE

AUGUST 26-27, 1987
ALBUQUERQUE, NEW MEXICO

APS.

Black & Veatch, Engineers-Architects
Kansas City

AUT SCOPE OF WORK

Task 1 — Review Study Guidelines

Task 2 — Provide Common Data
- External Salt Receiver
- Thermal Storage

— Conduct Trade Studies
- Select External Salt Receiver Versus Cavity Salt Receiver

APS.

CAVITY AND EXTERNAL SALT RECEIVER DATA
COMMON DATA (PARTIAL) - 100 MWt

	FW	B&W
Salt Flow Rate, kg/s (lb/h)	236.8 (1.88×10^6)	236.7 (1.879×10^6)
Optical Tower Height, m (ft)	75.8 (249)	117.6 (386)
Absorber Surface Area, m^2 (ft^2)	267.2 (2,876)	254 (2,738)
Total Operating Weight, 10^3 kg (10^3 lb) (Surge Tanks at 3/4-Full)	407 (898)	325 (717)
Tube O.D. x Wall Thickness, mm (in)	25.4 x 1.65 (1.0 x 0.065)	31.8 x 1.65 (1.25 x 0.065)
Salt Inlet Velocity, m/s (ft/s)	3.8 (12.3)	3.8 (12.3)
Design Point Frictional Pressure Drop, kPa (psi)	2,310 (335)	1,593 (231)
Peak Absorbed Heat Flux, MW/m^2 ($Btu/h\text{-}ft^2$)	0.75 (238,000)	0.75 (238,000)
Average Absorbed Heat Flux, MW/m^2 ($Btu/h\text{-}ft^2$)	0.37 (117,000)	0.39 (124,000)
Receiver Thermal Efficiency	0.93	.935

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CAVITY AND EXTERNAL SALT RECEIVER DATA
COMMON DATA (PARTIAL) - 343 MWt

	FW	B&W
Salt Flow Rate, kg/s (lb/h)	812.3 (6.45×10^6)	812.6 (6.452×10^6)
Optical Tower Height, m (ft)	140 (459)	215.5 (707)
Absorber Surface Area, m^2 (ft^2)	858 (9,232)	922 (9,922)
Total Operating Weight, 10^3 kg (10^3 lb) (Surge Tanks at 3/4-Full)	913 (2,013)	756 (2,430)
Tube O.D. x Wall Thickness, mm (in)	25.4 x 1.65 (1.0 x 0.065)	47.6 x 1.65 (1.875 x 0.065)
Salt Inlet Velocity, m/s (ft/s)	3.9 (12.7)	4.2 (13.7)
Design Point Frictional Pressure Drop, kPa (psi)	2,275 (330)	1,958 (284)
Peak Absorbed Heat Flux, MW/m^2 ($Btu/h\text{-}ft^2$)	0.74 (235,000)	0.75 (238,000)
Average Absorbed Heat Flux, MW/m^2 ($Btu/h\text{-}ft^2$)	0.4 (126,000)	.37 (117,000)
Receiver Thermal Efficiency	0.935	0.937

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CAVITY AND EXTERNAL SALT RECEIVER COMMON DATA ADJUSTMENTS

- Both Receiver Suppliers Can Design and Fabricate Either Type of Receiver
- Obtain Common Data for Same Peak Absorbed Flux (0.75 MW/m^2)
- Review Design Approach, Assumptions, and Results with Both Suppliers
- Obtain Detailed Information from Each Supplier on:
  - Design Description
  - Weight
  - Performance
  - Capital Cost
  - O&M Cost
- Eliminate Differences in the Two Receiver Designs Which are Not Unique to Each Receiver Configuration
- Adjust Weight, Performance, Capital Cost and O&M Cost on as Detailed a Basis as Possible

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RECEIVER CONFIGURATION SELECTION
WEIGHT COMPARISON - 343 MWt

Item	Adjusted Values Cavity (1,000 lb)	Adjusted Values External (1,000 lb)	Remarks
Structure	1,060	900	External Should be ~ 15% Lighter than Cavity
Absorber			
• Tubes	80	70	Proportional to Surface Area
• Headers	30	40	Proportional to Header Length
• Insulation	60	60	Proportional to Surface Area
Surge Tanks	110	110	Both Configurations Should Have the Same Tanks
Piping and Valves	140	130	Changed Cavity to All-Up and Alternate East-West Flow In-Line Cavity Should Require ~ 10% More Piping than Circular External Arrangement
Door	300	—	None
Miscellaneous	170	160	Cavity Should be ~ 5% Heavier Due to Wall Panels, Extra Insulation, and Heat Tracing
Total Dry Weight	1,950	1,470	

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RECEIVER CONFIGURATION SELECTION
CAPITAL COST COMPARISON - 343 MWt

Item	Adjusted Values Cavity ($1,000)	Adjusted Values External ($1,000)	Remarks
Structure	1,000	900	Proportional to Structure Weight
Absorber			
• Tubes	2,400	2,300	Proportional to Surface Area
• Headers	2,300	3,200	Proportional to Header Length
• Insulation	400	400	Proportional to Surface Area
Surge Tanks	500	500	Should be the Same
Piping and Valves	800	700	Proportional to Piping and Valves Weight
Instrumentation and Controls	500	500	None
Door	1,500	—	None
Miscellaneous Equipment	1,900	1,800	Proportional to Miscellaneous Equipment Weight
Freight	300	200	Proportional to Total Weight
Subtotal	11,600	10,500	
Engineering	2,100	2,000	Cavity Should be ~ 5% Higher
Erection	7,500	5,700	Proportional to Total Weight
Total Capital Cost	21,200	18,200	

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RECEIVER CONFIGURATION SELECTION TRADE STUDY GENERAL APPROACH

- Develop Cost/Performance Data for Integrated Single and Multiple Collector/Receiver Module Systems at Various Thermal Ratings
- Select Preferred Number of Collector/Receiver Modules at Each Thermal Rating
- Develop System Costs for Solar Multiples in 0.75 to 3.0 Range for 60, 100, 200 MWe Cavity, and 50, 100, 200 MWe External Plants
- Calculate Costs of Thermal and Electrical Energy for Each System

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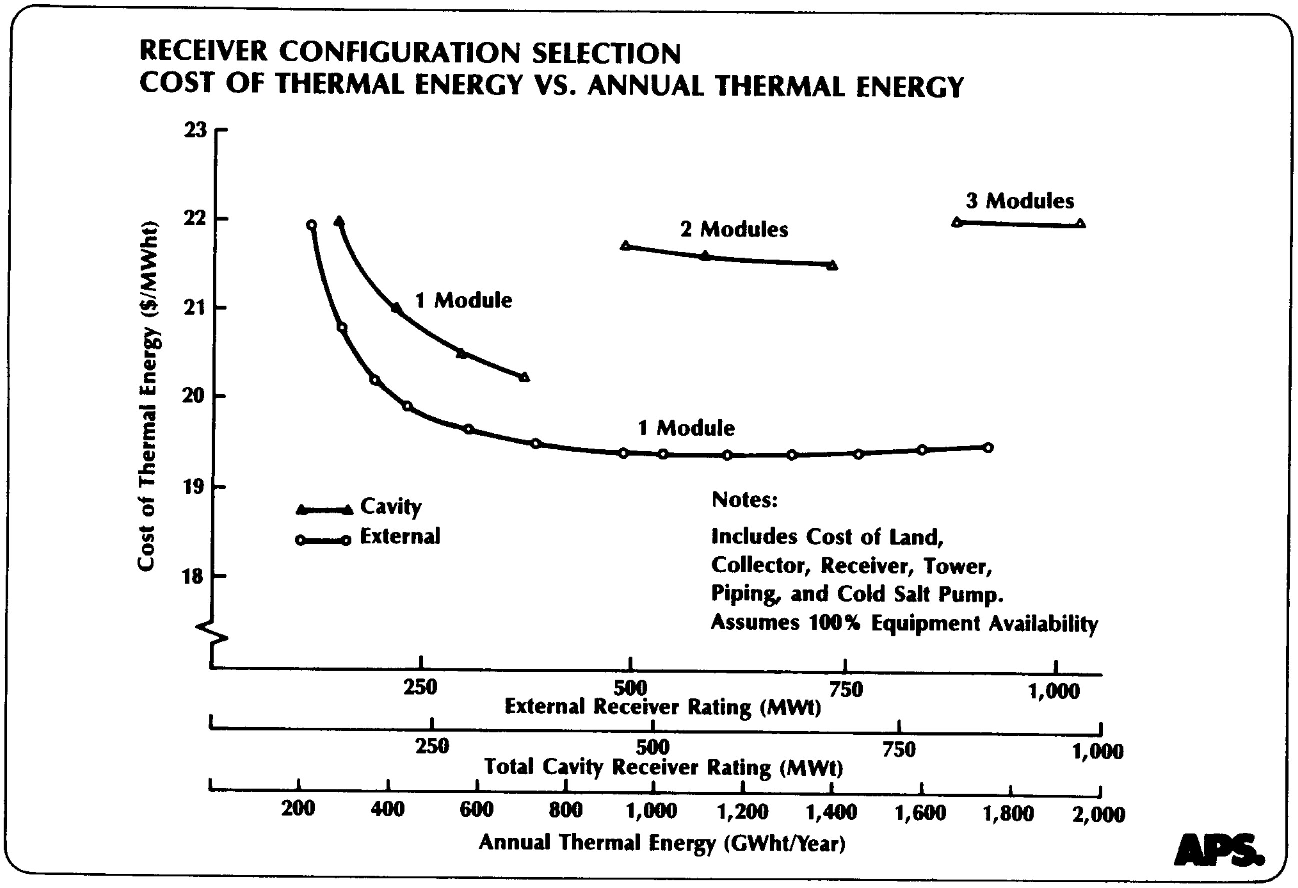

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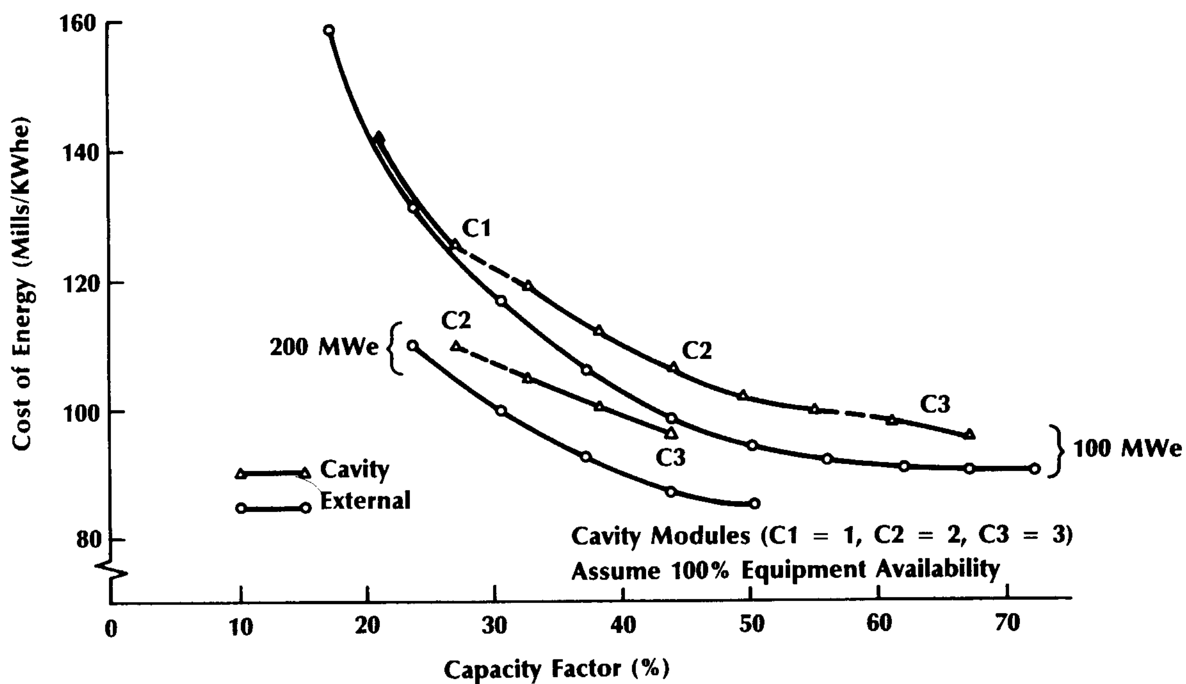
RECEIVER CONFIGURATION SELECTION
COST OF ENERGY VS. CAPACITY FACTOR



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RECEIVER CONFIGURATION SELECTION
OTHER CONSIDERATIONS

	Favors	Potential Impact
• Effect of Cavity/External Transient Operation Characteristics on Annual Energy Production	Cavity	Small to Medium
• Auxiliary Power Requirements Not Included in Thermal Costs of Energy	External	Small
• Piping Thermal Losses Not Included in Thermal Costs of Energy	External	Small
• Tube Length/Receiver Size Constraints	External	Medium to Large
• Flux Distribution in Cavities with Large Heliostats	?	Small
• Flexibility in Overnight Conditioning	Cavity	Small
• Controlability	Cavity	?
• Effects of Less Accurate Heliostats	?	?

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RECEIVER CONFIGURATION SELECTION

- Based on the Design Assumptions and Information Received, the External Receiver Should Produce Energy at a Cost of 5% Less than the Cavity
- For Cavity Module Sizes Larger than 100 MW, Multiple Modules are Necessary Due to the 100 Foot Receiver Tube Length Shipping Limitation
- As a Result of this Trade Study, the APS and Alternate Teams Selected an External Receiver Configuration for Proceeding to the Study Conceptual Design

APS.

UTILITY SOLAR CENTRAL RECEIVER STUDY

Arizona Public Service Company

E. R. Weber
Phoenix, Arizona 85036

Arizona Public Service (APS) and Pacific Gas & Electric (PG&E) have been co-funded by the U. S. Department of Energy to conduct a coordinated set of studies that will chart a course for the commercialization of solar central receiver plants based on a utility preferred system. In Phase I, the APS study has as its prime objectives to determine through trade studies whether modularization of Solar Thermal Central Receiver (STCR) plant is technically and economically viable, and if so, to develop a design concept of a commercial first plant.

The first half of Phase I trade study activities developed Common Data on the receiver tower and molten salt cavity receivers for a range of sizes from 17 to 343 MWt. The primary APS trade studies focused on modularization and solar/fossil hybrid plants. Modularization was determined to be feasible either by replicating or incrementing a plant module, which includes collector field, receiver, tower, thermal storage, steam generation and electric power generation systems. Trade studies were performed on modularization of STCR plants over a range of 7.5, 15, 30, 60 and 120 MWe modules based on a Saguaro-type cavity receiver. Selection of cost effective module size was based on three figures of merit: (1) cost of thermal energy, (2) cost of electrical energy, (3) cost-to-value ratio. A combination of incremental/replicative modules, using phased construction, was determined to be the most effective approach to reducing initial capital requirements to achieve a final desired plant size. A 60 MWe modularized plant configuration was developed from which capital and O&M costs, revenue generated, and initial capital outlay were determined.

The conceptual design of a first commercial plant was developed for a 110 MWe gross plant output with a solar multiple of 1.8, and a molten salt external receiver. The design approach utilizes modularization through two incremental modules of 55 MWe each to achieve the total plant size. Design requirements and performance estimates of the net annual energy generation are based on a Barstow, CA site.

ARIZONA PUBLIC SERVICE COMPANY

UTILITY SOLAR CENTRAL RECEIVER STUDY
SOLAR THERMAL TECHNOLOGY CONFERENCE

AUGUST 26-27, 1987
ALBUQUERQUE, NEW MEXICO

APS.

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Kansas City

APS SOLAR CENTRAL RECEIVER STUDY PRESENTATION OBJECTIVES

- To Give Results of Phase I
- To Describe Team-Generated Common Data
- To Present the Results of the APS Trade Studies
- To Evaluate the Feasibility of Phased Modular Construction of a 60 MWe Plant for Central Receiver Commercialization
- To Present the APS Receiver Configuration Selection for the Commercial Plant
- To Present the APS Team Conceptual Design of the Commercial First Plant

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APS SOLAR CENTRAL RECEIVER STUDY
KEY TRADE STUDY ISSUES

- Common Data and Comparable Results with Other Teams
- Opportunities for Increased Performance and Cost Reductions
- Replicative vs. Incremental Collector/Receiver Modules
- Integrating Modular Subsystems into Economic Central Receiver Plant Modules
- The Advantageous Use of Solar/Fossil Hybrid Systems
- Small Central Receiver Modules as an Aid to Commercialization Through Phased Construction
- Conditions Favoring the Use of North Field/Cavity or Surround Field/External Salt Collector/Receiver Systems
- Application and Use of Trade Study Results in Defining the Preferred APS Commercial First Plant Configuration

APS

APS TEAM-GENERATED COMMON DATA

- Data Developed:
  - — Tower Costs - Black & Veatch
  - — Cavity Receiver Costs - Babcock & Wilcox*
  - — Storage Costs - Pitt DeMoines
- Bases:
  - — Guidelines and Groundrules Document
  - — Sizes of Interest to Teams

* Cavity Receiver Flux Maps and Performance Estimates Provided by SPECO

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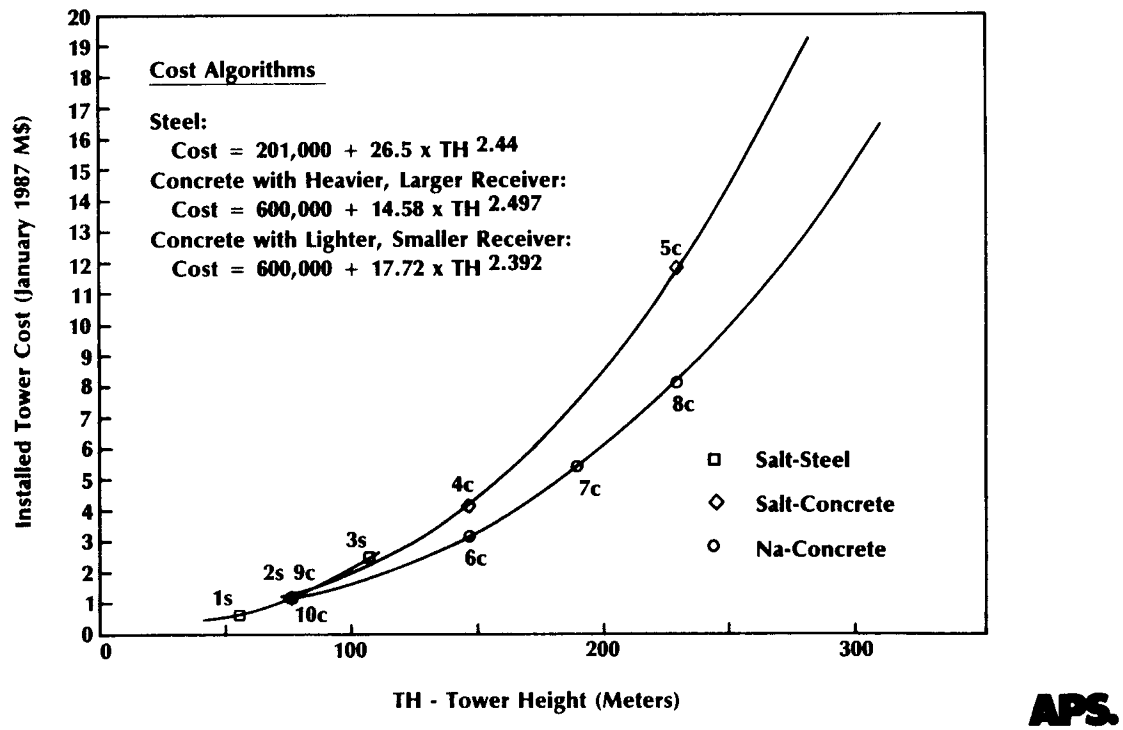
SOLAR CENTRAL RECEIVER STUDY
TOWER COST vs. HEIGHT



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Kansas City

CAVITY RECEIVER COMMON COST DATA*

Rating (MWe)**	Rating (MWt)	Capital Cost ($1,000)
7.5	27	5,319
15	52	6,741
30	100	9,197
60	190	14,044
120	343	22,565

* O&M Cost Estimated to be 1.5% of Capital Cost
** Solar Multiple = 1.1

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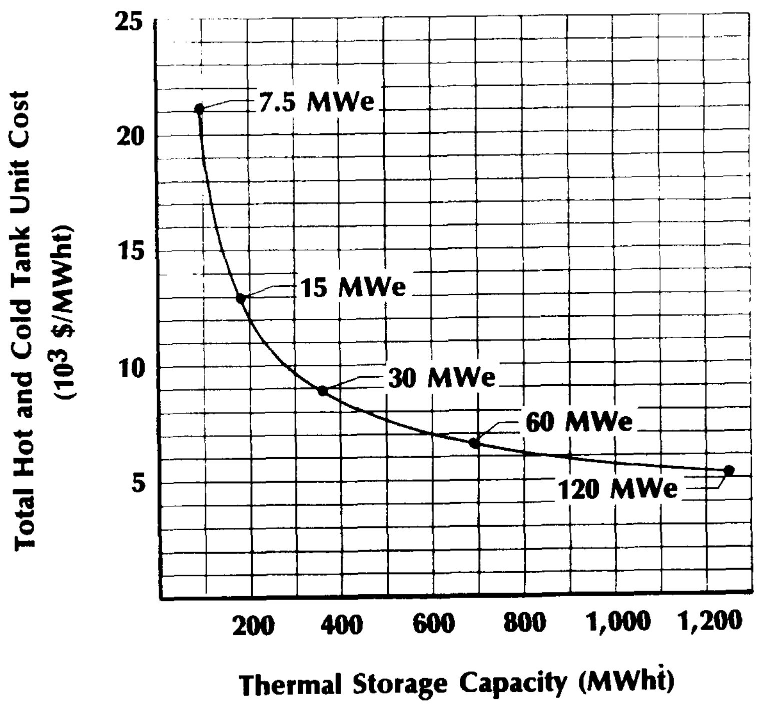
MODULE STORAGE UNIT COST



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APS SOLAR CENTRAL RECEIVER STUDY
MAJOR TRADE STUDIES

Modularity

Addresses the Issue of Economic Plant Modules in the 7.5-120 MWe Size Range that Can be the Basis for

1. Small Scale System Experiments for Affordable Technology Development, and
2. Building Blocks to Achieve Larger Capacity Commercial Plants in a Phased Construction Approach

Fossil Hybrid

Addresses the Operating and Economic Advantages for Solar/Fossil Hybrid Operation for the Purpose of Obtaining

1. Firm Capacity Credit
2. Increased Capacity Factor
3. Dependable Revenue Stream

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MODULARITY CONCEPTS

- Replicative Concepts
  - A. Multiple Towers - North Field Cavity Receiver Configuration Scaled from Improved Saguaro Design
  - B. Same as "A" Except for Surround Field External Receiver, Baseline Supplied by Other Teams
- Incremental Concepts
  - C. Full Size Receiver/Tower; Collector Field Constructed in Increments
  - D. Full Size Tower: Increment Receiver & Collector Field
  - E. North Field External Receiver with "Add-On" Cavity Option
  - F. Multiple Receivers on Single Tower/Collector Field
  - G. Increment Heat Absorption Panels

A., B., and C. Selected for Detailed Evaluation, with E. as a Potential Option

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Kansas City

COLLECTOR/RECEIVER FIELD MODULE DESIGN

- Addressed a Multiplicity of Cavity Receiver Sizes and Designs
  - 7.5, 15, 30, 60, 120 MWe
  - Geometrically Similar and Dissimilar Designs
- Used Scaling/Similarity Relations Where Applicable
  - Similar Systems Imply Replicative Modules
  - Dissimilar Systems Imply Incremental Modules
- Used Saguaro Design (60 MWe & 1.1 SM) as "Prototype" with Modifications
  - Improved (2-Dimensional) Aiming Strategy
  - Increased Peak Flux Limits
  - Reduced Size and Aspect Ratio (Cavity Depth/Aperture Width)
  - Large Heliostats

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ANNUAL ENERGY (MWht) - INCREMENTAL MODULARITY (650 ° F SALT INLET TEMPERATURE)

		Plant Size: 2 x 15 MWe		Plant Size: 2 x 30 MWe	
		First Module	Complete Plant	First Module	Complete Plant
Direct Insolation		201,829	376,546	383,474	715,438
Turndown Ratio Constraint (N/A)					
After Field Losses	(7.50)	151,372		287,606	
	(.658)		247,767		470,758
After Receiver Losses	(.837)	126,698		240,726	
	(.890)		220,513		418,975

Note: Field Losses Include Availability x Cosine x Reflectivity x Tower Shadow x Blocking x Attenuation x Spillage

Receiver Losses Include Reflectivity x IR x Convection & Conduction

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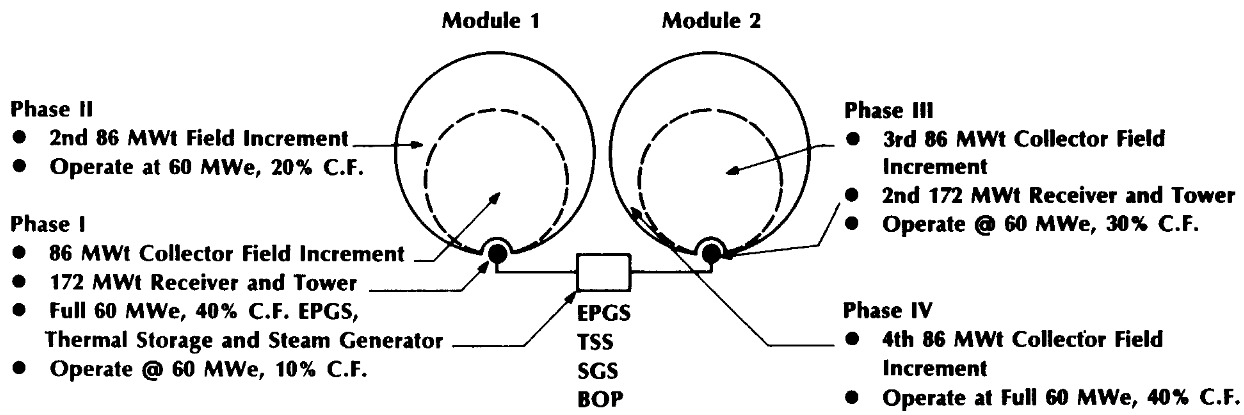
Kansas City

PHASED CONSTRUCTION OF A 60 MWe CENTRAL RECEIVER (CAVITY) PLANT

Solar Multiple = 2.0
Capacity Factor ≅ 40%
Combined Receiver Rating = 344 MWt



APS

Black & Veatch, Engineers-Architects
Kansas City

FOSSIL HYBRID CONCEPTS

1. Fossil Boiler in Parallel with Solar System
2. Fossil Salt Heater in Parallel with Solar Receiver
3. Fossil Salt Heater in Series with Solar Receiver
4. Fossil Separately-Fired Superheater
5. Gas Turbine with Waste Heat Boiler (WHB)
6. Gas Turbine Using Waste Heat in Salt Heater

APS.

Black & Veatch, Engineers-Architects
Kansas City

RECEIVER CONFIGURATION SELECTION

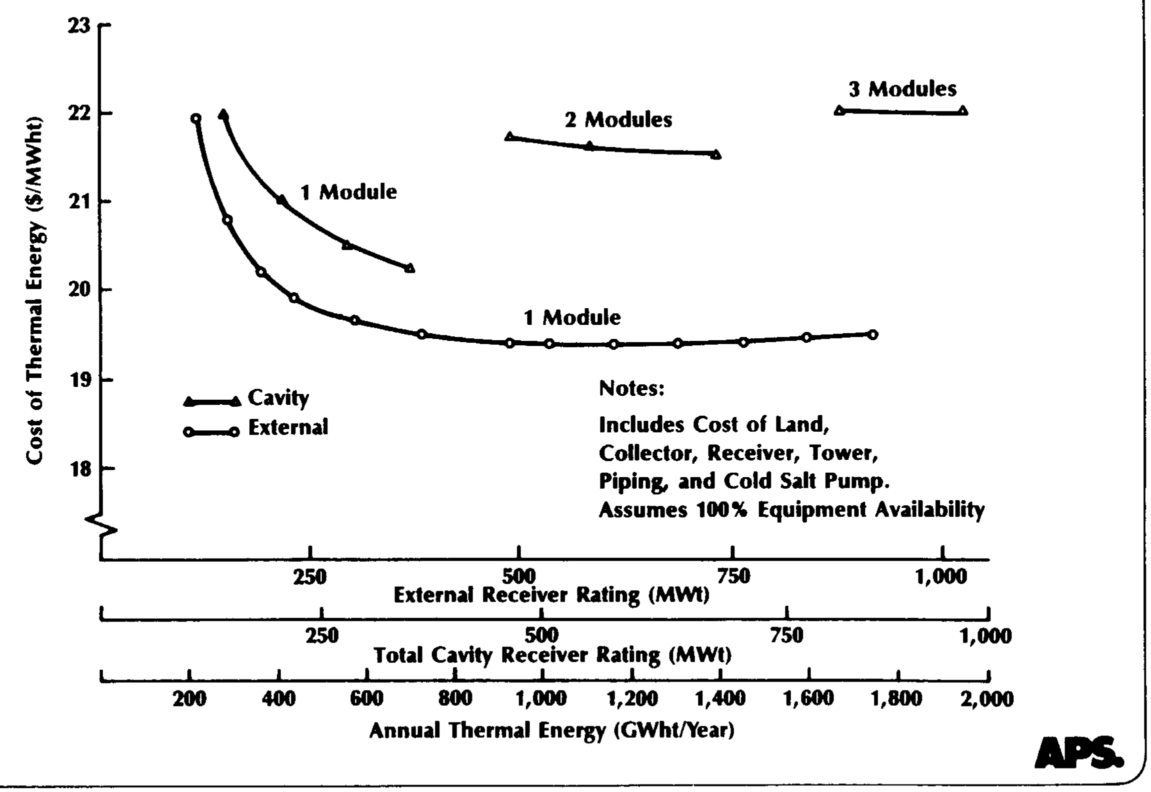
APS Selection Database

- Common Cavity Receiver Data
- Cavity Field Data
- Integrated Cavity System Cost/Performance Data
- Joint APS/AUT Cavity/External Data Adjustments
- Joint APS/AUT Meeting for Configuration Selection

APS.

Black & Veatch, Engineers-Architects
Kansas City

COST OF THERMAL ENERGY VS. ANNUAL THERMAL ENERGY



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Kansas City

APS SOLAR CENTRAL RECEIVER STUDY CONCLUSIONS

- Plant Sizes Smaller Than About 60 - 100 MWe are Not Economic for U.S. Utility Application
- Smaller Plant Modules Appear to be Useful for the Early Commercial Implementation of Central Receivers Through Phased Construction
- For the Current APS Avoided Cost Structure, the Optimum Capacity Factor for a 100 MWe Cavity Receiver Plant is About 40% (1.8 Solar Multiple)
- The Preferred Solar/Fossil Hybrid Concept Employs a Parallel Gas-Fired Boiler as the Heat Source

APS

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Kansas City

APS SOLAR CENTRAL RECEIVER STUDY CONCLUSIONS (Continued)

- For a Cavity Receiver, the Preferred Collector/Receiver System Module Configuration May Employ a Combination of the Incremental and Replicative Modules, Depending on Cash Flow Constraints
- Significant Reduction in Cavity Receiver Size and Capital Cost Has Been Achieved Through the Use of Improved Heliostat Aiming Strategies and Higher Allowable Incident Solar Fluxes
- The APS-Preferred Receiver Configuration for the Commercial Plant Design is External
- The Trade Study Results Provide a Good Basis for Configuring the APS Commercial Plant for Conceptual Design

APS.

Black & Veatch, Engineers-Architects
Kansas City

PACIFIC GAS AND ELECTRIC COMPANY
UTILITY SOLAR CENTRAL RECEIVER STUDY

T. Hillesland, Jr.

Pacific Gas and Electric Company
San Ramon, California 94583

Pacific Gas and Electric (PGandE) and Arizona Public Service have begun a cooperative set of studies, cofunded by the U.S. Department of Energy, the Electric Power Research Institute, and the utilities, that will chart a course for the commercial demonstration of solar central receiver power plants for utility application.

In Phase I of this study, the utilities will select the best type of solar central receiver technology for commercialization. Then in Phase II, a recommended strategy will be developed to bring the selected technology to commercial readiness, including component and system tests. This paper summarizes PGandE's current results from Phase I.

After a common set of guidelines were agreed upon by both utility teams, a number of trade studies were performed to select a plant that would be attractive for utility application. A target maximum allowable cost was developed based on a competing solar thermal technology. PGandE's projected power values and its risk weighting methodology (the Comprehensive Policy Score) were used to determine optimum solar multiple, storage requirements, capacity factor, and plant size. These results were also examined for the projected power values provided by San Diego Gas and Electric.

Two plant conceptual designs were developed in order to make a selection of a preferred receiver heat transfer fluid. The first system used liquid sodium in the receiver loop. The second system had a nitrate salt receiver. Both designs were of the external receiver type with surround fields and used nitrate salt for storage. To develop design requirements for an intermediate sodium/salt heat exchanger in the first system, reaction experiments were performed.

The parameters selected for the conceptual designs for a first commercial plant were: 110 MWe (gross), 1.8 solar multiple, 6 hours of storage, and a 468 MWt receiver rating. Stressed membrane heliostats were also selected for the plant. The designs include an estimate by scaling of the cost and performance of an "Nth" commercial plant were N is about 5. The Nth plant would be twice the rating of the first commercial plant.

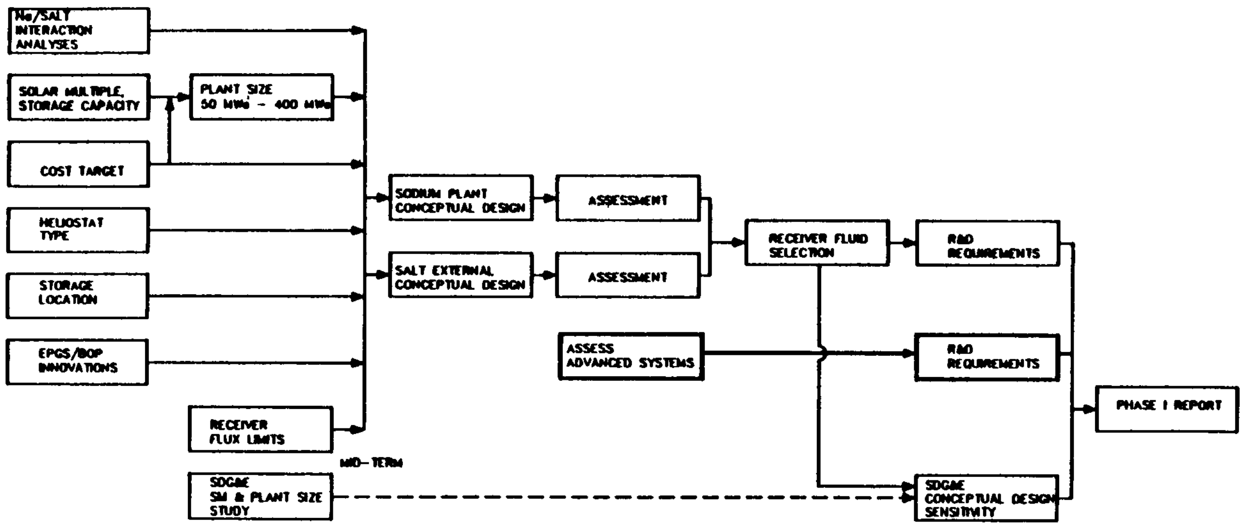
PG and E

PACIFIC GAS AND ELECTRIC COMPANY
UTILITY SOLAR CENTRAL RECEIVER STUDY

PRESENTED AT THE
SOLAR THERMAL TECHNOLOGY CONFERENCE
AUGUST 26-27, 1987

T. HILLESLAND, JR.
PGANDE
DEPARTMENT OF ENGINEERING RESEARCH
SAN RAMON, CALIFORNIA

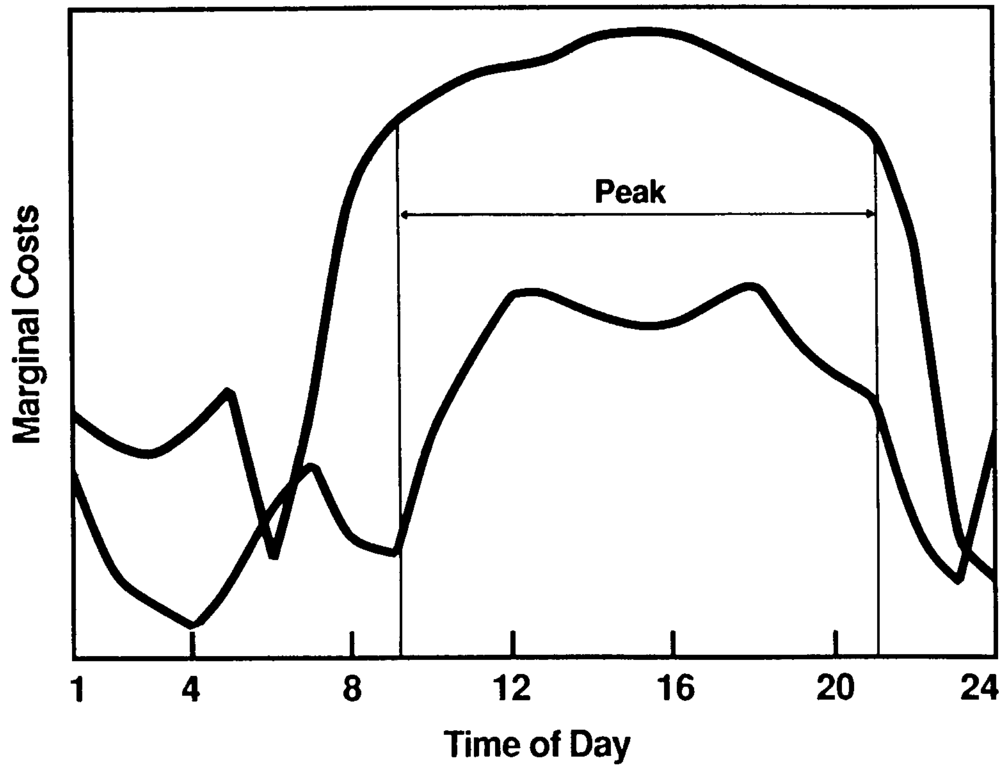
PG and E



Central Receiver Study
LOGIC FLOW DIAGRAM

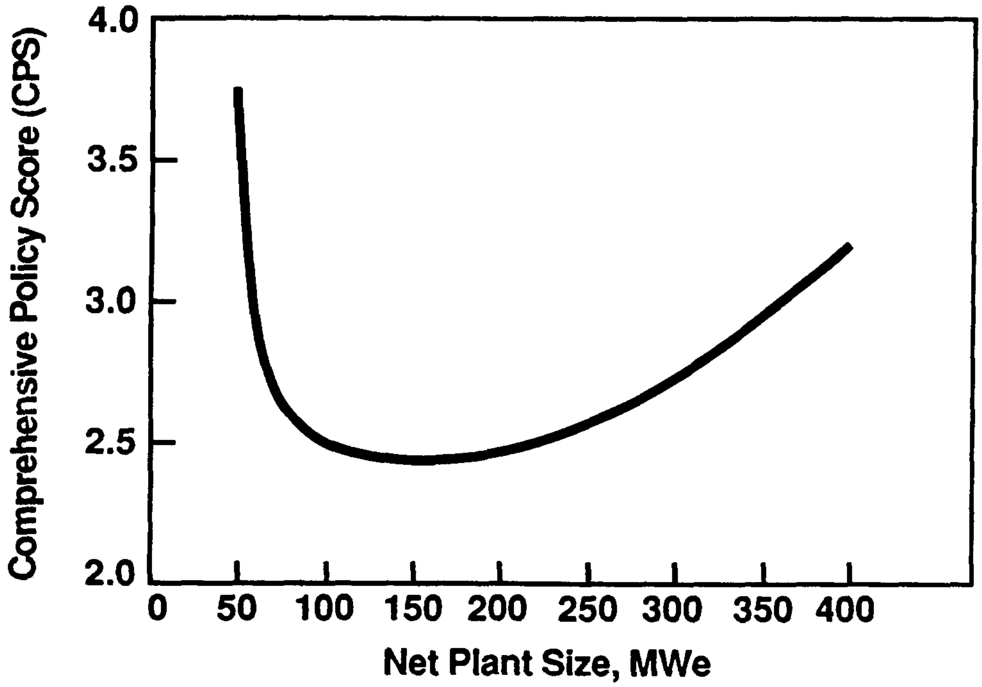
PG and E

PGandE Projected Marginal Costs
Season B



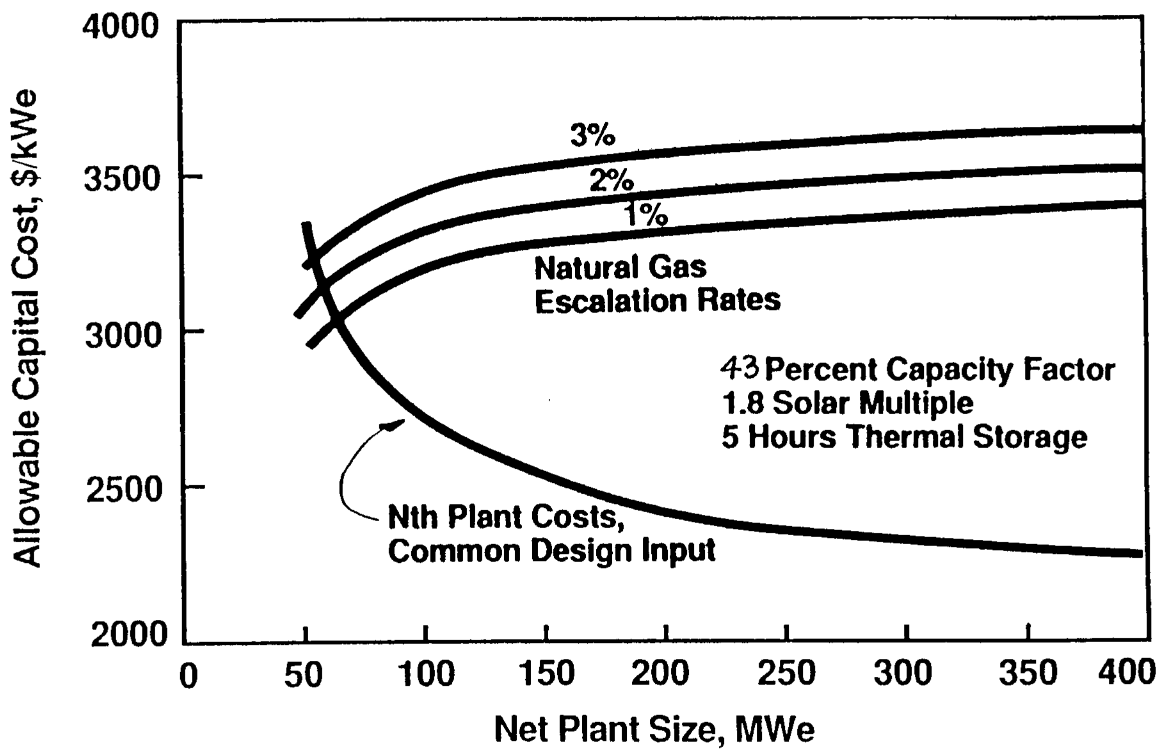
PG and E

First Plant
Comprehensive Policy Scores



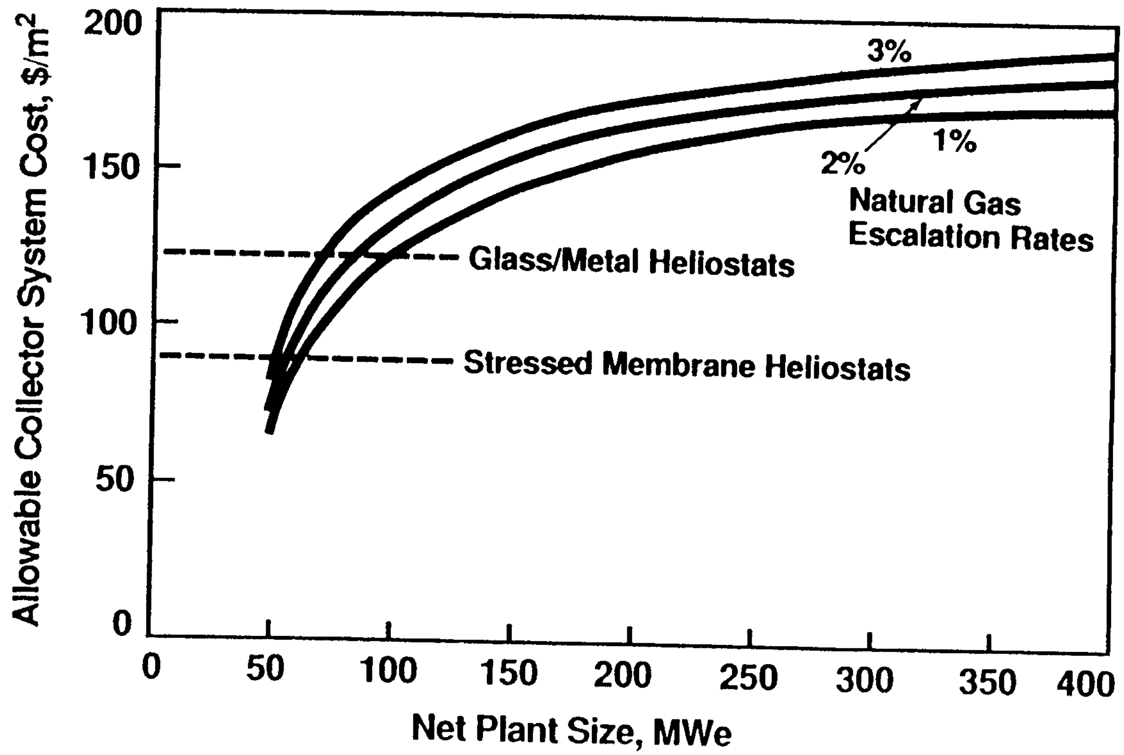
PG and E

Allowable Central Receiver Plant Costs



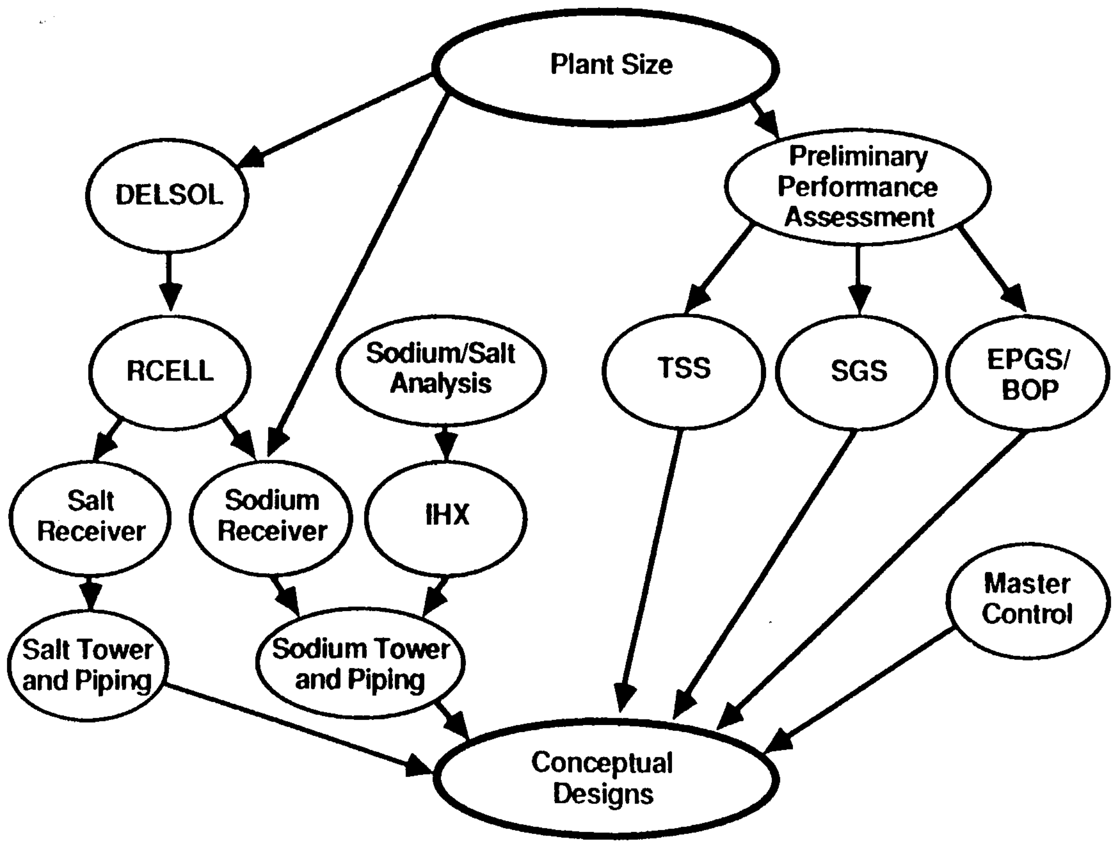
PG and E

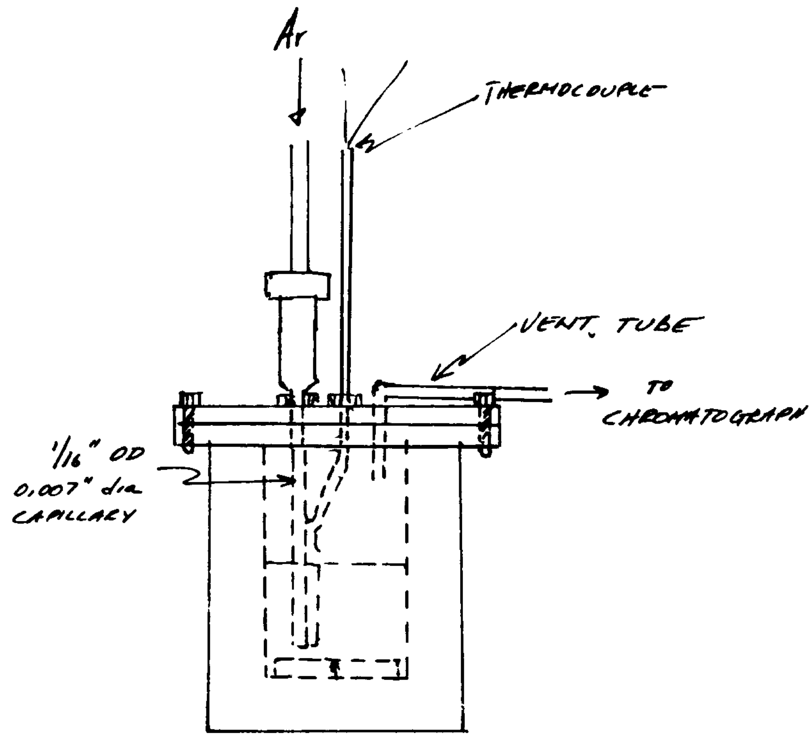
Allowable Collector System Costs



PG and E

Conceptual Design Approach

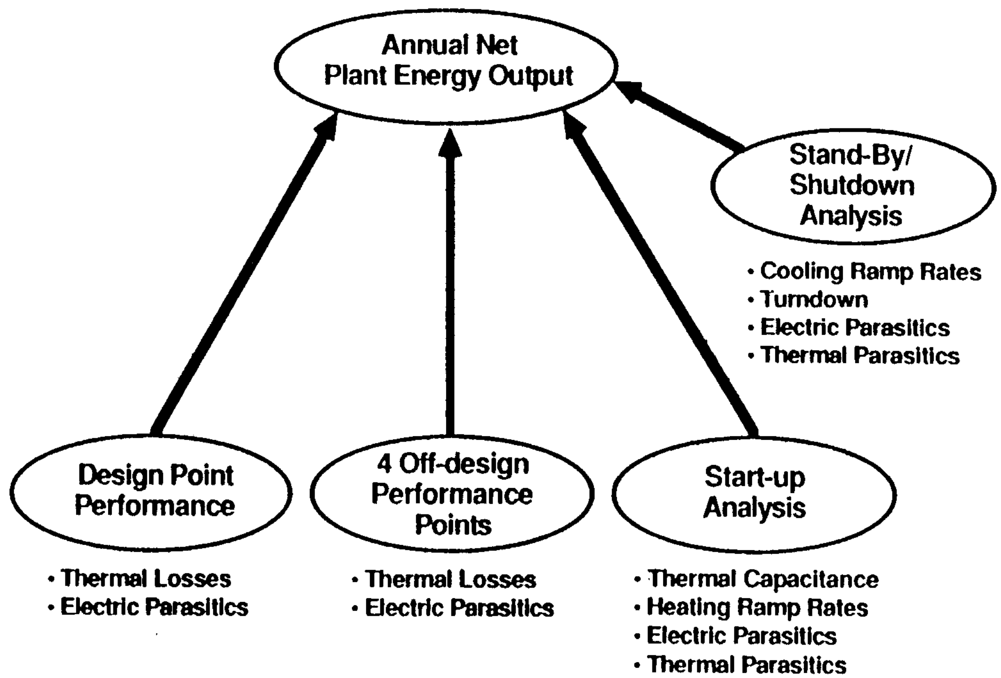




SODIUM - NITRATE SALT REACTOR

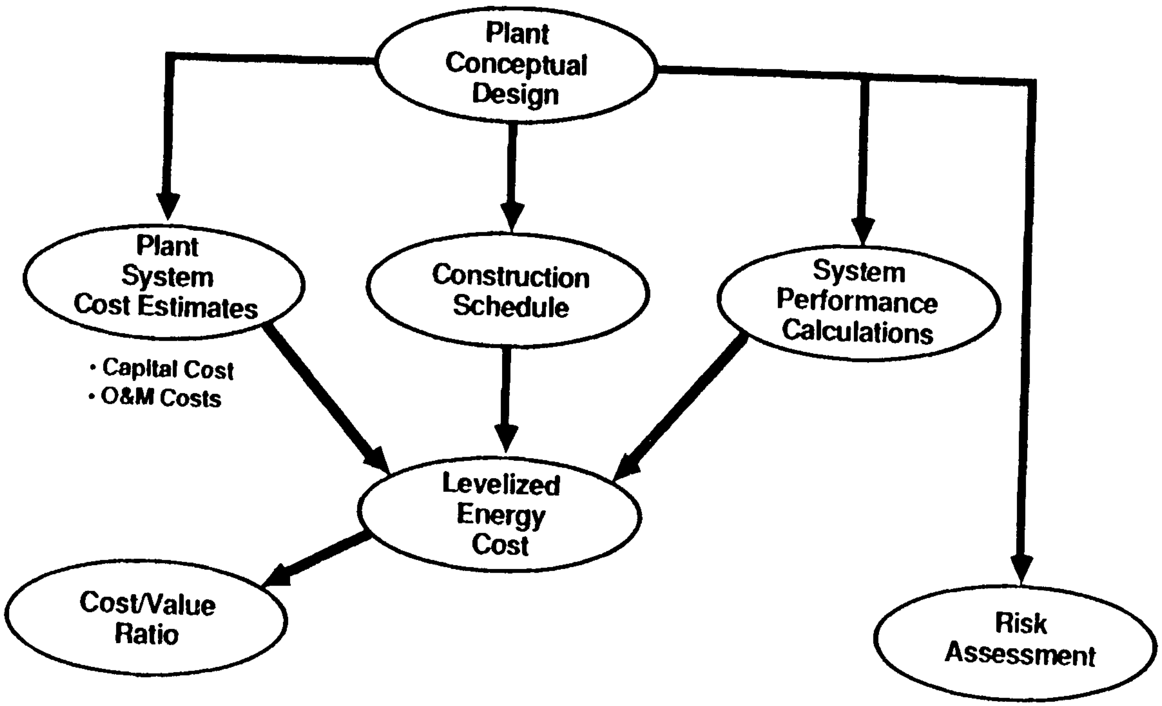
PG and E

Performance Calculations



PG and E

Assessment Approach



PG and E

Summary

PGandE Conceptual Design

- Surround field — stretched membrane heliostats
- Solar multiple — 1.8
- External receiver — 468 MWt
- Nitrate salt thermal storage — 5 hours
- 100 MWe nominal plant rating

SDG&E Sensitivity

- Solar multiple — 2.1
- Thermal storage — 10 hours
- Nominal plant rating >150MW

SESSION V

CENTRAL RECEIVER SYSTEMS

GREGORY KOLB

CHAIRMAN

Solar One Test Center

Solar One Power Production Phase

Solar Thermal Technology Conference

August 26-27, 1987

Albuquerque, New Mexico

Charles W. Lopez
Site Manager
Southern California Edison Co.

SOLAR ONE TEST CENTER

<u>Three-year Power Production Phase</u>

Objectives

- Plans
- Operating Modes

Budgets

Personnel

O&M Resources

Operating Events

Accomplishments

Plant Operation

- Power Generation/Capacity Factor/Use Factor
- Solar Efficiency
- Operating Times
- Plant Utilization
- Outage Times
- Heliostat Availability/Cleanliness

Milestones

Solar One Test Center

Three-Year Power Production Phase - Plans

Plant to be operated and maintained per procedures common to a conventional power plant to effect its safe, reliable, and efficient operation.

Plant to be evaluated in the utility sense regarding:

- Power Production
- Availability
- Reliability
- Operation and Maintenance Expense

Plant performance to include significant operation and maintenance experience to be documented.

The above information will be available to project participants to allow comparison of actual experience with design conditions.

The above information will also be available to public utilities and others interested in solar central receiver power generation systems.

<u>Three-Year Power Production - Operating Modes</u>

Generally, plant operation will be receiver direct to maximize power production.

Generally, the thermal storage system will be maintained with a fifty percent charge to:

- Provide a low cost auxiliary steam supply
- Allow plant operation on partially cloudy days with or without the turbine in service.

The thermal storage charging and extraction systems will be utilized weekly for power production to:

- Insure system integrity
- Allow evaluation of the thermal storage system
- Maintain operator familiarization with the system

Plant to perform special test on an exception basis as required to:

- Follow up on test and evaluation period performance results
- Evaluate and correct plant operating problems discovered during the power production phase
- Evaluate new operating strategies

Operators will routinely start up all plant systems manually to maintain their familiarity with plant system interrelationships.

Solar One Test Center

O&M Budget Comparison ($1,000)	FY 1984	FY 1985	Current 12 Months
Labor	1,368.10	1,419.29	1,204.40
Material	420.30	293.83	350.40
Contract	391.60	322.14	177.50
Other	52.60	67.40	98.40
Sub Totals	2,232.60	2,102.65	1,830.70
Division Overhead	218.90	287.32	255.50
Total Direct	2,451.50	2,389.96	2,086.20
Workman Compensation	11.40	10.24	8.20
Payroll Tax	89.00	105.75	94.80
Pension & Benefits	272.60	315.05	286.50
Administration & General	462.40	447.68	323.00
Total O&M Budget	3,286.90	3,268.68	2,798.70

Solar One Test Center

O&M Staffing	FY-85	Current Manning
Supervisor of Operations & Maintenance	1	0
Engineer	1	1/2
Shift Supervisors	4	1
Maintenance Foreman	1	1
Maintenance Planner	1	0
Stenographer	1	0
Accounting Clerks	2	1/2
Control Operators	5	6
Assistant Control Operators	4	4
Plant Equipment Operators	2	0
Instrument Technicians	4	2
Electricians	2	1
Boiler & Condenser Mechanics	2	1
Chemical Technician	1	1/2
Security Officer	1	0
Total	32	17 1/2

Cool Water O&M Support - Part Time

Station Management

Test Technician "A"

Welder

Machinist

Solar One Test Center

O&M Resources

1. Cool Water Generating and San Bernardino Generating Stations
   (a) Maintenance Support
   (b) Supervisor Support
   (c) Material Support

2. Steam Division Maintenance & Service Shop

3. Steam Division Chemical

4. Communications Maintenance Inc. (CMI)
   (a) Modcomp Service Agreement

5. SCE Procurement

6. SCE Software Engineer
   (a) Support for HAC, DAS, OCS, BCS

7. Beckman Instruments
   (a) Backup for Beckman Controls

SOLAR ONE TEST CENTER

Operating Events

Construction Deficiencies

Grid Power Outages

Grid Voltage Excursions

Steam Dump Valve

Piping/Heat Exchanger Leakage

- General
  - Valve Stem Packing
  - Valve Bonnetts
  - Piping Flanges
  - Rupture Disks
  - Heat Exchanger Tube/Tubesheet
  - Heat Exchanger Double Tube Sheet Shell Cracks
- Graphite Tape
- Selco Gaskets
- Torque Procedure
- Temperature Ramps

Control System UPS

Discrete Logic UPS

Turbine Gland Steam Exhauster/Service Water

4 kV Collector Field Cable Incident

Thermal Storage Insulation Fire

Thermal Storage Tank Fire

SOLAR ONE TEST CENTER

<u>Operating Events Continued</u>

Receiver Tube Leakage

- Type I
- Type II
- Type III

Receiver Panel Warpage

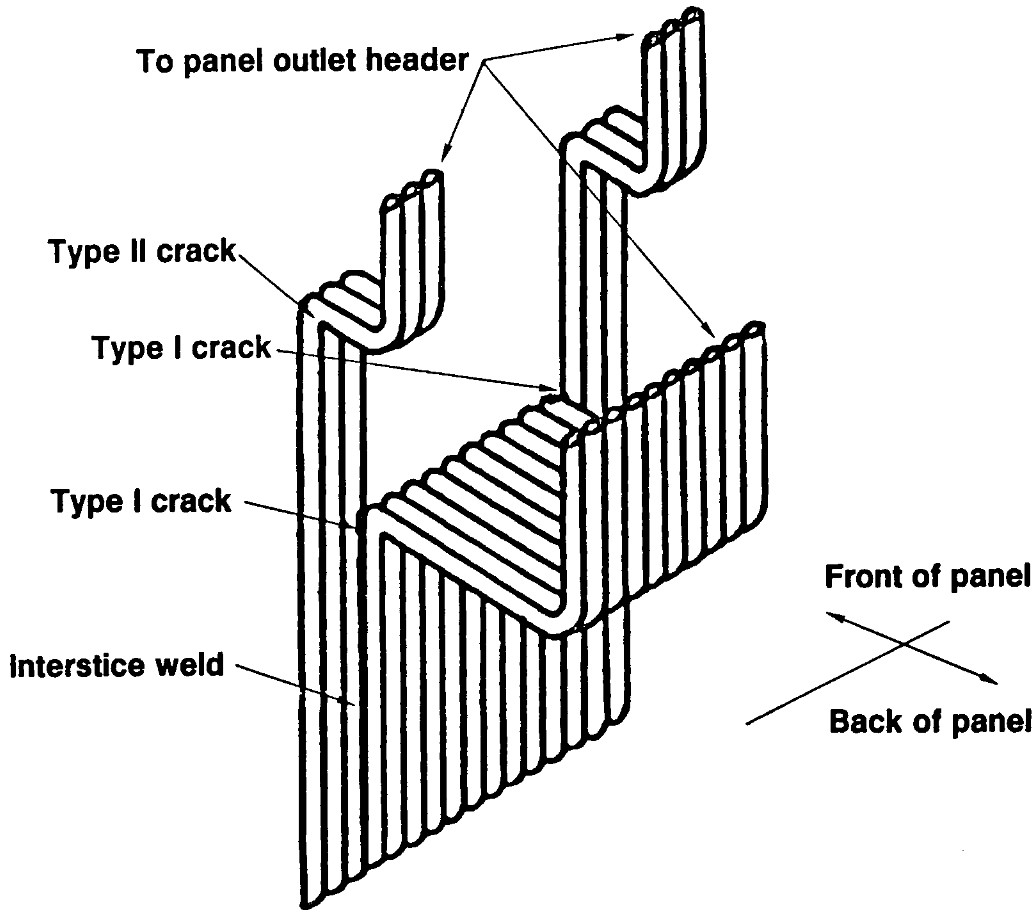
- Expansion Guides
- Differential Expansion
- Temperature Ramp
  - Start-up
  - Passing Clouds

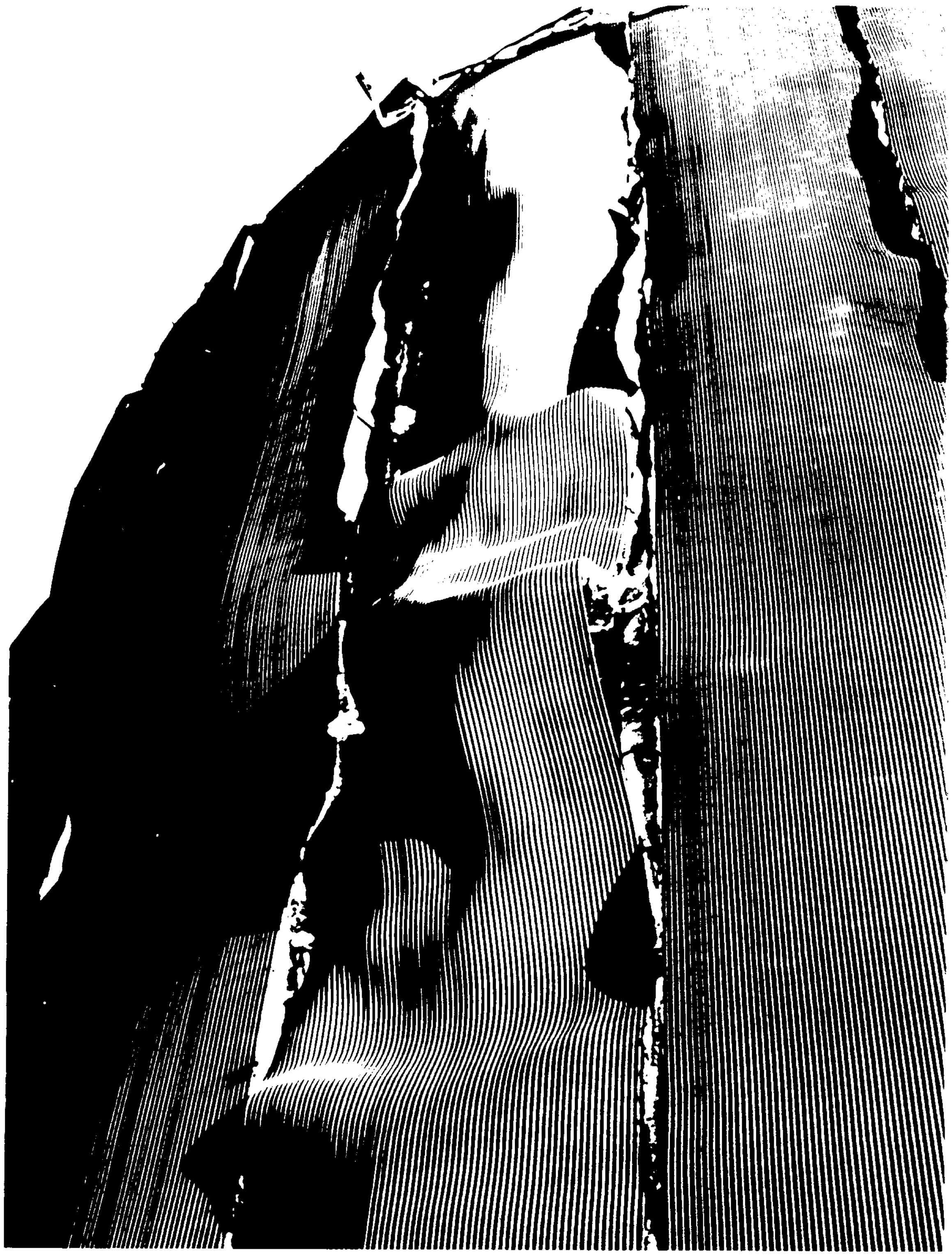
Heliostats

- HAC Failovers

SCHEMATIC OF A RECEIVER TUBE PANEL SHOWING THE LOCATION OF THE FAILURES

VHM516





SOLAR ONE TEST CENTER

Accomplishments

Agressive Operation

Inovative O&M

- Safety
- Heliostat Reliability
- Steam Dump Valve Trace Heating
- Steam Dump Valve Steam Warpage Bypass
- Condenser Vaccum

Maintenance Scheduling

Costs

Staffing

Parasitic Power

- Shut-down Non Essential Equipment
- Break Vacuum on Condenser
- Install Service Water Jockey Pump

Jockey Service Water Pump

Freeze Protection

Weather Monitoring

Receiver Panel Painting

Collector Field Corrosion Surveys

SOLAR ONE TEST CENTER

<u>Accomplishments Continued</u>

Heliostat Wash

- Insulator Wash-truck
- Heliostat Wash-truck
- Chemical Wash Test Program
- Heliostat Wash-truck Modification
- Chemical Wash South Collector Field

Collector Field

- Heliostat Reliability
- Capacitors
- Fuse Blocks
- Motor Overhaul

Contract Support

- Most Work Accomplished By On-Site O&M Personnel
    - Computers
    - Distributed Process Controllers
    - Programable Logic Controllers

		MWH(Gross)	MWH(Net)	CAPACITY FACTOR	USE FACTOR
	August	1328.64	883.02	11.87	51.66
	September	1311.36	895.98	12.44	51.81
	October	984.96	591.14	7.95	42.67
	November	687.36	322.52	4.48	31.66
	December	309.12	-41.30	-0.56	-9.27
1985	January	816.00	421.34	5.66	40.08
	February	19.20	-213.34	-3.17	-618.38
	March	293.76	-44.20	-0.59	-9.14
	April	1424.64	1014.44	14.09	52.83
	May	1672.32	1230.34	16.54	56.01
	June	1864.32	1406.94	19.54	58.11
	July	1259.52	834.98	11.22	51.26
	August	2267.52	1775.84	23.87	66.14
	September	1599.36	1186.92	16.49	60.52
	October	1203.84	799.38	10.74	53.59
	November	547.20	205.46	2.85	27.76
	December	549.12	185.54	2.49	28.69
1986	January	977.28	577.44	7.76	49.40
	February	800.64	453.30	6.75	53.24
	March	1119.36	723.02	9.72	56.28
	April	1476.48	1057.32	14.69	62.10
	May	1908.48	1426.88	19.18	58.80
	June	1288.32	875.18	12.16	53.81
	July	1643.52	1187.82	15.97	58.22
	August	1632.00	1160.48	15.60	56.11
	September	1618.56	1127.02	15.65	58.25
	October	1470.72	982.12	13.20	55.25
	November	1152.00	695.60	9.66	49.19
	December	585.60	161.68	2.17	21.94
1987	January	295.68	-65.80	-0.88	-18.50
	February	731.52	361.92	5.39	41.91
	March	1034.88	612.22	8.23	50.68
	April	1315.20	852.22	11.84	53.25
	May	1541.76	1034.26	13.90	51.89
	June	0.00	0.00	0.00	ERR
	July	0.00	0.00	0.00	ERR
TOTALS	A 84 - J 85	11971.20	7301.86	8.34	45.57
	A 85 - J 86	15381.12	10454.10	11.93	56.13
	A 86 - J 87	11377.92	6921.72	7.90	49.61

		MWH(Net)	USEABLE INSOLATION NIP kWh/M2	SOLAR EFFICIENCY %
	August	883.02	165.85	7.49
	September	895.98	177.00	7.12
	October	591.14	183.26	4.54
	November	322.52	139.40	3.25
	December	-41.30	81.27	-0.71
1985	January	421.34	134.93	4.39
	February	-213.34	133.46	-2.25
	March	-44.20	130.06	-0.48
	April	1014.44	188.87	7.55
	May	1230.34	210.73	8.21
	June	1406.94	231.45	8.55
	July	834.98	175.36	6.70
	August	1775.84	253.82	9.84
	September	1186.92	184.01	9.07
	October	799.38	173.24	6.49
	November	205.46	132.78	2.18
	December	185.54	130.77	2.00
1986	January	577.44	128.82	6.30
	February	453.30	120.49	5.29
	March	723.02	145.94	6.97
	April	1057.32	180.10	8.26
	May	1426.88	225.69	8.89
	June	875.18	225.09	5.47
	July	1187.82	213.83	7.81
	August	1160.48	192.00	8.50
	September	1127.02	186.98	8.48
	October	982.12	169.07	8.17
	November	695.60	152.69	6.41
	December	161.68	106.00	2.15
1987	January	-65.80	126.28	-0.73
	February	361.92	108.56	4.69
	March	612.22	157.70	5.46
	April	852.22	168.77	7.10
	May	1034.26	179.08	8.12
	June	0.00	0.00	ERR
	July	0.00	0.00	ERR
TOTALS	A 84 - J 85	7301.86	1951.63	5.26
	A 85 - J 86	10454.10	2114.58	6.95
	A 86 - J 87	6921.72	1547.14	6.29

		Power Production Hours	TSS Charging Hours	TSS Extraction Hours	Receiver+ Collector Hours
	August	170.92	24.08	0.00	195.00
	September	172.92	12.27	0.00	185.19
	October	138.53	19.42	0.00	157.95
	November	101.87	20.47	0.00	122.34
	December	44.55	23.98	0.00	68.53
1985	January	105.12	12.12	0.00	117.24
	February	3.45	8.05	0.00	11.50
	March	48.37	31.28	19.90	79.65
	April	192.02	16.80	0.00	208.82
	May	219.65	11.25	0.00	230.90
	June	242.13	14.63	0.00	256.76
	July	162.90	30.67	0.00	193.57
	August	268.50	7.58	0.00	276.08
	September	196.12	13.90	0.00	210.02
	October	149.17	26.93	0.00	176.10
	November	74.00	15.18	0.00	89.18
	December	64.66	13.40	0.00	78.06
1986	January	116.88	14.33	0.00	131.21
	February	85.15	17.65	0.00	102.80
	March	128.47	12.60	0.00	141.07
	April	170.27	10.20	0.00	180.47
	May	242.65	20.38	0.00	263.03
	June	162.65	14.27	0.00	176.92
	July	204.02	13.25	0.00	217.27
	August	206.83	3.98	0.00	210.81
	September	193.47	0.00	0.00	193.47
	October	177.75	0.00	0.00	177.75
	November	141.40	0.00	0.00	141.40
	December	73.70	0.00	0.00	73.70
1987	January	35.57	0.00	0.00	35.57
	February	86.35	0.00	0.00	86.35
	March	120.80	0.00	0.00	120.80
	April	160.05	0.00	0.00	160.05
	May	199.32	0.00	0.00	199.32
	June	0.00	0.00	0.00	0.00
	July	0.00	0.00	0.00	0.00
TOTALS	A 84 - J 85	1602.43	225.02	19.90	1827.45
	A 85 - J 86	1862.54	179.67	0.00	2042.21
	A 86 - J 87	1395.24	3.98	0.00	1399.22

		Receiver+ Collector Hours	USEABLE INSOLATION TIME HOUR	PLANT UTILIZATION %
	August	195.00	254.18	76.72
	September	185.19	273.83	67.63
	October	157.95	266.84	59.19
	November	122.34	205.73	59.47
	December	68.53	136.23	50.30
1985	January	117.24	193.39	60.62
	February	11.50	188.08	6.11
	March	79.65	214.32	37.16
	April	208.82	271.66	76.87
	May	230.90	312.64	73.85
	June	256.76	321.32	79.91
	July	193.57	272.23	71.11
	August	276.08	337.48	81.81
	September	210.02	264.58	79.38
	October	176.10	248.79	70.78
	November	89.18	195.93	45.52
	December	78.06	191.66	40.73
1986	January	131.21	192.09	68.31
	February	102.80	174.32	58.97
	March	141.07	215.87	65.35
	April	180.47	258.66	69.77
	May	263.03	318.03	82.71
	June	176.92	318.87	55.48
	July	217.27	305.28	71.17
	August	210.81	286.34	73.62
	September	193.47	260.89	74.16
	October	177.75	241.84	73.50
	November	141.40	221.68	63.79
	December	73.70	162.60	45.33
1987	January	35.57	188.05	18.92
	February	86.35	164.38	52.53
	March	120.80	226.00	53.45
	April	160.05	257.11	62.25
	May	199.32	265.32	75.12
	June	0.00	0.00	ERR
	July	0.00	0.00	ERR
TOTALS	A 84 - J 85	1827.45	2910.45	62.79
	A 85 - J 86	2042.21	3021.56	67.59
	A 86 - J 87	1399.22	2274.21	61.53

		Weather Outage Hours	Equipment Outage Scheduled Hours	Equipment Outage Forced Hours	Weather Overlap Hours
	August	124.90	0.00	19.53	0.00
	September	66.57	29.52	6.83	8.37
	October	59.75	3.82	46.72	0.00
	November	99.97	4.08	4.73	4.73
	December	158.32	0.00	13.82	8.27
1985	January	86.75	2.52	21.08	0.00
	February	98.85	180.62	10.60	52.55
	March	143.87	137.88	19.42	83.68
	April	88.38	0.00	14.42	5.77
	May	87.20	0.00	30.75	8.60
	June	65.20	0.00	23.88	1.10
	July	137.38	14.90	70.32	47.48
	August	31.93	0.00	20.53	0.00
	September	71.50	11.47	0.73	5.57
	October	83.80	2.12	8.43	0.00
	November	67.57	1.60	73.70	8.42
	December	61.72	112.38	4.17	35.43
1986	January	88.95	0.55	14.07	1.98
	February	110.15	0.00	37.27	16.92
	March	124.35	0.00	12.75	0.00
	April	108.35	0.00	14.78	2.63
	May	70.50	2.77	7.40	0.88
	June	47.12	0.00	121.93	7.47
	July	96.93	44.78	23.75	25.10
	August	91.45	12.08	48.53	23.13
	September	68.97	8.75	33.58	11.83
	October	93.23	0.00	11.08	0.62
	November	74.43	1.00	29.98	1.82
	December	130.65	0.00	39.45	6.82
1987	January	94.63	5.20	146.02	44.37
	February	123.98	17.62	24.72	25.42
	March	132.70	7.68	29.03	14.83
	April	118.08	24.48	25.83	12.12
	May	127.13	4.52	39.32	16.23
	June	0.00	0.00	0.00	0.00
	July	0.00	0.00	0.00	0.00
TOTALS	A 84 - J 85	1217.14	373.34	282.10	220.55
	A 85 - J 86	962.87	175.67	339.51	104.40
	A 86 - J 87	1055.25	81.33	427.54	157.19

		Heliostats Available Average	Cleanliness Percent	DATE of Reading
	August	1698.96	92.90	08/22/84
	September	1753.52	88.00	
	October	1693.87	84.00	
	November	1745.00	96.00	
	December	1730.26	98.00	
1985	January	1729.00	95.30	01/17/85
	February	1491.00	95.90	02/02/85
	March	1711.00	90.60	
	April	1750.00	92.00	05/06/85
	May	1810.00	83.00	
	June	1812.00	90.70	06/20/85
	July	1812.00	95.20	07/14/85
	August	1812.00	93.20	08/04/85
	September	1810.00	98.10	09/09/85
	October	1804.00	92.80	10/15/85
	November	1269.60	91.00	
	December	1765.90	93.01	12/04/85
1986	January	1791.00	92.80	01/20/86
	February	1776.00	94.90	02/06/86
	March	1800.00	95.17	03/13/86
	April	1807.00	95.30	04/09/86
	May	1776.00	89.43	05/29/86
	June	1796.00	95.52	06/20/86
	July	1803.00	97.00	07/22/86
	August	1806.00	90.29	08/13/86
	September	1801.00	0.00	
	October	1798.00	0.00	
	November	1811.80	0.00	
	December	1793.60	0.00	
1987	January	1791.10	0.00	
	February	1805.06	90.96	02/04/87
	March	1799.68	88.49	03/03/87
	April	1797.23	95.40	04/10/87
	May	1796.81	0.00	
	June	0.00	0.00	
	July	0.00	0.00	
TOTALS	A 84 - J 85	1728.05	91.80	
	A 85 - J 86	1750.88	94.02	
	A 86 - J 87	1800.03	91.29	

Solar One Test Center

Solar One Milestones
Test and Evaluation Phase

Solar One produced its first electrical energy on April 12, 1982. On completion of plant start-up activities, the plant began a two-year Test and Evaluation phase (August 1982 - July 1984) at which time it set the following thermal storage and combined system operating milestones.

A. First Electrical Power Production — April 12, 1982

B. Production of 43.8 MWh (net) electrical power using thermal storage system generated steam.

May 18, 1983 — 43.80 MWh (net)

This operation successfully demonstrated the design 28 MWh (net) storage capacitance of the thermal storage system

This operation also demonstrated the thermal storage system design power rating of 7.0 MWh (net) for four continuous hours.

C. Longest Operating Day (Receiver + Thermal Storage Steam)

June 21, 1983 — 14.95 Hours

D. Maximum Power Generation Day (Receiver + Thermal Storage Steam)

June 21, 1983 — 91.54 MWh (net)

E. Longest Continuous Operation (Receiver + Thermal Storage Steam)

June 27-28, 1983 — 33.57 Hours

Power generation for this operating period was 115.40 MWh (net)

F. Maximum Instantaneous Power Output (Receiver + Thermal Storage Generated Steam (Mode 3))

June 21, 1983 — 13.1 MW (Gross)
12.1 MW (Net)

Solar One Test Center

Solar Milestones
Power Production Phase

Solar One's operation during the latter months of the Test and Evaluation phase and the current Power Production pahse (August 1984 - July 1987) has been dedicated primarily to Mode 1 operation. In Mode 1 operation, receiver generated steam is directed to the turbine/generator rather than to the thermal storage system to attain manimum electrical energy production. The following is a tabulation of current Mode 1 power production milestones:

Power Generation:

A. Maximum Instantaneous Power Output

Friday, February 26, 1986 — 11.70 MW (net)

B. Maximum Power Production Day

Saturday, July 19, 1986 — 88.100 MWh (net)

C. Maximum Power Generation Week

Sunday, May 12 - Saturday, May 18, 1985 — 455.80 MWh (net)

D. Maximum Power Generation Month

August 1985 — 1,775.84 MWh (net)

E. Maximum Power Generation - Calendar Year

Jan 1 - Dec, 1986 — 10,427.86 MWh (net)

Power produced in 1986, January 1 through November 10, is 795.48 MWh greater than the power produced in the previous best power production year i.e., 1985 @ 8803.14 MWh (net)

F. Maximum Power Generation - Operating Year

August 1, 1985 - July 31, 1986 — 10,454.10 MWh (net)

Solar One Test Center

<u>Operating Time</u>

A.	Longest Operating Time - Day		
	Saturday, July 19, 1986	11.85	Hours
B.	Longest Operating Time - Week		
	Sunday, June 17 - Saturday, June 23, 1984	73.02	Hours
C.	Longest Operating Time - Calender Year		
	1986	2020.90	Hours
D.	Longest Operating Time - Operating Year		
	August 1, 1985 - July 31, 1986	2042.21	Hours
E.	Longest Consecutive Days of Operation		
	July 31 - September 4, 1986	36.00	Days

Solar One Test Center

Other

A. Maximum Power Generation Summer Solstice

Sunday, June 18, 1986 84.40 MWh (net)

B. Maximum Power Generation Winter Solstice

Saturday, December 21, 1985 54.00 MWh (net)

NOTE: The summer and winter solstice days are normally on June 21 and December 21 respectively. However, because of inclement weather that can occur on these specific days, the peak power output for the solstice days reported above is the maximum power output for the official solstice day ± 7 days.

C. Largest Number of Heliostats In Service

Wednesday, September 24, 1985 1818

This record was attained on two additional days in 1985 and six times in 1986. The maximum number of heliostats available in any one day in 1984 was 1784 (Sunday, June 24, 1984).

C.W. Lopez
Site Manager

Solar One Test Center

Solar One Future Plans

Solar Thermal Technology Conference

August 26-27, 1987

Albuquerque, New Mexico

Charles W. Lopez
Site Manager
Southern California Edison Co.

Solar One Test Center

Solar One Program

Test and Evaluation Phase	August 1982 - July 1984
Integrated Subsystems	
Automated Operations	
Computer Control	
Plant Performance/Design Comparison	
Power Production Phase	August 1984 - July 1987
Maximize Power Production	
Minimize Operation and Maintenance Cost	
Evaluation	
Plant Limitation	
Equipment Availability	
Plant Performance	
Recommendation for Future Solar Plants	

Solar One Test Center

Extended Operation

Purpose:

- Maintain Equipment in Operational State
- Continue Life Cycling of Equipment
- Operate Plant on a Near Break Even Cost Basis
- Continue Evaluation of Equipment System

Cost Responsibility:

SCE/LADWP	August 1987 - September 1987
SCE/LADWP/EPRI/DOE	October 1987 - September 1987
SCE/LADWP/EPRI/DOE?	October 1987 - September 1988

Solar One Test Center

Basis of SCE Proposal:

1. Both SCE and LADWP desire to keep Solar One operating after July 31, 1987 and until such time as the facility is too costly to operate and maintain or when modifications take place for future research experiments.

2. SCE will support continued operation of Solar One as long as our bare O&M out of pocket expenses do not exceed the value of the power produced by the facility.

3. The estimated annual O&M expenses for continued "bare bones" operation (5 days per week, 2 shifts per day) is $953,230 which do not include research personnel costs and are unloaded, i.e., without our labor and administrative overheads.

4. SCE will pay for its own research expenses.

5. SCE and LADWP will absorb the approximate $475,000/year labor and administrative overheads as our contribution to the plants continued operation.

6. The estimated annual production under "bare bones" is 7,718,000 kWhrs.

7. The value of this electrical energy, using the up to date values for electrical energy and capacity is estimated to be $622,250.

8. The difference between annual estimated O&M expenses and value of kWh production is $330,980.

9. EPRI has agreed to provide $100,000/year for the plant's continued operation.

10. Expected cost to the Department of Energy for the plant's continued operation would be approximately $250 - 300K.

11. Receiver panels 9 and 11 should be replaced during December 1988, with cost to be paid by the Department of Energy.

12. Any special tests required by a financial participant will be paid for by the participant to include the value of lost energy production.

13. Termination - Any financial participant can terminate participation with a sixty-day notice.

Solar One Test Center
"Bare Bones" O&M Manning

O&M Personnel:	
Shift Supervisor	1
Control Operators	6
Assistant Control Operators	2
Instrument Technician	1
Electrician	1
B&C Mechanic	1
Maintenance - Cool Water Support	1
Chemical Technician	1/2
Clerk	1/2
Management - Cool Water	1
TOTAL	15

Based on current reduced manning it may be cost effective to add to the above:

Instrument Technician	1
Maintenance Helper (Collector Field Wash)	1
	2

Solar One Test Center

Expected Operating Expense

FY-88	Net Value Power	O&M Cost	Delta $'s
Oct. 87	$ 23,128	$ 80,000	-56,872
Nov. 87	10,588	80,000	-69,412
Dec. 87	2,206	80,000	-77,794
Jan. 88	1,848	80,000	-78,152
Feb. 88	1,490	80,000	-78,510
March 88	5,370	80,000	-74,630
April 88	24,568	80,000	-55,432
May 88	34,047	80,000	-45,953
June 88	130,911	80,000	+50,911
July 88	127,092	80,000	+47,092
Aug. 88	140,618	80,000	+60,618
Sept. 88	120,397	80,000	+40,397
TOTALS	$622,263	$960,000	-337,737

OUTSIDE FUNDS AVAILABLE

EPRI - $100 K per year
DOE - $250-300K FY-88

Annual Energy Improvement Study

Daniel J. Alpert
Gregory J. Kolb

Central Receiver Technology
Division 6226
Sandia National Laboratories
Albuquerque, NM 87185-5800

Results of recent studies performed by Sandia indicate that significant improvements in central-receiver technology must be made if the annual efficiency goals in DOE's Five Year Plan are to be achieved. The purpose of Sandia's Annual Energy Improvement Study is to identify the improvements in current technology necessary to meet the goal. Principal tools in the study are the data bases from Solar One and other large-scale system experiments, the computer code SOLERGY - used to predict annual energy production, and dynamic process simulators for central-receiver power plants.

The first task in the Annual Energy Improvement Study is the validation of SOLERGY with data from Solar One. Data used as input to SOLERGY were developed from the Solar One data base. These data include observed insolation for 1985, plant design parameters, and plant operational characteristics. To model the water/steam system used at Solar One, a number of changes were made to the SOLERGY code. In addition, a new model for parasitic power was developed using a regression fit to plant data. With these changes, SOLERGY provides very good estimates of time-dependent power production on reasonably clear days. However, SOLERGY over predicts net energy on days with intermittent insolation due to passing clouds. The poor predictions on partly cloudy days are due to: 1) the inability of the 15-minute time steps used in SOLERGY to capture insolation transients lasting less then 15 minutes but sufficient to cause turbine trip and 2) unpredictable operator actions on cloudy days. Time-dependent power predictions for cloudy days were found to improve when 3-minute insolation data were used. SOLERGY does not model plant-operator actions in response to approaching clouds. Though SOLERGY predictions using 15-minute data are fairly poor for partly cloudy days, these days contribute only marginally to total annual energy production. On an annual basis, the SOLERGY prediction of net energy production for 1985 by Solar One is only 6% greater than the observed value.

The results of Task 1 identify where improvements in plant operation and performance are necessary to meet plant-efficiency goals. Possible alternative plant designs that could bring closer the achievement of the goals will be discussed.

Sandia's Efforts in Systems Analysis are Directed at Improving Annual Performance

Central-Receiver Annual Energy Goals Have Not Been Achieved

- Solar One Efficiency is around 7%
- SNLL's Systems Improvement Study (Salt/Sodium) ~15%
- DOE's 5-Year Plan says "Current" Technology ~17%
- DOE Long-Term Goal is 22%

DJA6.1

The Goal of the Annual Energy Improvement Study is to Identify Cost-Effective Ways to Improve Annual Energy

Task 1 of the Study is the Validation of the SOLERGY Computer Code Using Data from Solar One

- SOLERGY is useful to compare technological options (i.e. sodium vs. Salt, storage capacity)
- To assess the economic viability of various plant designs - both cost and value of energy
- SOLERGY models start-up and steady operation of all major plant components

SOLERGY Had To Be Changed To Model Solar One

- Only two plant-operation modes were modeled:
  1. Receiver to turbine
  2. Receiver to storage
- Storage was only used to provide service steam
- A strict sun-following dispatch strategy was modeled
- We developed a completely new parasitic model for Solar 1
- Both 3-minute and 15-minute time steps were used

DJA6.3

A Large Effort Went Into Developing Values for Parameters Used as Input

The Estimated Input Parameters Include:

- Receiver convective losses
- Time dependent heliostat cleanliness
- Time dependent heliostat availability
- Time dependent receiver absorbtivity
- Receiver cooldown time constant
- Receiver startup energy
- Turbine start-up sync delay
- Turbine start-up ramp delay
- Turbine full load and part load efficiency
- Plant down time

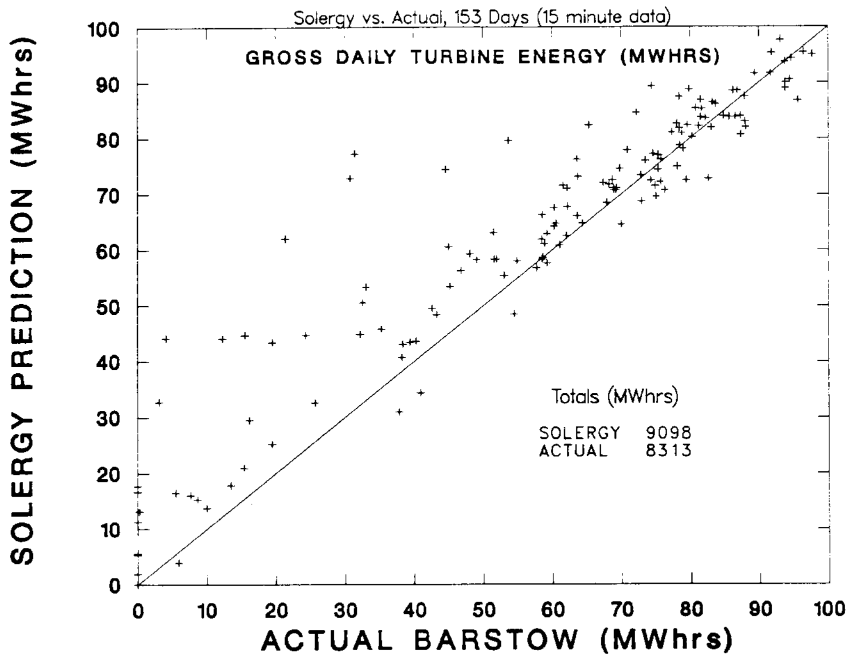
DJA6.4

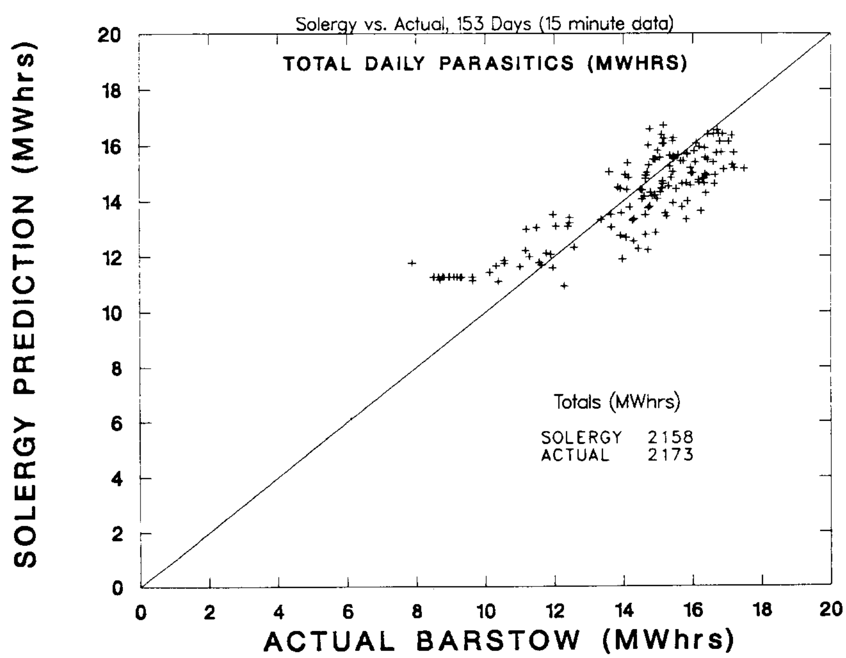
We First Compared Performance for 153 Days Scattered Throughout 1985

A day was selected if all of the following criteria were met:

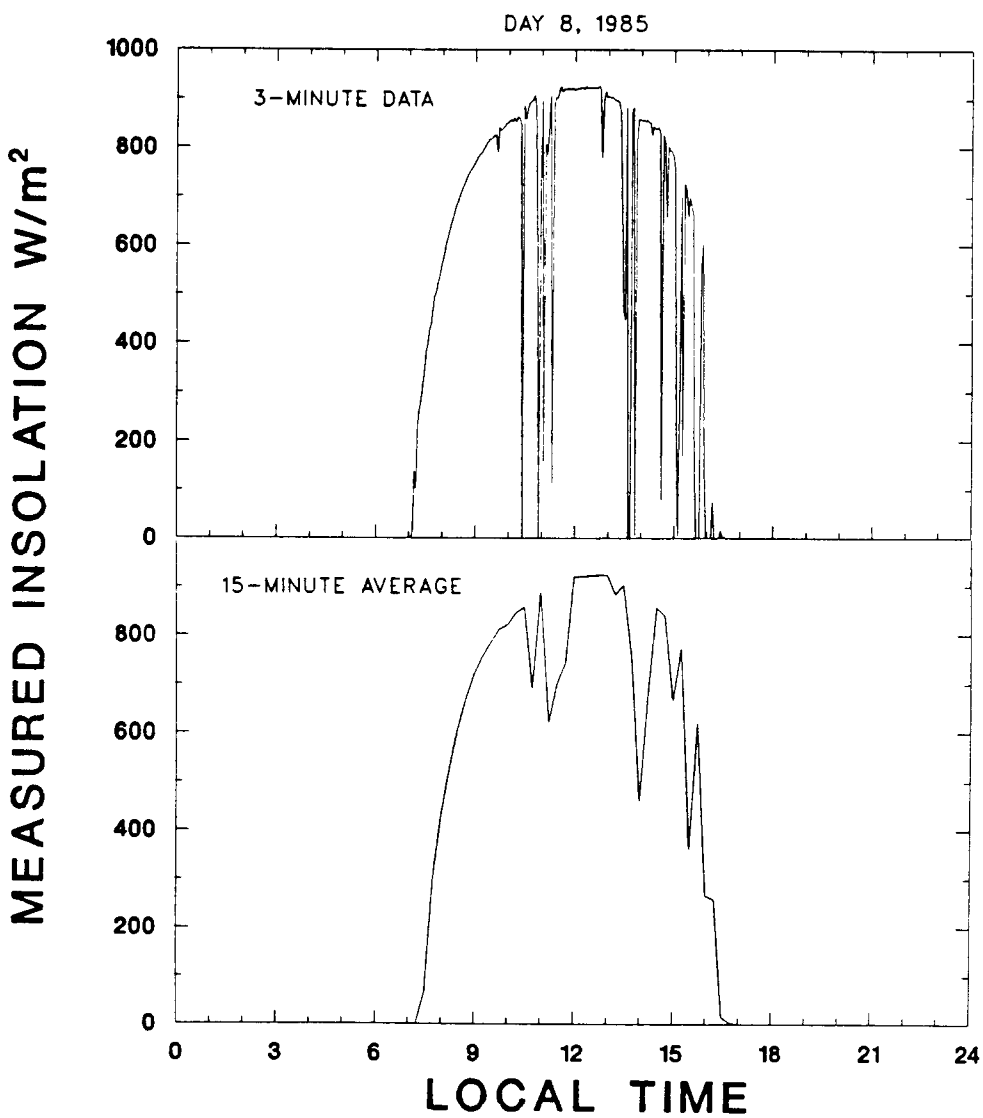
- There were no scheduled or forced outages
- Thermal storage was not charged during the day
- Solar One's Data Acquisition system was operational

DJA6.5


Solergy vs. Actual, 153 Days (15 minute data)
GROSS DAILY TURBINE ENERGY (MWHRS)
Totals (MWhrs)
SOLERGY 9098
ACTUAL 8313
SOLERGY PREDICTION (MWhrs)
ACTUAL BARSTOW (MWhrs)
0
10
20
30
40
50
60
70
80
90
100


Solergy vs. Actual, 153 Days (15 minute data)
TOTAL DAILY PARASITICS (MWHRS)
Totals (MWhrs)
SOLERGY 2158
ACTUAL 2173
SOLERGY PREDICTION (MWhrs)
ACTUAL BARSTOW (MWhrs)
0
2
4
6
8
10
12
14
16
18
20

MEASURED INSOLATION W/m²



SOLERGY Predicts Plant Performance Very Well on Days with Gradual Insolation Changes

However, agreement is poor on days with intermittent insolation because:

- SOLERGY uses 15–minute average weather data rather than 3–minute or instantaneous data. Therefore, insolation transients lasting less than 15 minutes, but sufficient to cause turbine trip, are missed.

- SOLERGY does not model operator actions in response to approaching clouds

We Next Compared Performance for all 365 Days in 1985

Again, Some Approximations Were Necessary:

- Days with partial charging of storage or partial outages were combined and treated as equivalent full days

- For days where the data acquisition system was not available, a weather file was "guesstimated" for that day

DJA6.10

SOLERGY Predicts Well the Annual Performance of Solar One for CY 1985

Results Comparing Performance for one full year:

	SOLERGY	BARSTOW	%DIFFERENCE
HOURS OF TURBINE OPERATION	1904	1726	+10%
GROSS ENERGY	14747	13363	+10%
OPERATING PARASITICS	1592	1460	+9%
TOTAL PARASITICS	4698	4737	−1%
NET ENERGY	10048	8625	+16%
ANNUAL ENERGY EFFICIENCY	5.6%	4.8%	+17%

DJA6.11

The SOLERGY Calculations Identify Where Improvement in Performance is Needed

ANNUAL EFFICIENCIES	SOLERGY (1985)	DOE LONG-TERM GOAL	Technology Alternative
PLANT AVAILABILITY	.80	.94 *	Rcvr Reliability
HELIOSTATS	.80	.92	Cleaning
FIELD	.70	.68 *	
RECEIVER	.69	.90	Rcvr Design/Fluid
TRANSPORT	.995	.99	
TURBINE	.30	.41 *	Re-Heat Cycle
AUXILIARIES (WITH STORAGE)	.61	.95 *	Larger Plant
PRODUCT	.056	.21	

* Guesstimated based on info presented in plan

DJA6.12

Conclusions of Task 1

- SOLERGY produces a very reasonable estimate of annual energy provided that the user of the code:
  - Obtains good estimates for input parameters
  - Uses a weather tape that is measured at time intervals shorter than the trip time of the plant given cloud cover
- SOLERGY will now be used to identify design and operational issues that might improve annual energy production

DJA6.13

Simulation of Solar Central Receiver Systems

G. J. Kolb
Sandia National Laboratories

T. L. Greenlee
M. R. Ringham
ESSCOR Corporation

We have recently developed computer models that simulate the dynamics of two solar central receiver systems. ESSCOR Corporation constructed a model of the molten salt cavity receiver system currently being tested at the CRTF. Sandia developed a model of a hypothetical direct absorption receiver. Both models run real time on an IBM AT microcomputer and were programmed via the System Simulation Language. These models are being used to accomplish the following objectives: 1) to understand central receiver system performance during transients, 2) to test, optimize, and design central receiver control algorithms, 3) to understand component response to component failures, and 4) to optimize annual energy production from central receiver plants. Initial work during FY 87 concentrated on the first two objectives.

The 135 ordinary differential equations comprising the CRTF system model simulate the cavity receiver, the molten salt thermal storage system, and the NET-90 control system. The user iteracts with the simulation while it is running via menus and several color graphic mimics of the system hardware.

We have compared the predictions of this CRTF model with those of a more detailed model developed by the designer of the control algorithm (McDonnel Douglas Corporation). We are also validating our model with experimental results. This effort has thus far indicated that our model is capable of producing very reasonable performance predictions. The model produced qualitative insights regarding system dynamics which were subsequently verified by experimental results. The model correctly predicted that all of the control loops must be operable to prevent overheating of the molten salt during severe cloud transients. The model also identified receiver temperature ramp rates during severe cloud transients which exceed values recently established by the receiver designers. Modifications to the receiver design and/or the control algorithm will be made to alleviate this problem. It would be preferable to modify the receiver design rather than the control algorithm in order to optimize the energy collection capability of the receiver.

The direct absorption receiver model is comprised of between 11 and 99 differential equations depending on the number of flow channels simulated. The model predicts average salt temperatures, back plate temperatures, and film thicknesses along the length of the flow channel as a function of time during cloud transients. A control algorithm was developed with the aid of root locus plots produced by the System Simulation

Program. Results of this effort indicate that salt overheating can be prevented during severe cloud transients with a much simpler control algorithm than the one developed for the CRTF cavity receiver. For example, it appears that flux sensors and flux feed forward control will not be necessary for a direct absorption receiver. This model also predicts that back plate temperature ramp rates may be excessive during cloud transients. It would be desirable to design a back plate to withstand these temperature ramps so that the energy collection capability of the receiver can be optimized.

During FY 88 we will also focus on objectives 3 and 4 listed in the first paragraph. In particular, we plan to use these models in conjunction with the SOLERGY annual energy code to identify design and operational changes that improve the annual energy efficiency of future central receiver plants.

SIMULATION OF CENTRAL RECEIVER SYSTEMS

Terry Greenlee
Mike Ringham
ESSCOR Corporation

Greg Kolb
Sandia National Laboratories

GJK1

SIMULATION OF CENTRAL RECEIVER SYSTEMS

OBJECTIVES

1. Understand system performance during transients
2. Test, optimize, and design central receiver control algorithms
3. Understand system response to component failures
4. Optimize annual energy production

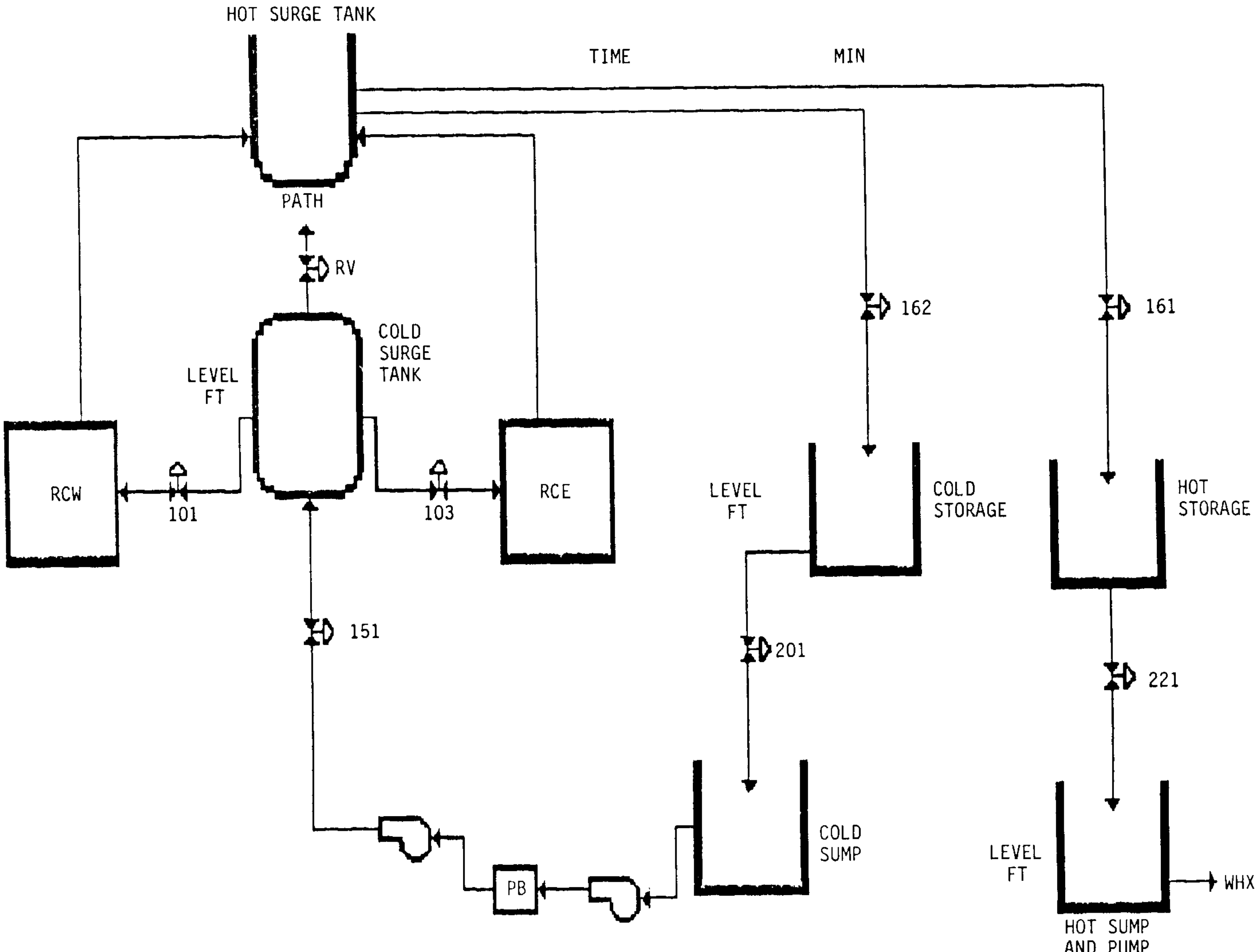
During FY 87 we focused on objectives 1 and 2.
In FY 88 we will also focus on objectives 3 and 4.

GJK2

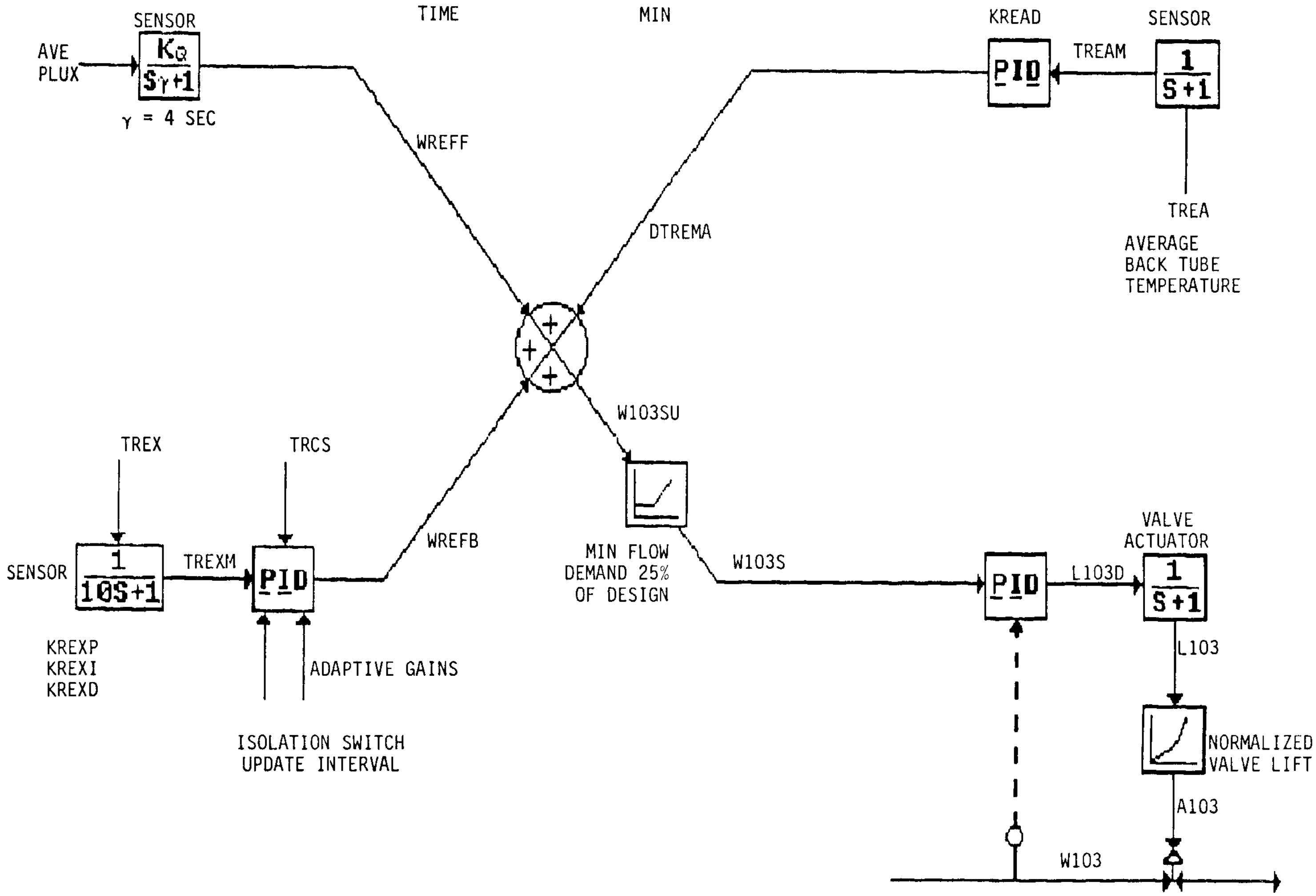
DESCRIPTION OF SIMULATION MODELS

- Dynamic models were developed for a tube receiver system and a direct absorption receiver
- Models run real time on an IBM AT
- Models are programmed via the SYSL simulation language
  - MSSCTE Category B tube receiver system model (developed at ESSCOR)
    - Simulates receiver, thermal storage, and NET–90 control system
    - 135 ordinary differential equations
    - Color graphic displays
    - User can interact with simulation as though he were operating the plant
  - Direct absorption receiver model (developed at Sandia)
    - Simulates receiver, and either a NET–90 or analog control system
    - 11 to 99 ODE's depending on the number of flow channels

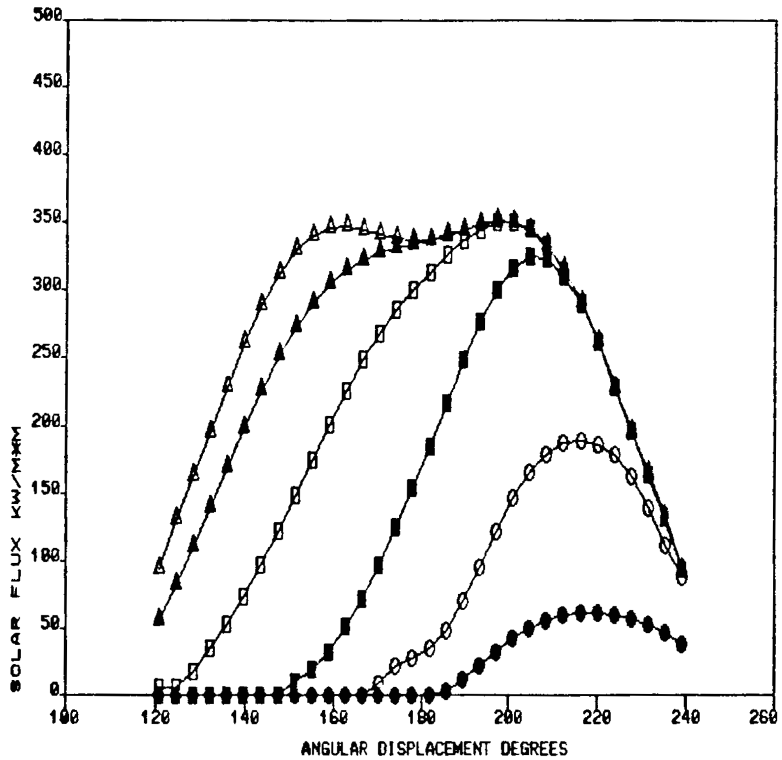
GJK3



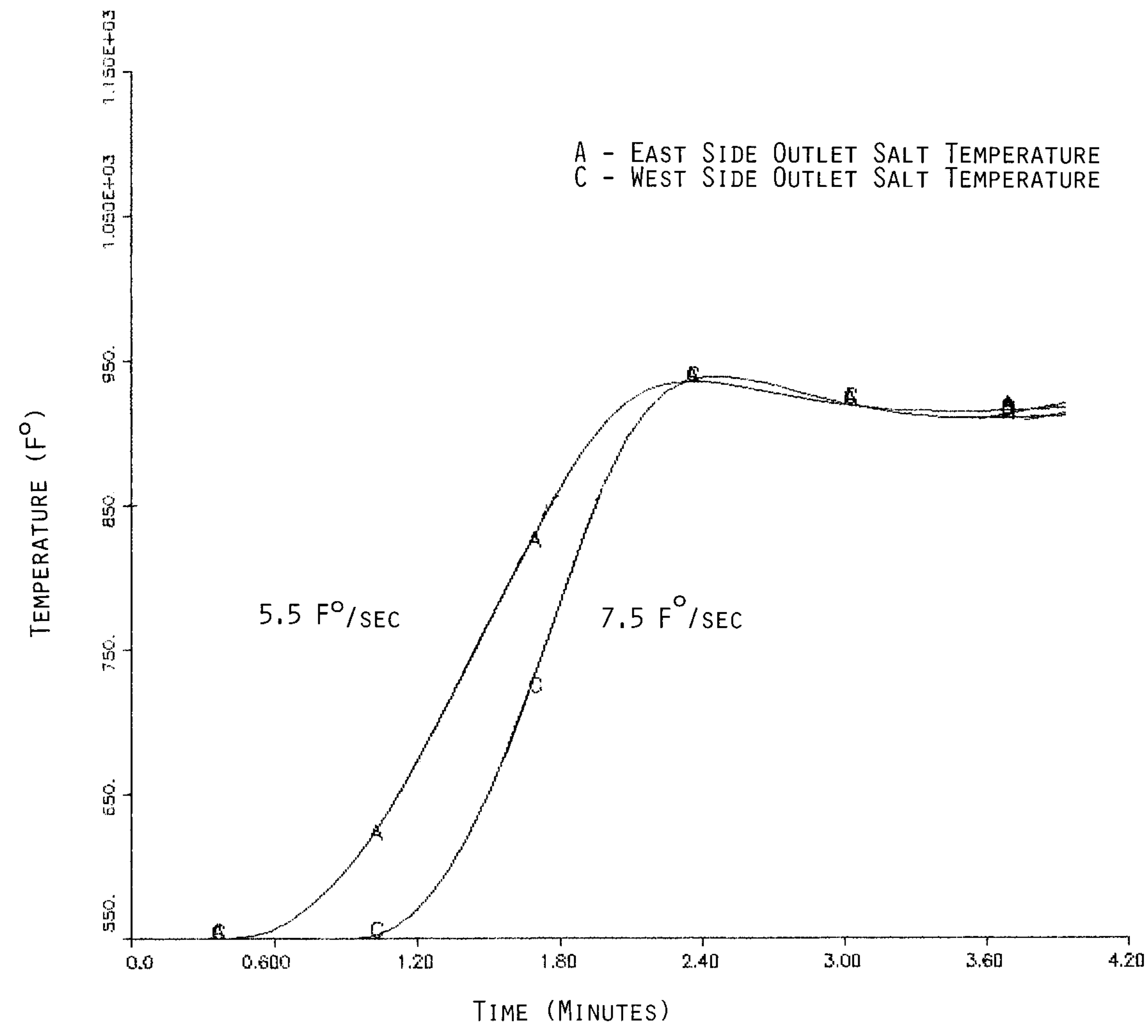
CRTF System Mimic



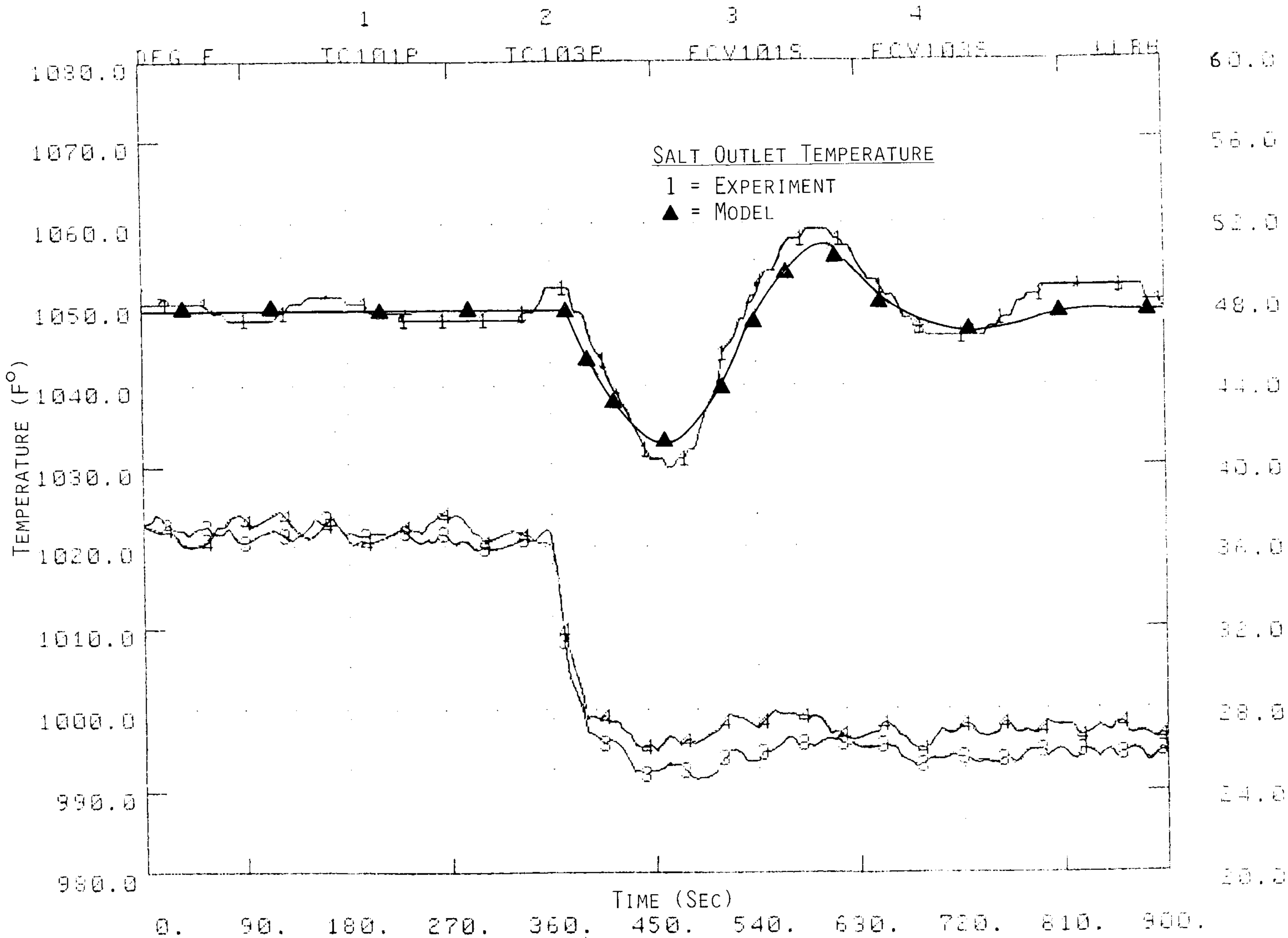
Mimic of the CRTF Control Algorithm



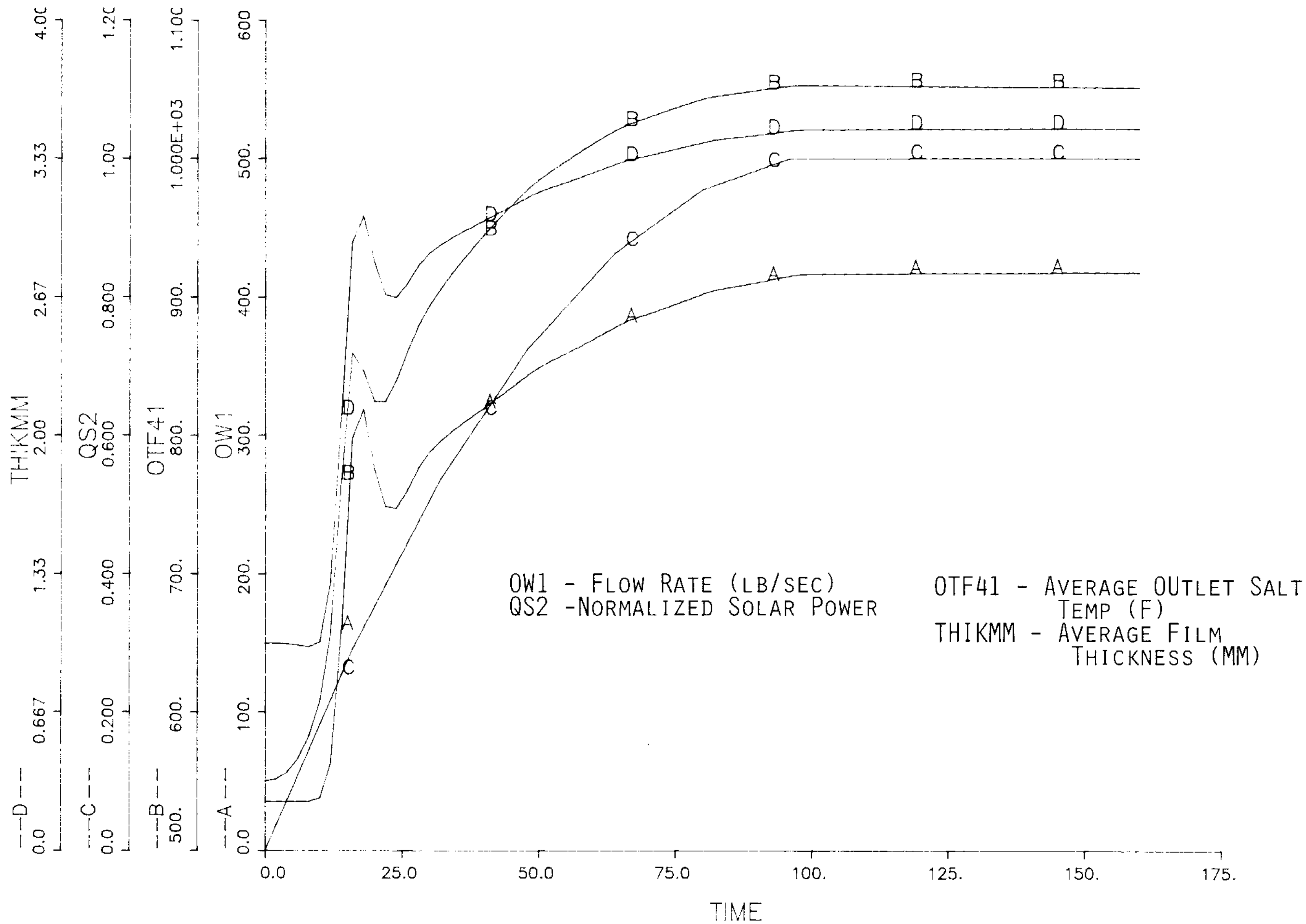
SOLAR FLUX TRANSIENT ON THE CRTF CAVITY RECEIVER



RESPONSE OF CRTF CAVITY RECEIVER TO A 12 MPH CLOUD

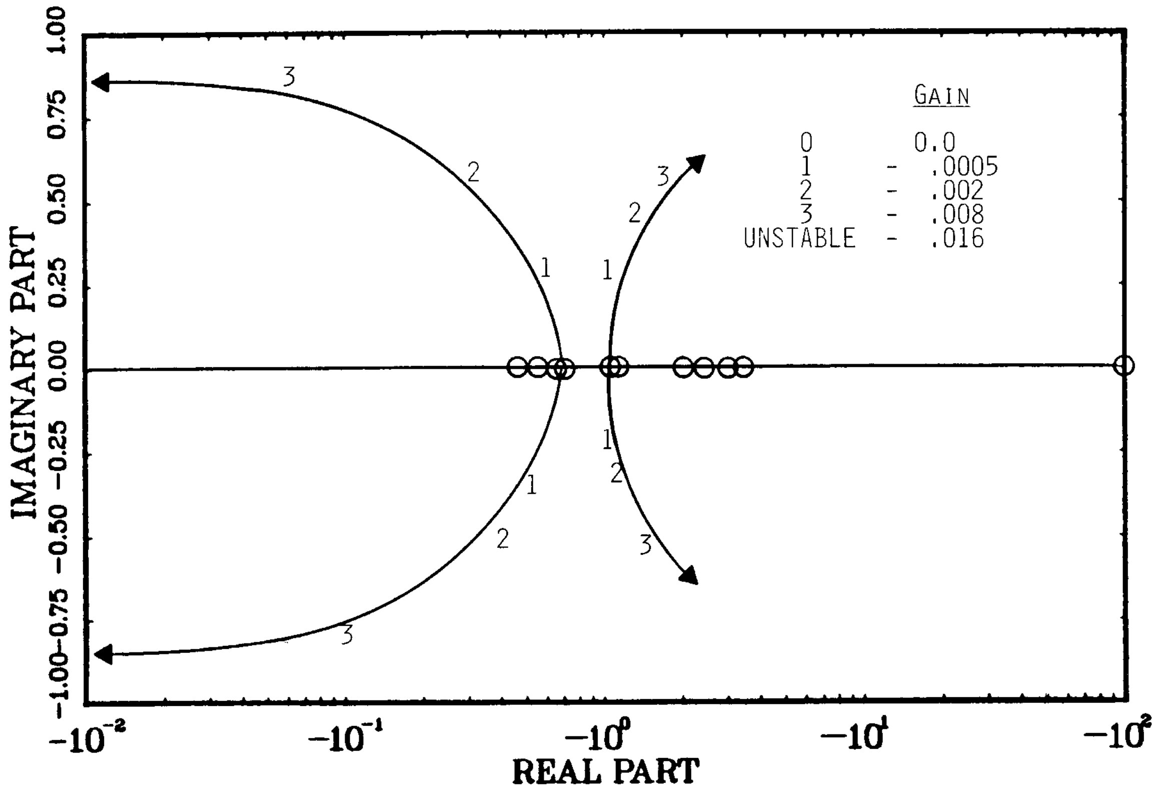


RESPONSE OF CRTF CAVITY RECEIVER TO A STEP CHANGE IN SOLAR FLUX



RESPONSE OF A DIRECT ABSORPTION RECEIVER PANEL TO A 25 MPH CLOUD

ROOT LOCUS FOR DAR NORTH PANEL



PRIMARY INSIGHTS FROM WORK PERFORMED IN FY 87

- MSSCTE Category B tube receiver
  - Preliminary validation results indicate that the model produces a very good estimate of actual system performance
  - All control loops of a complex control system must be active to prevent salt overheating during severe cloud transients
  - Receiver temperature ramp rates can exceed recommended values during cloud transients. Modifications to receiver design and/or control system are necessary to alleviate problem.

GJK4

PRIMARY INSIGHTS FROM WORK PERFORMED IN FY 87

- Direct absorption receiver
  - Simple control system can prevent salt overheating during cloud transients
  - Back plate temperature ramp rates may be excessive during cloud transients. Receiver designers should try to design a plate to withstand these ramps in order to optimize energy collection.

COMMERCIALIZING SOLAR THERMAL ELECTRIC AND INDUSTRIAL PROCESS HEAT PROJECTS: UNITED STATES MARKET EXPERIENCE

Carlo LaPorta
Analysis Review & Critique Division
R&C Enterprises

In the early 1980's, US industry attempted to build several solar thermal electric and industrial process heat projects as private commercial projects. Several companies successfully financed such projects with private investors, and the largest existing solar energy power systems are now found in California selling electricity to utility companies. Only a few industrial process heat projects have also been built.

The author reviews the experience of the companies that were trying to build the Solar 100 central receiver projects and the Carissa Plains 30 MW project, as well as the projects built by LaJet and Luz International. Several industrial process heat projects are also reviewed. From interviews with industry participants, the paper describes the factors that led to failure or success for large scale solar thermal projects in the commercial marketplace in the United States.

The paper summarizes key lessons industry learned regarding project scale, risk assumption, organization of approach to financing, role of government investment incentives, and impact of the prevailing energy and economic environment.

The author also interviewed representatives from a cross-section of financial and investment institutions in the United States to assess their attitudes towards various renewable energy technologies. The survey results chart how some technologies have moved from high risk project financing using independent third-party investors to a situation where companies may now offer debt finance packages. The attitudes of investors towards solar energy project finance and industry potential are revealed. The factors investors use to evaluate such projects for possible finance are described and ranked.

COMMERCIALIZING SOLAR THERMAL ELECTRIC AND INDUSTRIAL PROCESS HEAT PROJECTS: LESSONS INDUSTRY LEARNED

An account of work performed for Sandia National Laboratories under Contract 90-1513

By

Carlo LaPorta
Analysis Review & Critique Division of
R&C Enterprises
Santa Cruz, California -- Washington, D.C.

for the

Solar Energy Industries Association
Arlington, Virginia

Presentation for the Solar Thermal Technology Conference

August 26-27, 1987
Albuquerque, New Mexico

TASK I OF FIVE TASKS UNDERTAKEN FOR SANDIA NATIONAL LABORATORY, LIVERMORE, CALIFORNIA

*** TASK I:**	**COMMERCIALIZING SOLAR TERMAL ELECTRIC AND INDUSTRIAL PROCESS HEAT PROJECTS: LESSONS INDUSTRY LEARNED**
TASK II:	REVIEW OF SOLAR THERMAL POWER INDUSTRY: FUTURE OUTLOOK (SANDIA REPORT 86-8183)
TASK III:	UTILITY REGULATOR VIEWS ON PURPA AND SOLAR THERMAL TECHNOLOGY
TASK IV:	TECHNOLOGY TRANSFER FOR THE SOLAR THERMAL INDUSTRY
TASK V:	PERSPECTIVES ON UTILITY CAPACITY NEEDS IN THE SOUTHWEST

SCALE

BIGGER		BETTER BETTER BETTER
BIGGER	WILL BE	BETTER BETTER BETTER
BIGGER		BETTER BETTER BETTER

TECHNICALLY

ECONOMICALLY

FINANCIALLY

FOR THE CUSTOMER:

A. CREATE DEPENDENCE ON THE SYSTEM OUTPUT WITHOUT CREATING CONCERN ABOUT CONSEQUENCES OF NON-PERFORMANCE

FOR THE MANUFACTURER:

A. DO NOT EXPECT TO ESCAPE THE MANUFACTURING SCALE ECONOMIES ISSUE

-- NEED MORE PRODUCTION TO LOWER COSTS
-- NEED LOWER COSTS TO INCREASE PRODUCTION

LEARN HOW OTHER INDUSTRIES HAVE COMMERCIALIZED WITH THIS SAME GIVEN

B. KNOW YOUR BANKER/FINANCIAL INSTITUTION VERY WELL

-- KNOW THAT THEY KNOW YOUR TECHNOLOGY AND THE DEGREE OF EFFORT IT WILL TAKE FOR COMMERCIAL SUCCESS

MAKE THE CARROT LARGE ENOUGH TO GAIN COMMITMENT TO SUCCESS

INDUSTRIAL PROCESS HEAT MARKET

MARKET FOR PARABOLIC TROUGH TECHNOLOGY WAS HALTED BEFORE IT BEGAN

FIRST YEAR NEGATIVES

- FIRST COST
- TECHNICAL UNCERTAINTY
- TRADEOFF WITH OTHER USES FOR CAPITAL
- RELAXED ENERGY ATTITUDE (FALLING OIL AND GAS PRICES)
- CONCERN ABOUT VENDOR STABILITY AND PERFORMANCE GUARANTEES
- LAND AREA REQUIRED
- MAINTENANCE COST UNCERTAINTY

FIRST YEAR GAINS

- TAX CREDIT BENEFITS (FEDERAL AND STATE)
- DEPRECIATION BENEFITS
- ENERGY COST SAVINGS
- FUTURE ENERGY COST STABILITY (STILL UNCERTAIN)

SECOND YEAR GAINS

- DEPRECIATION TAX BENEFITS
- ENERGY SAVINGS
- FUTURE ENERGY COST STABILITY (MORE CLEARLY IN SIGHT)

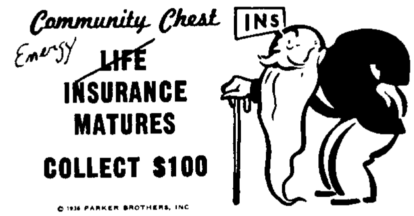
THREE THROUGH SEVEN YEAR GAINS

- SAME AS ABOVE LESS DEPRECIATION AFTER YEAR FIVE

YEARS AFTER PAYBACK COMPLETE

- NO COST ENERGY EXCEPT FOR MAINTENANCE

THE LESSON -- EXCEPT FOR MAINTENANCE, NO COST SOLAR **ENERGY CANNOT** BE SOLD TO **INDUSTRY UNDER CURRENT MARKET** CONDITIONS **IF THE FREE ENERGY (NIRVANA)** DOES **NOT ARRIVE IN LESS THAN THREE YEARS**



N I R V A N A

TO DEVELOP MARKETS FOR INDUSTRIAL PROCESS HEAT WITH SOLAR ENERGY, SOLAR THERMAL SYSTEM VENDORS MUST OFFER NIRVANA

NIRVANA IS: OBLIVION TO CARE, PAIN OR EXTERNAL REALITY

NIRVANA MEANS: FINAL EMANCIPATION

IMPLICATION #1 --- VERY HIGH PRIORITY FOR RELIABLE, DURABLE SYSTEMS GUARANTEEING LONG-TERM PERFORMANCE

IMPLICATION #2 --- THE OWNER WILL MAINTAIN THE SYSTEM BECAUSE THE OUTPUT APPEARS NEARLY FREE

IMPLICATION #3 --- INVESTORS (IF NOT END USERS) MUST BE GAINING SECURE, REASONABLY HIGH RETURN ON THEIR INVESTMENT

IMPLICATION #4 --- A LONG TERM, FIXED PRICE CONTRACT WITH THE SUN, OR WITH AN INVESTOR/LEASOR EXISTS

IMPLICATON # 5 --- THE FOLLOWING WILL NO LONGER MATTER

A. LAND AREA REQUIREMENTS EASIER TO HANDLE
B. FEAR OF NEW TECHNICAL OPTIONS
C. FEAR OF CAREER THREATENING CHOICES

CENTRAL RECEIVER COMMERCIALIZATION LESSONS

LESSON # 1

YOU CANNOT DRESS A DEMO PLANT IN COMMERICAL CLOTHES AND TAKE IT TO THE INVESTORS' CLUB TUESDAY LUNCHEON

LESSON # 2

WITHOUT FORTHRIGHT COMMUNICATION TO DEFINE AND APPORTION RISK, NO COUNSELOR CAN SAVE A TROUBLED MARRIAGE

THE KEY:

HOW DO YOU

1. DEFINE
2. PACKAGE
3. DISTRIBUTE

RISK®

TECHNICAL --- WILL THIS PROJECT DELIVER THE BTUS

FINANCIAL --- WILL THIS PROJECT PAY ITS BILLS

COMMERCIAL -- WILL THIS PROJECT LEAD TO MANY ANOTHERS

INVESTOR PERCEPTIONS OF SOLAR THERMAL

FIRST GIVEN: OPINION ABOUT SOLAR THERMAL TECHNOLOGY AND PROSPECTS IS WEAK

INVESTOR PRIORITIES:

1. QUALITY
2. CERTAINTY OF AN ATTRACTIVE RETURN ON INVESTMENT

IMPORTANT FACTORS:

1. CONFIDENCE IN COMPANY MANAGEMENT (ESPECIALLY VENTURE FIRMS)
2. CLEAR DELINEATION OF RESPONSIBILITIES
3. FIRM CONTRACTUAL RELATIONSHIPS AMONG PARTIES
4. VIABLE REMEDIES FOR FAILURE THAT PROVIDE DOWNSIDE PROTECTION FOR LENDERS

INVESTMENT PROBLEMS FOR COMPANIES IN SOLAR THERMAL TECHNOLOGY FIELD

A. SOLAR THERMAL COMPANIES PRESENT AN UNUSUAL PROFILE FOR INVESTORS

-- SEEMINGLY A CANDIDATE FOR VENTURE CAPITAL, SOLAR THERMAL COMPANIES ARE ACTUALLY DEVELOPING PROJECTS IN ORDER TO FINANCE PRODUCTION AND CAPITALIZE THEIR FIRMS.

THESE PROJECTS GENERALLY EXCEED THE AMOUNT OF CAPITAL VENTURE CAPITAL FIRMS COMMIT

-- VERY FEW VENTURE CAPITAL FIRMS ARE INTERESTED IN MARKETS THAY <u>MAY</u> OPEN IN THE MID TO LATE 1990S, BECAUSE THEY ARE INTERESTED IN SEEING VIABLE EXIT PATHS FOR THEIR CAPITAL IN A THREE-TO-SEVEN YEAR TIME PERIOD

B. MOST INVESTMENT INSTITUTIONS ARE JUDGING ENERGY-RELATED PROJECTS BY REFERENCE TO THE PRICE OF PETROLEUM

C. LACK OF IDENTIFIABLE MARKETS IS A KEY BARRIER RESTRICTING CAPITAL FOR SOLAR THERMAL COMPANIES

ADVANCING TO GO

FOR INDUSTRIAL PROCESS HEAT, THE KEY FACTORS ARE:

A. NATURAL GAS PRICES AND SUPPLY

B. POTENTIAL FOR RELIABLE, LONG-TERM FIXED PRICE ENERGY CONTRACTS

OR

B. LOW ENOUGH SYSTEM COSTS WITH PERFORMANCE OFFERING END USERS THREE-YEAR PAYBACKS

FOR SOLAR ELECTRIC POWER SYSTEMS, THE KEY QUESTION IS:

WHO WILL BE THE CUSTOMER?

-- UTILITIES ......

OR INDEPENDENT ENERGY PRODUCERS AND PROJECT DEVELOPERS

WHERE WILL THE CAPITAL COME FROM:

VENTURE CAPITAL -- ONLY WHEN THEY ARE CONFIDENT A PRODUCT HAS A COMPETITIVE MARKET AVAILABLE, AND ONLY FOR COMPANY AND PRODUCT DEVELOPMENT, NOT PROJECT FINANCE

INSTITUTIONAL -- WHEN COMPANY MANAGEMENT IS SOUND AND PROJECT ECONOMICS ARE VIABLE, A SMALL BUT EXPERIENCED GROUP OF INSTITUTIONAL INVESTMENT FIRMS EXISTS WITH CAPABILITY TO EVALUATE PROJECTS AND INTEREST

INTERNAL CORPORATE -- IF LARGE INTEGRATED MANUFACTURING COMPANIES COME BACK INTO THE BUSINESS WITH THE INTENT OF FINANCING EARLY COMMERCIAL PROJECTS TO CREATE THEIR MARKET

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