SAND79-2221
Unlimited Release
UC-62 Distribution

Technology Assessment : Line-Focus Concentrators

James F. Banas

Prepared by Sandia Laboratories, Albuquerque New Mexico 87185 and Livermore, California 94550 for the United States Department of Energy under Contract DE AC-04-76 DP00789

Reprinted, April, 1980

Sandia National Laboratories

SF 2900-Q(3-80)

Issued by Sandia Laboratories, operated for the United States Department of Energy by Sandia Corporation.

Printed in the United States of America

Available from
National Technical Information Service
U. S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

Price: Printed Copy $4.00 ; Microfiche $3.00

SAND79-2221
Unlimited Release

TECHNOLOGY ASSESSMENT: LINE-FOCUS CONCENTRATORS

James F. Banas
Component and Subsystem Development Division 4722

Sandia Laboratories
Albuquerque, New Mexico 87185

Presented at

National Conference on Solar
Industrial Process Heat
October 31 - November 2, 1979
Oakland, California

ABSTRACT

This paper describes the current engineering development status of line-focus solar concentrating collectors, specifically the parabolic trough, and briefly summarizes near-term development emphasis in the areas of structures, reflective materials, receivers, selective coatings, trackers, drives, wind loads, foundations, and field layouts.

CONTENTS

ILLUSTRATIONS

CONTENTS

ILLUSTRATIONS

TECHNOLOGY ASSESSMENT: LINE-FOCUS CONCENTRATORS

Introduction

Over the past five years, collector/system hardware experiences at Sandia Laboratories within the Solar Thermal Power Systems Program sponsored by the DOE Office of Energy Technology have been the following (Reference 1):

Linear Fixed Mirror, Movable Receiver Concentrator - GA
Linear Fresnel Lens Concentrator on Two Axis Tracker - MDAC
Parabolic Dish - Raytheon
Linear Fixed Receiver, Movable Mirror Concentrator - Suntec
Parabolic Trough - Hexcel
Linear Fixed Mirror, Movable Receiver Concentrator - SA
Parabolic Trough - Del
Moving Belt Fresnel Mirror Concentrator - FMC
Parabolic Trough - Acurex
Parabolic Trough - Sandia
MSSTF - 8000 Ft^2 Collectors, 32 kW_e Total Energy Plant
Willard - 14,000 Ft^2 Collectors, 25 HP Irrigation Plant

These eleven collectors and two systems were fabricated, tested, and evaluated in order to define engineering development problems requiring solution prior to commercialization initiatives. This paper describes the major engineering problems and near-term development emphasis.

Summary Status of Existing Technology

From an overall viewpoint the status of existing line-focus collector technology can be summarized by the following three points.

First, the thermal efficiencies of current collectors are not yet at the goal of between 60 and 70% at 600^oF although there appears a definite and encouraging trend with successive collector generations to meet this goal.

Second, the durability of existing collectors is low relative to requirements of 10 to 20 years dictated by economics. Both environmental degradation of materials and, as yet, inadequate treatment of system safeties contribute to this durability issue.

Third, existing technology does not yet lend itself to low-labor mass-production materials and processes which will be required to meet cost goals.

Collector Concept

The performance prototype concepts which have been evaluated at Sandia Laboratories include the tracking aperture type exemplified by the parabolic trough and the fixed aperture type exemplified by the Solar Linear Array Thermal System, the Fixed-Mirror Solar Collector, and the Faceted Fixed-Mirror Concentrator.

Utilizing measured normal-incidence thermal efficiencies, an estimate of annual average collector efficiency can be made which includes cosine losses. The results shown in Figure 1 as a function of average collector temperature indicate a substantial performance advantage to the tracking aperture type of collector mainly due to the lower average cosine losses relative to the fixed aperture type of collectc-

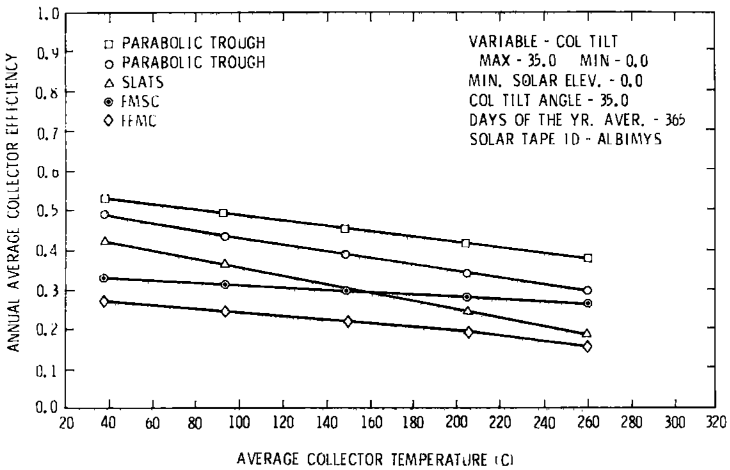

Figure 1 - Estimated Average Collector Efficiency Based on Measured Normal - Incidence Efficiencies

This performance advantage of the tracking aperture over the fixed aperture is a primary consideration to both near-term and longer-term applications of line-focus collectors. (Reference 2).

In the near-term, process heat is the likely application market because of system simplicity. Since approximately half of the process heat usage is below 600^{o}F, it is important, during market initiation, to identify a collector concept which is capable of giving high performance over this potential temperature-use spectrum.

In the longer-term, cogeneration which will obtain process heat from a power conversion cycle is the likely application market because of economic advantages of simultaneous production of electricity and process heat. In this case, it is important to identify a collector concept which is capable of high performance at elevated temperatures in order to provide high quality energy to the power conversion cycle to achieve reasonable thermal-to-electric conversion efficiencies.

Test and evaluation data to date indicate that the parabolic trough is the preferred line-focus collector concept for the near-term and longer-term potential markets.

Recent engineering development efforts at Sandia Laboratories have resulted in a parabolic trough collector which establishes the feasibility of meeting the thermal efficiency goal. Test data for the so-called Engineering Prototype Trough (References 3, 4) indicates 60% peak-noontime thermal efficiency at 600°F. To achieve the performance goal this collector embodies, as described in this paper, several design improvements in the areas of reflector material, structure, tracker, receiver and selective coating.

<u>Structures</u>

In order to achieve cost-effectiveness in mass-production, not only must the collector structure feature a high stiffness-to-weight ratio so as to keep material content to a minimum but also the collector structure must be amenable to low-labor manufacturing processes. Three structural concepts with high stiffness-to-weight ratios and potential for mass-production manufacturability are shown in Figure 2. Structural design analyses indicate for a 90 mph wind survival criterion that these concepts may weigh three to four pounds per square foot including mirrored glass which serves as the reflector.

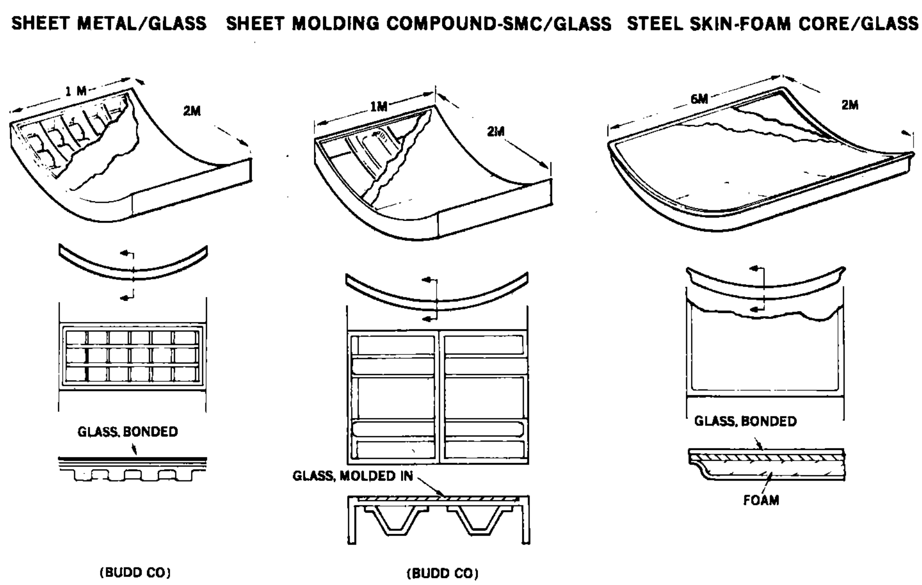

Figure 2 - Parabolic Trough Reflector/Structure Design Concepts

The first concept consists of a ribbed frame panel which is stamped from sheet metal and attached to a sheet metal skin supporting the reflector.

The second concept consists of a sheet molding compound (SMC) panel into which is molded the glass reflector to eliminate a separate bonding operation; hat sections are bonded to the panel to achieve high stiffness. The 2m x 1m dimensions of the sheet metal and SMC structures are constrained by current stamping and molding press capabilities in industry.

The Budd Company has recently initiated efforts to develop prototypes of the sheet metal and SMC concepts.

The third concept consists of a sandwich structure of high density foam core and steel skins in a size potentially as large as 2m x 6m.

Reflective Materials

Over the past several years at Sandia Laboratories accelerated environmental testing of materials has been performed (Reference 5). Anodized aluminum after one year of freeze/thaw cycling in a high humidity environment estimated to simulate twelve years of real time exposure shows severe corrosion of the material which significantly degrades reflectance.

Similarly, a variety of polymer film reflective materials have been tested including aluminized acrylic. After accelerated aging the material shows severe delamination occurring between the film and the structure which significantly reduces optical performance and, more importantly, lifetime. Lifetime of typical polymer films is further limited due to poor abrasion resistance of the film.

Based on environmental test data to date, mirrored glass appears to be a preferred reflector material for at least the near-term. Its advantages over alternative materials are twofold. First, specular reflectivity of 95% has been achieved with silvered glass as contrasted to only about 75% with anodized aluminum and about 85% with polymer films. Second, as supported by environmental testing, mirrored glass gives significantly better durability.

Development of mirrored glass for line-focus collectors has been slow for the following reasons: alternative materials are currently less expensive, glass is more difficult to design into a collector due to a long-term tensile stress limitation of about 1000 psi, and, finally, production sources have been unavailable.

Three potential concepts for glass are chemically strengthened, thermally formed, and, socalled, thin glass laminates. Development problems and issues with these concepts are listed in Figure 3.

Chemical strengthening, achieved by an ion exchange process, provides a high compressive stress state at the surface of the glass sheet. Thus, chemically strengthened glass can be elastically deformed into the collector to form the reflector surface. Corning Glass Company has initiated an effort to estimate cost of chemically strengthened glass in production volumes.

Thermal forming of automotive windshields is accomplished either by gravity sagging into a frame mold or press forming between male-female surface molds. Ford Glass Division using gravity sagging and PPG using press forming have initiated efforts to develop thermally formed glass prototypes of 1m x 1m dimensions. A key problem which has not yet been addressed is the silvering of large, contoured surfaces.

Thin glass laminates consist of perhaps a 10 mil mirrored glass sheet bonded to sheet steel. The neutral axis can be placed in the steel allowing the glass to remain in compression when elastically deformed. Because of the fragility of the thin glass between forming and lamination, manufacturability has been of serious concern.

CHEMICALLY STRENGTHENED: (50 mil x 45 in. x 40 in.)	• PRODUCTION COST - CORNING • LONG TERM DURABILITY IN STRESSED STATE
THERMALLY FORMED: (60 mil x 45 in. x 40 in.)	• PRODUCTION COST • CONTOUR TOLERANCES AND HANDLING - FORD GLASS DIVISION AND PPG • MIRRORING OF CURVED PIECES
LAMINATED: (10 mil x 45 in. x 40 in.)	• PRODUCTION COST • MANUFACTURABILITY • LONG TERM DURABILITY IN STRESSED STATE • HANDLING THROUGHOUT MANUFACTURING

Figure 3 - Development Problems/Issues for Glass As A Reflective Material

Receiver

Because of an apparent near-term cost advantage, current emphasis is on receivers which are sealed to the environment but non-evacuated.

Studies have indicated a significant performance advantage of 10% increase in thermal efficiency for the evacuated receiver but requires a laboratory type vacuum (References 6, 7, 8). Furthermore, accounting for thermal expansion in an evacuated receiver is a difficult design problem within a cost budget of about seven dollars per linear foot of receiver. A definite advantage of the evacuated receiver is that the cleaning problem of the receiver interior is eliminated.

In addition, an antireflection coating on both the interior and exterior surfaces of the receiver glass envelope appears from analysis to offer a significant performance advantage of 10% increase in thermal efficiency. Corning Glass Company has recently initiated an effort to develop a prototype glass envelope with an antireflection coating for test and evaluation at Sandia Laboratories. Both cost and durability due to environmental degradation are issues of concern for antireflection coatings.

It may be of interest, before leaving the topic of reflectors and receivers, to note a phenomenon which has been observed on several collectors. Discrete focal lines are seen on the receiver tube giving an appearance of light and dark stripes. Laser ray trace data confirms that the phenomena is a characteristic of the reflector. The effect has now been seen on the Acurex trough with either anodized aluminum or thin glass laminate, the Solar Kinetics trough with aluminized acrylic, the Custom Engineering trough with sagged glass, and the Sandia trough with chemically strengthened glass. Thermal analysis indicates a one percent efficiency degradation from the effect; of more concern may be the influence of the effect on performance of a photovoltaic receiver which requires more uniform illumination.

Selective Coatings

In order to achieve reasonable efficiencies at elevated temperatures, an external receiver in a line-focus collector must feature a selective coating. Such coatings maximize absorptance in the visible spectrum and suppress radiation in the infrared spectrum. Black chrome has been the most popular selective coating for line-focus collectors as well as flat plate collectors.

A thermal instability has been previously noted from typical black chrome plating baths in which solar absorptance is significantly reduced after only a few hundred hours at temperature (Reference 9).

It appears that current emphasis will remain with black chrome as a selective coating. It should be noted that SERI has recently initiated efforts to develop black cobalt as a selective coating.

Based on work over the past two years at Sandia Laboratories in cooperation with Harshaw Chemical Company, thermal stability of black chrome has been achieved in the laboratory using a modified plating bath composition.

Two efforts over the past year are being used to formulate a plating process definition. Honeywell has produced a preliminary draft of a plating handbook which relates optical properties to bath composition and plating parameters. Sandia in conjunction with Highland Plating has recently completed a production run of black chrome plating to investigate production process problems. It appears that typical production plating instrumentation may be inadequate to achieve at this time a specification for high quality selective coatings (Reference 4).

Trackers

Sun-tracking by means of the shadow band detector has been the popular method of providing the tracking function. Using sun-tracking, the average high intensity point in the sky is tracked. Problems to date include poor tracking accuracy, false locks on clouds or buildings, biases due to selective drifting of differential amplifiers, and maintenance due to dirt accumulation.

In addition to sun-tracking, there are two other methods of tracking: computer-tracking and aperture-tracking. Using computer-tracking the sun's theoretical position is computed based on a clock input; the collector can then be pointed to the computed angle using feedback from a position sensor. Using aperture-tracking the collector is positioned to maximize the flux on the receiver by means of a flux sensing device.

Current emphasis in tracking is directed (Reference 10) toward combining computer-tracking and aperture-tracking as shown in Figure 4. A search algorithm is periodically initiated to correct computer-tracking biases by means of aperture-tracking. Furthermore, aperture-tracking serves to integrate the flux distribution down the length of the receiver to find the best average position for the collector drive string.

A fine resistance wire, helically wrapped down the receiver, is being investigated as a fast responding flux sensor. Flux sensing based on fluid temperature appears to be too slow in response due to the relatively large thermal mass involved.

The key problem at this time appears to be identification of a collector position indicator giving tenth degree accuracy at a cost of only a few hundred dollars.

If microprocessors are utilized to support the tracking function, it is suggested that a process computer should be designed to integrate the tracking function, the fluid control function and the systems safeties.

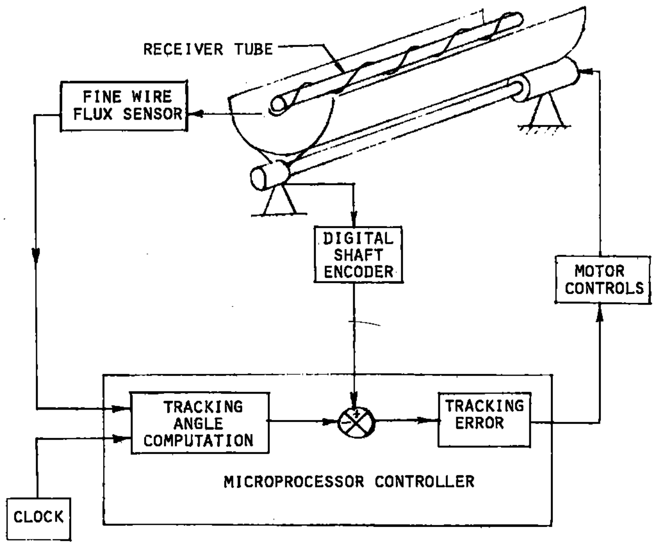

Figure 4 - Tracker Based on Combination of Computer-Tracking and Aperture-Tracking

Drive

Current emphasis in the drive system is the concept of an integral drive pylon which consists of an electrically driven pump interfacing with a hydraulic pressure accumulator and a hydraulic actuator to rotate the collector drive string. Several advantages can be listed for this concept: field layout only requires electrical wiring, high force capability at low speed, low instantaneous power requirement, and multiple speed capability with little additional cost. Perhaps the key advantage results from the emergency defocus requirement. The hydraulic accumulator in operation remains pressurized at all times; in an emergency stow condition the accumulator is dumped to drive the collectors to stow. Electromechanical drive systems must provide standby generator power or batteries both of which are subject to reliability problems. Design of a gearbox specifically for an electromechanical drive system is a key area requiring engineering development.

Wind Loads/Foundations

A consistent problem with existing solar collector installations has been high cost associated with pylons and foundations. Two recently completed test programs indicate that designs have been very conservative.

Wind loads on parabolic trough arrays have been measured by Colorado State University (Reference 11). Results indicate that fences combined with row-to-row shadowing cause reductions of peak lift and lateral forces by factors of two and four respectively. No significant reduction in pitching moment was observed by CSU indicating that reflector structure design has been adequate using previous wind loads. Finally, the test data indicates that mounting height of the collectors from the ground should be as small as possible to minimize wind loads and thereby reduce structural weight and cost.

A foundation design study and test program has been conducted by Higgins, Auld, and Associates (References 12, 13, 14). Results of the design study indicate that cylindrical reinforced concrete piers provide the most cost-effective foundation system of fifteen designs considered. Test data verified that restraining forces provided by the soil are substantial and should be accounted for in the foundation design at sites featuring good soil properties. This foundation work indicates that a goal of fifty cents per square foot of collector aperture for foundations may be feasible.

Collector Field Subsystem Layout

Two other consistent problems with existing solar collector systems have been high cost of the piping and high thermal losses in the field piping.

An ongoing field layout design study by Jacobs-Del Engineering has reached a number of preliminary conclusions. Unlike refinery type systems which run under steady state conditions, solar systems experience high thermal losses due to night cooldown; it appears that increased insulation is cost-effective in decreasing thermal losses. Furthermore, downsized piping to further reduce heat losses and thermal mass appears overall cost-effective even though cost of parasitic pumping may increase. Finally, and perhaps most importantly, the study indicates that a piping cost goal of twenty percent of installed field cost may be feasible.

State-of-The-Art Trough Design Features

Figure 5 summarizes suggested trough design features. A thermal efficiency goal of greater than 60% at 600°F requires a system error budget of seven milliradians which implies accurate structures with two milliradian slope error. Dimensions such as two meter aperture, 92° rim angle and six meter module length are suggested in order to begin some standardization to stimulate production oriented sources for structures and reflector materials during market initiation. Modular systems based on 50,000 square feet of collectors may be appropriate to attract user interest during market initiation but it is suggested that such modules be designed to be expandable to larger installations in the longer-term. Likewise, fluid control systems can be simple in concept for say 300°F process heat utilizing collectors capable of 600°F, however, cogeneration systems will require more accurate temperature controllers.

- SYSTEM ERROR BUDGET = 7 MR.
- 2 METER APERTURE, 92° RIM ANGLE, 6 METER COLLECTOR MODULE LENGTH
- 24 METER DRIVE STRING LENGTH WITH CENTER DRIVE
- 4608 SQUARE METERS FIELD MODULE EXPANDABLE TO 46080 SQUARE METERS
- INTEGRAL DRIVE PYLONG WITH ELECTRIC PUMP/HYDRAULIC ACCUMULATOR AND ACTUATOR
- SEALED/UNEVACUATED RECEIVER WITH BLACK CHROME SELECTIVE COATING AND OIL HEAT TRANSFER FLUID
- MICROPROCESSOR-BASED TRACKER WITH CLOSED LOOP INTEGRATING FLUX SENSOR
- CHEMICALLY STRENGTHENED OR THERMALLY FORMED GLASS REFLECTOR
- STRUCTURES BASED ON SHEET METAL, SMC, SANDWICH TECHNOLOGIES

Figure 5 - Suggested Trough Design Features

Conclusion

In conclusion, our common current aim in line-focus collector technology should be toward engineering development to establish a target collector with high performance, durability, and reliability utilizing mass-production technology with potential for low cost.

References

1. D. E. Randall, "A Compendium of Solar-Thermal Collector Procurement Activities At Sandia Laboratories," SAND 78-2183, Sandia Laboratories, Albuquerque, NM, May, 1979.

2. R. W. Harrigan, "Factors Affecting Market Initiation of Solar Total Energy," 1978 IEEE Region Five Annual Conference, Tulsa, OK, April 16, 1978.

3. L. M. Larsen, Editor, "FY78 Annual Progress Report: Midtemperature Component and Subsystem Development Project," SAND79-0800, Sandia Laboratories, Albuquerque, NM, September, 1979.

4. R. L. Champion, Editor, "FY79 Annual Progress Report: Midtemperature Component and Subsystem Development Project," SAND79-2204, Sandia Laboratories, Albuquerque, NM, to be published.

5. R. E. Allred, D. W. Miller, and B. L. Butler, "Environmental Testing of Solar Reflector Structures," Proceedings of the International Solar Energy Society, Atlanta, GA, June, 1979.

6. G. W. Treadwell, "Design Considerations for Parabolic-Cylindrical Solar Collectors," SAND76-0082, Sandia Laboratories, Albuquerque, NM, July, 1976.

7. A. C. Ratzel, "Evaluation of the Evacuated Solar Annular Receivers Used at the Midtemperature Solar Systems Test Facility (MSSTF)," SAND78-0983, Sandia Laboratories, Albuquerque, NM, July, 1979.

8. A. C. Ratzel, "Receiver Assembly Design Studies for 2-m 90° Parabolic-Cylindrical Solar Collectors," SAND79-1026, Sandia Laboratories, Albuquerque, NM, September, 1979.

9. R. E. Pettit and R. R. Sowell, "Recent Developments Regarding Electrodeposited Black Chrome Solar Coatings," Proceedings of the Second Annual Conference on Absorber Surfaces for Solar Receiver, Boulder, CO, January 24-25, 1979.

10. S. M. Kohler and J. L. Wilcoxen, "Development of a Microprocessor-Based Sun-Tracking System for Solar Collectors," SAND79-2163, Sandia Laboratories, Albuquerque, NM, to be published.

11. D. E. Randall, D. D. McBride, and R. E. Tate, "Parabolic Trough Solar Collector Array Wind Loadings," SAND79-2134, Sandia Laboratories, Albuquerque, NM, to be published.

12. H. E. Auld and P. F. Lodde, "Study of Low-Cost Foundation/Anchor Designs for Single-Axis-Tracking Solar Collector Systems," SAND78-7048, Prepared for Sandia Laboratories by University of New Mexico, Albuquerque, NM, January, 1979.

13. H. E. Auld and P. F. Lodde, "Study of Foundation Designs for Single-Axis-Tracking Solar Collector Systems Under Reduced Loading Conditions," SAND79-7016, Prepared for Sandia Laboratories by University of New Mexico, Albuquerque, NM, May, 1979.

14. H. E. Auld, "Analysis of Field Test Results for Single-Axis-Tracking Solar Collector Foundations." SAND79-7023, Prepared for Sandia Laboratories by Higgins, Auld, & Associates, Albuquerque, NM, July, 1979.

Distribution:

UC-62 (268)

J. Vindum
Acurex Corporation
485 Clyde Avenue
Mountain View, CA 94042

G. Hutchison
Solar Kinetics, Inc.
8120 Chancellor Row
Dallas, TX. 75247

V. Reese
Suntec Systems, Inc.
2101 Wooddale Drive
St. Paul, MN 55119

M. Delgado
Del Manufacturing Co.
905 Monterey Pass Road
Monterey Park, CA 91754

J. R. Schuster
General Atomic Company
P. O. Box 81608
San Diego, CA 92138

G. Branch
Hexcel Corporation
11711 Dublin Blvd.
Dublin, CA 94566

A. Stocker
Harrison Radiator Division
General Motors
Lockport, N.Y.

J. F. Britt
Technical Center
General Motors Corporation
Warren, MI 48090

J. Hamilton
Exxon Enterprises
P. O. Box 592
Florham Park, NJ 07923

W. W. Dickhart
Budd Company
Fort Washington, PA 19034

A. F. Shoemaker
Corning Glass Co.
Corning, N. Y. 14830

J. R. Williams
Energy Resources Center
Honeywell, Inc.
2600 Ridgeway Parkway
Minneapolis, MN 55413

M. Faeth
Highalnd Plating
1128 N. Highland
Los Angeles, CA 90038

H. J. Sund
Ford Aerospace and Communications
3939 Fabian Way
Palo Alto, CA 94303

P. Bender
Ford Glass Division
300 Renaissance Center
P. O. Box 43343
Detroit, MI 48243

W. J. Nagle
Ford Motor Co.
Room E-3184
Scientific Research Labs
Dearborn, MI 48121

R. C. Frounfelter
PPG Industries, Inc.
1 Gateway Center
Pittsburgh, PA 15222

D. L. Thomas
PPG Industries, Inc.
Glass Research Center
Box 11472
Pittsburgh, PA 15238

R. E. Cook
Donnelly Mirrors, Inc.
49 West Third Street
Holland, MI 49423

C. M. Lemrow
Electrical Products Division
Corning Glass Works
Corning, NY 14830

C. G. Lawson
Union Carbide Corp.
P. O. Box X
Oak Ridge, TN 37830

M. Mitchel
Jacobs Engineering Co.
251 South Lake Avenue
Pasadena, CA 91101

J. N. Epel
The Budd Company
Plastic R & D Center
356 Executive Drive
Troy, MI 48084

D. Lombardo
Haveg Industries, Inc.
12827 E. Imperial Highway
Santa Fe Springs, CA 90670

J. Rogan
McDonnell Douglas Astronautics Co.
5301 Bolsa Avenue
Huntington Beach, CA 92647

Solar Energy Research Institute (3)
1536 Cole Blvd.
Golden, CO 80401
Attn: B. Gupta
B. L. Butler
M. Cotton

U. S. Department of Energy (3)
Albuquerque Operations Office
P. O. Bo 5400
Albuquerque, NM 87185
Attn: J. Weisiger
D. N. Pappas
W. P. Grace

U. S. Department of Energy
San Francisco Operations Office
1333 Broadway
Oakland, CA 94612
Attn: W. D. Nettleton

U. S. Department of Energy (8)
Division of Central Solar Tech.
Washington, D. C. 20545
Attn: G. W. Braun
H. Coleman
M. U. Gutstein
J. E. Rannels
M. E. Resner

U. S. Department of Energy (2)
Agricultural & Industrial Process Heat
Conservation & Solar Application
Washington, D. C. 20545
Attn: W. W. Auer
J. Dolland

1472 L. G. Rainhart
1500 W. A. Gardner
1550 F. W. Neilson
1552 O. J. Burchett
1556 S. A. Ingham
2320 K. Gillespie
2323 C. M. Gabriel
2324 R. S. Pinkham
2326 G. M. Heck
3161 J. E. Mitchell
3700 J. C. Strassell
4000 A. Narath
4231 J. H. Renken
4700 J. H. Scott
4710 G. E. Brandvold
4720 V. L. Dugan (5)
4721 J. V. Otts
4722 J. F. Banas (25)
4723 W. P. Schimmel
4725 J. A. Leonard
5510 D. B. Hayes
5520 T. B Lane
5523 R. C. Reuter
5810 R. G. Kepler
5811 L. A. Harrah
5813 J. G. Curro

5820 R. E. Whan
5830 M. J. Davis
5831 N. J. Magnani
5833 J. L. Jellison
5840 H. J. Saxton
5842 J. N. Sweet
5844 F. P. Gerstle
5846 E. K. Beauchamp
8450 R. C. Wayne

3141 T. L. Werner (5)
3151 W. L. Garner (3)
For DOE/TIC
(Unlimited Release)
3154-3 R. P. Campbell (25)
6011 G. C. Newlin (3)
8266 E. A. Aas (2)

Second Distribution:
4722 J. F. Banas (100)

Third Distribution: Reprinted April, 1980
4722 J. F. Banas (100)

Org.	Bldg.	Name	Rec'd by*	Org.	Bldg.	Name	Rec'd by*

*Recipient must initial on classified documents.