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Albuquerque, New Mexico 87185

Presents

LINE-FOCUS SOLAR THERMAL ENERGY TECHNOLOGY DEVELOPMENT

A SEMINAR FOR INDUSTRY

ROSCOE L. CHAMPION
Division 4722
Conference Chairman

Four Seasons Motor Inn
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PREFACE

This document is a compilation of the abstracts of the papers presented at the Line-Focus Solar Thermal Energy Technology Development Conference, held at the Four Seasons Motor Inn, Albuquerque, New Mexico, under the sponsorship of the Department of Energy and Sandia National Laboratories. The proceedings of this conference will be published at a later date in a separate document.

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OVERVIEW OF LINE-FOCUS CONCENTRATOR PROGRAM

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ABSTRACT

The direct conversion of solar energy to thermal energy may be accomplished using a number of different hardware configurations. When temperatures above 100°C are required, the sunlight should be concentrated onto the receiver at which the conversion takes place. One type of solar collector system which is particularly useful for generating heat in the range 100-500°C is the line-focus concentrator.

The technical feasibility of this category of solar technology has been demonstrated and its economic viability is being rapidly developed along with improved system performance capability. Current technology emphases are the reduction of system installation costs, the enhancement of system reliability, and the implementation of production oriented engineering. A significant number of firms are currently involved in manufacturing line-focus concentrator hardware which will supply an active commercial market developing within the 1980's.

Session II - Line-Focus System Development

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SOLAR ENHANCED OIL RECOVERY

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ABSTRACT

For more than fifteen years, the production of many U.S. oil fields has been enhanced by the injection of huge quantities of steam, which permeates the reservoir, heating the heavy crude and reducing its viscosity. The idea behind Solar Enhanced Oil Recovery (SEOR) is simply that concentrating solar collectors instead of fossil-fired boilers are used to generate the steam. Since it combines aspects of renewable resource development and domestic production augmentation, SEOR is unique in that it can reduce dependency on foreign fuel imports in two ways: it can displace fuel which might have been used for steam generation, and it can (potentially) increase our recoverable petroleum reserves by more favorable economics.

The DOE program on SEOR can be divided into two parts. First, there have been a number of systems and feasibility studies undertaken by Sandia, SERI, Booz-Allen-Hamilton, and others. Second, there have been two Feasibility and Design Contracts awarded to respondents to a Program Opportunity Notice for SEOR released early in 1979. The two contractors were Exxon, Inc. and the team of General Atomic/Petro Lewis Corporation. Aerospace Corporation is the general technical coordinator of this program.

Subsequent to the completion of their study, Exxon has decided to proceed with construction of a 100,000 ft^2 field of parabolic trough collectors for SEOR without DOE's support. The principal reason is that, in addition to the solar tax credits, there exist substantial incentives in the Tertiary Incentive Revenue (TIR) program, designed to stimulate enhanced oil recovery in general. Because these incentive programs can be combined in SEOR projects, direct DOE subsidization is unnecessary. A number of other oil companies are also planning major independent SEOR field tests. Since the TIR program expires after 1981, a great deal of activity is expected in this area in the near future, and by 1982, SEOR will probably be the largest single application of solar in the industrial sector.

A SENSITIVITY ANALYSIS OF SOLAR RANKINE COGENERATION SYSTEMS

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ABSTRACT

The advent of high efficiency-low cost parabolic trough collectors may allow solar-thermal energy systems to become economically competitive with conventional energy sources in the near future. The design and economic feasibility of Solar Rankine Cogeneration (SRC) systems, which use trough collectors, are affected by many factors which include changes in component costs, competing energy costs, system operation, etc. Specific parameters which were varied to determine their effect include collector cost, thermal storage cost, collector outlet temperature, collector orientation, turbine thermodynamic cycle, turbine duty cycle, solar fraction and the relative cost of electricity and fossil fuel. The effect of some parameters, such as collector outlet temperature and turbine outlet temperature, can be quite large under most conditions while the effect of other parameters, such as turbine duty cycle and collector orientation, is variable depending upon the value of the other input parameters. A good SRSC design appears to be one with a collector whose outlet temperature is 600°F and which is used to power a turbine which has a cycle efficiency of 10% and which produces 340°F process steam.

The best SRC system was compared to a solar process heat (SPH) system which also produces 340°F process steam. Over a wide range of electricity-to-fossil fuel cost ratios, the SRC and SPH systems had the same economic feasibility characteristics. Thus, there was no economic penalty for shifting from a SPH to a SRC system which produces electricity as well as process heat. A turnkey cost of 210/m^2 in 1980 dollars for a collector field yields a system which is competitive with conventional energy sources whose costs are 4.1¢/kWh for electricity and \$4.60/10^6 Btu for fossil fuel with differential escalation rates of 3% and 2.5%, respectively.

SOLTES
(Simulator of Large Thermal Energy Systems)

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ABSTRACT

SOLTES simulates the steady-state response of thermal energy systems to time-varying data such as weather and loads. Thermal energy system models can easily be modularly construed from a library of routines for individual components. These routines mathematically model solar collectors, pumps, switches, thermal energy storages, thermal boilers, auxiliary boilers, heat exchangers, extraction turbines, extraction turbine/generators, condensers, regenerative heaters, air conditioners, process vapor, etc; SOLTES also allows user-supplied routines. Model construction is a natural extension of the system analyst's schematic. A pre-processor aids the user in constructing and editing system models and automatically constructs a SOLTES program that uses only those routines in the system model; thus, computer core requirements are minimized. Fluid names need only be specified in order to instruct SOLTES to obtain the proper heat-transfer fluid property data and power-cycle/refrigeration working fluid constants from a fluid property data bank. Load management allows SOLTES to simulate total energy systems that simultaneously follow process heat and power loads and demands. Generalized energy accounting is available and instantaneous and integrated values for system performance parameters may be automatically determined. Because of its modularity and flexibility, SOLTES can be used to simulate a wide variety of thermal energy systems such as solar power/total energy, fossil-fired power plants/total energy, nuclear-fired power plants/total energy, solar energy heating and cooling, geothermal energy, and solar hot water.

WILLARD SOLAR IRRIGATION PROJECT

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ABSTRACT

DOE support of the Willard Solar Irrigation Project was terminated in July 1980. This presentation will summarize the operation, maintenance and characterization of the facility during the past two years. NMSU assumed responsibility of the irrigation site in July 1980. Their future plans for the facility will be presented.

COOLIDGE 150 kW_e SOLAR IRRIGATION PROJECT

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ABSTRACT

Construction was completed on the Coolidge 150 kW_e Solar Irrigation Facility in the fall of 1979. The facility has been in operation since its dedication on November 9, 1979.

The purpose of the project is to demonstrate the feasibility of using a line-focus solar thermal system for the generation of electricity for irrigation.

Presented here will be a description of the facility, a report on construction and hardware costs, and a report on the performance history of the facility.

IEA/SSPS 500 kW DISTRIBUTED COLLECTOR SYSTEM

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ABSTRACT

This paper reviews the International Energy Agency (IEA) project for the design and construction of a 500 kWe (net) solar thermal-electric power generation system of the Distributed Collector System (DCS) type. An overview of the companion 500 kWe (net) Central Receiver System (CRS) Project is also presented. These projects make up the IEA Small Solar Power System (SSPS) Project, and are being constructed as a demonstration plant in the province of Almeria in southern Spain.

The DCS system final design, equipment fabrication, and construction is being performed by a nine nation team headed by a consortium of Acurex Corporation (U.S.), MAN (Germany), and Technicas Reunides (Spain), with Acurex as consortium leader. Construction is presently underway. The design consists of a mixed field of parabolic trough-type solar collectors of both German and U.S. design which are used to heat a thermal heat transfer oil. Heated oil is delivered to a thermocline storage tank from which heat is extracted and delivered to a boiler by a second heat transfer loop using the same heat transfer oil. Steam is generated in the boiler, expanded through a steam turbine, and recirculated through a condenser system cooled by a wet cooling tower.

AN OVERVIEW OF SOLAR INDUSTRIAL PROCESS HEAT

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ABSTRACT

Compared with other energy use sectors, Industrial Process Heat has several distinct advantages for solar displacement of fossil fuel use. For example: (1) a significant portion of IPH is at moderate temperatures; (2) year round utilization enhances solar economics; (3) it is routine in industry to invest capital for future returns and to maintain mechanical equipment for long periods of time; (4) the predominant fuels for conventional IPH are oil and natural gas, which are becoming increasingly expensive. However, there are also many problems, not the least of which is the heterogeneity of the market. In order to overcome some of these problems, the Department of Energy has, for several years, been conducting a Solar IPH Field Test Program, consisting of numerous solar facilities in a wide variety of configurations, industrial applications, and geographical locations. The program has several purposes. First, it is the only realistic way to understand the interface between solar technology and the industrial energy user. Lessons learned in this regard may result in system or component design modifications, or in the development of procedures for the user to make the introduction of solar into his process more effective. Second, it provides an effective minimal demand for collector manufacturers, encouraging innovation and progress in production techniques. Third, it introduces and validates the idea of solar energy as a practical energy alternative to a wide variety of industries, so that when economics are more favorable, market penetration will proceed more smoothly and quickly.

Currently, there are eight facilities in operation, six under construction, and nine in the design phase. The staged nature of the program allows lessons learned in one cycle to impact designs in subsequent cycles. An important adjunct to the Field Test Program is a series of collector materials exposure tests being conducted for Sandia by McDonnell Douglas at numerous proposed IPH sites around the country. By identifying any problems of reflector or receiver materials degradation, these tests allow timely action to be taken before the projects are constructed.

MODULAR INDUSTRIAL SOLAR RETROFIT PROJECT (MISR)

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ABSTRACT

This paper describes a major Department of Energy (DOE) thrust in line-focus solar thermal technology development to bring this technology to the point of commercial readiness. The project is based on the premise that thermal energy is the basic solar thermal system output and that low-temperature, fossil fuel applications are technically the first that should be retrofitted. Experience has shown that modularity in system design and construction offers potential for reducing engineering design costs, reducing manufacturing costs, reducing installation time and cost, and improving system operational reliability. The modular system designs will be a joint effort between Sandia National Laboratories and industry with the latter doing the final designs. The credibility of the systems will be demonstrated by industrial thermal energy users who will purchase the systems from the suppliers and operate them for a minimum of two years. Industries will be solicited by DOE/Albuquerque Operations Office to conduct these demonstration experiments in a cost-sharing manner. The selected industries will purchase systems from suppliers whose designs have been previously qualified. The Modular Industrial Solar Retrofit (MISR) Project is divided into three phases which represent three design and experiment cycles. The first cycle will use commercially available trough-type solar collectors and other components and will incorporate 5 to 10 experiments of up to 5000 m^2 each. The project was initiated in March 1980, and the project cycles are spaced to repeat in three-year intervals. The project is success-oriented, and if Cycle 1 indicates commercial readiness has been obtained, the project will be terminated. If not, a second cycle will incorporate improved solar technology components; possibly a third cycle incorporating advanced technology components will be conducted. The first experiment results are scheduled to be available in 1985.

Session III - Tour of MSSTF

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Session IV - Line-Focus Subsystem Development

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CROSBYTON SOLAR POWER PROJECT

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ABSTRACT

The world's largest single solar collector, a 65-ft mirrored dish, is in daily operation (when the sun is out). This scaled down version of one of ten planned 200-ft dishes is an Analog Design Verification System (ADVS) collecting data to verify the 5 MW_e solar-thermal-electric plant design concept. The ADVS is located in Crosbyton, Texas, and is currently undergoing an Experimental Test Plan (ETP) outlined to collect data, investigate optimum operating parameters, and integrate modifications for the follow-on large scale system.

The ADVS includes a concentrator (bowl) composed of 430 (40" x 40") mirrors; a receiver - an 18-ft helically wound boiler made up of two 0.25" ID Inconel tubes; a tracking and control system; a Data Acquisition System; and a 1,000 gallon oil storage system.

Incorporated in the ETP are operating temperatures ranging from 800° - $1000^{\circ}F$ and pressure ranges from 800 to 1000 psi. Control programs are continually being modified and updated for better tracking for improved fluid loop responses to transients caused by clouds. Maintenance and operational data are recorded and logged to analyze the responses of the ADVS to actual field operational conditions. The follow-on 200' dish and non-conventional 5 MW_e plant is planned for 1982 with the additional nine dishes to be constructed by 1984.

LARGE APERTURE TROUGH PROJECT

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ABSTRACT

Solar Kinetics, Inc. is under contract to Sandia National Laboratories, commencing June 1980, to provide four each T-2100 troughs - aperture size is 21 feet wide and 20 feet long. This presentation will summarize the progress to date.

MIDTEMPERATURE SOLAR SYSTEMS TEST FACILITY

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ABSTRACT

The MSSTF is a DOE facility operated by Sandia National Laboratories. The facility consists of a Subsystem Test Facility (STF) and a Collector Module Test Facility (CMTF) both of which support R&D and commercial activities related to the line focus program. This paper will:

(1) Outline the capabilities and current test programs at the STF.

(2) Briefly describe the CMTF test facility.

(3) Discuss current and future test procedures.

(4) Summarize the recent line focus concentrating collector test results.

ANNUAL PERFORMANCE PREDICTIONS FOR LINE-FOCUSING COLLECTORS

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ABSTRACT

The objective of this program is to increase the data base for the thermal performance of line-focusing solar collectors. Thermal performance predictions are being made for 16 line-focusing solar collectors that have potential for use in producing industrial process heat (IPH). The program was authorized by the Department of Energy (DOE), Division of Solar Application through the Solar Energy Research Institute (SERI).

The program involves seven steps:

1. Establish qualification requirements for commercial laboratories to test the collectors,
2. Survey commercial laboratories and determine which meet the qualifications,
3. Define specifications for collectors to be tested under the program,
4. Select collectors which meet the specifications,
5. Define and execute a test program to acquire the necessary data,
6. Prepare a computer program which uses weather data and test data to predict performance, and
7. Calculate predictions of thermal performance.

This paper identifies the laboratories judged to be qualified to perform the testing, identifies the collectors, describes the tests performed, tells how these tests are used to predict thermal performance for a typical meteorological year (TMY) and gives samples of the resulting predictions.

DESIGN OF COLLECTOR SUBSYSTEM PIPING LAYOUTS

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ABSTRACT

A parallel study focusing on the piping layout for a modular 50,000-ft^2 parabolic trough collector field has been conducted by Jacobs Engineering and Sandia National Laboratories. The goal of the study is to establish a design methodology potentially adoptable by A&E firms for solar thermal systems. Work to date suggests that a design handbook approach can be achieved for the piping layout.

Design points used in the piping layout were concerned with the thermal and electrical parasitics, capital costs and collector performance. Thermal parasitics consist of analytical estimates of steady state (operational) heat loss of the support piping, overnight cooldown of both the support piping and the receiver tube and the losses of potential thermal energy due to shading. The electrical parasitics are the pumping requirements for the support piping and the receiver tube. The capital cost of the support piping includes the cost of pipe, insulation, fittings and valves as well as the labor required for installation.

The annual parasitic cost of operating the modular field was determined by selecting a price for both the thermal and electrical energy and an amortization rate for the capital costs. Various field designs were considered by changing the length of the ΔT string and the spacing between rows of collectors. A minimum annual cost field design was then selected. Sensitivity analysis was used to determine how well this minimum annual cost modular field performs under different operational conditions.

SUBSYSTEM COLLECTOR PIPING HEAT LOSSES

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ABSTRACT

Computations of solar collector field performance typically underestimate the magnitude of field thermal losses because the computations usually ignore the effects of piping components such as valves and pipe anchors. These components can have large impacts since they typically represent highly conducting, uninsulated fins for thermal heat loss. In a well insulated piping arrangement, such components may, in fact, represent a dominant path for thermal heat loss in a collector field. In addition to strongly influencing thermal loss rates in operating solar collector fields, such piping components can accelerate thermal losses overnight as the collector field and associated piping cool down. A primary mechanism in accelerated thermal loss rates during overnight cooldown is convective transport of hot fluid, called thermosiphoning to such fins. Thermosiphoning from cold receiver tubes to hot insulated piping manifolds also contributes to increased heat loss from the collector field piping.

The effect of collector field components such as valves, pipe anchors, and receiver tubes on daily integrated field heat loss is being quantitatively evaluated in the Midtemperature Solar Subsystem Test Facility. The objective of this work is to determine the magnitude of such effects so that simplified heat loss calculations can be corrected to more closely represent actual situations and to determine piping configurations which minimize heat loss due to thermosiphoning.

FLUID CONTROL FOR PARABOLIC TROUGH COLLECTORS: SIMULATION STUDIES AND TEST RESULTS

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ABSTRACT

Techniques for controlling the temperature of the heat transfer fluid in parabolic-trough solar collector fields were studied by computer simulation. In particular, the rather stringent temperature control requirements associated with thermal electric power generation or co-generation systems are addressed. A specific control configuration was chosen consisting of a motor driven control valve and one or more temperature sensors to control the flow in each row of collectors. Various control algorithms were evaluated for stability and static errors, and time responses to startup transients and to partial and full collector cloud shadowing transients were obtained. The simulation results indicated that a simple proportional control algorithm operating off the row output temperature can satisfy most of the control requirements. Certain partial cloud cover conditions presented overtemperature problems which were corrected by the addition of a simple override control operating off a midrow temperature measurement.

The recommended fluid control system was tested in a 240 ft collector string at Sandia's Midtemperature Solar System Test Facility (MSSTF). The test results presented in this paper indicate that good temperature control is achieved under both steady state and transient conditions. Reasonable agreement was obtained between simulation and test results with the exception of a few discrepancies which have been attributed to test configuration peculiarities.

SUBSYSTEM DESIGN HANDBOOK

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ABSTRACT

A design handbook has been formulated for the design of solar thermal subsystems utilizing parabolic trough collectors. The principle objective is to provide techniques which will allow the rapid achievement of preliminary designs suitable for determining compatibility between an envisioned application and a solar thermal process heat system. The handbook carries the design process through two levels: conceptual design and preliminary design. Final design optimization and verification, which proceeds from that point, involves the use of computer simulation and is beyond the scope of this handbook.

Conceptual Design Level - The conceptual design addresses the question of the area of the collector field needed to displace a given thermal load. Collector field output is computed in the absence of shadowing, thermal losses in the field manifold piping, and parasitic requirements such as pumping power. Storage requirements to meet level load requirements are computed and collector field sizing strategies are outlined. The conceptual design is the simplest design stage at which compatibility between the solar technology and application requirements can be examined.

Preliminary Design Level - The preliminary design permits evaluation of the effects of constrained land availability on collector field energy output, quantity of parasitic power required for subsystem operation, effect of field piping configuration and components (e.g. pipe anchors and valves) on collector field energy production, and the effect of field operation conditions on subsystems such as as storage. Tradeoffs between such effects as shadowing due to collector spacing and thermal heat loss from field piping are also evaluated.

Data are presented in the handbook appendices which permit use of the design techniques developed here to be used at any of 26 SOLMET sites. Thus, application of the design techniques is limited primarily by lack of solar insolation data available at non-SOLMET sites.

SOLAR COLLECTOR CLEANING STUDY

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ABSTRACT

The objective of this program is to determine suitable and cost-effective cleaning materials, procedures, techniques, and equipment required for cleaning parabolic trough solar collector reflective surfaces. Procedures suggested by a study performed by McDonnell Douglas are being verified and extended.

Limited cleaning experiments are being conducted with 2 ft x 2 ft glass mirror samples. Eight of these samples have been exposed to the Albuquerque outdoor environment since November 1979. Six more 2 ft x 2 ft glass samples and two FEK-244 surfaced samples were added in May 1980. Specular reflectance measurements are made on each sample every week. Washing or rinsing cycles are being conducted on four and eight week intervals. Various cleaning combinations are being tried including:

1. Detergent wash - deionized water rinse.
2. Deionized water rinse - wash only.
3. Detergent wash - tap water with sheeting agent rinse.
4. Tap water with sheeting agent rinse - wash only.
5. Soft water rinse - wash only.
6. Two different pressure/flow rate pressure washes. (500 psi and 3 gal./min. and 1000 psi and 4 gal./min.)

Preliminary results of these various cleaning combinations will be presented. Procedures and techniques as they evolve are being utilized for the cleaning of full scale modules located in the Sandia Midtemperature Solar Systems Test Facility (MSSTF).

THERMOCLINE THERMAL ENERGY STORAGE

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ABSTRACT

Although the question of which thermal storage system is the most efficient from a first law standpoint may be argued, a second law effectiveness analysis quickly leads one to the conclusion that thermocline storage has the potentially highest effectiveness. Sandia National Laboratories is currently investigating thermocline storage as a candidate for the storage subsystem of mid-temperature solar systems. A notable achievement of the ongoing development work is the construction of a well-insulated, thoroughly instrumented large-scale 1200 gal thermocline tank. To be able to determine the physics of a thermocline, approximately 400 thermocouples have been installed in and around the tank. Parallel detailed, flexible, small-scale laboratory experiments on thermocline development, complementary analytical modeling, and the large-scale experiment will be discussed.

Session V - Line-Focus Component Development

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THERMOOPTICAL CONSIDERATIONS IN TROUGH DESIGN

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ABSTRACT

The design of a parabolic trough collector for the 150°F - 600°F operating range is significantly influenced by the thermooptical considerations which affect performance. While performance related design alternatives may be readily addressed in a theoretical manner, the ultimate selections must be based on performance and cost considerations.

Theoretical and experimental efforts have demonstrated an attainable goal for a selective receiver coating of 95% solar absorptance with a 25% total hemispherical emittance at 300°C. The receiver should be glass-jacketed with a controlled annulus dimension to minimize thermal losses from the system. Due to the low thermal losses from a jacketed receiver, it should remain symmetrical, and therefore, it is counterproductive to add insulation to further decrease losses since the optical losses are greater than the thermal savings.

The rim angle for a parabolic trough should be approximately 90 degrees. For a 2 m aperture trough with a system optical error of 10 mr, the optimum receiver diameter is 1.25-inches.

For the described design, a rather large range of tracking bias and/or receiver mislocation tolerances can be permitted without significant degradation of performance. A tracking bias of 1/4 degree and a mislocation of 0.2-in can be tolerated.

These conclusions hold for all geographic sites which have been analytically examined and probably for all sites in the United States.

WIND LOAD DEFINITION FOR PARABOLIC TROUGH SOLAR COLLECTORS

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ABSTRACT

The economic competitiveness of solar energy in the mid-temperature regime (~300°C) is strongly dependent upon the installed cost of the solar collector array. A prime contributing factor to this cost lies in the collector rigidity and foundation requirements necessary to withstand adverse wind loading. A proposal for wind load design criteria for line focus solar collectors is presented herein.

Procedures to be used in the estimation of wind loads for the design of buildings and other structures are defined in Section 6 of the American National Standard A58.1-1972. A primary consideration in the development of these standards is the safety and limitation of risk to personnel as well as to the general populace. The standards offer a range of basic design wind speeds based upon a statistical compilation of annual extreme fastest mile speeds for 129 U. S. Weather Service stations. A collector design value for the contiguous United States is recommended based upon an acceptable annual probability of exceedance. A boundary layer correction is made to this value to account for velocity gradient effects between the Weather Service data at a standard 10 meter elevation above the surface and a ground mounted collector array.

Two wind tunnel tests have been conducted by Colorado State University on parabolic trough collector configurations to obtain force and moment data. The two tests were conducted in different flow field environments. One, a uniform infinite airstream, the second, a simulated atmospheric boundary layer flow with the models simulating a ground mounted installation. The force and moment characteristics of both isolated single module troughs and of trough modules within array configurations have been defined over both operational and stow attitudes. A summary of this data including the influence of various geometric design parameters for collector modules and arrays is provided.

FOUNDATIONS FOR LINE-FOCUSING SOLAR COLLECTORS

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ABSTRACT

A line focusing solar collector system is subject to aerodynamic forces which result in fairly unique foundation loadings, i.e., eccentric inclined loads which have an upward component. The design of foundations for this loading environment is not straightforward, and there is only limited field test data available. Therefore, extremely conservative foundation designs have been executed for many systems built to date with resulting high construction costs.

A theoretical study was conducted to determine the most cost effective foundation designs for solar collector systems. This study concluded that the reinforced concrete cylindrical cast-in-place pier was the most economical design and recommended that this design be utilized whenever site conditions would permit. In addition, a rigid-pile theory was developed for the design of cost effective pier foundations.

Foundation loads for a typical line focusing solar collector system are based upon recent work accomplished by Sandia National Laboratories and take account of shielding allowances. The rigid-pile theory was utilized to design pier foundations which were subjected to specified loading conditions. The results are summarized for a line focusing solar collector system.

Experimental results are available from two recent foundation field test programs. One was conducted at Sandia National Laboratories' solar collector test area, and the other was conducted at the L.S.E. site at Shenandoah, Georgia. Another field test program is planned. Typical experimental results from those test programs are presented. These results confirm that theory can be utilized, with appropriate soil parameters, to predict the response of pier foundations to inclined eccentric loads.

PYLONS

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ABSTRACT

The pylon is the structural component of the line focusing collector which provides the interface between the foundation and the reflector structure; it is an upright beam or column support having a bearing and shaft assembly with features to attach to the various types of reflector structures under development. Assembly of multiple reflectors into a row with a common tracking drive, i.e., a drive string, requires a set of pylons with some differences in the requirements on the pylons within the set.

The functional requirements for the pylons are presented and some of the design choices are reviewed. Emphasis was placed on down-sizing the pylon to reduce cost, just satisfying the structural requirements and having a minimum gap between the reflector structures for reduced thermal loss. A double pylon serves to reduce the quantity of foundations required when multiple drive strings are aligned end-to-end in a field lay-out. In terms of the weight of all parts of the drive string, it is estimated these parts will be approximately 9% of the total weight of a system having glass reflectors.

Details of the proposed pylon designs other than the drive pylon are presented. These designs use standard structural shapes, i.e., junior beams, bars, angles, and plates of low carbon steel with welded assembly. Investigations of alternate techniques for fabrication will be discussed.

PARABOLIC TROUGH STRUCTURAL DESIGN AND PARAMETRIC EVALUATION

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ABSTRACT

Adequate stiffness and strength, low weight, manufacturability and low cost are reasonable design goals to impose on the parabolic trough reflector support structure. Much is expected of this structure as it must provide and maintain an acceptable optical shape for the reflective surface of the collector, and protect it from extreme and long-term environmental effects. To meet the design objectives, the engineering analyst and designer of the trough faces the task of selecting materials and design concepts from the myriad available. Even when trough geometry and performance and survival conditions are specified, the question remains regarding which materials and which designs, or construction concepts make sense. A partial answer to this question is found in the recognition that there are probably several materials and designs that qualify, and many that don't. The initial objective, then, is to identify those which should be disregarded from further consideration, and those which are worthy of engineering development.

The purpose of this paper is to review the analysis and numerical results which led to the rejection of several materials and design concepts, and the parameter studies which enhanced understanding of those that looked promising in terms of meeting design objectives.

SHEET METAL TROUGH REFLECTOR/STRUCTURE

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ABSTRACT

The automobile industry has long used stamped sheet metal for low cost structural panels. This mass-production technology has been adapted to the fabrication of parabolic trough reflector panels. A development effort has been in progress to investigate technology for structural back panels which can be assembled to front panels and/or mirrors on an accurate parabolic assembly fixture. Back panels with sections for stiffening have been successfully stamped. Prototype units have been assembled using both bonding and spot welding. Units have also been inspected with a laser ray trace system and subjected to environmental testing.

The problems of tooling design, stamping and assembly will be reviewed. Major design considerations in selecting the final three configurations have included: corrosion protection finishes for the steel panels (primers, paints, galvanized coatings and aluminized coatings); adhesive selection with evaluation of compatability with the silver coating on the mirror; shear stresses due to thermal expansion mismatch between glass and steel; and suitable production methods of applying either sagged, chemically strengthened, or thin glass mirrors to the stamped steel structural assembly.

SHEET MOLDING COMPOUNDS (SMC) REFLECTOR/STRUCTURE

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ABSTRACT

Collector components must be low cost for solar thermal systems to become competitive with other energy sources. Mass production techniques are vital to low cost fabrication of reflector structures. Sheet molding compound (SMC), which is a thermo-setting filled polyester resin reinforced with chopped fiberglass (20-40% by weight), offers several advantages for fabrication of parabolic trough reflector panels. With chemically strengthened glass, the mirror can be placed in the mold and the SMC molded around it, thus eliminating subsequent bonding operations and providing a good environmental seal for the silver coating on the back (molded) surface of the glass.

The history of the development efforts on 2 x 4 ft units which led to the present work will be reviewed covering the survival of the glass under the molding conditions of 300°F and 600 - 1000 psi, adhesion of the SMC to the mirror, and the results of environmental testing.

The present development effort investigates technology and molding techniques for panels of a 1 m x 1 m size. These panels extend from vertex to rim; two panels are fastened together at the vertex to form a 1 m x 2 m rim to rim reflector structure. The development problems and solutions will be reviewed along with the results of the laser ray trace inspections, and environmental test results to date.

HONEYCOMB REFLECTOR/STRUCTURE

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ABSTRACT

An all aluminum honeycomb parabolic trough collector with an acrylic film reflector and utilized in the Hexcel collector had demonstrated excellent contour accuracy and structural stiffness while producing high efficiency in performance testing. Second generation units were fabricated by Hexcel for Sandia National Laboratories in a one piece 2 m x 6 m aperture with aluminum core and 26 gauge steel skins. With silvered glass mirrors, these units achieved still higher peak efficiencies (60% at 316°C).

Sizing a solar concentrator is a trade off of optical and structural considerations. The stiffness of a one piece honeycomb structure allows fabrication of a large structure to accurate tolerances under factory controlled conditions. These units also allow easy shipment and simple attachment to pylons and drive systems in field installation. Structural analyses, including finite element analysis, indicated that a one inch thick aluminum core with steel skins could be fabricated with a 2 x 6 m aperture and would provide the required stiffness and accuracy for normal operational loads (diurnal thermal cycling, gravity and light winds); this design would also survive the specified extreme environmental conditions of high winds, rain, snow, hail, etc.

Two initial models were produced using flat chemically strengthened glass mirrors which were elastically deformed and bonded to the trough face. This process was labor intensive and not appropriate for high production. Processes are being developed for fabrication in the flat condition of the strengthened glass mirrors to an aluminized steel face skin. This flat laminate can be assembled as one skin of the honeycomb structure.

All aspects of the R & D effort will be covered, including: selection of adhesives, core cycles and application techniques; tooling and other production facilities; long-term corrosion protection; and evaluation results.

GLASS LAMINATE REFLECTOR/STRUCTURE

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ABSTRACT

A straightforward concept for a parabolic trough solar collector utilizes thermally formed glass mirrors which are supported by a steel structure. Automotive windshield type technology is used to form and laminate two sheets of glass. The front sheet which is second surface silvered is thin (2 mm) to minimize absorption. A thicker back sheet (6 mm) is used to provide structural support and to protect the silver. Currently available glasses in production have solar averaged reflectances slightly less than 90%. Fabrication of the laminate in the glass factory means that the collector manufacturer will not have to handle the relatively fragile thin glass mirror separately.

The glass laminates are approximately 1 m x 1 m. Twelve laminates are required for a 2 m x 6 m aperture trough. A strongback is required to support the glass laminates. A thin walled tube is used to transmit the drive torque and to resist the wind and gravity loads. Sheet metal ribs are used to attach the glass to the torque tube. A finite element analysis was performed to examine the stresses and slope errors for various mounting configurations and loads.

ANALYTICAL AND EXPERIMENTAL STUDIES OF SOME PARABOLIC LINE CONCENTRATOR DESIGN CONCEPTS

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ABSTRACT

The finite element method has been used as part of the evaluation process for design concepts for parabolic line concentrators. The finite element studies are used to calculate stresses in line concentrators arising from various load conditions and to examine the optical performance of concentrators.

This paper will discuss a procedure which is presently being used for concentrators which are essentially shell structures supported at a discrete number of points. This configuration leads to stress concentrations in the shell, a situation of concern when glass is used for the reflecting surface. Detailed finite element models offer a way to calculate the magnitude of these concentrations with reasonable accuracy. In working with detailed models of parabolic line concentrators, substructuring has turned out to be a very useful tool.

In addition to a finite element code, an optical post-processor is also used as part of the computer analysis. The post-processor uses results from finite analyses to calculate equivalent slope errors. The analyst can make a check of the magnitudes of the slope errors and quickly discern if the optical performance of the concentrator is acceptable.

Experimental tests have been used for verification of finite element predictions. For these tests, a gridwork of strain gauges is placed on the reflecting surface to obtain a picture of the overall stress state. Clusters of strain gauges are placed at points where stress concentrations arise. Loading conditions are chosen so that they will give useful information about the behavior of the structure in critical cases and so that they are easy to apply. They do not have to be exact or even close representations of load conditions the concentrator will see in the field. Once the finite element model is verified, it can easily be used to examine field loading conditions.

INTEGRATED SOLAR FIELD CONTROL SYSTEMS

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ABSTRACT

A control system for a solar collector field that integrates sun tracking, fluid control, system safeties and system status display is described. The controller consists of a microprocessor based signal processing board at each drive pylon that handles routine operation of that drive string in concert with the other processors in its ΔT string. Fluid control is implemented in one of the four boards in the ΔT string. Tracking and system safeties such as overtemperature, receiver tube overexpansion, loss of flow or communications are handled by the processor. The string operates in a fail-safe mode whereby only if everything is functioning normally (checked about once a second) will the string be allowed to come out or remain out of the stow position.

All the local drive string controllers are supervised by a field controller which, among other things, determines if the field should be running (it considers weather, time of day, BTU demand, etc.). It monitors and displays the status of the field, performs system diagnostics and aids in maintenance and repair.

This control system employing up-to-date but proven electronics and controls concepts promises to be the most effective and reliable control system yet developed for solar collector fields, but perhaps most importantly, this capability is available at reasonable cost.

DRIVES

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ABSTRACT

A drive mechanism is required to rotate a collector system as it tracks the sun during normal operation, and to rotate the collector to the stow condition when required.

Some of the considerations for this drive are:

- o High force low speed
- o Pulse and steady state operation
- o Sensitivity
- o Emergency power source consideration
- o Field wiring considerations
- o Hold force much higher than drive forces
- o Small power consumption
- o Environmental considerations.

The two approaches being pursued for drive system design are the electromechanical, consisting of a gear type speed reducer driven by an electric motor, and the hydraulic, consisting of a linear hydraulic actuator with a mechanism for translation to rotary motion. Each approach incorporates an emergency power source to stow the collectors when normal electric power is not available.

The drive system will operate in either direction at approximate 30 second intervals during normal tracking of the sun. It will also rotate the collectors to the stow condition within 5 minutes, maximum.

A test stand is available to test prototype drive systems under simulated collector loads.

NON-EVACUATED RECEIVERS

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ABSTRACT

Because of the construction complexity, the cost of replacement, and the limited performance enhancement resulting from the use of evacuated annuli, a receiver design with air in the annulus has been evaluated for performance and durability. The current results are reported.

Techniques to accommodate linear expansion of the receivers are reported upon. One of the techniques to accommodate linear expansion is to form an Omega-shape receiver support from steel rod and establish a rotation pivot line near the mirror vertex. As the reciver support rotates about the pivot line due to receiver length changes, the receiver is slightly raised or lowered into focus as a result of proper establishment of the ambient temperature receiver length. The other technique which has been evaluated is a track-rail shoe sliding assembly in which the receiver Swagelok union fitting is attached to the rail shoe. As the receiver assemblies expand due to temperature changes, the rail shoe slides along the track.

A technique to permit receiver rotation is described. Essentially it mounts the Swagelok union fittings into rotary bearings. The receiver rotation will minimize torsional loading of the flexible hoses which transport the heat transfer liquids to and from the receivers.

PASSIVELY EVACUATED RECEIVERS

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ABSTRACT

A set of receivers with passively evacuated annuli around their absorber tubes has been constructed and installed on the parabolic troughs provided by Custom Engineering, Inc., at the MSSTF.

Presented here will be a summary of the design, the construction process, and the performance results to date.

INSULATED METAL HOSE FOR TRACKING RECEIVER APPLICATIONS

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ABSTRACT

Heat transfer fluid must be conveyed between the solar receiver and the field distribution piping in a field of parabolic trough solar collectors. Metal hoses capable of the temperatures and pressures involved have been used for this purpose. Limited real-time experience to date suggests that the design and deployment of these hoses must be carefully done if the desired lifetime is to be realized.

The motions of the solar receiver which must be accommodated are discussed, along with their ramifications on hose design. The basic philosophy of using a hose to accommodate all the receiver motions, as opposed to other components which might be used in various combinations, is discussed. Hose design considerations as they relate to pressure, flexure, life, flow, and pressure drop are discussed.

A testing machine has been built which can subject test hoses to the motions experienced in actual use at an accelerated rate. Hoses are being tested in various deployments under temperature, pressure, and flow conditions which duplicate actual use. Results of the testing to date are presented.

Session VI - Materials Development

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BLACK CHROME SOLAR SELECTIVE COATING

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ABSTRACT

Electrodeposited black chrome solar selective coatings have experienced thermal stability problems when heated to temperatures above 250°C (480°F) in air. By reducing the trivalent chromium concentration in the standard black chrome plating bath, coatings on nickel substrates are obtained which are stable for thousands of hours at 350°C (660°F) and hundreds of hours at 400°C (750°F). These results have been obtained consistently on a laboratory scale, but difficulty in reproducing the results has been encountered in a production environment. A current study of the effects of known plating variables on the optical properties and thermal stability of coatings is aimed at establishing an acceptable range for each plating parameter. The results of this study will be presented. A planned demonstration of the improved process in a commercial plating facility and the status of comparative thermal aging tests in laboratory furnaces and in a collector environment are discussed.

FIBER REINFORCED CONCRETE

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ABSTRACT

SRI is currently under contract with Sandia National Laboratories to investigate the feasibility of using fiber reinforced concrete for trough structure. This talk will include the program objectives, current status and future plans.

SILVERED GLASS MIRRORS - DESIGN CONSIDERATIONS

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ABSTRACT

Silvered glass mirrors have received considerable attention as the reflective material for solar receivers. As currently manufactured in this country, glass has shown some advantages over other choices such as aluminized polymer films and anodized aluminum in terms of increased reflectance and environmental stability. Some new developments have been required to adapt glass mirrors to parabolic troughs. These developments include use of chemically strengthened, low iron float, and high transmittance glasses as opposed to the traditional soda lime glass typically used for mirrors; however, these improvements have imposed cost penalties.

The silver on glass mirrors presents environmental problems. Designs which expose mirrors to moisture, adhesives and edge seals which out-gas sulfides or amines, and mismatches in thermal expansion can cause silver delamination or corrosion. It appears, however, that proper designs can minimize most of these disadvantages.

DEVELOPMENT AND TESTING OF POLYMER REFLECTORS

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ABSTRACT

Metallized polymer sheets and films offer the potential of providing a low cost, light weight and easily installed solar reflector surface. One of the primary concerns associated with their use is their susceptibility to abrasion from wind blown sand and cleaning operations. Several approaches to the attainment of an abrasion resistant metallized polymer were evaluated: (1) an aluminized acrylic film was coated with a developmental abrasion resistant resin, (2) an organosilane was plasma deposited on an aluminized acrylic film, (3) an abrasion resistant cast acrylic sheet was aluminized by an ion plating process and (4) a first surface reflector consisting of an aluminized high temperature polymer was protected with a conventional abrasion resistant coating. The abrasion resistance, solar reflectance and weatherability of the reflectors were evaluated. The first and third reflectors are now being prepared on 0.6 x 1.2 m steel sheets and their performance will be field tested.

MATERIALS COMPATIBILITY/LIFE PREDICTIONS

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ABSTRACT

Economics of solar systems are usually based on system lifetimes of 10-30 years. Many of the material combinations and configurations used in the components for solar systems are new. The result is that very little realtime aging data on any of these components is available. Some materials chosen for components in use at the present time have resulted in system degradation or failure. Thus, to make dependable economic projections, a program has been initiated to attempt to make realistic lifetime predictions based on a framework developed by Gillian and Mead of Sandia National Laboratories.

This framework has two basic tenets. First, to identify failure modes in accelerated testing. Failures that are a result of materials incompatibility can result in design changes. Should design changes not be necessary, the second tenet is utilized; namely, kinetic studies wherein Arrhenius type analysis provides quantitative lifetime predictions.

Applications to solar systems, principally trough modules, will be discussed emphasizing temperature, humidity and temperature cycling effects upon the structural and functional integrity of the trough.

Session VII - Instrumentation Development

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PORTABLE INSTRUMENTATION FOR SOLAR ABSORPTANCE AND EMITTANCE MEASUREMENTS

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ABSTRACT

Two portable instruments, designed for solar absorptance and emittance measurements, have been evaluated. The instruments are manufactured by Devices and Services Co., Dallas, TX. Solar absorptance properties are measured with a Solar Spectrum Reflectometer while emittance properties for a 65°C blackbody are measured with a model AE Emissometer. The Solar Spectrum Reflectometer uses four different detector/filter combinations to match an air mass two (AM2) solar spectral distribution. From measurements of a variety of black chrome solar selective coatings, the solar absorptance values were determined with an accuracy of ± 1%. We have adapted the instrument so that the solar absorptance properties of receiver tubes down to 13 mm in diameter can be measured. For second-surface solar mirrors, the instrument under estimates the solar reflectance (hemispherical); we are investigating ways to correct this problem. The emissometer consists of a heated measurement head and separate display unit. Samples to be measured must be flat and at least 5.7 cm square. The accuracy of this instrument is currently being checked for a variety of optical materials.

OPTICAL TESTING OF LINE-FOCUS SOLAR CONCENTRATORS BY LASER RAY TRACE

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ABSTRACT

Successful development of line-focus collector systems requires the ability to measure the geometric accuracy of the fabricated mirrors. Suppliers need this information to adjust processes, tools or molds. System designers use this information in computer simulations and performance predictions.

A computer controlled Laser Ray Trace system to measure the geometric optical quality of parabolic line-focus collectors has been developed and is in operation at Sandia National Laboratory in Albuquerque.

The theory and method of the optical test will be presented as well as the instrumentation employed. Data from the test of a typical collector will be shown.

The tester can test collectors of up to 10 feet in aperture 5 feet long and focal length to 8 feet.

Alternative optical tests will be discussed which require only simple apparatus. These tests can be made quantitative, but the data reduction is laborious.

FIELD LASER RAY TRACE TESTER

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ABSTRACT

When a laser ray trace (LRT) technique is used to measure the slope errors (deviations from theoretical surface) of a parabolic trough reflector, it is desirable to scan the laser beam by pure translation, so it remains parallel to the reflector focal plane (infinite conjugate method) as is done in the laboratory LRT tester. However, this geometry is not practical for a portable instrument capable of testing full-size parabolic trough reflectors in the field, so the field LRT tester was developed, based on a pivoting laser beam (finite conjugate method). This method requires a large (about 1 m) detector to track the reflected laser beam. It also introduces some difficulties in alignment. The hardware will be described, and several possible alignment techniques will be discussed.

Data analysis for both methods depends on the concept of a reference surface, which is usually a "best fit", in some way, to the surface under test. Methods of finding this surface, and what it implies about slope error statistics and best focal line, will be discussed. Typical data formats will be presented, and examples of data analysis techniques will be given, including slope error, surface displacement, ray plots and statistics.

FLUX MAPPER

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ABSTRACT

The BDM Corporation is under contract to Sandia National Laboratories commencing July 1, 1980, to develop a flux measuring device for a parabolic trough. Using these measurements, a more efficient receiver tube will be designed. Their presentation will summarize the progress to date.

THE DEVELOPMENT OF A SECOND GENERATION PORTABLE SPECULAR REFLECTOMETER

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ABSTRACT

The second generation design of a portable specular reflectometer developed by Sandia National Laboratories has been completed together with a detailed drawing package. Two prototype second generation instruments have been fabricated and evaluated. It has been demonstrated that the instruments respond linearly ($\pm$ 0.006 transmission units) to variations in intensity of incident and reflected beams and that the readings are not affected by the presence of stray light. As a result of this feature, the reflectometer is well suited for outdoor field use in a normal sunlight environment.

A major improvement in the second generation reflectometer involves the use of larger optics to allow averaging over a greater surface area of a mirror. The new reflectometer also has the capability of a straight-through beam configuration, allowing direct determination of the signal level corresponding to 100% reflectance. This capability also allows the user to measure the transmittance of materials.

The reflectometer has been tested by measuring the specular reflectance of polished aluminum, metallized plastic film, and silvered glass. The reflectance values of these materials were found to be within $\pm$ 0.010 reflectance units of those obtained by appropriately averaging reflectance versus wavelength data taken with a laboratory bidirectional reflectometer.

In order to provide the most economical and efficient instrument possible for field use, Sandia is presently seeking the assistance of optical instrument manufacturers to evaluate the reflectometer from a design and manufacturability standpoint, incorporate desirable improvements, and actually manufacture a number of prototype units.