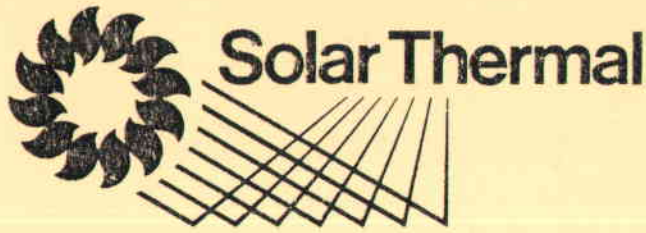
SERI/MR-251-1471 August/September



Solar Thermal Research Program

Status Report

August 1985
September 1985

Issued October 18, 1985

SERI

Solar Energy Research Institute
A Division of Midwest Research Institute

1617 Cole Boulevard
Golden, Colorado 80401

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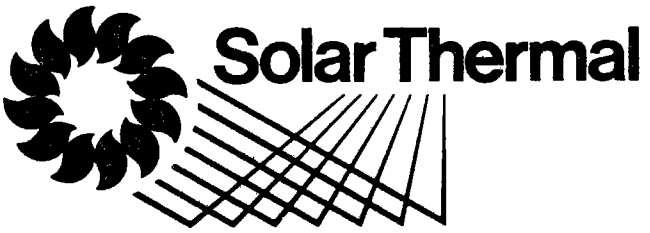

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SERI

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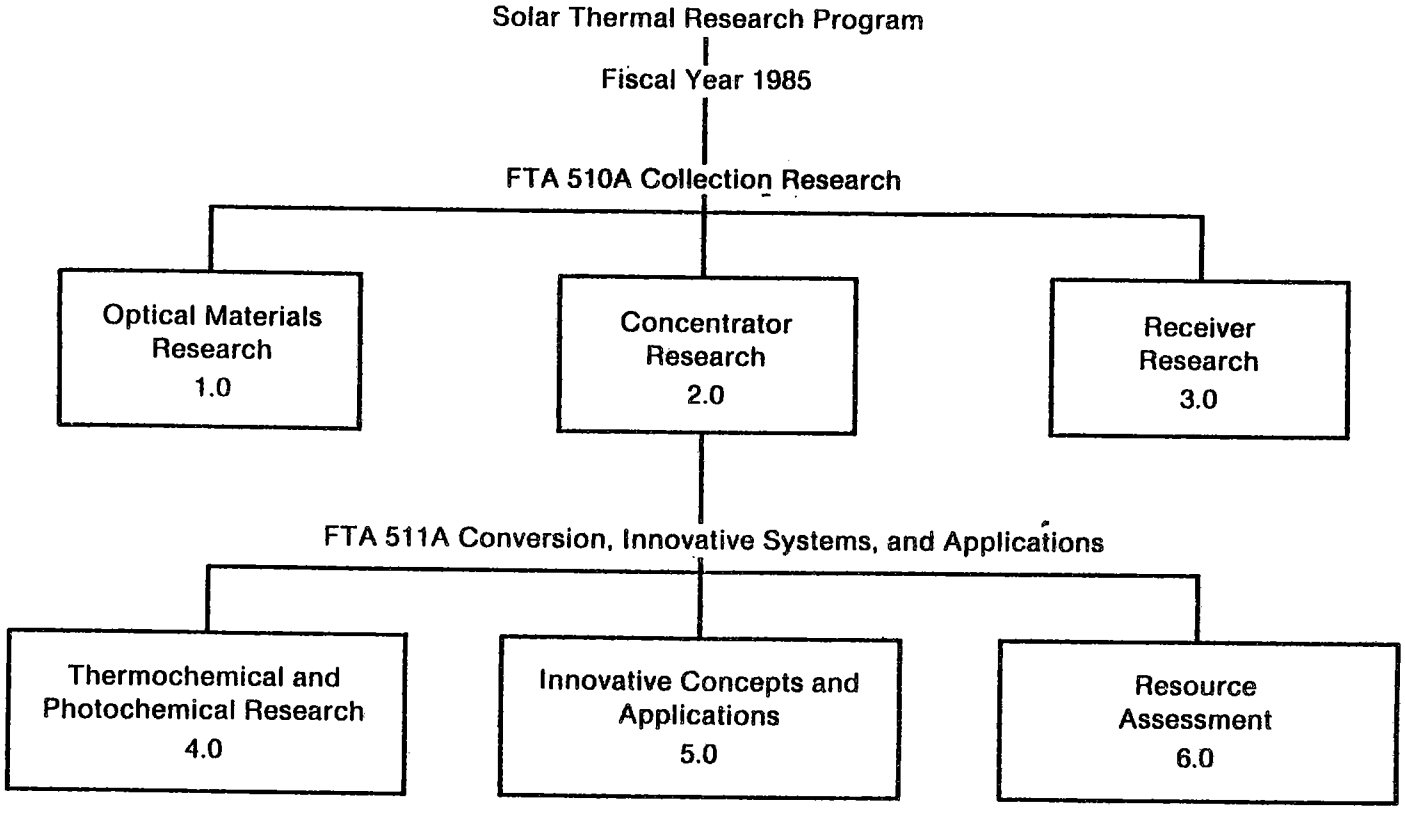


SUMMARY

SIGNIFICANT EVENTS

The issues and questions regarding effects of high solar flux on materials were addressed in a two-day discussion session at SERI. The Session brought together experts in the physics of visible radiation effects on materials as well as materials and program specialists from the various laboratories and universities in the Solar Thermal Program. The limits of current knowledge in this field and many suggestions for significant research were discussed.

Real-time, photoassisted conversion of acetone to other chemicals was conclusively proven at SERI in experiments that combined the efforts of Professor M. Antal of the University of Hawaii and Dr. T. Milne of SERI. Butene was produced in the experiments only when the ultraviolet component of the radiant flux was not removed by filters, even when the total energy flux on the reaction was maintained constant. Clearly, direct solar photolysis of organic materials is readily possible.

A Langmuir-Blodgett film deposited under the Southern Research Institute subcontract produced a very interesting result. While the film was somewhat nonuniform and streaked, it did provide surprisingly good protection from sulfur corrosion on a silver film that was stored in a sulfurous atmosphere. This preliminary result is very promising. (Page 8)

SERI authors have incorporated modifications based on peer-reviewer s comments into a stretched-membrane heliostat analysis. Result of additional analysis indicates that in the face of uncertainty, it is prudent to design for too high a surface error rather than to design for too low a surface error. This result occurs because the receiver performance is much more sensitive to optical spillage losses than to thermal losses.

The University of Dayton has completed the control experiments for thermal detoxification of hazardous wastes. Experiments with concentrated sunlight are underway to define the enhancement.(Page 19)

TECHNICAL DESCRIPTION

A. FIELD TASK AGREEMENT 510A COLLECTION RESEARCH

This research encompasses optical materials, concentrators, and receivers. Optical materials research centers on improving reflector materials and obtaining better absorber coatings. Concentrator concept research is focused on light-weight, low-cost innovative collector designs. Receiver concept research is focused on low-cost and high-efficiency configurations with good durability, and on extending the temperature range beyond the current technology.

PROGRAM ELEMENT 1.0 OPTICAL MATERIALS RESEARCH

Optical materials research is directed at three areas: mirrors, absorbers, and windows. The objective of mirrors research is to obtain reflecting surfaces which meet high performance requirements in specularity and which satisfactorily operate in the solar environment. Absorber coatings improve the thermal performance of receivers by increased absorptance. Some receiver concepts require a closed cavity with a window to contain reactants. Research on windows aims at understanding the unique effects of high solar flux on specific candidates for window materials capable of sustained operation at elevated temperatures.

Mirror esearch in this fiscal year amplifies research from fiscal year 1984 on silver/polymers. During fiscal year 1985, it is anticipated that SERI will identify silver/polymer combinations which show no short-term ultraviolet degradation, will produce and test silicon nitride film deposits on both sides of a silver mirror, and will identify the sources of optical irregularities inside, as well as on the surface of commercially available polymers. SERI expects to identify the controlling factors determining metallic surface roughness, and will produce and test metallic substrates with polymeric leveling layers. SERI expects to identify the factors affecting black chrome performance when deposited on stainless steel. In research on windows, SERI, in conjunction with Georgia Institute of Technology, expects experimentally to characterize at least one coating material and to understand mechanisms in devitrification.

PROGRESS

Silver Polymer Reflectors

The research to achieve high specularity of silvered polymers has progressed beyond the original goals for fiscal year 1985 which were 90% reflectance in 6 mr. In the last bimonthly period, researchers using the new Devices and Services (D&S) reflectometer noted that measurements of specularity show excellent agreement with results obtained by the 3M Company. The SERI D&S reflectometer was realigned by the D and S Company. Comparisons of SERI's instrument with another from the D and S Company and one from 3M Company showed that there is noticeable variation between units. SERI researchers have concluded that when used at its lowest (3.5 milliradian) setting, the D and S instruments cannot be expected to yield agreement between different units for input beams narrower than 2.5 mr. Therefore, SERI staff will report specularities as read by SERI's realigned instrument, but must expect some variance when compared to 3M data, for example.

The limitation on specularity data below 3.5 mr is not critical for current mirror demands. Better measurements are needed for research purposes, and a high resolution reflectometer has been designed to assess specularity down to 1 milliradian. Assembly of the new unit is scheduled for October, and no problems are expected.

Polymer Glazing

Polymer coatings can serve as protective covers for the silver on mirrors. These coatings must be highly stable against environmental (particularly ultraviolet radiation) attack and must not limit the specularity of the mirror. While such films are of great importance in silvered polymer reflectors, researchers find that their performance on silvered glass reflectors is an excellent test of their expected behavior on silvered polymers while offering an easier research approach than the use of silvered polymers.

Severe delamination of the silver from its substrate is observed in the Weather-Ometer in areas where salt films accumulate on the polymer surface and ultraviolet radiation reaches the surface. In areas where the delamination does not occur, the specularity shows little degradation for most coatings. Unstabilized PMMA coatings show a marked loss of reflectance.

Cast PMMA Glazings

Hemispherical and specular reflectances (7.5, 4.2, and 3.5 mrad) have been measured for the stabilized PMMA-glazings of the R12-178-X (some with polymeric stabilizers) series after four weeks of QUV testing and outdoor weathering. Reflectance values were found to be, in general, comparable to the initial values. Specularity values, measured at all three acceptance angles, remained above 90 percent.

The presence of light-absorbing impurities in the commercial PMMA samples was reduced, but not completely eliminated during a purification using methylene chloride as a solvent and methanol as a precipitant for the polymer. Further experiments with different solvents are in progress.

A highly specular PMMA-coated silver mirror (97 percent at 7 mrad) has been prepared at SERI for measurement of specularity at smaller acceptance angles by R. B. Pettit's group at Sandia.

The results of a literature survey concerning soiling/cleaning problems of polymer surfaces were summarized in a draft report. The work to be accomplished in this work element is being defined.

ECP 300-Type Materials

The ECP 300X samples that have been in test outdoors at SERI for over one year have begun to show blister formation that visually is similar to the failure mode that was reported for the QUV tests after less than eight weeks. There has been verbal corroboration of blister formation in approximately the same time frame outdoors from J. Hull (Acurex), T. Mancini (Sandia), and B. Benson (3M). Blister formation causes severe loss of specular reflectance and makes the performance (statistics) of mirrors quite variable from point to point over the surface. After 57 weeks outdoors, the

average values and standard deviations as measured with the SERI instrument are: specular reflectance at 7.5 mrad 1/2-angle (94.0, 1.3); at 3.5 mrad (85.6, 4.3). The respective maximum values are: 7.5 mrad, 94.7; 3.5 mrad, 90.4. The large standard deviation at 3.5 mrad is probably due to incipient blister formation. At 3.5 mrad, the earlier calibrations indicate that the SERI instrument reads about 2 points lower than the average of three D&S instruments; so, the above values are probably very conservative. In contrast to the decrease in specular reflectance, after 57 weeks of outdoor exposure, the hemispherical reflectances of the ECP 300X samples are hardly changed (average 92.8).

The early warning of blister formation in the QUV test alerted researchers to the potential need for improved durability, and this is now confirmed by the outdoor tests. Several sets of altered ECP 300 materials have been prepared at 3M and are in test at SERI as well as elsewhere. The most recent test set is ECP 300 (lot 8).

Ten samples of ECP 300 (lot 8) laminated to smooth aluminum were evaluated optically and were placed into tests (3 outdoors, 3 QUV, 3 Weather-Ometer, on witness). Optical evaluation was performed at 3M, and independently, at SERI. The average values and standard deviations as obtained for the 10 mirrors (5 measurements for each mirror) at 3M and SERI for 12.5, 7.5, 4.2, and 3.5 mrad (1/2-angle) are presented in Table 1.

Similarly, data for ten samples of ECP 300 (lot 8) laminated to aluminum that was first coil-coated with white polyester paint are also presented in Table 1.

Table 1. Specular Reflectance Mrad, 1/2-Angle ECP 300 Lot 8

	12.5		7.5		4.2		3.5	
	$\bar{x}$*	s*	$\bar{x}$	s	x	s	$\bar{x}$	s
ECP Lot 8 Aluminum Substrates								
SERI	97.5	0.2	97.4	0.2			90.6	2.1
3M	97.3	0.6	97.3	0.2	94.2	0.8		
ECP Lot 8 Coated Aluminum Substrates								
SERI	97.6	0.3	97.4	0.3			89.4	2.7
3M	97.2	0.2	97.0	0.2	93.3	0.6		

*$\bar{x}$ = average reflectance, s = standard deviation, for ten mirrors and five measurements per mirror.

Stabilizers

Stabilizers that protect the polymers (either as substrates or as protective coatings) from effects of solar ultraviolet radiation are critical elements in the successful use of silvered/polymer mirrors. Many stabilizers are lost either by evaporation from the polymer or by leaching from it by surface water (dew or rain). The research here aims at

developing stabilizers that are firmly attached to the polymer or that are trapped in its structure in order to be permanent parts of the glazing or coating. One class of stabilizers known as hindered amines (HA) is under consideration.

A new hindered amine monomer has been synthesized and successfully purified by recrystallization with a 40.2 percent yield. The monomer has been copolymerized with methylmethacrylate (MMA). The copolymer is presently in the purification stage.

To determine the composition of the synthesized copolymers of an ortho-hydroxygenzophenone monomer with methylmethacrylate, a calibration curve was established by using light absorption data from the benzaphenone homopolymer. It has been observed that the extinction coefficients, calculated from monomer data, exceed the ones calculated from the homopolymer data due to reasons presently unknown.

As a preliminary study to assess feasibility of determining stabilizer leaching rates of exposed stabilizer/polymer blends and copolymers by using FTIR reflection-absorption (FTIR-RA) spectroscopy, the IR absorption spectra of several stabilizers and a stabilizer/MMA copolymer were obtained. Feasibility of this technique had been demonstrated previously for Uvinul-400 and Tinuvin-P stabilizers blended at 1 to 3 percent (wt.) in PMMA because these stabilizers have sharp, characteristic IR absorption maxima at frequencies well isolated from the PMMA absorption features at 3000-2800, 1731, 1500-1400, 1300-1100, and 990 cm^{-1}. The object of the present work is to determine if other stabilizers considered for use with PMMA have similarly isolated characteristic absorption maxima. The absorption spectra of the candidate stabilizers, dispersed in potassium bromide pellets, were measured by using the Nicolet 7199B FTIR spectrometer at SERI. Results of the preliminary study are presented in Table 2.

All of the stabilizers should be detectable in PMMA by using FTIR-RA spectroscopy. However, based on previous experience, the technique will be most sensitive for detection of stabilizers such as Goodrite UV 3125, Chimasorb 944, and benzaphenone (MS 1-11-5), which have medium or strong absorption in the region of 1700 to 1500 cm^{-1}. Absorbed water in the exposed samples may also produce interfering absorption at 3500 to 3300 cm^{-1} and at 1620 cm^{-1}. These results show that the FTIR-RA technique provides quick and accurate assessment of the presence or loss of stabilizers.

Professor L. Lambing completed his summer term at SERI; his activities, related to stabilizing polymeric glazings for collectors, are also relevant to mirror glazings. He synthesized copolymers of PMMA and PAN, and also copolymerized analogues of Irganox 1010 and Irgastab 2002 with PMMA/PAN. These polymeric stabilizers are just the type of stabilizers that workers at the University of Denver (DU) find are most effective in PAN. These materials will allow DU to compare polymeric to nonpolymeric stabilizers in their PAN/silver mirrors. Professor Lambing had time during his short stay to accomplish some characterization of these materials, but more work should be done. The results are sufficiently encouraging that the materials have been given to the University of Denver to incorporate into PAN/silver studies.

Table 2. Characteristic Infrared Absorption Maxima Useful for Distinguishing the Corresponding Stabilizer in a PMMA Matrix

Stabilizer	Frequency and Relative Strength of Absorption Maxima, cm^{-1}
Tinuvin 292	1365 (m)
Irganox 1010	3560 (m), 760 (m)
Irgastab 2002	1632 (w), 1050 (s)
Goodrite UV 3125	3600 (m), 1690 (s), 770 (m)
Chimasorb 944	1569 (s), 1534(s), 809 (w)
Spinuvex A36	1633 (2), 1365 (m), 703 (m)
MS 1-11-5 (BP/MMA Copolymer)	1633 (m), 732 (w)

s = strong, m = medium, w = weak

Other Reflector Materials Research

Several approaches have been initiated in this subtask, which seeks to produce silver reflectors having metals as their substrates rather than polymers or glass. These approaches all focus on ways of achieving an optically flat primary surface on which to deposit a silver film.

In addition to seeking ways to produce an optically smooth metal surface, research is also underway in the various ways in which a surface can be coated with a polymeric or glass material to achieve optical smoothness. In this approach, research is continuing under the subcontract with Acurex Corporation to develop ways of achieving optical smoothness through the application of thin films of borophosphorasilicate glass as a leveling agent.

Several LASER mirrors were obtained and evaluated. These excellent, ground and polished mirrors define what is possible with stainless steel and provide a basis for comparison with other types of metal finishes. In Table 3, mirrors 1 to 3 are uncoated stainless steel mirrors and 4 to 7 are stainless steel that is silver-coated and then overcoated with a protective film. The small decrease in reflectance, as the aperture is reduced to 7.0 mrad, is indicative of very specular surfaces.

For comparison, Table 3 also includes measurements made by Acurex by using their D&S instrument for three types of finishes on ferritic stainless steels. The absolute size of the numbers is less important than their trend, which indicates less than maximal specularity. Whether they are adequate will be determined after silvering. It is curious that polishing and buffing improves the absolute size of reflectance while not improving the rate of decrease as the aperture is closed.

Table 3. Specularity of Commercial Metal Laser Mirrors and Polished Ferritic Steels

Sample No.	MRAD			
	25	15	8.4	7.0
1*		65.8	65.6	65.6
2 uncoated stainless steel		65.9	65.6	65.6
3		65.7	65.4	65.3
4		97.5	97.3	97.2
5 silvered stainless steel		97.6	97.3	97.2
6 with protective coating		97.6	97.4	97.3
7 (probably silica)		97.5	97.3	97.1
Acurex**(Polished Ferritic Steels)				
Bright-annealed	43.1	41.9	40.0	
Buffed-in-line	46.3	45.2	44.3	
Polished and Buffed	54.2	52.2	50.0	
Electro Polished	Not considered cost effective			

*Each value is the average of five measurements made with the D&S instrument that is rented from D&S.
**Measured by Acurex with their D&S instrument.

Absorbers

A cermet absorber coating, which was produced by Telic Company under a SERI subcontract, was tested for short-term thermal stability. The test consisted of heat-soaking the coated steel tube in air and measurement of the solar-weighted (A.M. 1) absorbance and the total emittance at room temperature. While absolute measurements on a round specimen are difficult to make, the data show no appreciable change in absorptance or emittance due to the heat-soak tests. The absorber coating consists of a sputtered layer of alumina on a stainless steel (type unidentified) with finely divided platinum concentrated in the mid-plane of the layer. The heat soak of 750°C/10 hour produced fine chipping of the surface as might result from thermal-stress-induced spalling. The apparent stability of the optical properties of the material suggests that an effort to improve its thermal shock resistance is well justified.

Subcontract Activities

Researchers at the Southern Research Institute are encouraged by recent data which show the potential of amphiphilic films to protect first surface mirrors. The researchers are proceeding in an orderly fashion with identification, preparation and evaluation of coatings. However, one of the first samples was inadvertently stored about a month in a biological sample area subject to high concentrations of sulfur and high relative humidity. Visually, fully coated areas survived with no discernable change, whereas uncoated areas were badly tarnished. Data taken on various areas of the sample using

energy dispersive X-ray analysis are (concentration expressed as counts-arbitrary):

CONDITION	SILICON	SILVER	SULPHUR
Unprotected	314 counts	1718	123
Thinly coated	190	1700	63
Full coating	236	1769	not detectable

The data indicate that a full coating (about 10 monolayers thick) is quite impermeable to airborne corrosive agents, such as sulfur. More detailed testing of various coatings is being conducted.

Studies of the effects of high solar flux on 304 stainless steel are being performed by the University of Houston by using a solar simulator at 1.7 MW/m^2. Exposure at 400°C for one hour in this flux produced four times the thickness of oxide that was produced by equivalent heating in an oven. More significantly, the radiation-produced oxide was mostly Fe_2O_3, whereas the oven-produced oxide was Cr_2O_3. This result strongly suggests photoenhanced diffusion of iron through the Cr_2O_3 barrier normally found on the 304 SS. The evidence for such a process suggests at least one mechanism of materials degradation in solar flux that would not be shown by oven tests.

Materials for high-temperature solar application continue to be studied by Georgia Tech under a subcontract. Cyclic heating and thermal shock effects were to be measured by an apparatus built as part of the task. Further analysis of the potential apparatus has led to redirecting the effort toward measuring the cyclic effects by using the existing GTSF test set-up. Results of those tests will provide a more sound basis for planning the more detailed tests and designing the facility for those tests.

High-temperature ceramic materials are also under study in the Georgia Tech subcontract. These tests focused initially on selecting commercial materials and on designing tests and selecting test parameters for the evaluation of those materials. Subsequent studies showed that failure mechanisms of the materials were affected by impurities and suggested that some photoeffects were involved in the degradations observed. The possibility that impurities affect the temperature produced in the ceramics by solar radiation was shown by studies of titania-doped, high purity alumina-silica ceramic. The doped specimens operated at consistently higher temperatures in a given flux level than did their undoped counterparts.

An FTIR (Fourier Transform Infra Red) spectrometer has been obtained and is in final stages of installation. This device will allow direct observation of changes in the chemistry of surfaces of receiver materials under solar flux. It will be particularly valuable for observing changes in optical properties that indicate changes in the oxidation states of absorber materials under solar flux.

PROGRAM ELEMENT 2.0 CONCENTRATOR RESEARCH

Concentrator research at SERI in fiscal year 1985 is investigating ways of reducing current support structure requirements. Research on concentrators utilizing silvered polymers aims at development of potentially lightweight, low-cost, durable concentrators with high performance; in particular, the stretched metallic and polymeric membrane heliostat and dish concepts are considered. Demonstration of the technical feasibility of lightweight stretched membrane concepts through experimentally verified analyses of subscale test modules is to be accomplished. Greater durability (at least five years) with retention of optical quality in solar reflector use is to be evaluated and verified by environmental testing. Configurations for the various concepts are to be defined, and cost comparisons are to be carried out.

During fiscal year 1984, concentrator research focused on the study of the stretched membrane concentrator. Structural analysis, fabrication of a number of experimental prototypes, and measurements of their structural behavior advanced to the point that the technical feasibility of the membrane concept has been established, and the static structural/optical response of the membrane is predictable with sufficient accuracy. Also during this period, wind-load reduction and abatement studies were initiated at Colorado State University.

During fiscal year 1985, the research aimed at understanding and reducing wind loads on collector fields, including heliostats, dishes and troughs, will continue. The possibility of using composite materials for reflector surface backing as well as for structural members is to be studied. Structural and optical testing of the three-meter modules will take place. The definition of the structural response of membranes to static and dynamic loading and the preferred membrane attachment configurations are to be studied. A separate effort is to define the structural requirements for stretched membrane concentrators to be used for higher receiver temperature systems. Effort is to be initiated to define the performance of polymers as possible structural membranes. Finally, a research effort will aim at studying alternative mechanisms and strategies for focusing concentrators. The performance and the cost characteristics of selected Fresnel lens concentrators will be assessed.

PROGRESS

High-Flux Concentration Analysis

A number of design possibilities were analyzed for the two-stage system consisting of flat, tracking heliostat, long focal length primary and CPC secondary concentrators. These studies included the effects of off-axis designs at rim angles of both 10^{o} and 15^{o}. It appears that the cases with ten-degree angles have several advantages over the cases of fifteen-degree angles. The primary purpose of the off-axis design is to remove the focal point/experiment area from the heliostat-primary beam (to reduce blockage), and the ten-degree case allows for smaller off-axis angles and, hence, reduced aberrational effects. At this rim angle, the average, uniform flux into a five-centimeter-diameter target approaches 19,000 suns. In both the off-axis cases, the primary concentrator aperture can be oriented perpendicular to the heliostat-primary axis, perpendicular to the focal point-primary axis, or somewhere between. The optimum performance is obtained with an orientation about half-way between the axis. This orientation minimizes the blocking and shading of the primary mirror segments on one another. Another advantage of the ten-degree case is that it approaches the theoretical maximum somewhat closer than the fifteen-degree case.

Another trade-off study was directed at the effects of heliostat optical errors on system performance. This study showed that a significant improvement in system performance could be realized with reductions of errors in the heliostat surface slope. The next step in this particular study is to determine the additional costs involved in achieving those reductions, which represent errors below that typically achieved in state-of-the-art heliostats.

Detailed data on flux concentration for four cases have been generated for use by the University of Chicago in their secondary concentrator study. The four are the on-axis cases at ten-degree and fifteen-degree rim angles (used as a baseline for comparison) and the optimum off-axis cases for the same two rim angles. The University of Chicago is currently debugging their analytical tools for this study.

Stretched Membrane Module Testing and Analysis

Staff completed an initial draft paper (intended for publication) which studies the large axisymmetric deformation of stretched membranes resulting from focusing as well as the implication on the optical quality of the deformed surface. They developed a simple closed solution for the deformation based on the variational principle and compared predictions from this method with predictions from NASTRAN and a simple numerical integration. This closed form is useful for control purposes as well as for estimates of size and design. The primary conclusions from this study (consistent with the loading and material assumptions) include: (1) for typical, stretched membrane heliostats now under development, focusing should not cause the surface to differ significantly from the desired parabolic shape; (2) the load/deformation relationship is quite nonlinear (for typical designs) which is easily predicted and is presented in a simple form by using the variational principle; (3) the degree of nonlinearity increases with increased load, membrane diameter, membrane thickness and material modulus, but decreases with tension; (4) for the low tension designs, the short focal lengths do impact the membrane tension level significantly.

SERI researchers applied the large axisymmetric deformation analysis, which they developed for studies of heliostat focusing, to a model of the LaJet dish at LaJet's request. These analyses, which have been supplied to LaJet, included predicted distributions of focal length as a function of position on the membrane for several membrane designs and initial membrane tension levels. Based on telephone discussions with the LaJet personnel, the model appears to predict, at least qualitatively, the observed variations in focal length. SERI also provided a copy of the numerical model, useable on a PC computer to assist in the further sensitivity analysis.

Data from the first two-thirds of the testing of the dual-membrane module has undergone the first stage of processing. Surface-equation-fitting is the next step before obtaining plots of the rim and surface displacement for each of the test conditions. The no-load condition was observed many times during the test sequence; thus, it will be possible to detect any plastic deformation of the structure that may have occurred. Initial observations indicate that no such plastic deformations have occurred in the test so far.

A project status report was received from Colorado State University on the study of wind-induced membrane vibrations which may occur in the stretched-membrane heliostat. Staff personnel have studied the similarity and scaling requirements which will pertain to the upcoming wind-tunnel test of a two-foot diameter model. SERI determined that none of the film or sheets which are on hand are suitable for the model and have ordered some much lighter materials in polyester and in aluminum foil which

may prove adequate. In order to model survival winds over 100 mph, it appears that researchers must build a two-foot-model with a membrane tension at or below one-half pound per inch. Researchers are not confident that they can guarantee uniformity in tension with a tension level that low. They continue assembling the system for observing the movement of the membrane during the wind-tunnel test. The hardware will be used to perform virtual-image surface figure measurements via high speed motion pictures on the two-foot-diameter models which staff will be building. The 35 mm motion picture camera has been further checked out, and arrangements for digitizing and analyzing the recorded virtual image data are being made. Each frame will be digitized by using slightly modified SERI software which was previously developed to analyze the static test data. This software will compute the surface slopes and, thus, the optical quality of the module as a function of time.

The draft report from Colorado State University on wind loading was delivered to SERI. The report included extensive modifications and additions requested as a result of an earlier draft.

New Concentrator Concepts

Work was completed on the kinematic and structural model for an inverted-tripod inflatable heliostat drive/support. The model is written in FORTRAN and runs on an IBM-PC. Required inputs are: mirror radius, cable lengths, support location, mirror weight, inflation pressure. Given the tension in two of the supporting cables, the program calculates the tension in the remaining five cables and determines the resulting direction of the mirror surface normal. This model can be used to explore the performance characteristics of the inverted tripod and to determine the extent to which loading conditions impact mirror pointing accuracy. The model will also allow determining suitable inflation pressure, anchor placement, and inflation-sleeve design.

The first deliverable, evaluating the Fresnel lens concentrator, was received from Industrial Solar Technology (IST). The objective is to attain a fair but thorough comparison of linear Fresnel lens technology with parabolic trough technology. IST personnel recommended several system operating configurations for further study based on their investigation into establishing compatibility requirements for modeling linear Fresnel lens concentrators and systems with SOLIPH. The recommendations have been reviewed by SERI staff and will also be sent to Entech for comment. Entech is under contract to SERI to provide the necessary modeling parameters and performance information for evaluating their linear Fresnel lens technology.

A literature search has been completed and summarizes previous work done on solar thermal applications of Fresnel lens technology. Most of the references are results of research done to improve and optimize the optical performance of Fresnel lenses. A few references evaluate characteristics of Fresnel lens collectors, but no direct comparison to line focus troughs occurs. No system studies have been done recently enough to account for the possible advantages and capabilities of new optimized Fresnel lens designs. An initial draft of several major sections of the Fresnel study have been completed. Only the section on systems performance and the summary await material from Entech.

Staff met and agreed with IST (contractor) on the construction details of the three bench-scale cone collector models which the company is to build. These models will be used to study structural and fabrication issues pertaining to attachment, support, and centering control of SERI's proposed ninety-degree and forty-five-degree line-focusing conical concentrators. The ninety-degree cone will require a rim hoop of yet undetermined properties and will probably incorporate radial spokes to maintain

concentricity of the reflector and receiver. The ninety-degree concept is preferred due to its mechanical simplicity, although the forty-five-degree concept may result in some higher concentration. The SOLIPH model of the conical concentrator is nearing completion. Debugging and testing remain to be completed prior to its use for evaluation of the conical concept.

Research on Holograms

Researchers at Acurex have processed a large number of holograms which reflect in the infrared, and their profiles of efficiency and wavelength have been measured in the automatic monochromator. They then have been stacked with holograms previously processed to reflect in the visible part of the solar spectrum, and the profile of the stacks have been measured. Significant results have been achieved--notably, thirty-seven percent efficiency achieved by stacking two holograms can be considerably improved by optimizing the hologram processed to reflect the visible part of the solar spectrum. If three or more holograms were to be stacked, the improvement in efficiency can be even greater. These results are very encouraging. Acurex is also performing a preliminary cost analysis to define the economic incentive for holographic concentrators.

PROGRAM ELEMENT 3.0 RECEIVER RESEARCH

Receiver research at SERI in fiscal year 1985 primarily is directed at defining durable configurations for metal and ceramic tube receivers as well as direct absorption concepts. Analytical and experimental studies are being used to define the performance drivers corresponding to various receiver concepts and approaches to enhance their performance. Materials research which is of primary importance is directed at developing high performance and long-life absorber surfaces and containment tubes. Metal or ceramic tubes for receivers are to face higher temperatures and more aggressive fluids such as molten salts or liquid sodium. Metal tubes for external receivers to about 600°C are now identified as research targets, but there is a need for diagnostic instruments to measure these and advanced receiver surface temperatures in operation. Studies on cavity configuration and phenomenology have broad application to dish and central receivers and correspond to fluid in tube and direct absorption concepts for a wide range of temperature applications up to 900°C. These investigations include detailed descriptions of loss mechanisms and techniques to reduce these losses, research leading to the development of secondary concentrators, and instrumentation to measure the thermal transport and structural performance parameters in situ during operation.

It is expected that the test loop for conducting the ACTF tests of the direct absorption concept will be constructed and checked out, and some early experiments will have been completed during fiscal year 1985. Also during fiscal year 1985, preliminary experimental data and analysis of sufficient quality are to be available for an initial evaluation of the direct absorption receiver concept. Historical data on failures of cavity tubes are to be collected. Analysis leading to modeling is to begin. Also, it is expected that quantitative correlations of the degradation of absorber coating as a function of impinging solar flux will be completed. It is expected that needs for diagnostic instrumentation will have been specified. An assessment of current errors in estimating convective losses from cavity receivers, including recommendations and a preliminary evaluation of the benefits of secondary concentrators, is also to be completed.

PROGRESS

Direct Absorption Concept Research - Solar Flux Tests

Subsequent to completion of the fabrication of the 900°C test loop by Industrial Welding and Supply (IW&S) of Sterling, Colorado, and successful acceptance tests there, the test skid was readied for transportation to Georgia Tech Research Institute (GTRI). It left Sterling, Colorado, on the morning of August 7, 1985, and arrived at GTRI on August 10, 1985. The test skid was unloaded and placed in a building prepared for the purpose of conducting ground-level testing.

The test loop survived the long trip with very minor problems, and those were corrected by IW&S at GTRI. Acceptance tests, consisting of testing each of the test loops systems, including pump and valves, electrical, air, and pipe suspension systems, were conducted. The only problems during acceptance testing were failure of one redundant heat trace element. These tests were conducted with SERI personnel present and were successful. At the same time, ACTF personnel connected the test loop instrumentation to the ACTF control room, and calibration of all channels ensued.

The cooling coil embedded in one of the two tanks in the loop was successfully tested. The function of the cooling coil is to remove from the salt the heat absorbed from the solar flux. It is essentially a "dummy load." Cooling is accomplished by circulating compressed air through the coils. A cooling capacity of 41 KW was attained--dropping

salt temperature in the tank from 604°C to 542°C. A variable pump speed control was added to the loop. This control enables the flow rate to vary continuously over a wide range of flow rates. Acceptance tests were completed on September 10, 1985. IW&S has been congratulated on the successful completion of the project and on the professional manner in which they handled the project.

Salt at 600°C has been circulated through the absorber assembly a number of times by using both the variable speed pump, and the pneumatic system. The flow rate can be controlled by either the pump RPM or valves, or both--thus providing good redundancy. The Kaman flow-rate meter has apparently been damaged, and a replacement is being sought. Redundant means of flow-rate measurement have been established by using the bubbler system in Tank 2, and by calibrating flow rates with pump rpm and separately with film height above the entrance weir.

Operation of the inlet and outlet manifolds were checked out, and these seemed to work well. Some modifications to the absorber were required to prevent salt from climbing over, flowing down the edges, and spilling out the bottom. These modifications involved adding to the absorber shoulder height by welding Inconel strips. The tendency of the salt to creep over the shoulders was greatly reduced by sharpening the edges of these strips because it is very difficult for the salt, even with its very high surface tension, to climb over a sharp edge. At this point it appears that researchers can achieve the maximum flow, 10 GPM, with no salt spillage. A video film was taken of the flow patterns and is available for review.

Early failure of one side of the Kaman pressure transducer required that researchers switch to the back-up plan for salt flow measurement. The failure was probably related to inadequate salt drainage from the transducer before cool down. Subsequent salt freezing probably destroyed the 0.003-inch foil diaphragm in the transducer. Since these transducers seem so fragile, staff decided to go to the weir method rather than trying to replace the Kamans. To implement this method, the team first operated the salt pump at various speeds and measured the depth of the salt at the top of the weir where the salt begins to flow downward onto the absorber panel. Then they pumped salt from Tank 2 by using the bubbler for an absolute measurement of flow, and they again measured the weir depth. The weir depth allows researchers ultimately to correlate the pump speed with the flow measured by the bubbler. They repeated this process for three temperatures, 500°C, 600°C, and 700°C, since the pump performance depends upon salt viscosity, and the viscosity, in turn, is a strong function of the temperature. These three temperatures give a range of about 3 to 1 on salt viscosity. The range of flows tested was from 1.5 gpm to 9.4 gpm. Repeatability of the pump-weir data was excellent. The bubbler-weir data follow closely available correlations for weir flow if one uses a discharge coefficient of 1.0, which is consistent with the weir being used. Now the computer can monitor the pump speed and salt inlet temperature and calculate (from a correlation equation to be generated from the data) salt-flow rate. Researchers now conclude that they have a very accurate and reliable method of measuring the salt flow rate.

Testing of the 900°C direct absorption receiver test loop at the ground level at the ACTF site of GTRI was successfully completed on schedule, on Friday, September 20, 1985.

Receiver Materials - Properties

Optical characterization of a sample of slip cast silica/alumina insulation material has been completed. This material is used by GTRI inside the flux redirector, designed to

reflect the up-pointing ACTF beam onto the direct absorption test section. Spectral, hemispherical reflectance measurements were made between room temperature and 900°C by using SERI's integrating sphere spectrometer. The solar-weighted absorptance was computed for an air mass 1.5 spectrum. Little variation in solar absorptance over the temperature range of 20°C to 900°C was found. The measured emittances are in general agreement with data reported for Mullite (alumina silicate) by Touloukian and DeWitt (Thermal Radiative Properties of Nonmetallic Solids, Vol. 8). Absorptance between .054 and .059 and emittance between .44 and .48 was measured over the entire temperature range.

Optical measurements of Inconel 600 samples, taken from the spillway of the absorber test section and thus exposed to the history of flowing molten carbonate salt, have also been made. These samples experienced molten salt heated to 900°C by the prototype test loop. The measured solar-weighted, hemispherical reflectance was approximately 0.06 to 0.09 for two specimens. Little spectral variation was found as a function of either temperature or wavelength. These results are in good agreement with previously reported data measured at SERI for similar, carbonate salt-Inconel 600, laboratory-prepared samples.

Receiver Research - System Studies

Studies with the aim of analyzing the coupling and combined performance of the heliostat field and the receiver are in progress.

In support of the evaluation effort for assessing the benefits of terminal concentrators at the entrance aperture of a receiver, a ray-tracing computer program has been written and tested with normal rays from the flux plane by using the simple test case. It was then tested by using one ray with finite values in all its direction cosines. The intercept points and reflected directions were printed and checked with hand calculations. It was determined that the computer program was working correctly. That program is now ready for use. Another program has been written and takes the zone-by-zone flux map output of DELSOL2 and processes it for input into the ray-tracing code. Checkout has been initiated, and results appear to be valid.

A tape and documentation of the central receiver analysis code HELIOS has been received from Sandia, Albuquerque. Effort is focused on bringing the code up on SERI's system and on benchmarking the example problem. This code will be evaluated against MIRVAL as a detailed performance model. Whichever code is selected will play an important role in several of SERI's future tasks, including the studies of terminal concentrators and an analysis of the feasibility of using central receivers in smaller plant sizes.

Receiver Research - Convection Losses

Writing of the review report on convective losses continued. Comparisons of the currently available predictive correlations for external cylindrical receivers show that the predicted heat loss values differ by about 50 percent by using different correlations. Since typical convective losses may represent about 4 percent to 7 percent of the total absorbed energy at the design point (these numbers are higher for higher temperatures), this represents an uncertainty of 2 percent to 3 percent in the prediction of the design-point energy production. The percentages will, of course, be much higher at off-design conditions.

B. FIELD TASK AGREEMENT 511A CONVERSION, INNOVATIVE SYSTEMS, AND APPLICATIONS

This research encompasses direct conversion from concentrated solar radiation to electricity or chemicals, transport and storage of thermal energy, and generation and assessment of innovative concepts.

PROGRAM ELEMENT 4.0 THERMOCHEMICAL AND PHOTOCHEMICAL RESEARCH

Research on process definition at SERI in fiscal year 1985 is to identify usable adsorption phenomena and processes. The research includes high-flux and high-temperature chemical bond interactions. Reaction research seeks to evaluate side reactions and other major reactions affected by high temperatures, and addresses the unique effects of a large radiant flux on such reactions. The aim of this research is to identify potentially useful conversion reactions and to quantify the effects of high flux and temperature on desired reactions. Research is also to be performed on hybrid processes to use combined solar energy and other fuel sources.

PROGRESS

Solar Photochemical Production of Fuels and Chemicals at the University of New Hampshire

Experimental work on the photonitrosation of cyclohexane by using the new photoreactor assembly was continued. In an effort to achieve higher quantum yields, some parameters such as HCl and NOCl rate, coolant rate and stirrer speed were varied judiciously. The highest yield obtained thus far was 0.57, which is about the same as reported in the literature.

Furthermore, the technique for separation and verification of the product has been improved. The product in the reactor is being dissolved in methylene chloride, and the solution then is transferred to a Buchii-Brinkmann rotovap. Evaporation of the solvent under vacuum takes place quite easily. The product is then weighed, and the quantum yield is calculated.

Improved quantum yields have spurred researchers to explore a suitable design for a solar receiver-concentration system. One such scheme is to direct sunlight, after collimation by a mirror-lens arrangement, on a holographic beam splitter. This focuses the desired rays (350 to 550 nm) to a point where they can be received by a bundle of optical fibres. These fibres then transmit the light onto a chemical reactor.

Researchers have begun to examine potential pathways for the use of solar-assisted photochemical reactions to produce high value chemicals. One possible application is the use of the photoaldol reaction to produce ephedrine. This is used to counteract hypotension associated with anesthesia and as an adrenergic (bronchodilator). The proposed solar photo-assisted pathway represents a potential elimination of two steps involving catalytic oxidation and reduction. Estimated cost of starting materials for the photoaldol reaction is also reduced. The proposed pathway is being evaluated.

Solar Detoxification of Hazardous Wastes at the University of Dayton

The University of Dayton researchers have solved the analytical problem which has impeded progress during the past two months. All thermal decomposition control experiments are now complete, and additional experiments are starting to determine the beneficial effect of directing concentrated sunlight into the thermal decomposition reactor. Control experiments were completed with benzo (e) pyrene (BeP), detrachlorabiphenyl (PCB) and tetrachloro-p-dioxin (TCDD). These compounds are quite stable thermally, with exposure at over 800°C required to destroy 99.99 percent of the PCB and BeP and over 900°C for the TCDD. The experiments on the photolytic enhancement effect should be completed during the month of October. Those experiments are critical to confirming the potential of the enhancement by concentrated sunlight.

Photo-Assisted Reactions at the University of Hawaii

Researchers at the University of Hawaii report positive results on the temperature calibration of the fast thermogravimetric analyzer (TGA) system. Based on the most recent results, the ambiguities regarding sample temperature measurements now seem to have been resolved. In addition, both the accuracy and the precision of this unique instrument appear excellent. The measurements were made with five Curie point reference standards from the National Bureau of Standards. The melting points of the standards ranged from 242°C to 771°C. Typical standard deviations were in the range of 4.8°C to 11.0°C, with the mean temperature always in the expected range. Typical heating rates were ~ 3500°C/minute. Researchers were also pleased with the response of microminiature thermocouples which display response times in the order of several milliseconds.

Researchers are beginning the next series of zinc sulfate decomposition runs, specifically investigating the effect of the reaction container material on the reaction rate. A platinum container appears to have a catalytic effect on the decomposition, whereas both fused silica and alumina containers show no catalytic influence. This research project is at the point of collecting the definitive data required to determine the extent and the mechanism of heating rate control of reaction pathways.

TECH Convertor at Hughes Aircraft Company

Experimental effort at Hughes has focused on the acquisition of materials and construction of the thermal testing apparatus. This apparatus will measure total and partial pressures of ammonia and water vapor over various mixtures of phosphoric acid and ammonium phosphate under equilibrium and kinetic conditions. Vapor compositions for equilibrium conditions will be monitored by weighing a gas sample followed by measuring the conductivity of a boric acid solution into which the gas sample has been dissolved. The conductivity of the sample will be proportional to the concentration of ammonium borate formed in the solution; water content will be found by subtraction. A calibration curve, relating conductivity to ammonium borate concentration, has been established. Kinetic measurements will be made by inserting a flowmeter into the sample line. The evolved gasses will be condensed into boric acid, and the conductivity will be monitored with time.

Hughes researchers have performed a preliminary cost analysis to estimate the cost of an

installed TECH system at \$484/KW_e (25 KW_e size), \$266/KWe (1 MW_e size) and \$201/KW_e (10 MW_e size). It must be emphasized that these estimates are preliminary and are based on the current state of the art with measurable projections for research advances. They are well done and are based on reasonable assumptions and on scientific and engineering facts. Nevertheless, they must be considered as indicative, rather than absolute. The potential of the TECH concept is obvious when these figures are combined with system efficiency estimates which approach 40 percent solar thermal heat to electricity.

Photocatalysis, Photo-Assisted Bond Breaking and Chemical Energy Storage at the University of Houston

Researchers configured the ammonium hydrogen sulfate (AHS) decomposition to occur in direct contact with a hot, compatible molten salt (CMS). This configuration greatly increased efficiency. Experimental effort is stressing the identification of the CMS. The most important property is the desired temperature range over which the CMS is liquid (550° to $900^{\circ}K$). In addition, the CMS must support, but not interfere with, the AHS decomposition reaction. The CMS must not be too corrosive and must be inexpensive. Researchers have developed an ion chromatographic technique for rapid identification of the eutectic compositions of various salt mixture. To date, significant advance has been made in identifying the CMS, with efforts continuing to investigate cations other than Li, Na, K and Zn.

To aid the experimental investigation, the researchers have developed a statistical thermodynamic model of molten salts. The model is being reduced to a computer algorithm for rapid determination of the effects of various components on the CMS properties.

The compounds studied thus far in the solar-assisted reaction research have been small organic molecules (CH_3OH, CH_3CH_2OH, $CH_3CHOHOH_3$, and CH_3COCH_3) with the principle purpose of understanding this new reaction input consisting of both thermal and radiation energy. Most of the work has been with CH_3OH which gives a variety of possible reactions, depending upon the catalyst and reaction conditions. Acetone decomposition is complicated by the fact that apparently carbon deposits on the catalyst alter the reaction. Generally, however, the reaction proceeds rapidly in the presence of radiation. More work is necessary to characterize the reactions with different catalysts.

Most of the recent quantitative work has been devoted to the decomposition of CH_3OH, which is highly dependent on the catalyst. The V_2O_3 catalyst produces large amounts of CH_4 and CO and very little CO_2 whereas Cr_2O_3 produces large amounts of H_2 and CO_2 and very little CH_4 and CO. This can be reasonably understood by assuming V_2O_3 causes the dehydration to CH_3OCH_3 and H_2O and the subsequent decomposition of CH_3OCH_3 into CO, H_2, and CH_4. On the other hand, Cr_2O_3 decomposes into CO and $2H_2$ and the subsequent reaction of CO with H_2O to give CO_2 ane H_2.

The effect of radiation is not apparent in regard to the yield of reaction. Its effect is, however, apparent in regard to the rate of reaction. Researchers carried out the reaction by adding the CH_3OH continuously into the reactor with a liquid pump rather than by injection of discrete samples with a syringe. The liquid pump available has a maximum rate of 3.2 cm per minute and is adjustable to smaller rates. However, the lower rates cannot be set accurately below 0.32 cm^3/min. For the reactor this flowrate is too large. Researchers would like flowrates on the order of 0.5 ul per second equal to

0.030 cm^3 per minute. In order to use the available pump, the setting was made roughly at about 0.3-1.0 ul/second. This flowrate remained constant, but could not be accurately measured. The reaction was run at 450°C with and without the lamp on. The rate observed for the production of H_2 with the 3.9 percent Cr_2O_3/Al_2O_3 catalyst increased by a factor of 3.5 when the lamp was turned on. The supplemental heater was reduced when the lamp was turned on to account for the heat absorbed from the radiation. This is a rather remarkable result when one considers that the radiation illuminates only about one-tenth of the surface of the bed. Presumably the increase would be more dramatic if the entire surface were illuminated. From these preliminary results researchers think that the effect of radiation on the reaction can best be evaluated by adding reactants continuously to the reactor. The effect of the ultraviolet portion of the spectrum will also be evaluated by using the continuous reaction by placing cut-off absorption filters in the light path.

The photoenhanced catalysis research is currently limited to fabrication of an experimental system suitable for generation of data to explain the previously observed effect. That experiment showed over 100 percent increase in yield for the methanation reaction as a result of high flux irradiation.

Non-Equilibrium Reactions Research

Research confirmed the theoretical feasibility of obtaining higher yields of desirable chemical species by use of concentrated solar flux to cause rapid heating and non-equilibrium chemical reactions. These processes were first described for air in a foreign paper. The first step of research at SERI consisted of duplicating the spotty results reported in that paper.

Secondly, a more realistic process sequence than the one described in the paper for obtaining NO (nitrous oxide) from air was developed, and the chemical and thermodynamic equations for these processes were developed. Solutions of the resultant differential equations yielded the result that rapid heating can, in fact, augment the equilibrium yield of NO by approximately 15 percent as compared to the maximum equilibrium concentration. However, this occurred at a very high temperature (approximately 5000°K) and required very high heating rates (10^9°K/second). SERI researchers are defining the quenching process, and are seeking the advice of experts to identify desirable reactions that can be performed by using the same phenomena at lower temperatures and heating rates.

PROGRAM ELEMENT 5.0 INNOVATIVE CONCEPTS AND APPLICATIONS

Researchers' systems and applications technology at SERI in fiscal year 1985 have emphasized generation and characterization of innovative concepts and applications. Innovative concepts and applications are guided by the need to make significant improvements in solar energy cost-effectiveness by providing a much more attractive application or a new concept. The approach is: (1) to identify the concept or application; (2) to do sufficient research to characterize the concept or application; (3) to perform a comparative analysis of alternatives; and (4) if attractive, to integrate any further research into the primary program.

It is planned that during fiscal year 1985 the definition and technical feasibility of various new concentrator concepts will have been completed, with identification of those that show promise for further development. Also, a preliminary assessment of the technical feasibility of the holographic concentrator is to be completed. SERI plans to complete the assessment of non-equilibrium, rapid reactions and to identify the most promising ones. A survey of current scientific developments with relevance to solar thermal systems is to be completed. As a result of planned workshops, new ideas with potential are to be pursued.

PROGRESS

Compound Secondary Concentrators Research at the University of Chicago

The University of Chicago researchers fabricated 10 terminal concentrators and initiated tests at the ACTF at Georgia Tech Research Institute. The CPC secondaries have an opening angle of 25°, a nineteen-inch entrance with an eight-and-a-half-inch exit aperture, corresponding to a concentration ratio of 5X. To fabricate these, first a template was made of brass from computer-generated coordinates. With this template, a stainless steel mandril was machined. Six copper and six aluminum CPC concentrators were spun on this mandril.

Six silvered copper, two polished aluminum and two silvered aluminum CPC concentrators were taken to the ACTF. Initially, the ACTF heliostats were configured to give a primary concentration ratio of 43, which (coupled with the secondary concentration ratio of 5) gives an overall concentration of 215. Preliminary experimental results indicate that the efficiency of the CPC is in the range of 90 percent to 95 percent, as anticipated. Tests will continue into early October.

Spectral Shifting at Hughes Aircraft Company

Researchers were able to obtain the emission spectrum in the visible and far IR by using a CO_2 laser to heat the sample. In the wavelength range of 0.4 to 0.9 micrometers, a Spec Spectrometer was used to measure the spectrum. A small sample, two millimeters square, was heated with a CO_2 laser. The output of the CO_2 laser was very unstable, and an absolute measurement of power could not be made. A relative measurement was possible by monitoring the laser beam indirectly. The CO_2 laser illuminated the small sample which was placed in a thermally insulated holder. The emissions from the sample were monitored by using a broad-band silicon detector to indicate the power level variations from the laser. This level was then compared to the emission spectra as recorded by the spectrometer to separate laser variations from spectral variations.

When the variations due to the laser were studied in the measured spectra, it was found that all samples of the different mixtures of the Welsbach material behaved like black bodies. This result means that the emissivity is high and constant throughout the range of 0.4 to 0.9 micrometers. This, combined with a low emissivity in the wavelength range above 2.0 micrometers, is the desired result.

To measure the long wavelength portion of the emission spectra, a Perkin-Elmer spectrophotometer was used in the range of 2.0 micrometers to 12.0 micrometers. The spectrophotometer is normally used to measure the transmission characteristics of a sample by measuring the difference of two beams. As an option, the machine has the provision for measuring the emission spectra of a heated sample. This mode only gives qualitative information. The spectrophotometer was used in the emission mode with both beams blocked and essentially the same experimental set-up for heating the sample as described above. Again, the laser was monitored and compared to the measured spectrum. For the Cr-Dy-Hf mixture, the results showed very little emission in the range of 2.0 micrometers to 5.0 micrometers, increased emissivity between 5.0 and 7.0 micrometers, and the increasing emissions peaking at 10.6 micrometers. These results are very encouraging. Remaining yet is measuring the emission spectra in the range of 0.9 micrometers to 2.0 micrometers to determine the characteristics of the transition from high emissivity to low emissivity.

Spectrally Selective Beam Splitters (SSBS) at the University of Arizona

Researchers at the University of Arizona think that they can define spectrally selective beam splitting which can be tailored to fit the needs of a specific application. Both liquid filters and interference filters are being evaluated to determine performance. The potential usefulness of the concept is also being defined.

PROGRAM ELEMENT 6.0 RESOURCE ASSESSMENT AND INSTRUMENTATION RESEARCH

The two objectives of this program element during Fiscal Year 1985 are: (1) to evaluate, to establish the uncertainty, and to improve the National Direct Beam Insolation Data Base and Monitoring Network; (2) to develop instrumentation to measure and to characterize the nature of terrestrial spectral ultraviolet (UV) solar radiation and suspected bursts of such radiation. The Instrumentation and Measurement Workshop in fiscal year 1984 established the improvement of the National Direct Beam Insolation Data Base and Monitoring Network as a number one priority for instrumentation and measurement in the Solar Thermal Program. This critical need is the direct result of two unrelated circumstances affecting the National Direct Beam Data Base. First, prior to 1975 almost no direct beam measurements had been made within the United States. For this reason, the direct beam data contained within the SOLMET and ERSATZ data bases and the Solar Radiation Energy Resource Atlas of the United States were generated in their entirety by computer models. Recent evaluations of these models have shown the potential for 10 percent to 30 percent errors. The second unfortunate circumstance, solar tracker and data recording failures, has seriously degraded the quantity and quality of direct beam data collected by the National Weather Service Solar Radiation Network since 1977. In cooperation with NOAA, SERI will assist in the evaluation of improved solar trackers.

There has been recent speculation that short bursts of ultraviolet energy at wavelengths less than 300 nm may initiate and/or accelerate the degradation of polymer materials. Since there are no known instruments capable of detecting and measuring bursts of ultraviolet energy in selected spectral bands, the development of such an instrument is being undertaken. The results of this research will directly impact the development of silver polymer reflectors under Program Element 1.0.

PROGRESS

Solar Tracker Evaluations

Solar tracker evaluations were initiated at the Solar Radiation Research Laboratory (SRRL), but tests have again been delayed at Bluefield State. Bluefield State has now completed preparation, but problems with weatherproofing the position sensor forced postponement of operation there. Given favorable results at SRRL during October, installation of equipment at Bluefield State is planned for the first week in November.

NOAA received six proposals for improved solar trackers in response to their requests. The Source Evaluation Board (E. L. Maxwell, SERI, is a member) rejected four of the proposals because of price and the other two because they did not meet specifications. The procurement was subsequently cancelled. Following revisions of the specifications and restructing of the procurement, a new request for purchase will be issued in October or November. An upgrading of the NOAA Solar Radiation Network will eventually take place.

Direct Beam Data Base Evaluations

Multivariate analyses were performed on a special data set obtained from the Georgia Institute of Technology. The variables in this data set included direct normal, global, and diffuse radiation components as well as percent sunshine, precipitable water, visibility,

turbidity, opaque cloud-cover, and total cloud-cover. The analyses of these data have shown that turbidity values can be extracted from diffuse radiation and visibility data. Furthermore, it has been shown that statistical analyses of radiation data can be used to identify clear sky conditions, without human examination of data. This will greatly simplify and improve quality control procedures and will lead to an increase in the quantity and quality of direct normal data in the national solal radiation data bases.

Diagnostic Instrumentation Research at GTRI

The "straw-man" optical design of the second-generation four-color pyrometer of Georgia Tech Research Institute was submitted to a consultant for an independent critical review. The design review, while not completed yet, has indicated that the optical design achieves the stated goals. To date, the review has consisted of running ray-trace analysis programs to confirm specifications for the field of view (spatial resolution) and the detector-size.

The ray-trace analysis considered both spherical and chromatic observations. This analysis suggests that first surface optics in the form of Cassegrain optics rather than refracting optics would result in higher signal-to-noise ratios at the detector. Furthermore, it was determined that an appropriately placed field stop would be better for defining the field-of-view than by using a small detector as the defining stop. Such "non-imaging" optics allows one to use a larger detector in a "light-bucket" mode with a measurable improvement in signal-to-noise. Vendors for the infrared optics and cyrostatically cooled detectors have been identified. Lead times of up to 12 weeks are required for the narrow-band infrared filters. Simulation studies of the "straw-man" design indicate that the designed low-temperature limit of $400^{o}K$ ($127^{o}C$) is achievable.

REPORT CONTRIBUTORS

A. Field Task Agreement 510A COLLECTION RESEARCH

1.0	Optical	G. Gross
2.0	Concentrator Research	M. Murphy
3.0	Receiver Research	M. Carasso

B. Field Task Agreement 511A CONVERSION, INNOVATIVE SYSTEMS AND APPLICATIONS

4.0	Thermochemical and Photochemical Research	G. Nix
5.0	Innovative Concepts and Applications	G. Nix
6.0	Resource Assessment and Instrumentation Research	E. Maxwell

SOLAR THERMAL RESEARCH PROGRAM SUBCONTRACTS

Subcontractor	WBS Number	Subcontract Title/Activity	Value (000$)	Type Business	Status	Technical Monitor
The 3M Company	1.0	Silver/polymer reflector material research	Cost Shared Subcontract of 199.5	Industrial Firm	Awarded	P. Schissel
Jet Propulsion Laboratory	1.0	Stabilization of polymer materials against UV degradation	50.0	Federal Laboratory	Awarded	P. Schissel
University of Denver	1.0	Stabilization of Silver/ Polymer reflector materials against UV degradation	40.0	University	Awarded	P. Schissel
Acurex	1.0	Low-cost, lightweight silver-coated front surface metal reflectors	35.0	Solar Thermal Industrial Firm	Awarded	P. Schissel
University of Denver	1.0	Polymer-protected silver mirrors and mirror degradation mechanisms	42.0	University	Awarded in FY 1984 and continuing into FY 1985	P. Schissel
Southern Research Institute	1.0	Development of novel protective coatings for solar reflectors	68.3	Not-for-profit Corporation	Awarded	G. Nix
To Be Determined	1.0	Optically uniform surfaces	To Be Determined	To Be Determined	Planned for award in July, 1985	M. Murphy
To Be Determined	1.0	Polymer laminates for stretched membrane reflectors	To Be Determined	Industrial Firm	Planned for award in July, 1985	M. Murphy
To Be Determined by A Competitive Procurement	1.0	Optical quality of polymer films for protecting silver mirrors	To Be Determined		Planned for award in December 1985	P. Schissel

SOLAR THERMAL RESEARCH PROGRAM SUBCONTRACTS

Subcontractor	WBS Number	Subcontract Title/Activity	Value (000$)	Type Business	Status	Technical Monitor
Dan/Ka Products	2.0	Design and fabrication of five scale-model stretched membrane reflector modules	110.0	Solar Thermal Industrial Firm/Small Business	Awarded in FY 1984 and continuing into FY 1985	M. Murphy
Colorado State University	2.0	Identification and evaluation of wind avoidance/reduction schemes for concentration collectors	70.0	University	Awarded in FY 1984 and continuing into FY 1985	M. Murphy
Consulting Agreement with Dr. Sachin Bhaduri (University of Texas/El Paso)	2.0	Provision of technical support to SERI on wind avoidance/ reduction schemes for concentrating collectors	27.0	Consulting Agreement	Awarded in FY 1984 and continuing into FY 1985	M. Murphy
Consulting Agreement with Dr. Bing Chen (University of Nebraska/Omaha)	2.0	Design, fabrication and evaluation of experimental RF systems for controlling heliostat fields	7.0	Consulting Agreement	Awarded in FY 1984 and continuing into FY 1985	M. Murphy
Consulting Agreement with Dr. James Pearson (John Brown University, Siloam Springs, AK)	2.0	Design, fabrication and evaluation of experimental RF systems for controlling heliostat fields	7.0	Consulting Agreement	Awarded in FY 1984 and continuing into FY 1985	M. Murphy
University of Arizona	2.0	Fabrication and evaluation of graphite fiber composite solar concentrators	30.0	University	Awarded in FY 1984 and continuing into FY 1985	M. Murphy
Acurex Solar, Inc.	2.0	Silver/metal reflector materials evaluation	11.0	Solar Thermal Industrial Firm	Awarded in FY 1984 and continuing into FY 1985	P. Schissel

SOLAR THERMAL RESEARCH PROGRAM SUBCONTRACTS

Subcontractor	WBS Number	Subcontract Title/Activity	Value (000$)	Type Business	Status	Technical Monitor
Industrial Solar Technology	2.0	Fresnel lens concentrator computer modeling	11.0	Solar Thermal Industrial Firm/ Small Business	Awarded	M. Murphy
Industrial Solar Technology	2.0	Analysis and fabrication of scale model conical concentrator reflector modules	10.0	Solar Thermal Industrial Firm/Small Business	Awarded	T. Windelin
Consulting Agreement with Dr. A. H. Soni (Oklahoma State University)	2.0	Analysis and design of adjustable cable restraints for air-inflated heliostat drive/supports	10.0	Consulting Agreement	Awarded in FY 1984 and continuing into FY 1985	R. Wood
Acurex Solar Corporation	2.0	Holographic solar concentrators	205.7	Solar Thermal Industrial Firm	Awarded Follow-on anticipated in November, 1985	G. Nix
University of Nebraska/Omaha	2.0	Stretched membrane reflector dynamic analysis	31.2	University	Awarded	M. Murphy
Colorado State University	2.0	Wind response on stretched membrane reflectors (follow-on research)	50.0	University	Awarded	M. Murphy
University of Arizona	2.0	Composite structural materials for stretched membrane reflector modules	78.8	University	Awarded	M. Murphy
ENTECH, Inc.	2.0	Computer Model for the evaluation of refractive concentrators	45.0	Solar Thermal Industrial Firm/Small Business	Awarded	M. Murphy
Dan-Ka Products, Inc.	2.0	Stretched membrane reflector structural requirements definition	10.0	Small Business	Awarded	M. Murphy

SOLAR THERMAL RESEARCH PROGRAM SUBCONTRACTS

Subcontractor	WBS Number	Subcontract Title/Activity	Value (000$)	Type Business	Status	Technical Monitor
Georgia Institute of Technology	1.0 3.0	University research in support of the FY 1985 Solar Thermal Research Program (Thermal materials, direct absorption, etc.)	660.0	University	Awarded	G. Nix
Georgia Institute of Technology	3.0	Operation and maintenance of the Advanced Components Test Facility (ACTF)	235.0	University	Awarded	G. Nix
Consulting Agreement with Dr. Richard Bradt (University of Washington)	3.0	Four-point flexural testing and provision of technical support to SERI on high temperature materials	19.0	Consulting Agreement	Awarded in FY 1984 and continuing into FY 1985	T. Coyle
Black & Veatch Consulting Engineers	3.0	Research program planning support to SERI	75.0	Solar Thermal Industrial Firm	Awarded in FY 1984 and continuing into FY 1985	L. Shannon
Consulting Agreement with Mr. Conrad M. Vineyard (Loveland, CO)	3.0	Solar thermal technology cost estimation technical support	10.0	Consulting Agreement	Awarded in FY 1984 and continuing into FY 1985	M. Murphy
Consulting Agreement with Mr. George M. Kaplan (Reston, VA)	3.0	Solar Thermal Research Program Support	5.0	Consulting Agreement	Awarded in FY 1984 and continuing into FY 1985	B. Gupta
Industrial Welding Supply	3.0	Fabrication of a 900°C molten salt test loop	226.0	Industrial Firm	Awarded	M. Carasso

SOLAR THERMAL RESEARCH PROGRAM SUBCONTRACTS

Subcontractor	WBS Number	Subcontract Title/Activity	Value (000$)	Type Business	Status	Technical Monitor
University of Houston	3.0 4.0	University research in support of the FY 1985 Solar Thermal Research Program (Photodegradation research, thermochemical energy storage systems, etc.)	350.0	University	Awarded	G. Nix
Hughes Aircraft Company	4.0	Thermoelectrochemical converter research	221.7	Industrial Firm	Awarded	G. Nix
University of New Hampshire	4.0	Solar photochemical production of fuels and chemicals	56.0	University	Awarded	G. Nix
Lawrence Berkeley Laboratory	4.0	Direct radiant heating of solid suspensions	32.6	Federal Laboratory	Awarded	G. Nix
University of Hawaii	4.0	Direct flux decomposition of particles	74.7	University	Awarded	G. Nix
Hughes Aircraft	4.0	Thermoelectrochemical conversion devices	To Be Determined	Industrial Firm	Follow-on research planned for award in January, 1986	G. Nix
University of Arizona	5.0	Spectrally selective beam splitters for thermally decoupled quantum/thermal hybrid systems	69.5	University	Awarded	G. Nix
Hughes Aircraft Company	5.0	New ideas for solar thermal conversion (Welsbach Effect Research)	58.9	Industrial Firm	Awarded	G. Nix
University of Chicago	5.0	Compound optical systems with maximal concentration for solar thermal conversion	77.1	University	Awarded	G. Nix

SOLAR THERMAL RESEARCH PROGRAM SUBCONTRACTS

Subcontractor	WBS Number	Subcontract Title/Activity	Value (000$)	Type Business	Status	Technical Monitor
Radiation Research Associates	6.0	Generation of Monte Carlo simulation estimates of attenuation and scattering between heliostats and a receiver	25.0	Small Business	Awarded in FY 1984 and continuing into FY 1985	G. Maxwell
Bluefield State University	6.0	Resource data monitoring	7.5	Historically Black University	Awarded	G. Maxwell

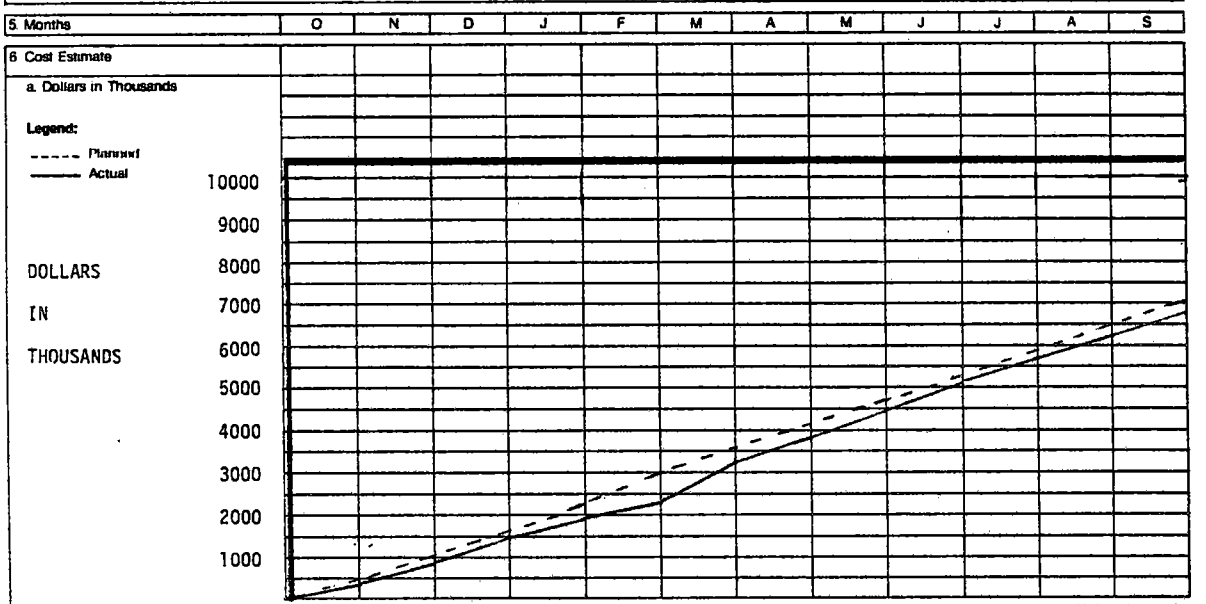
APPENDIX B

RESOURCE EXPENDITURE

RESOURCE EXPENDITURE

Budget Status

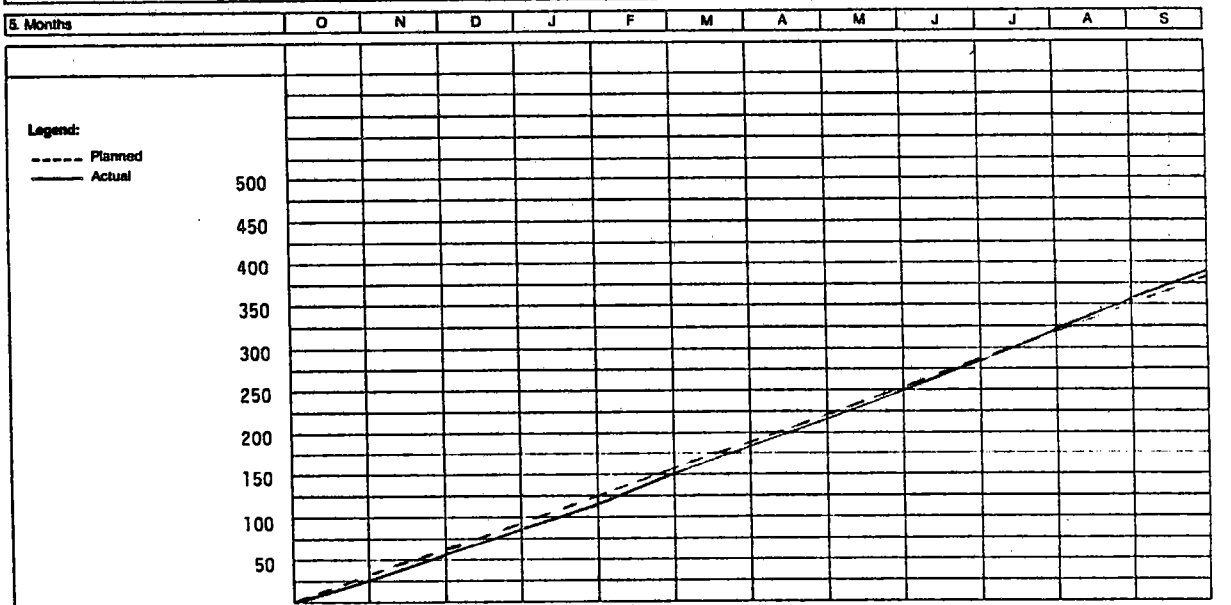
1. Contractor (name and address)	2. Reporting Period
Solar Energy Research Institute **1617 Cole Boulevard** **Golden, Colorado 80401**	From: 10/1/84 To: 9/30/85
3. Program Identification: FY1985 Solar Thermal Research Program	
4. WPA/Task: COST SUMMARY: OVERALL PROGRAM TOTALS	



Accrued Costs		O	N	D	J	F	M	A	M	J	J	A	S	
	b. Planned	499	1047	1608	2350	3030	3568	4172	4752	5323	5890	6446	6999	b. Planned
	c. Actual	458	969	1517	1936	2398	3281	3862	4432	5084	5667	6232	6778	c. Actual
	d. Variance	41	78	91	414	632	287	310	320	239	223	214	221	d. Variance

Manpower

1. Contractor (name and address)	2. Reporting Period
Solar Energy Research Institute **1617 Cole Boulevard** **Golden, Colorado 80401**	From: 10/1/84 To 09/30/85
3. Program Identification: FY1985 Solar Thermal Research Program	
4. WPA/Task: FTE SUMMARY: OVERALL PROGRAM TOTALS	

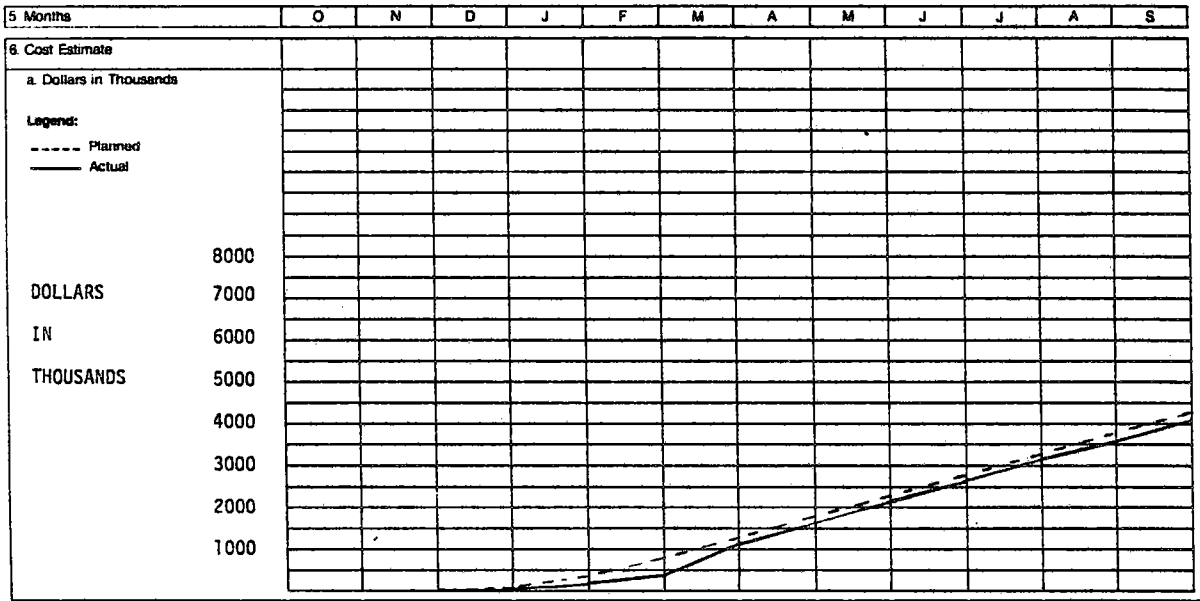


		O	N	D	J	F	M	A	M	J	J	A	S	
	Planned	29.8	60.1	89.4	126.4	160.9	191.7	225.93	256.7	287.2	317.8	348.5	379.5	Planned
	Actual	26.7	56.3	83.8	119.7	155.4	188.5	222.92	253.5	287.1	319.4	354.2	386.4	Actual
	Variance	3.1	3.8	5.6	6.7	5.5	3.2	3.01	3.2	.1	(1.6)	(5.7)	(6.9)	

RESOURCE EXPENDITURE

Budget Status

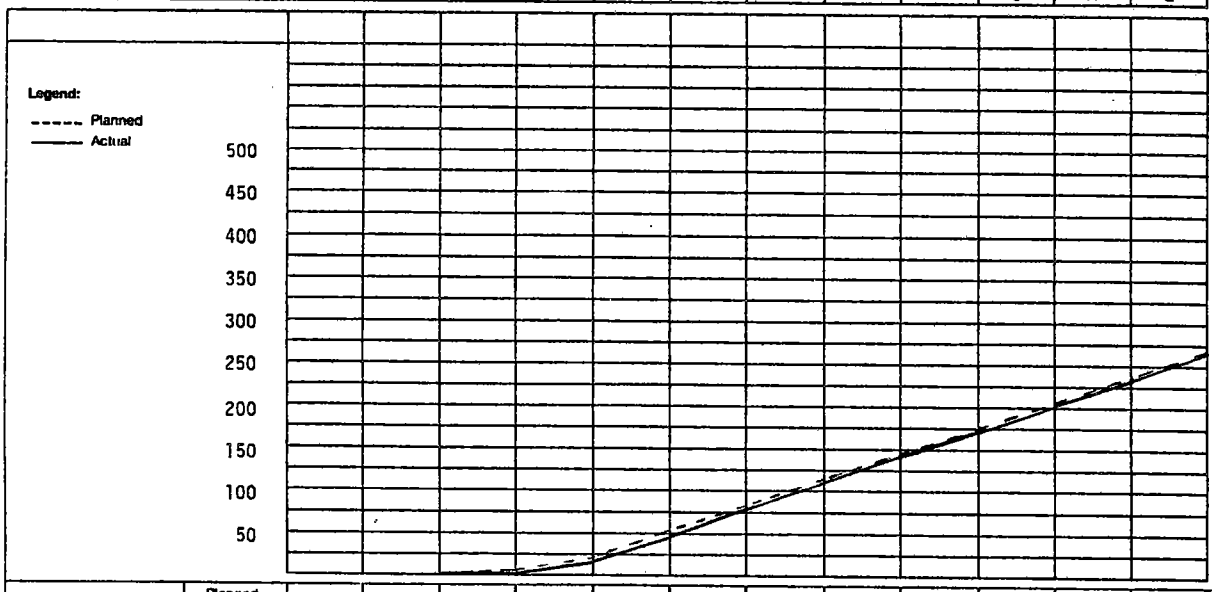
1. Contractor (name and address)	2. Reporting Period
Solar Energy Research Institute 1617 Cole Boulevard Golden, Colorado 80401	From: 10/1/84 To: 9/30/85
3. Program Identification: FY1985 Solar Thermal Research Program	
4. WPA/Task: COST SUMMARY: FY1985 FTP 510 and FTP 511	



		O	N	D	J	F	M	A	M	J	J	A	S	
Accrued Costs	b. Planned	0	0	22	417	858	1303	1802	2292	2779	3263	3736	4204	b. Planned
	c. Actual	0	0	12	189	469	1202	1603	2133	2566	3131	3603	4065	c. Actual
	d. Variance	0	0	10	228	389	101	104	159	113	132	133	139	d. Variance

Manpower

1. Contractor (name and address)	2. Reporting Period
Solar Energy Research Institute 1617 Cole Boulevard Golden, Colorado 80401	From: 10/1/84 To 09/30/85
3. Program Identification: FY1985 Solar Thermal Research Program	
4. WPA/Task: FTE SUMMARY: FY1985 FTP 510 and FTP 511	

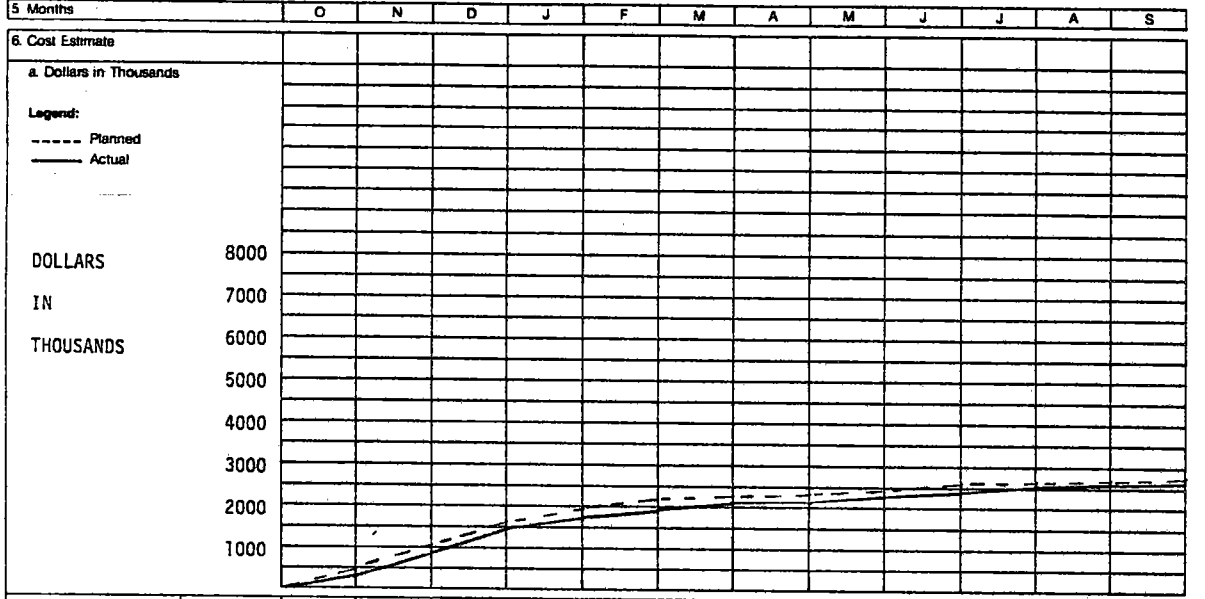


	O	N	D	J	F	M	A	M	J	J	A	S	
Planned	0	0	2.5	23.7	52.8	82.4	116.6	147.3	177.9	208.5	239.2	270.2	Planned
Actual	0	0	1.1	22.5	49.8	79.8	114.2	142.7	174.0	204.8	238.5	270.0	Actual
Variance	0	0	1.4	1.2	3.0	2.6	2.4	4.6	3.9	3.7	.7	.2	

RESOURCE EXPENDITURE

Budget Status

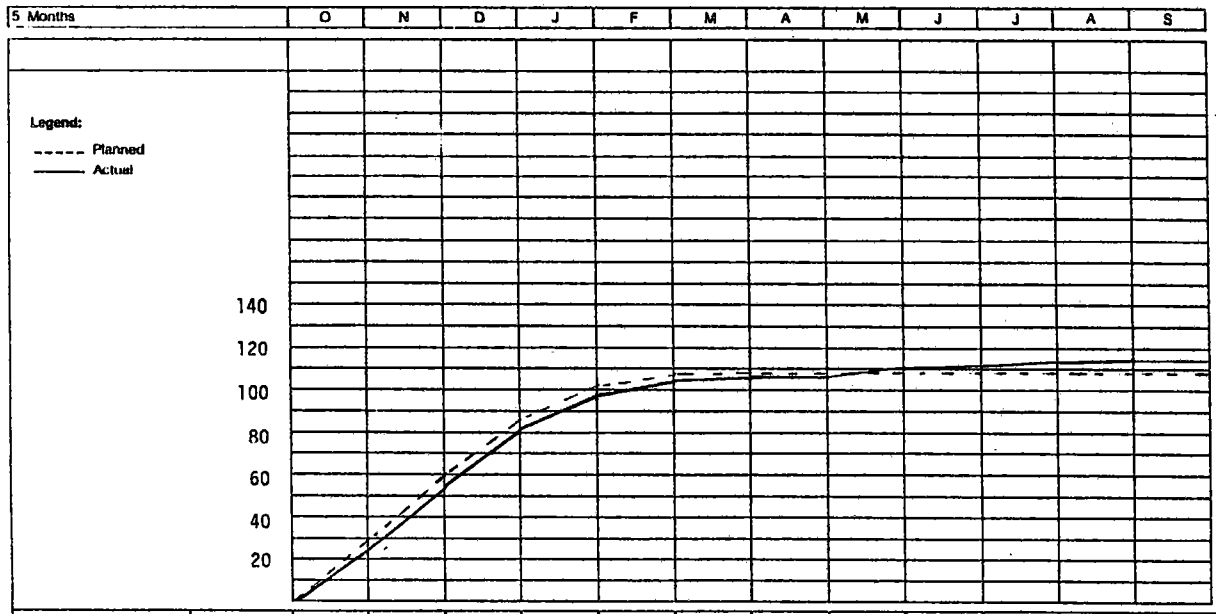
1 Contractor (name and address)	**Solar Energy Research Institute** **1617 Cole Boulevard** **Golden, Colorado 80401**
2. Reporting Period	From: 10/1/84 To: 9/30/85
3 Program Identification	FY1985 Solar Thermal Research Program
4. WPA/Task	COST SUMMARY: FY1982 - FY1984-FTP 416, FTP 417, FTP 440, FTP 463



		O	N	D	J	F	M	A	M	J	J	A	S	
Accrued Costs	b Planned	499	1047	1586	1933	2172	2265	2370	2460	2543	2627	2710	2795	b. Planned
	c. Actual	458	969	1505	1747	1929	2079	2164	2299	2418	2536	2629	2713	c. Actual
	d. Variance	41	78	81	186	243	186	206	161	125	91	81	82	d. Variance

Manpower

1 Contractor (name and address)	**Solar Energy Research Institute** **1617 Cole Boulevard** **Golden, Colorado 80401**
2 Reporting Period	From: 10/1/84 To 09/30/85
3 Program Identification	FY1985 Solar Thermal Research Program
4 WPA/Task	FTE SUMMARY: FY1982 - FY1984 - FTP 416, FTP 417, FTP 440, FTP 463



		O	N	D	J	F	M	A	M	J	J	A	S	
	Planned	29.8	60.1	86.9	102.7	108.1	109.3	109.33	109.3	109.3	109.3	109.3	109.3	Planned
	Actual	26.7	56.3	82.7	97.2	105.6	108.7	108.72	110.8	113.1	114.6	115.7	116.4	Actual
	Variance	3.1	3.8	4.2	5.5	2.5	.6	.61	(1.5)	(3.8)	(5.3)	(6.4)	(7.1)	

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SOLAR THERMAL ENERGY PROGRAM

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SOLAR THERMAL ENERGY PROGRAM

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Copeland, R. J.; Newell, T. A.; Wang, K. Y. (In progress) A Report on Direct Absorption Receiver Falling Film Flow Characteristics. SERI/TR-252-2641. Golden, CO: Solar Energy Research Institute.

Direct Absorption Receiver System Steady-Phase II. (In Progress) SERI/SP-253-2592. Golden, CO: Solar Energy Research Institute.

Lazaridis, A.; Copeland, R.; Althof, J. (In progress) Temperature Distribution in a Solar Irradiated Liquid Layer Flowing Over a Wall of an Optical Cavity. SERI/TR-252-2221. Golden, CO: Solar Energy Research Institute.

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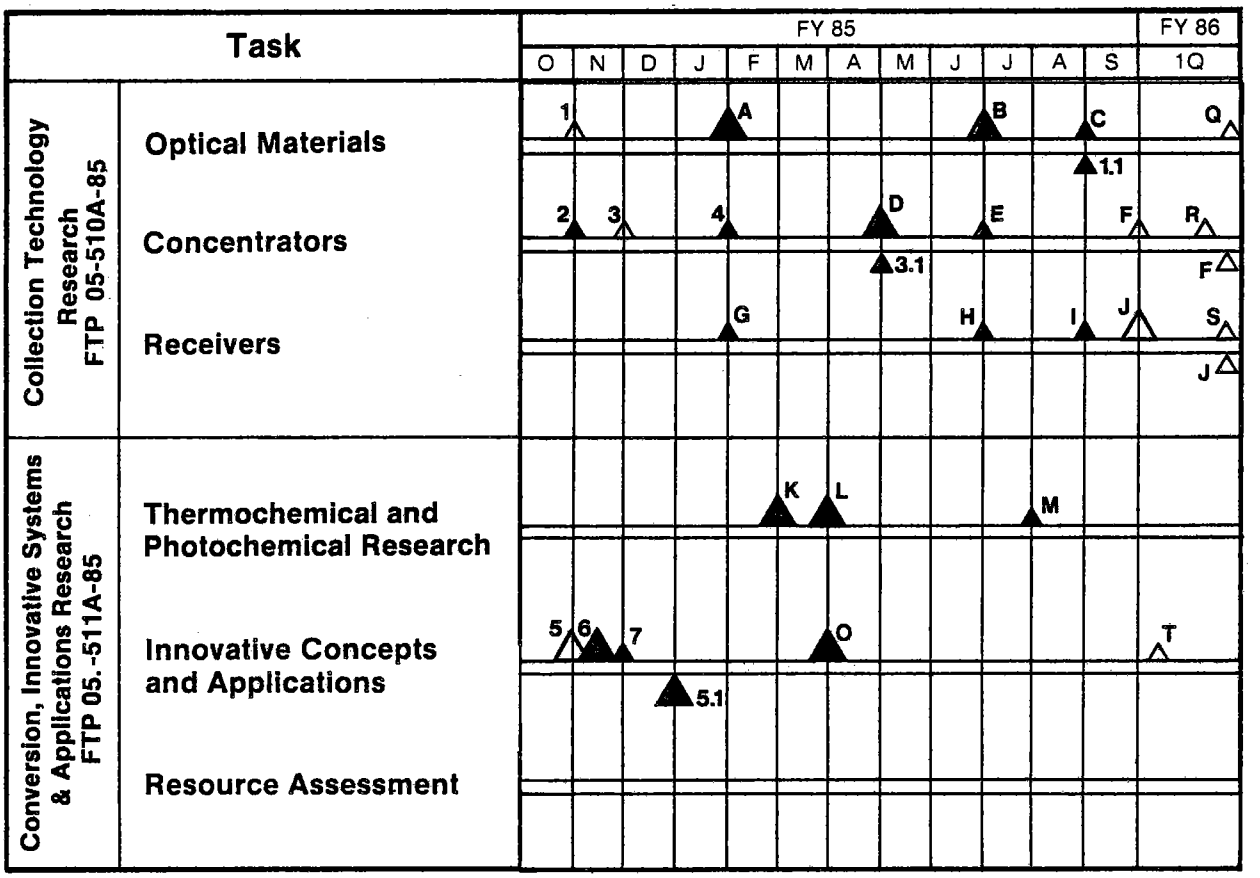
Zangrando, F. (In progress) Survey of Density Measurement Techniques for Application in Stratified Fluids. SERI/TR-252-2221. Golden, CO: Solar Energy Research Institute.

Solar Thermal

Major Milestone Schedule



FY84 Funded Effort (FTP 05-463--84)

1. 3M film surface durability improvement
2. Membrane surface deformation and tension load effects
3. Membrane comparison with glass/metal heliostat
4. Membrane frame coupling concept
5. Award Phase II innovative research contracts
6. Award new innovative research contracts
7. Experimental H yield from 10 sun photoconversion process

FY85 Funded Effort

A. Silver/polymer UV protection approaches
B. Solar test on mosaic windows
C. Silver/polymer film samples with UV protection
D. Steel membrane module performance projection
E. Wind load reduction concepts for concentrators
F. Fresnel lens concept assessment
G. Award 900°C loop fabrication contract
H. Carbonate salt and Inconel optical properties up to 900°C
I. Four wavelength pyrometer experience and data
J. Direct absorption receiver concept feasibility
K. Evaluate research progress in unique and beneficial use of concentrated solar flux
L. Concentrated flux effects on surface reaction
M. Materials effects experiments with concentrated flux
N. High flux experiment support equipment - Deleted
O. Direct thermal conversion concepts evaluation
P. UV radiation measurement instrumentation - Deleted
Q. Silver/polymer film useful service life prediction
R. New, innovative concentrator concepts assessment
S. Direct absorption concept benefits assessment
T. Recommend concepts for further evaluation

APPENDIX E

SCIENTIFIC MEETINGS AND PRESENTATIONS

SCIENTIFIC MEETINGS AND PRESENTATIONS

G. Jorgensen and colleagues wrote two papers on optical property measurements of materials at high temperatures and instrumental capabilities: Optical Properties of High-Temperature Materials for Direct Absorption Receivers and An Integrating Sphere Spectrometer for High-Temperature Materials Characterization. SERI staff members presented these papers at the Society of Photo-Optical Instrumentation Engineers (SPIE) Conference on Optical Materials Technology for Energy Efficiency and Solar Energy Conversion on August 18 to 23 in San Diego, California.

K. Wang and F. Kreith completed a paper titled "Heat Transfer Research for High-Temperature Solar Thermal Energy Systems." This paper was accepted for presentation at the U.S.-Japan 1985 Heat Transfer Seminar on September 17 to 20, in San Diego, California.

M. Bohn gave a presentation on the Direct Absorption Task before the advisory board of the Solar Heat Research Division at SERI.

Staff members working on concentrators visited Sandia National Laboratory, Albuquerque, to discuss activities for fiscal year 1986 and to help better coordinate future mutual and related activity.

Researchers held technical discussion with the following people regarding polymers and mirrors: C. Kipphot, Bausch and Lomb; J. Albright, DOE; A. Bronstein, Sunsteam Ltd.; W. Smith, A-a-e-affiliates; F. Wright, Key Technologies; and I. Mayer, Commonwealth Scientific and Industrial Research Organization (CSIRO).

Three papers were presented at the SPIE Conference in August at San Diego, California: (1) Photodegradation Studies of Silver-backed Polycrylonitrile (PAN) Films by D. M. Smith, A. R. Chughtai, C. Sergides, P. Schissel; (2) Polymer Glazing for Silver Mirrors by H. H. Neidlinger and P. Schissel; (3) Specularity and Stability of Silvered Polymers by A. W. Czanderna and P. Schissel.

SERI staff held a technical discussion with J. Kleinwachter from Bomin, Inc., (West German) regarding polymeric materials for mirrors. Dr. Kleinwachter promised to supply some of their polymer film samples as well as related specularity data.

The efforts of the Solar Thermal Technology Program in direct-flux capture and conversion were well represented by papers presented at the 23rd National Heat Transfer Conference in Denver, Colorado. A. Hunt presented a paper on the LBL research on radiant heating of solids. M. Antal presented his research at the University of Hawaii on radiant decomposition of zinc sulfate. J. Hruby and G. Evans of SNLL each presented papers describing the solid particle receiver. K. Drost presented the PNL volumetric receiver concept. G. Nix of SERI organized and chaired the session. Several of these papers represent SERI contract research. The session was attended by about 30 people who engaged in lively discussion of each paper. Total conference registration was 738. Conference sponsors were the American Institute of Chemical Engineers and the American Society of Mechanical Engineers.

E. L. Maxwell attended a Source Evaluation Board meeting at NOAA, Boulder, Colorado, to begin the development of new specifications for solar trackers to upgrade the National Solar Radiation Network.

SERI staff working on concentrator research supported an SAI stretched-membrane, design review held by Sandia/Livermore in San Diego, California. They also met with SAI staff to discuss progress on composite materials. They visited with personnel at the University of California, Berkeley, to discuss application of the university's expertise in composite materials to concentrators.

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BI-MONTHLY STATUS REPORT

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Carasso, M.
Czanderna, A.
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Gupta, B.
Hewett, R.
Hubbard, H.
Johnson, D.

Kreith, F.
Lewandowski, A.
Maxwell, E.
Murphy, L. M.
Neidlinger, H.
Nix, G.
Olsen, K.
Schissel, P.
Shannon, L.
Thornton, J.

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